3rd GLOBEC Open Science Meeting

From ecosystem function to prediction

Victoria Conference Centre
Victoria, BC, Canada
22-26 June 2009

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Foreword

In the late 1980s, when the Global Ocean Ecosystem Dynamics (GLOBEC) programme was being developed by the United States on Georges Bank, the scientific view of the ocean was very different from what it is today. Oceanographers and fisheries scientists were just beginning to work together in a true inter-disciplinary fashion, images of a global ocean from satellites were becoming available, desktop computers were slow and bulky, the internet (and Email) did not exist, and the major forcings on the ocean were seen to be climate variability (by oceanographers) and fishing (by fisheries scientists). Today, 21 years after the workshop in Wintergreen, VA that led to the GLOBEC approach, the marine world looks very different. Satellites provide rapid and global coverage of an increasing array of ocean properties, massive amounts of data are instantly available over the internet, young scientists are routinely trained with both oceanographic and fisheries backgrounds, multi-disciplinary research projects are being developed in full collaboration with social scientists, and the main drivers of change in marine ecosystems are realised to be climate, humans, and their interactions. As the sessions and presentations at this 3rd Open Science Meeting (OSM) will show, the international GLOBEC programme has had a large role in effecting these changes.

The aim of GLOBEC has been to advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems, and its response to physical forcing so that a capability can be developed to forecast the responses of the marine ecosystem to global change. The purpose of this OSM is to contribute to the synthesis and integration of the results of GLOBEC international activities. This involves two days of intense and detailed workshops on 10 focused topics, a day of reviewing and summarising GLOBEC achievements to date, and plenary sessions on the latest advances in *ecosystem structure, function and forcing; ecosystem monitoring and prediction; and ecosystem management and their human dimensions*. The OSM concludes with a thought-provoking session on *Marine ecosystem science: into the future* and, since GLOBEC will formally close in early 2010, a symbolic “hand-over” of GLOBEC’s outstanding research questions to the Integrated Marine Biogeochemistry and Ecosystems Research (IMBER) project.

GLOBEC’s three main sponsoring organisations have been unfailingly supportive. The Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of the United Nations adopted GLOBEC as one of their large ocean programmes in 1992, followed in 1995 by the acceptance of GLOBEC as a core project of the International Geosphere-Biosphere Programme (IGBP). The continued support by all of these organisations and the personal support of their staff has been absolutely invaluable. GLOBEC science projects were funded by individual countries and, in several cases, by Regional Science organisations such as ICES and PICES; each is thanked for their support. In particular, we wish to thank the United States National Science Foundation, the United Kingdom Natural Environmental Research Council and the Plymouth Marine Laboratory for their support of the international organisational work of GLOBEC and the International Project Office, whose staff (especially Dawn Ashby, Lotty Dunbar and Milly Hatton-Brown) have been indispensable to the smooth operation of GLOBEC, and to the careful planning of this meeting.

This 3rd OSM would not have happened without the support of several of GLOBEC’s partner organisations. We thank our co-sponsoring organisations (DFO, ICES, ICOR, NSF, Ocean Networks Canada, PICES, SCAR, SCOR, Research Council Norway, University of Victoria) for all of their support. We also wish to thank the members of the Scientific Steering Committee, the members of the GLOBEC International Project Office, and the members of the Organising Committee for their hard work, without which this symposium would not have happened.

Finally, we wish to thank all of you, the scientists of GLOBEC, for your dedication, commitment, and enthusiasm, which has made this programme such a success. And a success it has been, with over 3200 publications to date (over 2700 of them refereed), 26 special issues in peer-reviewed journals, and five books - and still counting.

This OSM is planned as, and intended to be, a celebration and a party of GLOBEC and its achievements. We hope that you leave Victoria filled with excitement and new ideas, and perhaps plans for new collaborative research projects.

Enjoy the meeting!

The Convenors: Ian Perry, Manuel Barange, Eileen Hofmann

The organisation and sponsors

Symposium Convenors:

Manuel Barange (GLOBEC IPO, UK)
Eileen Hofmann (CCPO, USA)
Ian Perry (DFO, Canada)

Symposium Scientific Steering Committee:

Jürgen Alheit (Germany)
Harold Batchelder (USA)
Keith Brander (Denmark)
Wendy Broadgate (Sweden)
David Checkley (USA)
Dale Haidvogel (USA)
Julie Hall (New Zealand)
Roger Harris (UK)
George Hunt (USA)
Astrid Jarre (South Africa)
Salvador Lluch-Cota (Mexico)
Olivier Maury (France)
Yasunori Sakurai (Japan)
Svein Sundby (Norway)
Qisheng Tang (China)
Edward Urban (USA)
Francisco Werner (USA)

Symposium Organising Committee:

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Manuel Barange (GLOBEC IPO)
Alex Bychkov (PICES)
Lotty Dunbar (GLOBEC IPO)
Edmand Fok (DFO)
Milly Hatton-Brown (GLOBEC IPO)
Skip McKinnell (PICES)
Rosemary Ommer (ICOR)
Ian Perry (DFO)
Martin Taylor (Ocean Networks Canada)
Gary Tunnell (ICOR)

Sponsoring organisations:

Global Ocean Ecosystem Dynamics

National Science Foundation

North Pacific Marine Science Organization

Fisheries and Oceans Canada

Intergovernmental Oceanographic Commission

International Council for the Exploration of the Sea

Institute for Coastal and Oceans Research (ICOR)

Ocean Networks Canada

Scientific Committee on Oceanic Research

Scientific Committee on Antarctic Research

The Research Council of Norway

University of Victoria

Notes for guidance

Registration

Registration will take place between 16:00 and 19:00 on Sunday 21 June and from 07:30 on Monday 22 June to Wednesday 24 June.

Once you have registered and received your name badge please ensure that you wear it throughout the meeting. Please remember to wear it to the official conference reception at the Royal British Columbia Museum on Monday evening so that members of staff are able to identify you as a conference delegate.

Oral presentations

To assist with the smooth running of the symposium all speakers are asked to adhere strictly to their allocated presentation times. Those chairing sessions will be strict about enforcing time limits.

If you are giving an oral presentation you will need to bring your work on a memory stick to the registration desk. Registration will be open from 16:00–19:00 on Sunday 21 June and we would be grateful if those who are presenting on Monday could upload talks at this time. Files should be named using the following format: Session_ author last name (eg. S2_Moloney). All other presenters will need to bring their work to the registration desk the day before their talk (at the latest).

Oral presentations should be prepared in either Microsoft Powerpoint (version 2007 or earlier) or pdf format. Macintosh computers are not available in the meeting rooms, and Mac users will be asked to check their presentation at the registration desk.

Poster presentations

Posters will need to fit onto a board of 120cm (width) x 240cm (height). Boards will be available the morning of Wednesday 24 June to Friday 22 June and will remain on display throughout this period. You will be given a poster number at registration to identify your allocated board. Velcro and push pins will be available at the registration desk.

Presenters must be beside their posters for the duration of their allocated session.

Poster session 1:	Ecosystem structure function and forcing 24 June 2009, 15:30–16:30 - Saanich room
Poster session 2:	Ecosystem observation, modelling and prediction 25 June 2009, 15:30–16:30 - Oak Bay room
Poster session 3:	Ecosystem approach to management. 26 June 2009, 15:00–16:00 - Esquimalt room

Posters for Workshop D will be displayed during the workshop in Saanich room 2 from 22 June. Please bring your poster along to the workshop on Monday where boards will be available for you to use.

Refreshments

Refreshments will be available during the morning and afternoon breaks in the pre-function area on the 1st floor of the Victoria Conference Centre. Lunches and dinners can be purchased at nearby restaurants.

Internet access and computing

Wireless internet will be available throughout the meeting (passwords will be made available) however this will be limited to 100 connections at any one time.

The Sooke room will be available for general use computing (PCs with internet access will be available) and the Victoria room can be used for offline meetings – a booking sheet will be fixed to the door should you wish to reserve this space at anytime during the conference.

Social events

Monday 22 June: **Official reception at the Royal British Columbia Museum**.

18:30 Please bring the drinks tickets provided in your registration packs (food served from 19:00-21:00, bar closes at 21:30).

Thursday 25 June: **Conference banquet at the Hotel Grand Pacific**

19:00 The conference banquet is only open to ticket holders. If you have requested a ticket and have not completed online payment you will be asked to pay in cash at the registration desk. The cost of the banquet for registered participants is 30CAD. Accompanying persons who are not registered for the OSM will be charged the full rate of 50CAD. If you have not yet registered your interest in attending but would like to attend please contact the registration desk for availability. On receipt of payment (or at registration if you have paid online) you will be issued with a banquet ticket – please remember to bring this with you on Thursday evening.

Workshops

Workshop	Room	Date and time
A: Modelling ecosystems and ocean processes	Lecture Hall	22 June 08:30–18:00 23 June 08:30–18:00
B: Comparisons of processes and climate impacts in sub-Arctic and Antarctic marine ecosystems	Esquimalt	22 June 08:30–17:30 23 June 08:30–12:30
C: Worldwide large scale fluctuations of sardine and anchovy	Sydney	22 June 08:30–18:00 23 June 08:30–18:00
D: Krill biology and ecology in the world's oceans	Saanich 1 and 2	22 June 08:30–17:00 23 June 08:30–17:30
E: Biogeochemistry of the oceans in a changing climate	Oak Bay 1	22 June 08:30–17:30
F: Continuous Plankton Recorder surveys of the global ocean	Oak Bay 2	22 June 08:40–17:30
G: Cod and climate change: the past, the present and future challenges	Colwood	22 June 09:00–17:00
H: Plankton phenology and life history in a changing climate: observation and modelling	Oak Bay 1	23 June 08:30–17:30
I: Climate impact on ecosystem dynamics of marginal seas	Oak Bay 2	23 June 08:30–17:30
J: Socio-economic dynamics and ecosystems, governance implications	Colwood	23 June 08:30–17:00

Plenary sessions

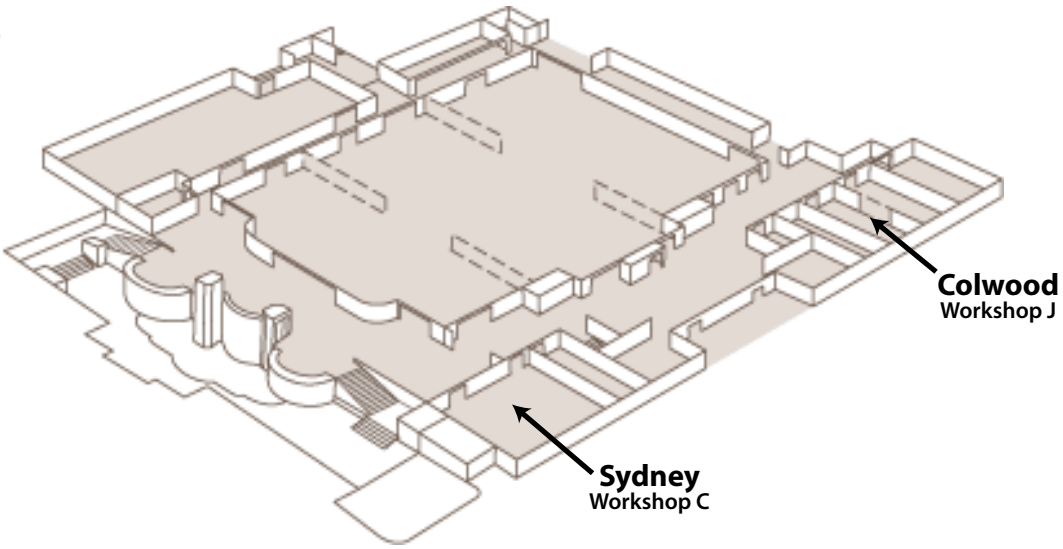
All plenary sessions will be held in the Lecture Theatre, see programme for further details.

Proceedings

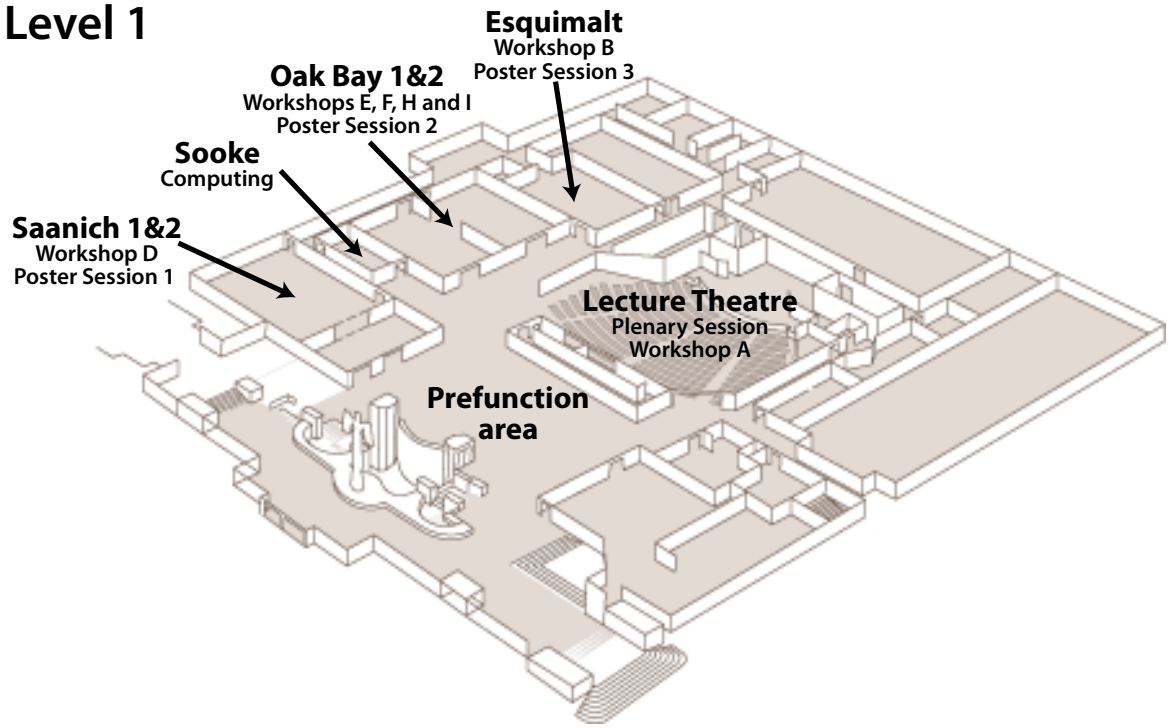
The proceedings of the 3rd GLOBEC Open Science Meeting will be submitted for publication as a special issue of Progress in Oceanography. The Convenors invite manuscripts from the plenary, workshop and poster sessions, with particular interest in contributions that provide synthesis and integration of GLOBEC or GLOBEC-related studies. The deadline for submissions is 1 October 2009 to allow for interactions at the OSM to be included in the contributions. Instructions for the submission of manuscripts will be available during the meeting.

Victoria Conference Centre

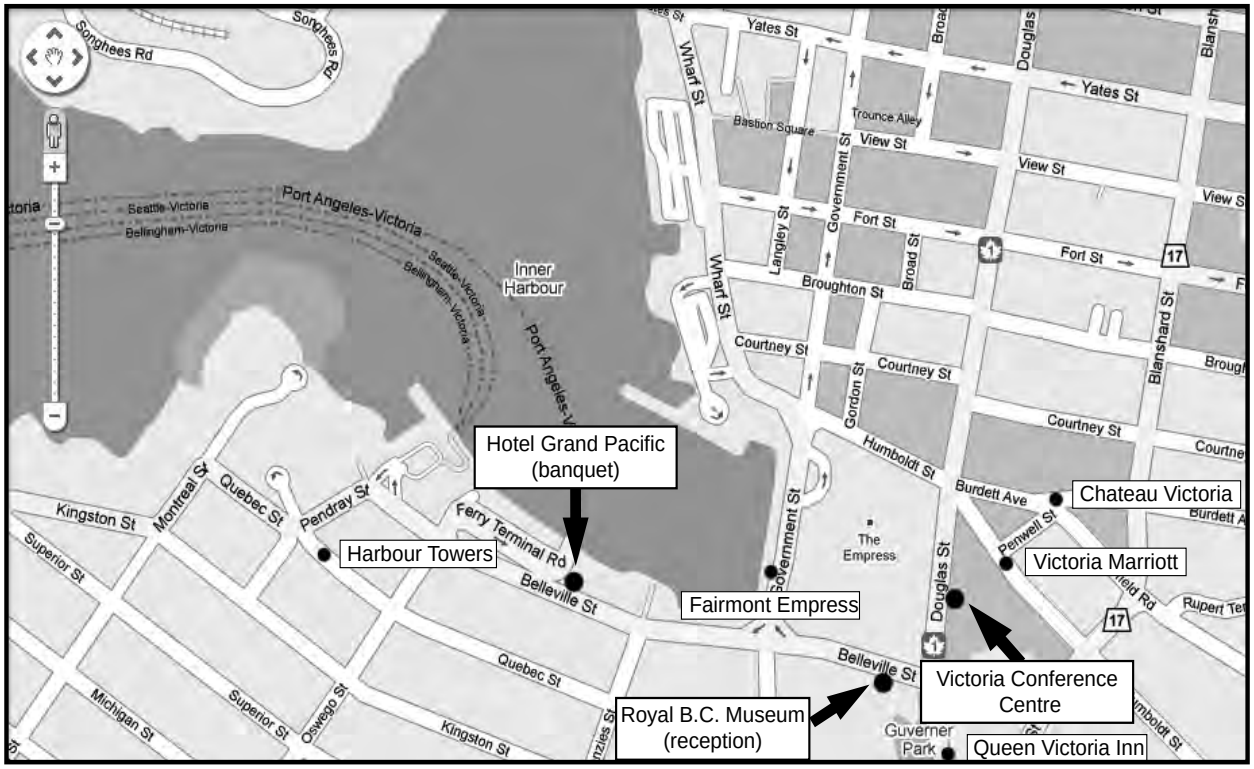
Level 2



Level 1



Map of the Victoria area



General programme

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Opening ceremony</td><td rowspan="2">Session 3
Ecosystem structure, function and forcing</td><td rowspan="2">Session 6
Ecosystem approach to management</td></tr>
<tr><td>10:00-10:30</td><td colspan="4">Coffee</td></tr>
<tr><td>10:30-11:30</td><td rowspan="2">Workshops (A–G)</td><td rowspan="2">Workshops (A–D, H–J)</td><td rowspan="2">Session 2
GLOBEC achievements</td><td rowspan="2">Session 4
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Ecosystem approach to management</td></tr>
<tr><td>11:30-12:30</td><td>Session 7
Marine ecosystem science: into the future</td></tr>
<tr><td>12:30-14:00</td><td colspan="5">Lunch</td></tr>
<tr><td>14:00-15:00</td><td rowspan="2">Workshops (A–G)</td><td rowspan="2">Workshops (A–D, H–J)</td><td rowspan="2">Session 3
Ecosystem structure, function and forcing</td><td rowspan="2">Session 4
Ecosystem observation, modelling and prediction</td><td>Session 7
Marine ecosystem science: into the future</td></tr>
<tr><td>15:00-15:30</td><td>Poster session 3
Ecosystem approach to management</td></tr>
<tr><td>15:30-16:00</td><td>Coffee</td><td>Coffee</td><td colspan="3">Coffee and poster sessions</td></tr>
<tr><td>16:00-16:30</td><td rowspan="2">Workshops (A–G)</td><td rowspan="2">Workshops (A–D, H–J)</td><td>Poster session 1
Ecosystem structure, function and forcing</td><td>Poster session 2
Ecosystem observation, modelling and prediction</td><td rowspan="2">Session 8
Closing ceremony</td></tr>
<tr><td>16:30-17:30</td><td>Session 3
Ecosystem structure, function and forcing</td><td>Session 5
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<tr><td></td><td>Welcome reception (18:30–22:00)</td><td></td><td>BASIN Open Meeting (18:00–19:30)</td><td>Conference banquet (19:00–23:00)</td><td></td></tr>
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All plenary sessions and the BASIN Open Meeting will be held in the Lecture Theatre, for room locations for the workshops see page viii.

Agenda and schedules by session

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Workshops

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B: Comparisons of processes and climate impacts in sub-Arctic and Antarctic marine ecosystems: observations and modelling approaches 19

C: Worldwide large-scale fluctuations of sardine and anchovy: revisiting Schwartzlose *et al*. 21

D: Krill biology and ecology in the world's oceans 22

E: Biogeochemistry of the oceans in a changing climate 25

F: Continuous Plankton Recorder surveys of the global ocean 26

G: Cod and climate change: the past, the present and future challenges 27

H: Plankton phenology and life history in a changing climate: observation and modelling 28

I: Climate impact on ecosystem dynamics of marginal seas 30

J: Socio-economic dynamics and ecosystems, governance implications 32

Plenary: Wednesday 24 June

S1: Opening ceremony

Chair: Ian Perry

08:30 **Welcome addresses**

Laura Richards
Regional Director of Science, Pacific, Fisheries and Oceans Canada, Nanaimo, BC, Canada

Martin Taylor
President and CEO, Ocean Networks Canada, Victoria, BC, Canada

Wendy Broadgate
Deputy Director, Natural Sciences, IGBP Secretariat, Stockholm, Sweden

S2: GLOBEC achievements

Chairs: Manuel Barange and Ian Perry

09:10 **Roger P. Harris and Elizabeth Gross**
A history of GLOBEC (S2-O1)

09:30 **Eileen Hofmann, Francisco Werner and Eugene J. Murphy**
Physical-biological coupling in marine ecosystems (S2-O2)

10:00 ***Tea/coffee break***

10:30 **Coleen Moloney**
Food web processes in marine ecosystems (S2-O3)

11:00 **Svein Sundby**
Impacts of climate/global change (S2-O4)

11:30 **Yasuhiro Yamanaka**
Forecasting and predicting marine ecosystem responses to climate change (S2-O5)

12:00 **Ian Perry, Manuel Barange and Rosemary Ommer**
The human dimensions of global environmental change in marine systems (S2-O6)

12:30 ***Lunch***

S3: Ecosystem structure, function and forcing

Chairs: Salvador Lluch-Cota, Yasunori Sakurai, George Hunt and Qisheng Tang

14:00 **Mark Ohman**
Climate signals in the California Current holozooplankton: resolving the invisible present (S3-O1)

14:30 **Wuchang Zhang**
Paired standard and size fractionated dilution incubations in southern Yellow Sea (S3-O2)

14:45 **Jay O. Peterson, Megan Pros, William T. Peterson and Cheryl A. Morgan**
Hypoxia in the northern California Current: interannual variability and influence on copepod recruitment (S3-O3)

15:00 **Suzanne Strom, Michael Dagg, Kenneth Coyle, Russell Hopcroft, Terry Whitledge and Lewis Haldorsen**
Oceanographic conditions and lower trophic level responses leading to variable pink salmon recruitment in the coastal Gulf of Alaska (S3-O4)

15:15 **Angus Atkinson, Katrin Schmidt and David Pond**
Seasonal and regional importance of copepods, protozoans, diatoms and sediment as alternative food items for Antarctic krill (S3-O5)

15:30 **Poster session 1: Ecosystem structure, function and forcing**

16:30 **Ebru Unal, Ann Bucklin and Peter H. Wiebe**
Testing the three-gyre hypothesis: basin-scale population genetic structure of *Calanus finmarchicus* in the North Atlantic Ocean (S3-O6)

16:45 **Katrin Schmidt, Angus Atkinson and David Pond**
Regional differences in overwintering of Antarctic krill, *Euphausia superba* (S3-O7)

17:00 **Stephen Nicol**
Can the ecology of krill be described simply? (S3-O8)

17:15 **Maria Gasalla**
Six decades of change in the South Brazil Bight fishery ecosystem (S3-O9)

18:00-19:30 **BASIN Open Meeting***

*BASIN is a joint EU/North American research initiative designed to elucidate the mechanisms underlying observed changes in North Atlantic ecosystems and their services as well as to quantify and predict consequences of climate and environmental variability and change on the system. This open meeting will provide the opportunity to discuss the current status of BASIN programme development on both sides of the North Atlantic. All are welcome and it is hoped that there will be a free and open discussion of plans and future strategy. The BASIN science plan is located at: http://www.globec.org/structure/multinational/basin/basin.htm

Poster Session 1: Ecosystem structure, function and forcing

15:30, Wednesday 24 June

PS1-P1 **Angus Atkinson and Katrin Schmidt**
Fecal pellet production by Antarctic krill in summer: egestion rates, fecal pellet composition and sinking rates

PS1-P2 **Erik Chapman, Walter Golet and Molly Lutcavage**
The influence of environmental variability on Atlantic bluefin tuna (*Thunnus thynnus*) growth, migration, and reproduction

PS1-P3 **Pavel Chernyshkov, Igor Polishchuk, Vladimir Shnar, Svetlana Kasatkina and Fedor Litvinov**
Inter-annual and seasonal variability of pelagic ecosystem and krill resources parameters in the Scotia Sea in relation to oceanographic conditions

PS1-P4 **Pavel Chernyshkov and E.N. Timokhin**
Variability of oceanological conditions in the southern Pacific and structure of the pelagic ecosystem

PS1-P5 **Fidel Echevarria, Xabier Irigoien, Antonio Bode, Enric Saiz, Jose Luis Acuña, Pablo Sangrá, Santiago Hernández-León and Andrés Uriarte**
The GLOBEC programme in Spain: a decade of marine ecosystem research

PS1-P6 **Maria Luz Fernandez de Puelles and Juan-Carlos Molinero**
Ocean-climate variability and zooplankton in the Balearic Sea, western Mediterranean

PS1-P7 **David Fields, Steven Shema, Lewis Incze, Scott Kraus, Nicholas Wolff and Adam Baukus**
Are surface swarms of *Meganyctiphanes norvegica* a response to passing internal waves?

PS1-P8 **Marta Gluchowska, Slawomir Kwasniewski, Katarzyna Wojczulanis-Jakubas, Dariusz Jakubas, Nina J. Karnovsky, Wojciech Walkusz, Katarzyna Blachowiak-Samolyk and Lech Stempniewicz and Malgorzata Cisek**
Zooplankton distribution and Little Auk feeding in Spitsbergen marine frontal zones – is there a carrot among the weeds?

PS1-P9 **Lingfeng Huang, Shiquan Lin, Zhisheng Zhu and Xiaoyan Jia**
A preliminary study on factors shaping the distribution patterns of heterotrophic nanoflagellate in the Yellow Sea Cold Water Mass region and ambient waters

PS1-P10 **Lingfeng Huang, Zhisheng Zhu and Shiquan Lin**
A preliminary study on bacterivory of heterotrophic nanoflagellate upon heterotrophic bacteria and cyanobacteria in the Yellow Sea Cold Water Mass area

PS1-P11 **Zengjie Jiang, Jianguang Fang and Jihong Zhang**
Sediment resuspension mechanisms and their effect on nutrient exchange in the aquaculture area of Sanggou Bay

PS1-P12 **Xianshi Jin, Xianseng Li, Jun Wang, Yi Cui and Tao Zuo**
Long-term variations of ecosystem structure in the Laizhou Bay of Bohai Sea, China

PS1-P13 **Magnus Johnson, Geraint Tarling and Andrew Mehta**
Measuring the behaviour of individual mesopelagic crustaceans - in homage to Haeckel

PS1-P14 **Alanna Krepakevich and Vera Pospelova**
Dinoflagellate cysts as indicators of the sewage impact on coastal waters in the greater Victoria region of southern Vancouver Island

PS1-P15 **Youngju Lee and Joong Ki Choi**
Spatial distribution of phytoplankton and primary production of the Yellow Sea in January 2008

PS1-P16 **Chaolun Li, Song Sun, Bo Yang, Fang Zhang and Peng Ji**
Seasonal abundance and development of *Calanus sinicus* in relation to phytoplankton and hydrography in the southern Yellow Sea

PS1-P17 **Lingbo Li and Tony Pitcher**
Exploring marine mammal and forage fish interactions

PS1-P18 **Chenggang Liu, Xiuren Ning, Qiang Hao, Jun Sun, Jing Zhang, Feng Zhou and Fengfeng Le**
Relationship between the “dead zone” and phytoplankton blooms off the Changjiang Estuary

PS1-P19 **Min Liu, Tian Xiao, Bing Deng, Tao Zhang and Wuchang Zhang**
Variations of bacterial community structure in different habitats in China Sea

PS1-P20 **Min Liu, Tian Xiao, Xiuren Ning, Ying Wu and Wuchang Zhang**
Succession of the bacterial community during the spring diatom bloom in the Yellow Sea

PS1-P21 **Marina Marrari, Kendra Daly, Alexander Timonin and Tatjana Semenova**
The zooplankton of Marguerite Bay, western Antarctic Peninsula: abundance, distribution, and controls on interannual variability

PS1-P22 **Ricardo Palomares and Jaime Gómez-Gutiérrez**
Seasonal vertical distribution of copepods in the central Gulf of California, Mexico

PS1-P23 **Cécile Persohn, Pascal Lorance and Verena Trenkel**
Impact of environmental change on demersal fish growth: a comparative study

PS1-P24 **Langdon Quetin, Robin Ross, Maria Vernet, Wendy Kozlowski, Lynn Yarmey, Alex Lowe, Margaret Amsler, Christian Fritsen, Oscar M.E. Schofield and Deborah Steinberg**
Grazing by larval Antarctic krill and phytoplankton dynamics during the fall west of the Antarctic Peninsula

PS1-P25 **Jingling Ren, Jing Zhang, Wei Wei Dou and Guo Ling Zhang**
Scavenged aluminium during the spring bloom and its records in the sediments of the Yellow Sea

PS1-P26 **Christian J. Salvadeo, Daniel Lluch-Belda, Alejandro Gómez-Gallardo and Jorge Urbán-Ramírez**
Climate change and poleward shift in a dolphin species at the northeastern Pacific

PS1-P27 **Jie Shi, Hao Wei, Liang Zhao and Ye Yuan**
Hydrodynamic structures in a typical coastal mariculture area of China: observations and simulations

PS1-P28 **Xiaoxia Sun and Song Sun**
Long-term changes in the ecosystem of Jiaozhou Bay, China

PS1-P29 **Qisheng Tang, Jilan Su, Daji Huang, Xianshi Jin, Xiuren Ning, Song Sun, Hao Wei, Tian Xiao and Jing Zhang**
Classification of ecological geography of the Yellow Sea

PS1-P30 **Brenda Temperoni and Maria Delia Viñas**
Seasonal reproductive biology of *Oithona nana* (Copepoda: Cyclopoida): first record in temperate coastal waters off Argentina

PS1-P31 **Nikolay Usov, Daria Martynova, Igor Primakov and Inna Kutcheva**
Long-term zooplankton dynamics and environment in the White Sea since 1957 (WH-O4)

PS1-P32 **Ying Wu, Na Wang and Jing Zhang**
Compound-specific isotope analysis of fatty acids as indicators of trophic interactions in East China Sea ecosystem

PS1-P33 **Bo Zhang, Qisheng Tang and Xianshi Jin**
Functional groups of fish assemblages and their major species at a high trophic level in the East China Sea

PS1-P34 **Fang Zhang, Song Sun and Chaolun Li**
Large jellyfish assemblage in the Yellow Sea and East China Sea

PS1-P35 **Fang Zhang, Song Sun and Chaolun Li**
The seasonal and geographical distribution of hydromedusae, siphonophores and ctenophores in the China Seas

PS1-P36 **Jing Zhang, Zhuo-Yi Zhu, Ying Wu, Lei Zhang, Jin-Zhou Du, Su-Mei Liu, Jing-Ling Ren and Gui-Ling Zhang**
Seasonal hypoxia off the Changjiang Estuary and in the inner shelf of East China Sea

PS1-P37 **Tao Zuo**
Biomass size-spectra of plankton in the Yellow Sea

Plenary: Thursday 25 June

S3: Ecosystem structure and functioning

Chairs: Salvador Lluch-Cota, Yasunori Sakurai, George Hunt and Qisheng Tang

08:30 **David G. Ainley and K. David Hyrenbach**
Top-down and bottom-up factors affecting seabird population trends in the California Current System (1985-2006) (S3-O10)

08:45 **Jeffrey Runge, Walter Golet, Jason Stockwell, Graham Sherwood, Andrew Pershing and Molly Lutcavage**
Bottoms up: potential effects of environmental forcing on apex predators in the Gulf of Maine (S3-O11)

09:00 **Eugene J. Murphy, Jon L Watkins, Phil Trathan, Michael Meredith, Simeon Hill, Nadine Johnston, Rachel Cavanagh, Eileen Hofmann, John Turner and Andrew Clarke**
Changes in the Antarctic marine ecosystems: uncertainties in drivers and responses (S3-O12)

09:15 **Christian Möllmann, Thorsten Blenckner, Rabea Diekmann, Anna Gaardmark, Lena Bergström, Michele Casini, Bärbel Müller-Karulis, Juha Flinkman and Martin Lindegren**
Climate-induced synchronous regime shifts along environmental and diversity gradients in Baltic Sea sub-systems (S3-O13)

09:30 **Evgeny Pakhomov, Brian Hunt, Yasha Podeswa and Ulrich Bathmann**
Preliminary investigation of the mesopelagic food webs in the tropics and Antarctic using stable isotope analyses (S3-O14)

09:45 **Geir Ottersen, Esben Moland Olsen, Nils Chr. Stenseth**
Spawning stock and recruitment relationship in North Sea cod shaped by food and climate (S3-O15)

10:00 ***Tea/coffee break***

S4: Ecosystem observation, modelling and prediction

Chairs: Harold Batchelder, Roger Harris and Dale Haidvogel

10:30 **David Mackas and Sonia Batten**
Perspectives on a decade of change in the Alaska Gyre: a comparison of two deep ocean zooplankton time series (S4-O1)

10:45 **Kerim Aydin, Nicholas A. Bond, Enrique Curchitser, Georgina Gibson, Katherine Hedstrom, Albert Hermann and Ivonne Ortiz**
Integrating data, fieldwork, and models into an ecosystem-level synthesis: the modelling challenge of the Bering Ecosystem Study/Bering Sea Integrated Research Program (S4-O2)

11:00 **Naoki Yoshie, Kosei Komatsu, Shin-ichi Ito, Takuhiko Kameda, Tsuneo Ono, Kiyotaka Hidaka, Toru Hasegawa, Akira Kuwata, Miwa Nakamachi, Yuji Okazaki, Takeshi Okunishi, Kazuaki Tadokoro, Hiroaki Saito and Yasuhiro Yamanaka**
Dynamics of lower-trophic-level ecosystems in five ecological regions in the western North Pacific simulated by an ecosystem model eNEMURO (S4-O3)

11:15 **Rubao Ji, Cabell Davis, Changsheng Chen and Robert C. Beardsley**
Modelling spatio-temporal distributional patterns of copepod populations in the Gulf of Maine - Georges Bank region (S4-O4)

11:30 **Ana Sirovic and John Hildebrand**
Using passive acoustics to model blue whale habitat off the Western Antarctic Peninsula (S4-O5)

11:45 **Anne Hollowed**
A global initiative to forecast climate change impacts on fish and shellfish (S4-O6)

12:00 **Frode Vikebo, Jon Albretsen and Bjørn Ådlandsvik**
Operational larval drift modelling in the northeast North Atlantic (S4-O7)

12:15 **Olivier Maury**
Size-structured energy fluxes through global pelagic ecosystems: seasonal, inter-annual and decadal variability in the three oceans (S4-O8)

12:30 ***Lunch***

14:00 **James Ruzicka, Elizabeth Daly, Cheryl A. Morgan, Robert Emmett, Jeannette Zamon, Richard Brodeur and Thomas Wainwright**
Inter-annual variability in the northern California Current food web structure: revealing trophic pressures upon juvenile salmon (S4-O9)

14:15 **Marcos Llope, Georgi Daskalov, Tristan Rouyer, Vesselina Mihneva, Kung-Sik Chan and Nils Stenseth**
Predicting regime shifts under different scenarios in the Black Sea (S4-O10)

14:30 **Maria Garcia Rojas, Deborah Thiele and Edwin Chester**
Antarctic sea ice: measuring habitat complexity, and seasonal and regional variability in habitat use for minke whales (S4-O11)

14:45 **Eleuterio Yanez, Francisco Plaza, Nibaldo Rodríguez, Juan Gutiérrez-Estrada, Guido Plaza, Inmaculada Pulido-Calvo and Cinthya Borquez**
Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) landings forecast off northern Chile: a multivariate neural networks ecosystemic approach (S4-O12)

15:00 **Shin-ichi Ito, Naoki Yoshie, Takeshi Okunishi, Tsuneo Ono, Yuji Okazaki, Akira Kuwata, Taketo Hashioka, Kenneth A. Rose, Bernard A. Megrey, Michio J. Kishi, Miwa Nakamachi, Yugo Shimizu, Shigeho Kakehi, Hiroaki Saito, Kazutaka Takahashi, Kazuaki Tadokoro, Akira Kusaka and Hiromi Kasai**
Lower-trophic-ecosystem monitoring in the Oyashio region and application of an automated approach for calibrating the NEMURO nutrient-phytoplankton-zooplankton food web model in the Oyashio region (S4-O13)

15:15 **Thomas Wilderbuer, Nicholas A. Bond and William Stockhaussen**
An example of estimating future Bering Sea northern rock sole productivity from statistical downscaled IPCC models (S4-O14)

15:30 **Poster session 2: Ecosystem observation, modelling and prediction**

S5: Workshops feedback

Chair: Manuel Barange

16:30 **Workshops feedback**

19:00 **Conference banquet (Hotel Grand Pacific)**

Poster Session 2: Ecosystem observation, modelling and prediction

15:30, Thursday 25 June

PS2-P1 **Harold Batchelder, Enrique Curchitser and Katherine Hedstrom**
Modelling physical processes in the northeast Pacific: model-data comparisons for assessing when model skill is sufficient as a basis for ecosystem simulation

PS2-P2 **Gary Borstad, William Crawford, Leslie Brown, Richard Thomson, Mark Hipfner, Mar Martinez and Peter Willis**
Satellite oceanography near the seabird colony on Triangle Island, British Columbia, Canada

PS2-P3 **Francois Carlotti**
Overview of the French GLOBEC activities

PS2-P4 **Francois Carlotti**
A synthesis of observation and modelling of zooplankton spatio-temporal distributions in the northwestern Mediterranean Sea

PS2-P5 **Wei Cheng, Albert Hermann, Nancy Kachel and Phyllis Stabeno**
Mechanisms of sustained primary productivity in the Portlock Bank region: modelling and observations

PS2-P6 **Enrique Curchitser, Kenneth A. Rose, Katherine Hedstrom, Jerome Fiechter, Shin-ichi Ito, Salvador Lluch-Cota and Bernard A. Megrey**
Marine ecosystem models: strategies, applications, and future directions

PS2-P7 **Kevin Denis, Jean-Yves Parent, Véronique Rousseau, Christiane Lancelot and Philippe Grosjean**
Near-real time monitoring of plankton in the Belgian coastal zone using Zoo/PhytoImage and the FlowCAM

PS2-P8 **José F. Domínguez, Demetrio de Armas and José Escánez**
Overview of oceanographic features in the Canary Basin

PS2-P9 **Øyvind Fiksen and Christian Jørgensen**
Is prey abundance important for growth and survival in larval cod?

PS2-P10 **Amane Fujiwara, Toru Hirawake, Koji Suzuki and Sei-Ichi Saitoh**
Development of an empirical model to estimate phytoplankton size structure using in-water optical properties in the Chukchi and Bering shelf region

PS2-P11 **May Gómez, Ico Martinez, Santiago Hernández-León and Theodore Packard**
Kleiber's Law works because biomass packages the respiratory ETS

PS2-P12 **Manuel Hidalgo, Yvonne Gusdal, Gjert E. Dingsør, Lorenzo Ciannelli, Dag Øistein Hjermann, Geir Ottersen, Leif C. Stige, Ingerid Fossum, Arne Melson and Nils Stenseth**
Relative contribution of oceanographic conditions and spawning aggregations to cod larvae and 0-group seascape in the Barents Sea under different climatic scenarios

PS2-P13 **Arantza Iriarte, Guillermo Aravena, Ibon Uriarte, Fernando Villate, Marcos Llope and Nils Stenseth**
Modelling the effect of temperature and chlorophyll-*a* on dissolved oxygen in two contrasting estuaries of the Bay of Biscay

PS2-P14 **Shin-ichi Ito, Taizo Morioka, Yasuhiro Ueno, Satoshi Suyama, Masayasu Nakagami, Akihiro Shiomoto, Fumitake Shido and Michio J. Kishi**
Pacific saury response to climate change and its improvements by considering the influence of Japanese sardine and laboratory experimental approaches

PS2-P15 **Jihong Zhang, Jianguang Fang, Zengjie Jiang and Wei Wang**
Effect of large-scale long-line mariculture on ecosystem of Sungo Bay: results of numerical model simulation

PS2-P16 **Yang Soon Kang, Young Shil Kang and Heon Meen Bae**
The National Investigation of Marine Ecosystem and some results in the seas adjacent to the Korean peninsula

PS2-P17 **Michio J. Kishi and Fumika Komatsu**
The effect of climate change on the growth of Japanese chum salmon (*Oncorhynchus keta*) and other pelagic fish using a bioenergetics model coupled with a three-dimensional lower trophic ecosystem model, NEMURO

PS2-P18 **Thomas Kline**
Empirical evidence for meso-scale forcing in Gulf of Alaska based upon the variability in the stable carbon isotopic composition of northern lampfish, *Stenobrachius leucopsarus* (Myctophidae) in relation to copepods and marine survival rate of salmon

PS2-P19 **Keita Kodama, Toshihiro Horiguchi, Gen Kume, Masaaki Oyama, Jeong-Hoon Lee, Atsuko Yamaguchi, Yasuyuki Shibata, Hiroaki Shiraishi, Masatoshi Morita and Makoto Shimizu**
Long-term dynamics of the megabenthic assemblage in Tokyo Bay, Japan: possible linkage to environmental variations

PS2-P20 **Kui Wang, Jianfang Chen, Haiyan Jin, Mingming Jin, Hongliang Li, Yong Lu, Jie Xu and Wenliang Wang**
Seasonal and spatial variations in the limiting factor regulating phytoplankton growth in the Yangtze River estuary and adjacent East China Sea

PS2-P21 **Brie Lindsey and Harold Batchelder**
Diel-vertical migration behaviour of *Euphausia pacifica* in a dynamic coastal upwelling environment: 2-D modelling at the Oregon coast

PS2-P22 **Chenggang Liu, Xiuren Ning, Ming Liu, Tian Xiao, Qiang Hao, Hao Wei and Jie Shi**
Process study of spring phytoplankton bloom in the Yellow Sea

PS2-P23 **Eddie Loos and Maycira Costa**
The inherent and apparent optical properties of the Strait of Georgia, British Columbia, Canada

PS2-P24 **Gorka Merino, Manuel Barange, and Christian Mullon**
Modelling the potential impacts of aquaculture expansion and climate fluctuations on global reduction fisheries and fishmeal markets

PS2-P25 **Eugene J. Murphy, Nadine Johnston, Rachel Cavanagh and Eileen Hofmann**
Integrating Climate and Ecosystem Dynamics: circumpolar analyses of Southern Ocean ecosystems

PS2-P26 **Xiuren Ning, Qiang Hao and Fengfeng Le**
Timing of spring phytoplankton bloom before development of the thermocline in the central southern Yellow Sea

PS2-P27 **Takeshi Okunishi, Taketo Hashioka, Takashi Sakamoto, Naoki Yoshie, Hiroshi Sumata, Shin-ichi Ito, Yumiko Yara and Yasuhiro Yamanaka**
Impacts of climate change on growth and migration of Japanese sardine (*Sardinops melanostictus*) in the western North Pacific

PS2-P28 **M. Borja Aguiar-González, May Gómez, Elisa Berdalet, Sylvie Roy and Ted Packard**
Metabolic theory of ecology cannot predict respiration during nutrient limitation in marine bacteria

PS2-P29 **Theodore Packard and May Gómez**
Modelling zooplankton respiration from ETS activity

PS2-P30 **Philippe S. Sabarros, David Grémillet, Sophie Bertrand, Raphaël Duboz, Nils Chr. Stenseth and Eric Machu**
Determinism of seabird foraging trajectories – a modelling approach

PS2-P31 **Cosimo Solidoro, Donata Melaku Canu, Vinko Bandelj, Gianpiero Cossarini and Simone Libralato**
A multi- ecological models analysis of effects of global changes on fishing and aquaculture activities in coastal area

PS2-P32 **Christoph Stegert, Andreas Moll and Wilfried Kühn**
Simulation of zooplankton prey fields in the German Bight to study sprat growth variability in time and space

PS2-P33 **Ronald Tanasichuk**
The influence of interannual variations in euphausiid population productivity on the production of herring and salmon along the west coast of Vancouver Island, Canada, with implications for understanding ecosystem function

PS2-P34 **Sally Thorpe, Eugene J. Murphy, Jonathan Watkins, Geraint Tarling and Martin Robbins**
Modelling the circumpolar distribution of Antarctic krill

PS2-P35 **Meng Zhou, Francois Carlotti, Kurt Tande and Yiwu Zhu**
Biomass fluxes and biomass spectra in an ecosystem model

Plenary: Friday 26 June

S6: Ecosystem approach to management

Chairs: Dave Checkley, Keith Brander and Astrid Jarre

08:30 **Lynne J. Shannon, Astrid Jarre and Samantha Petersen**
Developing a science base for the ecosystem approach to South African fisheries (S6-O1)

09:00 **Astrid Jarre, Michael Smith, Janine Basson, Barbara Paterson and Lynne J. Shannon**
Models for synthesis and communication: expert systems and frame-based models as decision support tools in support of an ecosystem approach to fisheries management in the Benguela (S6-O2)

09:15 **Jason Link, Dawit Yemane, Lynne J. Shannon, Marta Coll, Yunne-Jai Shin, Louize Hill, Fatima Borges, Alida Bundy and Kerim Aydin**
Contrasting drivers of ecosystem response via the comparison of marine ecosystem indicators: multiple ecosystems and multiple indicators (S6-O3)

09:30 **Alida Bundy, Lynne J. Shannon, Marie-Joëlle Rochet, Yunne-Jai Shin, Louize Hill, Sergio Neira and Kerim Aydin**
A tripartite classification of ecosystem trends (S6-O4)

09:45 **Dian Gifford, John Steele and Jeremy Collie**
Combining constraints from predation and competition to determine expected fishery yields on Georges Bank (S6-O5)

10:00 ***Tea/coffee break***

10:30 **Cameron Ainsworth, Isaac Kaplan and Phil Levin**
Spatial ecosystem modelling of the upper Gulf of California using Atlantis (S6-O6)

10:45 **Howard Browman**
The ecosystem approach to managing marine resources is missing the ecology (S6-O7)

11:00 **Elizabeth Fulton, A.D.M. Smith and David Smith**
No silver bullets (S6-O8)

11:15 **Elizabeth Turner**
Transitioning of US GLOBEC results to applications (S6-O9)

S7: Marine ecosystem science: into the future

Chairs: Wendy Broadgate and Olivier Maury

11:30 **Ken Denman**
GLOBEC – a view from the outside (S7-O1)

11:55 **John Steele**
Beyond GLOBEC (S7-O2)

12:20 ***Lunch***

13:45 **John Field**
GLOBEC-IMBER transition (S7-O3)

14:00 **Julie Hall**
Integrated Marine Biogeochemistry and Ecosystem Research project (S7-O4)

14:25 **Discussion**

15:30 **Poster session 3: Ecosystem approach to management**

Session 8: Closing ceremony - views of the sponsors and chairs of GLOBEC

16:00 **Wendy Broadgate (IGBP)**

16:10 **Luis Valdes (IOC)**

16:20 **Stephen de Mora (PML)**

16:30 **Peter Burkill (SCOR)**

16:40 **Brian Rothschild (GLOBEC Chair, 1991-1995)**

16:45 **Roger Harris (GLOBEC Chair, 1995-2002)**

16:50 **Cisco Werner (GLOBEC Chair, 2003-2007)**

16:55 **Ian Perry (GLOBEC Chair, 2008-2009)**

17:00 **Concluding remarks**

Poster Session 3: Ecosystem approach to management

15:00, Friday 26 June

PS3-P1 **Kerim Aydin, Jennifer Boldt, Anne Hollowed and Pat Livingston**
Advances in ecosystem assessments in Alaska: responding to recent and predicted future interactions between climate and fisheries

PS3-P2 **Claudio Castillo-Jordán and Luis A. Cubillos**
Length-based inter-cohort growth variability in common sardine (*Strangomera bentincki*) off central Chile (1990-2007)

PS3-P3 **Maria Gasalla, Amanda Rodrigues and Luis Felipe Duarte**
A multi-fleet cost analysis of industrial fishing in São Paulo, Brazil

PS3-P4 **Ramasamygowder Jaganathan**
GIS and ecosystem assessment for sustainable fisheries management: a case of the Tamil Nadu coastal region, India, during pre- and post-tsunami

PS3-P5 **Michael D. Smith, Astrid Jarre and Anthony M. Starfield**
Modelling regime shifts in the Southern Benguela: a frame-based approach

PS3-P6 **Jianguang Fang, Jihong Zhang, Zengjie Jiang and Yuze Mao**
Development of Integrated Multi-trophic Aquaculture in Sungo Bay, China

PS3-P7 **William T. Peterson, Edmundo Casillas, Hui Liu and Cheryl A. Morgan**
Forecasting returns of coho and chinook salmon in the northern California Current: a role for high-frequency long term observations

PS3-P8 **Marta Coll, Lynne J. Shannon, Dawit Yemane, Jason Link, Henn Ojaveer, Yunne-Jai Shin, Sergio Neira, Didier Jouffre, Pierre Labrosse, Kerim Aydin and Fatima Borges**
Ranking ecological relative status of exploited ecosystems using multiple indicators

PS3-P9 **Yunne-Jai Shin, Lynne J. Shannon, Alida Bundy, Jason Link, Marta Coll, Julia Blanchard, Kerim Aydin and Didier Jouffre**
Comparing indicators across fished marine ecosystems: the IndiSeas experience

PS3-P10 **Mali Skogen, Dag Øistein Hjermann, Geir Ottersen and Nils Christian Stenseth**
Population dynamics of blue whiting: density-dependent and density-independent effects

PS3-P11 **María José Zúñiga Basualto and Luis A. Cubillos**
Pattern of spatial occupation of the realised spawning habitat of anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) off central Chile

Workshop A: Modelling ecosystems and ocean processes: the GLOBEC perspective of the past present and future

Chairs: ***Enrique Curchitser, Alejandro Gallego, Michio Kishi and Emanuele Di Lorenzo***

Monday 22 June

08:30 **Introduction**

Topic 1: Physical and biological modelling

08:40 **Francisco Werner**
Topic 1 review: Physical and biological modelling (WA-O1)

09:00 **John Klinck, Michael Dinniman and Laurence Padman**
Large scale context for oceanic processes on the west Antarctic Peninsula (WA-O2)

09:20 **Michael Dinniman, John Klinck and Walker Smith, Jr.**
Differences in the fate of Circumpolar Deep Water advected onto the continental shelf in the Ross Sea and the West Antarctic Peninsula (WA-O3)

09:40 **Ayan Chaudhuri, Avijit Gangopadhyay and James Bisagni**
Response of the western North Atlantic to characteristic high and low NAO phases (WA-O4)

10:00 ***Tea/coffee break***

10:30 **Albert Hermann**
Regional modelling of the coastal Gulf of Alaska: progress and pitfalls (WA-O5)

10:50 **Kenneth Coyle, Albert Hermann and Sarah Hinckley**
Northern Gulf of Alaska shelf ecosystem: refining our understanding of the spatial distribution of plankton production and biomass using GLOBEC observations and an ecosystem model embedded in a ROMS circulation model of the shelf environment (WA-O6)

11:10 **Angelica Pena and Michael Foreman**
Modelling plankton dynamics and biogeochemical cycles on the Pacific coast of Canada (WA-O7)

11:30 **Wendy Gentleman and Pierre Pepin**
Improving confidence in copepod mortality estimates: choosing formulas and quantifying errors (WA-O8)

11:50 **Susan Allen and Megan Wolfe**
An example of the use of simple models for process studies (WA-O9)

12:10 **Georgina Gibson**
Simulating lower trophic levels ecosystem dynamics during ‘cold’ and ‘warm’ years: an ecosystem model for the Bering Sea (WA-O10)

12:30 ***Lunch***

14:00 **Feng Zhou and Daji Huang**
Variations of the Changjiang diluted water and their potential ecological influences in summer of 1999 and 2006 (WA-O11)

14:20 **Discussion Topic 1: Physical and biological modelling**

Topic 2: Biological and advanced ecosystem models

14:50 **Raghu Murtugudde**
Regional earth system prediction: microbes to man (WA-O12)

15:10 **Louis Botsford, Mike Fogarty, Francis Juanes, Alan Hastings, Steve Teo, Matt Holland and Hui-Yu Wang**
Variation in species response to environmental variability (WA-O13)

15:30 ***Tea/coffee break***

16:00 **Steven Teo, Louis Botsford and Alan Hastings**
Environmental influences on marine survival and maturity schedule of coho salmon from California to Alaska (WA-O14)

16:20 **Michael Foreman, Dario Stucchi, Ming Guo and Piotr Czajko**
A coupled biophysical model for resource management in the Broughton Archipelago (WA-O15)

16:40 **Julie Keister, Neri Mariani, Vincent Combes, Cheryl A. Morgan, William T. Peterson and Emanuele Di Lorenzo**
Model experiments link zooplankton species distribution and ocean transport in the Northern California Current (WA-O16)

17:00 **Christoph Stegert, Rubao Ji, Cabell Davis and Andreas Moll**
Congener copepods in the northern Atlantic Ocean: an inter-regional modelling analysis on the response to changes in environmental conditions (WA-O17)

17:20 **Myron Peck, Hans-Harald Hinrichsen, Wilfried Kühn, Ute Daewel, Thomas Pohlmann and Rudiger Voss**
Biophysical modelling of early life stages of sprat in the North and Baltic Seas: process knowledge gained during the German GLOBEC programme (WA-O18)

17:40 **Pavel Chernyshkov**
Seasonal and annual distribution of small pelagic fish stocks related to environmental conditions in the Canary upwelling area from 1994 to 2007 (WA-O19)

Tuesday 23 June

08:30 **Announcements**

08:40 **Martin Huret, Pierre Petitgas, Fabien Léger and Mathieu Woillez**
Sensitivity of anchovy larval dispersal to climate change in the Bay of Biscay (WA-O20)

09:00 **Discussion Topic 2: Biological and advanced ecosystem models**

Topic 3: Frontiers in ecosystem modelling

09:20 **Mick Follows**
Topic 2 review. A self-organising approach to modelling marine ecosystems (WA-O21)

09:40 **Jerome Fiechter, Ralph Milliff, Chris Wilke, Andy Moore, Mark Berliner and Zack Powell**
Topic 3 review: Estimating ecosystem model uncertainties and climate change impacts in the North Pacific Ocean (WA-O22)

10:00 ***Tea/coffee break***

10:30 **Mathieu Woillez, Pierre Petitgas, Martin Huret, Caroline Struski and Fabien Léger**
Monitoring spatial patterns for ecosystem assessment: the Bay of Biscay pelagic zone (WA-O23)

10:50 **Jason Link, Robert Gamble and Elizabeth Fulton**
Presentation of an ATLANTIS application for the NEUS ecosystem: a scary model, lots of data, comforting validation, and a naïvely optimistic step towards Ecosystem Approaches to Management (WA-O24)

11:10 **Ivonne Ortiz Fortunat, Kerim Aydin and Albert Hermann**
The FEAST model for the Bering Sea: forage/euphausiid abundance in space and time (WA-O25)

11:30 **Enrique Curchitser, Kenneth A. Rose, Katherine Hedstrom, Jerome Fiechter, Shin-ichi Ito, Salvador Lluch-Cota and Bernard A. Megrey**
Marine ecosystem models: strategies, applications, and future directions (WA-O26)

11:50 **Hiroshi Sumata, Taketo Hashioka, Naosuke Okada, Maki Aita, Naoki Yoshie, Takashi Sakamoto, Tatsuo Suzuki and Yasuhiro Yamanaka**
Eddy permitting simulations of 3D-NEMURO in the global ocean (WA-O27)

12:10 **Michael Follows**
What regulates large scale patterns of diversity in marine microbes? (WA-O28)

12:30 ***Lunchfs***

14:00 **Sarah Gaichas, Kerim Aydin, Garry Odell and Robert Francis**
Complex systems models of trophic and fishing interactions with implications for research and management (WA-O29)

14:20 **Elizabeth Fulton, Randall Gray, Miriana Sporcic and Roger Scott**
Using agent-based models to capture the dynamic nature of marine systems (WA-O30)

14:40 **Thomas Anderson and Bablu Sinha**
Emergent properties of a complex ecosystem model in a global general circulation model: sensitivity to grazing parameterisations (WA-O31)

15:00 **Discussion Topic 3: Frontiers in ecosystem modelling**

15:30 ***Tea/coffee break***

Topic 4: Climate change in regional marine ecosystems

16:00 **Ken Drinkwater**
Topic 4 review. Climate change in regional marine ecosystems: requirements and challenges (WA-O32)

16:20 **Jason Holt, Icarus Allen, Robert Holmes and Manuel Barange**
Climate change effects on primary production in coastal and shelf seas (WA-O33)

16:40 **Nicholas A. Bond, Muyin Wang and Albert Hermann**
Evaluation of the oceanographic component of climate models used by the IPCC (WA-O34)

17:00 **Emanuele Di Lorenzo**
Linking Pacific climate variability with eastern boundary ecosystem dynamics (WA-O35)

17:20 **Vadim Navrotsky**
Life and global climate change: the world ocean input (WA-O36)

17:40 **Discussion Topic 4: Climate change in regional marine ecosystems**

Workshop B: Comparisons of processes and climate impacts in sub-Arctic and Arctic marine ecosystems: observations and modelling approaches

Chairs: ***Eileen Hofmann, George Hunt, Bernard A. Megrey, Eugene Murphy, Sei-ichi Saitoh and Hyoung-Chul Shin***

Monday 22 June

08:30 **Introduction to the goals of the workshop**

Topic 1: Setting the stage - climate studies

08:40 **Charles Greene**
Remote climate forcing of regime shifts in northwest Atlantic shelf ecosystems (WB-O1)

09:10 **Eugene Murphy**
Informal presentation on climate studies (WB-O2)

Topic 2: Arctic and Antarctic system comparisons

09:40 **Hyoung Chul Shin, Jeong Hee Shim, Young Chul Kang, Jisoo Park, Sung Ho Kang and Hyun Cheol Kim**
South Shetland Islands, resemblance and relevance to other polar systems (WB-O3)

10:00 ***Tea/coffee break***

10:30 **Eugene J. Murphy, Eileen Hofmann, Rachel Cavanagh, Simeon Hill and Nadine Johnston**
Modelling Southern Ocean ecosystems: developing food web modelling in ICED (WB-O4)

10:50 **George Hunt**
Informal presentation of Arctic and Antarctic system comparisons (WB-O5)

11:10 **Eileen Hofmann**
The Southern Ocean Global Ocean Ecosystem Dynamics programme (WB-O6)

11:30 **Discussion**
Led by Kenneth **Drinkwater**

Topic 3: Lower trophic level comparisons

14:00 **Kohei Mizobata, Koji Shimada, Atsushi Matsuoka, Amane Fujiwara and Sei-Ichi Saitoh**
The spatiotemporal chlorophyll-*a* distribution under the influence of the changing Arctic ice-ocean circulation (WB-O7)

14:20 **Jisoo Park, Sinjae Yoo, Im-Sang Oh**
Seasonal and interannual variability of SeaWiFS chlorophyll-*a* in the south Atlantic sector of the Southern Ocean (WB-O8)

14:40 **Erica Head, Webjørn Melle, Pierre Pepin, Espen Bagøien and Cecilie Broms**
A comparative study of the ecology of *Calanus finmarchicus* in the Labrador and Norwegian Seas (WB-O9)

15:00 **Lewis Incze, Scott Kraus, David Fields, Nicholas Wolff, Adam Baukus, Andone Lavery, Peter Stevick and James Lerczak**
Internal waves, topographic highs and upper trophic level feeding in the Gulf of Maine (WB-O10)

15:30 ***Tea/coffee break***

16:00 **Sally Thorpe, Eugene J. Murphy, Geraint Tarling, Jonathan Watkins and Martin Robbins**
Modelling the life cycle and distribution of Antarctic krill (WB-O11)

16:20 **Kenneth Drinkwater**
Some results and thoughts on comparative studies within sub-Arctic seas (WB-O12)

16:50 **Discussion: implications of differences in lower trophic level processes and limiting controls**
Led by Bernard A. **Megrey**

Tuesday 23 June

Topic 5: Arctic and Antarctic top predator studies

08:30 **James Lovvorn, Jacqueline Grebmeier, Lee Cooper, Joseph Bump and Samantha Richman**
Modelling the energetics of an avian bottom predator during long-term change in sea ice and benthos of the Bering Sea (WB-O13)

08:50 **Konstantin Rogachev and Natalya Shlyk**
Split-up of the Alaskan Stream into Aleutian eddies and their impact on lanternfishes (WB-O14)

09:10 **John Bengtson**
The importance of sea ice to seals in sub-Arctic and Antarctic marine ecosystems (WB-O15)

09:30 **Martin Renner, Julia Parrish, G. Byrd, John Piatt, Kathy Kuletz and George Hunt, Jr.**
Modelling the distribution and abundance of marine top-predators in relationships to physical parameters sensitive to climate change (WB-O16)

09:50 **Anne-Cecile Dragon, Frederic Bailleul, Cedric Cotte, Stephane Blain, Lionel Chiron, Jean-Benoit Charassin, Fabien Roquet, Young-Hyang Park, Yves Cherel and Christophe Guinet**
Southern elephant seals instrumented with oceanographic sensors: insights into their foraging ecology and input as autonomous samplers (WB-O17)

10:00 ***Tea/coffee break***

10:30 **Daniel Costa, Daniel Crocker, Mike Fedak, Michael Goebel, Luis Huckstadt and Birgette McDonald**
Habitat selection of three seals in the Western Antarctic Peninsula (WB-O18)

10:50 **Discussion: Arctic and Antarctic predators**
Led by George **Hunt**

12:00 **Summary of workshop and discussion of workshop products**
Led by Eileen **Hofmann**, George **Hunt**, Bernard A. **Megrey**, Eugene **Murphy**, Sei-ichi **Saitoh** and Hyoung Chul **Shin**

Workshop C: Worldwide large-scale fluctuations of sardine and anchovy: revisiting Schartzlose *et al.* (1999)

Chairs: ***Jürgen Alheit, Salvador Lluch-Cota and Carl van der Lingen***

This will be a Dahlem style workshop where invited participants prepare background material which is distributed prior to the workshop. During the workshop there will be only discussion and a few very short *ad-hoc* presentations. Background material can be viewed at http://www.globec.org/structure/regional/spacc/OSMwksp7.htm. Submitted abstracts are listed below.

Monday 22 - Tuesday 23 June

Timothy Baumgartner, Guillermo Auad, Kevin Hill and Arthur Miller
Response of sardine recruitment success to climate forcing on the California Current (WC-O1)

Anja Kreiner and Erling Stenevik
Horizontal distribution of early life stages of pelagic fish species in relation to temperature and dissolved oxygen in the northern Benguela during a low upwelling phase (WC-O2)

Miguel Ñiquen, Cecilia Peña and Marilú Bouchon
Strong fluctuations of pelagic fish stock in the southeast Pacific (WC-O3)

Yao Sun, Haibo Jia, Meixun Zhao, Xiaoxia Sun and Qisheng Tang
The spatial distribution and back-calculation potential of anchovy-scale-deposition information in the anaerobic sediments of the Yellow and East China Seas (WC-O4)

Workshop D: Krill biology and ecology in the world's oceans

Chairs: ***Angus Atkinson, Jaime Gómez-Guitérrez, Bettina Meyer and William Peterson***

Monday 22 June

08:30 **Introduction to workshop**

08:40 **Angus Atkinson and Geraint Tarling**
Krill research at the British Antarctic Survey: current and future study areas, achievements and sticking points (WD-O1)

09:00 **So Kawaguchi and Stephen Nicol**
Australian research on Antarctic krill (WD-O2)

09:20 **Bettina Meyer**
Krill research at the Alfred-Wegener Institute, Germany: current and future activities (WD-O3)

09:40 **Peter Wiebe, Carin Ashjian, Gareth Lawson, Nancy Copley and Andone Lavery**
Horizontal and vertical distribution of euphausiid species on the Western Antarctic Peninsula Southern Ocean GLOBEC study site (WD-O4)

10:00 ***Tea/coffee break***

10:30 **Kendra Daly and Marina Marrari**
Distribution, overwintering strategies and recruitment of Antarctic krill: Southern Ocean GLOBEC process studies (WD-O5)

10:50 **Christian Reiss**
Antarctic krill (*Euphausia superba*) research in the South Shetland Islands, Antarctica: linking physical processes and biology to the reproductive success of land-based predators (WD-O6)

11:10 **Robin Ross and Langdon Quetin**
Ecology of Antarctic euphausiids within the Palmer LTER region west of the Antarctic Peninsula 1990-2008 (WD-O7)

11:30 **Deborah K. Steinberg, Oscar M.E. Schofield, William R. Fraser and Hugh W. Ducklow**
Future plans for krill and other macrozooplankton research in the Palmer, Antarctica Long-Term Ecological Research Program (WD-O8)

11:50 **Sergey Ignatyev, Ekaterina Solomonova and V. Timofeev**
The main results of study of the biological state of krill in the coastal waters of the Argentines Islands archipelago (Antarctic Peninsula) (WD-O9)

12:10 **Eileen Hofmann and Eugene J. Murphy**
Modelling krill biology and ecology – current status (WD-O10)

12:30 ***Lunch***

14:00 **Patricia Ayón, Tarsicio Antezana, Rubén Escribano and Pepe Espinoza**
Advances in the knowledge on distribution and the ecological role of euphausiids in the Humboldt Current System (WD-O11)

14:20 **Jaime Gómez-Gutiérrez, Israel Ambriz-Arreola, Iván Castellanos-Osorio, Roxana De Silva-Dávila, Jaime Farber-Lorda, Rebeca Gasca, Diane L. Gendron, Bertha E. Lavaniegos, Samuel Martínez-Gómez and Carlos J. Robinson**
Biology and ecology of subtropical euphausiids: research from Mexico (WD-O12)

14:40 **William T. Peterson**
An overview of krill research in the California Current, Gulf of Alaska and Bering Sea (WD-O13)

15:00 **David Mackas, Douglas Sameoto, Yvan Simard and Ron Tanasichuk**
Dominant themes in Canadian research on euphausiid ecology: spatial aggregation, interannual variability, and interactions with vertebrate predators (WD-O14)

15:20 ***Tea/coffee break***

16:00 **Yuji Okazaki and Kazuaki Tadokoro**
Euphausiid research in Japan (WD-O15)

16:20 **Song Sun and Zhencheng Tao**
Euphausia pacifica ecology research in the Yellow Sea and East China Sea (WD-O16)

16:40 **Jeannette Yen, Kimberly Catton and Donald Webster**
The hydrodynamic wake of two species of swimming krill (WD-O17)

Tuesday 23 June

08:30 **Hyoung Chul Shin, Sejong Ju, Young Shil Kang, Hyung Ku Kang, Won Duk Yoon, Hae Lip Suh, Don Hyug Kang and Chul Park**
Korean euphausiid research efforts (WD-O18)

08:50 **Stein Kaartvedt, Thor A. Klevjer and Anders Røstad**
Use of bottom mounted, upward facing echosounders to study the behaviour of krill (WD-O19)

09:10 **Leah Feinberg, Hongsheng Bi and William T. Peterson**
Stage specific mortality rates for *Euphausia pacifica* larvae from the Oregon coast (WD-O20)

09:30 **Jarrod Santora, William Sydeman, Christian Reiss, Sonia Batten, Steve Ralston and Richard Veit**
Response of predators to hierarchical euphausiid patch dynamics in the Antarctic, California Current and North Pacific (WD-O21)

09:50 ***Tea/coffee break***

10:20 **Discussion**

12:30 ***Lunch***

14:00 **Discussion**

15:30 ***Tea/coffee break***

16:00 **Discussion**

Workshop D posters

WD-P1 **Matthew Brown, So Kawaguchi, Steven Candy and Patti Virtue**
Temperature effects on the growth and maturation of Antarctic krill (*Euphausia superba*)

WD-P2 **Qian Gao, Zhao-li Xu and Yun Li**
Effects of global warming on the abundance and distribution of *Pseudeuphausia sinica* in the East China Sea

WD-P3 **Jaime Gómez-Gutiérrez So Kawaguchi and Stephen Nicol**
Global diversity, prevalence and intensity of the parasites of euphausiids (krill)

WD-P4 **Jaime Gómez-Gutiérrez, Carlos J. Robinson, So Kawaguchi and Stephen Nicol**
Euphausiid species abundance and swarming behaviour influence their parasitic load: a comparison between *Nyctiphanes simplex* and *Nematoscelis difficilis* along northwestern Mexico

WD-P5 **Xue-zhong Chen, Zhao-li Xu and Hong-liang Huang**
Analysis of the exploitation strategies to the Antarctic krill for China

WD-P6 **Se Jong Ju, Woong Seo Kim, Rachael Pleuthner and Henry Harvey**
The application of lipid trophic markers to track the diet history of T*hysanoessa rashii* in the Bering Sea

WD-P7 **Hui-Lian Liu, Song Sun, Zhencheng Tao, Ying Xu and Shiyun Sun**
Larval developmental pathway of *Euphausia pacifica* in the southern Yellow Sea off the China coast

WD-P8 **Hui-Lian Liu, Song Sun, Zhencheng Tao, Juan Chen and Liang Xue**
Length-weight relationships of *Euphausia pacifica* in the southern Yellow Sea off the China coast

WD-P9 **Valerie Loeb, Eileen Hofmann, John Klinck and Osmund Holm-Hansen**
ENSO and variability of the Antarctic Peninsula pelagic marine ecosystem

WD-P10 **Samuel Martínez-Gómez, Jaime Gómez-Gutiérrez and Carlos J. Robinson**
Seasonal somatic growth and egg production of *Nyctiphanes simplex* in the Gulf of California

WD-P11 **Jennifer Menkel and William T. Peterson**
What is the true biomass of krill? *Euphausia pacifica* and *Thysanoessa spinifera* in the California Current: a comparison of sampling methods and data sets

WD-P12 **David W. Murphy, Don R. Webster, So Kawaguchi, Rob King, Fotis Sotiropoulos and Jeannette Yen**
Kinematics of various swimming modes in Antarctic krill

WD-P13 **Stephanie Oakes, Langdon Quetin and Robin Ross**
Grazing of larval and juvenile Antarctic krill, *Euphausia superba*, on the natural community of sea ice biota

WD-P14 **Maria Andrea Pinones, Eileen Hofmann, Michael Dinniman and John Klinck**
Circulation on the Western Antarctic Peninsula: implications for biological production

WD-P15 **Anna Schukat, Reinhard Saborowski and Wilhelm Hagen**
Food utilization of the Antarctic euphausiids *Euphausia superba* and *Thysanoessa macrura*: ontogenetic and seasonal variations of digestive enzymes

WD-P16 **Zhao-li Xu**
Ecological distribution and pattern of euphausiids in the East China Sea

WD-P17 **Zhao-li Xu**
The optimal temperature and salinity of pelagic euphausiids in the East China Sea

Workshop E: Biogeochemistry of the oceans in a changing climate

Chairs: ***Francis Chan and Debby Ianson***

Monday 22 June

08:30 **Roberta Hamme, Sonia Batten, Maria Kavanaugh, William Crawford, Kathleen Dohan, Karina Giesbrecht, Jim Gower, Deirdre Lockwood, Christopher Sabine and Frank Whitney**
Widespread high-productivity event observed in the northeast Pacific, August 2008 (WE-O1)

09:00 **Daniel Harrison**
Culture bottle studies on the availability of micronutrients to support anthropogenic macronutrient driven photosynthesis in oligotrophic near shore ocean waters (WE-O2)

09:15 **Xiujun Wang and Michael Landry**
Regulation of carbon to phytoplankton ratio by light, nutrients and temperature in the equatorial Pacific: a model-data synthesis study (WE-O3)

09:30 **Ricardo Letelier**
Can we identify long-term microbial and biogeochemical trends in the eastern North Pacific? (WE-O4)

10:00 ***Tea/coffee break***

10:30 **Discussion: Biogeochemical observations needs in a changing climate**

10:45 **Andreas Schmittner**
Discussion: biogeochemical observations needs in a changing climate (WE-O5)

11:15 **Xiujun Wang, Raghu Murtugudde, Antonio Busalacchi, Dongxiao Zhang and Michael McPhaden**
Biogeochemical responses and feedbacks to the climate forcing in the tropical Pacific Ocean over the past decades (WE-O6)

11:30 **Stephanie Henson and Jorge Sarmiento**
How large will the oceanic ecosystem response to climate change be? (WE-O7)

11:45 **Laura Bianucci and Ken Denman**
Low oxygen and ocean acidification in the Vancouver Island shelf (WE-O8)

12:00 **Richard Matear**
Historical and future changes in the Southern Ocean biogeochemical cycling (WE-O9)

12:30 ***Tea/coffee break***

14:00 **James Christian**
Ocean biogeochemistry in the enhanced greenhouse (WE-O10)

14:30 **Discussion: Biogeochemical modelling challenges in a changing climate**

14:45 **Discussion: Workshop synthesis I. Ocean biogeochemistry in a changing climate -state of current understanding**

15:30 ***Tea/coffee break***

16:00 **Discussion: Workshop synthesis II. Ocean biogeochemistry in a changing climate -future directions**

Workshop F: Continuous Plankton Recorder surveys of the global ocean

Chairs: ***Sonia Batten and Peter Burkill***

Monday 22 June

Topic 1: Recent results from CPR surveys around the world

08:40 **Sonia Batten**
The North Pacific Continuous Plankton Recorder survey (WF-O1)

09:00 **Anthony Richardson, Graham Hosie, Frank Coman, Claire Davies, John Kitchener, David McLeod and Anita Slotwinski**
A new plankton observing programme: the Australian Continuous Plankton Recorder (AusCPR) survey (WF-O2)

09:20 **Sonia Batten and Graham Hosie**
SCAR Southern Ocean Continuous Plankton Recorder survey (WF-O3)

09:40 **Abigail McQuatters-Gollop and David Johns**
Changes in the northwest Atlantic phytoplankton community (WF-O4)

10:00 ***Tea/coffee break***

10:30 **Andrew Pershing, Charles Greene and Erica Head**
Response of northwest Atlantic plankton communities to freshwater anomalies (WF-O5)

10:50 **Marcos Llope, Priscilla Licandro, Kung-Sik Chan and Nils Stenseth**
Spatio-temporal shift in the plankton trophic interactions in the North Sea over the last 50 years (WF-O6)

11:10 **Philip Reid**
A vision for a global Continuous Plankton Recorder survey integrated with single site and other ocean observing programmes (WF-O7)

11:40 **Discussion**

12:30 ***Lunch***

Topic 2: Novel approaches, applications and methodologies using CPR samples and data

14:00 **Jack Jossi**
SAHFOS-US NOAA Fisheries CPR Surveys: comparison of methods and data (WF-O8)

14:20 **Juha Flinkman, Tony Walne and Joh Sidey**
Mesh size and type: CPR experiments and comparisons in the Baltic Sea (WF-O9)

14:40 **Brian Hunt and Graham Hosie**
Quality vs. quantity: reductions in taxonomic resolution as a means to merge disparate plankton data sets for enhanced spatial and temporal coverage (WF-O10)

15:00 **William Sydeman, Jarrod Santora, Sonia Batten, Mike Henry and Ken Morgan**
The endless summer revisited: climate, macro-ecology, and seabird-plankton associations within and across the North Pacific (WF-O11)

15:30 ***Tea/coffee break***

16:00 **Discussion**

Workshop G: Cod and Climate Change: the past, the present and the future

Chairs: ***Øyvind Fiksen, Jeff Runge and Fritz Köster***

Monday 22 June

09:00 **Introduction to workshop**

09:10 **Keith Brander**
History and summary of CCC related activities (WG-O1)

10:00 ***Tea/coffee break***

10:30 **Geir Ottersen**
Retrospective studies: time series analyses of cod and climate (WG-O2)

11:00 **Friedrich W. Köster, Michael J. Fogarty, Karin Hüssy and Margit Eero**
Cod recruitment and climate change: a comparative approach (WG-O3)

11:30 Christian **Moellman**
Cod and climate change in the Baltic Sea (WG-O4)

12:00 **Ian Bradbury, Sophie Hubert, Brent Higgins, Sharen Bowman, Ian Paterson, Paul Snelgrove, Corey Morris, David Hardie, Jeff Hutchings and Paul Bentzen**
Parallel adaptive evolution in Atlantic cod in response to ocean temperature (WG-O5)

12:30 ***Lunch***

14:00 **Brian J. Rothschild, Changsheng Chen, Song Hu, Robert C. Beardsley, Yue Jiao and Emily F. Keiley**
How does the global warming impact the Gulf of Maine and Georges Bank ecosystem? A retrospective analysis of the climate change in the past 30 years (WG-O6)

14:20 **Jeffrey Runge, Adrienne Kovach, Rebecca Jones, Shelly Tallack, James Churchill, Changsheng Chen, Graham Sherwood, Hunt Howell, Jonathan Grabowski and David Berlinsky**
Understanding climate impacts on the spatial dynamics of Atlantic cod in coastal waters of the Gulf of Maine (WG-O7)

14:40 **Anna Neuheimer, Christopher Taggart and J. Mark Hanson**
Cod size-at-age: disentangling effects of climate and fishing (WG-O8)

15:00 **Trond Kristiansen, Frode Vikebø, Gregory Lough, Svein Sundby and Cisco Werner**
Factors determining growth and survival in the early life stages of North Atlantic cod: a comparative study between the NW Atlantic and Norwegian Sea ecosystems (WG-O9)

15:20 ***Tea/coffee break***

16:00 **Brain Rothschild and Svein Sundby**
Perspective summaries and general discussion: future of CCC research

Workshop H: Plankton phenology and life history in a changing climate: observation and modelling

Chairs: ***Rubao Ji, Dave Mackas and Martin Edwards***

Tuesday 23 June

08:30 **David Mackas, Wulf Greve, Martin Edwards, Sanae Chiba, Sonia Batten, Anthony Richardson, Kazuaki Tadokoro, Alessandra Conversi, Damien Eloire, Gregory Beaugrand and Catherine Johnson**
Changing seasonal timing of zooplankton populations, and their link to ocean climate (WH-O1)

09:00 **Juan-Carlos Molinero, Ibanez Frederic and Paul Nival**
Assessing critical windows for the development of zooplankton populations (WH-O2)

09:15 **Guang-Tao Zhang**
Population structure and life cycle of *Calanus hyperboreus* in western Arctic in summer (WH-O3)

09:30 **Nikolay Usov, Daria Martynova, Igor Primakov and Inna Kutcheva**
Long-term zooplankton dynamics and environment in the White Sea since 1957 (WH-O4)

09:45 **Øystein Varpe**
Phenology as part of life-history strategies: annual routines of zooplankton (WH-O5)

10:00 ***Tea/coffee break***

10:30 **Andrew Leising, James Pierson, Jeffrey Runge and Catherine Johnson**
Why doesn't *Calanus marshallae* live in the Atlantic: a comparison across the copepod genus *Calanus*' physiological rates with implications for mortality rates under climate variability (WH-O6)

10:45 **Anna Neuheimer, Wendy Gentleman and Pierre Pepin**
Regional variability in copepod phenology: application of a new individual-based model and implications for a changing climate (WH-O7)

11:00 **Jeffrey Runge, Andrew Leising, Catherine Johnson and Fréderic Maps**
Population responses to environmentally forced shifts in timing of diapause in *Calanus finmarchicus* in the Gulf of Maine (WH-O8)

11:15 **Discussion**

12:30 ***Lunch***

14:00 **Andrew Thomas and Ryan Weatherbee**
Satellite-measured time and space patterns of chlorophyll phenology in the California Current (WH-O9)

14:15 **Abigail McQuatters-Gollop, Laurence Mee, Georgy Shapiro and Dionysios Raitsos**
Non-linear effects of climate on Black Sea phytoplankton phenology (WH-O10)

14:30 **Desiree Tommasi, Rick Routledge, Brian Hunt and Evgeny Pakhomov**
Variability in the timing of the spring bloom and observed changes in the zooplankton community of a coastal fjord (WH-O11)

14:45 **Rubao Ji, Cabell Davis, Changsheng Chen and Robert C. Beardsley**
Influence of environmental forcing on plankton dynamics in the Gulf of Maine region (WH-O12)

15:00 **Pierre Helaouet**
Eco-physiological niche modelling as a tool in understanding the relationship between phenological and biogeographical responses to climate change (WH-O13)

15:15 **Chad Gilbert, Wendy Gentleman, Catherine Johnson, Claudio DiBacco, James Pringle and Changsheng Chen**
Implications of a spring spawn for long-term sustainability of Georges Bank scallop populations (WH-O14)

15:30 ***Tea/coffee break***

16:00 **Discussion**

Workshop I: Climate impact on ecosystem dynamics of marginal and semi-enclosed seas

Chairs: ***Yasunori Sakurai and Christian Möllmann***

Tuesday 23 June

08:30 **Introduction to workshop**

08:40 **Juan-Carlos Molinero, Michele Casini, Jakov Dulcic, Branka Grbec, Lyudmila Kamburska, Priscilla Licandro, Marcos Llope, Mira Morovic, Andreas Lehmann and Ulrich Sommer**
Climate and pelagic ecosystems in semi-enclosed marginal seas: the case of European shelf seas (WI-O1)

09:00 **Juergen Alheit**
Reaction of northern hemisphere ecosystems to the climate events in the late 1980s: a comparison (WI-O2)

09:20 **Aida Sartimbul, Hideaki Nakata, Ian Perry, Erfan Rohadi and Beni Yusuf**
The dynamics of chlorophyll-*a* concentration due to climate change and its possible impact on *Sardinella lemuru* at Bali Strait, Indonesia (WI-O3)

09:40 **Christian Möllmann and Michele Casini**
Climate and overfishing cause change in a semi-enclosed sea: a review of central Baltic pelagic ecosystem dynamics (WI-O4)

10:00 ***Tea/coffee break***

10:30 **Maria Luz Fernandez de Puelles and Juan-Carlos Molinero**
11 year zooplankton time-series related to North Atlantic climate changes in waters of the Balearic Sea (western Mediterranean) (WI-O5)

10:50 **Masahide Kaeriyama**
Effect of the long-term climate on growth and survival of Japanese chum salmon in the Okhotsk Sea (WI-O6)

11:10 **Piotr Margonski, Sture Hansson, Maciej Tomczak and Ryszard Grzebielec**
Climate impact on Baltic cod, sprat, and herring stock-recruitment relationships: an INEXFISH project experience (WI-O7)

11:30 **Sami Lakkis**
Biological invasion in the Levantine Basin (east Mediterranean) (WI-O8)

11:50 **Young Shil Kang, Sukgeun Jung and Yang Soon Kang**
Responses of meso-zooplankton communities to long-term oceanographic changes in the northwestern Pacific marginal seas (WI-O9)

12:10 **Manuel Hidalgo, Tristan Rouyer, Enric Massutí, Joan Moranta, Beatriz Guijarro and Nils Stenseth**
A combined effect of climate and fishery harvesting triggered a shift in a hake (*Merluccius merluccius*) population of the NW Mediterranean (WI-O10)

12:30 ***Tea/coffee break***

14:00 **Salvador Lluch-Cota, Gaston Bazzino, Alejandro Pares-Sierra, Francisco Arreguín-Sánchez and Víctor Magaña-Rueda**
Changing climate in the Gulf of California (WI-O11)

14:20 **Juan-Carlos Molinero, Mirna Batistic, Nejib Daly-Yahia, Ons Daly Yahia-Kéfi, Davor Lucic, Maria Fernandez de Puelles, Lyudmila Kamburska, Priscilla Licandro, Alenka Malej, Laura Prieto, Ioanna Siokou-Frangou and Sultana Zervoudaki**
Climate and jellyfish outbursts in the Mediterranean Sea: a synthesis through meta-analysis (WI-O12)

14:40 **Shiquan Lin, Zhisheng Zhu, Xiaoyan Jia and Lingfeng Huang**
Distribution and bacterivory of heterotrophic flagellate in the Yellow Sea during the spring diatom bloom (WI-O13)

15:00 **Song Sun and Shiwei Wang**
The population dynamics of *Calanus sinicus* (WI-O14)

15:20 ***Tea/coffee break***

16:00 **Discussion**

Workshop J: Socio-economic dynamics and ecosystems, governance implications

Chairs: ***Kathleen Miller and Anthony Charles***

Tuesday 23 June

08:30 **Kathleen Miller and Anthony Charles**
Introduction to workshop

08:40 **Gordon Munro**
Keynote: The governance of multi-national capture fisheries under uncertainty (WJ-O1)

09:15 **Rod Dobell**
Place-based oceans governance in a Web2.0 world (WJ-O2)

09:37 **Ralph Matthews and Robin Sydneysmith**
Assessing the adaptive capacity of ecosystem governance processes: a new institutional analysis perspective (WJ-O3)

10:00 ***Tea/coffee break***

10:30 **Anthony Charles**
The Ecosystem Approach to Fisheries: human dimensions and governance challenges (WJ-O4)

10:52 **Ahmed Khan and Barbara Neis**
Fisheries governance and the recovery imperative (WJ-O5)

11:14 **Ruth Pincinato and Maria Gasalla**
Priceless prices and marine food webs: long-term patterns of seafood markets in southeastern Brazil (WJ-O6)

11:36 **Ahmed Khan, Ratana Chuenpagdee, Barbara Neis, Robert Hooper and Rashid Sumaila**
A fish chain analysis of Northern Gulf cod fisheries pre-collapse (WJ-O7)

11:58 **Kathleen Miller, Peter Golubtsov and Robert McKelvey**
Game theoretic insights on multinational tropical tuna fishery management (WJ-O8)

12:20 **Synthesis: key ideas from the session**

12:30 ***Lunch***

14:00 **Discussion. Project and publication planning: marine governance trends and tools**

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S2 GLOBEC achievements

Chairs: Manuel Barange and Ian Perry

24 June, 09:10 (S2-O1 invited)

A history of GLOBEC

Roger P. **Harris**[1] and Elizabeth **Gross**[2]

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[2] College of Marine and Earth Studies, Robinson Hall, University of Delaware, Newark, DE 19716, USA. E-mail: egross@scor-int.org

The talk will review the evolution of this major international global change programme from its early beginnings to the final phase of integration and synthesis.

After an initial phase of development, particularly in the United States, GLOBEC was initially co-sponsored in 1991 by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission of UNESCO. Subsequently it was adopted as a core project by the International Geosphere-Biosphere Programme (IGBP) and for the ten years duration of GLOBEC the three co-sponsors have provided valued support and guidance. Two Regional Programmes also benefited regional sponsorship from the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES).

From the outset GLOBEC research was organised around four foci: Retrospective analyses and time series studies, Process studies, Predictive and modelling capabilities and Feedback from changes in marine ecosystem structure. The work was initially developed within four Regional Programmes: Southern Ocean GLOBEC (SO GLOBEC), Small Pelagic Fishes and Climate Change (SPACC), ICES-GLOBEC Cod and Climate Change Programme (CCC) in the North Atlantic and the PICES-GLOBEC Climate Change and Carrying Capacity Programme (CCCC) in the North Pacific. In the later stages two additional Regional Programmes were started: Climate Impacts on Top Predators (CLIOTOP) and Ecosystem Studies of Subarctic Seas (ESSAS). National funding supported active GLOBEC programmes in many countries, for example, Canada, Chile, China, France, Germany, Japan, Korea, Mexico, Norway, Peru, Portugal, Spain, UK and USA.

International cooperation and coordination has been a hallmark of GLOBEC and this approach will be a continuing legacy after GLOBEC itself has ended.

24 June, 09:30 (S2-O2 invited)

Physical-biological coupling in marine ecosystems

Eileen **Hofmann**[1], Francisco Werner[2] and Eugene J. Murphy[3]

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[2] Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Road, New Brunswick, NJ 08901, USA.
[3] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK.

The GLOBEC programme led a fundamental change in research into marine population variability. The use of coupled physical-biological models of marine ecosystem dynamics that are based on processes that influence individual organisms has been a core approach used in GLOBEC. As a result, integration of physical-biological modelling and observations was done from the outset in GLOBEC science programmes and the success of this approach has resulted in a shift in how marine ecosystem research is now structured. Mechanistic understanding of the variability in abundance and distribution of marine populations is now emerging, which is allowing linking of processes across local, regional and basin scales. This presentation will provide an overview of the advances in understanding of physical-biological coupling and of the connectivity between the environment and organisms at a range of space and time scales that have resulted from GLOBEC science. Many of these advances underlie recent efforts link marine population variability to climate change and make projections of this response a feasible goal.

24 June, 10:30 (S2-O3 invited)

Food web processes in marine ecosystems

Coleen **Moloney**

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GLOBEC studies focused on biological-physical interactions of target species in different study regions, emphasising responses of organisms to varying physical forces. Because of this focus, the importance of population-level processes for food web dynamics was highlighted, with responses often being ecosystem-specific. This presentation aims to describe some of the advances that have been made over the past decade in understanding food web processes. These include the effects of variability in the timing of biological events, which are susceptible to environmental change and which cause shifts in physiology, population dynamics and ecology. It is apparent that many species are able to adapt to change, especially in terms of their feeding modes and diets. Unfavourable conditions can also cause organisms to move elsewhere, changing the community composition and the vertical and horizontal linkages between ecosystems with unknown consequences. Trophic controls in food webs vary over time and space and food web structures also change, both over the short term and through shifts in regimes, sometimes irreversibly. There is an ongoing requirement to integrate ecological processes, from biogeochemistry to top predators, to understand potential consequences of global change.

24 June, 11:00 (S2-O4 invited)

Impacts of climate/global change

Svein **Sundby**

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The regional GLOBEC projects all address impacts of climate/global change but with different foci. This reflects that structure and function of the various marine ecosystems are different, but also that scientists associated with the various regional projects have different perspectives and approaches to the problems of climate change. What are the common processes and food web features across marine ecosystems and what are the specific features different in each of them? A natural start to exploring impacts of climate variability and climate change is correlative studies between climate variables and ecosystem properties. But such studies are of limited value without a parallel development of the understanding of the governing processes behind the correlations. Subsequent extension of data sets or time series in such studies most often results in that the earlier significant established correlations break down, not necessarily because the possible mechanisms though of were wrong, but because new processes or factors might become critical under a different physical setting or a different state of the ecosystem. In high latitude marine ecosystems changes in temperature has been shown to have strong and extensive impacts on distribution and productivity for the organisms. But such strong responses have often multiple causes in addition to the temperature effect itself. In other marine ecosystems different climate variables than temperature might be critical for growth and distribution of the organisms. The recipe for advancing our understanding of the impacts of global climate change on marine ecosystems is already set in the objectives and scientific themes of GLOBEC, but a stronger emphasis is needed on the interaction between process studies in the field and development and validation of ecosystem models. Finally, established time series must be maintained, and new time series must be established.

24 June, 11:30 (S2-O5 invited)

Forecasting and predicting marine ecosystem responses to climate change

Yasuhiro **Yamanaka**[1,2]

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[2] Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology Agency, Japan.

We need integrated ocean models linking climate change with fish resources, to clarify the impact of climate change on natural marine environments. Such models are also useful to assess systematically local human impacts such as overfishing, eutrophication and pollution, as well as global impacts such as global warming and ocean acidification.

We ultimately need fully-coupled models including the interactions of three components: climate, lower tropic levels (plankton), and higher trophic levels (fish). Under the limitation of computer resources, however, the simplest approach is to model each component separately, using a one-way interaction from climate change

to fish resource variations, analogous to relaying a baton. We have already constructed such two-component models with couplings for either climate-plankton or plankton-fish interactions. The former models often focus on climate feedback of biogeochemical cycles including plankton dynamics, especially the carbon cycle, with global domain with coarse resolution. The latter models have been developed to represent food-web dynamics such as top-down and bottom-up controls in regional domains at high spatial resolution. Several groups in the world are developing prototypes of fully-coupled models using their own particular approaches (e.g. NEMURO, OSMO, QUEST-Fish).

I would like mainly to introduce the results of our recently developed integrated ocean model as mentioned above: a 3-D high-resolution ecosystem model, COCO-NEMURO, and an individual-based model coupled with bioenergetics for small pelagic fish. We evaluated the impact of global warming on the ecosystem in two ten-year scenarios: a control experiment (present climate state), and a double CO_2 experiment (gradually increasing atmospheric CO_2 by +1% per year from the present to approximately double by the 70th–80th year). In the double CO_2 scenario, the spring bloom occurs 10-20 days earlier than under the present climate in both the transition and subarctic regions. The signal of global warming is statistically significant at the 95% level, relative to natural variability (both inter-annual and fluctuation due to the meso-scale eddies). In present High Nutrient Low Chlorophyll regions, the biomass maximum associated with the spring bloom increases because the positive effect of increased temperature on growth rate overwhelms the negative effect of reduced nutrient supply from deep water.

The timing of the spring bloom and the subarctic-subtropical transition region are essential for growth and survival of small pelagic fish. Global warming might significantly decrease the abundance of fish resources. In future projections for Japanese sardine, the spawning period in winter near the south coast of Japan shortens by around two months, and growth rate decreases for the juvenile stage, which reduces their survival rate. However, the size of adult fish remains the same due to the temperature dependence of their growth rate.

24 June, 12:00 (S2-O6 invited)

The human dimensions of global environmental change in marine systems

Ian **Perry**[1], Manuel Barange[2] and Rosemary Ommer[3]

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GLOBEC began with a focus on the impacts to marine ecosystems of climate variability and change, and these are reflected in the early activities and successes of the programme. It was recognised, however, that human activities such as intensive fishing also have strong impacts on marine ecosystems, which may occur on more immediate time scales than those of climate change. This presentation reviews the human dimensions of global change in marine ecosystems, and expands on the concept of coupled marine social-ecological systems. Fishing and climate forcing interact on marine populations, marine communities, and ecosystems to bring them into states that are more sensitive to climate forcing. From the human side, how human communities respond to marine ecosystem variability can ameliorate or exacerbate these changes. At shorter time scales, coping responses by both human and non-human marine systems have common elements; at longer time scales, however, many adaptive responses by human communities have no analogues in non-human marine ecosystems. Marine resource managers must develop approaches which maintain the resilience of individual fish and individual people, of populations of both fish and humans, of communities of both fish and humans, and their coupled social-ecological marine systems to the combined and interacting effects of climate and fishing. Overall, a less-heavily fished marine system, and one which shifts the focus from individual fish species to functional groups and fish communities, is likely to provide more stable catches under normal conditions than would a heavily fished system, although under climate variability the whole ecosystem may alter in ways we cannot yet predict. In addition, it is becoming apparent that good fisheries management alone may not be able to recover a depleted stock under unfavourable environmental conditions, and poor management can prevent the recovery of a stock even if environmental conditions become favourable. A full social-ecological system approach to the management of marine resources would involve multiple-scale (from government to local fishing sectors) objective setting based on societal choices, including ecological, economic and social considerations. Operational objectives need to be established, requiring the identification of indicators and reference points for sector impacts. Decision support and performance evaluation rules need to be established, including their uncertainties. Future change in marine systems is not and will not be due to climate alone, but to the interactions of climate variability, climate change, and direct-human effects, and future marine research and management must take account of this reality.

S3 Ecosystem structure, functioning and forcing

Chairs: ***Salvador Lluch-Cota, Yasunori Sakurai, George Hunt and Qisheng Tang***

24 June, 14:00 (S3-O1 invited)

Climate signals in the California Current holozooplankton: resolving the invisible present

Mark **Ohman**

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Slowly moving environmental changes, and those that act with time lags, can have a strong structuring influence on ecosystems, but remain invisible to the typical short-term research programme. This is the conundrum of the "invisible present," as coined by John Magnuson. In this presentation I will illustrate insights into climate-scale influences on the California Current pelagic ecosystem that have come from analysis of the CalCOFI holozooplankton record and related variables over the past six decades, together with the 1400 year context provided by the sedimentary record of planktonic foraminifera from the Santa Barbara Basin. CalCOFI is one of the few ocean ecosystem measurement programmes capable of resolving longer-term climate influences and differentiating them from interannual-scale perturbations. With advances made in the GLOBEC era, plus the recent development of the California Current Ecosystem-LTER programme, it is now becoming possible to not only characterise the climate footprint–and thus begin to resolve the invisible present–but to understand mechanistically the processes that lead to these variations over time.

24 June, 14:30 (S3-O2)

Paired standard and size fractionated dilution incubations in southern Yellow Sea

Wuchang **Zhang**

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Paired standard and size fractionated dilution incubations of waters from 10 m depth were carried out in three stations with different trophic status in southern Yellow Sea in May 2007. Station S2-2 was located in the Yangtse River plume with lower salinity, higher nutrient concentrations and higher chl-*a* (chlorophyll-*a*) concentration (2.02 µg/L), 61% of which was in the <20 µm fraction. Standard dilution incubation in S2-2 showed that about 66% of the chl-*a* production was grazed by microzooplankton. Therefore, the phytoplankton standing stock accumulated in this station. Stations S1-4 and S1-4-2 were located in the central southern Yellow Sea with higher salinity, lower nutrient concentrations and lower chl-*a* concentration (0.26–0.33 µg/L), 96% of which was in the <20 µm fraction. Microzooplankton grazed nearly 100% of the chl-*a* primary production. As a result, the phytoplankton standing stock was stable. Although ciliate abundance in the dilution series kept an approximately proportional relationship with dilution factor, heterotrophic flagellates (HF) abundance grew more rapidly in the more diluted series than in the standard dilution incubations. The grazing rates on <20 µm chl-*a* were lower in size fractionated dilution incubations than in standard dilution incubations in all paired incubations. However, grazing rates on HF were higher in size fractionated dilution incubations than in standard dilution incubations in all paired incubations. These results suggested that microzooplankton >20 µm were important grazers of the community, and removing them from the experiments would result in higher phytoplankton net growth rates. Ciliate-HF relationship was more than a simple predator-prey relationship. It is suggested that there might be trophic cascades in different HF groups.

24 June, 14:45 (S3-O3)

Hypoxia in the northern California Current: interannual variability and influence on copepod recruitment

Jay O. **Peterson**[1], Megan Pros[2], William T. Peterson[3] and Cheryl A. Morgan[1]

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Low oxygen (hypoxic) bottom waters are common in many bays, estuaries, and enclosed seas throughout the world, and may persist annually, seasonally, or at less predictable intervals. Along the shelf of Oregon and Washington, within the northern California Current, hypoxic bottom waters appear seasonally (May–October)

during the period of upwelling and may occupy 30% of the water column and cover 60% of the shelf. Over the last ten years, surveys of oxygen distribution indicate that the severity of oxygen depleted bottom waters has been increasing. Hypoxic waters are known to displace highly mobile fish species and kill slow or stationary benthic invertebrates, such as crabs and anemones. The impact on less mobile pelagic species, especially zooplankton early life history stages (e.g. eggs, nauplii), is not as well understood. We studied the impact of naturally occurring hypoxic waters on the copepod *Calanus marshallae* and found that hatching success and early development was greatly reduced at low oxygen concentrations. Above the traditional cutoff for hypoxia (1.4 ml L^{-1}), hatching success was >80% with most nauplii developing to stage NIII. In hypoxic water, both hatching success and development rate drastically declined with oxygen concentration. These results indicate that hypoxia may negatively impact copepod recruitment in the northern California Current ecosystem.

24 June, 15:00 (S3-O4)

Oceanographic conditions and lower trophic level responses leading to variable pink salmon recruitment in the coastal Gulf of Alaska

Suzanne **Strom**[1], Michael Dagg[2], Kenneth Coyle[3], Russell Hopcroft[3], Terry Whitledge[3] and Lewis Haldorsen[4]

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Several lines of evidence indicate that growth conditions during the juvenile stage in the coastal ocean are key to recruitment of pink salmon, *Oncorhynchus gorbuscha*, in the Gulf of Alaska. We examined data from cruises, moorings, and other sources during two years with strongly contrasting pink salmon returns: high in 2002 (8.5% to Prince William Sound hatcheries) and low in 2003 (3.6%) to obtain a mechanistic understanding of the regulation of primary production and planktonic food web structure. Three main topics were investigated:

1) *Spring food web*. Conditions in 2002 were generally colder and more saline, but 2002 supported an earlier spring bloom, likely due to reduced cloud cover (increased solar irradiance) in early April 2002 as well as later deep mixing in April 2003. In addition, the 2002 bloom was more intense and spatially extensive, probably due to higher concentrations of nitrate and silicate available at bloom onset. In contrast, there were not major differences in the abundance of *Neocalanus* spp., the dominant spring mesozooplankton.

2) *Summer food web*. Summer is the key season for salmon in coastal waters; juveniles occupy the inner and mid shelf July–September. In summer 2003, the mixed layer was shallower and, somewhat paradoxically, phytoplankton biomass appeared higher than in 2002. In contrast, 2002 summer zooplankton were more abundant, particularly the large copepod *Calanus marshallae*, an important prey species for juvenile pink salmon. Production of these long-lived zooplankton could represent a connection between spring bloom production and the summer food web supporting pink salmon. Possible differences in abundance of other important pink salmon prey, the mucous net feeders including pteropods and larvaceans, will also be discussed.

3) *Offshore influences*. Slope eddies were present in both years but the eddy was larger and persisted longer in 2003. Various biological and chemical data provide evidence for invasion of offshore water as far as the mid-shelf in 2003, possibly associated with eddy circulation patterns. Offshore water in this region is iron-limited and supports only a modest production rate; this could have led to reduced shelf productivity in 2003.

Our current understanding is that food availability for juvenile salmon in the summer is linked to both spring and summer conditions, and is related to physical processes that drive large-scale movements of water masses on the shelf.

24 June, 15:15 (S3-O5)

Seasonal and regional importance of copepods, protozoans, diatoms and sediment as alternative food items for Antarctic krill

Angus **Atkinson**, Katrin Schmidt and David Pond

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The large size and high biomass of Antarctic krill means that its feeding behaviour impacts trophic levels both above and below it. During GLOBEC much effort has been spent sampling krill from a variety of regions and seasons, but their feeding behaviour is still unclear even after 80 years of study. This reflects the fact that a) each feeding method has serious shortcomings and they are seldom employed consistently in combination, b) krill feeding varies seasonally and regionally, and c) individual studies are often of insufficient regional and

seasonal scope to be able to make firm generalisations. We attempted to address these issues by collating frozen postlarvae across 13 cruises during the GLOBEC era, including samples from the krill fishery. These surveys spanned all four seasons, with 90 stations analysed in a consistent manner across the open ocean, high latitude shelves and low latitude shelves. We combined stomach content analysis with fatty acid biomarkers in stomach and tissue, and this breadth of coverage allowed some slightly more generalised suggestions about the alternative food sources for krill. While it has long been known that krill utilise diatom blooms efficiently, models point to the importance of alternative food sources even in summer. We therefore tested the hypothesis that copepods were a major alternative food source, since many incubation experiments have pointed to this. Based on visual stomach content analysis and fatty acid markers, our results forced us to reject this hypothesis, since copepods formed on average <10% of the estimated dietary intake volume. The abundance of copepods, thecate dinoflagellates and tintinnids in the stomachs increased when krill were feeding on blooms, implying that these heterotrophs were abundant then and eaten alongside the dominant diatoms. To our surprise, the stomachs of postlarval krill from many of the stations contained lithogenic sediment. The krill were caught from the surface layers, so potential sources of the particles include glacial/fluvial run-off, dirty icebergs and the seabed/nepheloid layer. Evidence for feeding on the seabed comes from the number and size of the particles (up to ~3 million per stomach, up to 100 micron diameter), their co-occurrence with benthic diatoms, plus their close relationship with water depth but no correlation with surface chl-*a*. Several studies have observed krill at the seabed, in one instance feeding there at >3500 m depth. We will summarise the diverse evidence for krill - seabed interactions, often provided by benthic ecologists and not quoted in the krill literature. Our study further shows that sediment feeding, rather than being occasional, is a major component of krill biology since it occurs commonly, year-round and in a variety of habitats. In this talk we will discuss some of the implications of benthic feeding - for example its benefits and risks for krill, the rapid vertical exchange for elements and as a problem for scientists trying to assess krill biomass.

24 June, 16:30 (S3-O6)

Testing the three-gyre hypothesis: basin-scale population genetic structure of *Calanus finmarchicus* in the North Atlantic Ocean

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The calanoid copepod *Calanus finmarchicus* has been hypothesized to inhabit three semi-distinct gyre systems across the North Atlantic Ocean, with limited exchange among the gyre populations, which may exhibit divergent life history, population ecology, and population genetic characters. Our null hypothesis is that populations in different gyres will be genetically homogeneous resulting from panmixia (i.e. random interbreeding across the sampled population). This hypothesis was tested by population genetic analysis of 23 single nucleotide polymorphisms (SNPs) at sites of silent substitutions (i.e. nucleotide substitutions that do not change the amino acid sequence) in nuclear genes encoding three metabolic enzymes: citrate synthetase (CS), heat-shock protein (HSP-70), and AMP-kinase (AMP-K). SNPs were detected using multiplexed protocols developed with a commercial kit, SNaPshot (Applied Biosystems, Inc.).

For this study, *C. finmarchicus* was sorted from zooplankton samples collected during 2005 from 55 stations located throughout the eastern (Barents and Norwegian Seas), northern (Irminger and Labrador Seas), and western (Gulf of St. Lawrence, Scotian Shelf, Gulf of Maine) North Atlantic gyres. An ocean-basin scale view of the population genetic diversity and structure of *C. finmarchicus* was developed, analysed, and interpreted using standard statistical and population genetic approaches. Tests of neutrality were performed for each locus; allele frequencies were statistically analysed using Structure 2.2 and AMOVA (Analysis of MOlecular VAriation) to evaluate molecular covariance within and among samples, regions, and gyres.

Preliminary results from Monte Carlo Chi-square tests for each gene indicated significant genetic heterogeneity among all gyres for CS and HSP-70 (both $P = 0.000 + 0.000$), but less so for AMP-K ($P = 0.0270 + 0.0051$). Significant heterogeneity among samples within the Eastern and Northern gyres ($P = 0.000 + 0.000$), but not the western gyre, was observed for CS. Further analysis is needed to resolve hierarchical patterns of genetic structure over the range of spatial scales. The proportion and significance of the molecular covariance explained by comparisons among samples and among regions was used to statistically estimate exchange among geographic populations of *C. finmarchicus* at a range of spatial scales. These estimates of exchange will be compared directly to those computed from the model solutions by Dennis McGillicuddy (WHOI) and others, as part of a collaborative GLOBEC synthesis effort.

24 June, 16:45 (S3-O7)

Regional differences in overwintering of Antarctic krill, *Euphausia superba*

Katrin **Schmidt**, Angus Atkinson and David Pond

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Antarctic krill were a focus of Southern Ocean GLOBEC due to their role in the food web, biogeochemistry and fisheries. Their overwintering has been of especial interest in the GLOBEC era, since this is a major part of their life cycle and very few data exist. Winter is considered a time of special hardship for Antarctic krill as their major food source, pelagic algae, is in short supply. Most previous studies tend to suggest that adult krill spend this time in a passive mode (no food uptake, reduced metabolic rates, usage of storage lipids, and shrinkage in body size) and that the changing day length triggers their behaviour. However, some field-collected krill have shown full stomachs even in winter and authors pointed to the importance of ice biota, copepods or seabed detritus as alternative food sources. Active versus passive over-wintering will greatly affect population dynamics. We addressed this debate by analysing winter krill from three habitats differing in latitude, ice coverage and water depth (Lazarev Sea, Bransfield Strait and South Georgia). The krill were either caught from ~150 m water depth by a commercial fisheries trawl or directly under the ice with a custom build trawl. From each station, krill were scored for stomach fullness, their lipid content and fatty acid composition was analysed and the stomach contents were examined under the microscope. In addition, a database of krill length-frequencies was used to test for growth or shrinkage during winter. Krill from the Lazarev Sea were lipid-rich and most individuals had an empty stomach. However, a few krill had recently fed on algae, protozoa and copepods. Overall, low proportions of diatom-indicating fatty acids in their tissues suggest that ice algae had not been ingested in significant quantities. South Georgia krill contained less lipid, but ~50% of the stomachs were at least half-full, with some being completely full. The ingested food was a mixture of lithogenic sediment, various diatom species, protozoa and copepods. High proportions of diatom- and flagellate-indicating fatty acids [16:4(n-1); 20:5(n-3); 18:4(n-3)] in their tissue confirmed on-going feeding activities. Krill from the Bransfield Strait showed a third combination of characteristics: their lipid content was as high as in krill from the Lazarev Sea, while their feeding activity and fatty acid composition resembled that of krill from South Georgia. Length frequency data from South Georgia and the Bransfield Strait showed no evidence for body shrinkage during winter but rather for slight positive growth. In conclusion, adult krill might use different overwintering strategies according to their habitat. Feeding activities can be high even in winter and seem to depend not only on light levels but also on the availability of suitable food. Our results draw attention to seafloor material rather than copepods as an alternative food source for krill.

24 June, 17:00 (S3-O8)

Can the ecology of krill be described simply?

Stephen **Nicol**

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Antarctic krill must be one of the world's best studied pelagic organisms, with intensive investigations continuing since the 1930s, yet many critical aspects of their ecology remain somewhat enigmatic. Southern Ocean GLOBEC adopted a focus on krill to investigate a number of the ambiguities surrounding krill, and significant advances have been made as a result of these studies. Despite this progress, attempts to make generalisations about the distribution and abundance of krill have often produced unsatisfactory results. Antarctic krill are thought of as creatures of the pack ice zone, yet large portions of the population are found in ice free areas such as at South Georgia. Krill populations require large quantities of food yet there is a mis-match between the areas of highest oceanic production and the distribution of krill. Adult krill are conventionally thought of as near surface creatures yet there are numerous accounts of populations at great depth, or actually at the surface. Attempts have been made to explain krill distributions using the movements of ocean currents yet there is now evidence of directed horizontal migrations of krill independent of currents. Krill distributions have been related to the position of major frontal systems yet the relationship between krill and oceanography appears to vary regionally. Many of these issues arise because of the difficulties of sampling Antarctic krill and because of the blunt instruments we have to carry out these studies. Improved instrumentation is rapidly changing our views of krill ecology. Further difficulties arise because of the difficult nature of the Southern Ocean environment as a study site and because most ship-based studies are short-lived and time series data are rare. Recent studies, such as SO-GLOBEC, however, have focused on the time periods where gaps in data are most critical and have produced a wealth of information that will inform future syntheses of krill biology. Parallel to these field based approaches, experimental and modelling studies have provided novel information that will inform future conceptual models of how krill populations interact with their physical, chemical and biological environment. In this talk I will examine some of the recent information that has changed some of the paradigms of krill biology and outline some areas of research that are necessary to arrive at a holistic view of krill ecology.

24 June, 17:15 (S3-O9)

Six decades of change in the South Brazil Bight fishery ecosystem

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The South Brazil Bight is a productive coastal system physically forced by both wind-driven seasonal upwelling of the South Atlantic Central Waters, shelfbreak eddies, and sub-Antarctic northward lateral intrusions advected by a coastal branch of the Malvinas current. It sustains a number of goods and services, and supports an intense fishery activity which remains substantial to national marine harvest standards, i.e. the Brazilian sardine stock confines within the area. This paper addresses major changes that have been affected natural, human and management subsystems during recent decades, with a particular emphasis on fisheries. The evolution of catch rates, landings, abundance and market data, and available environmental variables are evidenced, including testimonies of veteran fishers. The system which is often considered as complex, highly diverse, and data-poor especially by the absence of reliable scientific time-series, was examined in the perspective of signals of decadal change. The presently impacted ecosystem can be followed from its pre-fished state and trends in exploited populations regarded by both single and multispecies indicators. Fishery-dependent and independent data evidenced shifts in fish communities, species composition, trophic levels, and individual mean lengths. On the other hand, recent satellite data seems to reveal two distinct colder and warmer periods during recent decades. The physical-biological environment has been placing basic constraints on the development of the human subsystem, which in turn has actively modified it. Although complex compensatory mechanisms of both bottom-up and top-down trophic controls may have shaped the recent history of this fishery ecosystem, key forcing functions are discussed. The systemic comparison and knowledge integration appeared to be reasonable to widely explore marine ecosystem change.

25 June, 08:30 (S3-O10)

Top-down and bottom-up factors affecting seabird population trends in the California Current System (1985-2006)

David G. **Ainley**[1] and K. David Hyrenbach[2]

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To characterise the environmental factors affecting seabird population trends in the central portion of the California Current System (CCS), we analysed standardised vessel-based surveys collected during the late spring (May–June) upwelling season over 22 years (1985–2006). We tested the working hypothesis that population trends are related to species-specific foraging ecology, and predicted that this variation should be most extreme in diving species with higher energy expenditure during foraging. We related variation in individual species abundance (number km^{-2}) to seasonally lagged and concurrent ocean conditions — late winter, early spring, late spring — and to long-term trends (using a proxy variable: year) during a multi-decadal period of major fluctuations in the *El Niño*-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). We considered environmental variables both remote (multivariate ENSO Index, PDO) and local (coastal upwelling indices and sea surface temperature) as proxies for ocean productivity and prey availability. We also related seabird trends to those of potentially major trophic competitors: baleen whales. Cyclical oscillations in seabird abundance were apparent in the Black-footed Albatross, and decreasing trends were documented for Ashy Storm-Petrel, Pigeon Guillemot, Rhinoceros Auklet, Cassin's Auklet, and Western Gull; Sooty Shearwater, exhibited a marked decline before signs of recovery at the end of the study period. The abundance of nine other focal species varied with ocean conditions, but without decadal or long-term trends. Six of these species have the largest global populations in the CCS, and four are highly energetic, diving foragers. Three of the diving species trends were negatively correlated with the abundance of humpback whales, a direct competitor for the same prey. Therefore we hypothesize that the seabirds were affected by decreasing carrying capacity of the CCS and an increase in the prevalence of previously exploited but now increasing baleen whales. Overall, our study highlights the complexity of explaining seabird population trends in a highly variable and rapidly changing ecosystem.

25 June, 08:45 (S3-O11)

Bottoms up: potential effects of environmental forcing on apex predators in the Gulf of Maine

Jeffrey **Runge**[1], Walter Golet[2], Jason Stockwell[1], Graham Sherwood[1], Andrew Pershing[1] and Molly Lutcavage[2]

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The Gulf of Maine, a highly productive shelf region in the northwest Atlantic, supports a large biomass of energetically rich prey species such as Atlantic herring, Atlantic mackerel, and the planktonic copepod, *Calanus finmarchicus*. Seabirds, marine mammals and large pelagic fish migrate seasonally to this region where consumption of this prey base yields rapid accumulation of lipid stores used for reproduction and migration. Oceanographic data indicate that periods of rapid change in temperature, salinity, primary and secondary productivity have occurred during the last five decades in the Gulf of Maine. Generalised additive models used to assess Atlantic herring and bluefin tuna condition suggests these oceanographic shifts may have contributed to significant changes in fish condition and lipid energy stores during the last few decades. For example, medium and giant size classes of bluefin tuna experienced a 5–25% decline in summer body weight between the mid-1980s and mid-1990s. Such reductions to key energy stores have the potential to severely alter migration and reproductive patterns of highly mobile species and highlight the importance of understanding and incorporating the effect of bottom up forcing in fisheries management.

25 June, 09:00 (S3-O12)

Changes in the Antarctic marine ecosystems: uncertainties in drivers and responses

Eugene J. **Murphy**[1], Jonathan Watkins[1], Phil Trathan[1], Michael Meredith[1], Simeon Hill[1], Nadine Johnston[1], Rachel Cavanagh[1], Eileen Hofmann[2], John Turner[1] and Andrew Clarke[1]

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The Southern Ocean is undergoing rapid physical change, but there is marked regional variation in the form and magnitude of this change. Here we discuss how Southern Ocean ecosystems have responded by considering past and present influences on their structure and function. We draw on studies of interannual variability to consider how variation is generated and propagates in these ecosystems. These studies highlight the complex physical-biological interactions at a range of temporal and spatial scales, which generate direct and indirect responses in these ecosystems (including lag-effects). We also consider potential future responses to change in these ecosystems, in which the effects of historical harvesting are ongoing, and there are major uncertainties in the physical drivers and the responses of individual species and food webs.

25 June, 09:15 (S3-O13)

Climate-induced synchronous regime shifts along environmental and diversity gradients in Baltic Sea sub-systems

Christian **Moellmann**[1], Thorsten Blenckner[2], Rabea Diekmann[1], Anna Gaardmark[3], Lena Bergström[3], Michele Casini[4], Bärbel Müller-Karulis[5], Juha Flinkman[6] and Martin Lindegren[7]

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Marine ecosystems are currently under strong atmospheric and anthropogenic pressure. Besides natural and human-induced changes in climate, major anthropogenic drivers such as overfishing and eutrophication are significantly affecting ecosystem structure and function. Recently studies demonstrated the existence of ecosystem regime shifts which have been explained mainly as a result of multiple causes, e.g. climatic regime shifts, overexploitation or a combination of both. The occurrence of ecosystem regime shifts has important management implications as they can cause significant losses of ecological and economic resources. Also the

Baltic Sea, the largest brackish water body in the world ocean, and its sub-systems are strongly affected by atmospheric and anthropogenic drivers. In recent years climate-induced changes in temperature and salinity, eutrophication and high fishing pressure had severe impacts on the entire Baltic. To assess changes in the structure and function of the ecosystem and to evaluate the relative effects of the different external forcing factors we performed principal component and regime shift analyses as well as generalised additive modelling using large datasets of hydro-climatic, nutrient, phyto- and zooplankton as well as fisheries variables. We investigated ecosystem structure and function during the period 1979–2006 in seven Baltic sub-systems, each representing different environmental conditions and food web structures. This meta-analytic approach enabled us to study the importance of global (i.e. climatic) relative to local (e.g. fisheries and eutrophication) forcings. It further allowed us to investigate if the response of ecosystems with different environmental and structural settings respond in common or idiosyncratic ways to external forcing.

25 June, 09:30 (S3-O14)

Preliminary investigation of the mesopelagic food webs in the tropics and Antarctic using stable isotope analyses

Evgeny **Pakhomov**[1], Brian Hunt[1], Yasha Podeswa[1] and Ulrich Bathmann[2]

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The mesopelagic zone has been recognised as one of the three least understood regions of the world ocean. Subsurface plankton and micronekton collected down to 1000 m depth off Oahu Island, Hawaii during October 2004 and in the Lazarev Sea, Atlantic sector of the Southern Ocean during December 2005–January 2006 and June 2006 were analysed for carbon and nitrogen stable isotope signatures in order to elucidate the mesopelagic food web. This study highlights the differences in the food web structure and carbon cycling between these two very different ecological regions, tropics and Antarctic. Preliminary results indicate that the tropical mesopelagic community is more diverse compared to the Antarctic community. In addition, using extensive measurements, the model for the lipid-normalised carbon stable isotope values for both tropical and Antarctic regions is revisited and the implications of this to the food web structure interpretation is discussed.

25 June, 09:45 (S3-O15)

Spawning stock and recruitment relationship in North Sea cod shaped by food and climate

Geir **Ottersen**, Esben Moland Olsen, Nils C. Stenseth

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The “recruitment problem” - trying to understand what regulates recruitment variability in marine fish populations - has been the number one issue in fisheries science since the early twentieth century. Intuitively, the size of the spawning stock should influence recruitment. In practice, however, the relationship is most often weak, complicating fisheries management and causing much controversy. Thus, the value of fitting stock-recruitment relationships for marine fish populations could be questioned. Nonetheless, the weak connections found may be due to insufficient data or models, and a general denial of meaningful stock-recruitment relationships would have rather alarming consequences on the science of fish population dynamics. A more constructive approach is to expand upon the established knowledge, both by introducing refined models and by including other sources of data. Specifically, theoretical work suggests that the shape and the position of the stock recruitment curve will be influenced by the environmental conditions experienced by the fish larvae. Pioneering work by Cushing and Horwood showed unexpected support for strong density-dependent mortality of fish larvae, even with low observed larval densities. Their model suggests a positive link between the number of food organisms and the slope of the stock-recruitment relationship, with potentially important implications for population dynamics. More recent work suggests that a Ricker-type stock-recruitment relationship, i.e. overcompensation, could be expected at limited food levels, while as food availability improves the recruitment curve becomes monotonically increasing towards an upper limit, i.e. a Beverton-Holt type stock-recruitment relationship. In both of these modelling approaches, the time to metamorphosis appears important for recruitment. Lack of food will slow down the growth of the larvae and delay the time to metamorphosis. This may cause the larval cohort to experience density-dependent mortality to the extent that the recruitment curve becomes overcompensatory.

Building upon the unique Continuous Plankton Recorder (CPR) zooplankton data, classical theoretical work and recent modelling advances, we here employ a novel approach to the recruitment problem to the once large North Sea cod (*Gadus morhua*) stock. We find that a model combining the Ricker and Beverton-Holt stock-recruitment models has considerably more explanatory power than any of the two in isolation. In essence, food availability (zooplankton) determines whether the Ricker or Beverton-Holt model applies. Furthermore, we find evidence for an effect of temperature displacing the recruitment curve upwards (good recruitment) during cold years and downwards during warm years (poor recruitment). These findings shed new light on the recruitment problem in general, and specifically support earlier studies in that full recovery of the North Sea cod stock should not be expected until the environmental conditions become more favourable.

S4 Ecosystem observation, modelling and prediction

Chairs: Harold Batchelder, Roger Harris and Dale Haidvogel

25 June, 10:30 (S4-O1)

Perspectives on a decade of change in the Alaska Gyre: a comparison of two deep ocean zooplankton time series

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Numerous GLOBEC-era analyses have demonstrated that zooplankton time series can be very useful for detecting multi-year fluctuations and trends in pelagic ecosystems, and for interpreting their association with various modes of ocean climate variability (e.g. ENSO, PDO, NAO, NPGO, boundary current strength, upwelling intensity and timing, etc.). To separate interannual variability from spatial patchiness and seasonal fluctuations, the ideal zooplankton sampling 'grid' is dense in both time and space. One consequence is that the majority of zooplankton time series come from relatively nearshore locations; open-ocean time series are rare and valuable. One of the earliest and longest open-ocean zooplankton time series was collected from Canadian ships assigned to Ocean Weather Station P in the Alaska Gyre (50°N 145°W), but the weathership programme ended in 1980, and the majority of its samples were analysed only for total biomass. Our Alaska gyre zooplankton time series sampling resumed in 1997 after an unfortunately long break. For the past decade, we have taxonomically-resolved data from two programmes–the North Pacific Continuous Plankton Recorder (6–9 surface layer transects per year), and seasonal Line P research vessel cruises (0–150 m vertical net tows at six standard stations, three times per year). These records have become long enough to allow quantification of both climatologic norms and interannual anomalies. Despite the differences in sampling design and depth, our two data sets reveal very similar patterns of seasonal and interannual variability, which we will summarise in this presentation. Zooplankton seasonality in the Alaska Gyre is very strong, with the abundance and biomass maxima occurring late spring to early summer (May to early July depending on location and year; earliest timing in warm years and toward the southern and eastern coastal margins of our survey lines). Both abundance and biomass are strongly dominated by copepods, especially large ontogenetic migrators such as *Neocalanus* spp., *Calanus pacificus*, and *Eucalanus bungii*. Other dominant taxa include chaetognaths, pteropods, hyperiid amphipods, euphausiids and medusae. Similar to our 'northern California Current' continental margin time series, the Alaska Gyre time series can be divided between cool and warm periods, each with characteristic anomalies in zooplankton community composition and phenology (seasonal timing). Cool episodes were 1999–2002 and 2007–2008 (with 2008 the 'coolest' in terms of zooplankton response); warm episodes 1997–1998 and 2003–2006 (with 2005 the 'warmest'). In the cool years, the abundance and biomass peak of *Neocalanus* spp. is later and broader. Warm years often show negative anomalies of subarctic taxa (especially *N. flemingeri* and *N. cristatus*), and invariably show strongly positive anomalies of subtropical-origin copepods such as *Mesocalanus* and *Clausocalanus*.

25 June, 10:45 (S4-O2)

Integrating data, fieldwork, and models into an ecosystem-level synthesis: the modelling challenge of the Bering Ecosystem Study/Bering Sea Integrated Research Program

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The Bering Ecosystem Study/Bering Sea Integrated Research Program (BEST-BSIERP, http://bsierp.nprb.org/index.htm) is a five-year programme of over 90 principal investigators at multiple institutions, jointly sponsored by the National Science Foundation (NSF) and the North Pacific Research Board (NPRB) to provide a synthesis of key hypotheses that govern the effects of climate on the Bering Sea ecosystem, and provide a set of tools for forecasting long-term production and distribution of marine resources (e.g. plankton, fish, birds, and mammals), especially for use by management agencies and local communities. BSIERP is unique in its approach to integrating data, fieldwork with modelling efforts throughout all years of the project. First, scoping models (e.g. food web,

bioenergetics, and nutrient-phytoplankton-zooplankton models) guided project design, for example by investigating the link between ice and plankton or between fish growth and prey variation. Second, the models are being developed concurrently with (rather than after) the field programme, to guide sampling priorities and help interpret observations. Third, model components are modular, so that "alternate modules" (e.g. behavioural models, or models with differing resolutions) may be substituted to determine the most appropriate toolbox for forecasting. Finally, the modelling is under the oversight of an independent panel charged with ensuring that models are relevant to management and explicit in their reporting of uncertainty. Here, we discuss preliminary results of the modelling effort, FEAST (Forage-Euphausiid Abundance in Space and Time). FEAST is a multispecies bioenergetics model for forage and predatory fish species linked to NPZ (Nutrient-Phytoplankton-Zooplakton) and ROMS (Regional Ocean Modelling System) for the Northeast Pacific and Bering Sea at a 10 km resolution. FEAST models nine fish species (walleye pollock, Pacific cod, arrowtooth flounder, salmon, capelin, herring, eulachon, sandlance and myctophids) which have a two way interaction with the seven zooplankton groups in the NPZ model (small/large microzooplankton, small/large copepods, euphausiids, jellyfish, and benthic infauna) and the underlying physical and climate models. We show results of all portions of the vertically integrated model (climate downscaling, ROMS, NPZ and FEAST), emphasizing results of near-term predictions of recent, present, and immediately future field conditions combined with data assimilation and validation. We focus on providing immediate feedback between field researchers and modellers as well as ultimately improving our understanding of the long-term (20–50 year) outlook for the Bering Sea ecosystem.

25 June, 11:00 (S4-O3)

Dynamics of lower-trophic-level ecosystems in five ecological regions in the western North Pacific simulated by an ecosystem model eNEMURO

Naoki **Yoshie**[1,2], Kosei Komatsu[3], Shin-ichi Ito[2], Takuhiko Kameda[4], Tsuneo Ono[5], Kiyotaka Hidaka[4], Toru Hasegawa[6], Akira Kuwata[2], Miwa Nakamachi[2], Yuji Okazaki[2], Takeshi Okunishi[2], Kazuaki Tadokoro[2], Hiroaki Saito[2] and Yasuhiro Yamanaka[7,8,9]

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Spatiotemporal variations of the lower-trophic-level marine ecosystem in the western North Pacific were investigated by an ecosystem model, for understanding mechanisms of the variations and developing prediction skills of ecosystem responses to climate changes. We developed a plankton functional types model eNEMURO (3N-4P-4Z-4D), which was an extend version of NEMURO (North Pacific Ecosystem Model Understanding for Regional Oceanography, a standard lower-trophic-level marine ecosystem model of PICES) by introducing the microbial food web and dividing diatoms to two compartments according to temperature dependency. We applied eNEMURO to five different ecological regions in the western North Pacific (subarctic: Oyashio region, subarctic-subtropical transition: Oyashio-Kuroshio transition region, continental slope: the slope water south of Honsyu island, subtropical: an offshore station at 138°E–30°N, and continental shelf: East China Sea), and compared this with biogeochemical and ecological data observed at the seasonally repeated monitoring stations in each region. The model successfully reproduced the seasonal variations of the biomasses of total-phytoplankton and meso-zooplankton and the concentrations of nitrate in all regions, although the concentrations of silicic acid were slightly overestimated. The comparison of plankton community structures between the model and observation showed underestimation of pico-phytoplankton and overestimation of nano-phytoplankton and macro-zooplankton in all regions. The following processes were thought to be causally related to the discrepancies between the model and observation; strong low-temperature inhibition for pico-phytoplankton, low grazing pressure for nano-phytoplankton, and slow mortality rate for macro-zooplankton. We tuned the biological parameters controlling above processes in order to resolve the discrepancies. After the tuning, the discrepancies were reduced in all regions, and the simulated community structures became more realistic. eNEMURO was coupled with an eddy-resolving ocean general circulation model assimilated to satellite altimetry and sea-surface-temperature (C-HOPE + TAMC). However, the integration was conducted using pre-tuned parameters. Even though, the model results showed high performance to reproduce chlorophyll-*a* distribution and variability with eddy to synoptic spatial and week to interannual time scales. The new tuned parameters will improve the reproducibility of the plankton community structures. We will continue to improve the model and carry out further investigation to elucidate the mechanism of lower-trophic-level ecosystem responses to the climate forcings.

25 June, 11:15 (S4-O4)

Modelling spatio-temporal distributional patterns of copepod populations in the Gulf of Maine - Georges Bank region

Rubao **Ji**[1], Cabell Davis[1], Changsheng Chen[2] and Robert C. Beardsley[1]

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Life history traits play a significant role in determining the spatiotemporal distributional patterns of marine zooplankton, but biological-physical mechanisms controlling the population dynamics remain poorly understood. In this study, we used a coupled biological-physical model to examine the processes controlling the observed distributional patterns of three representative copepod populations in the Gulf of Maine-Georges Bank region including *Pseudocalanus* spp., *Centropages typicus*, and *Centropages hamatus*. The model results support the empirical observation: *Pseudocalanus* spp. have a relatively short stage duration at cold temperature and an egg-carrying reproductive strategy that allows an earlier population development compared to *Centropages* spp., which have a relatively long stage duration at cold temperature and have an egg-broadcasting reproductive strategy. The model further reveals that predation mortality plays an important role in the decline of *Pseudocalanus* spp. in the warm season; and that the resting egg strategy is crucial for the persistence of the *C. hamatus* population in the Gulf of Maine-Georges Bank region. Analyses of observational data and model results suggest that temperature- and food-dependent egg production and development rates, temporally and spatially varying mortality rate, as well as physical transport and biological behaviours are all important contributors to the formation of characteristic distributional patterns for the copepod populations in the system.

25 June, 11:30 (S4-O5)

Using passive acoustics to model blue whale habitat off the Western Antarctic Peninsula

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Habitat preferences of calling blue whales were investigated using data from two multidisciplinary oceanographic cruises conducted off the Western Antarctic Peninsula (WAP) during the austral autumns of 2001 and 2002. Data were collected on depth, temperature, salinity, chlorophyll-*a* (Chl-*a*) concentration, krill biomass, zooplankton abundance, and blue whale call presence. In 2001, the study area was sea ice free, high Chl-*a* concentrations occurred over a small area, krill biomass and zooplankton abundance were high, and few blue whale calls were detected. In 2002 the sea ice covered the southern part of the survey area, Chl-*a* was high over a large area, krill and zooplankton were low, and there were more blue whale calls. Logistic regression analysis revealed blue whale calls were positively correlated with depth and SST, and negatively correlated with the mean zooplankton abundance from 101–300 m and the mean krill biomass in the top 100 m. The negative correlation between blue whale calls and zooplankton could occur if feeding animals do not produce calls. Our survey area did not cover the full range of blue whale habitat off the WAP, as blue whales probably follow the melting and freezing ice edge through this region. Passive acoustics can provide insight into mesoscale habitat use by blue whales in the Southern Ocean where visual sightings are rare, but the ability to localise on the calling animals would greatly improve the ability to model at a finer scale.

25 June, 11:45 (S4-O6)

A global initiative to forecast climate change impacts on fish and shellfish

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There is growing consensus that climate change is likely to have lasting impacts on marine ecosystems. Quantitative forecasts of the potential impact of these changes are needed to provide ecologists, commercial stakeholders, natural resource managers with the best available information for decision making. In response to this need, interdisciplinary research teams have been formed to attempt to develop ecological models to quantify climate change impacts on fish and fisheries throughout the world. To facilitate the advancement of this critical research, ICES and PICES formed the working group on Forecasting Climate Change Impacts on Fish and Shellfish (WG-FCCIFS). Comparison of research programmes throughout the world reveals that three modelling approaches are typically applied to evaluate the impacts of climate change on fish and shellfish resources:

1) *Statistical downscaling*: Regional scenarios are estimated from IPCC model projections and are used to forecast time series of regional environmental variables (e.g. monthly temperature, advection, prey availability, predator abundance, habitat volume) that are incorporated into stock projection models to estimate future fish or shellfish production.

2) *Dynamical downscaling on regional scales*: IPCC model output is coupled to regional ocean models to project changes in nutrients, phytoplankton, zooplankton and higher trophic level responses and feedbacks.

3) *Dynamic global models*: Fully coupled biophysical models at the global scale that operate at time and space scales relevant to coastal domains.

The tradeoffs between all three modelling approaches are discussed. Selected case studies are presented that reveal the similarities and differences of expected impacts and their associated key uncertainties are presented.

25 June, 12:00 (S4-O7)

Operational larval drift modelling in the northeast North Atlantic

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Norwegian-Spring Spawning herring (NSS) and Northeast Arctic Cod (NEA) are two of the largest commercial stocks in the world. Their habitat includes spawning grounds along the Norwegian Coast (from 60–70°N at ~10°E) and nursery grounds in the Barents Sea (cod and herring) and the Norwegian Sea (herring). Their importance as human food-supply makes it imperative to evaluate the risk associated with non-fishing activities. Oil and gas production, and the number of oil tankers sailing from Russian terminals through Norwegian waters, are steadily increasing. These activities present a potential source of pollution and real-time evaluation of overlap between ichthyoplankton and spill would be a most-wanted management tool. In addition, these stocks are sampled at several stages during their ichthyoplankton phase and an operational product quantifying their real-time distribution could potentially improve the sampling strategy. Such a product is developed in cooperation with the Norwegian Meteorological Institute. An evaluation of this tool along with a presentation of the operational larval drift web page will be given.

25 June, 12:15 (S4-O8)

Size-structured energy fluxes through global pelagic ecosystems: seasonal, inter-annual and decadal variability in the three oceans

Olivier **Maury**

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In this communication, we present and use the ecosystem model APECOSM, which is currently being developed in the framework of the CLIOTOP synthesis and modelling working group, to study the propagation of environmental variability through size-structured pelagic communities in the global ocean. APECOSM represents the basin wide spatialised dynamics of open ocean pelagic ecosystems from zooplankton up to fishing with a special emphasis on top predators. Physical forcing (temperature and currents from the OPA-NEMO OGCM), biogeochemical forcing (primary and secondary production, light and oxygen from the PISCES biogeochemical model) are explicitly taken into account. In this talk we focus on the component of APECOSM which represents energy fluxes through Open Ocean Pelagic Communities (OOPCs) with three coupled size-structured partial differential equations in five dimensions (3D space, time and organism weight). The epipelagic, mesopelagic migratory and mesopelagic non-migratory communities are explicitly distinguished. Their respective biomasses emerge from opportunistic size-based trophic interactions controlled by the environmentally driven vertical and horizontal distribution of organisms. The model is consistent with the DEB theory which specifies energy allocation through physiological functions of living organisms. The diversity of life-history traits is explicitly considered in each of those three communities which encompass implicitly an infinite number of different species. A long term simulation (1958–2001) based on a NEMO-PISCES run forced by the ERA40 reanalysis is described. The horizontal and vertical distribution of the three different communities as well as the transfer of energy from the epipelagic community to the mesopelagic communities is analysed. The effects of different modes of environmental variability (seasonal, inter-annual and decadal) are characterised in terms of the regional structuring of the pelagic ecosystem and the variability of energy transfer and dissipation through the size-spectrums.

25 June, 14:00 (S4-O9)

Inter-annual variability in the northern California Current food web structure: revealing trophic pressures upon juvenile salmon

James **Ruzicka**[1], Elizabeth Daly[2], Cheryl A. Morgan[2], Robert Emmett[3], Jeannette Zamon[3], Richard Brodeur[3] and Thomas Wainwright[3]

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The Northern California Current off Oregon and Washington is a seasonally productive and open ecosystem. It is home to both a diverse endemic community and to seasonally transient species migrating mostly from the south. Ecosystem productivity and food web structure vary on seasonal, inter-annual, and decadal time scales due to the timing and strength of the coastal upwelling, timing and numbers of migratory species entering the system, and forcing by climate-scale physical processes (*El Niño*, Pacific Decadal Oscillation). These affect the survival and productivity of all members of the community. Ocean survival of juvenile salmon correlates with lower trophic-level productivity and with the abundance of predatory fishes. Both bottom-up and top-down processes regulate juvenile salmon survival, but the strength and relative importance of these processes vary among years. During May, June, and September of 1998–2008, we conducted hydrographic, plankton, seabird, and juvenile salmon surveys off Oregon and Washington, USA between 44.6° and 48°N latitude. These surveys provide data on the pelagic community composition (forage fishes, predatory fishes, seabirds, and zooplankton community composition) and the diets of juvenile salmon. We synthesize the June community composition dataset into a series of independent, mass-balanced food web models (Ecopath platform) from which we quantify inter-annual changes in bottom-up and top-down pressures acting upon juvenile coho salmon (*Oncorhynchus kisutch*) and juvenile Chinook salmon (*O. tshawytscha*). We compare food web structure for three consecutive, but contrasting years: 2003 (high spring upwelling, high predator and forage fish abundance, relatively good coho salmon survival), 2004 (low spring upwelling, high predator and low forage fish abundance, relatively poor coho salmon survival), 2005 (low spring upwelling, low predator and low forage fish abundance, relatively poor coho salmon survival). From each model, we derive a set of simple indices describing direct and indirect trophic interactions between juvenile salmon and the rest of the pelagic community: a) predation pressure, b) the mediation of predation by the availability of alternate prey, e.g. forage fishes, c) food availability (lower trophic production) and realised consumption, and d) competition for food. The constructed models vary only with the observed changes in community composition and diet; we minimise differences of all other parameters between models. In this comparative study, our goal is to document inter-annual variation in trophic interactions as inferred from available observations.

25 June, 14:15 (S4-O10)

Predicting regime shifts under different scenarios in the Black Sea

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The Black Sea is a deep almost enclosed basin in eastern Europe. Dramatic environmental changes in recent decades have increased its importance as a “natural laboratory” for studying marine ecosystem dynamics. The Black Sea food web is relatively simple and effects of both productivity (bottom-up) and predation (top-down) have been identified. Data series accounting for the various trophic levels as well as some environmental variables were used to investigate the dynamic structure of the food web of the Black Sea ecological system. To do this we used threshold Generalised Additive Models (tGAM). This modified GAM formulation allows for non additive effects of the explanatory variables below and above a certain value of a threshold variable, the threshold value being estimated from the data. The annual averages of each of the trophic levels’ biomasses were used as the response variable and regressed against the various biotic (i.e. the other trophic levels) and environmental variables the year before. In an attempt to evaluate the predictive capability of these empirically-deduced models we used them to simulate the observed dynamics after linking all the trophic levels together. By doing this, we let the food web interact according to the statistically estimated relationships/thresholds. Once the models were estimated and the simulations succeeded to reproduce the observations, we used them to explore what would have happened if the conditions had been different, i.e. we simulated the system on hypothetical scenarios. To do so, we focused on key variables (nutrient concentration and fish biomass) that could cascade up and down in the food web in order to track their effect. The procedure consisted of three steps: 1) a number of scenarios were defined where these variables were either increased or decrease by a percentage over the mean (e.g. -10%, -5%, 5%, 10%, etc.), 2) these modified variables or scenarios were input to the empirically-deduced skeletal food

web model, and 3) the 'simulated system' (i.e. the biomass for the different trophic levels under a given scenario) was investigated with reference to the prevailing food web control (bottom-up vs. top-down) by means of phase space plot (consumer vs. resource). We found that in some periods and for certain trophic levels the type of trophic regulation could shift to the alternative (e.g. top-down to bottom-up) under slightly different conditions, while some others were very stable to any external forcing. This novel approach can help us to explore the effects that possible future scenarios could have on the type and strength of trophic links in the marine system.

25 June, 14:30 (S4-O11)

Antarctic sea ice: measuring habitat complexity, and seasonal and regional variability in habitat use for minke whales

Maria Garcia **Rojas**, Deborah Thiele and Edwin Chester

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Minke whales (*Balaenoptera bonaerensis*) are found in association with sea ice in the Antarctic year round, often occurring hundreds of kilometres into the pack. The sea ice is a dynamic and complex region of the Antarctic marine ecosystem in both physical and biological terms that provides habitat for many species, including minke whales. Here we investigate the extent to which sea ice can be categorised in an ecologically meaningful way for the Antarctic minke whale, particularly how the patchiness of their distribution in ice relates to the heterogeneity of the ice landscape. A comprehensive sea ice classification system developed by sea ice physicists was integrated with a cetacean sighting survey regime to describe habitat on a series of studies across three regions of the Antarctic. Work was conducted during spring, summer and autumn from 2004–2006 primarily to investigate relationships between minke whale distribution and sea ice characteristics. The sea ice classifications for a subset of the data were first fuzzy coded, and then used in multiple correspondence and discriminant analysis to explain variability of the pack ice at a high temporal sampling resolution. Marginal frequencies for fuzzy-coded ice variable modalities were examined to characterise the sea ice conditions found throughout each data set: marginal frequencies for records where minkes were sighted indicated potential habitat. Ordination through multiple correspondence analysis explained variability among the fuzzy-coded records according to the influence of the original ice variables: complexity was high with samples at a ten minute temporal resolution, and several ordination axes were required to explain >50% of variance in the data. Hypotheses were tested in East Antarctica, the Ross and the Weddell Sea by deriving canonical functions from axis scores, i.e. discriminating ice records associated with minke whales, and from different locations/times. Some potential for classifying minke habitat was found in some areas and seasons and a number of multivariate tests showed significant differences (i.e. minke whale habitat was discriminated in the analysis during summer in the Ross Sea). It was evident that different seasons and locations presented clear differences in their ice characteristics. Interestingly minke whale distribution was associated with ice patterns only in particular seasons. Identifiable minke whale "habitat" was not evenly distributed across bathymetric zones. In all seasons and regions studied whale concentrations could be best explained by sea ice "habitat" alone, except in the Ross Sea, in spring, where whale distribution was most strongly associated with bathymetric zone.

25 June, 14:45 (S4-O12)

Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) landings forecast off northern Chile: a multivariate neural networks ecosystemic approach

Eleuterio **Yanez**, Francisco Plaza, Nibaldo Rodríguez, Juan Gutiérrez-Estrada, Guido Plaza, Inmaculada Pulido-Calvo and Cinthya Borquez

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The performance of artificial neural networks (ANNs) to forecast monthly anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) catches in northern Chile (18°21'S–24°S), using environmental variables, and anchovy and sardine catches between 1963 and 2007, was evaluated. For this purpose a previous analysis of the data was carried out consisting of a non-linear cross correlation analysis in order to estimate the time lags for each input variable. The model used was a multi layer perceptron architecture trained with the Levenberg-Marquardt algorithm. The results showed two final models, for anchovy and sardine landings respectively. For the anchovy forecast model the inputs consist of local and global environmental variables, showing both local and remote effects over landings. For the ANN sardine forecast the best model showed that global environmental variables had more effect over sardine landings. On both models the explained variance was slightly higher than 86% and the standard error of prediction was lower than 20%. The strong correlation between estimated and observed sardine catches suggests that ANNs models captured the trend of the historical data. Also, the generalisation capacity plus the sensibility analysis allowed us to identify the variables with a high weight in the model and partially to interpret the statistical functional relationships between the environmental variables and landings.

25 June, 15:00 (S4-O13)

Lower-trophic-ecosystem monitoring in the Oyashio region and application of an automated approach for calibrating the NEMURO nutrient-phytoplankton-zooplankton food web model in the Oyashio region

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A seasonally repeated observation line (A-line) was set from Akkeshi Bay in Hokkaido to the southeast offshore in the northwestern Pacific and lower-trophic-level ecosystem monitoring (including hydrographic observations) has been conducted since 1988. To investigate the seasonal to interannual variation of the lower-trophic-level ecosystems on the A-line, a nutrient-phytoplankton-zooplankton food web model, NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) was developed. The corresponding abundance of each of the ecosystem compartments in NEMURO was estimated using data from the A-line and other historical observations, and climatological seasonal change of nutrients and plankton in the Oyashio region was described. Using these data, the automated calibration software PEST (Model-Independent Parameter Estimation) was applied to the box-version of NEMURO as an alternative to the usual *ad-hoc* calibration. In NEMURO, large zooplankton appear in the surface mixed layer in spring and retreat to the deep layers in autumn. Thus, the simulated system has two different states depending on the presence or absence of large zooplankton in the mixed layer. Prior to applying PEST to field data situations, several twin experiments were conducted to evaluate the performance of PEST. In the twin experiments, model predictions were used as virtual observations and then PEST was started with arbitrary parameter values to determine if PEST could recover the original parameter values. First, a twin experiment was conducted that included vertical ontogenetic migration of large zooplankton. In this case, PEST failed to find the original parameter values. The instantaneous discontinuity in the state of the simulated system during periods of ontogenetic migration created estimation problems for PEST. Experiments without ontogenetic migration successfully recovered model parameters. Therefore, the simplest way to apply PEST calibration to NEMURO is to exclude ontogenetic migration from the model. A PEST calibration was applied to NEMURO using the observational climatology of the nutrients and plankton. The PEST calibration estimated higher growth of phytoplankton and higher predation pressure on phytoplankton from zooplankton. To test the influence of parameter changes, a 3-D NEMURO model coupled to an ocean general circulation model was integrated using the original parameter set and the newly estimated one by PEST. The parameters estimated by PEST revealed better consistency with the satellite observed chlorophyll distribution in the northwestern Pacific.

25 June, 15:15 (S4-O14)

An example of estimating future Bering Sea northern rock sole productivity from statistical downscaled IPCC models

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There is an increasing interest in forecasting the implications of climate change on the production of marine fish. These analyses involve five steps: 1) identification of mechanisms underlying the reproductive success, growth and distribution of major fish and shellfish populations; 2) assessment of the feasibility of down-scaling implications of IPCC scenarios on regional ecosystems to select environmental indicators; 3) evaluation of climate model scenarios and select IPCC models that appear to provide valid representations of forcing for the region of study; 4) extracting environmental indicators from climate scenarios to and incorporating indicators into projection models for fish and shellfish; and 5) evaluation of the mean, variance, and trend in fish and shellfish production under a changing ecosystem. An example is presented where downscaled estimates of future springtime wind direction from IPCC models are used to estimate the impacts of climate change on cross-shelf transport of northern rock sole (*Lepidopsetta polyzystra*) larvae in the Bering Sea. Results show climate change may result in a modest increase in the frequency of strong year classes of northern rock sole through 2050.

S6 Ecosystem approach to management

Chairs: Dave Checkley, Keith Brander and Astrid Jarre

26 June, 08:30 (S6-O1 invited)

Developing a science base for the ecosystem approach to South African fisheries

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South Africa is committed to making substantial progress towards implementation of the Ecosystem Approach to Fishing (EAF) by 2010. This requires a solid scientific basis comprised of a toolkit of varied and concerted efforts from which management measures can be carefully considered and put into place. A series of workshops was held to assist in the identification of issues in South Africa's key fisheries that are cause for concern and may have EAF implications. Several of these issues were addressed under various projects. Food web studies have been undertaken and models have been constructed of the changes in the structure and functioning of the southern Benguela upwelling system in response to fishing. The impacts of demersal trawls on the benthos and demersal fish assemblages is being examined. Fishing does not act in isolation, however, and thus the combined effects of fishing and environmental change on South African fisheries have been examined using various observation-based and modelling methods. These are contributing to the assessment of changes at multiple spatial and temporal scales, spanning from the impact of pelagic fishing in key foraging areas of critically-dependent predators, to decadal-scale dynamics and global comparative classifications of ecosystem status. A pivotal aspect of implementation of an EAF is the identification and use of indicators of ecosystem change and response to fisheries management measures. To address some of the EAF issues, practical implementation measures are being developed and applied in consultation with stakeholders. Stakeholders are also actively involved in the development of indicators to address the human dimensions of EAF, and knowledge-based systems are being developed as management decision support tools. Future directions and research initiatives are outlined in support of EAF for South Africa.

26 June, 09:00 (S6-O2)

Models for synthesis and communication: expert systems and frame-based models as decision support tools in support of an ecosystem approach to fisheries management in the Benguela

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An ecosystem approach to fisheries management spans a multitude of issues and needs to find viable compromise in a situation with multiple stakeholders, conflicting interests, and high scientific uncertainties. Management needs build on best available science, in a classical as well as in an ecosystem approach. The communication of the characteristics, strengths and weaknesses of models underlying classical fisheries advice among stakeholders typically has proved to be difficult, and has led to complacency or rejection of the basis for advice and lack of co-operation in the management process, an unhealthy position for fisheries management to find itself in. However, a management approach that is holistic and participatory, as implicit in an ecosystem approach, requires meaningful communication with a range of stakeholders. Seeking to combine the need for scientific rigour with the property of communicability, we explore the use of two semi-quantitative modelling approaches synthesizing complex, detailed scientific knowledge, for improved communication among stakeholders. The first, frame-based modelling, is a technique particularly well suited to explore dynamic changes on the scale of an ecosystem in the long term. Results of a second prototype on anchovy-sardine dominance in the southern Benguela under long-term climate variability and fishing suggest its potential use as a communication/training tool to understand, in principle, the consequences of different fishing strategies. The latter prototype also shows promise as a tool to generate indicators for the probability of (fisheries) management actions inducing ecosystem changes under long-term ecosystem change.

The second approach relies on expert (or knowledge-based) systems, and is particularly well suited to integrate information from a multitude of indicators into an overall assessment or advice. To illustrate the use of this methodology, we present recent progress with a tool to assess the implementation of an ecosystem approach to the south African pelagic fisheries with respect to the ecological and human dimensions, as well as a related tool on the coastal Namibian rock lobster fishery. In addition, we present progress with an expert system aimed at detecting and predicting long-term ecosystem changes in the southern Benguela.

26 June, 09:15 (S6-O3)

Contrasting drivers of ecosystem response via the comparison of marine ecosystem indicators: multiple ecosystems and multiple indicators

Jason **Link**[1], Dawit Yemane[2], Lynne J. Shannon[3], Marta Coll[4], Yunne-Jai Shin[5], Louize Hill[6], Fatima Borges[6], Alida Bundy[7] and Kerim Aydin[8]

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Indicators to detect ecosystem change are dependent upon three things: data to estimate the indicator, the ability to detect change in an indicator, and the ability to link said change in an indicator as a response to a known intervention or pressure. In this paper we specifically examine the third aspect of indicator change, with an emphasis on multiple methods to explore the “relativity” of major ecosystem drivers. We use two multivariate methods to explore the relationships between a pre-established set of fisheries-oriented ecosystem status indicators and the key drivers for those ecosystems (particularly emphasizing proxy indicators for fishing and the environment). We executed our analyses for 19 marine ecosystems from a wide range of the oceanic systems. Our results showed the relative importance among fishing and environmental factors, which differed notably across the major types of ecosystems. Yet our results also demonstrated common patterns in which most ecosystems and indicators of ecosystem dynamics are largely driven by fisheries (landings) or human (IHD) factors, and secondarily by environmental drivers. We conclude by discussing how one might utilise this empirical evidence in future efforts for Ecosystem Approaches to Fisheries, particularly in the context of the EUR-OCEANS Indiseas project.

26 June, 09:30 (S6-O4)

A tripartite classification of ecosystem trends

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Globally, marine ecosystems have been subject to decades, and in some cases centuries, of exploitation and are growing increasingly vulnerable to potential collapse and irreversible change. How do we know when an ecosystem may be in danger? A measure of the status of individual stocks is only a partial gauge of the status of an ecosystem. It does not include changes occurring at the broader ecosystem level, to non-commercial species, or to the structure or functioning of the ecosystem. These broader changes can be captured by a suite of indicators, such as those explored and developed within the EUR-OCEANS IndiSeas project. Six ecosystem indicators measuring trends over time, mean length of the fish community, trophic level of the landings, total biomass of surveyed species, proportion of predatory fish, mean life span, and inverse fishing pressure were collated for nineteen ecosystems for time series ranging from 15 to 44 years. These indicators correspond to four ecological goals, resource potential, ecosystem structure and functioning, conservation of biodiversity, and ecosystem stability and resistance to perturbations. Using a decision theoretic approach, a definition of initial

ecosystem state (impacted or non-impacted) and the trends in the ecosystem indicators, the nineteen ecosystems were classified into one of three conditions: better (improving), flat (stationary) and worse (deteriorating).This classification provides an initial evaluation to scientists, resource managers, stakeholders and the general public of the global status of ecosystems.

26 June, 09:45 (S6-O5)

Combining constraints from predation and competition to determine expected fishery yields on Georges Bank

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Predation between, and competition within, trophic levels are regarded as the principal processes prescribing community structure. Neither process directly determines the potential fishery yield of particular stocks in the fish community, but together they can constrain the expected yields of individual species. An end-to-end budget for Georges Bank is used to determine the plankton and benthos production available for three predator guilds—planktivores, benthivores and piscivores—under a range of scenarios describing possible climatic changes and habitat disturbances. Species/abundance rankings and other measures of diversity set limits on abundance of individual fish species, and generate measures of community response, without identifying the species. Together the requirements imposed by food web fluxes of plankton and benthos, and by patterns of relative abundance, provide constraints on the species that can be dominant within the fish community. These ecosystem-based constraints can be used to set limits to possible values for production under a range of possible management scenarios which, in turn, can provide the basis for multi-species maximum sustainable yields. These general principles are illustrated by application to Georges Bank.

26 June, 10:30 (S6-O6)

Spatial ecosystem modelling of the upper Gulf of California using Atlantis

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A spatially explicit biogeochemical food-web model of the upper Gulf of California (Sea of Cortez) is developed using the Atlantis modelling framework. The purpose of the study is to simulate and test various ecosystem-based management (EBM) strategies for the upper Gulf to determine likely impacts on artisanal fisheries and conservation of marine resources, including rare and endemic species. Parameterisation of the model in this data-poor region has relied on numerous field studies directed to provide original data for the Atlantis model. Efforts include trawl sampling, reef diving transects, stomach content analysis, community interviews, port-level sampling, log book analysis, and reconstruction of biomass trends from local ecological knowledge interpreted using a fuzzy logic approach. A new spatial biomass allocation algorithm based on substrate, habitat affinities and other factors increases the applicability of biomass data. A novel maximum-likelihood method is used to interpret stomach content data for the diet matrix. Modifications have been made to Atlantis to improve representation of the area's ecology and take advantage of specialised data. Recommendations from this project will influence regional EBM plans and species-specific management plans to be adopted by Mexican fishery authorities in the 2010–2012 time frame.

26 June, 10:45 (S6-O7)

The ecosystem approach to managing marine resources is missing the ecology

Howard **Browman**

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The urgent need to reduce the intense pressure and destructive power that modern fishing practices apply to the world's fisheries, and the oceans that support them, is now widely recognised. However, there is far less agreement over the exact levels to which fishing mortality must be reduced and over how to reduce the indirect effects of fishing (e.g. bycatch, destruction of the seafloor, changes to trophic structure (ecosystem overfishing)) in order to ensure sustainability of catches and the health of marine ecosystems. In recognition of the significant direct

and collateral impacts that fishing and other human activities impose on marine ecosystems, ecosystem-based approaches to managing aquatic resources (EBM) have been adopted by institutions worldwide that are charged with stewardship of the marine environment. The EBM implicitly recognises that the value (to humanity) of the whole ecosystem is much greater than the sum of its parts — a commendable step forward in-and-of itself. However, there is some disagreement over whether the EBM truly represents an approach that will be any more effective in assisting us with sustainable management of marine resources than historical practices. In this talk, I will briefly present the history of the EBM, including where it originated and why it has been so rapidly adopted, define what it is, and then take a provocative "devil's advocate" position in addressing the following questions associated with it: 1) Can it be operationalised and, if so, how?; 2) Is there any ecology in it (that is, have core ecological principles been incorporated into the EBM); 3) is ecology necessary to meet the main objectives of the EBM?; 4) is EBM really needed to improve the sustainable management of marine resources.

26 June, 11:00 (S6-O8)

No silver bullets

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Ecosystem-based management (EBM) has already meant many things to many people. A common feature of many discussions is the presentation of "silver bullet" solutions where single approaches (e.g. spatial management or individual transferable quotas) are presented as the most effective form of resource management and EBM. As no single solution has solved fisheries management issues worldwide there is no reason to think one would solve ecosystem-based management. Instead it needs to be recognised and accepted that EBM will not be simple or static; its form from place to place is likely to include system specific components and to evolve through time (just as the cultures and ecological systems it spans do).

26 June, 11:15 (S6-O9)

Transitioning of US GLOBEC results to applications

Elizabeth **Turner**

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GLOBEC scientists, and the results of their studies, are intimately involved in the preservation and sustainable use of our ocean environment and resources. However, the direct transfer of ocean science results to application in the policy and management context remains a challenge. In part this is due to differences in culture between scientists and managers, time constraints on both sides, lack of unambiguous scientific results, and difficulties in communication between scientists, managers, and policy makers. This presentation will explore how US GLOBEC has begun to take research results to applications in fisheries management, ocean observation systems, and operational ocean modelling. I will examine some characteristics of US GLOBEC that have facilitated transition, and review selected examples.

S7 Marine ecosystem science: into the future

Chairs: Wendy Broadgate and Olivier Maury

26 June, 11:30 (S7-O1 invited)

GLOBEC – a view from the outside

Ken **Denman**

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GLOBEC can rightfully claim many scientific accomplishments, but perhaps its two key successes are socio-political rather than scientific. First, GLOBEC has created a global network of scientists outside national government organisations, whereby different fisheries ecosystems can be contrasted and compared relatively free from the self interests of individual nations. Second, GLOBEC has reached beyond traditional fisheries foodweb science both to embrace paleoclimatic science and to bring people into the foodweb ecosystems under study. While GLOBEC has examined the past in great detail, in its 'retrospective' activities, and the present, the challenge that I see is to 'examine' the future in even greater detail. Over the next century, fisheries food webs are going to find themselves in a very different and changing oceanic environment. What are some of the changes, known and potential, that we will have to address?

Although considerable progress has been made in identifying and analysing 'regime shifts' in fisheries ecosystems, less progress has been made in understanding the drivers of regime shifts, which is required if we are to attempt to quantify the probability of abrupt change in marine ecosystems, both regionally and globally. Abrupt change can be considered in the context of dynamic systems, where the system may exist in two or more preferred states with rapid transition between them. Such systems are characterised by hysteresis, whereby a control variable may have to recover well beyond its value when the abrupt change was precipitated before the system reverts to its original state. The crash of the northern cod in the western North Atlantic appears to be one such example. Another case where we seem to have passed a 'tipping point' is the emergence of an ice-free Arctic Ocean during summer, which is now estimated to occur in one to several decades from the present. However, we have yet to develop comprehensive food web models embedded in coupled climate models such that we can explore the possible foodweb ramifications of an ice free Arctic Ocean during summer.

In the last two decades, fisheries foodweb research has diverged from ocean biogeochemical research, which is driven by the need to understand the ocean's role in climate. The recent 'End to End Foodweb' theme explored by GLOBEC/IMBER implicitly recognised the need to reintegrate these diverging themes. But, from a biogeochemical viewpoint, a more apt title might have been 'Back to Front Analysis' of parallel but connected elemental cycles in the ocean: C, N, O, P, S, Si, Fe, etc. These multiply-connected elemental cycles affect and are affected by marine food webs over a broad range of temporal and spatial scales. Two specific and connected issues that illustrate these interactions are the increase in ocean acidity (decrease in pH) caused by adding carbon dioxide to the oceans and the observed decrease in subsurface dissolved oxygen over large regions of the ocean. Of special importance to GLOBEC is the advection of low oxygen, low pH waters onto continental shelves in upwelling regions, where local remineralisation of organic matter in subsurface waters further reduces both the oxygen concentration and the pH to levels that are harmful to marine organisms.

26 June, 11:55 (S7-O2 invited)

Beyond GLOBEC

John **Steele**

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Introduction

My involvement with GLOBEC has been long term but very sporadic. I was around at its creation in the US; and now have some funding to participate in its final synthesis. In between I have been an interested spectator. There appear to be two quite distinct questions linking the past with the future. The first concerns the science. A major programme like GLOBEC can be judged as much by the future scientific challenges and opportunities it creates as by its acknowledged accomplishments. The second concerns the form that future research should take. Do we need another large international programme? How would it relate to the rest of marine research; and, of course, nowadays, to society?

I shall try to explore these issues by, first, reminding you of the milieu from which GLOBEC grew to an international programme–the past as prologue. Then I want to link the achievements documented in the talks and the GLOBEC international synthesis book (in press), to the challenges as unfinished business. Lastly there are the "practical" questions. Are we looking to build on the past concepts, organisation and methodologies. Or do we plan a quite different approach beyond GLOBEC?

I. The Past as Prologue

GLOBEC was one of a group of "global" programmes started in the 1980s. The divisions between WOCE, JGOFS and GLOBEC (and RIDGE) were disciplinary and the aims were scientific. The programmes starting in this new century are (or should be) quite different. The stated objectives are societal and the individual aims are problem driven.

WOCE was essentially a data gathering programme to fill out concepts developed by Stommel, Munk, Wunsch and others. "The aims of the programme were to establish the role of the oceans in the earth's climate and to obtain a baseline dataset against which future change could be assessed. Sophisticated numerical ocean models were also developed to provide a framework for the interpretation of the observations and for the prediction of the future ocean state". It is interesting that there was no formal publication from a final meeting. In fact a focus was on the next project.

> "Both the health of our science, and societal needs, require that we collectively sustain the kind of thought and effort that led to WOCE" Carl Wunsch, 2002

JGOFS came at a time when ideas on production processes were being formulated and new technology, such as satellite colour and sediment traps, were being developed. The combination of theory and observation resulted in a truly global perspective for cycling of nutrients, including iron, and fluxes of carbon. The increasing focus on climatic change gave these results considerable relevance that is the basis for new programmes such as Ocean Carbon and Biogeochemistry (OCB). These gave impetus for continued programmes.

> "As JGOFS comes to a close, new observational and hypothesis driven research programmes must emerge to assimilate and extend these studies". David Karl *et al*., 2003

GLOBEC's many successes, amply illustrated in this meeting, have increased our understanding of the processes underlying a variety of regional systems such as Eastern Boundary Upwelling, Antarctic ecosystems North Atlantic cod, etc. Perhaps the most important overall achievement was in demonstrating the general significance of the direct relations between physical dynamics, plankton and pelagic fish populations. But this required some simplification in depiction of the food web particularly on the shelf where benthic fauna are a major component. This philosophy was expressed by Brad de Young *et al.* (2005). "Rather than model the entire ecosystem we should focus on key target species and develop species-centric models". The power of this approach is apparent in recent publications dealing with physically complex shelf ecosystems (Wiebe *et al.*, 2001; this meeting). This approach is complemented by the wasp-waist concept of Philippe Cury and others, of minimal diversity at middle trophic levels, focusing attention on a small number of species. The constraints follow from the focus on spatially detailed models for individual species. Thus, I would suggest that the central GLOBEC theme, "Global Ecosystem Dynamics" still remains a challenge.

This quick review indicates the very different outcomes of these three programmes. WOCE helped refine existing "global" models. JGOFS, by fortunate timing, helped create the first global perspective on ocean biogeochemical cycles. GLOBEC, I would suggest, has laid the foundations for population dynamics but is still working towards its "global ecosystem" goal. Such a goal would require generic tools with a dynamic ability to address multi-scale processes, capture the differences between ecosystem types and develop generic currencies (*e.a.* like C was for JGOFS) to allow quantitative comparisons between these types. Although these three programmes were quite distinct, there were three features that brought them together: 1) an integrated approach to agencies, 2) a disciplinary ordering of priorities, and 3) an optimism about funding. So, as well as the future scientific challenges, do we need to consider these non-scientific components?

A point worth noting is that, while JGOFS and WOCE were "global" but driven by a very small number of countries, GLOBEC was "world-wide" and strongly implemented in many countries and regions.

II. Unfinished Business

I have the feeling that GLOBEC researchers are reluctant to abandon this programme. Not only are there a large number of interesting individual challenges and opportunities arising from GLOBEC and set out during the meeting; but also the central GLOBEC question remains–how can marine ecology or biological oceanography establish "global" generalisations about the overall dynamics of ecosystems under a wide range of habitats and forcing functions. This challenge is not peculiar to marine ecosystems, but applies to ecology in general.

The outstanding successes of GLOBEC have come from the use of models of regional physical environments to drive age-structured pelagic populations. These models are generally not coupled, with information only going one way, but this is a quibble. These built on the advances in modelling the details of advection and mixing especially for regions of the continental shelf with complex topography.

The role of these models in explaining the physical basis for features of population life histories has had an impressive cumulative impact. The connectivity of coral reef fish populations is not a long distance random process but much more controlled by local circulation. The overwintering locations of different *Calanus* populations is closely linked to the circulation in deep basins. The progression from cartilaginous elasmobranchs to bony gadoids is marked by an increasing dependence on the regularities in shelf current systems for part of the life cycle. All of these adaptations involve reliance on the relative reliability of long term "predictions" of advection and mixing in the ocean.

It appears from the papers for this meeting and the draft GLOBEC Synthesis book that much of the application of these ideas has been towards relatively short term variations in recruitment of larval fish to the adult stocks. This focus on early life histories has been less than successful for fisheries management, mainly because, perforce, the adult, and often benthic, life stages are ignored. I would suggest that the longer term, evolutionary, implications are of greater general interest and are also of practical significance, as we try to predict the implications of gradual climatic trends. For example, many of the regular features that are utilised by fish larvae, such as tidal rectification, are relatively independent of "climate"; others such as shelf edge flows like the Labrador or Norwegian Coastal Currents are climate dependent. How will this affect not only recruitment of individual species but the species composition of communities under various climate scenarios?

Questions about the changing composition of communities involve the inherent complexities in the structure and dynamics of marine food webs. This has led to two major simplifying concepts–species centric, focusing on physical processes affecting particular pelagic species, especially the early life stages of fish and is the theme for much of GLOBEC. The alternative approach we can call trophic-centric, emphasizing energy flow through broad functional groups, from nutrient input to fish production (and following the JGOFS budget approach). These two concepts are complementary. The former "horizontal" approach emphasizes the processes that link individual species or single trophic guilds directly to their physical environment. The latter "vertical" method focuses on the flux of nutrients from inorganic states to the upper levels in the food web and utilises complicated optimisations with large matrix inversions to resolve fluxes in linear steady state systems. Together they embrace most food web processes and answer different questions. They can describe features of spatial distribution of individual species, and of food web structure, especially those relevant to fish communities. They can rely on substantial ecological theory to look for patterns and parameterise processes, but they cannot provide general explanations for the factors determining changes in abundance of individual fish species. This remains the central theoretical and practical challenge for biological oceanography. The issue for future research is how far these methods, jointly, can illuminate some of the central problems in marine ecosystems. Each approach involves trade-offs. The former has complex physical processes and relatively simple population dynamics; the latter combines complicated food webs with linear steady state descriptions of processes. There are no contradictions between these two sets of simplifying assumptions. They are complementary–or "orthogonal", and answer different questions. The problem is whether, together, they can answer major practical issues concerning the conservation and management of marine ecosystems and their resources.

The issue at this time is whether we see this integration of different perspectives, and their application to policy advice, as a further development of GLOBEC; or as a quite distinct new programme. This is, in part, a question about the science and, in part, about the social setting in which we work.

III. Looking Forward

The need to integrate these disparate scientific questions with new methodologies is not in doubt. There is a range of initiatives that aims to achieve this scientific integration; in particular IMBER at the international level. There are a large number of meetings focusing on "end-to-end" analysis of food webs. The problem is–how different should all this be from an extension of GLOBEC research?

The other major factor is the stress on relevance of societal concerns. Climatic change, ocean acidification, over-fishing, loss of diversity, near and offshore pollution–the list grows longer and gets more public attention. The expectation that by 2050 almost seven billion people (more than currently inhabit the planet) will live within 150 km of the coast justifies these concerns. Can this drive us towards a radically different structure for future small and large scale ocean ecology programmes? What should be the ideal level of interaction between marine science and society?

Has this increasing societal focus led to a different emphasis in other emerging programmes, from that of the previous disciplinary pattern? At first glance, it does not appear so, or at least not yet. CLIVAR is about climatic change but deals with "physical processes responsible for climate variability and predictability on seasonal, inter-annual, decadal, and centennial time-scales". OCB aims "to establish the evolving role of the ocean in the global carbon cycle, in the face of environmental change, through studies of marine biogeochemical cycles and associated ecosystems".

Should the GLOBEC community accept some corresponding definition (like CLIVAR and OCB have done) in terms of disciplinary boundaries? In terms of the scientific problems this may at least require redrawing of the boundaries. In this meeting we have focused on the scientific achievements of the "physical-biological coupled models". But we should also recognise the achievement in "coupling" physical and biological oceanographers. For the future, the biggest challenge in creating an "end-to-end" approach to food web analysis, may be in

persuading biogeochemists, fisheries ecologists and socio-economists to work together.

There is, however, a further, potentially critical, difference between GLOBEC and previous programmes. Both CLIVAR and OCB accept the societal drivers but their relation with society appears to be relatively straightforward. The explicit purposes are to provide relevant information–"Decision Support Tools" in the latest jargon–and not to take part directly in the decision making process. This seems a sensible course of action, but different from GLOBEC's international approach, which is anchored in the understanding that humans are not just "drivers" of change but that their activity interacts with climate variability to change ecosystem processes and their structure in profound ways. For example, fishing can change the responses of species and ecosystems to climate variability by switching top down to bottom up controls or by making populations more reliant on incoming annual recruitments. This recognition demanded a much more active and dynamic relationship between GLOBEC science and human society, including management implications. Will successors to GLOBEC follow this approach or the less-engaging CLIVAR-OCB pattern?

A problem that GLOBEC is yet to resolve is how to reconcile the species centric and trophic centric scientific approaches that dominate its discourse, and how to carry this over into the practical questions of how to reconcile estimates of fisheries yields based on the dynamics of individual species (MSY) with estimates based on energy flow, habitat or migratory considerations (EBY = Ecosystem Based Yields). These various estimates can be put forward by different communities of researchers, introducing possibly divergent recommendations. GLOBEC's successors need to resolve this controversy if they are to further their engagement with human society. Ludwig *et al.* (1993) said; "Resource problems are not really environment problems: they are human problems that we have created many times and in many places". More recently Beddington *et al.* (2007) said that "our analysis (of fisheries) suggests that management authorities need to develop legally enforceable harvest strategies, coupled with appropriate rights based incentives to the fishing community". These and many other comments on conservation and management imply that a halt to the apparently inevitable decline in fish stocks requires change in ocean governance rather than refinements of scientific knowledge; moving from Arvid Parvo's declaration of the oceans as "the common heritage of mankind" to an acceptance of the implications of Garrett Hardin's "tragedy of the commons". This demands a recognition of "property rights" and property owners; not only in fisheries, mining and waste disposal, but also for conservation (MPAs) and, increasingly, for mariculture. In turn we need to recognise that, as with enclosures on land in the 18th century, the economic benefits will incur equally great social costs. Do we need to reposition the "science" in response of expected development in global governance of marine ecosystems?

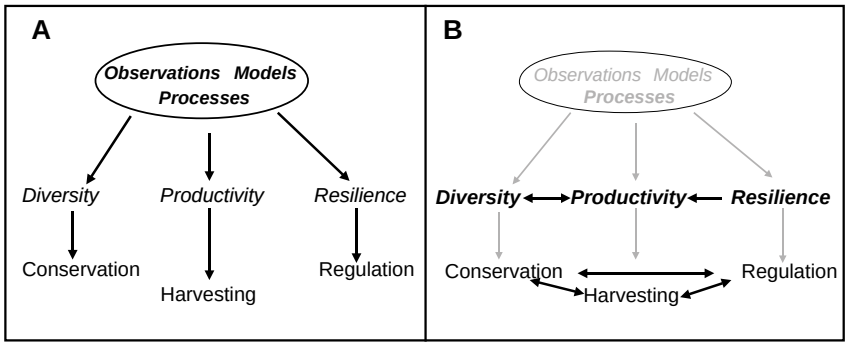

Figure 1. Stove pipes or plateaus.

Further down this path is a challenge, not just in terms of how to avoid entrapment in political controversy, although that may be difficult, but what kind of science will be relevant to resolution of these issues. An illustration of the mix of issues, Figure 1a shows the usual "stove pipes" where we relate diversity to conservation, productivity to harvesting of commercial species, and resilience to regulation. But the overall management issues (Fig. 1b) lie between these sectoral concerns, especially if we accept some forms of property rights for conservation, fishing, farming, recreation etc. Similarly the fundamental questions for our science concern the relations between the basic concepts or metrics including diversity, productivity and resilience.

Both sets of interactions are, of course, the subject of long term arguments; the science with limitations imposed by uncertainty in our observations and lack of generality in our concepts: management with conflicting economic interests and divergent values. Our focus as oceanographers should be on the upper set of horizontal connections. The fact that they map onto the social/economic issues gives our research its relevance. A much more difficult question is how to make connections between the upper and lower horizontal sets. Just as the relation between "observationalists" and "modellers" must be two-way and iterative (Fig. 2), so the interactions between "scientists" and "managers" depends on long term interchange of information and ideas rather than one way transfers.

Our special role in the upper sets of Figure 2 does not give us privileged status in the decision-making process.

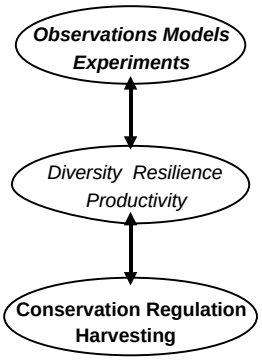

Figure 2. The links between 1) data and concepts; 2) science and management are interactive and iterative.

26 June, 13:45 (S7-O3 invited)

GLOBEC-IMBER transition

John **Field**

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The Transition Task Team (TTT) was set up to recommend to SCOR and IGBP how the second phase of the IMBER programme should proceed to accommodate new developments in marine ecosystem research that need addressing after the completion of the GLOBEC. The Task Team met in Reading, UK from 30 July–1 August, and in Washington DC from 15–17 December 2008. The TTT decided that its report should include a draft Implementation Strategy for the second phase of IMBER (2010–2014) and is seen as an Appendix to the IMBER Science Plan and Implementation Strategy (SPIS) published by the IGBP in 2005. It is noted that several potential regional programmes of IMBER are only just starting and most are planned as ten year programmes running well after the present projected life of IMBER. The potential regional programmes may need to adapt their plans to fit in with IMBER's too. Thus there may be a need for a follow on SCOR/IGBP Ocean research programme after IMBER ends in 2014.

With accelerating global change the urgency of achieving the IMBER vision and goal is even more apparent five years after the IMBER Science Plan was written and will build on the IMBER activities to date. The transition task team identified areas that need new or renewed emphasis so that IMBER Phase II will achieve its scientific vision and goal. These areas are:

- integrating human dimensions into marine global change research
- regional research programmes
- comparative studies within and across regional programmes, including ecosystem models that incorporate the human dimension
- incorporation of emerging scientific themes

The talk will consider these in more depth and incorporate feedback received from individuals, research programmes and sponsors. TTT Members: Ken Drinkwater, Hugh Ducklow (2nd meeting only), John Field (chair), Roger Harris, Eileen Hofmann, Olivier Maury (1st meeting only), Kathleen Miller, Mike Roman, Qisheng Tang; Raleigh Hood participated in discussions of SIBER on 15 December 2008.

26 June, 14:00 (S7-O4 invited)

Integrated Marine Biogeochemistry and Ecosystem Research project

Julie **Hall**

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IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) is a decade long international project that will develop new knowledge of ocean biogeochemical cycles and ecosystems. The project goal is to investigate the sensitivity of biogeochemical cycles and marine ecosystems to global change on time scales ranging from years to decades. To achieve this goal, IMBER will identify key interactions between marine biogeochemical cycles and ecosystems and assess how these interactions respond to complex natural and anthropogenic forcing factors in key areas of the world's oceans. The project is focused on the impacts of 1) physical drivers for example, stratification and circulation, 2) changes in CO_2 concentrations for example CO_2 storage and ocean acidification, 3) changing supplies of macro and micro nutrients and 4) harvesting. With the synthesis of GLOBEC research new questions have been identified and ongoing GLOBEC projects are considering becoming part of the IMBER project. An addendum to the IMBER Science Plan and Implementation Strategy has been developed by the GLOBEC/IMBER Transition Team. The implementation of this plan will be discussed.

26 June, 14:25

Discussion

WA Modelling ecosystems and ocean processes: the GLOBEC perspective of the past, present and future

Chairs: ***Enrique Curchitser (USA), Alejandro Gallego (UK), Michio Kishi (Japan) and Emanuele Di Lorenzo (USA)***

One of the salient features of GLOBEC research has been the use of dynamical, statistical and conceptual numerical modelling techniques to investigate marine ecosystem processes and their link to ocean climate. A wide array of models has been developed and implemented, including community and individual based biological models, regional to basin-scale physical models and coupled physical-biological models. The goal of the workshop is to describe and compare different modelling approaches and their ability to elucidate physical/ biological dynamics.

The workshop will be structured along the following four sub-topics:

1) Physical and biological modelling
2) Biological and advanced ecosystem models
3) Frontiers in ecosystem modelling
4) Climate change in regional marine ecosystems

22 June, 08:30
Introduction

Topic 1: Physical and biological modelling

22 June, 08:40 (WA-O1 invited)
Topic 1 review: Physical and biological modelling

Francisco **Werner**

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GLOBEC studies have greatly expanded our understanding of the structure and functioning of marine ecosystems, in particular demonstrating the importance of life history dynamics in determining the influence of physical processes on organisms in the ocean. Linkages between physical and biological processes have been explored through novel approaches to experimentation in the laboratory, in the field and through biophysical models of the coupled dynamics. New observations and the development of realistic physical circulation models have made it possible to quantitatively explore the relation between advection by large-scale hydrodynamic fields, motions of actively behaving organisms at the scale of the individuals, and the response of organisms to dynamically evolving predator/prey fields. Scale dependence has also been demonstrated through observations that cover a wide geographic range and models that allow a high resolution ranging from the continental shelf to oceanic basin scales. These ideas and approaches to biophysical coupling are reviewed through research highlights that have been carried out during the GLOBEC programme during the past two decades.

22 June, 09:00 (WA-O2)
Large scale context for oceanic processes on the west Antarctic Peninsula

John **Klinck**[1], Michael Dinniman[1] and Laurence Padman[2]

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[2] Earth and Space Research, 2101 Fourth Avenue, Suite 1310, Seattle WA 98121, USA.

Biological and physical processes on the continental shelf of the western Antarctic Peninsula (WAP) have been the focus of observations and models in the Southern Ocean GLOBEC programme. Larger scale atmospheric and oceanic conditions influence the observed variability in the WAP region. For example, the variation in location of the atmospheric polar trough affects the direction of winds along different parts of the Peninsula and the typical path of storms. These location variations are mainly seasonal but are also interannual. Simulations of WAP shelf circulation were obtained with a regional numerical circulation model based on the

Regional Ocean Modelling System (ROMS) that includes dynamic sea ice and thermodynamically active ice shelves. Simulated circulations were forced with atmospheric conditions from either the US National Center for Environmental Prediction (NCEP) or Antarctic Meteorology Prediction System (AMPS) forecasts which are augmented with scatterometer observations (over ice-free areas). These simulations show that changes in the alongshore transport over the shelf are correlated with variations in alongshore winds. These transport variations affect the strength of the CDW intrusions across the shelf break. These intrusions have been shown to be important for the heat and nutrient balance over the WAP shelf. Correlations between atmospheric conditions and climate indices, such as the Southern Annular Mode and ENSO, allow extrapolation of the model solutions to other times for which observations or simulations do not exist but for which climate indices have been estimated.

22 June, 09:20 (WA-O3)

Differences in the fate of Circumpolar Deep Water advected onto the continental shelf in the Ross Sea and the West Antarctic Peninsula

Michael **Dinniman**[1], John Klinck[1] and Walker Smith, Jr.[2]

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[2] College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA 23062, USA.

Relatively warm, nutrient-rich Circumpolar Deep Water (CDW) can be found near the continental shelf break around most of Antarctica. Transport of this water onto continental shelves and coastal seas has important effects on physical and biological processes. For example, the advection of this warm water across the continental shelf to the base of floating ice shelves is thought to be critical in determining why ice shelves of similar thickness can have vastly different basal melt rates. Biologically, CDW exchange provides macro, and perhaps micro, nutrients that can stimulate primary production. However, the characteristics of the CDW along the shelf break, as well as what happens to it once it has been advected onto the continental shelf, differ spatially. In this study, high resolution (4–5 km) regional models of the Ross Sea and the west Antarctic Peninsula coastal ocean are used to compare differences in CDW transport. Examining the fluxes of not only heat, but a simulated “dye” representing oceanic CDW, shows that in both cases CDW crosses the shelf break in specific locations primarily set by the bathymetry and eventually floods much of the shelf. The primary difference between the CDW on the Ross vs. the West Antarctic Peninsula shelf is that there is much more vigorous mixing of the CDW with the surface waters in the Ross Sea, especially in the western Ross Sea where High Salinity Shelf Water is created. The models show that the CDW moving across the open continental shelf towards the base of the ice shelves along the Antarctic Peninsula not only starts out warmer and travels a shorter cross-shelf distance than that being advected towards the base of the Ross Ice Shelf, but it is also subjected to less vertical mixing and exchange with surface waters, which affects the heat available to be advected under the ice shelves. This difference in vertical mixing also leads to differences in the supply of nutrients from the CDW into the upper water column, and thus modulates the impacts on surface biogeochemical processes.

22 June, 09:40 (WA-O4)

Response of the western North Atlantic to characteristic high and low NAO phases

Ayan **Chaudhuri**, Avijit Gangopadhyay and James Bisagni

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We investigate the role of the NAO in regulating oceanic circulation in the western North Atlantic (WNA). WNA response to NAO-induced variability is studied by using a 1/6°-resolution ROMS model. The model is forced with “adjusted” National Center for Climate Prediction (NCEP) Reanalysis data-derived atmospheric fields which are averaged into climatologies characteristic of high and low NAO phases. Success criteria relies on accurately reproducing 1) general circulation for the WNA, 2) high-NAO versus low-NAO behaviour of the Gulf Stream (GS) position and 3) southwestward Labrador Current intrusions into the WNA during high and low-NAO phases. Model results show the mean GS position to be northward (southward) during high (low) phases, in agreement with previous studies. Furthermore, annual mean density estimates exhibit larger inflow of the denser Labrador Current water during low-NAO phases.

Additionally, the model results are used to address a particular ambiguity in the current understanding of the GS transport. Studies by Gangopadhyay *et al*., (1992) and Baringer and Larsen, (2001) suggest higher transport during low NAO phases whereas Curry and McCarthy (2001), Sato and Rossby (1995) and deCoetlogon *et al*., (2006) suggest higher transport in high NAO phases. Results indicate that the western boundary current

limb of the GS, upstream of Cape Hatteras, exhibit higher transport during low NAO periods. However, further downstream of Cape Hatteras, after the GS separates from the coast, an inverse relationship is observed such that higher GS transport is seen during high NAO periods. The converse is true for high NAO periods.

22 June, 10:30 (WA-O5)

Regional modelling of the coastal Gulf of Alaska: progress and pitfalls

Albert **Hermann**

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The Coastal Gulf of Alaska (CGOA) is a topographically and biologically complex region, and hence naturally fascinating to regional modellers within GLOBEC and related programmes. Here we review some of the primary model-derived findings, and technical/mathematical hurdles, which have accompanied our hindcasts of hydrodynamics and biology of the CGOA at a horizontal grid resolution of ~3 km. Major model findings include: 1) the importance of wind stress curl and localised tidal mixing, as a supplement to more traditional sources of coastal macronutrients (e.g. upwelling/downwelling events); 2) the essential role of iron in setting the cross-shelf spatial pattern of production. Major technical hurdles have included the realistic parameterisation of sub-gridscale estuaries and near-surface mixing. These shortcomings have broad consequences to biological models of the region, as they profoundly impact stratification. Considering the tradeoffs between desirable and achievable spatial and temporal resolution, we suggest ways to advance the realism of future Eulerian (nutrient-phytoplankton-zooplankton) and Lagrangian (individual-based) models of the CGOA and nearby regions.

22 June, 10:50 (WA-O6)

Northern Gulf of Alaska shelf ecosystem: refining our understanding of the spatial distribution of plankton production and biomass using GLOBEC observations and an ecosystem model embedded in a ROMS circulation model of the shelf environment

Kenneth **Coyle**[1], Albert Hermann[2] and Sarah Hinckley[3]

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[2] Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA 98195, USA.
[3] NOAA Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA.

Long-term observations and remote sensing have revealed fairly rapid ecosystem shifts, commonly referred to as regime shifts, in response to climate. To gain a better conceptual understanding of the mechanisms linking the ecosystem to climate, a long term observation programme was undertaken on the northern Gulf of Alaska shelf (the Seward Line) from 1997 through 2008. The mathematical descriptions of our conceptual mechanisms linking climate and the ecosystem have been incorporated into an ecosystem model embedded in a general circulation model (the regional ocean modelling system or ROMS) to provide a quantitative tool to test and refine our understanding of these mechanisms, with the ultimate goal of prediction. The ecosystem model was tuned and refined by comparison of model output to observations of primary production, nutrient concentrations, and phytoplankton and zooplankton biomass at 13 stations along the Seward Line in 2001. The model in its current form was able to simulate the seasonal cycle of nutrients, phytoplankton, microzooplankton and mesozooplankton on the shelf and in the high nutrient low chlorophyll (HNLC) adjacent deep ocean for the year 2001. Satellite observations and model results indicate low plankton production and biomass along the Seward Line relative to regions further west. Simulations suggest that the lower production in the Seward Line region may be due to greater summer water column stability relative to regions further west, and periodic entrainment of iron-depleted HNLC water onto the shelf near the Seward Line.

22 June, 11:10 (WA-O7)

Modelling plankton dynamics and biogeochemical cycles on the Pacific coast of Canada

Angelica **Pena** and Michael Foreman

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The development of a quantitative understanding of the interactions between physical, chemical and biological processes is critical for predicting the marine ecosystem response to climate change. Results from coupled plankton/circulation models (ROMS) developed to study factors influencing bloom dynamics on the coastal region of Vancouver Island will be presented. The biological model includes two size classes of phytoplankton and zooplankton, nitrate, ammonia and silicate. Model results show the influence of upwelling, fresh water inputs,

and the Juan de Fuca eddy located off the mouth of the Strait of Juan de Fuca, on the growth of phytoplankton and the fate of the organic matter produced. The importance of different sources of nutrients (i.e. wind-driven upwelling, topographically controlled upwelling, and the outflow from Juan de Fuca Strait) on primary production and biogeochemical cycles is evaluated. The use of this type of model to assess the potential responses of the marine ecosystem to climate change scenarios will be discussed as well as the limitations of present biogeochemical models to predict future climate change.

22 June, 11:30 (WA-O8)

Improving confidence in copepod mortality estimates: choosing formulas and quantifying errors

Wendy **Gentleman**[1] and Pierre Pepin[2]

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[2] Fisheries and Oceans Canada, St John's, NL, Canada.

Estimates of copepod mortality rates from survey data are used to analyse trophic interactions, assess the importance of predation vs. advective losses, and specify model parameters. Accurate estimates are critical, and even small uncertainty in mortality can produce large uncertainty in predicted copepod population dynamics and production. The literature abounds with methods for calculating stage-dependent mortalities, each comprising a host of underlying assumptions that are not always evident. This makes it difficult to choose appropriate formulas or determine associated errors. Here, we provide researchers the means to improve confidence in their mortality estimates by conducting a quantitative analysis of different candidate formulae. We review the common vertical life table approach, and then explain its mathematical relationship to other steady-state equations. The effect of specific assumptions is quantified by comparison of mortality estimates for *Calanus finmarchicus* in the Northwest Atlantic using different estimation methods. An individual-based model of *C. finmarchicus* is then used to evaluate how these errors scale with those due to violation of other assumptions (e.g. steady-state). Finally, we make recommendations for types of field data that can be used to help reduce uncertainty in estimated mortality rates.

22 June, 11:50 (WA-O9)

An example of the use of simple models for process studies

Susan **Allen** and Megan Wolfe

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Simple models are particularly useful for quantitative process studies because they help elucidate the key cycles and parameters. On the other hand, they are limited by the strength of the original assumptions. Here we will use the example of a one-dimensional coupled bio-physical model designed to predict the timing of the spring bloom within an estuarine circulation. We will discuss the choices made, the results, the insight gained and the limitations. The model was chosen to be a simple as possible: a one-dimensional mixing-layer model, with two-dimensional estuarine processes parameterised, coupled to a single phytoplankton and nitrate biological model. For the Strait of Georgia, the model was tuned, for a single parameter, based on four years of data. The model was then used to produce an empirical relationship between wind, cloud-fraction and the timing of the spring bloom. This relationship has been successfully used to predict the bloom in 2006, 2007 and 2008. Using the coupled bio-physical model we have made hindcasts for the spring bloom for the last 30 years and evaluated the impact on the timing of the spring bloom of temperature change, wind and cloud changes and freshwater input changes over that time. One of the advantages of a simple model is a clear understanding of its limitations. We will discuss impacts of those limitations on the hindcast.

22 June, 12:10 (WA-O10)

Simulating lower trophic levels ecosystem dynamics during 'cold' and 'warm' years: an ecosystem model for the Bering Sea

Georgina **Gibson**

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A lower trophic level (LTL) ecosystem model for the Bering Sea has been developed as part of a Bering Ecosystem Study/Bering Sea Integrated Research Program (BEST-BSIERP) integrated modelling effort to downscale global climate projections to the ecosystems of the Bering Sea. The core of the LTL model is an

NPZ (nutrient-phytoplankton-zooplakton) model initially developed for the Gulf of Alaska through the GLOBEC programme. Adaption of the model to the Bering Sea Ecosystem includes the addition of jellyfish, and ice and benthic biology sub-models. The LTL model is coupled to a higher trophic level model (FEAST) and a physical ocean model (ROMS). A fundamental test of an LTL ecosystem model for the eastern Bering Sea is its ability to simulate the striking changes in seasonal production and in zooplankton community structure observed during warm and cold years. The approach taken and the challenges faced in simulating LTL dynamics in the Bering Sea under warm and cold conditions will be discussed along with the steps taken to quantify uncertainty in ecosystem model projections in light of climate-induced changes in physical forcing.

22 June, 14:00 (WA-O11)

Variations of the Changjiang diluted water and their potential ecological influences in summer of 1999 and 2006

Feng **Zhou** and Daji Huang

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A large area of hypoxia has been reported respectively after two interdisciplinary investigations off the Changjiang Estuary in summers of 1999 and 2006. The hypoxic zone shows distinct inter-annual variations. Analysis of oceanographic observational data revealed a large difference in the Changjiang Diluted Water (CDW) between the two periods. The change mechanism is related to the reduction of freshwater discharge as well as surface Ekman transportation variations resulting from wind forcing. It was also found that the monthly mean volume of the Kuroshio increased by 2.4 sv (1 sv = 10^6 m^3/s) in the west of Taiwan in August 2006 compared to 2006 derived from general circulation models. The Regional Ocean Modelling Systems (ROMS) is then applied to the East China Sea to evaluate the contributions and relative importance of impacts from the river discharge, wind forcing and incursion of the Kuroshio and its branches. Our simulations suggest that the CDW extends northeastward in 2006, which is consistent with the observed less saline water to the northeast of the mouth of the Changjiang River.

22 June, 14:20

Discussion Topic 1: Physical and biological modelling

Topic 2: Biological and advanced ecosystem models

23 June, 14:50 (WA-O12 invited)

Regional earth system prediction: microbes to man

Raghu **Murtugudde**

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As the impacts of climate change manifest themselves in all components of the earth system, producing usable information for Joe the plumber, on the environment, agro-economics, human health, energy and water resources, etc. from days to seasons becomes as crucial as providing decadal information for policy makers and managers as well as superusers such as transportation, energy, insurance, and other industries. While the national weather service focuses on the physical system out to 8–10 days and national centres focus on global warming projections, the subseasonal to decadal window remains wide open. A prototype regional downscaling system has been developed for Chesapeake Bay watershed to produce high resolution atmospheric, watershed, and estuarine forecasts which are presently limited to 16 days due to a lack of boundary information from National Centers for Environmental Protection GENS for longer periods. Experimental seasonal forecasts are made from NASA GMAO forecasts. Linked products include land use scenarios and the impacts on the bay, dissolved oxygen, HABs (*Karlodinum*, *Microcystis*, *Pseudo-nitzschia*), striped bass, pathogens such as *Vibrio cholerae*, *Vibrio vulnificus*, and *Vibrio parahaemolyticus*. Statistical downscaling is being developed to go from km scale to metre scale environmental information combined with pollution/pathogen/allergen data to produce personalised, pre-emptive, and predictive health information. Standard suites of products also include waves and inundation with DEMs to track street-level flooding to navigate emergency workers and police. The concept is developed to make the system modular so that it can easily be transplanted to any part of the US or the world.

22 June, 15:10 (WA-O13)

Variation in species response to environmental variability

Louis **Botsford**[1], Michael J. Fogarty[2], Francis Juanes[3], Alan Hastings[1], Steven Teo[1], Matt Holland[1] and Hui-Yu Wang[3]

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GLOBEC and other similar research programmes seek to identify environmental influences on higher trophic level, age-structured populations, often by detecting them through covariability between environmental time series and population time series. Description of the proposed mechanism underlying environmental influences often involves local physical and biological processes (e.g. upwelling, primary productivity), but seldom considers the specific population dynamics of the affected species. This ignores the fact that different species, with different life histories will respond to environmental variability in different ways. Furthermore, responses will also differ depending on whether the environment is causing variability in rates of survival, development or reproduction. Here we explore the differences in response to environmental variability that differences in population life histories and point of action can make using Pacific and Atlantic salmon and cod, a range of species involving several GLOBEC targets, as examples. Our primary result is the demonstration of how species life history affects the time scales of environmental variability to which populations will respond. For example semelparous species tend to respond to specific frequencies in environmental variability differently than iteroparous species. Also, variability in development rate has a greater tendency to cause cohort resonance than does variability in survival. Importantly for detection of biological effects of climate change, populations can differ substantially in their sensitivity to slow changes in the environment.

22 June, 16:00 (WA-O14)

Environmental influences on marine survival and maturity schedule of coho salmon from California to Alaska

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Traditionally, smolt to adult returning (SAR) and smolt to jack returning (SJR) ratios have been used as indices of marine survival in coho salmon, and subsequently to develop models relating environmental variability to changes in coho marine survival. However, SAR and SJR ratios are conflations of survival in the first and second years at sea, as well as the maturity schedule (probability of early maturity), all of which are subject to different environmental influences. In this study, we developed a model to examine explicitly the environmental influences on both age-specific marine survival and maturity schedule. We fit coded wire tag (CWT) data from California to Southeast Alaska (SEAK) to our model and various environmental indicators, including sea surface temperature, mixed layer depth, upwelling intensity, spring transition date, and climatic indices like ENSO and PDO. We also accounted for biological influences such as smolt size, time of release, and growth rate. One of the main advantages of determining age-specific environmental influences on survival and maturity schedule is the ability to use these relationships in age-structured population dynamics models. Our results from this study can be used to compare the relative influence of environmental variability on the age-specific survivals and maturity schedules. This is important because previous analysis of coho and Chinook salmon population dynamics suggest that variability in development rate is more likely to cause cohort resonance as compared to variability in survival.

22 June, 16:20 (WA-O15)

A coupled biophysical model for resource management in the Broughton Archipelago

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Recent research on the interactions between sea lice and wild and farmed salmon in the Broughton Archipelago of British Columbia, Canada has underlined the need to better understand the role that physical oceanography plays in the development, behaviour and movement of these lice. In this talk we will describe a model that simulates both the dispersion of lice eggs originating on salmon farms and their development through the nauplii and copepodid life stages. This biological model is coupled to a finite volume circulation model that in turn provides the three-dimensional salinity, temperature and velocity fields that control movement and growth/mortality. A three week simulation for March 2008 will be evaluated against available observations and the utility of these coupled models in helping to design a coordinated aquaculture management plan in 2009 will be briefly discussed.

22 June, 16:40 (WA-O16)

Model experiments link zooplankton species distribution and ocean transport in the Northern California Current

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In the Northern California Current, copepod communities show interannual and multi-year shifts in the dominance of species that relate to survival of fish populations. These copepod community changes are correlated with the Pacific Decadal Oscillation (PDO) index. A “warm-water” copepod species group is more abundant during warm (positive) phases of the PDO and less abundant during cold (negative) phases; the reverse occurs for a “cold-water” species group. This led to the hypothesis that the relative dominance of warm/cold copepod communities in the Northern California Current is associated with changes in the horizontal advection of surface water over different phases of the PDO. We investigated variation in surface water advection to the Oregon coast over the period of 1950 to 2008 using a Regional Ocean Modelling System (ROMS) and passive tracer simulations. Results of the simulations were compared to observations of the species composition of zooplankton collected bi-weekly off Newport, Oregon (44.7°N, 124.2°W) from 1996 to 2008. We show that horizontal surface water movements change with the phase of the PDO and are related to the regional changes in copepod species dominance. The principal changes in transport associated with the PDO are in the east-west direction. The surface current anomalies during the positive phase of the PDO show average downwelling conditions (west to east transport) and stronger northward currents at the coast. These anomalies are predominantly Ekman driven and tend to transport warmer waters and the associated warm-water copepod species into the region. To a lesser extent, there is increased advection along the coast from the south, and a concurrent decrease in the intrusion of water from the north, which also contributes to positive anomalies in warm-water taxa. During the negative phase of the PDO, an increase in surface currents originating from the north enter the study area, and intrusion from the south and west declines. Overall, the modelled transport anomalies explained a significant part of the variation in copepod species composition. Anomalies in the abundance of the “cold water” copepod species correlate to survival of salmon in the Pacific Northwest. Therefore, elucidating the mechanisms of variability in copepod community composition will further our understanding of the physical controls on ecosystem processes in the Northern California Current.

22 June, 17:00 (WA-O17)

Congener copepods in the northern Atlantic Ocean: an inter-regional modelling analysis on the response to changes in environmental conditions

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As the investigation of key copepod species gained a special interest within GLOBEC several population models have been used within different regional projects. Copepods of the genera *Pseudocalanus*, *Centropages* and *Calanus* are widespread in the northern Atlantic Ocean and are stockforming in different areas. While some species are present in the whole North Atlantic *Pseudocalanus* is separated into habitats of congener species of which *P. newmani* and *P. moultoni* are found in the Gulf of Maine whereas *P. elongatus* inhabits the European Continental Shelf. Population dynamics of these copepods are investigated within three-dimensional ecosystem models using different stage grouped population models. Within the US GLOBEC programme a population model was developed and applied to the Gulf of Maine. The model estimates temperature dependent developmental rates calculating the abundance of four stage groups where development is controlled by their mean age. Using temperature data from climate models potential biogeographical boundaries are determined for different species. As food concentration can limit growth rates in certain species, the uptake of food was considered in another model, in which individual growth is controlled by the mean mass. Investigations in the North Sea within the German GLOBEC project provide the interaction with other trophic levels. Using both approaches developmental rates under changing conditions are compared to time series at single stations. The population life history, its structure, growth and distribution are examined in the context of seasonal and inter-annual climate variability.

22 June, 17:20 (WA-O18)

Biophysical modelling of early life stages of sprat in the North and Baltic Seas: process knowledge gained during the German GLOBEC programme

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Coupled, 3D biophysical models were developed and utilised within the GLOBEC Germany programme to examine how abiotic and biotic factors influence the early life history dynamics of sprat (*Sprattus sprattus*) in the Baltic Sea (Bornholm Basin) and North Sea (German Bight). The North Sea and Baltic Sea provide interesting biophysical contrasts, especially in features (e.g. in prey diversity, habitat complexity, role of physical forcing) that potentially regulate the strength of various control processes (e.g. bottom-up versus top-down) impacting marine fish early life stage growth and survival. Individual-based model experiments performed on eggs and larvae of sprat addressed a variety of key processes including how environmental variability impacted the retention of early life stages within nursery grounds (member-vagrant), changes in larval fish prey requirements within those habitats as well as changes in the availability of key prey species (match-mismatch dynamics). A variety of spatiotemporal scales were investigated including short-term/small-scale studies (e.g. consequences of changes in vertical migration behaviour over 10s of metres), mesoscale/seasonal studies (e.g. mechanisms responsible for frontal zone aggregation), as well as long-term and large-scale studies (e.g. climate-driven decadal patterns in transport, growth and survival). This presentation summarises process knowledge gained using models on the factors that likely contribute to recruitment variability of sprat in these European seas and recommends future avenues of post-GLOBEC modelling research addressing early life stages of marine fish species within these regions.

22 June, 17:40 (WA-O19)

Seasonal and annual distribution of small pelagic fish stocks related to environmental conditions in the Canary upwelling area from 1994 to 2007

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A large amount of data on fishery statistics, biologic parameters of populations, interannual variability of biomass and fish distribution has been collected to date, including data charactersing the Canary Upwelling region. Geographic Information System technology is the most appropriate instrument for maintenance and analysis of such database. One of the main oceanographic features of waters off the northwest African coast is the boundary between the North Atlantic Central Waters (NACW) and the South Atlantic Central Waters (SACW), which occurs near Cab Blanc. The location of this boundary can be defined on the basis of oceanographic surveys. Multivariate statistical analysis of temperature and salinity data, obtained from eight cruises in the Canary Upwelling region in 1994–2007, was applied to reveal the spatial variation of the boundary in the upper layer. The main reasons for the boundary shifts were dynamic factors, such as intensity of the North branch of Equatorial Counter Current (NECC) and the Canary Current (CC). The number of comprehensive surveys which were carried out off the northwestern African coast in 1994–2007 demonstrated that interannual variability in recruitment abundance and distribution might be partly explained by environmental factors. The main factors are mesoscale physical processes (e.g. coastal upwelling, eddies and hydrographic fronts). Remote sensing data (e.g. satellite altimetry) are a good addition to the *in situ* measurements and allow peculiarities of environmental conditions to be revealed. The analysis demonstrated that in some cases interannual variability of the recruitment abundance index might be caused by the cohort's abundance rate, whilst in the other cases the index was mostly influenced by survey conditions. Thus, it was quantitatively demonstrated that environmental share might prevail among all the other factors.

23 June, 08:30
Announcements

23 June, 08:40 (WA-O20)
Sensitivity of anchovy larval dispersal to climate change in the Bay of Biscay

Martin **Huret**, Pierre Petitgas, Fabien Léger and Mathieu Woillez

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Transport of fish early life stages is key in the recruitment process. It defines which environmental history eggs and larvae will encounter for growth and predation along their trajectories. In the context of climate change, this environment will be impacted, modifying characteristics of the dispersal through changes in the hydrodynamics, temperature and prey fields. We propose to test the sensitivity of the dispersal, in a modelling framework, to modification of the environment through projected scenarios of climate change. First, we defined indices to describe the dispersion of anchovy larva distribution in the Bay of Biscay with simulations of Lagrangian trajectories in a 3-dimensional physical/biogeochemical model with realistic forcing. The dispersal kernel has first been defined in the literature as the probability for a larva to reach a given distance. In complex dynamic systems with strong anisotropy and variability of the circulation like coastal areas, a two dimensional description of this dispersal kernel is more suitable. Our chosen indices can be gathered in three main groups: 1) mean transport (distance, orientation), 2) parameters of inertia of the distribution, and 3) parameters of patchiness of the distribution. Then these indices were calculated using different scenarios of atmospheric forcing for the coupled model. Scenarios are based on results of global model runs in the year 2100 assessed in the IPCC framework. Because of strong uncertainties in these results, especially at regional scale, as well as unsolved technical challenges, we have not processed a downscaling of these IPCC scenarios. Instead, we simply modified mean atmospheric parameter values (air temperature, wind, river run-offs, and a combination of them) with respect to the IPCC likely projections over the Bay of Biscay, and run scenarios using the modified atmospheric forcing of the two contrasting years 2001 and 2002. In this context our experiments may be seen as a sensitivity analysis to projected changes of particular atmospheric variables rather than a test of the impact of the projected climate change as a whole. We assessed an analysis of the difference between scenarios and a reference run, looking at the pelagic ecosystem from the physics to the primary production, and finally to the dispersal kernel of anchovy larvae. The latter is mostly affected by temperature rise through reduction of the drift duration. Results are also interpreted in terms of adaptation of the adult population to changes: earlier spawning would induce change in the seasonality of the dispersal kernel characteristics with respect to the Bay of Biscay circulation, modifying in turn the annual dispersal kernel of the population.

23 June, 09:00
Discussion Topic 2: Biological and advanced ecosystem models

Topic 3: Frontiers in ecosystem modelling

22 June, 09:20 (WA-O21 invited)
Topic 2 review: A self-organising approach to modelling marine ecosystems

Michael **Follows**

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We assume that marine ecosystems are organised by the relative fitness of the myriad of potentially viable phenotypes in a given environment. With this guiding principle we seed a model ocean with many tens or hundreds of plausible phytoplankton physiologies and allow the system to "self-organise". A familiar pattern of biogeographical provinces emerges with a subset of the initialised organisms ultimately dominating the population of each province. The emergent biogeography is broadly plausible, with pleasing correspondence between observed and model-analog ecotypes of the cyanobacterium *Prochlorococcus*. The complex model solutions can be understood using established ecological concepts, in particular we find that resource competition theory accurately anticipates the characteristics of the modelled subtropical ecosystems. We argue that such "self-assembling" ecosystem approaches are particularly suitable for modelling the broader food web and will provide preliminary illustrations incorporating heterotrophic microbes and predators in a similar manner.

23 June, 09:40 (WA-O22 invited)

Topic 3 review: Estimating ecosystem model uncertainties and climate change impacts in the North Pacific Ocean

Jerome **Fiechter**[1], Ralph Milliff, Chris Wilke, Andy Moore, Mark Berliner and Zack Powell

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A sequence of Bayesian Hierarchical Models (BHM) is being developed to synthesize coastal ecosystem dynamics and responses to climate change across three regions bounding the North Pacific Ocean (Kuroshio-Oyashio Extension, Coastal Gulf of Alaska, and California Current System). BHM is a unified probabilistic modelling approach that updates uncertain distributional knowledge about process models and parameters in the presence of multi-platform observations. Summary measures of the resulting “posterior” distributions provide realistic quantitative estimates of central tendencies and uncertainties. Process model distributions are based on NPZD-type lower trophic level ecosystem models, including the North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO) specifically developed and parameterised for the North Pacific Ocean.

Hence, a significant outcome of BHM will be a quantitative understanding and comparisons of the relative uncertainties of NEMURO state variables and parameters, region-by-region across the North Pacific Ocean. The initial BHM implementation is a relocatable, time-dependent, one-dimensional (vertical) model intended to summarise ecosystem dynamics for different regimes (shelf, slope, upwelling loci, boundary current extensions, etc.) within the three regions of interest, fully exploiting data from multi-disciplinary observational programmes (e.g. GLOBEC, PICES) and deterministic coupled ocean-ecosystem models. The 1D BHM will then be implemented in climate-scale calculations to document and compare climate change impacts within and across North Pacific coastal ocean ecosystems, and to quantify uncertainties in these comparisons. Ultimately, BHM will be implemented in three dimensions, accounting for mesoscale ocean dynamical impacts on the coastal ecosystem regions, and demonstrating potential ecosystem management advantages of the BHM approach.

23 June, 10:30 (WA-O23)

Monitoring spatial patterns for ecosystem assessment: the Bay of Biscay pelagic zone

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As part of the ecosystem approach to fisheries management, the monitoring of fish spatial distributions and their environment is key for detecting climate change impacts, making fishery-independent diagnostics, preserving essential habitats or defining spatial management plans. However, methods for ecosystem monitoring are still largely to be developed. We propose here a methodology to monitor time series of maps of fish distributions and environmental indices. Fish distribution maps were derived from fisheries research surveys. Maps of environmental indices were operational oceanographic products derived from a 37 year hindcast of a coupled physical-biogeochemical model. The space-time variability in the maps was decomposed using Empirical Orthogonal Functions (EOF) into time-invariant spatial patterns and time-varying amplitudes for these patterns. A statistical quality control procedure was then applied to the time series of the amplitudes. In that way, changes were detected with known statistical performance. Also the monitoring system the length of the changes to be specified and which years, seasons and zones were affected. Results for all indices were assembled in a traffic light table, which is the basis for an integrated ecosystem assessment. The procedure was applied to the Bay of Biscay pelagic ecosystem. The environmental indices were maps characterising the evolution of hydrological structures such as fronts, freshwater plumes, temperature, water column stratification, gyres and primary production. The fish data were maps of abundance at length for the pelagic species. A major result was that sea surface temperature increased significantly in the last decade and particularly in the northern part of the Bay, while the spatial extension of river plumes over the shelf showed an alternation of wetter/dryer years. The decrease in small size pelagic fish (length<17cm) abundance and contraction of their distribution to their coastal core habitats was also noticeable. The procedure provides an integrated view of the ecosystem variability and change in all its components and their spatial organisation.

23 June, 10:50 (WA-O24)

Presentation of an ATLANTIS application for the NEUS ecosystem: a scary model, lots of data, comforting validation, and a naïvely optimistic step towards Ecosystem Approaches to Management

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Multiple processes affect the function, structure and dynamics of marine ecosystems. The challenge has been to evaluate such processes simultaneously to understand the relative magnitude (and thus relative importance), spatio-temporal dynamics, interactions among, and responses of the ecosystem components to such processes. Increasingly, such considerations come to the fore in the context of living marine resources and ocean-use management. One way to elucidate this broad range of considerations is to use full ecosystem models. We present one such model, ATLANTIS, as applied to the northeast US large marine ecosystem. This work documents the structure of the "virtual ecosystem" including the dynamics of water mass flow, nutrient, lower trophic level, upper trophic level, fleet, and fishery market. We then highlight the main features of the calibration and validation process of this virtual system, executed at three levels of dynamism. Our results indicate that we can reasonably capture many of the main features of this ecosystem, particularly the dynamics of ecologically and commercially important biota. We also note instances where disconnects in our model validation exercise led to improved understanding of the ecosystem. We conclude by discussing how one might utilise this modelling approach as an operating model towards the implementation of Integrated Ecosystem Assessments in particular and Ecosystem Approaches to Management in general.

23 June, 11:10 (WA-O25)

The FEAST model for the Bering Sea: forage/euphausiid abundance in space and time

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FEAST (Forage-Euphausiid Abundance in Space and Time) is a multispecies bioenergetics model for forage and predatory fish species linked to NPZ (nutrient-phytoplankton-zooplakton) and ROMS (Regional Ocean Modelling System) for the Northeast Pacific and Bering Sea at a 10 km resolution as part of the Bering Sea Integrated Research Program (BSIERP). FEAST models nine fish species (walleye pollock, Pacific cod, arrowtooth flounder, salmon, capelin, herring, eulachon, sandlance and myctophids) which have a two way interaction with the seven zooplankton groups in the NPZ model (small/large microzooplankton, small/large copepods, euphausiids, jellyfish, and benthic infauna). Additionally, temperature and advection from the ROMS are used in the bioenergetics and movement components. The operating hypothesis in FEAST is that forage fish and macrozooplankton (e.g. euphausiids) are tightly coupled in a two-way interaction, and the dynamics of this interaction under different climate scenarios is a strong structuring element for the ecosystem as a whole. For example, variation in late summer prey supply may affect the autumn diet transition of predatory fish switching from plankton to fish, affecting the year-class strength of multiple species and overall availability of forage species within the ecosystem. Retrospective data analysis provides some basic parameters and initial conditions for FEAST. FEAST will also make extensive use of data collected by other BSIERP projects, particularly those related to acoustic surveys, fish distribution and functional foraging responses. FEAST itself will ultimately be incorporated into economic and spatial fishery predictions, as well as into management strategy evaluations which are also part of BSIERP. Among the challenges faced in the design of FEAST were the two-way coupling with an existing high-resolution NPZ model, and the statistical framework for this model, which was geared from the beginning, by the needs of the overall BSIERP programme, to make long term predictions which included estimates of forecast uncertainty based on model validation; a task often not performed with large 3-dimensional models due to run-time requirements and other barriers. Here, we will discuss the design of FEAST towards these challenges and describe some implications of the initial results for our understanding of Bering Sea dynamics.

23 June, 11:30 (WA-O26)

Marine ecosystem models: strategies, applications, and future directions

Enrique **Curchitser**[1], Kenneth A. Rose[2], Katherine Hedstrom[3], Jerome Fiechter[4], Shin-ichi Ito[5], Salvador Lluch-Cota[6] and Bernard A. Megrey[7]

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An ecosystem approach to understanding large-scale patterns in exploited systems caused by both climate change and human activity increasingly relies on the use of numerical models. In the past, physical, lower and higher trophic level models were developed, tested and implemented independently of each other. As part of the GLOBEC programme, progress was made in coupling physics and lower trophic level models. The next step is to extend this work towards a comprehensive (end-to-end) ecosystem model including humans where all models are tightly integrated. Despite the fact that the subject of the coupling ecosystem models has received considerable world-wide attention, there are few examples which demonstrate tightly coupled systems and their practical implementation. This is partly due to the perception that blending separate yet complex sub-models is impractical because of demanding computational requirements and partly due to the respective communities working independently. In this presentation, we compare past and present modelling strategies and applications to a new modelling framework where the widely-used ROMS (Regional Ocean Modelling System) circulation model, the NEMURO Nutrient-Phytoplankton-Zooplankton (NPZ) model, and a multi-species individual-based spatially-explicit fish population dynamics model that includes fishing fleets as a “predator species” are tightly coupled. All of these models exist in various forms, but the individual sub-models have never been harmonised together into one integrated analysis tool useful for synthesis, integration, and prediction. This model framework was designed to investigate the effects of climate and fishing on marine ecosystems within one model that includes dynamical feedbacks between the different systems. We describe the conceptual and technical challenges involved in assembling and implementing such a model and we will present some early results of this effort.

23 June, 11:50 (WA-O27)

Eddy permitting simulations of 3D-NEMURO in the global ocean

Hiroshi **Sumata**[1], Taketo Hashioka[2], Naosuke Okada[1], Maki Aita[2], Naoki Yoshie[3], Takashi Sakamoto[2], Tatsuo Suzuki[2] and Yasuhiro Yamanaka[1]

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A 3D ecosystem-biogeochemical model simulation is performed in order to investigate seasonal to inter-annual variations of the lower trophic ocean ecosystem. The model has a horizontal resolution of 1/4° x 1/6° and 51 vertical levels, covering the entire domain of the world ocean. The ecosystem-biogeochemical part of the model is based on NEMURO (North Pacific Ecosystem Model Used for Regional Oceanography), and is coupled with the ocean general circulation model COCO (CCSR Ocean Component Model) by an offline technique. The physical part of the model is driven by the inter-annual forcing by CORE (Common Ocean-ice Reference Experiments) data from 1959 to 2004, and reasonably simulates seasonal to inter-annual variations of ocean conditions related to biogeochemical cycles. These properties of the physical model with its eddying field enable us to reproduce the realistic distributions of nutrients and plankton productions. Statistical analysis of the model results and comparisons with SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data show that the model reasonably reproduces variations of surface chlorophyll-*a* on timescale of less than one month to decades. In addition, the spatial length scale of mesoscale variabilities of modelled chlorophyll-*a* is consistent with that derived from SeaWiFS.

23 June, 12:10 (WA-O28)

What regulates large scale patterns of diversity in marine microbes?

Michael **Follows**, Andrew Barton, Stephanie Butiewicx, Jason Bragg, Oliver Jahn and Glenn Flierl

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We examine a global ocean model with a self-organising representation of marine phytoplankton communities. Many tens of plausible phenotypes are initialised and their relative fitness in different environments determines community structure. In the quasi-equilibrium state about 20 phenotypes account for more than 99.9% of the phytoplankton biomass in the model. The solutions exhibit low diversity in polar regions, higher diversity in subtropical latitudes, and the highest diversity in regions of energetic circulation features. These patterns are consistent with sparse observations of marine microbial diversity from both microscope and genomic analyses. The background meridional gradient is consistent with the decline in species richness with latitude for both marine and terrestrial ecosystems. The patterns in the global model can be interpreted to depend upon the nature of variability in the physical environment and transport by swift boundary currents. The model solutions suggest strategies for testing these hypothesized mechanisms with new observations.

23 June, 14:00 (WA-O29)

Complex systems models of trophic and fishing interactions with implications for research and management

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Viewing ecosystems as complex adaptive systems presents both opportunities and challenges for ecological modelling, which in turn suggests new directions for process oriented field studies and monitoring. We present two modelling approaches to identify both static and dynamic sources of robustness in Alaskan ecosystems, and also potential ecosystem thresholds where the state of the ecosystem is prone to rapid change. First, we apply graph theory and network analysis to the food web of the Gulf of Alaska marine ecosystem to classify its structural properties, which suggest how the ecosystem as a whole may respond to heavy fishing pressure on its components. Second, we simulated effects of alternative fishing intensities in the Gulf of Alaska ecosystem model to determine whether thresholds existed where fishing fundamentally changed system properties. Initial results from both approaches suggest that small set of fished species support critical structural connections, and that there is a clear threshold between moderate and heavy exploitation rates where fishing damaged the robustness of the ecosystem, and was more likely to contribute to system restructuring in the Gulf of Alaska. Applying these modelling approaches to the adjacent Bering Sea ecosystem revealed differences suggesting alternative field studies to explore critical interactions and processes in the two systems. Combining these and other modelling approaches with a realistic accounting of uncertainty can support fishery sustainability in the ecosystem context, allowing managers to prioritise field research and monitoring which can then be used to further improve modelling, prediction, and ecologically based management.

23 June, 14:20 (WA-O30)

Using agent-based models to capture the dynamic nature of marine systems

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Many forms of modelling (and the resource management based on them) assume some equilibrium state. While that has led to some significant insights it will not be sufficient in the long term. All aspects of marine systems (ecological, economic and social) change through time. To successfully consider the full implications of ecosystem dynamics and human activities the true dynamic nature of the system must be considered. This is a daunting but not impossible task. An example drawn from Australia's northwest coast will show how thoughtfully embracing complexity across the system can give insights into system function and feedbacks between changing social, economic and ecological components.

23 June, 14:40 (WA-O31)

Emergent properties of a complex ecosystem model in a global general circulation model: sensitivity to grazing parameterisations

Thomas **Anderson** and Bablu Sinha

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The structure of marine ecosystems is central to carbon cycling and export in the ocean. The current trend in marine ecosystem modelling is therefore to explicitly represent different plankton functional types (PFTs), with ever more complex models coming to the fore. Can, however, the emergent behaviour of such models be reliably predicted? We incorporated the PLANKTOM5.0 ecosystem model, which includes three phytoplankton and two zooplankton functional types as well as multiple nutrients, into a global general circulation model. Predicted distributions of PFTs were remarkably sensitive to the choice of grazing formulation, with implications for carbon export from the euphotic zone. Results are discussed in context of the ongoing requirement for biogeochemical predictions in climate models.

23 June, 15:00

Discussion Topic 3: Frontiers in ecosystem modelling

Topic 4: Climate change in regional marine ecosystems

23 June, 16:00 (WA-O32 invited)

Topic 4 review: Climate change in regional marine ecosystems: requirements and challenges

Kenneth **Drinkwater**

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Marine system models have made large strides over the last number of years. This has resulted in increasing pressure to use them to forecast what will happen under future climate change. In this talk I will discuss some of the progress that has been made but concentrate more on where and what future improvements are needed. This includes the difficulties in downscaling from the Global Circulation Models and what is needed. As well as requirements for clear indices of uncertainty in the model predictions, both physical and biological, so that non-modellers can better assess how useful the models are, more emphasis is required on the underlying processes and mechanisms linking climate to ecosystem responses. Closer two-way communication between modellers and observationalists is required for the latter to learn where the critical areas are to sample as well as the frequency of sampling and to keep the former on track. The ultimate response of commercial and some non-commercial fish stocks will depend upon fishing intensity. As a result, more research is needed to assess the non-linear interactions between climate and fishing that makes separation of variability in fish abundance all but impossible to assign to one cause or the other.

23 June, 16:20 (WA-O33)

Climate change effects on primary production in coastal and shelf seas

Jason **Holt**[1], Icarus Allen[2], Robert Holmes[2] and Manuel Barange[2]

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Primary production is the driving force of marine ecosystems and an important control on global fisheries and the marine carbon cycle. However, none of the global general circulation models (GCMS) used in the future projections documented in the IPCC 4th Assessment Report, are capable of representing processes in shelf seas and near coastal regions. This is despite the fact that these regions have been identified as making a substantial contribution to the global primary production total. Regional models can make accurate simulations of shelf seas. However, globally a wide range of different coupled hydrodynamic-ecosystem models is used, each with different process representation and consequently varying biases. This makes an inter-comparison of model results from different regions very difficult, unless a systematic approach is adopted. In the Global Coastal Ocean Modelling Project, we have developed a system for deploying a regional coupled hydrodynamic-ecosystem model

(POLCOMS-ERSEM) in all of the coastal and shelf seas around the globe. This approach has been adopted in the QUEST-FISH project to explore the effects of global climate change on regional marine ecosystems. Multiple regional models are forced with output from coupled ocean-atmosphere climate GCMs, which themselves are driven by a range of emissions scenarios. The focus of the project is on the 20 large marine ecosystems that account for a large fraction of the global fish production. We investigate how projected changes in the global physical environment impact the circulation, mixing and stratification of coastal and shelf seas, and how this in turn influences the supply of nutrients to the euphotic zone and the net primary production. Preliminary results suggest tidally active shelf seas are less susceptible than the open-ocean to changes in primary production resulting from changes in stratification. However, these results also demonstrate that near coastal primary production is highly sensitive to the light climate and hence variations in the inherent optical properties of the water. The results are considered in the context of satellite and *in situ* estimates of primary production. Other components of the QUEST-FISH project build on these results to investigate the consequences for fish and the economic impact on fisheries.

23 June, 16:40 (WA-O34)

Evaluation of the oceanographic component of climate models used by the IPCC

Nicholas A. **Bond**, Muyin Wang and Albert Hermann

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Sets of global climate simulations have been carried out for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. A total of 23 different coupled atmosphere-ocean general circulation models were employed under common emission scenarios. We have previously evaluated the atmospheric and sea ice components of the 20th century hindcast simulations by these models, with the National Center for Climate Prediction (NCEP) Reanalysis and observations of sea ice as validating data sets. The results of these evaluations have been used to select and weight the models' forecasts for the first half of the 21st century, with the ultimate goal being projections of climate forcing indices known to be important to marine populations. As part of the Bering Ecosystem Study/Bering Sea Integrated Research Program (BEST-BSIERP) modelling effort, the IPCC climate models are being used to force a high-resolution numerical ocean model (ROMS), which in turn represents a foundation for linked lower-trophic, upper-trophic and human/socioeconomic models. The ROMS simulations require lateral boundary conditions, and the reliability of the oceanographic component of the IPCC models for specifying these boundary conditions is an open question. The present work pursues this issue. Sub-surface properties from various IPCC model hindcasts for the latter portion of the 20th century are validated with their counterparts from the Simple Ocean Data Assimilation (SODA), along boundaries anticipated for the ROMS modelling of the SE Bering Sea shelf. Our results pertain in general to other efforts involving dynamical downscaling using regional oceanographic models.

23 June, 17:00 (WA-O35)

Linking Pacific climate variability with eastern boundary ecosystem dynamics

Emanuele **Di Lorenzo**

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Large-scale decadal Pacific climate indices such as the Pacific Decadal Oscillation have been linked to changes across multiple trophic levels of marine ecosystems along the eastern and western boundaries. Recent studies of the Northeast Pacific by the PIs show that other independent climate modes are equally important in explaining changes in coastal ocean upwelling and transport dynamics–the fundamental processes controlling regional nutrient fluxes and planktonic ecosystem dynamics. This suggests that the interplay of forcing functions associated with multiple large-scale climate modes must be considered to adequately diagnose the dynamics and mechanics underlying variations in regional ecosystems. With this framework, our study combines extensive national and international *in situ* and satellite observations with numerical and statistical physical-biological models to diagnose the response of four Pacific boundary ecosystems to large-scale natural and anthropogenic climate forcing. The focus regions are: the Gulf of Alaska, the California Current System and the Peru-Chile Current System region.

23 June, 17:20 (WA-O36)

Life and global climate change: the world ocean input

Vadim **Navrotsky**

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To understand mechanisms of global climate change we should recall that climate is not only the globally averaged temperature for some conventional periods of time, but a space-time distribution of a set of climatic parameters with some limited spatial and temporal dispersions of these parameters. The main energy of climate change is not in mean values, but in the dispersions. If we take temperature as the main climatic parameter, its dispersion can change due to a change in the unevenness (patchiness) of heat distribution over the globe and due to a change in the amplitudes of space-time heat fluctuations. Here we are analysing the role of the earth's living matter, especially in the world ocean, in both of the processes. It is known that on a long time scale the observed characteristics of land, ocean and atmosphere are due to life–medium interactions. This is possible if life is not only forced by the abiotic environment, and its impact on the environment is not only a feedback to climate forcing, but if life is an active part in the interactions. The earth's living matter has always been affected by solar and cosmic radiation, and corresponding changes in its characteristics and distribution over the globe have led to changes in life-medium interactions. Now comparable and maybe greater effects on living matter are due to anthropogenic forcing, which works on very short time scales. The main climatic effect of living matter is a change in solar heat refraction, assimilation and accumulation. The world ocean is the main accumulator of solar heat, and changes in the accumulated heat amount and redistribution inevitably lead to changes in the ocean-atmosphere interaction, that is to climate change. We are analysing the different mechanisms of extraterrestrial and intraterrestrial forcing of the ocean biota (mainly phytoplankton) fluctuations, estimating consequent changes of water optical characteristics (based on the existing models of phytoplankton production), solar heat accumulation, ocean and land heat anomalies generation, redistribution and interaction with atmosphere. An attempt is made to answer two questions: 1) Are there and what can be stable states (limit cycles) in todays land-ocean-atmosphere-biota-mankind interactions? 2) Is it possible to change the solar energy balance between biota (long-term deposit) and active heat in the ocean, land and atmosphere? The problem of ocean ecosystems sensitivity to climate and non-climate forcing needs additional special investigation.

23 June, 17:40

Discussion Topic 4: Climate change in regional marine ecosystems

WB Comparisons of processes and climate impacts in sub-Arctic and Antarctic marine ecosystems: observations and modelling approaches

Chairs: ***Eileen Hofmann, George Hunt, Bernard A. Megrey, Eugene Murphy, Sei-ichi Saitoh and Hyoung-Chul Shin***

This two-day workshop will compare observations and modelling of processes and climate impacts in the maritime Antarctic with those in the sub-arctic seas. It will be structured around the following topics and will consist of oral presentations, informal presentations and discussion sessions:

1. Setting the stage - climate studies
2. Arctic and Antarctic system comparisons
3. Lower trophic level comparisons
4. Arctic programme overview
5. Arctic and Antarctic top predator studies

The workshop will provide an opportunity for the modelling communities in the Antarctic and the sub-arctic to compare approaches and progress toward functional end-to-end models of the effects of climate change on marine ecosystems and their ability to support upper trophic level organisms including sustainable fisheries. The first level of comparisons will help establish practical marine ecosystem topologies useful to GLOBEC and future studies. The workshop will explore the similarities and differences in ecosystem structure and function and what are the processes that lead to these differences. As well, comparisons between the impacts of physical forcing such as sea ice, winds, and advection will be investigated. The anticipated responses of each ecosystem to climate change and global warming will be compared.

The outcome of this workshop will be a paper synthesising the results of the workshop for the OSM special issue plus a white paper or blueprint for moving forward end-to-end modelling comparisons.

22 June, 08:30

Introduction to the goals of the workshop

Topic 1: Setting the stage - climate studies

22 June, 08:40 (WB-O1)

Remote climate forcing of regime shifts in northwest Atlantic shelf ecosystems

Charles **Greene**

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Regime shifts occur when perturbations to a system drive it from one alternative stable state, or regime, to another. Regime shifts in large marine ecosystems have often been associated with bottom-up forcing by climate, top-down forcing by overfishing, or some combination of the two. Determining the relative roles of climate and overfishing in forcing such regime shifts can be challenging because of our limited understanding of marine ecosystem dynamics and their responses to both natural and anthropogenic perturbations. Here, I focus on the role of climate in forcing regime shifts in northwest Atlantic shelf ecosystems. Specifically, I explore teleconnections linking the dynamics of these ecosystems to two important modes of high-latitude climate variability, the North Atlantic Oscillation and the Arctic Oscillation. I will conclude by discussing some implications of these findings for the management of northwest Atlantic shelf ecosystems and their living resources during the coming decades.

22 June, 09:10 (WB-O2)

Informal presentation on climate studies

Eugene J. **Murphy**

British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK. E-mail: e.murphy@bas.ac.uk

Topic 2: Arctic and Antarctic system comparisons

22 June, 09:40 (WB-O3)

South Shetland Islands, resemblance and relevance to other polar systems

Hyoung Chul **Shin**[1], Jeong Hee Shim[2], Young Chul Kang[1], Jisoo Park[3], Sung Ho Kang[1] and Hyun Cheol Kim[1]

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The South Shetland Islands, Antarctic and the vicinity harbour a range of environmental settings and hence offer an opportunity for multiple spatial and temporal scales, and multiple-component system research. Even when governing factors in operation are similar, the relative importance of each factor and the timing and duration these factors take effect all vary, and therefore natural experiments to examine how these interact to generate the system productivity and variability emerge. Examples include small coastal bays, open waters less sea-ice affected and more sea-ice affected. Uneven concentration of biological abundance and subsequent different biogeochemistry are common features. Sea ice both as light shading cover and biological production stimulator, and melt water input are critical. Water masses of outside deeper basin origin shoaling from below to the surface or advected horizontally and the bottom topography are important. Small contained systems, particularly when shallow, are more influenced by high sediment loads nearshore and dominated by highly fluctuating, more dramatic, shorter term temporal variability. Longer term, often multi-year trends prevail in open water systems. These are shared by other polar systems at the other end of the globe, such as Bering Sea, Barents Sea and Svalbard waters. Commonalities will be discussed and examples will be illustrated.

22 June, 10:30 (WB-O4)

Modelling Southern Ocean ecosystems: developing food web modelling in ICED

Eugene J. **Murphy**[1], Eileen Hofmann[2], Rachel Cavanagh[1], Simeon Hill[1] and Nadine Johnston[1]

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[2] Center for Coastal and Physical Oceanography, Old Dominion University, 4111 Monarch Way, Norfolk, VA 23528, USA.

Southern Ocean ecosystems are changing rapidly and a major challenge is to develop circumpolar views of their structure, function and response to change. This is key to developing the basis for predicting the impacts of climate and harvesting in the Southern Ocean. Developing such circumpolar views requires integrated ecosystem models. However, Southern Ocean ecosystem modelling is in its early stages, with much of the work restricted in geographic and/or trophic scope. There are also considerable questions regarding appropriate model structures that allow for integration of species-centric and trophic-centric approaches.

A primary goal of the recently established Integrating Climate and Ecosystem Dynamics in the Southern Ocean programme (ICED) is to facilitate development of the next generation of Southern Ocean ecosystem models. Here we highlight some of the outcomes of the first ICED modelling workshop, which assembled experts from a range of scientific disciplines, focusing on the development of Southern Ocean food web models. The workshop began to characterise Southern Ocean food webs across a range of species, trophic levels and geographical areas, with a view towards developing end-to-end food web models. The discussions highlighted the importance of understanding the physical and biological process interactions at different scales generating structure in the ecosystem and noted the importance of emergence of structure at different scales. We discuss the current status of Southern Ocean food web models, explore the potential issues associated with generating a circumpolar food web model(s), and make recommendations for future directions in Southern Ocean ecosystem modelling.

22 June, 10:50 (WB-O5)

Informal presentation of Arctic and Antarctic system comparisons

George **Hunt**

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22 June, 11:10 (WB-O6)

The Southern Ocean Global Ocean Ecosystem Dynamics programme

Eileen **Hofmann**

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The Southern Ocean Global Ocean Ecosystems Dynamics (SO GLOBEC) Programme objectives focus on understanding physical and biological factors that contribute to Antarctic krill (*Euphausia superba*) growth, reproduction, recruitment, and survivorship throughout the year. Overwintering strategies were highlighted as an important but largely unknown component of the Antarctic ecosystem. The SO GLOBEC science questions reflect a broad view of the Antarctic marine ecosystem that includes studies of the habitat, prey, predators and competitors of Antarctic krill, as well as studies specifically focused on Antarctic krill biology and physiology. This programme included national field efforts in different areas of the Antarctic and is now in its synthesis and integration phase. The extensive multidisciplinary data sets resulting from SO GLOBEC are providing new and important understanding of Antarctic marine ecosystems. This presentation overviews the SO GLOBEC programme and highlights key results. The knowledge gained from the SO GLOBEC programme provides a strong basis for the next phase of Southern Ocean research.

22 June, 11:30

Discussion

Led by Kenneth **Drinkwater**

Topic 3: Lower trophic level comparisons

22 June, 14:00 (WB-O7)

The spatiotemporal chlorophyll-*a* distribution under the influence of the changing Arctic ice-ocean circulation

Kohei Mizobata[1], Koji Shimada[1], Atsushi Matsuoka[2], Amane Fujiwara[3] and Sei-Ichi **Saitoh**[3]

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[3] Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1, Minato-cho, Hakodate, Hokkaido 041-8611, Japan.

Recently, drastic sea ice reduction and changes in ocean circulation have been observed in the western Arctic Ocean. Changes of the oceanic physical environment have an impact on both the climate system and marine ecosystems. In the western Arctic Ocean, phytoplankton biomass is a key parameter to understand the whole ecosystem, because of short food chains. In this study, we investigated recent changes in the spatio-temporal chlorophyll-*a* (chl-*a*) distribution in the western Arctic Ocean, using hydrographic/biogeochemical datasets from R/V *Mirai* cruises and the SBI (Western Arctic Shelf-Basin Interactions Project) database, and satellite multi-sensor remote sensing. Satellite ocean colour sensors, SeaWiFS and MODIS show northwestward long distance transport of high chl-*a* waters from Barrow Canyon and from the estuary of the Mackenzie River to the Canada basin in 2007 and 2008. This basin-ward transport was due to the intensified Beaufort clockwise ice-ocean circulation, which was confirmed by the AMSR-E ice motion dataset. On the other hand, *in situ* measurements revealed the increased chl-*a* values in the surface layer (5–50 m water depth) over the Northwind Ridge (NWR) and Chukchi Plateau (CP) in 2004 and 2008, when wide open water was formed. In 2008, relatively high chl-*a* was also found at the northern Chukchi shelf-slope. These results indicate that chl-*a* at NWR and CP increased due to both increased light availability and increased horizontal advection from the Chukchi Sea shelf via canyons. Future response of primary productivity to the Arctic ice-ocean-climate system also will be discussed.

22 June, 14:20 (WB-O8)

Seasonal and interannual variability of SeaWiFS chlorophyll-*a* in the south Atlantic sector of the Southern Ocean

Jisoo **Park**[1,2], Sinjae Yoo[1] and Im-Sang Oh[2]

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Eleven year monthly time series of satellite data have been examined to explain the dominant temporal and spatial patterns of chlorophyll-*a* in the south Atlantic sector of the Southern Ocean. Here we used EOF (empirical orthogonal function) analysis for classifying the study area to several sub-regions. Our major objectives are as follows: 1) utilise satellite chlorophyll-*a* data to classify biological domains over an extended region which includes

the Antarctic Peninsula, Scotia Sea, and downstream area of South Georgia; 2) evaluate spatial patterns and seasonal-to-interannual variability of chlorophyll-*a* of the study area; and 3) identify possible mechanisms that could control the seasonal pattern of phytoplankton dynamics at each classified region. Chlorophyll-*a* variability in the south Atlantic is very high both in magnitude and peak timing. Seasonality shows different patterns at each region; for example, the early (November–December) and regular pattern of bloom in the southern Drake Passage was in good contrast to the late (December–March) and irregular pattern of that in the northern part of the Scotia Sea and downstream area of South Georgia. Another intriguing point was that decadal scaled interannual variations of chlorophyll-*a* have periodicity (~7 years), except in the northern region of the Drake Passage. The periodicity seemed to relate to the Southern Oscillation.

22 June, 14:40 (WB-O9)

A comparative study of the ecology of *Calanus finmarchicus* in the Labrador and Norwegian Seas

Erica **Head**[1], Webjørn Melle[2], Pierre Pepin[3], Espen Bagøien[3] and Cecilie Broms[2]

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The Norwegian Sea is generally warmer than the Labrador Sea and despite its more northerly location, the spring bloom generally starts earlier in the Norwegian Sea, although within each sea there are regional and inter-annual differences in temperature and spring bloom dynamics. The responses of *Calanus finmarchicus* populations to these differences include differences in physical characteristics, physiological rates and seasonal cycles. Females are generally larger in the Labrador Sea and have higher egg production rates than those in the Norwegian Sea. Within and among areas, in both seas, as temperatures increase and spring blooms tend to occur earlier, *C. finmarchicus* start to reproduce earlier, the new generation develops faster, and in some areas a second generation ensues. In areas where near surface temperatures are high in summer and/or where phytoplankton growth rates are low in summer or autumn, reproduction and development cease, and *C. finmarchicus* desert the surface layers for their overwintering depths. This occurs in the Norwegian Sea in summer and in the central Labrador Sea in autumn. By contrast, in areas where near surface temperatures remain cool in summer and where phytoplankton growth persists through the autumn, reproduction and development can continue through summer and autumn, probably until winter vertical mixing prevents phytoplankton growth. This occurs on the south Newfoundland Shelf. If the size of the overwintering population is used as an index of net productivity then for equivalent regions in the Norwegian Sea and Labrador Sea (the areas of each most affected by Atlantic inflow), the differences in ambient temperatures and bloom dynamics apparently have little impact. With global warming, as temperatures in the Norwegian and Labrador seas increase up to a certain threshold, the timing of life history events for *C. finmarchicus* will likely be advanced and the time spent in the near surface layers will probably decrease, although the effect on net productivity may not be large.

22 June, 15:00 (WB-O10)

Internal waves, topographic highs and upper trophic level feeding in the Gulf of Maine

Lewis **Incze**[1], Scott Kraus[2], David Fields[3], Nicholas Wolff[1], Adam Baukus[4], Andone Lavery[5], Peter Stevick[1] and James Lerczak[6]

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Internal waves are replete through much of the Gulf of Maine (45°N, northwest Atlantic Ocean). Our work on a small (9 x 15 km) offshore bank and a larger bank/ridge system shows that the internal wave field is displaced toward the surface during periods of strong tidal flow (internal tides). Interaction of the waves with the shallow surface layer (convergence, divergence and shearing) results in the formation of ephemeral but very dense surface patches of euphausiids and an ensuing rapid feeding response by herring, marine mammals and birds. Humpback whales (*Megaptera noviangliae*) use only a small portion of the bank where this coupled process is maximised, and they appear to use some aspect of the internal wave itself to time their approach to the surface to feed on the short-lived patches. Euphausiids are not always abundant in this portion of the Gulf of Maine, however, and the bank may be "hot" with predators or be comparatively still. Whales and other highly

mobile predators thus must search among networks of sites and employ flexible feeding habits. The mechanism we have identified depends on the horizontal patterns of abundance and advection of euphausiids and their vertical position above the pycnocline. The coupled biophysical processes associated with internal waves and topographic forcing can help explain observations of geographic feeding patterns among some predators, and should add to our understanding of temporal variability and possible future changes in these patterns.

22 June, 16:00 (WB-O11)

Modelling the life cycle and distribution of Antarctic krill

Sally **Thorpe**, Eugene J. Murphy, Geraint Tarling, Jonathan Watkins and Martin Robbins

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Antarctic krill, *Euphausia superba* Dana, is a key species in the Southern Ocean ecosystem. It has a heterogeneous distribution with a large proportion of the circumpolar population located in the southwest Atlantic sector of the Southern Ocean. These populations are believed to be maintained from upstream krill stocks, with field studies and modelling analyses illustrating the connective pathways. A key component of these links is the close association of Antarctic krill with sea ice which provides a critical habitat during winter. The interaction of the krill with the sea ice can, depending on locality, create regions of rapid dispersal or increased retention. This means that Antarctic krill are vulnerable to physical forcing and model results show that the probability and timing of transfer between populations can show large variability due to fluctuations in local environmental conditions. The advection model is being further developed with a coupled life cycle model for Antarctic krill. Functions for egg development, growth and spawning based on remotely-sensed measurements of sea surface temperature and chlorophyll-*a* concentrations are embedded within the advection model. This coupled physical-biological model will allow further investigation into key regions of the circumpolar Southern Ocean for the life stages of Antarctic krill and the impact of environmental variability.

Topic 4: Arctic programme overview

22 June, 16:20 (WB-O12)

Some results and thoughts on comparative studies within sub-Arctic seas

Kenneth **Drinkwater**

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A central component of the ESSAS programme has been on comparative studies within sub-Arctic seas. It is seen as a means of gaining improved insights into the role of physical forcing on the biological components of marine ecosystems, in particular what are fundamental processes and what might be considered unique to a particular sub-Arctic region or regions. This talk will highlight two major comparative studies undertaken as a part of ESSAS. The first was NORCAN (Comparison of Marine Ecosystems of Norway and Canada), which has compared particular aspects of the Barents Sea/Norwegian Sea with the Labrador Sea and shelves. The second was the MENU project (Marine Ecosystem Comparisons of Norway and the United States) that compared the Bering Sea and Gulf of Alaska in the Pacific with Georges Bank/Gulf of Maine and the Barents/Norwegian Seas in the Atlantic. Both studies began from workshops. NORCAN developed writing groups mainly along disciplinary lines comparing separately the physical oceanography and climate forcing and various aspects of the food web including phytoplankton, zooplankton, fish and marine mammals. MENU on the other hand brought datasets to the workshop and decided on two avenues of attack. The first was to compare the general structure and function of the different marine ecosystems with emphasis on the biological communities. The second was to compare the physical and biological responses to recent changes in the climate forcing. Results from these studies will be presented. A new project (MENUII) will be described that carries on the work begun under MENU but with the emphasis on modelling. The lessons learned from these ESSAS investigations and their implications for comparative studies between the sub-Arctic and Antarctic will be discussed.

22 June, 16:50

Discussion: implications of differences in lower trophic level processes and limiting controls

Led by Bernard A. **Megrey**

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Topic 5: Arctic and Antarctic top predator studies

23 June, 08:30 (WB-O13)

Modelling the energetics of an avian bottom predator during long-term change in sea ice and benthos of the Bering Sea

James **Lovvorn**[1], Jacqueline Grebmeier[2], Lee Cooper[2], Joseph Bump[3] and Samantha Richman[1]

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The world population of Spectacled Eiders, a threatened species, winters in pack ice of the Bering Sea. Assessing habitat needs of this species requires identifying thresholds of adequate resources, and long-term shifts in the mosaic of those resources that suggest future variability. We linked data on benthic prey, sea ice, and weather from 1970–2001 with a spatially-explicit simulation model of eider energy balance that integrated field, laboratory, and remote sensing studies. Areas estimated to have prey densities adequate for eiders in 1970–1974 did not include most areas that were viable 20 years later (1993–1994). The area with adequate prey in 1993–1994 was greatly reduced by 1999–2001. These patterns suggest decadal changes in wind-driven currents that redistribute settled organic matter and associated benthos. During long non-foraging periods (as at night), eiders can save much energy by resting on ice versus floating on water; thus, loss of ice cover in the future might substantially decrease the area in which prey densities are adequate to offset the eiders' energy needs. Regarding food webs leading to eiders, changes in key benthic species from almost complete absence to superabundance at the same locations suggest the importance of refugia to recolonisation. Thus, resilience of these food webs to perturbation, typically modelled in terms of functional redundancy, may depend strongly on spatial heterogeneity in communities that maintain sources of dispersing recruits and opportunities for settlement. Explicit consideration of such spatiotemporal effects, and the physical and biological factors that maintain heterogeneity, may be critical to modelling long-term patterns in benthic food webs that lead to top predators. Possibly excepting the Blue-eyed Shag around the northern Antarctic Peninsula, no predators comparable to bottom-feeding sea ducks exist in the Antarctic. Moreover, the high abundance of both endothermic and ectothermic benthic predators, and the shallow water depths that increase carbon flux to benthos and access to diving endotherms, are fundamental differences in comparing sub-Arctic to Antarctic ecosystems. Benthic predators such as sea ducks, walruses, bearded seals, and grey whales are highly mobile, and their impacts tend to be localised according to spatial heterogeneity in prey. Crabs, mostly lacking in the Antarctic, are perhaps the most abundant and omnipresent benthic predators in the northern sub-Arctic, but still show strong spatial variations. Modelling benthic food webs that are so important in the sub-Arctic may require differing approaches to spatial heterogeneity than modelling pelagic systems in the sub-Arctic or Antarctic.

23 June, 08:50 (WB-O14)

Split-up of the Alaskan Stream into Aleutian eddies and their impact on lanternfishes

Konstantin **Rogachev** and Natalya Shlyk

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The Alaskan Stream breaks-up into Aleutian eddies at ~172°E. Aleutian eddies are a major component of the Alaskan Stream water west of Near Strait. These eddies form an important mechanism by which Alaskan Stream water is transported into the Oyashio and Kamchatka region. The transport of warm water into the Oyashio is accomplished by eddies, rather than by a continuous flow. The Oyashio intermediate water exhibits a warming trend. Historical data show that Oyashio temperature increased by 1.37°C during 1953 to 2008 at potential density of 26.75 σ_θ at depths of approximately 170 m. This rate of warming is much faster than that of the global ocean and the Okhotsk Sea. New data show that western Bering Sea intermediate water temperature increased by 1.66°C during 1955–2007 at the same potential density. Oyashio warming is likely linked to the penetration of warm Alaskan Stream water westward. Therefore, the Okhotsk Sea warming is likely linked to the increased transport of warm water westward by the Alaskan Stream and Aleutian eddies. Our observations indicate that the Alaskan Stream breaks up into large eddies at the present intensity. The size of eddies were significantly reduced during 1990s. Mesopelagic fishes in the region have been studied using sound-scattering layers. Due to their abundance and vertical migratory behaviour lanternfishes play a major role in the oceanic food web. There is clear evidence that large eddies significantly effect the structure of sound-scattering layers.

23 June, 09:10 (WB-O15)

The importance of sea ice to seals in sub-Arctic and Antarctic marine ecosystems

John **Bengtson**

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Ice-associated seals are recognised as being ecologically important components of both sub-Arctic and Antarctic marine ecosystems. As upper-trophic level predators with broad distributions, these seals can also provide a potential source of information about ecosystem interactions and environmental variability integrated over a wide range of spatial and temporal scales. In the Pacific sector of the sub-Arctic, there are four species of ice-associated seals: ringed, *Phoca hispida*; bearded, *Erignathus barbatus*; spotted, *Phoca largha*; and ribbon, *Phoca fasciata*. Four species of ice-breeding seals can also be found in the Antarctic: crabeater, *Lobodon carcinophaga*; leopard, *Hydrurga leptonyx*; Ross, *Ommatophoca rossii*; and Weddell, *Leptonychotes weddelli*. Ice-associated seals use sea ice for several key activities and life history events, including pupping, molting, resting, and as substrates associated with foraging. Seals use the physical aspects of sea ice (e.g. for hauling out onto the ice) as well as relying on the food webs that are fostered within sea ice ecosystems. Seals from both polar regions utilise pack ice as well as fast ice habitats. For sympatric species, the seals' different uses of sea ice have evolved into a habitat partitioning that supports the various species' contrasting life histories. At present we do not fully understand how or to what extent specific features of the biological and physical environments influence ice-associated seals, either directly or indirectly. But recent studies of the spatial relationships and distribution patterns of seals, their physical environment, and their prey have provided new insights into how seals interact with polar ecosystems. Shifting patterns of seasonal sea ice distribution, timing, and other ice characteristics are likely to impact different species of ice-associated seals in different ways. This presentation explores and compares how eight species of ice-associated seals utilise and depend on sea ice, and how changing sea ice patterns in the context of global warming may affect these species.

23 June, 09:30 (WB-O16)

Modelling the distribution and abundance of marine top-predators in relationships to physical parameters sensitive to climate change

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Northern Fulmars are one of the most numerous species in the Bering Sea and susceptible to affects from both climate change and fishing activities. In many parts of their range, the diet of fulmars has been supplemented greatly by offal discarded from industrial fisheries. Since the establishment of the Exclusive Economic Zone and enactment of the Magnuson-Stevens Act in 1983, however, the discard of offal has been increasingly restricted by fishing regulations. We examined data from the North Pacific Pelagic Seabird Database, supplemented by substantial number of surveys added recently, to see whether this change in discards could have affected the distribution of fulmars in the Bering Sea. We found that fulmars were more evenly distributed in the 1980s–2000s than in the 1970s. We postulate that fulmars were more aggregated in association with fisheries during the 1970s, whereas today they are more dispersed; as would be expected if they had increased their reliance on natural prey. Fulmars are also known to be sensitive to climate variability. The Bering Sea experienced a major ecosystem regime shift in 1977 and lesser ecosystem changes during subsequent decades. To examine climate effects on fulmars, we modelled fulmar densities against a suite of physical variables describing the seascape (e.g. bathymetry, SST, distance from the shelf), mostly derived from remote sensing. The relationship of fulmar density and sea surface temperature was nonlinear. When we compared the residuals of this model with the Pacific Decadal Oscillation (PDO) index we found a positive relationship between PDO and fulmar populations at sea that was strongest at a time lag of two years. These results suggest that it may be possible to predict the effects of different climate change scenarios on fulmar populations in the Bering Sea. The pattern of population changes since 1975 suggests that so far, fisheries, through offal discards, had a greater impact on fulmars than climate.

23 June, 09:50 (WB-O17)

Southern elephant seals instrumented with oceanographic sensors: insights into their foraging ecology and input as autonomous samplers

Anne-Cecile **Dragon**[1], Frederic Bailleul[2], Cedric Cotte[3], Stephane Blain[4], Lionel Chiron[4], Jean-Benoit Charassin[5], Fabien Roquet[5], Young-Hyang Park[5], Yves Cherel[3] and Christophe Guinet[3]

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[5] MNHN, Paris, France.

From 2004 to 2008, 55 elephant seals from the Kerguelen Islands were fitted with a new generation of temperature and salinity satellite-relayed data loggers, collecting temperature and salinity throughout the top 1000 m of the water column. Some individuals even dived up to 1998 m deep providing a large snapshot of the hydrographic conditions of the Southern Ocean depths. Oceanographic data as well as foraging behaviour and success information were obtained over a vast area extending from the Polar Front to the Antarctic continent. The spatial variation of the foraging success of female and male Southern elephant seals highlighted the importance of the most productive SO subsystems: the Frontal Zone, located between the Subtropical and Polar Fronts and characterised by intense mesoscale eddies, and the Marginal Ice Zone for female seals. In contrast, the highly productive Kerguelen Heard and the peri-Antarctic plateau constitute the main foraging area of males Southern elephant seals. An analysis of blood and nail stable isotopes of C and N confirmed for a large number of individuals the findings on foraging movements and allowed to precisely locate the place of those deep-diving and wide-ranging predators in the SO trophic food-web. Furthermore these devices have the potential to provide detailed oceanographic information in logistically difficult areas at comparatively low cost, being therefore highly interesting for the oceanographic community as well. We briefly show how the seal temperature and salinity data allowed the major fronts to be mapped south of 60°S, provided a detailed picture of the ocean circulation over the Kerguelen plateau, and allowed sea ice formation rates to be inferred from changes in upper ocean salinity. Since 2008 the new generation of data-loggers provides, besides insights into temperature and salinity, fluorescence data sampled on the upper 200 metres of the water column leading to a 3-dimensional synoptic view of chlorophyll-*a* distribution in the Southern Ocean. The development of the CTD-Fluo tags produces an invaluable tool for assessing seasonal and inter-annual variations in the primary production in relation to physical oceanographic anomalies and climate change. In the future, this information will also be used to examine the role of hydrographic parameters on the Southern elephant seal foraging behaviour in this complex and dynamic environment.

23 June, 10:30 (WB-O18)

Habitat selection of three seals in the Western Antarctic Peninsula

Daniel **Costa**[1], Daniel Crocker[2], Mike Fedak[3], Michael Goebel[4], Luis Huckstadt[1] and Birgette McDonald[1]

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The Western Antarctic Peninsula (WAP) is a region of the world undergoing the most dramatic increase in temperature. In an attempt to understand how climate change might impact Antarctic seals in the WAP we examined the habitat utilisation of three of the most common seals in this region. Using Satellite Relay Data Loggers we examined the foraging behaviour of 42 adult female southern elephant seals, *Mirounga leonina* over four years (2005–2008), 43 crabeater seals, *Lobodon carcinophaga* over three years (2001, 2002 and 2007), and two Weddell seals, *Leptonychotes weddelli* (2007) foraging in the Western Antarctic Peninsula (WAP). Southern elephant seals made the deepest (357 m) and longest dives (24.3 min). Some elephant seals remained in WAP foraging along the continental slope in all years and some remained in the pack ice as it formed during the winter. During 2006 some elephant seals foraged well into the Amundsen Sea some 5400 km west. In contrast during 2007 all elephant seals remained in the WAP region or in the Drake Passage. These changes correspond to marked differences in SST between years. Crabeater seals did not show as dramatic variations in their habitat utilisation. They foraged along the continental shelf and remained deep within the pack ice throughout the winter, remaining closer to shore than elephant seals. Some moved considerable distances (664 km to northeast, 1147 km to southwest), but most remained within 300 km of their tagging location. Average dive depths for crabeater seals were 61 m, and lasted 3.8 min. The Weddell seals remained within 94 km of where they were tagged and made surprisingly shallow dives averaging 91 m that lasted 11.5 min (deepest 455 m, longest 27.5 min). Our data suggest that elephant seals forage in a greater range of habitat types and that crabeater seals are more dependent on sea ice and thus would be more impacted by climate change.

23 June, 10:50

Discussion: Arctic and Antarctic predators

Led by George **Hunt**

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23 June, 12:00

Summary of workshop and discussion of workshop products

Led by Eileen **Hofmann**[1], George **Hunt**[2], Bernard A. **Megrey**[3], Eugene J. **Murphy**[4], Sei-ichi **Saitoh**[5] and Hyoung Chul **Shin**[6]

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WC Worldwide large scale fluctuations of sardine and anchovy: revisiting Schwartzlose *et al.*

Chairs: Jürgen Alheit, Salvador Lluch-Cota and Carl van der Lingen

This will be a Dahlem style workshop where invited participants prepare background material which is distributed prior to the workshop. During the workshop there will be only discussion and a few very short ad-hoc presentations. Background material can be viewed at http://www.globec.org/structure/regional/spacc/OSMwksp7.htm. Submitted abstracts are listed below.

A number of new and revised ideas about the causes of anchovy and sardine alternations have been proposed during the decade since publication of the landmark paper by Schwartzlose et al. (1999) that summarised the findings of SCOR WG 98 on "Worldwide Large-scale Fluctuations of Sardine and Anchovy Populations" which had a joint meeting with SPACC in 1997. Since then the subject of anchovy/sardine alternations has been discussed at several regional meetings organised by the GLOBEC Focus 1 group and SPACC. That some of these alternations are synchronous at basin scales has been taken as evidence for long-term oceanic forcing driven by shifts in global climate, but the mechanism/s linking global climate cycles and regional or local processes that impact on sardine and anchovy and may drive species alternations remains unresolved.

Changing physical regimes that result in food environments that favour one genus over the other because of their differing trophic ecologies have been suggested, as have differential optimal temperatures for growth rates of early life history stages of sardine and anchovy, and differences in spawning temperature optima of these and other small pelagic species. Alternative explanations for anchovy/sardine alternations are related to the "loophole hypothesis", boundary current flow or advection of different water masses.

This workshop will bring together participants who are familiar with and interested in this topic in order to:

1. Update and synthesize information collected over the past decade on anchovy and sardine alternations from a variety of systems,
2. Discuss and review recent hypotheses about possible causes of these alternations,
3. Attempt to attain consensus on such mechanism/s,
4. Identify new research areas, including meta-analyses and simulation models, to test hypotheses concerning such mechanisms.

22-23 June (WC-O1)

Response of sardine recruitment success to climate forcing on the California Current

Timothy **Baumgartner**[1], Guillermo Auad[2], Kevin Hill[3] and Arthur Miller[2]

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We investigate the relationship between recruitment success of the springtime spawning stock of the Pacific sardine and the climate and ocean conditions in the central region of the California Current system by means of a statistical model set up to reflect sensitivity of specific life stages to seasonal climate forcing. The series of sardine recruitment success is taken from annual stock assessments over the period 1982–2007 by the Southwest Fisheries Science Center of NOAA-NMFS. Ocean climate variability is represented by monthly values of the Pacific Decadal Oscillation Index (PDOI; from http://jisao.washington.edu/pdo/), plus monthly indices of coastal upwelling and Ekman pumping off central California (from http://las.pfeg.noaa.gov/las6_5/servlets/dataset). We selected a suite of four seasonal indices for each climate variable (a total of 12 climate indices) by prescreening successive, overlapping 3-month means of each of the three climate series from evaluation of their lagged correlations with the series of annual sardine recruitment success. This prescreening process identifies seasonal periods of the three forcing variables that exert the strongest influence on each of the life stages in the recruitment process specified as 1) environmental conditioning of prespawning adults, 2) spawning and larval growth//mortality, 3) juvenile growth/mortality, and 4) the stage of recruitment to the adult population that together extend over a span of 27 months. We use a stepwise regression procedure to develop a general linear model for annual recruitment success by selecting five of the original 12 seasonal climate variables that optimises the level of skill and degrees of freedom of the model estimates. The model results indicate that the interannual variability of the PDOI is strongly linked to recruitment success through its positive association with environmental conditioning of prespawning adults and with the stage of spawning and larval development (i.e. warming episodes

over the NE Pacific favour recruitment success). Model results further indicate that a decadal scale increase in Ekman pumping after 1990 had a significant negative effect on recruitment success mainly through its negative influence at the stage of juvenile growth. Likewise, two of the four coastal upwelling series, those corresponding to the stages of juvenile growth and then recruitment, were also inversely related to recruitment success over the period of 1982–2007. The skill of the model will be assessed for use in the next step of development as an experimental forecast tool. The presentation will conclude with an examination of the inferred mechanisms of physical-biological coupling that underlie the associations between the sardine recruitment success and the seasonal indices of climate forcing in the regression model.

22-23 June (WC-O2)

Horizontal distribution of early life stages of pelagic fish species in relation to temperature and dissolved oxygen in the northern Benguela during a low upwelling phase

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Most studies on the horizontal distribution of eggs and larvae of sardine, anchovy and horse mackerel in the northern Benguela originate from the 1970s and 1980s. The northern Benguela system has been in a high upwelling regime during those decades. Since the early 1990s upwelling favourable winds have decreased and an increasing trend in sea surface temperature has been observed. It has further been suggested that changes in biomass and stock structure of sardine and horse mackerel has led to a change in spawning behaviour. Data on the distribution of eggs and larvae collected between 2000 and 2005, however, show that horizontal distributions of early life stages are very similar to those observed historically and no major shifts in spawning location, due to a change in environmental regime or population structure, have occurred.

22-23 June (WC-O3)

Strong fluctuations of pelagic fish stock in the southeast Pacific

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Strong fluctuations of pelagic fish stocks in the southeast Pacific have been observed over the last four decades, particularly for anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*), horse mackerel (*Trachurus murphyi*), and mackerel (*Scomber japonicus*). During this period, maximum annual landings were 13.0 millions metric tons (MT) in 1970 for anchovy, 6 million MT in 1985 for sardine and 4.5 million MT in 1995 for horse mackerel. These changes are mainly driven environmentally, by short term *El Niño*/*La Niña* events and long-term *El Viejo*/*La Vieja* periods. The timing of the short term *El Niño* (positive temperature anomalies) and La Niña (negative anomalies) events is critical depending on whether they occur during *El Viejo* (also positive anomalies) or *La Vieja* (also negative anomalies) periods.

Biological processes such as feeding, spawning and recruitment have also great relevance for the strong fluctuations of pelagic fish stocks in the southeast Pacific. Under normal conditions, there is a high abundance of anchovy in the coastal zone of the northern-central region of Peru related to the principal upwelling areas, whereas a high abundance of horse mackerel is encountered in the central–southern zone of Chile related to frontal structures or downwelling areas. However, during the 1982–83 *El Niño* event spatial variability was observed in the primary productivity levels and the biomass distribution of main pelagic stocks changed accordingly. About 8 million tons of sardine and horse mackerel migrated from Peru to northern-central Chile between summer 1982 to spring 1983. This was probably one of the largest movements of living resources in the world. In the southeast Pacific, the Peruvian northern-central region is a source of very high productivity. During *El Niño*, this productive zone shifts to the centre and south of the Humboldt current system, whereas, during the *La Niña* phase, it moves to the north and the Equatorial Central Pacific where an increase of the tuna stocks has been observed then. With respect to longitudinal distribution of pelagic stocks, it has been noted that the epipelagic anchovy has a high biomass inshore under normal environmental conditions, while the mesopelagic lanternfish (*Vinciguerria lucetia*) has its highest abundance in offshore waters. There is a definite latitudinal gradient of sizes of pelagic fish in the southeast Pacific. Smaller sizes are found in the northern-central region of Peru, mainly based on anchovy of 12 to 16 cm. Larger sizes are encountered in the central-southern region of Chile, mainly horse mackerel of 20 to 45 cm. The general rules of distribution of pelagic resources are: 1) anchovy dominates the northern area of the southeast Pacific and the sardine-horse mackerel complex dominates the central-southern area, and 2) anchovy dwells in inshore waters and sardine, horse mackerel, and mackerel are found in offshore waters.

22-23 June (WC-O4)

The spatial distribution and back-calculation potential of anchovy-scale-deposition information in the anaerobic sediments of the Yellow and East China Seas

Yao **Sun**, Haibo Jia, Meixun Zhao, Xiaoxia Sun and Qisheng Tang

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In order to achieve sustainable utilisation of marine fish resources, it is essential to establish scientific management methods and put them into practice, which will need further understanding of population dynamics. In past studies, we have found that it is very difficult using routine resource surveys to establish whether significant changes in population structure and decline of fish resources were caused by humans or nature. It is fortunate that Soutar and Issacs found that the amount of fish-scale-deposition varied with time in the sediments of Santa Barbara of South California and had a quantitative relationship with fish resources. Without doubt, the new paleoecology method, which could trace fish population dynamics back a thousand years, supplied an important tool for us to establish the relationship of fish population dynamics with environmental change and human disturbances. So far, there have only been a few studies that used this method which were mainly focused on the California Current and Gulf, Peru-Chile Current, Benguela Current and the Baltic Sea.

Anchovy-scale-deposition abundance (ASDA) of 47 surface and six core stations from anaerobic sediment areas in the typical fishery waters of the Yellow and East China Seas have been investigated in this study. The results showed that anchovy scales made up to 75% of all fish scale fossils in the central Yellow Sea. High ASDA in surface sediments was always found at high biomass stock waters, such as overwintering waters in the central Yellow Sea, but high ASDA was not found in all surface sediment of these waters. ASDA values in surface sediment may be controlled by some other factors than for anchovy stock biomass. The vertical distributions of ASDA of three cores in central Yellow Sea were inhomogeneous with depth, which showed a positive linear correlation with anchovy stock biomass of the same ages. Moreover, the anchovy-scale-deposition information in vertical anaerobic sediment section was steady enough have back-calculation potential for the last two hundred years. ASDA information and its quantitative relationship with anchovy stock biomass stock was applied to three cores from the central Yellow Sea to reconstruct anchovy population change over the last 150 years which obtained some satisfactory results.

WD Krill biology and ecology in the world's oceans

Chairs: Angus Atkinson, Jaime Gómez-Guitérrez, Bettina Meyer and Bill Peterson

The workshop will be a gathering of krill biologists and ecologists from around the world to discuss the life history and population dynamics of all krill species. This is timely because krill have been important elements of a number of the GLOBEC core programmes and a great deal has been learned from the GLOBEC fieldwork that needs to be synthesized.

These discussions were first initiated at the International Zooplankton Production Symposium, in Hiroshima, May 2007 where the workshop was overwhelmed with presentations and attendance.

The aims of the workshop will include:

- Synthesis of krill research from GLOBEC fieldwork.
- Discussion of methods and approaches that have proved effective for one species and consideration of whether they can be applied to other euphausiid species.
- To make sure there is a degree of harmony in approaches to krill research and to improve technical aspects of specific methods.
- To generate ideas for future collaborations, for example laboratory/seagoing exchanges of personnel and of exchange and pooling of datasets to address wider-scale issues.
- To produce a tangible product, to show where krill research is at the moment, hurdles to progress and potential solutions.

22 June, 08:30

Introduction to the workshop

22 June, 08:40 (WD-O1)

Krill research at the British Antarctic Survey: current and future study areas, achievements and sticking points

Angus **Atkinson** and Geraint Tarling

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The British Antarctic Survey has done a large number of acoustics- and net-based surveys in the South Georgia/Scotia Sea region since the 1970s. All euphausiid species present in net catches are included in traditional community analyses, but detailed ecological studies are currently confined to those on *Euphausia superba* and to a lesser extent on northern krill, *Meganyctiphanes norvegica*. For *Euphausia superba* there are also active research groups at BAS working on the predators of krill as well as on their potential competitors and food sources. This "food web" type of approach also extends to more fisheries-orientated modelling and involvement in the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), including the use of fisheries data. While the focus of fieldwork is still on the Scotia Sea area, our approaches to data integration and modelling are extending in time and space scales to include circumpolar and long term, for instance the remote drivers of population dynamics such as ENSO. At BAS, currently active research areas specifically on *E. superba* include a) behaviour associated with swimming and swarming, b) acoustics, including swarming, biomass estimation and target differentiation, c) seasonal and regional variation in feeding (from gut contents, fatty acid and isotope makers) and condition indices including overwintering adaptations, d) biogeochemical role of excretion and defecation, e) reproduction and specifically egg production and early larval modelling, f) large-scale (up to circumpolar) distribution, growth, production and mortality, g) reproduction - specifically egg laying and modelling the early life cycle, h) genetics, particularly to examine relatedness of populations, evolutionary history and genetic function in overwintering cues, i) modelling, especially of interactions within commercially important food chains, the early life cycle, population dynamics, and the role of large-scale advection. Three members of this research group are also working on *M. norvegica* caught from Kristineberg Marine station on the west coast of Sweden. Aspects here include acoustics, vertical migration, and feeding. In this talk we will briefly highlight these current research areas in BAS and outline the directions in which they are heading. We will describe areas of progress, specifically where approaches or method refinements could be transferred to other krill species, but pinpoint also some critical bottlenecks that continue to hamper our progress.

For instance we are still grappling with accurate biomass determination, seasonal changes in behaviour including overwintering, the energy budget, feeding plasticity, determination of mortality rates and its main sources, and developing a unified model/understanding of swarming. A big issue that overarches many of the research strands above is to determine the degree of flux or connectivity between specific sub-populations which appear to have different age structures, distributions and behaviour. To what extent do krill move between these areas and how do they do so?

22 June, 09:00 (WD-O2)

Australian research on Antarctic krill

So **Kawaguchi** and Stephen Nicol

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Australian research on Antarctic krill began in the late 1970s and has continued at the Antarctic Division in Kingston, Tasmania where live krill have been maintained since 1981. Experimental krill research has been greatly assisted by the construction of a sophisticated cold-water aquarium where krill have been maintained since 2003. This facility has enabled large populations of krill (>5,000) to be held in captivity for long periods of time under simulated Antarctic temperature and light regimes as well as under modified environmental conditions. Studies that have been conducted using this captive population include: accumulation rates of age pigments, spawning and reproductive rates, developmental studies, effects of light regimes on physiology, growth studies, effects of elevated CO_2, feeding rates and diet, swimming, turbulence and schooling. The aquarium has become a centre for international krill researchers with scientists from Australia, the US, Japan, the UK, Mexico, Germany and France collaborating on aspects of krill research that can be most easily studied in the laboratory. There is also an active Australian field research programme that focuses on the conservation biology of krill through the Commission for the Conservation of Antarctic Marine Living Resources and through programmes such as Southern Ocean GLOBEC. Most of the waters off east Antarctica have now been surveyed in two large multidisciplinary studies and these have produced a wealth of information on the distribution and abundance of krill in relation to its physical, chemical and biological environment. Individual studies have also focused on the structure of krill swarms and their relationship to the physical environment and also to feeding behaviour of predators such as penguins. A final strand of Australian krill research examines the behaviour of the krill fishery through analysis of fisheries data and through interpretations of the historical patterns of fisheries operations. The aim of all of these studies is to better understand krill biology and ecology so that management of the krill fishery can be based on sound scientific information.

22 June, 09:20 (WD-O3)

Krill research at the Alfred-Wegener Institute, Germany: current and future activities

Bettina **Meyer**

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After a period of over ten years of no krill research at the Alfred-Wegener Institute (AWI), a new working group was established in January 1999. The research focused mainly on the overwintering behaviour of larval and postlarval krill in the Lazarev Sea. Our studies comprised the German contribution to the SO-GLOBEC programme and thus broadened the coverage of study regions within the programme. This area represents the eastern part of the hotspot region of krill abundance, reaching from the western Antarctic Peninsula to the Greenwich Meridian. It shows the widest latitudinal range of krill occurrence throughout their entire circumpolar distribution, stretching from 60°S to the Antarctic continent at 70°S. The continental shelf is narrow and the majority of krill lives in a region of more than 4000 m depth. Only a limited set of historical data exists on krill from this area, focusing mainly on krill distribution and abundance. Future activities in krill research at AWI will focus on adult krill and on the driving forces that determine their physiological adaptation to the highly seasonal environment. Our results from the Lazarev Sea give evidence that krill have evolved control mechanisms to perceive seasonal variations in light conditions and thereby to anticipate the succession of the season. This enables krill to regulate its physiology according to the pronounced seasonal differences in environmental conditions. This research will involve mainly laboratory studies in close cooperation with the krill group at the Australian Antarctic Division. For larval krill our focus will be on the effect of changing sea ice conditions on the life cycle of krill. Our central question is how sensitive are larvae to environmental changes during winter? In order to perform these studies a winter cruise is planned in the eastern Weddell Sea for 2012. In this talk I will briefly outline the future research activities on adult krill mentioned above and the winter cruise planned in 2012 to study the cross-linkage between larval krill and sea ice in the eastern Weddell Sea region.

22 June, 09:40 (WD-O4)

Horizontal and vertical distribution of euphausiid species on the Western Antarctic Peninsula Southern Ocean GLOBEC study site

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The Western Antarctic Peninsula (WAP) is a primary site of krill abundance and a likely source for krill populations found to the north and east of the area. The Southern Ocean GLOBEC programme studied factors that contribute to the overwintering success of krill in the region of Marguerite Bay, WAP, these include the role of physical features and mechanisms such as the vertical hydrographic structure, upwelling of nutrient rich water along the continental shelf, winter ice cover, an alongshore current flowing from north to south along the shelf and through Marguerite Bay, and a persistent cyclonic gyre found on the shelf off of Marguerite Bay that might retain larval krill populations on the shelf. Underway acoustic backscatter and velocity, video, hydrographic, and discrete location sampling using a MOCNESS net system was conducted to sample the vertical distribution and abundance of zooplankton relative to physical features (hydrography, circulation) during four broad-scale survey cruises in the autumn and winter of 2001 and 2002. Analyses of multi-frequency acoustic data demonstrated strong spatial and temporal variability in the horizontal and vertical distribution of krill aggregations, consistently associated with food availability, temperature, and predators. The acoustic methods could not distinguish between the two species of aggregating euphausiids present (*Euphausia superba* and *E. crystallorophias*), and furthermore mostly targeted only larger krill size classes. The distributions of the four prevalent euphausiid species (*E. superba*, *E. crystallorophias*, *E. triacantha*, and *Thysanoessa macrura*) have therefore been determined based on the enumeration to species and, in two cases, life stage of a selected set of the MOCNESS tows. All four species were found distributed throughout the study area on all four cruises. The species had significantly different horizontal and vertical distributions. Both *E. superba* and *T. macrura* were broadly distributed throughout the area, but the central 50% of their vertical distributions were separated with *E. superba* dominating in the upper 100 metres and *T. macrura* found between 100 and 250 m. *E. crystallorophias* had a more coastal distribution and was usually found deeper than *E. superba* and either overlapping or above *T. macrura* in depth. *E. triacantha* was much rarer and sporadically distributed in the study site and was found substantially deeper (centre of distribution of about 300 m) than the other three euphausiid species. By virtue of the species vertical distributions, the temperature and salinity regimes of their central distributions were distinctive on all four cruises. Thus, *E. superba* was generally found in the coldest freshest water (average temperature and salinity: -1.13°C; 33.80 PSU). *E. crystallorophias* occurred in slightly warmer and saltier water (-0.44°C; 34.00 PSU); *T. macrura* was third in the progression (0.01°C; 34.23 PSU); and *E. triacantha* was living in the warmest saltiest water (1.40°C; 34.65 PSU). The larval distributions for *E. superba* and *E. crystallorophias* indicated that the populations did not develop solely as a result of offshore reproduction and transport onto the shelf, but rather appear to also have resulted from shelf reproduction and development, contrary to the prevailing paradigm of *E. superba* spawning. Future analyses will involve comparisons to similar studies of the biological and physical factors governing krill distribution (primarily *Meganyctiphanes norvegica*) ongoing in the Gulf of Maine and Georges Bank GLOBEC region.

22 June, 10:30 (WD-O5)

Distribution, overwintering strategies and recruitment of Antarctic krill: Southern Ocean GLOBEC process studies

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The Southern Ocean GLOBEC Programme hypothesized that the central western Antarctic Peninsula continental shelf is an area of unusually high krill production due to environmental conditions favourable for krill survival overwinter, including 1) a cyclonic circulation that retains krill in the region, and 2) an early and long-lasting ice cover, which provides a dependable food resource and protection for larval krill. Four process cruises were conducted in the vicinity of Marguerite Bay during autumn and winter 2001 and 2002. An unusually high reproduction in *Euphausia superba* during 2000/2001 was coincident with above-average chlorophyll-*a* concentrations during summer (based on SeaWiFS images), which resulted in a large juvenile recruitment. Two other euphausiids, *Euphausia crystallorophias* and *Thysanoessa macrura*, also showed a similar population response to the high summer chlorophyll. Sea ice, which formed late in autumn, did not appear to provide a significant source of food for overwintering larvae, particularly in 2002. Low gut fluorescence values indicated that little nutrition was derived from autotrophs in winter. Instead, larvae were opportunistic scavengers exploiting all available food sources, including microzooplankton, benthic larvae, detritus, scarce phytoplankton, and sea-ice biota. Larval krill exhibited several overwintering behaviours: 1) flexible feeding, 2) flexible morphology (i.e. delayed development),

3) flexible physiology (i.e. increased intermolt period, reduced growth, reduced metabolism), 4) moderate lipid storage, and 5) ability to withstand starvation by combusting body C and N. Because most larvae did not shrink in length, this measure may not be a good indicator of the body combustion strategy. At these high latitudes, sea-ice biota may not be a primary source of food during winter, but progressively more important in spring as irradiance levels increase. The highest densities of young *E. superba* larvae occurred offshelf in the Antarctic Circumpolar Current and late-stage larvae occurred predominately on the inner shelf, suggesting that onshore transport and retention by the Marguerite gyre may be important to recruitment as well. *Thysanoessa* juveniles and adults occurred across the shelf, whereas *E. superba* and *E. crystallorophias* occurred primarily in aggregations in inner shelf bays and fjords during autumn and winter, where they provided a concentrated food source for upper trophic level predators. In addition, the three euphausiid species had vertically separated depths of maximum abundance, thus avoiding competition for resources.

22 June, 10:50 (WD-O6)

Antarctic krill (*Euphausia superba*) research in the South Shetland Islands, Antarctica: linking physical processes and biology to the reproductive success of land-based predators

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For approximately 20 years the US Antarctic Marine Living Resources Programme (US AMLR) has undertaken a study of Antarctic krill (*Euphausia superba*) abundance, demography and distribution in the South Shetland Islands, Antarctica in support of the CCAMLR Fisheries Treaty. Specifically, the Treaty requires that both environmental and fishing effects be examined in order to determine the impact on land-based mammals and birds. Because of the necessity to inform management, most studies have focused on population level issues regarding krill. Early studies established the link between krill reproductive success and sea-ice dynamics, and more recently have shown the more subtle effects of atmospheric teleconnections. Krill research has also focused on the development of novel acoustic techniques and methods to quantitatively assess krill biomass culminating in the development of the three-frequency, physically-based models for the discrimination of krill from other acoustic signals. Some of these have been incorporated into research in other areas (Santorra, this meeting). The results of these new acoustic techniques and a comparison with older acoustic models provide a “competing models approach” for the assessment of management strategies using different temporal patterns in biomass. For at least the same period of time, diets and reproductive success of land-based predators (three species of penguins and the Antarctic fur seal) have also been monitored with the goal of assessing the relative impacts of krill fishing and environmental changes on these protected species. Considerable evidence has been gained over recent years showing that the foraging duration of Antarctic fur seals is inversely proportional to the mean krill size, and with the mean krill biomass in the study area. Similarly, diet studies of penguins have shown similar patterns of krill size distribution in diets. The length of the US AMLR programmes studies are now sufficient to begin to discern decadal scale variability in the dynamics of Antarctic krill, and concomitant studies on shorter lived species of euphausiids (*Thysanoessa macrura*) and others will help to differentiate between various hypotheses regarding the impact of climate variability on ecosystem dynamics in the peninsula area of the Antarctic and changes in availability of krill owing to oceanographic changes in the surrounding environment. In this talk, I will review the major findings and techniques of this longitudinal study and their use in the management of this fishery. I will also discuss the impact of climate variability and recent environmental changes, some of the most dramatic on the planet, occurring in this region. I will then conclude with some ideas for future research questions, knowledge gaps and requirements for better addressing future challenges impeding our understanding of euphausiid population dynamics in the Antarctic Peninsula area.

22 June, 11:10 (WD-O7)

Ecology of Antarctic euphausiids within the Palmer LTER region west of the Antarctic Peninsula 1990-2008

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Three of the species that dominated the zooplankton biomass west of the Antarctic Peninsula were relatively long-lived euphausiids: Antarctic krill (*Euphausia superba*), *Thysanöessa macura*, and ice krill (*E. crystallorophias*). Zooplankton sampling and process studies within the Palmer Long-Term Ecological Research programme were concurrent with observations on sea ice dynamics, physical oceanography, primary productivity, microbial loop

activity, sediment flux and sea bird abundance. Seasonal sampling was conducted from small boats operating out of Palmer Station on Anvers Island, west of the Antarctic Peninsula, and a regional annual summer cruise occupied the coastal, shelf and slope areas between Anvers Island and the southern end of Adelaide Island. Temporal-spatial variability in the patterns of distribution and abundance of these species and any detected cycles and trends can be explored in conjunction with possible mechanistic drivers such as sea ice, heat content of the shelf waters, primary production and teleconnections to ENSO. Process studies focused on Antarctic krill, with experiments on secondary production (growth and reproduction), grazing and selectivity by both adult and larval Antarctic krill and their impact on primary production and the phytoplankton community, and larval krill–sea ice interactions. Based on LTER sampling over three full cycles in the population dynamics of Antarctic krill and primary production, we and collaborators are investigating: dependence of cycles in population dynamics upon biological-physical interactions, including the relative importance of reproductive output and larval survival to recruitment in Antarctic krill, and the temporal-spatial variability in the grazing impact and role in the biogeochemical cycle of the Southern Ocean (carbon sequestration by large sinking faecal pellets) of large macrozooplanktonic grazers such as Antarctic krill and salps.

22 June, 11:30 (WD-O8)

Future plans for krill and other macrozooplankton research in the Palmer, Antarctica Long-Term Ecological Research Program

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The West Antarctic Peninsula (WAP) is one of the most rapidly warming regions on earth. The Palmer, Antarctica Long-Term Ecological Research Programme (Pal LTER) has sampled an extended grid along the WAP each January since 1993 to investigate marine ecosystem response to this climate change. Future work in the PAL LTER will focus on the hypothesis that regional warming and sea ice decline in the northern part of the study area have altered key phenological relationships, leading to changes in species distributions, increasing trophic mismatches and changes in habitat, food availability, ecosystem dynamics and biogeochemical cycling. We will also test the hypothesis that deep, cross-shelf canyons characterising the study region are focal areas for ecosystem processes that result in predictable, elevated food resources for top-predators. The objectives of krill and other macrozooplankton research in the Pal LTER are to determine: 1) the effects of changing zooplankton community structure on biogeochemical cycling of carbon and other elements, 2) the contribution of krill and other zooplankton grazing to loss of primary production in the WAP, 3) how changes in climate forcing affects krill number, physiology, and quality, and 4) how these changes affect penguins and other higher trophic levels. Krill grazing and faecal pellet production experiments, microscopic analysis of faecal pellets in long-term sediment traps, analysis of krill lipid/fatty acid content, and diel vertical migration studies will be used to meet these objectives. An autonomous, underwater robotic glider fleet will also expand our spatial and temporal sampling of the WAP, with one of the gliders equipped with an Acoustic Doppler Current Profiler system to provide estimates of krill biomass. A passive acoustic system will also record fish and mammal vocalisations, which will be correlated in both space and time with the concentrations of zooplankton to test our hypotheses concerning biological “hot spots” in cross-shelf canyons.

22 June, 11:50 (WD-O9)

The main results of study of the biological state of krill in the coastal waters of the Argentines Islands archipelago (Antarctic Peninsula)

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The western area of the Antarctic Peninsula is examined as an area of intensive development of krill. Although this region is the object of the complex ecological monitoring, the state of krill populations of these shallow coastal waters remains to be studied in detail. Therefore, knowledge of the state of the krill population (size-sexual structure, reproductive cycle) is necessary for the better understanding of biological processes in the region. The first information about the biology of the krill from the coastal waters of the Argentina Islands was obtained in the 3rd Ukrainian Antarctic Expedition (UAE; 1998–1999). The krill research was continued in the 7th (2002–2003) and the 12th (2007–2008) UAE. Measurements were made using standard methods throughout the Antarctic year and these results will be referred to in this presentation. This region is the area of the interaction between

South America and Antarctic water masses and is notable because of its high biological production. Biodiversity is high in this area and 24 species of seabirds and 8 species of mammals were observed here. Antarctic krill is an aggregate of 11 euphausiid species, which live to the south of the 60th parallel. Only one species *Euphausia superba* dominates in abundance, biomass and distribution. In the coastal waters of Argentina Island this species is food for the numerous representatives of the highest trophic levels. Many indigenous species (Weddell seals, terns, Adeline penguins, snow petrels) feed extensively on these crustaceans. Another three euphausiid species were found in coastal waters of the Argentina Islands: *Thysanoessa macrura*, *E. triacantha* and *E. frigida*. The krill is met in the coastal waters of the Argentina Islands all year. The krill population is presented two "groupings" with different size-sexual structure, behaviour and other biological characteristics. Solitary ("dissipated") krill, which does not form the aggregations, presents the reproductive part of a population. Usually these are large, mature individuals, which are observed along the ice border or at old icebergs. "Swarm" krill forms the dense aggregations and is presented as uniform-sized (even-aged) individuals. The size-sexual structure of krill varies by season. In the Antarctic spring (November–December) "solitary" krill is presented as small-sized, juvenile crustaceans with length not more than 26 mm. Large-sized mature crustaceans form the swarms. In the Antarctic autumn (April–May) and in winter the basis of the swarms are small-sized ripening crustaceans, and large-sized, mature krill are found separately. The blended aggregations are characteristic of the Antarctic summer. Such seasonal changes of the biological state of krill were characteristic for 1998–2003. The season 2006–2007 was different from preceding years by the considerable rise in the temperature of the salt water and late freezing-up. An average temperature of the water in March–April 1998–2003 was -1.20°C whereas in March–April 2006–2007 it was + 0.60°C. Therefore, the reproduction of krill began in the month before and all changes in the biological structure were broken, which may be a reaction to a general rise of temperature in the region. The average abundance of krill in the swarms was from 4–11 ex/m^3, and the average biomass ranged from 480 mg/m^3 in the spring to 2000 mg/m^3–in the autumn.

22 June, 12:10 (WD-O10)

Modelling krill biology and ecology – current status

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An integral component of developing models that can be used to understand responses of marine populations to variability and change is the inclusion of details of the physiology, biology and life history of key species, such as Antarctic krill (*Euphausia superba*). Much of the work done to date in modelling this species has used Lagrangian particle simulations to determine major transport pathways and residence times in key habitats. Individual-based models have been developed for Antarctic krill that include complex physiology and life history details. These models have provided insights into controls on the distribution and growth of this species. The challenge is to now include these insights in models that extend to a larger trophic scope and geographic regions. This presentation will overview the current state of modelling Antarctic krill with a view to developing new directions in modelling that include coupling a detailed life cycle to models of the larger food web, biogeochemical cycling, and habitat. These new models will require detailed resolution at local and regional scales, which has implications for the types of data that are needed. Also, inclusion of recent developments in models that link genotype and phenotype will allow connectivity in circumpolar krill distributions to be examined and enhance results of Lagrangian particle tracking simulations.

22 June, 14:00 (WD-O11)

Advances in the knowledge on distribution and the ecological role of euphausiids in the Humboldt Current System

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The Humboldt Current System has one of the most productive ecosystems in the world ocean, where one of the largest fisheries targets a single anchovy species. Recent ecosystem dynamic studies suggest that euphausiids as prey of anchovy (besides sardine, mackerel, and several other fish) may be the most important primary link between plankton and fish in the food web. Knowledge on natural history, production and distribution of euphausiids, as well as of other zooplanktonic prey of fish are highly needed. Plankton surveys and monitoring of key species are to be implemented. Euphausiid distribution varies in the Humboldt Current Ecosystem (HCE)

according to latitude distance offshore and vertically, as it is affected by intermingling of water masses and currents from the equator, the south pole and the central Pacific. Diversity of species seems to decrease from north to south, and from west to east. Some of the most common and abundant epipelagic species off Peru are *Euphausia mucronata*, *E. eximia*, *E. tenera*, *E. lamelligera*, *Nematoscelis gracilis*, *Stylocheiron affine* and *S. carinatum*. These and other common species off Chile are *E. gibboides*, *E. recurva*, *E. mutica*, *E. gibba*, *Nematoscelis megalops*, *Nematobrachion flexipes* and *Thysanoessa gregaria*. Home ranges and boundaries of indicator species, which could help define biogeographic-biogeochemical regions are not well established along the latitudinal range of the HCE. Vertically, the presence of hypoxic conditions in the oxygen minimum zone excludes most of the zooplankton, but does not prevent several species of euphausiids to DAILY migrate into it. Short vertically migrator *S. affine* is an exception as in other regions of the ocean. Little is known on the effect of *El Niño-La Niña* upon euphausiids distribution and production. Re-examination of long-term series of zooplankton sample collections off Peru and specifically oriented sampling for euphausiids in future events will help understanding their effect in community structure and secondary production. Although larval development and identification of stages, phases and forms of several key species are still incomplete, long-term abundances of life stages reveal multi-decadal variability in their abundance and distribution across the continental shelf. The influence of ambient conditions on pathways of larval development of some species and molting and their impacts on their population growth are of particular interest in these highly changing environments. *Euphausia mucronata* has a wide distribution along the Peruvian and Chilean coasts, is closely associated to upwelling areas and is suggested as the most common and abundant euphausiid in the diet of fish in the HCE. Population dynamics of dominant species and its spatial distribution reveal its major contribution to zooplankton biomass and secondary production over the coastal upwelling region off central/southern Chile and hence its key role to sustain fish production. Euphausiids are in fact the main source of carbon in anchovy and sardine diet off Peru and off jack mackerel at least off Chile. Short time-series (1990–2003) of anchovy stomach contents off Peru reveals that euphausiid values can increase positively associated with anchovy length. Future work in Peruvian waters will focus on population dynamics and population structure of selective species of euphausiids.

22 June, 14:20 (WD-O12)

Biology and ecology of subtropical euphausiids: research from Mexico

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Currently five research groups study the euphausiid biology and ecology in Mexico. Two groups, based at Ensenada BC (CISESE), study 1) long-term (quarterly frequency) variability of euphausiid distribution and abundance along the west coast of the Baja California peninsula (IMECOCAL region, 1997–present) and 2) vertical distribution, biochemical composition and ecophysiology of tropical euphausiids in the eastern tropical Pacific region and mouth of the Gulf of California. Two other research groups, based in La Paz, BCS (CICIMAR), conduct studies on both sides of Baja California peninsula, on 3) whale-krill interaction using stable isotopes and fatty acids, 4) vertical distribution (hydroacoustic and net samples), secondary productivity, eco-physiology (lipid content, respiration rates, and oxidative stress), reproductive biology, and parasitism of the euphausiids. One other research group is based in Quintana Roo (ECOSUR) on the east coast of Mexico and studies 5) diversity, distribution, and abundance of euphausiid associated with mesoscale oceanographic structures in the Gulf of Mexico and the Caribbean Sea. Of the 48 euphausiid species, 40 are distributed along the Pacific coast and 34 in the Gulf of Mexico and Caribbean Sea. Euphausiids have their highest biomass and abundance off both coasts of the Baja California peninsula, in shelf waters. *Nyctiphanes simplex* is the best studied and the most abundant species along the Pacific coast and plays a key trophic link for multiple planktophagous predators. Moreover, its biomass and production rates are sufficiently high to support commercial harvest. However, *Euphausia lamelligera* is the dominant neritic species along the tropical low-oxygen area. About 20–50% of the *N. simplex* population does not grow (or even shrink) throughout the year with highest biomass and abundance associated with cold periods and near-shore coastal upwelling events during both *El Niño* and *La Niña* periods. Future priorities for study of euphausiids by Mexican scientists will be on predator-prey interaction (using biochemical tracers), survey of the diversity and distribution of deep-living species, the effects of the depth of the oxygen minimum layer on vertical distribution patterns, estimation of secondary productivity of tropical euphausiid species, acoustic estimation of biomass, and continuation of the IMECOCAL programme to study long term variability of euphausiid biomass and abundance in the southern part of the California Current System.

22 June, 14:40 (WD-O13)

An overview of krill research in the California Current, Gulf of Alaska and Bering Sea

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The goals of my talk are to review research conducted by US scientists in the northeast Pacific on the distribution of krill species and spatial variations in krill biomass, seasonal cycles of abundance of eggs, larvae, juveniles and adults, egg production and growth rates, and fecundity and mortality rates (where possible). Krill research has a long tradition in the California Current due to regular monitoring of ocean conditions and plankton initiated by the CalCOFI programme in 1949. Thanks are due to the pioneering efforts by Ed Brinton and others at the Scripps Institution of Oceanography to enumerate these samples and make sense of krill ecology in the southern California Current. Sampling of zooplankton by the CalCOFI programme continues today on a quarterly basis making this one of the world's longest zooplankton time series. The most abundant species, *Euphausia pacifica*, has received the most attention. Studies of krill (mostly *E. pacifica*) within the LTER programme at Scripps include feeding, egg production and molting rates. Krill are also sampled within Monterey Bay (37°N) quarterly along a CalCOFI transect line (Line 67) and within Monterey Bay on a monthly basis over the past decade by scientists from Monterey Bay Aquarium Research Institute and the University of California (UC) at Santa Cruz. A new "long-term" cross-shelf transect line was initiated by scientists from UC Davis off Bodega Bay, CA (38.5°N) in September 2008 which will ultimately produce a monthly time series of hydrography and zooplankton including euphausiid eggs and larvae. Further up the coast, off Trinidad, CA (41°N), krill are sampled with Bongo nets during night time cruises on a monthly basis as part of a time series initiated in 2007 by scientists from NOAA-Fisheries and Humboldt State University. Krill eggs and larvae have been sampled on a biweekly-monthly basis by scientists from NOAA Fisheries and Oregon State University along the Newport OR Hydrographic Line (45°N) since 1996. In 2001 night time cruises were initiated so as to sample adults as well. During these monitoring cruises, brood size and molting rates are measured on *E. pacifica* and *Thysanoessa spinifera*; experimental work in the laboratory is now being carried out on feeding rates of *E. pacifica*. Broad scale surveys are carried out several times per year between 42°N to 48°N usually in spring and summer during which eggs, larvae and adults are sampled at 50–100 stations. Off southeast Alaska (58°N), zooplankton (Bongo net) samples are taken monthly from May–September by scientists from the NOAA-Fisheries lab in Auke Bay as part of a time series established in 1997. Further north and east in the Gulf of Alaska, hydrography and zooplankton (including euphausiids) are sampled at least quarterly by scientists from the University of Alaska, Fairbanks along the Seward Line (60°N) as a continuation of sampling initiated by the US GLOBEC programme in 1998. Finally, euphausiid eggs and larvae are sampled as part of routine zooplankton/ichthyoplankton surveys carried out by NOAA-Fisheries in both the Shelikof Strait and the SE Bering Sea. A new research programme in the Bering Sea (Bering Sea Ecosystem Studies–BEST) includes study of euphausiid egg production, molting and feeding rates in the SE Bering Sea, with a focus on the *Thysanoessa* species. Given the rapid warming of the Bering Sea and loss of sea ice in some winters, it is likely that a greater amount of research will be conducted in the Bering Sea in the future. Finally, a considerable amount of krill work is carried out off the coast of British Columbia which will be reviewed by Dave Mackas in this same workshop.

22 June, 15:00 (WD-O14)

Dominant themes in Canadian research on euphausiid ecology: spatial aggregation, interannual variability, and interactions with vertebrate predators

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During the past three decades, there has been a considerable amount of Canadian research on euphausiid ecology. The majority has been by government scientists, and most has been field (rather than laboratory) based, although there are also some key university field and laboratory studies. Study areas in the Atlantic have included the Gulf of St. Lawrence (Simard and colleagues), the Nova Scotia continental margin (Sameoto and colleagues), and the Bay of Fundy (Steve Nicol). Dominant species in the Atlantic are *Meganyctiphanes norvegica* and *Thysanoessa raschii* and *T. inermis*. In the Pacific, most work has been located over the outer-coast continental margin (Fulton, Mackas, Simard and colleagues), in Barkley Sound (Tanasichuk and colleagues), and in the Strait of Georgia and its adjoining deep fjords and inlets (Mackas, Romaine, and colleagues). There has also been some recent open-ocean research on zoogeographic distributions and their anomalies within the Alaska

Gyre (Batten and colleagues). Dominant Pacific species are *Euphausia pacifica*, *Thysanoessa spinifera* (on and near the continental shelf), and *T. inspinata* (at higher latitudes and further offshore). Much of the Canadian research can be grouped within three 'themes':

1) Euphausiids as a 'wasp-waist' species in regional food webs. For many vertebrate predators (herring, hake, salmon, rockfish, baleen whales, colonial seabirds), euphausiids are a preferred and normally a quantitatively-dominant component of the diet. Changes in euphausiid abundance, spatial and temporal distribution, and resulting 'availability' have been shown to have large ecosystem consequences in terms of predator reproductive success, survival, and/or distribution/migration/residence.

2) Locations, mechanisms, and consequences of euphausiid spatial patchiness. Euphausiids show an extreme degree of spatial heterogeneity (factor of 100–1000 differences in concentration over vertical separations of 10–20 m, and horizontal separations of 1–10 km). Where bottom depths are between 100–1000 m, the horizontal aggregations of adult euphausiids are often spatially recurrent and aligned along bathymetric 'edges'. They are caused primarily by relatively rapid (time scale: hours to a few days) interactions between euphausiid behaviour (vertical movement in response to light and turbulence) and flow fields (convergence/divergence and shear of horizontal currents). However, the dense patches also produce locally intensified rates of trophic interactions that are extremely important for both the euphausiids and for mobile and sedentary predators. Euphausiid patches therefore provide an excellent model for study of how the "aggregation" and "retention" components of the Bakun Triad affect ecosystem productivity.

3) Seasonal-to-interannual changes in population size and age structure, links to ocean climate, and consequences for predator populations. In non-Arctic Canadian waters, euphausiids typically have an annual to biennial life cycle. Most reproduction and individual somatic growth occurs in spring and summer. From late autumn through winter, populations decline numerically, and mean body size plateaus or shrinks. Both seasonal and interannual components of total biomass variability are typically ~10x. The interannual differences are probably caused by both growth conditions and predation mortality, but show fairly strong correlation with climate and upwelling indices.

In this presentation, we will show and interpret examples of Canadian research results on each of these themes, and also discuss how they are linked.

22 June, 16:00 (WD-O15)

Euphausiid research in Japan

Yuji **Okazaki** and Kazuaki Tadokoro

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Thirty eight euphausiid species are recorded in Japan. However, most of the current studies on the biology and ecology of euphausiids around Japan have been limited to sub-Arctic species such as *Euphausia pacifica* and *Thysanoessa* spp. in the western North Pacific. Euphausiids (mostly *E. pacifica*) are an important fishery resource in the coastal area of northeast Japan. Therefore, previous studies on the biology and ecology of euphausiids around northeast Japan have focused on the continental shelf and its adjacent area. On the other hand, although euphausiids are widely distributed in oceanic waters, much has been conducted in the offshore area of northeast Japan. Therefore, we have investigated the biology and ecology of euphausiids in the Oyashio and Kuroshio-Oyashio transition region since 2006. Our result showed that 21 species of euphausiids were collected in this region. *E. pacifica* and *Thysanoessa* spp. were dominant taxa in the Oyashio region (temperature at 100 m ≤5°C). *E. recurva*, *E. mutica* and *Nematoscelis microps* occurred year round in the Kuroshio-Oyashio transition region (temperature at 100 m >5°C). *Stylocheiron* spp., *Thysanopoda* spp. and *E. brevis* occurred from summer to autumn in the Kuroshio-Oyashio transition region. We will study the change of the spatial distribution on *E. pacifica* associated with life stages and long term variation of abundance in the western North Pacific in future. These results will contribute to marine ecosystems study and further developing the ecological model (e.g. NEMURO).

22 June, 16:20 (WD-O16)

Euphausia pacifica ecology research in the Yellow Sea and East China Sea

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Euphausia pacifica plays a vital role in the Yellow Sea and East China Sea. It is the one of the dominant zooplankton species in these seas, and is the main food for many fishes. *E. pacifica* abundance and distribution change will affect the ecosystem dynamics and fishery resource variation in the Yellow Sea and East China Sea.

The distribution pattern, seasonal and annual change, egg production, population recruitment, growth rate and feeding activities etc. were studied based on the samples collected in the last ten years and field experiments. The relationship between population dynamics and environmental factors such as temperature, food availability, water mass, current and water front were also analysed, which forms a part of the systematic results of China GLOBEC. The survey data analysis and experimental results show that *E. pacifica* spawns only in the spring and the adult in the spring was bigger than in the autumn. The Yellow Sea Bottom Cold Water Mass play a very important role in the distribution and life cycle of *E. pacifica* in the Yellow Sea. In the spring, *E. pacifica* was mainly distributed in the coastal area and in the central part of the Yellow Sea where is the Cold Water Mass is located during summer. In the autumn, the distribution centre moved to the southern part of the Yellow Sea.

22 June, 16:40 (WD-O17)

The hydrodynamic wake of two species of swimming krill

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Krill are often found in unorganised swarms or coordinated schools depending on the species. To test if group organisation is related to the hydrodynamic wake produced by swimming krill we quantified the flow structure in the wake of *Euphausia superba*, a schooling Antarctic krill, and *Euphausia pacifica*, a swarming Pacific krill. In this study, we used infrared Particle Image Velocimetry (PIV) to analyse the structure of the hydrodynamic disturbance of free-swimming individual specimens. The downward directed jet produced by *E. pacifica* has a lower maximum velocity (3.4 ± 1.1 cm/s vs. 6.2 ± 1.3 cm/s), has a steeper wake angle (59 ± 20 degrees vs. 48 ± 14 degrees), and decays faster (0.3 s vs. 0.6 s) than the jet of *E. superba*, which suggests that the wake is less persistent for signalling in the smaller krill species (*E. pacifica*). Time record analysis reveals that the wake flow is very weak beyond 0.5 body length for *E. pacifica* and beyond one body length for *E. superba*. Since *E. superba* separation distances within a school range from one to three body lengths (from previous data), it appears that *E. superba* may not be using solely the hydrodynamic signal to facilitate schooling.

23 June, 08:30 (WD-O18)

Korean euphausiid research efforts

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Euphausiids, although occurring throughout Korean waters, have hardly been major target species in most marine ecological investigations, and only limited advancements were made in a few particular aspects of krill biology selected by individual scientists. Nevertheless, a bimonthly regular sampling and observational programme covering much of the Korean waters resulted in a large collection of euphausiid specimens over a decade, even if the sampling methods and gears were not quite adequate. Fairly comprehensive description of krill distribution off the west coast of Korea was made, and larval *Euphausia pacifica* in the area was re-described in detail with comparison to the specimens from other parts of the world. There was a case where entrapped euphausiids clogging the seawater intake of power plants offered specimens for population studies of surface aggregations. Unfortunately acoustics have hardly been employed in krill studies in domestic waters, and this was a major hindrance to determining synoptic and dynamic krill distribution in wider temporal and spatial scale. Investigations in different water masses around Korea are likely to offer different merits in krill studies; euphausiids off the west coast of Korea appear to live closer to their upper temperature limit and may have needed to adapt in unique ways. Off the east coast of Korea, there is better historical data and more active interdisciplinary research. These differences will have to be considered in constructing future research plans.

Korean efforts in krill research also took place outside national waters, particularly in the Southern Ocean mostly by the polar programme. One of these was the development of biochemical age and feeding descriptors. Characterising krill aggregations and linking them to some environmental factors were attempted, and this might represent a response to a spectrum in food condition, and an interaction with predators. Collaboration with colleagues employing animal-born loggers and camera appears promising in examining the aggregation dynamics of krill affected by the foraging of predators.

Future efforts both in Korean waters and outside will include the examination of historical specimens and data, and newly designed field studies as a core part of larger multi-discipline programmes. Combining sustained acoustic observation with other environmental data collection from chosen spots might be one of the new experiments. In any case, krill biology will not be a stand-alone push but be integrated with biogeochemistry, wider ecosystem studies in a fisheries management perspective.

23 June, 08:50 (WD-O19)

Use of bottom mounted, upward facing echosounders to study the behaviour of krill

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Traditionally, acoustic studies of krill have been carried out from moving vessels, but recent results from stationary moorings prove the potential of this type of approach. There are currently many initiatives to establish ocean observatories that will be cabled to shore for unlimited power supply and data storage capacities. Echo sounders will become components of such observatories. Here we demonstrate some opportunities that this may provide for studies of krill, focusing on results from a mooring situated at 150 m depth in the Oslofjord, Norway, used to study both population (scattering layers) and individuals of the krill *Meganyctiphanes norvegica*. Records spanned the period from late autumn to spring during three subsequent winters, with a sampling frequency of nearly two per second. In this way, long-term high quality data were obtained at low operational costs. Current meters and CTDs were associated with the acoustic mooring, surface light was measured and a shore based webcam monitored ice conditions in the fjord. The continuous measurements were supplemented with intermittent sampling campaigns of krill and their physical and biological environment. The extended and uninterrupted temporal records made it possible to unveil seasonal patterns in krill behaviour, as well as to observe responses in krill distribution and behaviour associated with unpredictable changes such as water renewals and freezing of the fjord. The use of a stationary echosounder mounted on a stable substrate in a low-advective fjord basin also made it possible to study individual krill over many subsequent “pings” so that their swimming behaviour in the acoustic beam could be addressed. In this talk we provide data on the krill diel vertical migration patterns, comprising effects of freezing and subsequent snow cover on the ice. We also evaluate diel patterns in the swimming speed of individual *M. norvegica*. We further address the effect of hypoxia, both on population vertical distribution and individual swimming behaviour. In conclusion we argue that submerged, stationary echosounders will become a powerful tool for studying krill biology.

23 June, 09:10 (WD-O20)

Stage specific mortality rates for *Euphausia pacifica* larvae from the Oregon coast

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We are working on the population dynamics of *Euphausia pacifica* off the coast of Oregon and have made great progress in understanding rates of reproduction and growth but are now focused on mortality. Mortality calculations are not very common for euphausiids, likely because the available data sets are often not suitable for the calculations due to infrequent sampling or a sampling bias for certain developmental stages. Our studies are based on a combination of laboratory experiments and the regular collection of plankton samples from the field. We were able to compare the patterns of mortality in cohorts of *E. pacifica* raised in our laboratory for development experiments with “cohorts” observed in the field through our biweekly net sampling of zooplankton from a transect off of Newport, Oregon (1996–present). We have long suspected through observations of abundances of euphausiids in the field that survivorship from egg to adult, or even to some of the early larval stages, is very low. This was the case for our laboratory cohorts which had very high mortality in the egg and naupliar stages. Recent calculations of mortality rates from our field data provide an interesting comparison to laboratory results and insights into the population dynamics of *E. pacifica*. We calculated stage-specific mortality rates using the mean spring (March–May) and summer (July–September) densities of eggs and each larval stage of *E. pacifica* (egg through furcilia 3), corrected by stage duration, for 1996–2006. These periods were chosen because observation of the data showed consistent, discrete pulses of egg production, resulting in cohorts of animals that could be followed through time. Cohorts were prominent each summer; however they were less apparent in spring. Thus, only two years (1999 and 2003) had large enough *E. pacifica* egg production events in spring for these calculations. Highest stage specific mortality rates (2–242, average = 46 d^{-1}) were in the egg stage, followed by the naupliar stages (0.5–122, average = 11 d^{-1}), similar to patterns observed in the laboratory.

There is a great deal of variability in rates between years. There is also a very strong positive relationship ($r^2 = 0.99$) between seasonal mean egg density and seasonal egg mortality. This suggests that years of greater egg production may have less impact on recruitment success to adult stages than expected. Recruitment may be more sensitive to relatively small changes in mortality in the later furcilia stages than to large interannual differences in egg density and mortality. These results will be discussed in relation to life history strategies for *E. pacifica* and interannual variability in ocean conditions off Oregon.

23 June, 09:30 (WD-O21)

Response of predators to hierarchical euphausiid patch dynamics in the Antarctic, California Current and North Pacific

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It is now widely acknowledged that global climate change is influencing marine ecosystem organisation and functions. A framework for comparing marine ecosystems, explicit in scale, and treatment is needed to understand and forecast future responses of marine systems to climate and other anthropogenic pressures (e.g. fishing). In concept, investigations of predator-prey dynamics where predators and prey fill similar niches should provide the insight we seek. In the Southern Ocean, California Current, and North Pacific, euphausiid crustaceans (“krill”) are integral to ecosystem organisation and food web dynamics. Penguins and auks, shearwaters and petrels, and baleen whales, respectively, comprise key predators on which comparative analysis of marine ecosystem functions can be based. In this study, we investigate the spatial organisation of krill patches and their influence on foraging seabirds and whales in three ‘krill-centric’ marine ecosystems. We synthesize data from three studies where foraging seabird, whale, and krill distributions were collected simultaneously over 2002–2008, and thereby present a comparative analysis of krill-krill predator spatial dynamics in two hemispheres, and across multiple coastal marine habitats (from the Antarctic Peninsula to the Aleutian Chain). Seabird density was estimated using visual surveys while krill were sampled using a combination of hydroacoustics, nets, or by Continuous Plankton Recorder (North Pacific). We analyse patch characteristics and tested the hypothesis that foraging seabirds respond to patch structure by foraging in regions of repeatable krill patches (i.e. size and connectivity). Key questions to be addressed are: 1) Where are the persistent krill-seabird ‘hotspots’ in representative study regions? 2) Does the patchiness of krill and foraging seabirds vary consistently or inconsistently between oceans? 3) Do similar seabirds (e.g. auks and penguins) respond in similar ways to krill patchiness? 4) what habitat features (bathymetric and hydrographic) appear to be associated with krill-seabird “hotspots” in these different ecosystems. We conclude by addressing how climate change may alter the resilience and predictability of krill-krill predator dynamics in these disparate marine ecosystems.

23 June, 10:20-12:30, 14:00-15:30, 16:00-18:00

Discussion

Workshop D poster session

Poster WD-P1

Temperature effects on the growth and maturation of Antarctic krill (*Euphausia superba*)

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This paper describes growth and maturation of individual Antarctic krill for a complete annual cycle in an artificially controlled environment. Antarctic krill were kept individually and maintained under temperature regimes of -1°C, 1°C and 3°C, while light conditions simulated natural seasonal conditions for the 14 months of the experiment starting in April. The growth increment (GI), instantaneous growth rate (IGR), daily growth rate (DGR), intermoult period (IMP) and maturity scores (MS) were tracked by measuring the consecutively moulted exoskeletons and modelled using linear mixed models (LMMs). There was a clear seasonal cycle of growth and maturity in the three different temperature treatments. Males generally reached peak growth rates and matured earlier than the females, but the females showed higher growth rates overall. Negative growth occurred towards the end of January for both males and females, coinciding with the regression of the external sexual characteristics. There was, as expected, a significant decline in IMP with increasing temperature, which was moderated by increasing trends with total length (TL) and month for the -1°C treatment. For the 1°C and 3°C treatments there was no relationship with TL and the seasonal effect declined after October and December, respectively. For a TL of 40 mm in October, the predicted mean IMP values for -1°C, 1°C and 3°C were 28 days, 24 days and 19 days, respectively. There was some evidence to suggest that 1°C was optimum for growth, as the IMP was significantly lower than the -1°C treatment, but the difference in GI between the two temperatures was not significantly different from zero, while all growth variables were significantly lower for the 3°C compared to the -1°C treatment. For the first time, this study has been able to confirm, by fitting a bivariate LMM, that compensation mechanisms do exist between IMP and IGR and to quantify the degree of compensation at both the between- and within-animal levels. This will allow modelling of growth trajectories in the wild to quantify the distribution of length given age.

Poster WD-P2

Effects of global warming on the abundance and distribution of *Pseudeuphausia sinica* in the East China Sea

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Based on data from the spring, summer, autumn, and winter of 1981 and 2002, the abundance and distribution patterns of *Pseudeuphausia sinica* were analysed in the East China Sea, especially in the water off the Changjing (Yangtze River) Estuary (CE). The salinity and temperature adaptations of *P. sinica* were also discussed. In addition, historic data (during 1979, 1981 and 2000–2007) was employed to explore the effects of climatic change on the distribution and abundance of *P. sinica* in the study area during spring. The results indicate that geographically *P. sinica* was most abundant in the waters off the CE, even though it was widely distributed in the East China Sea. The species showed a clear seasonal succession, and its density was maximised in summer. Moreover, the highest abundance occurred at a sea-surface temperature (SST) 24.5–28.2°C and sea-bottom temperature of 22.5–27.3°C. For this reason, *P. sinica* is considered to be a subtropical species. During the recent three decades, the abundance of *P. sinica* increased significantly accompanied by rising SST in the East China Sea. On one hand, the average abundance of *P. sinica* in 2002 was higher than that in 1981; on the other hand, there was a significant positive relationship between the SST and average abundance in spring according to historic data. In short, the increase of SST was thought to be beneficial to the population of *P. sinica*. Therefore, *P. sinica* is an important indicator of global warming in the East China Sea, particularly in the waters off the CE.

Poster WD-P3

Global diversity, prevalence and intensity of the parasites of euphausiids (krill)

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Parasitism is the most common trophic strategy with interactions that range from almost innocuous paratenic association to parasitoidism. Euphausiids throughout the world's oceans appear to host a highly diverse parasitic assemblage. We review the global diversity of euphausiid parasites focusing on the parasite-host association and their ecological role in the euphausiid population dynamics. So far 16 types of parasites from 55 genera and 38 species are known with a large number of records (>110) without species name. Viral infection of Euphausiids has not been reported but is largely un-studied. Bacterial strains have been reported from krill and can be associated with black spots and sometimes bacteremia. Ectoparasites can attain high prevalences (>50%) and sometimes high intensities typically cause minor harm to the krill health with typically a small parasite/host size ratio (these include: diatoms, chitinoclastic bacteria, yeasts, apostome exuviotrophic spostome ciliates, suctorians, and bopyridae isopods). Trophically transmitted parasites (sporozoa) seem to be ubiquitous and can affect the euphausiid health (with prevalence rates typically >70%). Although parasitic castrators (ellobiopsids, trematodes, helminths, acanthocephalans, and Dajidae isopods) usually have large parasite/host size ratio they generally have extremely low prevalence rates (<1/1000) and intensity having presumably little impact on krill at a population level. Although parasitoids have a small individual cell parasite/host size ratio they can transform virtually all the biomass of the host into parasite biomass. Only two types of euphausiid parasitoids are currently known (both protists): dinoflagellates (*Chytrodinium*, *Syndinium*) that eat euphausiid eggs (apparently with moderate prevalence) but with a so far unknown negative effect on the krill population egg mortality, and the hystophagous apostome *Collinia* ciliates that are known to affect at least six euphausiid species in the northern hemisphere. *Collinia* ciliates are the most dangerous parasite due their short life cycle, relatively high prevalence with significant potential to cause epizootic events in euphausiid species that attain large biomasses in the pelagic ecosystem.

Poster WD-P4

Euphausiid species abundance and swarming behaviour influence their parasitic load: a comparison between *Nyctiphanes simplex* and *Nematoscelis difficilis* along northwestern Mexico

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The parasitic diversity of *Nyctiphanes simplex* and *Nematoscelis difficilis*, the two most abundant euphausiid species along the northwest coast of Mexico, was compared during six oceanographic cruises made near Bahía Magdalena and the Gulf of California, Mexico. We tested the hypothesis that *N. simplex* has a more diverse parasitic assemblage than *N. difficilis* because it is a neritic species, has significantly larger population abundance and biomass, and tends to form denser and more compact swarms than *N. difficilis*. These biological and behavioural features may enhance parasite transmission within swarms. We detected six types of ectoparasites: 1) epibiont diatoms *Licmophora* sp., 2) suctorian ciliates *Ephelota* sp., 3) exuviotrophic apostome ciliates *Gymnodinoides* spp., 4) an ectoparasite *Epicaridean cryptoniscus* larvae (isopoda) and two ectoparasitic castrators 5) ellobiopsid *Thalassomyces fagei*, and 6) the Dajidae isopod *Notophryxus lateralis*. We also detected seven types of trophically transmitted endoparasites: (1–3) three distinct forms of unidentified Helmintha cestode larvae, 4) a Trematoda (metacercarial stage) *Paronatrema* sp., 5) the nematode *Anisakis simplex* (L3), and two undescribed endoparasitoid protists, 6) an apostome ciliate species of the genus *Collinia* and 7) dinoflagellates, likely *Syndinida*, that kill eggs. We demonstrated that *N. simplex* exhibits all types of parasites identified, except the isopod *N. lateralis* (Dajidae) and has a considerably larger parasitic diversity and prevalence rates than *N. difficilis* on both coasts of the Baja California Peninsula. In Oregon coast samples *N. difficilis* is also infested by epibiont suctorian ciliates (*Ephelota* sp.) and endoparasitoid *Syndinida* dinoflagellates that infect its eggs but these parasites are not observed in *N. difficilis* from Mexican waters. Although swarming of euphausiids is a successful adaptive strategy behaviour for reproduction, protection against predators, and increased efficiency in food searching, it has a negative effect because several parasites have evolved to attack primarily species that form dense swarms and have high population densities. Overall, the advantages of aggregation must overcome the reduction of population individual fitness induced by parasites, but parasites, of all types, can affect about 14% of individuals in a *N. simplex* population and must occasionally have a significant influence on population mortality perhaps comparable to that inflicted by krill predators.

Poster WD-P5

Analysis of the exploitation strategies to the Antarctic krill for China

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The resource of Antarctic krill - *Euphausia superba* is very abundant, and engaging in the exploitation Antarctic krill is one of the most important tactics to maintain the sustainable offshore fishery for China. The resource of Antarctic krill is huge in theory; however, its exploration is in decline. Thus, it is necessary to analyse the strategies before exploitation of the Antarctic krill. The exploration cost for Antarctic krill is obviously higher compared with other fishery resources, which is due to the fishery's remote location–far from major ports–and very inhospitable conditions. However, people could improve their quality and raise their added value to compensate the high expense of exploration. In short, the exploitation of Antarctic krill is characterised by the high-risk and high expense. Therefore, the exploration of Antarctic krill should be guided by the end-product design and research on related processing machines and technology. In the meanwhile, the analysis of profit outlook should be valued greatly. On the condition that there was no definite profit expectation, the large scale exploration was not advocated.

Poster WD-P6

The application of lipid trophic markers to track the diet history of T*hysanoessa rashii* in the Bering Sea

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As a component of the Bering Ecosystem Study (BEST) programme, a suite of lipid trophic markers is being examined and validated as markers of the dietary history and trophic transfer of carbon of the euphausiid *Thysanoessa rashii*. Animals were collected by MOCNESS in the Bering Sea during the summer of 2008. Individual tows were split with a subset of krill immediately frozen until lipid analysis and others used for shipboard feeding experiments. Experimental feedings included various diets (i.e. *in situ* seston and seston supplemented with protists and ice algae) to compare with the field collected animals. All samples were analysed for total lipid, major lipid classes, and individual lipid trophic markers. The lipid contents in *T. rashii* were up to 43% of dry weight with a dominance of phospholipids (>46% of total lipid). Triacylglycerols appeared as the major storage lipid class, while wax esters were only present as a minor component. The relative abundances of fatty acids useful as trophic markers (including 16:1(n-7), 20:5(n-3), and 22:6(n-3)) were substantially altered after feeding compared to the composition of seston or food additions. Results of these short term feeding experiments suggest that selected lipid markers may reflect rapid changes in diet. Moreover, some lipid markers (such as sterols) may provide information on a long-term feeding history. Lipid profiles which encompass a suite of lipids may be useful to track changes in the diet history of Bering Sea euphausiids.

Poster WD-P7

Larval developmental pathway of *Euphausia pacifica* in the southern Yellow Sea off the China coast

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The larval development of *Euphausia pacifica* in the Southern Yellow Sea west of 124°E was studied. The total length of each larval stage was determined with an ocular micrometer. Results showed that larval development of *E. pacifica* west of 124°E was similar to that east of 124°E, i.e. including two naupliar, one metanaupliar, three calyptopis and six furcilia stages, and each furcilia stage contains one or more developmental pathway. A total of 27 different furcilia larvae developmental pathways were observed during our study, and the dominant pathways were as follows: Calyptopis^{III} → Furcilia^{I} (0′7, 1′7) → Furcilia^{II} (3′1″7, 1′4″7) → Furcilia^{III} (5″7) → Furcilia^{IV} (5″5) → Furcilia^{V} (5″3) → Furcilia^{VI} (5″1), this was the same with that east of 124°E. The total length of each larval form or stage varied to some extent in different months and different stations.

Poster WD-P8

Length-weight relationships of *Euphausia pacifica* in the southern Yellow Sea off the China coast

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The relationships between total length and wet weight and between total length and dry weight were examined for *Euphausia pacifica* in the Southern Yellow Sea. In addition, dry weight to wet weight ratio, mean length and mean weight were included in this study. No significant differences were found as a function of sex or sampling time in either total length and wet weight or total length and dry weight. But changes were found as a function of sampling station. Though the ratios of dry weight to wet weight of female adults were a little higher than those of male adults, no significance was found, so this ratio can be regarded as a constant. The mean length and mean weight changed little with sex, sampling time and sampling station.

Poster WD-P9

ENSO and variability of the Antarctic Peninsula pelagic marine ecosystem

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The West Antarctic Peninsula region is an important source of Antarctic krill (*Euphausia superba*) in the Southern Ocean. From 1980–2004 abundance and concentration of phytoplankton and zooplankton, krill reproductive and recruitment success and seasonal sea ice extent here were significantly correlated with the atmospheric Southern Oscillation Index and exhibited three to five-year frequencies characteristic of *El Niño*-Southern Oscillation (ENSO) variability. This linkage was associated with movements of the Southern Antarctic Circumpolar Current front and boundary, changing influence of Antarctic Circumpolar Current and Weddell Sea waters, and eastward versus westward flow and mixing processes that are consistent with forcing by the Antarctic dipole high-latitude climate mode. Identification of hydrographic processes underlying ecosystem variability presented here were derived primarily from multidisciplinary data collected by the US Antarctic Marine Living Resources (AMLR) Programme during 1990–2004, a period with relatively stable year-to-year sea ice conditions. These results differ from the overwhelming importance of seasonal sea ice development previously established using 1980–1996 data, a period marked by a major decrease in sea ice from the Antarctic Peninsula region in the late 1980s. As a consequence, the newer results reveal the more subtle consequences of ENSO variability on biological response. The underlying variable atmospheric-oceanographic processes, however, are consistent with those reported from the 1911–1975 period. These results highlight the necessity of internally consistent long-term multidisciplinary data sets for understanding ecosystem variability and ultimately for establishing well-founded ecosystem management. Furthermore, natural environmental variability associated with interannual- and decadal-scale changes in ENSO forcing must be considered when assessing impacts of climate warming in the Antarctic Peninsula-Weddell Sea region.

Poster WD-P10

Seasonal somatic growth and egg production of *Nyctiphanes simplex* in the Gulf of California

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Nyctiphanes simplex somatic growth and egg production was first estimated in the central Gulf of California during warm-cold transition (November 2005), warm (July 2007), and cold (January 2007) seasons. During January occur high chlorophyll-*a* concentrations (<2.4 mg chl-*a* m^{-3}) and low temperatures (16–20°C), in July lower chl-*a* concentrations were detected (<1 mg chl-*a* m^{-3}) and highest temperatures (27–31°C), and November had intermediate values. *N. simplex* productivity should have considerable seasonal changes in response to this pronounced seasonal environmental variability. The juvenile-adult abundance and biomass was estimated per

size class (Bongo 505 µm) and 48 h shipboard incubations (16°C, darkness) were done to estimate instantaneous growth rate, intermolt, and interbrood periods. The average instantaneous growth rate was higher in January (0.0009 mg C d^{-1}) than in November and July (<0.0001 mg C d^{-1}). About 22–31% of the population does not grow and between 15–24% of the population shrinks independently of the season. An extrapolation of these average rates to a seasonal scale indicate that mean daily somatic productivity was 2.4 (cold season = December–May), 1.7 (warm season = July-October), and 0.6 mg C 1000 m^{-3} d^{-1} during both transition periods (November and June). This is equivalent to an integrated value of 442 (cold season), 206 (warm season), and 34.4 mg C 1000 m^{-3}, (transition periods). The mean egg production was 0.2, 0.16, and 0.1 mg C 1000 m^{-3} d^{-1} in January, July, and November, respectively. This is equivalent to 40.2 (cold season), 20 (warm season), and 2.5 mg C 1000 m^{-3} d^{-1} (both transitional seasons). Annual integrated production of somatic growth (682.4) and egg production (62.7) was 745.1 mg C 1000 m^{-3} y^{-1} (92% somatic growth, 8% egg production). The molt secondary production estimation is currently in progress. *N. simplex* somatic and egg production had a positive association with chl-*a* and negative association with temperature in response to the pronounced seasonal variability of the primary production of the gulf. We detected similar regional patterns of chl-*a* and *N. simplex* secondary productivity with high values along the east coast of the gulf during the cold season and along the west coast during the warm season.

Poster WD-P11

What is the true biomass of krill? *Euphausia pacifica* and *Thysanoessa spinifera* in the California Current: a comparison of sampling methods and data sets

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What is the true biomass of krill? Different projects have used different types of nets to sample krill. How do we bridge the gap between historical data sets, which likely under-sampled euphausiids, vs. modern technologies such as acoustics? Another unknown is the size of “krill swarms” and “patchiness”. What we know is that *Euphausia pacifica* and *Thysanoessa spinifera* exhibit extreme variability both across their range and among years. We will summarise the status of reported information on *E. pacifica* and *T. spinifera* densities and biomass from historical data sets collected within the California Current, including La Jolla, Monterey, Newport and Vancouver Island. We will also discuss the catch rate of krill by species, length, and reproductive state for several net types: MOCNESS, Bongo and vertical net. We will compare traditional samplers - bongos and multi-nets, with simple vertically-towed ring nets, and compare krill biomass estimates derived from net tows and acoustics.

Poster WD-P12

Kinematics of various swimming modes in Antarctic krill

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The locomotion of Antarctic krill (*Euphausia superba*) is known to depend on the metachronal paddling of the animal’s five pairs of pleopods. A wave passing along these swimming appendages from posterior to anterior transfers momentum to the surrounding fluid, thus producing thrust. The kinematics of these pleopods, however, have not been fully characterised. Determining the kinematics of krill in various swimming modes will shed light on the fluid mechanics of krill locomotion and thereby deepen our understanding of krill sensing and schooling. High speed footage (250 fps) of freely swimming juvenile and adult Antarctic krill was acquired at the Australian Antarctic Division in Hobart, Tasmania. Various swimming modes were identified based on swimming angle and behaviour, and two-dimensional kinematic parameters such as pleopod stroke frequency, amplitude, stroke overlap, and animal velocity were investigated as a function of these swimming modes. The variability of these parameters over time provides insight into the high sensitivity and responsiveness of krill to their hydrodynamic environment. Useful comparisons can also be made to previously gathered kinematics data for Pacific krill (*Euphausia pacifica*), which live in a much lower viscosity environment. These parameters will prove necessary in future computational fluid dynamics simulations of krill locomotion.

Poster WD-P13

Grazing of larval and juvenile Antarctic krill, *Euphausia superba*, on the natural community of sea ice biota

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Grazing experiments were conducted during an austral winter cruise to determine whether feeding in winter by young (larval and juvenile) Antarctic krill (*Euphausia superba*) was selective and to examine the relative importance of autotrophic versus heterotrophic food sources in their diet. Krill were kept at winter temperatures (-1.5 ± 0.16°C) and fed endemic sea ice microorganisms to determine whether clearance rates and ingestion rates on autotrophic and heterotrophic microorganisms were affected by total food availability and/or community composition. Wet mass specific average maximum clearance rate for young krill (6–12 mm) feeding on heterotrophic carbon was higher than for total and autotrophic carbon. Maximum ingestion rates on total and autotrophic carbon were higher than for heterotrophic carbon. Total carbon ingestion increased with increasing concentration until a critical concentration of 45 µg/l was reached. Heterotrophic carbon ingestion was not correlated with carbon concentration. Larval and juvenile krill were usually able to meet their minimum winter daily carbon requirement when total carbon was as low as 12 µg/l. Daily rations suggest that during winter young krill ingestion, at comparable food concentrations, is similar to ingestion in autumn and spring. This suggests seasonal reduction of metabolism in winter in young krill is a function of temperature or limited food intake rather than a physiological adaptation for winter survival. Clearance rates and electivity indexes showed no clear patterns of selection with carbon concentration or community composition. Autotrophic cells were important sources of carbon. *Phaeocystis* sp. and autotrophic *Gymnodinium* sp. were often dominant and consumed. In some cases, cells identified as autotrophic *Gymnodinium* sp. were rejected and suggested the presence of undesirable species of autotrophic dinoflagellates may inhibit krill feeding.

Poster WD-P14

Circulation on the Western Antarctic Peninsula: implications for biological production

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Field observations from the US Southern Ocean Global Ocean Ecosystem Dynamics programme showed that marine mammals and other predators concentrate in specific areas of the Western Antarctic Peninsula (WAP) continental shelf. The relative contribution of circulation in producing these regions was investigated with Lagrangian particle tracking studies. The circulation for the WAP region was simulated using a high-resolution version of the Regional Ocean Modelling System (ROMS) that included a dynamic sea-ice model with thermodynamically active ice shelves. Floats were released along the WAP outer, mid and inner-shelf regions at a range of depths in different seasons. The simulated particle trajectories showed preferred sites for cross-shelf exchange and onshelf intrusions, which corresponded to areas where higher predator abundance was observed. These results suggest that circulation is potentially important in developing localised areas of high predator abundance perhaps through facilitating aggregation of prey and/or providing areas of enhanced nutrient availability and biological production. The trajectories of floats released along the southwestern portion of the model domain showed inputs to the WAP shelf from the Bellingshausen Sea (BS) with a time scale that is consistent with the time required for Antarctic krill eggs spawned in the BS to develop into larvae. These results suggest connectivity between WAP and BS Antarctic krill populations.

Poster WD-P15

Food utilization of the Antarctic euphausiids *Euphausia superba* and *Thysanoessa macrura*: ontogenetic and seasonal variations of digestive enzymes

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The dominant euphausiids in the seasonal pack ice zone, *Euphausia superba* and *Thysanoessa macrura*, are confronted with dramatic seasonal fluctuations in food availability. How they cope with this situation is still under debate. In order to gain information about their overwintering strategies various developmental stages of *E. superba* and *T. macrura* were sampled in December 2005 (early summer) and June to August 2006 (winter) in the Lazarev Sea (Atlantic sector). Total proteolytic activity as well as the activities of selected digestive enzymes (trypsin, chymotrypsin, lipase) were determined in both species to provide insights on the seasonal, stage- and species-specific potential of food utilisation. The total proteolytic activity of *E. superba* showed no differences between postlarval stages (juveniles, subadults and adults). It was significantly higher

in winter than in early summer (with generally higher activity of trypsin than chymotrypsin in both seasons). These results suggest a more efficient assimilation of nutrients at low food availability. In contrast to postlarval stages of *E. superba*, different lipase/esterase isoforms were identified in the furcilia larvae, indicating a diverse lipid catabolism. No significant seasonal differences of proteolytic activity were found in postlarval *T. macrura*, suggesting a less pronounced dietary variability between different seasons. However, both euphausiids expressed polymorphic proteinases and lipases/esterases, implying an adaptive potential to seasonal changes in diet composition.

Poster presentation WD-P16

Ecological distribution and pattern of euphausiids in the East China Sea

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Based on the data of four seasonal investigations in the East China Sea (23°30′–33°N, 118°30′–128°E) from 1997 to 2000, this paper discussed the species composition and the diversity of euphausiids and their relationship with environmental factors. Furthermore, the distribution and the seasonal changes of euphausiid abundance and dominant species were also discussed. In addition, the relationship between the abundance and ecological characteristics of the dominant species were also discussed through qualitative and quantitative methods.

Results showed that there were a total of 23 different species of euphausiids, in which 16 occurred in spring and autumn respectively; 15 were present in summer and only 10 present in winter. A clear seasonal alternation was found according to the value of alternation fraction (R). In spring, the surface salinity was a major factor influencing the euphausiid richness (i.e. species number of euphausiids). In summer, however, there were no significant relationships between the euphausiid richness and environmental factors (e.g. temperature, salinity). Yet, in autumn, both surface and bottom temperatures were important in determination of the euphausiid richness. In winter, the euphausiid richness was determined by several factors. There was no significant difference between the species number of euphausiids. Most of the euphausiids found in the East China Sea are warm current originated. Therefore, the euphausiid richness was closely related to the water temperature and salinity except in summer. Moreover, uneven individual assignment among different species of euphausiids, and aggregation characteristics of dominant euphausiids brought its low diversity in the East China Sea.

The total abundance of euphausiids peaked in autumn (151 ind/100 m^3), followed by spring (42 ind/100 m^3), summer (30 ind/100 m^3) and winter (31 ind/100 m^3). Numerically, *Euphausia nana* was the dominant species in spring, summer and winter. *Pseudeuphausia sinica* was the predominant one in autumn. Moreover, it was found that the total abundance in summer showed a linear correlation with bottom water temperature and 10 m salinity, while the abundance in the other three seasons did not show a significant correlation with hydrographic factors. The highest abundance area of euphausiids was located in the converging area of the Taiwan warm current and other water masses in autumn. Moreover, it was also found that the high abundance area nearly overlapped the grazing areas of some economic fishes such as *Trichiurus lepturus*, *Scomber japonicus* and *Larimichthys polyactis*, which might be important to form a fishery ground in the East China Sea.

Altogether four numerically dominant species of euphausiids were recorded in the East China Sea, *Euphausia nana* Brinton, *Euphausia pacifica* Hansen, *Pseudeuphausia sinica* Wang and Chen, and *Pseudeuphausia latifrons* (S.O. Sars). The four dominant euphausiids belonged to different ecological groups according to their temperature adaptation. During winter and spring, the euphausiid community was dominated by temperate species including *E. nana* and *E. pacifica*. The number of *E. nana* and *E. pacifica* peaked in spring and winter respectively. These two species had low densities in summer and autumn. The dominant species during the summer and autumn were *P. sinica* and *P. latifrons*, both of which have low densities in the winter and peak in the autumn. Therefore, *P. sinica* and *P. latifrons* are regarded to be sub-tropical or tropical species. They exhibited higher abundances than the temperate ones in the East China Sea. For example, mean densities in autumn were 95.46 ind/100 m^3 for *P. sinica* and 37.77 ind/100 m^3 for *P. latifrons*, while in the spring the annual maximum density of *E. nana* was only 35.55 ind/100 m^3. In the spring, *E. nana* represented up to 85.5% of total species abundance. Sub-tropical and tropical species displayed higher occurrence. However, the index of clumping 1) indicate that temperate species are more aggregative, the highest values were 24.68 for *E. nana* in the summer and 26.05 for *E. pacifica* in the spring, much higher than those for *P. sinica* (13.21 in the summer) and *P. latifrons* (12.62 in the autumn). *P. sinica* is distributed in nearshore waters and tolerates a wide range of temperatures. *P. latifrons* is mainly distributed in the offshore area of the East China Sea and its distribution is highly warm-water-dependent. The two temperate species, *E. nana* and *E. pacifica*, are both halophilic. *E. nana* prefers higher water temperatures and blooms mainly in the south or in the offshore waters. However, the area with high abundance of *E. pacifica* was located much closer to the continental shelf where it has adapted to a lower temperature and salinity than *E. nana*.

Poster WD-P17

The optimal temperature and salinity of pelagic euphausiids in the East China Sea

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Distribution patterns and abundance of the euphausiids were examined in the East China Sea (23°30´–33°00´N, 118°30´–128°00´E), in relation to temperature and salinity. The data were collected in four surveys from 1997 to 2000. The density or yield density model was used to predict optimum temperature and salinity of water for euphausiids occupations, thereafter, distribution patterns of euphausiids were determined based on the predicted parameters. Of 23 species, *Euphausia pacifica*, *E. nana*, *Pseudeuphausia sinica*, and *P. latifrons* were numerically dominant. The analyses indicate that *E. pacifica* is an offshore temperate water species, *E. nana* is an offshore temperate warm water species, *P. sinica* is a coastal subtropical water species, and *P. latifrons* is an oceanic tropical water species. The four species occupied four different water masses respectively, cold water mass, transitional zone where cold and warm water masses are mixed in the winter and spring, transitional zone where cold and warm water masses are mixed in the summer and autumn, as well as warm water. These could be the designator of individual water masses. The predicated optimal temperatures for *E. tenera*, *Stylocheiron carinatum*, *E. diomedeae*, *S. affine*, *Nematoscelis* sp., *N. gracilis*, *N. atlantica*, *Stylocheiron* sp. and *S. suhmii* are all >25°C. These species are mainly distributed in southern Kuroshio in the winter and spring, the Kuroshio, the Taiwan Warm Current and Tsushima Current during the summer and autumn, and the equatorial waters of Pacific Ocean and the eastern waters of Taiwan. They are designated as oceanic tropical water species. *Nematoscelis tenella* and *Thysanopoda tricuspidata* are referred to as offshore subtropical water species according to their geographic distributions, even if they are halobionts. *Euphausia sanzoi* is considered as a typical offshore subtropical water species, which inhabited waters below 25˚C. *Stylocheiron microphthalma*, occupied warm current waters where temperature and salinity is nearly 25˚C, 34 in the summer and autumn, is designated as oceanic tropical water species. In the same way, *E. similes*, *E. mutica*, *Euphausia* sp., *E. brevis* and *E. recurva* are classified into offshore subtropical water species in accordance with the optimum temperature and salinity of waters, as well as locations and seasons of their occurrence. Optimum temperature, rather than salinity is a better parameter in determining the distribution patterns of euphausiids.

WE Biogeochemistry of the oceans in a changing climate

Chairs: Francis Chan and Debby Ianson

Geochemical processes, many of which are linked, are sensitive to global variations in climate forcing and its ocean signals. These processes affect individual marine organisms as well as populations and ecosystem structure. Ocean acidification, hypoxic "dead zones", carbon cycling, nutrient ratios, and methane hydrates are examples of the possible imprint of recent climate change in marine ecosystems. While we have a growing level of evidence – much the result of long-term GLOBEC measurements and research – that climate change is influencing these processes, and that ocean biogeochemistry will be very different under the projected future climate, we lack a comprehensive understanding of the mechanisms linking climate change to these critical ocean processes, and even less understanding of the consequences to marine populations and their ecosystems. Furthermore, most observing programmes are regional and short-term, limiting the prospects of comprehensive long-term monitoring necessary to understand and track future changes in these processes. This workshop will provide an overview of our understanding of the relationship between global climate change and marine biogeochemical processes, and identify the monitoring and research requirements for addressing how these processes will evolve in time and space under the future climate.

22 June, 08:30 (WE-O1 invited)

Widespread high-productivity event observed in the northeast Pacific, August 2008

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Two cruises in the eastern subarctic North Pacific in August and September 2008 observed unusually high productivity for this region. Discrete and continuous measurements of dissolved O_2/Ar supersaturations, a measure of net community production, were two to three times higher than previous measurements in late summer. Gross production rates, as measured with short-term ^{14}C incubations, were three-fold higher than the previous August. The drawdown of both nitrate and silicate from June to August was greater than the 1988–2007 mean from previous summer cruises. Dissolved pCO_2 measured continuously on a mooring at Station P (50°N, 145°W) abruptly decreased by 30 ppm in mid-August 2008 and stayed low. Mesozooplankton biomass, derived from continuous plankton recorder surveys in this region, was higher in August 2008 than previously seen in this month during 2000–2007. Satellite-derived monthly surface chlorophyll showed the highest average values seen in this region since 1997, when SeaWiFS measurements began, and additionally show that the phenomena was widespread over the entire Gulf of Alaska and adjacent subarctic Pacific. High productivity areas are often associated with eddies in this region. However, satellite altimetry and altimetrically derived currents show very low eddy activity during late summer 2008; the widespread nature of the event also argues against eddies as a cause. QuikSCAT winds for the region show that August 2008 was only somewhat windier than average, suggesting that enhanced vertical mixing was not a primary driver. A large-scale iron fertilisation of the region remains a principal hypothesis for this event.

22 June, 09:00 (WE-O2)

Culture bottle studies on the availability of micronutrients to support anthropogenic macronutrient driven photosynthesis in oligotrophic near shore ocean waters

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New primary production in much of the open ocean is believed to be limited by the availability of macronutrients such as nitrogen and phosphorus. An increase in supply of reactive nitrogen and phosphorous to the photic zone could be expected to increase oceanic drawdown of carbon dioxide, provided there are sufficient excess micronutrients (such as iron) available to support the increased phytoplankton biomass. Micronutrient concentration measurements in the open ocean are difficult to perform and require specialised equipment, so we do not have an accurate global understanding of the spatial distribution of micronutrients. The availability of micronutrients to support increased plankton growth can be gauged indirectly at a specific location by performing culture bottle experiments where nitrogen and/or phosphorous are added to collected seawater and the growth of phytoplankton monitored under simulated natural conditions. Oligotrophic sites in the east Pacific Ocean, west Pacific Ocean, Atlantic Ocean, Tasman Sea, and Sulu Sea have been investigated for the potential to increase plankton biomass by the addition of nitrogen and phosphorous. In all experiments, naturally occurring assemblages of phytoplankton collected away from the coast were cultured in simulated natural conditions. Changes in phytoplankton biomass were monitored by estimating chlorophyll-*a* daily with a fluorescence probe. In some cases phytoplankton species analysis were undertaken to examine shifts in community structure. All locations showed an increase in chlorophyll-*a* above control cultures when treated by the addition of nitrogen and phosphorous in the Redfield ratio. Chlorophyll-*a* increase averaged around 1 $\mu g\, L^{-1}$ per µM nitrogen added. The Sulu Sea experiment showed the highest chlorophyll increase per micromole of nitrogen. In all locations treatments of nitrogen alone resulted in a lower chlorophyll yield than those where both nitrogen and phosphorous were added. This result suggests that for the locations sampled a lack of phosphorous prevented further growth in the culture bottles before micronutrients became exhausted. In the Sulu Sea experiment no significant growth compared to the control was observed with the addition of nitrogen alone, this is consistent with previous studies showing no excess phosphorous in the Sulu Sea basin. In the experiments where species composition was monitored, communities exhibited a shift towards diatom domination with the addition of nitrogen and phosphorous. The waters sampled were oligotrophic but within or just beyond the continental margin so silicate is likely to have also been present. Comparable culture bottle experiments reported in the literature have been conducted in the Sargasso Sea and off Baja California in the eastern Pacific. Currently anthropogenic activities add around 89 $Tg\, N\, yr^{-1}$ nitrogen to the ocean surface waters. The limited global region of the ocean-land interface is creating undesirably high nutrient concentrations in shallow coastal regions, causing eutrophication and a host of associated negative environmental impacts. Assuming an efficiency of 90% nitrogen eventually exported, the Redfield ratio suggests a current human induced carbon drawdown of around 1670 $Tg\ CO_2\, yr^{-1}$. Although a very sparse sampling globally, the results of this study suggest that there are sufficient excess micronutrients available in much of the near shore oligotrophic ocean waters to support additional photosynthesis when macro nutrients are introduced. Anthropogenic macro nutrient supply to the oceans is likely to increase in the future as more land is cleared for agriculture, nitrogen production is increased, and the world continues to rely on fossil fuel derived energy. Ocean enrichment with macro nutrients for the purposes of sequestering carbon and increasing wild fish production has been proposed and will also be able to utilise available micronutrient concentrations to promote phytoplankton growth.

22 June, 09:15 (WE-O3)

Regulation of carbon to phytoplankton ratio by light, nutrients and temperature in the equatorial Pacific: a model-data synthesis study

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The relationship between phytoplankton carbon biomass and chlorophyll concentration is non-linear because of the complex influences by light, nutrients and temperature in the euphotic zone. There are big spatio-temporal contrasts in physical and biogeochemical fields in the equatorial Pacific Ocean, suggesting large spatial and temporal variations in phytoplankton carbon to chlorophyll (C:Chl) ratio. Here, we report a model-data synthesis study, aiming to better understand the mechanisms regulating the phytoplankton C:Chl ratio in the equatorial Pacific, a region playing a large role in the global carbon cycle. Our study includes three major parts. First, we use early *in situ* data collected along 180° during October–November 1996 to derive a relationship between the phytoplankton C:Chl ratio and regulating factors (i.e. light, nutrients and temperature), and to tune a basin-scale model to match the observations. We then validate the model by using recent *in situ* C:Chl data collected from

the eastern equatorial Pacific, and by using the ten years of satellite derived surface Chl. Finally, we carry out a sensitivity study to assess the relative roles of light, nutrients and temperature in regulating the phytoplankton C:Chl ratio for different parts of the equatorial Pacific Ocean. Our study demonstrates that combination of nitrate and iron regulates the spatial and temporal variations in the phytoplankton C:Chl ratio. Particularly, nitrate is responsible for the high C:Chl ratio in the western warm pool while iron is responsible for the frontal features in the C:Chl ratio between the warm pool and the upwelling region. In addition, iron plays a dominant role in regulating the spatial and temporal variations of the C:Chl ratio in the central and eastern equatorial Pacific. While temperature has a relatively small effect on the C:Chl ratio, light is primarily responsible for the vertical decrease of phytoplankton C:Chl ratio in the euphotic zone.

22 June, 09:30 (WE-O4 invited)

Can we identify long-term microbial and biogeochemical trends in the eastern North Pacific?

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Marine microbes play a critical role in the control of global biogeochemical cycles and the hospitability of our planet. For this reason, understanding and predicting the response of microbial assemblages to long-term climate trends is a fundamental goal driving present day ecosystem research in marine pelagic environments. In this context, long term time-series programmes are crucial to the characterisation of temporal variability in the composition and function of microbial assemblages. However, interpreting this variability and the derived long-term trends in the context of climate change research presents several challenges due to the spatial and temporal limitations of our sampling strategies. Over the past few decades several long-term monitoring programmes in the eastern North Pacific Ocean, such as CALCOFI, HOT, Line P and the NH line, have generated large physical, biological and chemical datasets that are being used to assess the stability of pelagic ecosystems. In this presentation I will review some of the major findings from these time-series and discuss the extent to which they can be used to predict the biological response of pelagic microbial ecosystems to climate change.

22 June, 10:30

Discussion: biogeochemical observations needs in a changing climate

22 June, 10:45 (WE-O5 invited)

Modelling long term impacts of a changing climate on the biogeochemistry of the global oceans

Andreas **Schmittner**

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Long term projections of climate change impacts on ocean biogeochemistry are currently a challenge. Some responses of the physical climate system are well known, at least qualitatively. Continued increases in atmospheric CO_2 concentrations will undoubtedly lead to more warming of the surface ocean and to increased stratification. This is expected to decrease the vertical exchange between surface and subsurface waters. We also know that the surface ocean will become more acidic. However, the response of the ocean's ecosystem and biogeochemistry to this forcing is much less certain. Increased stratification will lead to reduced nutrient input to the euphotic zone and consequently to reduced export production. Warming, on the other hand, will increase nutrient recycling in the upper ocean and increase primary productivity. How will these opposing effects affect primary production? If global net primary productivity increases this might also increase the alkalinity pump and affect the rain ratio (calcium carbonate over organic carbon export). Models give qualitatively different results on the future evolution of the rain ratio. Acidification will lead to a decrease and warming to an increase. These changes will affect the carbon uptake of the ocean and hence feedback on the climate. What is the ocean carbon cycle - climate feedback? I will present initial results from a new method of fusing ocean biogeochemical tracer observations with models in order to reduce the uncertainty of future projections. Together with structural improvements of ocean ecosystem models this new method is a promising tool to reduce the uncertainty of future projections.

22 June, 11:15 (WE-O6)

Biogeochemical responses and feedbacks to the climate forcing in the tropical Pacific Ocean over the past decades

Xiujun **Wang**, Raghu Murtugudde, Antonio Busalacchi, Dongxiao Zhang and Michael McPhaden

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The tropical Pacific Ocean experienced approximately a 1°C warming post 1977, which is consistent with the phasing of the Pacific Decadal Oscillation (PDO). The oceanic physical changes associated with the PDO shift in 1977 have been reported by McPhaden and Zhang, (2002). As summarised by Mantua and Hare (2002), the 1977 regime shift has had widespread impacts on natural systems. However, little is known about the impacts of the 1977 PDO event on the ocean biogeochemistry in the tropical Pacific. Moreover, largely unknowns also are the possible feedbacks of the tropical Pacific biological and chemical changes to global climate. Here, we employ a basin-scale physical-biogeochemical model to study the responses of tropical Pacific ecosystems, biogeochemistry and carbon cycle to climate change associated with the 1977 PDO event. We compare model simulations of nutrient concentration, phytoplankton biomass, carbon uptake, and sea-to-air CO_2 flux between the 20 years prior to 1977 and the 20 years after 1977. Our results indicate significant changes in physics and biogeochemistry associated with the 1977 PDO shift, including sea surface temperature increase, nutrient concentration decrease, and phytoplankton biomass decline. However, reduction in carbon uptake is smaller relative to the decrease in nutrient concentration, due to phytoplankton photoadaption, which leads to an increased carbon to chlorophyll ratio in the upper euphotic zone. Photoadaption also results in clearer waters near the surface, allowing more solar radiation to penetrate to a depth which enhances sub-surface production and leads to less heating near the ocean surface. Our studies suggest that under a warm climate, the tropical Pacific Ocean releases less CO_2, and absorbs more heat, creating negative feedbacks to the atmosphere.

22 June, 11:30 (WE-O7)

How large will the oceanic ecosystem response to climate change be?

Stephanie **Henson** and Jorge Sarmiento

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Predicting the response of different oceanic ecosystems to climate change is key to understanding how the planet's carbon cycle will be altered by global warming. Using coupled climate models which include biogeochemistry to investigate oceanic primary production response to increased greenhouse gases is now becoming possible. An alternative approach to the coupled models is to develop an 'empirical model', which estimates primary production as a simple function of physical parameters. In this study, we expand this approach by using interannual variability in primary production as an analog for the response of phytoplankton to future climate change. We apply the empirical model to IPCC scenario global warming simulations for the years 2050 and 2090. We then contrast results from the empirical approach to predictions of primary production from three far more complex, mechanistically-based, coupled climate models (NCAR-CCSM, MPI and IPSL models). In general, the predicted change in primary production is considerably less in the coupled models than in the empirical model. Does this suggest that primary production responds more strongly to interannual variability in physical forcing than to long-term, global warming-like, trends? And what do the large differences between models tell us about the possible range of ecosystem responses to global warming?

22 June, 11:45 (WE-O8)

Low oxygen and ocean acidification in the Vancouver Island shelf

Laura **Bianucci**[1] and Ken Denman[2]

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Low oxygen events have been observed in the recent years along the west coast of North America (off Oregon and California). In contrast to other regions where coastal hypoxia is due to anthropogenic eutrophication, the key mechanisms in this region are the advection of oxygen-depleted waters from offshore and the high local biological consumption. When oxygen concentrations become lower than a certain threshold, the ecosystem is severely affected and turns into a 'dead zone'. The two processes that drive oxygen levels down also increase dissolved inorganic carbon (DIC) in the shelf: physical upwelling brings up DIC-rich waters from the deeper ocean, while remineralisation in the shelf breaks organic matter into its inorganic constituents. This DIC increase leads to a pH reduction in the coastal ocean. Hence, there is a link between ocean acidification and hypoxia which has not been explored in depth. These phenomena can deeply affect ecosystems, and under a changing climate where oxygen depletion and pH decline keep progressing, it is crucial to assess how marine ecosystems

will respond to both acidification and hypoxia occurring together. Here we will discuss a model study of the carbon and oxygen coupling on the Vancouver Island shelf, which represents the northern end of the wind-driven upwelling margin off western North America. Although low oxygen events have not been extensively studied in this region, there is some evidence of their occurrence. Moreover, the proximity to an oxygen minimum zone offshore and the observed decline of oxygen in the northeast Pacific provide this shelf with the right conditions to suffer from low-oxygen events. The main focus of this presentation will be on the connection between acidification and hypoxia, and the role of biology versus physics. The model used is the Regional Ocean Modelling System (ROMS) in a quasi-2D configuration of the shelf (across-shore section with uniform properties alongshore). The biogeochemical model has carbon, oxygen, and nitrogen as state variables, and includes cycling of dissolved organic matter. Carbon and oxygen cycles are coupled through ecosystem processes such as photosynthesis and remineralisation, while they are decoupled by other processes (e.g. nitrification and denitrification).

22 June, 12:00 (WE-O9 invited)

Historical and future changes in the Southern Ocean biogeochemical cycling

Richard **Matear**

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The Southern Ocean plays an important role in the earth's climate and biogeochemical cycling. In this talk, I will first review some of the historical changes in the Southern Ocean environment and the associated biogeochemical changes. Second, I will discuss how projected global warming in the Southern Ocean may impact biogeochemical cycling. Finally, I will use simulations from CSIRO Mk3.5 Climate Model to investigate how primary producers in both the southern hemisphere oligotrophic and high nutrient low chlorophyll regions respond to global warming.

22 June, 14:00 (WE-O10)

Ocean biogeochemistry in the enhanced greenhouse

James **Christian**[1,2]

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Global climate change and accumulation of anthropogenic CO_2 are superimposed on a large background of natural interannual and interdecadal variability. Understanding variability requires consideration of anthropogenically induced changes that have occurred throughout the modern era of ocean observation. The Canadian Centre for Climate Modelling and Analysis Earth System Model CanESM1 is a global climate model with fully interactive ocean and terrestrial ecosystem and carbon cycle models. Simulations with CanESM1 illustrate trends in ocean anthropogenic CO_2 accumulation and carbonate undersaturation under anthropogenic forcing including projections of future climate according to IPCC emission scenarios. Substantial shoaling of the calcite and aragonite saturation horizons has already occurred and is likely to accelerate. Global extratropical ocean export production is projected to decline by 5–10% by 2100. Ocean uptake of anthropogenic CO_2 will continue, but will saturate in the next few decades under scenarios of reduced atmospheric CO_2; climate change is beginning to reduce rates of uptake relative to a state with equivalent emissions, but no climate change. Projected decline of CO_2 uptake is particularly rapid in the North Pacific Ocean. Natural CO_2 sinks in the mid-latitude oceans are vulnerable to anthropogenic impacts including dust mobilisation and ocean acidification.

22 June, 14:30

Discussion: biogeochemical modelling challenges in a changing climate

22 June, 14:45

Discussion: workshop synthesis I. ocean biogeochemistry in a changing climate -state of current understanding

22 June, 16:00

Discussion: workshop synthesis II. ocean biogeochemistry in a changing climate -future directions

WF Continuous Plankton Recorder surveys of the global ocean

Chairs: Sonia Batten and Peter Burkill

Continuous Plankton Recorders (CPRs) have been used for many years to sample plankton around the globe: in the North Sea for over 70 years, the North Atlantic for over 50 years, the Southern Ocean since 1991 and 2009 will mark the 10th year of CPR sampling in the North Pacific. These time series have each produced numerous publications and locally important studies. However, the focus is now turning towards global changes and global issues and this is a timely opportunity to discuss complementarity amongst the CPR time series (and with other regional sampling programmes), to highlight the need for consistency in sampling and to identify future directions. Recent advances in technology, analytical and statistical techniques have also broadened the applicability of the sampler and the data it generates. Raising awareness of the surveys, the samples and data available to address global issues would be a desirable outcome of this workshop. The workshop will consist of two sessions of presentations followed by a discussion period in each case to identify complementarities among regions, issues arising and future avenues for study.

The session titles are:

1. Recent results from CPR surveys around the world.
2. Novel approaches, applications and methodologies using CPR samples and data.

Topic 1: Recent results from CPR surveys around the world

22 June, 08:40 (WF-O1)

The North Pacific Continuous Plankton Recorder survey

Sonia **Batten**

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The first routine Continuous Plankton Recorder tows in the North Pacific took place in 2000 and since then sampling has been maintained along two transects providing seasonal sampling between spring and autumn. One transect spans the width of the basin sampling the eastern sub-arctic gyre, southern Bering Sea and western sub-arctic gyre on a great circle route from western North America to Japan. The second transect samples the northeast Pacific from the Strait of Juan de Fuca to Cook Inlet. Without the lengthy time series and extensive archive of the North Atlantic survey, data analysis focused on regional and life history studies but the publications of the first few years have been quite diverse. The dominant climate signal of the region, the Pacific Decadal Oscillation, has switched phase with high frequency over the last decade so that the short time series covers an initial cool period, then a few warm years followed by a return to cool conditions. The lower trophic levels have responded to these switches, evidenced in changes in timing of peak biomass, distribution and community composition changes. This presentation will highlight the achievements of the North Pacific survey and invite discussion on future directions.

22 June, 09:00 (WF-O2)

A new plankton observing programme: the Australian Continuous Plankton Recorder (AusCPR) survey

Anthony Richardson[1], Graham Hosie[2], Frank Coman[1], Claire Davies[1], John **Kitchener**[2], David McLeod[2] and Anita Slotwinski[1]

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Plankton respond rapidly to changes in ocean conditions making them invaluable indicators of ecosystem health and environmental change. Globally, plankton time series have been used as baselines for answering questions concerning effects of climate change, fisheries, eutrophication, pollution and species introductions on marine ecosystems. The largest plankton time observing programme in the world is the Continuous Plankton Recorder (CPR) survey in the North Atlantic, that has collected and counted >210,000 samples from behind commercial vessels since 1938. In the Southern Ocean, the SCAR (Scientific Committee on Antarctic Research) Southern Ocean CPR survey, based at the Australian Antarctic Division (AAD), has been in operation for

19 years, using research and resupply vessels. Building on this experience, the AusCPR survey, a joint project of the Commonwealth Scientific Industrial Research Organisation (CSIRO) and the AAD, has been initiated to develop a CPR survey in Australian waters and beyond as a guide to the health of our oceans. The AusCPR survey is now operational and observing plankton along two routes behind commercial ships: the first from Brisbane to Melbourne, and the second from Hobart to Dumont d'Urville in Antarctica. Details of the AusCPR survey methodology and data from these routes is presented. Challenges of starting the newest CPR survey are discussed, culminating in a list of recommendations for starting such a survey.

22 June, 09:20 (WF-O3)

SCAR Southern Ocean Continuous Plankton Recorder survey

Sonia **Batten**[1] and Graham Hosie[2]

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Antarctic plankton are expected to be particularly sensitive and vulnerable to climate change. Global warming will affect sea ice patterns and plankton distributions. Increased UV levels, ocean acidification, invasive plankton species, pollution and harvesting impacts are also potential major threats. The synergistic effect of any of these threats working in combination is not known. The SCAR SO-CPR Survey was established in 1991 by the Australian Antarctic Division to map the spatial-temporal patterns of zooplankton, and then to use the sensitivity of plankton to environmental change as early warning indicators of the health of the Southern Ocean. It also serves as reference for other monitoring programmes such as CCAMLR's Ecosystem Monitoring Program C-EMP and the developing Southern Ocean Observing System (SOOS). Fourteen countries have participated in the Survey to date, Australia, Japan, Germany, New Zealand, United Kingdom (by SAHFOS and the British Antarctic Survey), USA, Russia, and the South American consortium of Brazil, Uruguay, Argentina, Chile, Peru, Ecuador and Venezuela. This has provided a near circum-Antarctic Survey. France will join in the near future with tows between Hobart and the French station Dumont d'Urville. These tows will also contribute to the new Australian AusCPR Survey. The SO-CPR Survey is supported by the SCAR Expert Group on Continuous Plankton Research, which helps promote and develop the Survey. The Southern Ocean CPRs are towed from research and supply vessels that also collect simultaneously underway environmental data, e.g. sea surface temperature, salinity, fluorometry, light, meteorological observations. The silks are processed in the laboratory by trained plankton taxonomists in Australia, Japan and the UK (SAHFOS). Other centres are being developed in New Zealand and another likely to be established in South America. All plankton in five nautical mile equivalent sections are identified to the lowest possible taxa, usually species, and counted. Antarctic krill and other euphausiids are identified to developmental stage. Plankton counts are combined with averaged environmental data for each 5 nmile section. Approximately 40–50 tows are made each year, although 90 tows were completed in the 2007–2008 International Polar Year for the Census of Antarctic Marine Life. 144,000 nmiles of data have been collected since 1991, producing more than 28,800 samples for 200+ taxa coupled with environmental data. Most data comes from the October to April period. Some winter tows south of Australia have been made. The SO-CPR Survey has already identified two major changes in zooplankton composition in eastern Antarctic waters. The first was in the sea ice zone (SIZ) around the year 2000 when smaller zooplankton became more dominant instead of Antarctic krill. The second change occurred in 2004/05 north of the SIZ when pelagic foraminiferans exceeded 50% of the numerical abundance instead of the 2% long term average, replacing *Oithona* as the dominant species. Such changes in food size and type could have a major impact on the survival of higher predators.

22 June, 09:40 (WF-O4)

Changes in the northwest Atlantic phytoplankton community

Abigail **McQuatters-Gollop** and David Johns

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The Northwest Atlantic is directly impacted by changes in the Arctic; the melting of sea ice has produced modifications in salinity, stratification and circulation, making the region particularly sensitive to climate change. Changes in higher trophic levels such as pelagic and demersal fish and the zooplankton community have received ample attention. However, although phytoplankton are sensitive to changes in their environment and alterations in their abundance and composition are likely to impact higher trophic levels, relatively little is known about changes in the structure of the northwest Atlantic phytoplankton community. Recent work has focused on a number of individual phytoplankton species, most notably the trans-Arctic migration of the Pacific diatom *Neodenticula seminae*, which is now an established member of the North Atlantic phytoplankton community, and an increase in arctic/boreal dinoflagellates. Here we examine data from the Continuous Plankton Recorder in

order to further explore changes in species composition and abundance of the northwest Atlantic phytoplankton community during the time periods 1962–1978 and 1991–2007. Changes in distribution of key phytoplankton components are spatially analysed and discussed in relation to variations in thermohaline circulation, sea surface temperature and salinity of this hydrographically complex region.

22 June, 10:30 (WF-O5)

Response of northwest Atlantic plankton communities to freshwater anomalies

Andrew **Pershing**[1], Charles Greene[2] and Erica Head[3]

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The Gulf of Maine ecosystem underwent a dramatic reorganisation in 1990. At the heart of this reorganisation was a strong bottom-up chain that included increased autumn phytoplankton abundance, increased small copepod abundance, especially in autumn-winter, and decreased abundance of *Calanus finmarchicus*. The phytoplankton changes were associated with reduced salinity and likely increased autumn stratification. The salinity changes were part of a broader pattern of freshening extending upstream to the Labrador Sea. Many of the copepod taxa that responded strongly to the 1990s salinity changes in the Gulf of Maine exhibited similar changes along the entire northwest Atlantic Shelf. The link between salinity anomalies derived from higher latitudes and food chain reorganisations downstream provides new insights into the future responses of marine ecosystems to remote hydrographic forcing associated with climate change.

22 June, 10:50 (WF-O6)

Spatio-temporal shift in the plankton trophic interactions in the North Sea over the last 50 years

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Traditionally, marine ecosystem structure was thought to be bottom-up controlled, although there were also a few examples of top-down regulation. Evidence is accumulating that the type of trophic forcing varies temporally and spatially and an integrated view is emerging. Correlations between multidecadal time series of the abundances of adjacent trophic levels are conventionally used to assess the type of control: bottom-up if the correlation is positive or top-down if this is negative. However, this approach implies assuming that there is no temporal change in the type of trophic regulation over time and therefore can hide part of this temporal variability. Using spatially-referenced phyto- and zooplankton biomass extracted from the Continuous Plankton Recorder, this study addresses the potential dynamic character of trophic structure at the planktonic level in the North Sea, usually considered to be bottom-up. By using a novel spatio-temporal statistical approach, which allows for non-additive dynamics, we show that the type of relationship between phytoplankton and zooplankton might have shifted from a positive relationship to a negative one. Moreover, the new regime would be characterised by a spatial component.

22 June, 11:10 (WF-O7)

A vision for a global Continuous Plankton Recorder survey integrated with single site and other ocean observing programmes

Philip **Reid**

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The Continuous Plankton Recorder (CPR) methodology has been used extensively throughout the world since the deployment of the Type I machine in the Southern Ocean as part of the Discovery Expedition to Antarctica in the 1920s. Subsequently deployed as a ship-of-opportunity sampling system for the plankton, well over 5 million miles of transects by commercial ships have been traversed by Type II machines since 1931. Tows have been made in almost all the major ocean basins of the world with more than 500 taxa of phytoplankton and zooplankton identified and counted on substantially more than 200,000 analysed samples. Surveys are currently operational in the North Atlantic, North Pacific, Southern Ocean and in waters close to Australia and New Zealand with others in the planning stage. The plankton are a crucial component of the Earth's biosphere, providing the food for almost all life in the oceans and play a major role in climate change through the transfer of large quantities of CO_2

to the deep ocean by a process known as the biological pump. They have also proved to be excellent indicators of change in the oceans, recording patterns of spatial and temporal change often before they are measured by other physical or chemical means. Given their importance the development and implementation of an integrated and appropriately funded observation programme to sample the plankton is urgently needed. This programme needs to be backed up by research to help understand processes. Existing and new CPR programmes should be used as a template to provide basin wide network coverage for other traditional and new plankton sampling and analysing technologies. Standardised protocols (where possible) and quality control procedures also need to be put in place. A vision will be outlined placed in the context of global patterns of change and exemplars from past research in all CPR programmes currently operating. Reference will be made to plans for the new SCOR/IAPSO OceanScope working group where some of the ideas presented will be discussed. It is hoped that final authorship of the presentation will include representatives from all current surveys.

22 June, 11:40

Discussion

Topic 2: Novel approaches, applications and methodologies using CPR samples and data

22 June, 14:00 (WF-O8)

SAHFOS-US NOAA Fisheries CPR Surveys: comparison of methods and data

Jack **Jossi**

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The Northeast United States CPR Survey, managed by the US National Oceanic and Atmospheric Administration's (NOAA) Fisheries has sampled four routes: Boston to Nova Scotia (1961–present); New York towards Bermuda (1976–present); Narragansett Bay–Mount Hope Bay–Rhode Island Sound (1998–present); and eastward of Chesapeake Bay (1974–1980). NOAA's involvement began in 1974 when we assumed management of the Edinburgh Oceanographic Laboratory's Boston to Nova Scotia route. Training, equipment, and computer software were provided to ensure continuity of methods and for anticipated new CPR routes off the northeast coast of the United States. Data for the first fourteen years of the route were provided to us and added to databases of our design. In the subsequent decades, several site visits by staff of both our laboratory and the Oceanographic Laboratory's successor, SAHFOS, have taken place for the purpose of verifying the continuity of standards. These visits revealed several inconsistencies that largely have been corrected. Beginning in 2006, methods and data comparability between surveys were more thoroughly examined. Thus far, indications are that our collection methods; sample processing; and sample identification, staging, and counting techniques are mostly consistent with those of SAHFOS. One exception was a departure from phytoplankton counting standards for a finite period in the middle of two of our time series. A correction for this departure has been developed, but not yet applied. An additional issue, although not directly inconsistent, is taxonomic and life stage names, and their consistent, or inconsistent use through the history of a CPR route. To address this issue, we have developed a cross reference table containing SAHFOS ID, our taxonomic code, our life stage code, NODC taxonomic code, ITIS serial number and authority, and consistent taxa/stage time series by route. This table has yet to be reviewed externally, but was essential when adding SAHFOS's route Eb data to our database. Further, our database does not contain occurrences of an organism observed but not counted during the routine analyses (pluses). Quality controlled acsii files containing these data exist and are being used to correct this oversight. In anticipation of increased CPR data exchange we have developed software for reading SAHFOS data and writing our database records, and vice versa.

22 June, 14:20 (WF-O9)

Mesh size and type: CPR experiments and comparisons in the Baltic Sea

Juha **Flinkman**[1], Tony Walne[2] and Joh Sidey[2]

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In order to design an adequate CPR survey for the Baltic Sea, the characteristics of its zooplankton communities must be taken into account. For instance, mesozooplankton in the Baltic Sea is generally of a much smaller size than in adjacent areas like the North Sea. Furthermore, since the CPR survey has not so far covered the Baltic Sea, equipment different from original SAHFOS concept can be used without causing problems to consistency

of the data. In order to determine the correct mesh size and type to use for the CPR surveys in the Baltic Sea, we experimented with different mesh sizes and CPR-type plankton sampling devices, and made comparisons to vertical WP-2 nets. We compared 1) simultaneously towed CPR loaded with 280 µm silk mesh to a Utow equipped with a Valeport mechanism loaded 200 µm nylon mesh, and 2) WP-2/100 µm vertical net samples to samples obtained by a CPR equipped with Chelsea mechanism and 100 µm nylon mesh towed before and after net samplings. Our findings were: 1) original 280 µm silk mesh has too large apertures for Baltic plankton 2) mesh aperture size together with weave type and thickness determine the actual catching and filtering capacities 3) Baltic zooplankton are vertically stratified especially in relation to the summer thermocline, hence even relatively small differences in towing depth affect species diversity in the samples. We discuss the effects of mesh type and size to actual filtering capacity, as well as the significance of towing depth to species diversity in the samples. To further enhance CPR type plankton surveys, we discuss the advantage of developing a robust flow meter for the filtering mechanism, and ship of opportunity type undulating towed vehicle.

22 June, 14:40 (WF-O10)

Quality vs. quantity: reductions in taxonomic resolution as a means to merge disparate plankton data sets for enhanced spatial and temporal coverage

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One of the difficulties in tackling the impacts of global scale environmental change on pelagic ecosystems is the non-compatibility of regional data sets and paucity of long-term data sets. There are few plankton monitoring programmes that have been running for more than four decades, e.g. the UK-based CPR survey and CALCOFI. In Antarctica, Japan has maintained a routine though low resolution sampling programme using NORPAC nets on route to and from the Japanese station Syowa since 1972. Since 1991, the spatial coverage of Southern Ocean sampling has been substantially increased by the growth of a southern CPR survey. A means to create global databases and overcome the problem of few long-term data sets is through merging of historical surveys. This is hampered by differences in the taxonomic resolution applied by analysts, and between study variation in taxon specific densities and frequencies related to the application of different net types with different sampling efficiencies. However, it has been demonstrated that in the absence of preferred species level data, low taxonomic resolution plankton data can be effectively applied in ocean basin scale biogeographic studies. Here, we discuss the reduction of data sets to lower taxonomic levels as a means to amalgamate data sets composed at different taxonomic resolutions, and collected with different sampling apparatus, and hence enable the post hoc production of time series for the investigation of large spatial and temporal scale change. In particular we focus on the comparability with and between CPR surveys.

22 June, 15:00 (WF-O11)

The endless summer revisited: climate, macro-ecology, and seabird-plankton associations within and across the North Pacific

William **Sydeman**[1], Jarrod Santora[1], Sonia Batten[2], Mike Henry[3] and Ken Morgan[4]

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In temperate to sub-Arctic oceans, the seasonal cycle is one of the strongest forces influencing the timing and magnitude of primary to tertiary productivity, and macro-scale changes in the distribution of top predators. Seabirds are highly mobile predators, capable of rapid, long-distance (>10,000 km) movements in search of adequate prey resources. Many southern hemisphere seabirds migrate to the North Pacific during their austral winter to maintain foraging in a productive “endless summer” of environmental conditions. For example, it is well known that shearwaters (migrating from Australia, New Zealand and the sub-Antarctic) occur in vast numbers (sometimes >1 M birds) in proximity to Unimak Pass, AK, apparently to forage on zooplankton (euphausiid crustacean, *Neocalanus* copepods) swarms in the region at that time. Although this “hotspot” of predator-prey dynamics has been well documented, very little is known about interannual variability and the persistence of hotspots elsewhere in the North Pacific or during autumn and winter. Herein, we investigate seasonal and spatial variability of seabird-zooplankton hotspots by using data collected during the PICES North Pacific Continuous Plankton Recorder (CPR) and Canadian Line P projects during 2002–2007 over three seasons. Visual surveys

of seabirds were conducted simultaneously while the vessel towed a CPR, or zooplankton were sampled using acoustics or nets. We use a combination of GIS, kernel density estimates of zooplankton and predator distributions, and models of spatial associations to address: 1) Are there, and where are the seasonal ‘hotspots’ located? 2) What are the spatial relationships between seabirds and zooplankton within ‘hotspots’, regionally and over macro-scales? 3) What are the implications of seasonal ‘hotspots’ to assessing the impacts of climate change on ecosystem dynamics, and in relation to spatial fisheries and place-based management?

22 June, 16:00

Discussion

WG Cod and climate change: the past, the present and future challenges

Chairs: Øyvind Fiksen, Jeff Runge and Fritz Köster

This workshop will include an invited presentation summarising the state of the art within the field before the formation of the Working Group on Cod and Climate Change (WGCCC), several presentations on knowledge gained within the programme, and a summary and discussion session on questions for future research.

The presentations on knowledge gained during the programme will include:

- Results of comparative analyses (across cod stocks, geographical areas and with other species, e.g. pollock or Pacific cod) on growth, recruitment, distribution and processes important for early life stages and adults.
- Advances in modelling, e.g. hierarchy of models.
- Effects on stock assessment and management, implications on policy.

Discussions among Cod and Climate Change scientists and feedback from colleagues working on other systems will be very helpful towards steering future work on climate effects on fish stocks in the ICES area in the most fruitful direction.

22 June, 09:00

Introduction to workshop

22 June, 09:10 (WG-O1 invited)

History and summary of CCC related activities

Keith **Brander**

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The CCC programme began in 1989 when ICES approved a Study Group on Cod Stock Fluctuations. This was the forerunner for the GLOBEC programme. A major symposium in 1993 provides a benchmark against which progress over the last 15 years can be evaluated. The principal activities were conducted via a series of workshops and theme sessions, which produced many publications and catalysed national and regional research programmes. There has been a strong emphasis on breadth of scientific input, construction and analysis of long physical and biological time series, coupled physical and biological modelling, comparative studies across all ecosystems in which cod occur, assessment of climate impacts and application of results in fisheries and marine ecosystem management. Process studies were not neglected and a number of major advances in our understanding of recruitment, growth, mortality and distribution emerged and are being assimilated in the mainstream of marine ecology. Although CCC has remained very close to the original aims of the programme over the past two decades, three fundamental changes have shaped its evolution. The first is that our perception of the “recruitment problem” and what constitutes a solution to it in fisheries has changed. The second is that our perception of “Climate” in the title has shifted from being mainly concerned with interannual to decadal environmental variability to being mainly concerned with anthropogenic climate change. The third is that the dominance of the single species “book-keeping” approach to fish population assessment, which excludes everything except internal population characteristics, is gradually giving way to a view that the rest of the ecosystem and the environment also need to be included. The lasting legacy of CCC can be viewed in terms of the symposia, workshop reports and publications which can be attributed to it. However its influence on the development of individual, national and regional marine science programmes is more difficult to measure and record. It has been an intellectual nursery area for many active marine scientists who continue to develop the underpinning research agenda and to apply the knowledge gained in relation to current concerns over management of marine ecosystems and global environmental change.

22 June, 10:30 (WG-O2 invited)

Retrospective studies: time series analyses of cod and climate

Geir **Ottersen**

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Retrospective analysis, “learning about the future by studying the past” is one of the main approaches applied by the Cod and Climate Change group (CCC). In this talk I will, through examples, review time series oriented statistical analyses and other data driven work within the CCC framework. The examples shown will span the North Atlantic, relating to single-stock analyses from different regions, but I will also show results of comparative

analyses across stocks and geographical areas. The focus will be on how variability in climate and regional environment affects the cod stocks. Several of the studies I draw upon deal with recruitment and survival through early life stages, but the environment also affects the fish at later immature and mature stages, not least through affecting growth and distribution, and also this will be exemplified. Finally I will touch upon some methodological issues relating to studies of ecological responses to an environmental signal.

22 June, 11:00 (WG-O3)

Cod recruitment and climate change: a comparative approach

Friedrich W. **Köster**[1], Michael J. Fogarty[1], Karin Hüssy[2] and Margit Eero[1]

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The present contribution reviews progress made during the Cod and Climate Change programme with respect to our understanding how climate change affects cod recruitment, considering as well other natural and anthropogenic factors. First it follows conceptually the developmental success of a year-class during ontogeny from spawner abundance through the egg and larval to the juvenile stage. Secondly, it identifies critical life stages in reproductive success and the processes affecting these life stages for different environments, contrasting northern (e.g. Labrador/Newfoundland and north east Arctic) and southern stocks (e.g. Georges Bank and North Sea), as well as marine and estuarine stocks (i.e. the Baltic and the Gulf of St. Lawrence). Based on this comparative review, variables and proxies representing major processes affecting critical early life stages of cod are discussed.

22 June, 11:30 (WG-O4 invited)

Cod and climate change in the Baltic Sea

Christian **Möllmann**

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Eastern Baltic cod (*Gadus morhua callarias*) experienced a similar catastrophic decline as many cod stocks in the world ocean, and remained constantly below safe biological limits during most of the recent two decades. While a non sustainable fishing pressure was a major reason behind the collapse and the lack of recovery, climate-induced changes in the physical oceanography of the Baltic Sea were a major driver as well. Unlike other cod stocks, Eastern Baltic cod did not primarily suffer from changed temperature conditions, but rather was affected by lowered salinity and oxygen conditions causing high egg and larval mortality. The collapse of the stock was furthermore embedded in a major climate-related reorganisation of the whole food web, an ecosystem regime shift with species dominance changes on all trophic levels. Here I first review the different direct and indirect effects of climate-induced changes in the physical oceanography negatively affecting eastern Baltic cod recruitment. Secondly, I will discuss the importance of overfishing for the ecosystem reorganisation and the negative feedbacks the regime shift potentially had on cod stock recovery. Eventually, I present an attempt to forecast the potential future of eastern Baltic cod using an ensemble of different single- and multispecies models as well as a full food web model. These model simulations are forced by different climate change scenarios and are intended to explore future management approaches for a sustainable future of this commercially important fish stock.

22 June, 12:00 (WG-O5)

Parallel adaptive evolution in Atlantic cod in response to ocean temperature

Ian **Bradbury**[1], Sophie Hubert[2], Brent Higgins[2], Sharen Bowman[2], Ian Paterson[1], Paul Snelgrove[3], Corey Morris[4], David Hardie[1], Jeff Hutchings[1] and Paul Bentzen[1]

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Understanding the genetic basis of adaptive evolution is paramount to the conservation of wild populations. Uncertainties regarding the geographic scale of population structuring and the short-term evolutionary dynamics have undoubtedly contributed to the failure of many marine fishes to recover from unprecedented collapses. Atlantic cod, *Gadus morhua*, is historically one of the most exploited and studied marine species; however both the scale of adaptive variation and the genetic basis for population-specific adaptive responses remain largely

unknown. Here we document fine-scale adaptive differentiation in a broadcast spawning of marine fish, and show evidence for the parallel adaptive evolution of cod inhabiting either side of the Atlantic in response to ocean temperature. We identify a subset of independent gene-associated polymorphisms for which allele frequencies show parallel temperature associated clines on either side of the Atlantic, and test positive for signatures of selection. The results are consistent with parallel adaptive co-evolution of multiple genes in response to gradients in ocean temperature. These results document the presence of small-scale local adaptation despite high dispersal potential; and for the first time provide a basis for the spatial management of a marine species based on its adaptive landscape.

22 June, 14:00 (WG-O6)

How does the global warming impact the Gulf of Maine and Georges Bank ecosystem? A retrospective analysis of the climate change in the past 30 years

Brian J. **Rothschild**[1], Changsheng Chen[1], Song Hu[2], Robert C. Beardsley[3], Yue Jiao[1] and Emily F. Keiley[1]

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The surface heat flux over the Gulf of Maine (GoM)/Georges Bank (GB) region from 1978 to present was reconstructed using a high-resolution meso-scale meteorological model with data assimilation. The net annual flux indicates that the global warming has led to a warming trend near the coast and over GB, Nantucket Shoal, and the Nova Scotia shelf. A simple heat balance box model suggests that the average water temperature in the GoM bounded by a 200 m isobath increased dramatically in the past 30 years because of climate-induced local warming. This result contrasts with long-term sea-surface water temperature measurements from NOAA buoys in the GoM, which shows a cooling trend off of GB during the past 30 years. An analysis was made to link the GoM to the upstream Labrador Sea and Arctic Ocean. The cooling trend is coherent with decreasing ice coverage in the Arctic Ocean. Our analysis is that the impact of the Arctic Ocean and Labrador Sea climates on the GoM has significantly increased. This upstream effect is much stronger than the change of heat flux due to the climate-induced local weather change. This index should be taken into account in the study of the interannual and long-term variability of fisheries stocks over the Scotian and New England shelves. The evidence to support our argument will be presented in this paper.

22 June, 14:20 (WG-O7)

Understanding climate impacts on the spatial dynamics of Atlantic cod in coastal waters of the Gulf of Maine

Jeffrey **Runge**[1], Adrienne Kovach[2], Rebecca Jones[1], Shelly Tallack[1], James Churchill[3], Changsheng Chen[4], Graham Sherwood[1], Hunt Howell[2], Jonathan Grabowski[1] and David Berlinsky[2]

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We put forward a combined observing and modelling strategy for forecasting effects of climate change on the dynamics of spatially structured cod populations spawning in the western Gulf of Maine. Present understanding indicates at least two genetically differentiated complexes: a late-spring spawning, coastal population centred in Ipswich Bay and a population that spawns in winter inshore and on nearshore banks in the Gulf of Maine and off southern New England. The two populations likely diverge in trophic interactions and physiological and behavioural responses to different winter and spring environments. Coupled physical-biological modelling has advanced to the point where forecasting of environmental conditions for recruitment into each of the two populations is feasible, backed by hydrographic, primary production and zooplankton data collected by local remote sensing and fixed station sampling. Forecasts of environmental influences of dispersal and growth of planktonic early life stages, combined with understanding of possible population-specific usage of coastal habitat by juveniles and differential resident and migratory patterns of adults can be used to develop scenarios for spatially explicit population responses to multiple forcings, including climate change, anthropogenic impacts on nearshore juvenile habitat and management interventions such as regional fisheries closures.

22 June, 14:40 (WG-O8)

Cod size-at-age: disentangling effects of climate and fishing

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Fish growth is affected by variations in a number of factors including temperature, food consumption and size-selective fishing. The effects of these factors on resulting size-at-age variation must be disentangled to allow for the development of successful management strategies. Here we examine the various factors affecting size-at-age in southern Gulf of St. Lawrence Atlantic cod (*Gadus morhua*) where a significant decline in size-at-ages is observed over the past 30 years; a decline that is coincident with high fishing pressure and changing environmental conditions. We employ an integrated temperature metric (growing degree-days) and disentangle the effects of temperature, food consumption and size-selective fishing on size-at-age among years and year-classes over the three-decade period. We conclude the declines are most parsimoniously explained by size-selective fishing, consistent with other studies using different methods, and coincident with another gadoid populations in the North Atlantic (haddock, *Melanogrammus aeglefinus*). We further demonstrate that subtle changes in climate may have a large effect on fish size-at-age, something that is not easily predicted using the various extant fish-growth models.

22 June, 15:00 (WG-O9)

Factors determining growth and survival in the early life stages of North Atlantic cod: a comparative study between the NW Atlantic and Norwegian Sea ecosystems

Trond **Kristiansen**[1], Frode Vikebø[2], Gregory Lough[3], Svein Sundby[2] and Francisco Werner[4]

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Growth and survival in early life stages of cod are highly affected by environmental conditions such as temperature and light. Variations in these environmental properties create differential survival conditions between years and habitats. However, we do not understand how the strong latitudinal gradients of light and temperature create differences in the biology of larval cod. We present a comparative study between the latitudinal extreme nursery grounds of larval cod located at Georges Bank (42°N) and Lofoten in the Norwegian Sea (68°N). We applied an individual based model (IBM) to simulate the early life history of cod within these areas and between years to test for differences in larval cod growth rates. The model is forced with modelled light, idealised prey fields, and observed temperature profiles at selected locations and years during spring seasons. We found that the light and temperature regimes of ecosystems explain differences in the life history of cod populations including the timing of spawning.

22 June, 16:00

Perspective summaries and general discussion: future of CCC research

Brain **Rothschild**[1] and Svein **Sundby**[2]

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WH Plankton phenology and life history in a changing climate: observation and modelling

Chairs: Rubao Ji, Dave Mackas and Martin Edwards

Phenology, the study of annually recurring biological phenomena in relation to climate conditions, is particularly useful in examining the system responses to major external disturbances. Such studies have been conducted extensively in terrestrial and freshwater systems, and have begun to receive attention in coastal and open ocean systems. Increasingly available datasets from GLOBEC and other related programmes have revealed phenological changes in many aspects of plankton dynamics, including the timing and magnitude of phytoplankton blooms and zooplankton biomass peaks, species composition of plankton communities, as well as physiological and reproductive responses. Empirical analyses and quantitative modelling approaches have been used to identify and understand the underlying forcings that drive phenological shifts.

This workshop will bring together studies from various GLOBEC research sites around the world that contribute to 1) valuations of plankton phenological and life history changes in different ecosystems using existing datasets and/or models; 2) providing observational and/or theoretical approaches for identifying phenological changes over a range of temporal and spatial scales and underlying biological and physical driving forcings; 3) examining the linkages between phenological changes in lower and higher trophic levels including fisheries; 4) new statistical approaches to quantifying trophic mismatch; 5) providing evidence for phenotypic plasticity and potential adaptation of marine organisms to climate change impacts; and 6) reviewing/discussing current status and future observation/modelling needs for plankton phenological studies.

23 June, 08:30 (WH-O1)

Changing seasonal timing of zooplankton populations, and their link to ocean climate

David **Mackas**[1], Wulf Greve[2], Martin Edwards[3], Sanae Chiba[4], Sonia Batten[5], Anthony Richardson[6], Kazuaki Tadokoro[7], Alessandra Conversi[8], Damien Eloire[9], Gregory Beaugrand[10] and Catherine Johnson[11]

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The short life span (weeks to a year) of most mesozooplankton allows their population size to respond rapidly to interannual environmental changes, but also usually leads to large within-year cycles of abundance, biomass, species composition, and/or age structure within species. In any given region, the pattern of zooplankton seasonality is approximately periodic and repetitive from year to year. However details of seasonal phasing and amplitude are often highly sensitive to interannual differences in environmental conditions. The resulting potential for timing match-mismatch between prey and predators makes this an ecologically important and interesting signal, which can be tracked by either population size or age-stage structure. Several recent studies have found year-to-year differences of one to several months in the timing of the one-to-two-month-wide annual peak of abundance and biomass. Compared to phenologic shifts seen in other taxa (e.g. bird reproduction, plant flowering, insect dormancy), the zooplankton timing shifts are large in time units, and extremely large relative to normal life cycle duration. Zooplankton timing variability is often strongly linked to, and predictable from, temperature anomalies during the current or previous growing season. However, temperature-timing regressions differ among species, functional groups, and locations, leading to different amounts of timing offset for a given temperature perturbation. High latitude and ‘spring’ species tend to have earlier seasonal maxima in years when temperatures are higher. But some subtropical and ‘fall bloom’ species show the opposite pattern–later maxima when temperatures are higher, suggesting that their population responses track autumn cooling and destratification rather than spring warming and stratification.

23 June, 09:00 (WH-O2)

Assessing critical windows for the development of zooplankton populations

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A foremost question at the centre of the current debate on climate change is the impact that changes in climate patterns could have on the timing of ecological events and the functioning of marine ecosystems. In the northwestern Mediterranean the interannual variability of zooplankton integrates the climate-related changes and close correlations between climate and the timing of ecological events have been detected. We illustrate that the sensitivity of particular species of copepods and gelatinous carnivores to environmental forcing relates to their seasonal appearance and peak of abundance. Our results highlight the occurrence of critical windows during which plankton species are more sensitive to environmental conditions, and favourable conditions may substantially enhance or depress their annual peaks. In addition, we identified threshold values from which climate effects on the timing of zooplankton species become noticeable, indicating that the climate–phenology relationship evolves according to the strength of climate forcing.

23 June, 09:15 (WH-O3)

Population structure and life cycle of *Calanus hyperboreus* in western Arctic in summer

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Calanus hyperboreus is a large calanoid copepod in arctic waters and areas of the sub-arctic Atlantic under the influence of southward advection of water of arctic origins. Population abundance, structure and prosome length of older stages of the Arctic copepod *C. hyperboreus*, as well as its geographical distribution, was investigated in the Chukchi Sea, Chukchi Plateau, and Canadian Basin in summer, 2003. *C. hyperboreus* was absent from the shallow areas of Chukchi Sea. Early stages (CI-III) were found in the north of Chukchi Sea, where water depth was quite deep, but no individuals elder than CIII was observed. All stages were captured in deep areas of both Chukchi Plateau and Canadian Basin. Size frequency distribution of prosome length of CIIII, CIV, CV and adult females were all normal, and no overlap was observed among different developmental stages. Life cycle of *C. hyperboreus* in the western Arctic Ocean was suggested at least four years, much longer than temperate and other smaller arctic calanoid copepods. Prolonged life cycle is suggested the most important factor limiting its geographical distribution in the western Arctic. Though early stages were found in north Chukchi Sea, no over-winter population was observed in such a shallow area. As ice coverage decreased from global warming, it can potentially invade into the productive Chukchi Sea area, and shorten its life cycle predominantly.

23 June, 09:30 (WH-O4)

Long-term zooplankton dynamics and environment in the White Sea since 1957

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Continuous observations on the zooplankton community and major hydrological parameters (temperature, salinity) have been held since 1957 at the monitoring station D-1 (65 m depth; 66°19'50''N, 33°40'06''E; Chupa Inlet, Kandalaksha Bay, the White Sea). Samples are taken with a ten day periodicity during the ice free season and monthly from ice. A Juday net (mesh size 170–200 μm, mouth diameter 36 cm) was used for zooplankton sampling and conductometers and reversing thermometers for salinity and temperature measurements. The data set of all zooplankton species abundance (for standard water layers: 0–10, 10–25 and 25–65 m) and data on temperature and salinity at standard depths (0, 5, 10, 15, 25, 50 and 65 m) were combined in one database. There were only minor breaks in observations in 1972 and in 1992–1997. The periodicity and continuity of the investigations are sufficient to analyse seasonal regularities in the zooplankton and to reconstruct life cycles of planktonic animals. The long-term changes of zooplankton abundance (year-to-year fluctuations, trends, cyclicity and correlation with environmental factors) can be also detected with great reliability. The zooplankton abundance demonstrates strong variability from year to year, reaching up to several orders of magnitude in specific cases. However, the abundance of key species usually restores rather quickly, only in some anomalous conditions (in extremely cold years 1966, 1969 and 1971) intensity of changes were so profound that it took more than one year for the

community to return to the average state. The coldest year of 1966 was characterised by low air temperatures and stable eastern winds, that kept ice in inlets of Kandalaksha Bay till July, which was absolutely anomalous. Such combination of conditions caused a significant decrease of total zooplankton abundance and biomass not only in 1966, but also negatively impacted the abundance of some warm-water animals in the following year. At the same time extremely warm years had no significant effect on the zooplankton community. Smoothing (5-year moving average) of time series revealed rather prolonged fluctuations of abundance, biomass, temperature and salinity with a period length of five to ten years. The long-term trends of the hydrological parameters were also observed. Thus, yearly temperatures in the 0–65 m layer in the decade of 1998–2007 increased by 1°C (from 1.5 to 2.5°C) and salinity decreased by 1‰ (from 27.4 to 26.6‰) compared to the period 1964–1976; all changes were significant (Mann-Witney U-test, $p = 0.05$). Abundance of different species of planktonic animals also demonstrates various trends, but only in a few cases this parameter correlates significantly to temperature and salinity dynamics. Thus, zooplankton community structure in the White Sea is quite sensitive to anomalous environmental events, but not sensitive to the same extent to long-term trends in hydrological variables. However, the zooplankton community demonstrates the ability to return to its normal state in a few years even in extreme conditions.

23 June, 09:45 (WH-O5)

Phenology as part of life-history strategies: annual routines of zooplankton

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In seasonal environments, timing of life-history events in the annual cycle links directly to individual fitness. Changes in one part of a life cycle, such as the phenology of life history decisions, may also change the optimal organisation of other activities over the year. Consequently, single life-history decisions, or single annual events, such as timing of egg production, energy storage, or seasonal migrations, should not be studied in isolation. A life-cycle perspective is therefore needed when predicting and understanding phenological changes. Here I present predictions from a zooplankton life-history model and show how optimal annual-routines change in response to phenological changes in food availability or predation risk. The modelled scenario is that of a high-latitude herbivorous copepod with winter diapause and extensive energy storage as part of its life cycle. Predictions from the model may serve as advice on how to analyse and interpret available time series on plankton phenology and which variables to measure in future field studies. I also discuss how proximate triggers behind life-history decisions, such as the triggers behind seasonal migrations, may differ in their ability to let the organism respond to ecological changes of importance, such as phenological changes in the food. Finally, I present data on zooplankton phenology from the highly seasonal oceans and fjords of the Arctic, a region where climate change results in rapid changes of the marine environment, particularly due to changes in sea-ice dynamics.

23 June, 10:30 (WH-O6)

Why doesn't *Calanus marshallae* live in the Atlantic: a comparison across the copepod genus *Calanus*' physiological rates with implications for mortality rates under climate variability

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In the northeast Pacific, *Calanus marshallae* and *C. pacificus* often dominate the coastal copepod community, whereas, *C. finmarchicus* and *C. helgolandicus* are the dominant forms in the North Atlantic. These copepods are critical prey sources for the larvae of many economically important fish species, small pelagic fish species, other invertebrates, and sometimes marine mammals. *C. pacificus* and *C. helgolandicus* are typically found in regions of warmer water, whereas *C. finmarchicus* and *C. marshallae*, are found in colder water, although there is some overlap in the species pairs. Although all four species share many similarities, each has distinct responses to temperature in their growth and development rates, which may control their success within the different habitats. For example, *C. marshallae* has the slowest developmental rate at a given temperature, due largely to a much longer C5 stage duration than the other species. Thus, this species theoretically faces higher sum mortality before reaching a reproductive state. *C. marshallae* also has the highest developmental rate Q10 (3.02), compared to *C. finmarchicus* (2.83), *C. pacificus* (2.56) and *C. helgolandicus* (2.51). On a temperature-

corrected stage-by-stage view, *C. pacificus* has some stages with durations similar to *C. marshallae*, and others more similar to *C. helgolandicus*, with the end result that total duration to adult is surprisingly most similar to *C. finmarchicus*, although the growth rates of *C. pacificus* are mostly lower than *C. finmarchicus*. *C. finmarchicus* has the shortest total duration to adult at low temperatures, presumably being more "cold-adapted" than the other species, thus giving it a way to reach maturity faster and avoid mortality in the cold regions in which it dominates. These examples, along with other trends in the developmental and growth rates of these species as a function of temperature, will be discussed, stressing the implications of species differences on their susceptibility to mortality and predation in the face of climate variability, with particular attention to how these parameters affect the construction of individual-based models.

23 June, 10:45 (WH-O7)

Regional variability in copepod phenology: application of a new individual-based model and implications for a changing climate

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The copepod *Calanus finmarchicus* plays key ecological roles linking primary production and higher trophic levels throughout the North Atlantic. *C. finmarchicus* dynamics and production are affected by temperature and food, such that the overall effects of environmental variability may be multiplicative or mitigating. Without realistic modelling, it is difficult to disentangle the relative influence of different environmental factors or predict responses of different populations to climate change. Here we employ a new stage-based model of individuals to investigate how environmentally dependent life history may result in regional differences in phenology among populations. The model is forced by regional temperature and chlorophyll data and includes results from GLOBEC studies to characterise relationships of temperature and food effects on development, mortality and egg production rates. We simulate dynamics of two northwest Atlantic *C. finmarchicus* populations that exhibit dramatic differences in seasonal peak abundance timing and magnitude. Hypotheses about controlling factors are tested by statistical comparison to data for copepod abundance and stage-structure. Results demonstrate that the relative importance of environmental (e.g. temperature, food) vs. biological (e.g. cannibalism) factors in shaping *C. finmarchicus* phenology varies between the regions. The implications of our results with respect to the influence of climate on copepod production, timing and trophic roles (i.e. implications for fisheries) are discussed.

23 June, 11:00 (WH-O8)

Population responses to environmentally forced shifts in timing of diapause in *Calanus finmarchicus* in the Gulf of Maine

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We test the power of a 1-D individual-based *Calanus* life cycle model that incorporates the Lipid Accumulation Window hypothesis to explain observed life cycle patterns of *Calanus finmarchicus* at fixed stations in coastal waters of the northwest Atlantic Ocean. According to this hypothesis, individual *Calanus* can only enter diapause if their food and temperature history allows them to accumulate sufficient lipid for overwintering, molting and early gonad development. The duration of the dormancy period is also variable, dependent on ambient temperature and the level of lipid stores. At some stations, the model reproduces the seasonal cycle very well; at other stations the fit is improved when advective influences are accounted for. We use the model to examine scenarios of change in seasonal primary productivity and ambient overwintering temperature on *C. finmarchicus* diapause timing in the western Gulf of Maine, where the species finds itself near the southern edge of its range, in order to test the hypothesis that timing of entry and exit from dormancy, as modulated by species-specific physiology and effects of climate-forced variability of food and temperature on lipid accumulation, exerts a critical biological control on *Calanus* population dynamics.

23 June, 11:15

Discussion

23 June, 14:00 (WH-O9)

Satellite-measured time and space patterns of chlorophyll phenology in the California Current

Andrew **Thomas** and Ryan Weatherbee

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Interannual variability is manifested both as anomalies from climatological means and as changes in phenology. Biologically, changes in phenology have strong implications for trophic interactions. Eleven years (1997–2007) of SeaWiFS satellite data are used to quantify large scale patterns of chlorophyll phenology in the California Current. We first map characteristics of the climatological seasonal cycles of surface chlorophyll concentration and then examine space patterns in interannual variability using two approaches, 1) a synthesis approach based on harmonic analyses of annual data and 2) extraction of key features in the chlorophyll-annual cycle, separating anomalies due to magnitude from those due to shifts in phenology. K-means clustering identifies regions of similar phasing providing a geography to the phenology and its variability. Strong temporal signals in these patterns are associated with the 1997–1998 *El Niño* and delayed spring development in 2005. Space patterns show strong regionality in the magnitude of phenological variability, strongest in the northwest Pacific and off northern California, weaker in regions offshore of the main current jet and in the Southern California Bight. Time and space patterns of phenology shifts in chlorophyll-are compared to local wind patterns and non-local forcing characterised by basin-scale climate signals.

23 June, 14:15 (WH-O10)

Non-linear effects of climate on Black Sea phytoplankton phenology

Abigail **McQuatters-Gollop**[1], Laurence Mee[2], Georgy Shapiro[3] and Dionysios Raitsos[4]

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The Black Sea ecosystem experienced severe eutrophication-related degradation during the 1970s and 1980s. In recent years the Black Sea has shown some signs of recovery which are often attributed to a reduction in nutrient loading; however a decreasing trend in primary production has been observed worldwide as SST increases, suggesting that reduced phytoplankton biomass in the Black Sea is not solely a factor of diminished nutrient loading. SeaWiFS chlorophyll-*a* (chl-*a*) was used to investigate spatio-temporal patterns in seasonal Black Sea phytoplankton dynamics and to explore the potential role of climate in recent phenological anomalies observed in the Black Sea. Changes in chl-*a* reveal intra-annual spatial and temporal variability of phytoplankton biomass in the Black Sea, particularly between the riverine-influenced northwest shelf and the open Black Sea. In the open Black Sea, the warmest winter in recent years resulted in anomalously high levels of chl-*a* and the occurrence of a double peak seasonal bloom cycle reminiscent of that common during the eutrophic 1970s and 1980s; this is a deviation from previous work which has linked warming SST and mild winters to the general decrease in Black Sea chlorophyll - and the occurrence of a single peak seasonal phytoplankton bloom pattern in the open Black Sea characteristic of warm oligotrophic systems. This apparent contradiction may be explained by a temperature-dependent non-linearity in the degree of subduction of nutrient-rich waters below the photic zone; the unusually warm and stable winter of 2000–2001 resulted in reduced vertical mixing of the water column and retention of nutrients in surface waters, causing abnormally high levels of chl-*a* and an altered bloom cycle in 2001. As global temperatures continue to warm this phenological anomaly may become a common occurrence in the Black Sea, resulting in unpredictable consequences on the Black Sea food web.

23 June, 14:30 (WH-O11)

Variability in the timing of the spring bloom and observed changes in the zooplankton community of a coastal fjord

Desiree **Tommasi**[1], Rick Routledge[2], Brian Hunt[1] and Evgeny Pakhomov[1]

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The phytoplankton and zooplankton dynamics in a coastal fjord in British Columbia were monitored in spring and early summer 2006, 2007, and 2008 to assess the annual variability in the timing of the spring bloom and zooplankton development. The spring bloom was delayed in 2007, occurring at least two weeks after the bloom in 2006 and 2008. It is hypothesized that higher freshwater discharge and more frequent wind events in early spring 2007 were the driving factors behind the observed shift in bloom timing. The delay of the phytoplankton bloom resulted in a later and lower zooplankton biomass peak, and a shift in zooplankton species composition. Coastal fjords are an important staging area for juvenile salmon during their ocean entry year, and the implications of the observed changes in zooplankton availability on juvenile salmon growth has to be assessed. This study provides the first baseline observation on the temporal scale of plankton phenological changes in the region. This knowledge will be critical to assess the impact of changing physical and biological forcing mechanisms to higher trophic levels.

23 June, 14:45 (WH-O12)

Influence of environmental forcing on plankton dynamics in the Gulf of Maine region

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Climate-induced variability of water properties and circulation patterns may have significant consequences for plankton dynamics and trophic interactions in coastal/shelf ecosystems. Observational data from the Gulf of Maine region suggest that changes in surface low-salinity Scotian Shelf water inflow and deep slope water intrusion appear to be the main drivers for the plankton phenological shift and productivity variation at higher trophic levels, possibly through a bottom-up process. However, the causal relationship is yet to be examined quantitatively. A 3-D coupled biological-physical model was used to examine the influence of environmental forcing on the timing and magnitude of phytoplankton blooms, net primary productivity, and copepod population dynamics in the Gulf of Maine. The model results indicate that 1) increased surface freshening can stimulate earlier phytoplankton blooms but may reduce overall winter-spring primary productivity by impeding vertical-mixing-induced nutrient supply; 2) phytoplankton biomass and productivity vary in response to the alternation in the intrusion of warm vs Labrador Slope waters that have different nutrient concentrations; and 3) bottom-up processes through phytoplankton-zooplankton interactions have limited contribution to the inter-annual variability of copepod populations, suggesting a level of predatory control in the system.

23 June, 15:00 (WH-O13)

Eco-physiological niche modelling as a tool in understanding the relationship between phenological and biogeographical responses to climate change

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Both structure and functioning of pelagic mid and high-latitude ecosystems are influenced by the dynamics of copepod populations. Among copepods, the species *Calanus finmarchicus* exerts a central role in the trophodynamics of subarctic ecosystems in the North Atlantic Ocean. *C. finmarchicus* has, along with all other species, to permanently adjust to spatial and temporal variability in their environment. To keep their critical developmental phases (e.g. egg production of eggs) tuned to the environment a species can attempt to adjust by modifying the timing of its life cycle. Changes in phenology constitute the first type of response of a species to changes in environmental forcing. Here, we combined a macroecological and a physiological approach to investigate how the environment controls the phenology of *C. finmarchicus* as well as its biogeographical distribution. Both approaches are based on the ecological niche concept (sensu Hutchinson). The macroecological approach was used to assess the realised niche by identifying the principal factors explaining the biogeographical distribution of the species. The physiological approach allows the fundamental niche to be assessed by investigating the link between egg production rate and sea surface temperature. Applied altogether at a seasonal scale, this enables a more complete characterisation of the factors that influence their spatial distribution and temporal changes and a better understanding of the mechanisms at work in periodic biological phenomena.

23 June, 15:15 (WH-O14)

Implications of a spring spawn for long-term sustainability of Georges Bank scallop populations

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The sea scallop (*Placopecten magellanicus*) population on Georges Bank is important both ecologically and commercially. Understanding how this stock is replenished is crucial to the development of sustainable fishing practices in the industry. Because scallop larvae are planktonic for the first several weeks of life, maintenance of the population requires that a sufficient number of larvae ultimately settle on the bank. The Georges Bank population is distributed between the three major commercial scallop beds: Northeast Peak (NEP), Southern Flank (SF) and Great South Channel (GSC). The major spawning event for *P. magellanicus* occurs in the autumn, but a spring spawn has also been observed. Such dual spawn periods suggest the potential for phenotypic plasticity that could mitigate the effects of environmental variability and contribute to the long-term sustainability of the population. This must be understood if the stock is to be managed effectively, particularly in the context of a changing climate. Towards this end, we developed a 3-D Lagrangian particle-tracking model to simulate larval transport due to 1) advection using seasonal velocity fields produced by the Finite-Volume Coastal Ocean Model (FVCOM), 2) vertical swimming behaviour, including passive dispersal, density-surface seeking and depth seeking, and 3) turbulent dispersion via a random-walk using diffusivities from FVCOM. Larval duration was estimated by a temperature-dependent growth relationship, with local temperatures derived from FVCOM. Field-data were used to identify the boundaries for the three beds of interest. Particles in the simulation were seeded on a uniform distribution within these beds and larval retention was defined as the successful settlement of a larva back onto a major bed. The fraction of particles that successfully settled on a bed after being seeded on a different bed was used to define an index of bed connectivity, which was used to quantify the connectivity of the population and forecast the long-term success of the population under different scenarios of spawning seasonality. Retention and connectivity were most strongly affected by seasonal changes in larval duration and circulation patterns on Georges Bank; vertical distribution had little influence on the transport pathways. Overall retention on the bank was lower in the spring than in the autumn. Population connectivity patterns among the scallop beds were also different in the two spawning seasons. In the autumn, the Georges Bank gyre is nearly closed and around-bank circulation transports particles from the NEP and SF onto the GSC, keeping retention high. In contrast, most larvae on the SF are transported south of the bank in the spring, although the transport from the GSC to NEP is intensified. We show how such seasonal variation in larval drift and retention suggests the spring spawn serves as a “bet-hedging” strategy that improves the long-term sustainability of the population in years when autumn-spawned larvae experience poor retention and/or recruitment. The implications for management of this population in the context of climate change are discussed.

23 June, 16:00

Discussion

WI Climate impact on ecosystem dynamics of marginal seas

Chairs: Yasunori Sakurai and Christian Möllman

Marginal and semi-enclosed seas contribute a substantial share to the world fisheries catch. GLOBEC researchers have been very active in studying the impact of climate (climate variability and climate change) on these ecosystems. This work was mainly focused on higher trophic levels, particularly on zooplankton and fish. However, whereas our knowledge on single marginal seas and semi-enclosed ecosystems has very much progressed in these fields, what is missing so far, is a synthesis of the respective results by GLOBEC as is being carried out, for example, for eastern boundary currents.

Consequently, this workshop will seek to compare climatic influences on semi-enclosed and marginal seas on a global scale. As marine ecosystems are not amenable to experimental investigations with respect to climate impact, the comparative method is the best way to enhance our knowledge on the reaction of ecosystems and the populations embedded in them.

The geographic focus of this workshop will be traditional GLOBEC study areas such as the Barents Sea, North Sea, Mediterranean, Baltic Sea, Black Sea, East China Sea, Yellow Sea, Okhotsk Sea, Sea of Japan, Georges Bank, Bering Sea, Gulf of Alaska, Scotia Sea (or other Southern Ocean regions). Particularly rewarding periods for cooperative studies are the late 1980s and 1990s, when dramatic changes have been observed in the North Pacific as well as in the North Atlantic in association with changes in climatic indices such as the NAO, AO and PDO.

23 June, 08:30

Introduction to workshop

23 June, 08:40 (WI-O1)

Climate and pelagic ecosystems in semi-enclosed marginal seas: the case of European shelf seas

Juan-Carlos **Molinero**[1], Michele Casini[2], Jakov Dulcic[3], Branka Grbec[3], Lyudmila Kamburska[4], Priscilla Licandro[5], Marcos Llope[6], Mira Morovic[7], Andreas Lehmann[8] and Ulrich Sommer[8]

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[8] IFM-GEOMAR, Kiel, Schleswig-Holsteins, Germany.

European shelf seas have undergone significant modifications, including ecosystem-wide shifts, changes in the timing of ecological events and alterations in species interactions. These changes have been identified over a large spectrum of the marine food web, ranging from phytoplankton to fish, and a significant amount of these variations has been linked to modifications in large scale climate patterns which occurred in the second half of the 20th century. In the European shelf seas the vulnerability of marine ecosystems to climate modifications is enhanced by increasing anthropogenic stress, e.g. excessive fishing. This particularly strong human pressure can trigger abrupt changes at the ecosystem level such as the collapse of fish stocks, the favouring of gelatinous plankton outbursts, or cascading effects that indirectly favour harmful algal blooms. Here we explore the response of plankton trophic levels to climate forcing in five European shelf seas: the northwestern Mediterranean, Adriatic Sea, North Sea, Baltic Sea, and Black Sea. Results showed that the relationship between climate and plankton reveals periods of coherent changes in which the two signals vary in synchrony and other periods in which their linkage is uncoupled. Overall, these results emphasize the non-stationary behaviour of the link between climate and plankton.

23 June, 09:00 (WI-O2)

Reaction of northern hemisphere ecosystems to the climate events in the late 1980s: a comparison

Juergen **Alheit**

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The “ICES/PICES/GLOBEC-SPACC workshop on changes in distribution and abundance of clupeiform small fish in relation to climate variability and global change” in 2008 compared the impact of the climate events in the late 1980s on several northern hemisphere systems whereby the focus was on Japan East Sea, Kuroshio and Oyashio ecosystems, California Current, Iberian Upwelling system, North Sea, Baltic Sea and Mediterranean. In spite of the very diverse structure of these different systems, all of them exhibited strong synchronous reactions in association with drastic changes in the northern hemisphere atmospheric mass distribution in the late 1980s. In most of the systems, regime shifts were observed at that time including dramatic changes on major trophic levels. Ecosystem dynamics were studied in relation to large-scale climatic phenomena such as the North Atlantic Oscillation, Arctic Oscillation, Siberian High, East Asian Monsoon and Aleutian Low which seem to link ecosystem reactions in different oceans.

23 June, 09:20 (WI-O3)

The dynamics of chlorophyll-a concentration due to climate change and its possible impact on *Sardinella lemuru* at Bali Strait, Indonesia

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The dynamics of chlorophyll-*a* concentration from 2003 to 2007 is studied at the Bali Strait using Aqua-Modis satellite data. Together with Catch per Unit Effort (CPUE) data for *Sardinella lemuru*, sea surface temperature (SST) and climate change parameters (Southern Oscillation Index (SOI) and *Niño* 3.4), their possible relationship was analysed. The relationship between SST and chlorophyll-*a* anomalies are showed by linear regression, $r = -0.56$ with $p<0.005$. The chlorophyll-*a* anomalies significantly increase reaching 1 mg/m^3 above normal by the end of 2006. This increase corresponds well with upwelling processes due to the drop of SST during the *La Niña* event at the end of 2006. Therefore, there is an unlagged response between chlorophyll-*a* and SST. However, there is lagged response between chlorophyll-*a* and CPUE of *S. lemuru*. Increasing CPUE of *S. lemuru* is followed by increased catch of *S. lemuru* four months later. There is a significant relationship between anomalies of chlorophyll-*a* and 4-months lagged CPUE that is shown by $r = 0.71$ with $p<0.005$. There is evidence that climate change may also lead to shift the parameter of the climate change, from SOI to *Niño* 3.4, and *vice versa*. SOI is suitable for examining *El Niño*, while *Niño* 3.4 is suitable for the *La Niña* phenomenon.

23 June, 09:40 (WI-O4)

Climate and overfishing cause change in a semi-enclosed sea: a review of central Baltic pelagic ecosystem dynamics

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The central Baltic is a semi-enclosed sea with a pelagic ecosystem characterised by a simple trophic structure and only a few species determining most of the ecosystem dynamics. The structural simplicity makes the system especially suitable for investigations on how climate and overfishing affect the overall ecosystem dynamics. Consequently a large number of studies have investigated single aspects of climate and fisheries effects. These range from studies on plankton (both phyto- and zooplankton) to investigations on the dominant fish species cod (*Gadus morhua*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). Recently system wide-changes caused by both climate and fishing have been intensively investigated addressing phenomena such as trophic cascades and ecosystem regime shifts. Here we review and synthesize the work on central Baltic ecosystem dynamics under the pressures of climate change and fisheries exploitation. By this we intend to summarise the different pathways of change into a holistic understanding of ecosystem functioning and hence to provide the basis for a reliable ecosystem-based management of the central Baltic Sea for the future changes to come.

23 June, 10:30 (WI-O5)

11 year zooplankton time-series related to North Atlantic climate changes in waters of the Balearic Sea (western Mediterranean)

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Seasonal and interannual patterns of zooplankton and oceanographic properties of the sea water column (75 m depth) are given for a monitoring station of the Balearic Sea, a boundary hydrographic area of the western Mediterranean. The results are based on 11 year samples collected every ten days during the period from January 1994 to December 2004. Temperature manifested clear seasonal cycles while salinity showed a larger variability modulated by the hydrological regime changes of the Balearic sea waters. During the total period, salinity revealed an increasing trend meanwhile annual temperature did not demonstrate any apparent trend. Zooplankton abundance and composition was in relation to the hydrographic variability and regional climate. Therefore zooplankton can be used as a valuable indicator of further studies of climate change, however the responses varied according to different life-histories of the main zooplankton groups. Yearly, two different periods were observed: the mixing period during winter and early spring, with a higher abundance of organisms and, the increased stratified period characterised by other species of small copepods, cladocerans and meroplankton. The larger period of stratification all along the study area affected the zooplankton structure. Moreover, during cool years a relation was found between strong anomalies of the North Atlantic climate (>1 standard deviation) and the highest zooplankton abundance of the main groups, when cooler northern Mediterranean waters reached the area. On the contrary, warmer years showing the lowest zooplankton abundances (1997–1998 and 2003), were associated with the inflow of less saline and nutrient-depleted more recent Atlantic waters. A downscaling process linking the North Atlantic climate and the hydrographic variability in the Balearic Sea was a proxy of the zooplankton structure. The synchronies in the zooplankton patterns with North Atlantic climate factors showed the fast responses of these organisms to signals of a scale that can be used for further studies of climatic changes. Although the time series analysed covers a relatively short period for investigating climate effects on marine ecosystems, the statistical results reported were consistent enough to stress the North Atlantic climate effect on the Balearic Sea and an ideal place to represent the oceanic western Mediterranean waters where potential consequences of global climate change can be investigated.

23 June, 10:50 (WI-O6)

Effect of the long-term climate on growth and survival of Japanese chum salmon in the Okhotsk Sea

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A temporal change in growth patterns of Japanese chum salmon was observed using the back-calculation method based on scale analysis. Chum salmon migrate from the river to the sea and spend two or three months in coastal waters before migrating to the Sea of Okhotsk. They spend summer and autumn (July to October) in the Sea of Okhotsk, and migrate to the northwest subarctic gyre in late autumn to winter. The survival rate of salmon is mostly determined immediately after migration to the sea and during the first wintering period there. For Japanese chum salmon, a larger body migrating to the sea and better growth in the Sea of Okhotsk result in a higher survival rate. The growth of Japanese chum salmon has been remarkable in the Sea of Okhotsk since the 1990s. Their growth increase is negative correlated with the extent of sea ice cover area (ICA), and positively correlated with the SST during summer and autumn in the Sea of Okhotsk. This means that the growth of chum salmon will be improved under the ocean condition of less ICA in winter and higher SST in summer and autumn in the Sea of Okhotsk. The sea ice concentration has been linearly decreasing during the last 100 years on the Hokkaido coastline of the Okhotsk Sea. Since temperatures have increased, this can be considered evidence of global warming. The result of temporal changes in the survival rate of chum salmon in Hokkaido, Iwate and Republic of Korea, Hokkaido population was an upward trend with a significant increase in the 1990s. This mostly corresponds with the growth patterns in the Sea of Okhotsk outlined above. On the other hand, survival rates in Iwate and Republic of Korea populations have significantly decreased since the late 1990s. The chum salmon in these areas are strongly affected by the Tsushima Warm Current (also known as the Tsugaru Warm Current in the Pacific Ocean) during their early ocean-life period. This phenomenon therefore suggests that global warming positively affects Hokkaido chum salmon in the Sea of Okhotsk and negatively affects those in Iwate, Republic of Korea and elsewhere in Tsushima Warm Current waters.

23 June, 11:10 (WI-O7)

Climate impact on Baltic cod, sprat, and herring stock-recruitment relationships: an INEXFISH project experience

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The main aim of the InExFish project was to increase the responsiveness of fisheries management to a range of anthropogenic and non-anthropogenic forcing factors. Stock-recruitment models including a wide range of possible recruitment drivers (e.g. spawning stock biomass, hydrography, climate, food availability) were constructed and tested. Four assessment units were included in the analyses: the eastern Baltic cod stock (ICES Subdivisions 25–32), the central Baltic herring stock(s) (SD 25–27, 28.2, 29, and 32), the Gulf of Riga herring stock (SD 28.1), and Sprat (SD 22–32). Climate impact expressed by different climatic indices or through changes in water temperature was always among the wining explanatory variables. The recruitment of both herring units appears to be influenced by slightly different factors. The spawning stock biomass (SSB), winter Baltic Sea Index prior to spawning, and potentially the November–December sea surface temperature (SST) during the winter after spawning were important to Gulf of Riga herring, while the best models for central Baltic herring included SSB and August SST. The recruitment of sprat appears to be influenced by July–August temperature, but it is independent of the biomass of spawners (SSB) when SSB>200,000 tonnes. The recruitment of eastern Baltic cod is significantly related to spawning stock biomass, the winter NAO index, and the reproductive volume in the Gotland Basin in May. Models including extrinsic factors significantly improved our prediction abilities.

23 June, 11:30 (WI-O8)

Biological invasion in the Levantine Basin (east Mediterranean)

Sami **Lakkis**

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The eastern Mediterranean, especially the Levantine Basin, including the Lebanese seawater is the most impoverished and oligotrophic water body in terms of nutrient concentration. Heavy evaporation and shortage of freshwater input make the east Mediterranean hyper-saline basin with relatively warm water body, where the temperature and salinity are the highest in the whole Mediterranean. During the last four decades of the survey on the hydrology of the area, we noted an average increase of temperature (~0.45°C) and salinity (~0.35); while the nutrient concentrations (phosphates, nitrate, silicates) are in continuous decrease. Several planktonic species, of Indo-Pacific and Eritrean origin have migrated into the Mediterranean since the opening of the Suez Canal, where they succeed to establish permanent populations and ecological niches along the Levantine coast including the Lebanese sector. Out of 400 phytoplankton species, 10% are invaders and became permanent inhabitants. From 750 zooplankton species present in the Lebanese sector, about 30% are in common with the Red Sea fauna. Out of 650 fish species so far recorded in the Mediterranean, from which 350 inhabit the Levantine Sea, 90 species representing 56 families were introduced mainly from Red Sea. From those, 57 were recorded in the Levantine Basin since the opening of Suez Canal. Most of these exotic fish species have adapted themselves to the new marine environment and established permanent populations along the coastal waters of Lebanon. 30% of the benthic species, namely from crustaceans and mollusks, are tropical invaders colonizing the eastern Mediterranean. Few of those Lessepsian migrants have succeeded to cross the Siculo-Tunisian channel toward the western Mediterranean. Are these exotic species considered as passive migrants into the eastern Mediterranean or as actively invaders colonising the new marine environment? The migration process has increased during the last four decades. Before the opening of the Suez Canal in 1869, we do not have clear data and information about the marine organisms in the area. The first reliable records found in the Mediterranean are from 1902. Marine surveys were rare in the early 20th century and we had to wait 80 years after the opening of Suez Canal to learn that about 20% of the species found in the Levantine Basin are Lessepsians and of Indo-Pacific origin. These hydrological changes are due not only to the regulation of the Nile flood by Aswan High Dam and the opening of Suez Canal, but also climate change and global warming observed during the last decades has induced ecological changes in the entire Levantine Sea. This is due not only to the man-made activity, but also to the climate change and global warming affecting the eastern Mediterranean as well as causing tropicalisation of the marine ecosystem which is seen by the close resemblances of hydrological conditions of the Levantine Basin with those of the Red Sea.

23 June, 11:50 (WI-O9)

Responses of meso-zooplankton communities to long-term oceanographic changes in the northwestern Pacific marginal seas

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To understand and project zooplankton responses to climate change in northeast Asia, we related zooplankton biomass and their species composition to long-term oceanographic changes in the northwestern Pacific marginal seas. The Korean peninsula is surrounded by the three distinctive marginal seas (Yellow, East China and East/Japan Seas), in which the National Fisheries Research and Development Institute has measured and compiled water temperature, salinity and meso-zooplankton abundance since 1962. Sea surface water temperature has gradually increased since the early 1990s, especially during the winter and early spring. However, the increasing trend extended to the all seasons after the late 1990s. On the other hand, salinity has decreased since the late 1990s. Zooplankton biomass showed an increasing trend after the early 1990s, and the increasing trend seemed to be accelerated after the mid-1990s. Copepod abundance also showed a similar pattern with zooplankton biomass except during 1997–1999, in which copepods, chaetognaths and euphausiids showed negative anomalies of abundance. We tentatively confirmed that oceanographic conditions and zooplankton communities in the northwestern Pacific marginal seas responded to the two global regime shifts in 1989 and 1997, and the sudden decline in abundances of copepods, chaetognaths and euphausiids, seem to be related with the *El Niño* in 1997–1998.

23 June, 12:10 (WI-O10)

A combined effect of climate and fishery harvesting triggered a shift in a hake (*Merluccius merluccius*) population of the NW Mediterranean

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The climate in the North Atlantic has been demonstrated to influence climatic conditions in the Mediterranean Sea at a regional scale. The climatic shift in the early eighties in the North Atlantic triggered changes in local weather and hydrographical conditions at different areas of the NW Mediterranean. Ultimately, those changes influenced the dynamics of the primary and secondary production and gelatinous carnivorous dynamics. On the other hand, the long term fishery harvesting of a demersal species such as the European hake (*Merluccius merluccius*) underwent changes in the population properties and structure in the early eighties off the Balearic Islands (NW Mediterranean), which could trigger a change in the ecological response to the climatic variability. In the present study, we investigate the hypothesis that the ecological shift for hake off the Balearic Islands resulted from a combined effect of fishery harvesting and environmental changes in the North Atlantic. We combine time series analyses (wavelet analyses) and population dynamics models to explore possible mechanisms. We hypothesize that the combined effect of climate and fishery harvesting in the early eighties was as follows. Before 1980, the North Atlantic climate influenced the population dynamics of hake which was healthy size structured with moderated fishery exploitation. Seven year cycles of the North Atlantic climate provided favourable conditions to build up consistent cycles in the hake populations off the Balearic Islands. After 1980, fishery exploitation eroded the size-structure of the hake population off the Balearic Islands, eliminating larger and older individuals which make the population strongly dependent on younger age classes (juvenescent population). At the same time, the North Atlantic climate shift reduced the window of favourable conditions to *ca*. five year cycles, and also triggered changes in local weather and hydrographical conditions, which were affecting hake dynamics. It was found that, under favourable conditions for hake off the Balearic Islands, the population does not have enough time to build up an equivalent population to the period prior to 1980. As a consequence, the hake population remained more dependent on inter-annual variation of recruitment after 1980, being closely related to inter-annual variability of local weather conditions.

23 June, 14:00 (WI-O11)

Changing climate in the Gulf of California

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The Gulf of California is an inner sea located in northwest Mexico. It provides nearly 70% of Mexico's fish production, and hosts the most important fisheries in terms of income and volume. It is also the most important region for aquaculture (shrimp) and a popular tourist and sport fishing area. Besides its economic and social significance, it is a centre of strong conservation concerns to many national and international organisations because of its environmental and biological diversity, the presence of emblematic species, and high endemism. Environmental variability is much more complex than many other areas of the eastern Pacific, especially due to apparently mixed signals from the low-frequency, high-latitude PDO and the high-frequency of the tropical ENSO. Regional scale long-term climate trends are controversial and particularly hard to investigate because no synoptic and long-term climate proxies exist, and the coarse resolution of interpolated global scale databases and model results cannot be used in this thin long sea. Retrospective analyses have shown evidences for three mutually exclusive future scenarios: 1) the lack of significant differences between present conditions and future climate scenarios as revealed by a nested atmospheric regional model, and forced ocean circulation models, suggests permanence of present conditions into the future, 2) the potential increment in the frequency and amplitude of ENSO events due to climate change that would result in more oligotrophic and warmer conditions; one major contribution in this report is the description of not homogeneously distributed impacts of this interannual signal on the physical and ecological properties of the Gulf, and 3)an upwelling index for the Gulf has shown a sustained trend upon higher levels of winter upwelling, similar to what has been observed for open ocean systems such as the California and Humboldt Currents, suggesting that a warmer climate would drive even stronger upwelling, transforming the Gulf into a system more similar to major upwelling areas. In this contribution we contrast the evidences for each case; we incorporate results from climate, oceanographic and ecological models, and discuss their likelihood and potential consequences.

23 June, 14:20 (WI-O12)

Climate and jellyfish outbursts in the Mediterranean Sea: a synthesis through meta-analysis

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Jellyfish are critical components of marine ecosystems. Whether variations in their population size are driven by human- or climate-mediated processes is a matter for current debate and a challenge in biological oceanography. In this work we gathered pluriannual information of Mediterranean jellyfish to synthesize long term variations of jellyfish outbreaks, their strength and frequency during the last decades in the Mediterranean Sea. Evidence has been found on the interactions between hemisphere-wide climate variability and regional atmospheric changes across the Mediterranean basin. The temporal dynamics of jellyfish outbreaks are consistent with the climate-related environmental changes the Mediterranean Sea undergone during the last decades. We found that jellyfish populations integrate climate related changes in the Mediterranean basin, and the strength of their link with climate variations has increased after the 1980s. The quantitative synthesis performed by meta-analysis provides evidence of an increase in gelatinous carnivore outbursts related to long term changes of sea surface temperature. However, we also found that the jellyfish increase has been indirectly favoured by anthropogenic stress (e.g. overfishing, habitat degradation) which has affected competitors and predators of jellyfish. These results constitute ecological warning indicators of significant changes occurred in the pelagic ecosystem of the Mediterranean Sea after the 1980s.

23 June, 14:40 (WI-O13)

Distribution and bacterivory of heterotrophic flagellate in the Yellow Sea during the spring diatom bloom

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The aim of this study was to determine the dynamics and functional role of heterotrophic flagellates (HF) during the spring diatom bloom in the central part of the Yellow Sea in April 2007. The abundance of HF ranged from 359 to 4875 cells/ml, with an average of 1366 cells/ml. The small size fraction of less than 5 µm dominated the HF populations, especially pico–flagellate, accounting for more than 40 percent of total HF abundance. To our surprise, the abundance of HF was much lower at high chl-*a* stations than that at low chl-*a* stations, however the densities of planktonic bacteria (generally regarded as the main prey of HF) showed no significant difference at all stations. The ingestion rates of heterotrophic bacteria, estimated on the basis of uptake of fluorescently labelled bacteria, varied from 3.91–10.50 cells HF^{-1} h^{-1}. Compared with the grazing rate in the bloom decline period, the grazing rate was obviously depressed in the bloom growing period, indicating that HF grazing activity was greatly inhibited by the diatom bloom. As a whole, HF removed 27.28% (9.67–42.38%) of the bacterial biomass and 14.67% (6.06–23.60%) of bacterial production, suggesting that the grazing by HF was unlikely to be responsible for the main fate of bacteria. Size-fractionated grazing experiments at stations BM4-A, BM4-B and BM4-C revealed that heterotrophic picoflagellates were the main grazers of bacteria, which accounted for about 49.25% of HF-induced bacterial mortality. Larger flagellates (10–20 µm) showed much less grazing on bacteria, implying that they had more important food resources other than bacteria, e.g. picoflagellates or small diatoms.

23 June, 15:00 (WI-O14)

The population dynamics of *Calanus sinicus*

Song **Sun** and Shiwei Wang

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As a key zooplankton species, the copepod *Calanus sinicus* occupies the central trophic position in the ecosystem of the Yellow Sea and East China Sea. It feeds on phytoplankton and microzooplankton and provides the main food for several economic fishes, thus its population dynamics will finally affect the fishery resources. The functional role of *C. sinicus* in the Yellow Sea and East China Sea is comparable to that of *Calanus finmarchicus* in the North Atlantic. The population dynamics and life history of this species were of major importance to understand the functioning of the ecosystem as well as the fishery fluctuation. Based on the data of the last ten years, the seasonal and regional variations of the population distribution, biomass, reproduction and recruitment were studied in relation to the temperature, food supply, cold water mass, fronts and lipid reserve. It is the systematic results of the key zooplankton species which is the focus of the 'China-GLOBEC' programme.

23 June, 16:00

Discussion

WJ Socio-economic dynamics and ecosystems, governance implications

Chairs: Kathleen Miller and Anthony Charles

Successful management of marine ecosystems requires good information, both about the socioeconomic factors driving exploitation, and about the status and dynamics of the exploited species and the ecosystems on which they depend. But even the best information may have little value in the absence of effective institutions for cooperative governance of those systems. Marine fisheries present particular management challenges due to the competing interests of the multiple resource users and nations benefiting from the fisheries. For open-ocean fisheries, the challenges are multiplied by the often wide-ranging movements of some fish stocks across both high seas areas and waters controlled by multiple nations. A central management problem for multi-national oceanic fisheries is the need to constrain competitive harvesting in order to avoid the depletion of fish stocks and the dissipation of potential resource rents that could otherwise occur. Ocean ecosystem governance encompasses not only the problem of effective management of single species fisheries, but also a much broader array of issues arising from multiple interactions across species, fisheries and other human activities.

This session will focus on questions pertaining to marine ecosystem governance, e.g. what constitutes effective governance for oceanic ecosystems and the fisheries that they support; how can this be achieved and maintained in the context of rapid socioeconomic change and a variable and changing climate; what type of information is needed from the science community to support effective resource governance; and what do we need to understand about the human dimensions of ecosystem use in applying the ecosystem approach to fisheries governance?

23 June, 08:30

Introduction to workshop

Kathleen **Miller** and Anthony **Charles**

23 June, 08:40 (WJ-O1)

Keynote: The governance of multi-national capture fisheries under uncertainty

Gordon **Munro**

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This presentation will focus on the governance of multi-national capture fisheries, under the evolving New International Law of the Sea. Most of the attention will be given to fishery resources to be found in all, or in part, in the high seas. The relevant fisheries are complex being typically multi-species, as well as multi-national. These fisheries can, of course, be managed effectively only through cooperative management arrangements. Given the complexity of both the fisheries and the underlying legal regime, establishing cooperative fisheries management arrangements that will be stable through time is difficult. It must be recognised that these arrangements are, under the best of circumstances, inherently fragile, being vulnerable to unanticipated shocks, particularly those arising from the environment, through, for example, climate regime shifts.

23 June, 09:15 (WJ-O2)

Place-based oceans governance in a Web2.0 world

Rod **Dobell**

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Increasingly powerful computing and communications technologies are supporting rapidly expanding networks of interaction among people. In this Web2.0 world of massive social networking, the demands of civic society for greater involvement and influence in the formation of public policy and the implementation of collective decisions are achieving much greater force. Together with growing acceptance of new understandings of the nature of science and scientific processes, this new social context is transforming the character of participatory governance. This proposed paper will examine the implications of these two transformative developments for regional oceans governance generally, and for devolution of federal responsibilities in management of marine resources to place-based institutions more specifically. Three examples of trans-boundary settings in British Columbia: the Salish Sea, the Big Eddy and the Pacific North Coast Integrated Management Area will be explored for illustration.

23 June, 09:37 (WJ-O3)

Assessing the adaptive capacity of ecosystem governance processes: a new institutional analysis perspective

Ralph **Matthews** and Robin Sydneysmith

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How do the cultures and structures within administrative systems influence the dynamic social processes involved in governance? This paper will introduce the sociological perspective known as 'new institutional analysis' and explore its relevance as an analytic tool for assessing the capacity of governance institutions to deal with eco-system change. The utility of the perspective as an analytic tool will be demonstrated by describing how it is currently being employed to explore the capacity of administrative processes in the City of Whitehorse and Yukon Territory as their administrations seek to deal effectively with both environmental change and subsequent social and economic development. It will be argued that the framework developed in that study is also a relevant basis for exploring other types of governance processes, including those relating to marine eco-systems. Based on that work, the presentation will conclude with a discussion of the empirical focus of new institutional analysis and will propose a tentative framework for examining the institutional dynamics of marine governance processes.

23 June, 10:30 (WJ-O4)

The Ecosystem Approach to Fisheries: human dimensions and governance challenges

Anthony **Charles**

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The Ecosystem Approach to Fisheries (EAF) is a framework for management and governance of fisheries and broader marine systems–one that is becoming increasingly adopted worldwide. The Food and Agriculture Organisation of the United Nations (FAO) is developing mechanisms to enable more effective adoption of EAF. In 2008, a report produced by the FAO (De Young, Charles and Hjort, "Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods", FAO Fisheries Technical Paper 489) addressed the need to better understand the economic, institutional and socio-cultural components within the EAF process and to develop methods to facilitate the adoption of EAF management. This presentation outlines the specific findings of that report, and subsequent efforts by the FAO to develop formal guidelines, in the context of the Code of Conduct for Responsible Fisheries, to support incorporation of human dimensions and governance reforms into the EAF framework. The coverage includes background material essential to embarking on EAF initiatives (e.g. key concepts and issues; approaches for valuation of aquatic ecosystems socially, culturally and economically; and relevant policy, legal, institutional, social and economic considerations). With respect to facilitating EAF implementation, the presentation explores the crucial aspects of: 1) determining the boundaries, scale and scope of the EAF; 2) assessing the various benefits and costs involved, from social, economic, ecological and management perspectives; 3) utilising appropriate decision-making tools in EAF; 4) creating and/or adopting internal incentives and institutional arrangements; and 5) finding suitable external approaches for financing EAF implementation. Finally, the challenging issue of scale will be explored–how EAF can be best implemented at scales ranging from the local to the global, and how governance arrangements can facilitate more effective cross-scale linkages.

23 June, 10:52 (WJ-O5)

Fisheries governance and the recovery imperative

Ahmed **Khan** and Barbara Neis

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Global marine capture fisheries are in a state of decline, with commercial species such as cod, tuna, marlin and swordfish endangered or threatened. There is growing concern that most commercial fish stocks could largely disappear in the next few decades in the absence of major interventions. Clearly this trend must be reversed. Sustaining the current misery would be ecologically, socially and economically irresponsible. What is required, instead, is substantial investment in the design and implementation of effective recovery strategies. However, relatively little is known about what these strategies might look like. Successful examples of recovery of major degraded fish stocks are few and far between. This paper outlines the rationale for the recovery imperative, reviews the limited research on recovery and contributes to this research by exploring three illustrative case studies of recovering collapsed fisheries in North America. The results of this review and our case studies highlight the socio-political and governance requirements for recovery. We also examine elements of recent research on governance through the

lens of the recovery imperative. Drawing upon clumsiness theory, we suggest that recovery strategies need to be exploratory. We argue that they need to go well beyond the prerequisites for ecological recovery to encompass the prerequisites for sustainable coastal communities for social justice reasons and because the latter are a resource for stewardship and conservation, institutional reforms and stakeholder partnerships.

23 June, 11:14 (WJ-O6)

Priceless prices and marine food webs: long-term patterns of seafood markets in southeastern Brazil

Ruth **Pincinato** and Maria Gasalla

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The lack of price information as a variable of fishery systems has often been cited as one reason for the problems in understanding marine ecosystem change and its management under an ecosystem perspective, i.e. fishers dynamics can be ambiguous, or the fishing down marine food webs effect can be masked in landings plots. However, price databases are usually scattered, incomplete and unavailable for marine researchers. This paper will show results of our efforts in tackling this problem in southeastern Brazil by compiling and analysing valuable data in depth for the region's larger wholesale seafood market which is based in the mega city of São Paulo. Landed values for the region comprising the South Brazil Large Marine Ecosystem (LME) were estimated and classified by trophic levels based on local research and literature. As for the period 1969–2007, a long-term analysis for an unstable economy required the adoption of deflators to account for inflation rates that reflects the percentage change in a price index over time. Thus, several national deflators were tested, such as the general, the consumer, the wholesale, and meat and seafood price indexes, which often reflected different fish price trends over time. Weighted price time-series were plotted by trophic level groups (TL) and for invertebrates separately. Trends of price and market amount values showed opposite peaks and troughs as expected. The relative price index (RPI) based on the slopes of monthly and annually price x TL level plots were also analysed. In general, seafood wholesale market price increased over time with a growing increase of high trophic level species (HTL) and invertebrates prices. RPI values decreased from 1969 to 1987 possibly due to the fact that HTL species became scarce and fisheries switched to target low TL species, i.e. mullets, and showed a smoothly increasing trend until 2007. Results showed that landing data alone do not show either the fishing-down phenomenon or the real fishery dynamics, while joint ecological and econometric detailed analyses evidenced it as well as a decrease of the LME landed value over time in an unexpected way. Results appear to be useful for cost-benefit analysis of different management proposals, i.e. fee or auction schemes for fisheries, and for the implementation of ecosystem approach to fisheries practices or modelling techniques.

23 June, 11:36 (WJ-O7)

A fish chain analysis of Northern Gulf cod fisheries pre-collapse

Ahmed **Khan**[1], Ratana Chuenpagdee[1], Barbara Neis[1], Robert Hooper[1] and Rashid Sumaila[2]

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This paper aims to generate a holistic understanding of the recovery status and prospects of Northern Gulf cod fisheries through a fish chain analysis. A fish chain analysis is an analytical framework for understanding fishery systems through the inter-linkages and interactions in the fish production stages from 'oceans to plate'. Despite two moratoria, the current recovery status of Northern Gulf cod stocks are below conservation reference points. Most recovery efforts have focused on ecological systems with little attention on the human dimension such as socioeconomics, markets and governance. To date, no systematic or complete analysis of the cod fish chain, including its role in exploring governance options for recovery, has been undertaken. Extending recovery studies to other facets of the fisheries chain is necessary to assess where in the chain there may be limiting factors and prospects to facilitate recovery. Moreover, comparing the fish chain pre- and post-collapse provides opportunities to assess ecological constraints, policy changes, socioeconomic impacts and to identify governance opportunities for recovery planning and implementation. We draw upon the interactive governance approach to characterise the various stages of the fish chain for Northern Gulf cod pre-collapse, starting with the pre-harvest, harvest, to the post-harvest stages. Using a governability assessment framework, we examine the various characteristics of the stages in the fish chain. A governability assessment framework entails a set of key questions on attributes along the fish chain to better understand governing quality and capacity, and potential limitations for recovery. This assessment is the first step in comparing the fish chain pre- and post collapse and to identify policy initiatives, spatial governance concerns, partnership arrangements, and environmental stewardship mechanisms for recovery.

23 June, 11:58 (WJ-O8)

Game theoretic insights on multinational tropical tuna fishery management

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In recent years, Regional Fishery Management Organizations (RFMOs) have been established to control harvesting pressure and promote a fair division of fishery benefits in some of the world's most important fisheries. RFMOs represent the interests of both harvesting nations and nations in whose waters the targeted fish populations reside, and both types of interests typically have a voice in setting policies. The outcomes of these policies will depend on subsequent interactions among the fleets and the fishing sites and the RFMO itself–an interplay that can be formally modelled as a multi-party harvesting and management game. This paper uses such a model to explore the consequences of alternative policies that might be pursued by the Western and Central Pacific Fishery Commission in its efforts to manage fisheries for tropical tuna in that region. The analysis indicates that while the RFMO can achieve any given biological objective by in a variety of ways, different types of policies will have very different implications for who benefits from the policy as well as for the overall level of the economic returns that can be obtained under the policy. Furthermore, policy outcomes will vary considerably depending on whether or not coalitions form among the various fishing nations and coastal nations in whose waters harvesting occurs. In addition, climate-related shifts in the distribution of the stocks between EEZs and the high seas can affect the biological and economic consequences of the RFMO policy choices.

23 June, 12:20

Synthesis: key ideas from the session

23 June, 14:00

Discussion. Project and publication planning: marine governance trends and tools

P1 Ecosystem structure, function and forcing

Poster PS1-P1

Fecal pellet production by Antarctic krill in summer: egestion rates, fecal pellet composition and sinking rates

Angus **Atkinson** and Katrin Schmidt

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The rates of production and sinking of zooplankton faecal pellets is a topic of interest both to biogeochemists and to ecologists. On the one hand large grazers such as krill produce rapidly sinking faecal pellets which contribute to the biological pump–krill pellets can be important in sediment trap catches in the Southern Ocean. On the other hand measuring the faecal pellet production gives an insight into feeding rate, by converting from egestion to ingestion via assimilation efficiency. Doing this for freshly caught krill is considered as one of the best ways yet available to derive its *in situ* carbon ration. There are still fewer than a dozen published estimates of egestion by krill, and even fewer measurements of faecal pellet composition or sinking rate. We measured these variables on freshly caught krill from 19 stations across a variety of chlorophyll-*a* concentrations in the Scotia Sea during January–February 2008. Concurrently we ran a through-flow incubation of krill fed from the ambient seawater running through the ship's non-toxic supply. Faecal pellets collected from the through-flow were collected every day for a month to examine their elemental composition in the UK with a CHN analyser. All components of the krill defecation process were highly variable. As well as overall C and N egestion rates varying between stations, so did the size, texture and composition of the pellets. For example the C content of the pellets, as a percentage of their dry mass, varied over 10-fold from 2.3–27% C (mean 11% C), and the values from the *in situ* experiments followed the same trend as that from the through-flow, suggesting that it was linked to regional changes in the ambient food environment. Sinking rates of pellets were determined from their settling velocity in a motionless column of seawater in a 1L measuring cylinder. Across 714 measured pellets from 16 stations, sinking rates varied nearly 30-fold, from 0.051–1.41 cm s^{-1} (corresponding to an equivalent theoretical sinking rate of 44–1218 m d^{-1}). We will discuss the likely causes of this variability in the defecation of krill and its biogeochemical and ecological implications.

Poster PS1-P2

The influence of environmental variability on Atlantic bluefin tuna (*Thunnus thynnus*) growth, migration, and reproduction

Erik **Chapman**, Walter Golet and Molly Lutcavage

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Improving our knowledge of migration and reproduction for Atlantic bluefin tuna ABFT (*Thunnus thynnus*) is central to developing effective management for this heavily exploited, large pelagic species. Over a 20–30 year lifespan ABFT exhibit a broad range of food habits and migratory patterns, supported by an optimised "bauplan": fast growth rates and a unique, warm bodied physiology. Energy acquisition and utilisation is thus likely to be a key component of their complex life history. Recent analyses of electronic tagging and physiological data have provided an insight into patterns of movement and somatic condition for juveniles and adults. However, critical elements of ABFT growth, maturation, migratory behaviour, and spawning schedules remain unclear. In order to extend our current understanding of the Atlantic bluefin's life history strategy, it is necessary to place field observations into an energetic context, and modelling studies can be an integral part of this process. Here, we present a state-dependent energy allocation and behaviour model for ABFT that uses an algorithm optimising individual life-long fitness under different environmental conditions. Initial simulations investigate the influence of prey variability, fishing mortality, and the distribution and quality of forage habitat on ABFT maturity, reproductive schedules and migration. Results highlight a range of potential explanations for observed movement and condition patterns while identifying gaps in current knowledge.

Poster PS1-P3

Inter-annual and seasonal variability of pelagic ecosystem and krill resources parameters in the Scotia Sea in relation to oceanographic conditions

Pavel **Chernyshkov**, Igor Polishchuk, Vladimir Shnar, Svetlana Kasatkina and Fedor Litvinov

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The variability of dynamic processes in the atmosphere and ocean (atmospheric transport, geostrophic circulations, water masses structure, krill drift) are considered in the western part of the Atlantic sector of the Antarctic (ASA) in relation to pelagic ecosystem parameters and distribution of krill as the key element of this ecosystem and a traditional fishing object. The available data for 1960–2008, including oceanographic and meteorological observations, data from acoustic and trawl surveys and catch statistics were used as primary material. Special attention was given to historical and recent subareas of krill fishery in the ASA: Antarctic Peninsular (48.1), South Orkneys (48.2) and South Georgia (48.3). It was demonstrated that the variability of oceanographic conditions in the ASA fishing areas are determined by large-scale atmospheric processes which occurred within the latitude band of 40°–65°S, dynamic regimes of the central and southern branches of the Antarctic Circumpolar Current and intensity of the western periphery of the Weddell Drift. Inter-annual fluctuations of climatic conditions in the studied areas are characterised by long-term trends of 30–40 years in duration. The synchronous fluctuations have been revealed in the atmospheric pressure anomaly fields at the sea level and in sea surface temperature anomalies on fishing grounds of the ASA. These variations interpreted as a quasi-4-year Antarctic circumpolar wave are typical to all areas researched. Spatial and temporal variability of the meridional air transfer significantly influences krill fishing effort patterns in the ASA, affecting krill aggregation availability, ice and weather conditions. Analysis of the krill fishery in the period of its peak activity in 1977–1992 revealed that fishing effort in the frame of the quasi-4-year cycles was highest in the subarea where the southern meridional transfers were also highest. The phenomenon was observed in subareas 48.1 (1981–1982) and 48.2 (1983–1986) under conditions of increased westward component of the zonal air exchange and in subarea 48.3 (1987–1988) of decreased westward component. The assessment of krill geostrophic transport characteristics in the ASA subareas were carried out, and the impact of transport on the krill distribution and catch per unit effort indices of commercial vessels in the fishing grounds were demonstrated. Characterisation of the water masses horizontal circulation and associated krill distribution based on long-term scientific observations and fishery data were provided; besides, biomass estimates and its commercial importance, indices of krill drift in different modifications of the Antarctic water masses were demonstrated. Finally, it was concluded that development of krill management options requires knowledge of spatial and temporal variability trends in krill distribution under the impact of oceanographic conditions.

Poster PS1-P4

Variability of oceanological conditions in the southern Pacific and structure of the pelagic ecosystem

Pavel **Chernyshkov** and E.N. Timokhin

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The southern part of the Pacific Ocean has a more extended boundary (about 3500 nm) with Antarctica as compared to the Atlantic and Indian Oceans, the larger volumes of the intermediate Antarctic water rich in nutrients penetrate into the temperate latitudes. Under the impact of cyclonic and anticyclonic circulations in the ocean frontal zones, this water mass ascends to the surface, where relatively isolated zones of high biological productivity, able to support individual jack mackerel stock units, are formed. Analysis of the principal components and classification (Word's method) of the atmospheric pressure (month, 1960–2008) and sea-surface temperature (month, 1982–2008) fields allowed considerably different areas in the seasonal and inter-annual variability patterns in the South Pacific Ocean to be revealed. Analysis of the ocean level anomalies on the basis of satellite altimetric data (month, 1992–2008) allowed determine zones of intensive eddy formation associated with the main frontal zones of the ocean upper layers to be determined. The results of measurements under the World Ocean Circulation Experiment (WOCE) programme indicated the existence of three closed circulations of the Antarctic intermediate water mass which is rich in nutrients. This water mass is ascends to the surface and is influenced by mesoscale eddies, facilitating the existence of relatively isolated zones with high biological productivity. In these zones the existence of individual jack mackerel stock units is possible.

Poster PS1-P5

The GLOBEC programme in Spain: a decade of marine ecosystem research

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In this presentation we review the contribution of Spain to GLOBEC during the lifetime of this programme. Around 50 individual projects funded by national, regional or European programmes have fed the activities performed. The effort made by the IEO (Spanish Institute of Oceanography) has also been important in maintaining a monitoring programme at several transects around the Spanish coast (Project Radiales). This effort to generate temporal series has been also supported by the Spanish Research Council (CSIC) and the Science Ministry, and recently followed by other institutions such as AZTI. The coordination of activities in the framework of GLOBEC Spain has been done through the GLOBEC Spain committee, and especially at the different symposia dedicated to this programme, from the first at El Puerto de Santa María (Cádiz) in 2001 to the last in Valencia in 2007. A special volume of the journal Progress in Oceanography (Echevarría *el al*., 2007) included a synthesis of the research done during the programme, with inclusion of GLOBEC activities in Portugal, thus including the whole Iberian peninsula for this synthesis. Spanish researchers have contributed to the four foci of GLOBEC and to most GLOBEC regional programmes, but especially to SPACC, CCC and Southern Ocean GLOBEC.

Poster PS1-P6

Ocean-climate variability and zooplankton in the Balearic Sea, western Mediterranean

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A central question in the current debate on climate effects on marine ecosystems is the impact modifications in climate could have on the functioning of marine ecosystems. Here we use a variety of techniques to demonstrate the downscale pathways linking the ocean-climate variability in the North Atlantic and the dynamics of hydro-climate conditions in the Balearic Sea, a boundary hydrographic area of the western Mediterranean. We show that such a relationship has substantially increased as increased extreme values of the North Atlantic climate. The close link between large and regional climate is captured by the variability of zooplankton functional groups during the years 1994–2003. These results suggest a bottom-up control modulated by the climate forcing on the hydrographic variability of the Balearic area. These results suggests that the consequences of such climate forcing may affect patterns of spatial distribution of small pelagic fish in the Balearic Sea as they appear to be driven by mesoscale hydrodynamic features.

Poster PS1-P7

Are surface swarms of *Meganyctiphanes norvegica* a response to passing internal waves?

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Transient surface and subsurface swarms of euphausiids (*Meganyctiphanes norvegica*, North Atlantic krill) are a regular biological feature in the Gulf of Maine, particularly on regions of the shelf with pronounced subsurface topography. It is well known that these topographic features are commonly associated with feeding areas of large mammals and seabirds and also mark fertile fishing grounds for commercial and recreational fishermen. In this study we are investigating the potential role of large- and small-scale fluid

features created by local topography in driving the swarming behaviour of krill. Acoustic Doppler profiling, CTD casts, and vertical temperature profiles were used to establish the presence and dynamics of internal waves on Platts Bank (35 nmi offshore in the Gulf of Maine). Fluid motion at the scale of the krill (cm scale) was measured using a Nortek velocimeter suspended from a spar buoy (to minimise the effects of surface wave motion in our measurements) during the passing of large internal waves. Field data was used to calibrate a small laboratory flume to quantify the behavioural and physiological thresholds of individual krill to unidirectional flows and shear stresses simulating the fluid characteristics of the internal waveforms. Trials are ongoing.

Poster PS1-P8

Zooplankton distribution and Little Auk feeding in Spitsbergen marine frontal zones – is there a carrot among the weeds?

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The Arctic is considered a very susceptible region for climate change. It is hypothesized that the true Arctic animals, such as the planktivorous Little Auks (*Alle alle*), will be affected first, and the most, due to deteriorating feeding conditions. Little Auks main food during the chick rearing period is the energy-rich Arctic copepod *Calanus glacialis* associated with cold waters of Arctic origin. In the years with a stronger influx of warm Atlantic waters, the availability of this preferred food in Spitsbergen area will be systematically declining, and of less calorific, Atlantic *Calanus finmarchicus* increasing. Little Auk colonies on Spitsbergen are distributed unevenly on the west coast, and are naturally exposed to various oceanographic conditions and, as a consequence, to changes in availability of potential prey. Here we present results of study on zooplankton composition and abundance in the potential feeding grounds of Little Auks in two different areas of the West Spitsbergen Shelf, adjacent to Magdalenefjorden (influenced by the warm Atlantic West Spitsbergen Current) and Hornsund fjord (predominated by the cold South Cape Current), along with results of simultaneous study on breeding and feeding ecology of Little Auks in two huge, nearby colonies in Magdalenefjorden and Hornsund. In the study year of 2007, in spite of prevailing Atlantic conditions on the shelf in the Magdalenefjorden area, the abundance of the Arctic *C. glacialis* in the sea (37 ind m^{-3}) was comparable to the one in the Hornsund area (55 ind m^{-3}). However, the proportion of Arctic to Atlantic food items was 1:14 in Magdalenefjorden, while it was 1:1 in Hornsund area. In both sites Little Auks fed their chicks mainly on coldwater *C. glacialis*, but the proportion of the coldwater copepods was greater in food loads in Hornsund than Magdalenefjorden. No differences were found in total abundance, biomass and energy content of zooplankters delivered to Little Auk chicks in each colony. However, the number of high energy meals (>30 kJ) was higher in Hornsund.

The longer duration of foraging trips, and higher number of feedings in Magdalenefjorden, could be a result of a lower rate (1:14) of the profitable prey items in the zooplankton community close to the colony. This might force parent birds to spend more time on feeding grounds of suboptimal condition, because selecting the preferred food items, such as *C. glacialis*, among abundant *C. finmarchicus*, may resemble “searching for a carrot in the field overgrown with weeds”, and is most probably time-consuming. Similarly a high proportion of *C. glacialis* in the Little Auk diet in the two studied colonies seems to support the notion that in spite of higher foraging effort (higher number of feedings and longer duration of foraging flights) of the birds from the Magdalenefjorden colony, they are still able to provide chicks with the amount of food required for their growth and development. The present study suggests that Little Auks breeding on Svalbard are threatened by climate change, causing increasing influx of Atlantic waters, advecting boreal zooplankton to the Arctic Ocean. As a result, availability of high energy Arctic copepods preferred by Little Auks will decrease, and consequently, their time and energy budget, breeding success and range of breeding distribution will deteriorate. However, this effect will be detectable in a longer perspective and at present the birds are able to compensate for this by a little modification of their feeding behaviour.

Poster PS1-P9

A preliminary study on factors shaping the distribution patterns of heterotrophic nanoflagellate in the Yellow Sea Cold Water Mass region and ambient waters

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The importance of environmental factors, prey resources and predators in shaping the distribution patterns of heterotrophic nanoflagellates (HNF) were evaluated in the Yellow Sea Cold Water Mass (YSCWM) region and ambient waters in October 2006. The abundance of HNF ranged from 303 to 1388 cells/ml in the study area, with an average of 884 cells/ml and a carbon biomass of about115.6% of that of bacteria. HNF were more abundant in the upper 30 m of the water column, and the cell density of HNF declined vertically form surface to bottom in most stations. Based on the depth of the mixed-layer and the data of bottom temperature, the sampling area was divided into two regions. Region-I was inside YSCWM and characterised by lower bottom temperature (<10°C) than that in Region-II (>10°C). The abundance of HNF was 364–908 cells/ml and 303–1388 cells/ml in Region-I and II, respectively, and independent-samples T-test showed a significantly lower abundance of HNF in Region-I than in Region-II ($p<0.05$). In Region I, the distribution pattern of HNF was basically in accordance with water temperature, while, in Region II, the pattern was more alike that of its prey, i.e. heterotrophic bacteria and *Synechococcus*. When the complete data set was considered, Pearson correlation analysis revealed that HNF abundance was significantly correlated with water temperature ($p<0.01$), salinity ($p<0.05$) and the abundance of *Synechococcus* ($p<0.05$). A step-wise regression analysis indicated that the abundance of *Synechococcus* together with water temperature could best explain the variation of HNF abundance in the study area. Thus we concluded that water temperature plays the most vital role in shaping the distribution pattern of HNF, and bottom-up control by bacterial food supply might be more important in regulating the population dynamics of HNF than top-down control by grazing in this area.

Poster PS1-P10

A preliminary study on bacterivory of heterotrophic nanoflagellate upon heterotrophic bacteria and cyanobacteria in the Yellow Sea Cold Water Mass area

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Predation on bacteria and cyanobacteria (*Synechococcus* spp.) by heterotrophic nanoflagellate (HNF) were measured at three stations in the Yellow Sea Cold Water Mass (YSCWM) area in October 2006. It was shown that the densities of HNF, bacteria and cyanobacteria were $0.36–1.13\times10^{3}$, $0.39–1.13\times10^{6}$ and $0.04–3.74\times10^{4}$ cells mL^{-1} respectively. The ingestion rate of heterotrophic bacteria, estimated on the basis of uptake of fluorescently labelled bacteria, varied from 5.33–14.89 cell HNF^{-1} h^{-1}. The grazing rate on cyanobacteria was calculated to be $0.26–23.10\times10^{-2}$ cell HNF^{-1} h^{-1}. HNF removed only 9.27–33.08% of bacterial biomass and 2.66–13.10% of bacterial production, while the consumption upon cyanobacteria was 8.12–16.09% of the production, indicating that the predation by HNF was unlikely to be responsible for the main fate of these two planktonic bacteria and their production in the YSCWM in autumn.

Poster PS1-P11

Sediment resuspension mechanisms and their effect on nutrient exchange in the aquaculture area of Sanggou Bay

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Sediments are the most important component of water environment, most trace elements and nutrients are associated with the surfaces of sediment particles, and are transported, deposited, and eventually buried with the sediments. Sediment resuspension, which is known to affect nutrient biogeochemical cycling and deposition of sediments, has long been recognised as an important internal process for the mobilisation and transportation of the trace metals and nutrients in shallow seas, coastal areas, lakes and ponds. While until now, less attention has been paid to the aquaculture area. Sanggou Bay (37°01'–37°09'N, 122°24'–122°35'E) located in Shandong province of China, is a small bay with a mean depth of 7.5 m, total area of about 133 km^2, opening to the ocean

and occupied by several types of aquaculture, e.g. kelp *Laminaria laminaria*, oysters *Crassostrea gigas* and scallops *Chlamys farreri* in lantern nets. It is one of the most intensively cultured bays in China. Based on the Bachmann concept of dynamic ratio which equals the mean water depth (m) of the lake divided by the square root of lake area (km^2), the dynamic ratio of Sanggou Bay is 1.54, which means that it has the potential dynamic condition for sediment resuspension. Due to low nutrient inputs from rivers, it is possible that the process of sediment resuspension plays an important role in nutrient supply to sustain the high production of macro-algae which is estimated as ~80 000 tonnes per year. Two investigation periods were conducted in May 2005 and April 2006. The parameters monitored included wind data (direction and speed), current (speed and direction) and turbidity (NTU) which were measured by a portable automatic weather station, Nortek 6M ADV and YSI 6600. Current-only bed shear stress and the orbital velocity near the bed were estimated by traditional velocity squared relation and linear Airy wave theory respectively. Taking the key factor (angle θ) into account, the combination effect between wave and current are computed by a special equation. As resuspension of sediment is highly controlled by the bottom shear stress, suspended sediment concentration (SSC) data have been used as the indication factor to identify resuspension. Moreover, adsorption-desorption characteristics of nitrogen and phosphate onto sediments were studied in the laboratory simulating conditions to get the equilibrium mass concentration (EPC0) value for distinguishing the function of resuspended sediments. Results showed that wind-waves and currents were the dominant driving force for sediment resuspension in Sanggou Bay. The correlation between SSC and turbidity (NTU) is $SSC = 15.908 \times \ln(NTU) + 7.0888$ ($n = 33$, $R^2 = 0.7209$). The critical shear stress for sediment resuspension in Sanggou Bay is about 0.059 N/m^2. The maximal stress depth is about 8.81 cm and the magnitude of sediment resuspension flux is 10^{-5}–10^{-6} kg m^{-2} s^{-1}. The suspended sediment concentration by resuspension can be predicted by a special model. The equilibrium mass concentration of nitrogen and phosphate is 5.72 µmol/L and 0.903 µmol/L, respectively. Combined with the concentration in different seasons in water column, it can be estimated that the function of resuspended sediment is as follows: nitrogen and phosphate source in spring; nitrogen sink and phosphate source in summer and autumn and nitrogen and phosphate sink in winter.

Poster PS1-P12

Long-term variations of ecosystem structure in the Laizhou Bay of Bohai Sea, China

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Based on long-term ecosystem observations from 1959 to 2008 during the main spawning period (May) in the Laizhou Bay of Bohai Sea changes in biomass and species composition of marine living resources, zooplankton, phytoplankton and nutrients were analysed. The biomass of living resources declined continuously from 423.6 kg/h in 1959 to 164.6 kg/h in 1982, 37.7 kg/h in 1993, and to less than 8 kg/h during 1998–2008. Meanwhile, the abundance of phytoplankton had increased from 1959 to 1982, then largely decreased in 1993, and increased again until 2004, but has been at very low levels in recent years. The dominant species of phytoplankton varied in different years. The biomass of zooplankton showed a increasing trend from 1959 to 2006 and slightly declined in 2008, the dominant species of zooplankton has not largely changed, but varied between *Calanus sinicus*, *Sagitta crassa* and *Centropages abdominalis*. The ratio of N:P has increased, and the ratio Si:P and Si:N have declined to disequilibrium during the same period. The variations of major nutrients and decreased runoff with sand from the Yellow River influenced by climate change and human activities may have a serious impact on the primary production, and subsequently on the structure and function of the ecosystem.

Poster PS1-P13

Measuring the behaviour of individual mesopelagic crustaceans - in homage to Haeckel

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Enormous challenges are encountered in trying to assess the behaviour of mesopelagic crustaceans both *in situ* and in the laboratory - particularly when the laboratory is at sea. Pelagic organisms generally do not appreciate being dragged from the cool, still and dark depths and dumped in a brightly lit aquarium where water movement in enclosed spaces generates confusing signals. Observing behaviour in such circumstances is challenging. We

describe a method that has been developed for use primarily with euphausiids and that has revealed information pertaining to reproductive, feeding and moult-stage specific behaviours of individual animals. The results of such work, while less satisfactory than direct observations of animals in their natural environment, can (as we have demonstrated) shed empirical light on hypothesised ecological and global processes.

Poster PS1-P14

Dinoflagellate cysts as indicators of the sewage impact on coastal waters in the greater Victoria region of southern Vancouver Island

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Concern about human-induced coastal eutrophication has prompted a search for biological indicators that can be used to assess present and past status of estuarine health. Since primary producers are sensitive to water temperature, salinity, light and nutrient availability paleoenvironmental reconstructions can be made based on the proxy indications of microfossils extracted from marine sediments. In this work we focus on the application of sedimentary dinoflagellate cysts and the diatomaceous proxy biogenic silica to estimate the possible impact of the greater Victoria region of southern Vancouver Island's current wastewater management practices on local phytoplankton. Three submerged outfall systems discharge raw sewage, after screening for solids, directly into coastal waters that are located within a complex physical environment. Despite dispersal by strong tidal currents and mixing of high-nutrient oceanic input into the estuarine circulation within Juan de Fuca Strait, the basin topography may allow for localised cultural eutrophication. This study investigates the impact of effluent by comparing organic-walled dinoflagellate cyst abundance and diversity from 37 surface sediment samples collected at randomly selected sites in September 2007 and July 2008. Site locations include those directly adjacent to the wastewater outfall at the Saanich Peninsula and Clover and MacCaulay Points, as well as from a variety of near-shore environments with differing tidal flow influences inclusive of Esquimalt Harbour, Cadboro, Cordova and Saanichton Bays. Excellent dinoflagellate cyst assemblages have been recovered and 32 cyst taxa were identified. In general, dinoflagellate cyst assemblages are characterised by a relatively high proportion of cysts produced by heterotrophic dinoflagellates (species of Protoperidiniaceae, Diplopsalidaceae and Polykrikaceae groups). The most common autotrophic cyst-producing taxa are *Protoceratium reticulatum*, *Pentapharsodinium dalei*, *Gonyaulax spinifera* complex and *Alexandrium* type species. Cyst abundance, species richness, the proportion of cysts produced by heterotrophic and autotrophic dinoflagellates and the composition of cyst assemblages are known to reflect spatial variation in two abiotic factors. Increased proportions of heterotrophic taxa, in particular cysts of Diplopsalidaceae and Polykrikaceae species, characterise areas affected by eutrophication as increased nutrient availability likely increases production of their prey, including diatoms. This signal is found directly adjacent to all three sewage outfalls, as well as in the more stagnant waters of Esquimalt Harbour and Cadboro Bay, and correlates with the concentration of biogenic silica in these sediment samples. Enhanced production of potentially toxic species, such as *Alexandrium* spp., is also observed in these areas. Sustainable management of urban coastlines requires detailed knowledge on both natural and anthropogenically-driven forcings that enact environmental change. Predictions on future phytoplankton production may be estimated using anticipated values of effluent discharge. Due to the basin topography of southern Vancouver Island, the potential of eutrophication and subsequent increase in production of toxic species is of greatest concern.

Poster PS1-P15

Spatial distribution of phytoplankton and primary production of the Yellow Sea in January 2008

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The Yellow Sea is a shelf sea surrounded by the Korean peninsula and the eastern coast of China. Phytoplankton abundance, photosynthetic pigments, and primary productivity of the Yellow Sea were studied in January 2008. In the Yellow Sea, nanoflagellates were special dominant species in 41 samples from a total of 57 samples and Cryptomonads and *Skeletonema costatum* occurred as the dominant species during the winter. The average phytoplankton abundance was 184,970 cells l^{-1} and chlorophyll-*a* concentration was 1.44 µg l^{-1} (microplankton: 18%, nanoplankton: 30%, picoplankton: 52%). The diatoms, which have diadinoxanthin and fucoxanthin as major pigments, showed a low concentration of pigments, and the flagellates, which have

peridinin, alloxanthin and chlorophyll *b*, showed a relatively high concentration of pigments. The average primary production of the Yellow Sea in January was 114.6 mg C m^{-2} d^{-1}. Vertical distributions of phytoplankton were homogeneous due to a turbulent mixing induced by wind and meteorological events. However three distinct water masses were identified by regional differences of physical characteristics; the western part, the southeastern part, and the middle of the Yellow Sea. In the western part of the Yellow Sea, the water masses is characterised by lower temperature, lower salinity, higher biomass, and higher primary production than the water mass in other regions. Size fractionated chlorophyll-*a* concentrations of the western part (microplankton: 60%, nanoplankton: 26%, picoplankton: 14%), the middle of the Yellow Sea (microplankton: 11%, nanoplankton: 22%, picoplankton: 67%), and southeastern part (microplankton: 15%, nanoplankton: 52%, picoplankton: 33%) showed distinct compositions. This study indicated that the physical characteristics of water column significantly influenced the distribution of the phytoplankton and primary production of the Yellow Sea in the winter.

Poster PS1-P16

Seasonal abundance and development of *Calanus sinicus* in relation to phytoplankton and hydrography in the southern Yellow Sea

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Calanus sinicus occurs continuously throughout the year in the Yellow Sea, but both its abundance and distribution show a strong seasonal variation. The objective of this study was to highlight major seasonal differences in the abundance and development of this copepod in the Southern Yellow Sea, in order to discuss the relationships between their life cycle, food availability and hydrographic conditions. Data for this study were collected from five cruises along a transect crossing the Southern Yellow Sea from September 2006 to August 2007. During the summer-autumn period, *C. sinicus* is mainly distributed in the Yellow Sea Cold Water Mass (YSCWM) where the temperature was below 12°C although the chlorophyll-*a* concentration was low (<1 mg m^{-3}). The CV copepodites dominated the population which means that the population was in the diapause. In the winter, the abundances decreased to the lowest in the year, but the proportion of mature females gradually increased to the major composition. In the early spring, the abundances started to increase with the phytoplankton increasing in the coastal areas. Also the proportion of young copepodites (CI-CIII) increasing indicated that the new generation was developing. The abundances were highest in the spring and the population was well developed and the old copepodites (CIV-CV) and adults became dominant. In the summer, the abundances decreased and their distribution shrinked again to the YSCWM. Although the higher temperature (>23°C) restricted the distribution, the food availability is more important to shape the population dynamics of *C. sinicus* in the Southern Yellow Sea.

Poster PS1-P17

Exploring marine mammal and forage fish interactions

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As populations of humpback whales and seals increase in the Strait of Georgia, there is concern about the dietary interaction between marine mammals and fisheries. In this study, we use an Ecosim ecosystem simulation model to explore this situation. We compare the current ecosystem with mammals present in the Strait of Georgia with scenarios where all marine mammals are removed, reduced or increased. We compare model projections of total yield and abundance of the main commercial species and the health of the ecosystem is also discussed in terms of the resilience, diversity and mean trophic level. Monte Carlo simulations and alternative dietary assumptions address the principal uncertainties in our results.

Poster PS1-P18

Relationship between the "dead zone" and phytoplankton blooms off the Changjiang Estuary

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Multidisciplinary marine investigations in the Changjiang River estuary and the adjacent coastal waters of the East China Sea were carried out for three cruises in June, August and October 2006, in order to get a better understanding of the relationship between spatial and temporal variability of phytoplankton productivity and formation and evolution of the "dead zone" (DOC, 2 mg L^{-1}) at the bottom water of the studied area. It was found that hypoxia zones (DO©,3 mg L^{-1}) existed in the coastal area of Zhejiang in all the three cruises during summer and autumn, while the large area of the dead zone (DOC, 2 mg L^{-1}, about 17,500 km^2) only appeared in the northern Changjiang River estuary in August, when phytoplankton productivity reached the highest values for the year. In comparison between field and remote sensing data of phytoplankton, it was revealed that the distribution of the hypoxic zone and the degree of hypoxia at the bottom layer in the Changjiang River estuary were closely related to the timing of the phytoplankton bloom. Decomposition and oxygen consumption of mass dead and settled phytoplankton at the bottom, following the upper layer phytoplankton blooms formed the hypoxic zone under conditions of oxygen supplementation being blocked by the thermocline. In August 2006, the major hypoxic zone in the Changjiang River estuary shifted northwards markedly relatively to the former. Moreover, its area increased greatly, and reached to over 17,500 km^2 within the observed region only. It was also found that the northward shifting of the hypoxic zone was closely related to the decrease in the Changjiang River runoff, which is caused by hot and dry weather on a large scale of the Changjiang River valley in summer and autumn of 2006, and the Taiwan Warm Current.

Poster PS1-P19

Variations of bacterial community structure in different habitats in China Sea

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The predominant bacterial community composition was analysed by PCR-Denaturing Gradient Gel Electrophoresis (DGGE) in hypoxic areas of the Changjiang estuary and the Yellow Sea Cold Water Mass (YSCWM). For hypoxia in the Changjiang estuary, DGGE bands reflecting various phylotypes were excised cloned and sequenced (25 and 24 respectively). Phylogenetic analysis of 25 cloned bands showed that bacterial phylotypes were made up by four phyla of bacteria: Proteobacteria, Cytophaga-Flavobacteria-Bacteroides, Firmicutes and Cyanobacteria. In spatio-temporal comparisons the bacterial community composition was different between hypoxia and non-hypoxia. There were four phyla in hypoxia, Proteobacteria, Cytophaga-Flavobacteria-Bacteroide, Firmicutes and Cyanobacteria, but no Cyanobacteria in non-hypoxia. The predominant bacterium was Flavobacteria in hypoxia in August. For YSCWM, the results analysed by Glyko Bandscan software showed that samples from all stations in April and stations in the YSCWM area in October had almost the same number of DNA bands (17 and 16 respectively) with high diversity. However, samples from the stations out of the YSCWM area had fewer DNA bands (about 12) with lower diversity. Phylogenetic analysis of 24 cloned bands showed that bacterial phylotypes were made up by two phyla of bacteria, Proteobacteria and Cytophaga-Flavobacteria-Bacteroides. It indicated that bacterial community composition, as well as the predominant bacterial groups, from all sampling stations in April (the temperature of seawater was around 7–12°C) and the interior of the YSCWM in October (≤10°C) was the same, and different from the exterior of the YSCWM (≥19°C). By comparing samples from the exterior of the YSCWM, the predominant bacteria groups were different with the different sampling stations. So it is suggested that bacterial community composition and the characteristics of predominant bacteria of the YSCWM may have something to do with the development of the YSCWM.

Poster PS1-P20

Succession of the bacterial community during the spring diatom bloom in the Yellow Sea

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The succession of the bacterial community during the spring diatom bloom and comparison between the bloom area and non-bloom area were investigated for the first time in the Yellow Sea. The surface chl-*a* concentration reached as high as 9.33 mg/m^3 and the vertical distribution of chl-*a* concentration changed dramatically in 24 h. The bacterial community was studied by PCR-Denaturing Gradient Gel Electrophoresis (PCR-DGGE) analysis and 16S rDNA clone libraries. The results examined by PCR-DGGE indicated that Alphaproteobacteria and Cytophaga-Flavobacteria-Bacteroides were predominant bacterial communities at the pre- and post-bloom, with Alphaproteobacteria predominating during the decline of bloom, whereas Alphaproteobacteria and Gammaproteobacteria were predominant bacterial communities in the non-bloom area. The clustering results of DGGE profile analysis by Quantity one and NTsys-pc2.02 software showed that the bacterial community in the bloom area were different from the non-bloom area. 16S rDNA clone libraries revealed that four libraries in the bloom area were dominated by Alphaproteobacteria, Gammaproteobacteria and the Cytophaga-Flavobacteria group, while three libraries of the non-bloom area were dominated by Alphaproteobacteria, Gammaproteobacteria, and unidentified bacteria. In the bloom area, the dominant operational taxonomic units (OTUs) were the Roseobacter and Cytophage-Flavobacteria groups at the peak- and post-bloom, whereas the numbers of Cytophage-Flavobacteria decreased sharply and Roseobacter became the only predominant OTU at the decline of bloom. In contrast, dominance of the OTUs with higher numbers was lower in the non-bloom area than the bloom area, and so no especially dominant OTUs were shown. Moreover, the Roseobacter OTUs were dominated by the NAC11-7 group during the bloom, with more clones at the decline of bloom. The results implied that bacteria from the Roseobacter and Cytophaga-Flavobacteria lineages occupying different niches are actively involved in the biogeochemical processes of POM and DOM during the bloom.

Poster PS1-P21

The zooplankton of Marguerite Bay, western Antarctic Peninsula: abundance, distribution, and controls on interannual variability

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The zooplankton community of Marguerite Bay, western Antarctic Peninsula, was studied during the austral autumn of 2001 and 2002 using net and environmental data. Interannual differences were observed in species composition and abundances, with generally higher densities in autumn 2001, which were linked to unusually high chlorophyll concentrations in the Bellingshausen Sea and Marguerite Bay during spring-summer 2000/2001. Copepods were more abundant in 2001 (means: 24,362 and 9,496 ind m^{-2} in 2001 and 2002, respectively), with *Calanoides acutus* and *Metridia gerlachei* dominating the community (means: 52 and 38% of total copepod abundance, respectively). In 2002, several species dominated, including *M. gerlachei* (32%), *Ctenocalanus* spp. (27%), *C. acutus* (18%), *Oithona* spp. (10%), and *Paraeuchaeta* spp. (8%). Euphausiid abundances were similar between years; however species composition showed interannual differences. *Thysanoessa macrura* dominated numerically during 2001 (geometric mean: 45.9 ind m^{-2}, 84% of total euphausiids), while *T. macrura*, *Euphausia crystallorophias*, and *E. superba* had similar abundances during autumn 2002 (16.2, 18.5, and 14.8 ind m^{-2}, respectively). *C. acutus*, *M. gerlachei*, and *T. macrura* showed a rapid population response to elevated chlorophyll concentrations during spring-summer 2000/2001, evidenced by the abundant juveniles and adults present during autumn 2001, whereas *E. superba* and *E. crystallorophias* had a longer term response, which resulted in increased recruitment in 2002. Other abundant zooplankton in Marguerite Bay included ostracods, pteropods, chaetognaths, polychaetes, medusae, amphipods, and mysids. Salps were present only occasionally and in low abundances. Overall, copepods were distributed deeper in the water column during autumn 2001, with mean depths of maximum abundance of 173 m in 2001 and 121 m in 2002, which is possibly the result of a combination of 1) the cruise taking place a month earlier the season in autumn 2002, and

2) reduced predation pressure from *E. superba* and other omnivorous/carnivorous zooplankton during the same year. Although the mean depths of maximum abundance for *E. superba* (102 and 105 m for 2001 and 2002, respectively), *E. crystallorophias* (107 and 79 m) and *T. macrura* (123 and 102 m) were not significantly different within or between years, the three species rarely overlapped at a given location, suggesting that these euphausiids vertically partition their habitat.

Poster PS1-P22

Seasonal vertical distribution of copepods in the central Gulf of California, Mexico

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This study represents the first attempt to understand the vertical distribution pattern of the epipelagic copepods in the Gulf of California. This area is probably one of the most studied regions in Mexico due to its high productivity, high biodiversity, and economical relevance. Zooplankton studies, however, have been focused mostly on copepod distribution and abundance obtained mainly from oblique Bongo net collections. Vertical zooplankton samples were collected using horizontal opening and closing nets at five depth strata (0, 25, 50, 75 and 100 m) during January and July 2007 in the central Gulf of California. Vertical distribution of environmental conditions during winter, showed a well mixed water column (average 90 m depth), and an oxygen minimum layer depth ($<1.5\ mg\ O_2\ L^{-1}$) at 120 m. Whereas during summer we observed a relatively shallow thermocline (20–50 m), and the low oxygen minimum layer depth (90 m) extended further north than during winter. These shifts in the thermohaline vertical structure and hypoxic conditions determined a strong change in the copepod community. During winter, *Pleuromamma gracilis*, *Calanus pacificus*, *Rhincalanus nasutus* and *Scolecithrix danae* accounted for the highest copepod abundance (weighted mean depth) and distributed in the first 50 m depth independently of the day/night collection time. This suggests non-migratory vertical behaviour, closely associated with the maximum chlorophyll-*a* depth (50 m). In contrast, the chlorophyll maximum occurred near the surface in summer, the weighted mean depth indicated higher density copepod populations located below the thermocline, and the copepod community was composed mainly of small tropical species like *Centropages furcatus*, *Clausocalanus furcatus* and *Canthocalanus pauper*. Our results suggest that the water mass circulation prevailing during each season of the year in the central gulf is the main driving force that structures the copepod vertical distribution relating most copepod species with the thermo-haline vertical structure of the water column and less with the availability of food, in terms of chlorophyll-*a* concentration.

Poster PS1-P23

Impact of environmental change on demersal fish growth: a comparative study

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The questions investigated in this presentation are how do environmental factors influence fish growth, and does this influence differ among ecosystems? The potential impact of recent climate change on fish physiological functions is difficult to comprehend overall, but there is general agreement that temperature can have a direct impact on the timing of reproduction and growth rate of young-of-the-year fish. Here, we focused on the impact of environmental variations on demersal fish growth. Using data from bottom trawl surveys, we estimated the size of young-of-the-year as the mean and standard deviation of the first peak in length-frequency distributions for different demersal fish populations for which no age data was available. Using multivariate regression we then examined which of the environmental parameters (water temperature, food input - i.e. primary production - and abundance of competitors) might best explain interannual variations in size. These investigations were carried out for hake, whiting, blue whiting, red gurnard, pout, poor cod and black seabream in four ecosystems: the North Sea, the Celtic Sea, the Bay of Biscay and the Gulf of Lions in the Mediterranean Sea. Across species and among ecosystem comparisons allowed us to separate species-specific effects from area dependent impacts.

Poster PS1-P24

Grazing by larval Antarctic krill and phytoplankton dynamics during the fall west of the Antarctic Peninsula

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Interactions between larval Antarctic krill, *Euphausia superba*, and the phytoplankton community during the austral autumn west of the Antarctic Peninsula are important to 1) variations in the autumnal decline in the standing stock of phytoplankton available in the water column to be scavenged during sea ice formation creating the base of the sea ice microbial community, and 2) the condition of the larvae and their ability to withstand periods of starvation as they enter the winter season. A grazing model for larval Antarctic krill was based on a series of laboratory experiments conducted at two temperatures and with chlorophyll concentrations ranging from 0.5 to 8 µg chl-*a* per litre. Larval krill were collected from the field and ranged in stage from furcilia 2 to furcilia 6. The functional response curve for each temperature showed a non-linear dependence on chlorophyll concentration, with ingestion rate increasing with increasing body weight as expected. However the allometric weight exponent was not significantly different from zero at either temperature, suggesting that in these early life history stages the weight effect is linear. There was an approximate doubling in the grazing rate with the three degree temperature increase between -1.5°C and + 1.5°C. The functional response curve for grazing was used in conjunction with a primary production model parameterised with estimates of photosynthesis vs irradiance response curve, mixed layer depth and euphotic zone depth from the 2001 and 2002 Palmer LTER and SO GLOBEC field seasons, and weekly temperature records from Palmer Station and Rothera Base (British Antarctic Survey). At high larval concentrations such as found west of Marguerite Bay in the autumn of 2001, larval krill grazing was a significant loss term in the decline of phytoplankton biomass in autumn, but not in years of low larval numbers. Grazing in the early austral autumn, with higher phytoplankton standing stock and higher temperatures, may serve as a critical energy input for larval krill prior to winter.

Poster PS1-P25

Scavenged aluminium during the spring bloom and its records in the sediments of the Yellow Sea

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The oceanic distribution of aluminium is primarily controlled by external sources and rapid scavenging from the water column, and is often applied as a sensitive tracer of water masses in the coastal and offshore seawater. The distributions of dissolved aluminium in the Yellow Sea showed the effect of land-source inputs from adjacent rivers (e.g. Huanghe and Changjiang) and the dissolution of the spring dust storm, with obvious seasonal variations. It was observed during a cruise in 2007 that the concentration of dissolved aluminium in the surface layer was elevated significantly after the intrusion of strong Asian dust storm. Four to five days after the dust storm, a large scale of phytoplankton bloom with concentrations of Chl-*a* up to 12 mg/m^3 occurred in the Yellow Sea. The concentrations of dissolved aluminium in seawater were decreased sharply during the bloom, which indicates the effect of biological scavenging. Initial results of intra- and extra-cellular aluminium during the diatom bloom using trace metal clean reagents are also presented.

Although both aluminium and titanium are traditionally considered to reside within terrigenous phases in marine sediment, extremely high Al/Ti ratios have been found in biogenic sediments from the central equatorial Pacific Ocean. Concentrations of aluminium and titanium in the core sediment collected by multi-corer and gravity corer from typical station in the central Yellow Sea are also presented. The excess aluminium signal can be quantified and varied between 5.4% and 15.9% in the central Yellow Sea, with an average of 11.7%. To understand the mechanisms that control the distribution of aluminium and titanium within marine sediments, the sequential extractions targeting the chemical signatures of the exchangeable carbonate, oxide, organic, opal, and residual fraction of sediment were performed. Dissolved aluminium is preferentially affiliated with the oxide fraction, while titanium is preferentially affiliated with the organic fraction.

Poster PS1-P26

Climate change and poleward shift in a dolphin species at the northeastern Pacific

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The increasing temperature due to global warming causes an isotherm shift poleward, moving tolerable habitats to higher latitudes. Such range shift has been recorded in several plant and animal species. In the last decade, there has been a decline in the presence of Pacific white sided dolphin (*Lagenorhynchus obliquidens*) in the southwest Gulf of California (GOC), which is considered the southern boundary of their distribution. Considering that the thermal environment is physiologically important to animals, we hypothesized that the shifts in their usual geographic coverage, due to long-term climate change, is the cause for their decline in GOC waters. To obtain a conceptual framework needed to discuss such hypothesis, we summarise and analyse current knowledge about Pacific white side dolphin in the southwest GOC and the SST variability at regional scale. Also, we believe that the recovery of the Pacific sardine can be another cause for which this species enter less in to the GOC.

Poster PS1-P27

Hydrodynamic structures in a typical coastal mariculture area of China: observations and simulations

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Seafood produced from mariculture is more and more important in China and a healthy mariculture model needs to be established for sustainable production. Two cruises were carried out in Sanggou Bay, a typical mariculture area of northern China coastal waters, during spring and summer of 2006 in order to study on the nutrient supply for the kelp and shells growth. Hydrological observations were made which revealed many interesting phenomena due to the high density aquaculture. The tidal system is irregular semidiurnal, while the tidal current is regular semidiurnal mainly back-and-forth in the east-west direction. The tidal current flow in from the north, runs along the coast and out from the south during flooding. The outflow is much weaker than the inflow due to the drag of mariculture activities. From the mouth to the top of the bay, data from current meter chains shows that the phase is delayed by one hour. The wave speed is 5.2 km/hour, less than 1/5 of the normal wave speed at this depth. The speed maxima decreased by 71% at these two sites 5.2 km apart. The current at the surface layer is half of that of the bottom layer at the middle of mouth but the phase of the peak is two hours earlier, which is also caused by the long kelp in the water. There forms another boundary layer at the surface due to the mariculture establishments. The current profile has the maximum value in the middle or lower layer and the phase lag propagates from upper to lower depths. These frictions make the current in the bay weaker and the nutrient supply from outside is much less than in normal bays. Based on the observations, two kinds of drag caused by the rafts and the kelp itself were parameterised. A modified POM (Princeton Ocean Model) with these two drags was established to simulate the hydrodynamic structures and assess the half-life time of the Sanggou Bay. Results only indicated the drags caused by the mariculture itself, and the model results were in good agreement with the observations in both the magnitude and the vertical features of the current. Suspended mariculture results in a 40% reduction in the average current speed at the surface, and 71% longer than the average half-life time compared with the absence of mariculture, i.e. disregarding of the physical barriers associated with mariculture will result in a serious overestimation of the nutrient and particle renewal term and overestimation of carrying capacity.

Poster PS1-P28

Long-term changes in the ecosystem of Jiaozhou Bay, China

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According to the annual and seasonal physico-chemical and biological data collected from 14 marine monitoring stations in Jiaozhou Bay in the past 30 years, the changes of the Jiaozhou Bay ecosystem were studied in this study. 1) The air temperature in the region of Jiaozhou Bay showed an increasing trend in the past 30 years, especially in winter. The mean annual and winter air temperature between 1990–2007 was 0.7°C and 1.46°C higher than that between 1973–1990. A similar trend was observed in the change of seawater temperature. The

mean annual and winter water temperature after 1990 was 0.45°C and 1.69°C higher than that before 1990. 2) The nutrient structure in Jiaozhou Bay was changed from a balanced state to unbalanced one before 2001, but the unbalanced state was mitigated after 2001 with the adoption of marine environmental protection measures. As the major composition of DIN, the NH_4^+-N concentration in 2001 was five times higher than that in 1981. With the decrease of NH_4^+-N concentration and increase of SiO_3^{2-}-Si concentration in recent years, the N/P ratio has decreased and the Si/N and Si/P ratios have increased. 3) Both the abundance of phytoplankton and the biomass of zooplankton have increased, especially after 2000. The mean density of phytoplankton and biomass of zooplankton after 2000 were 4.9 and 3.1 times higher than those of before 2000. Dominant species have considerably alternated. Some species such as *Chaetoceros affinis*, *Thalassionema nitzschioides*, *Rhizosolenia setigera*, *Coscinodiscus radiacus* have been replaced by *Asterionella kariana*, *Thalassiosira nordenskioldi* and *Nitzschia paradoxa*. Some eutrophic species such as *Skeletonema costatum* and warm water species such as *Lithodesmium undulatum* increased abundantly. For the zooplankton community, the species number and abundance of medusa increased in recent years. The biodiversity of phytoplankton and zooplankton increased slightly. 4) The total biomass of benthic organisms increased during 1981–2007, which was mainly due to the increase of mollusk biomass. Among the four major benthic groups, the densities of Polychaeta, Mollusca and Crustacea were increased but the density of echinodermata decreased during 1981–2007. The diversity of the benthic community showed an increasing trend before 2001 but declined slightly after that. Above results indicated that the concurrent impact of climate change and anthropogenic activities have led to obvious changes on the structure and function of the Jiaozhou Bay ecosystem.

Poster PS1-P29

Classification of ecological geography of the Yellow Sea

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As defined in the UN Convention on Biological Diversity, a marine ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. However, methodology to delineate the geographical scales and boundaries of a marine ecosystem is yet to be agreed upon, thus rendering it is difficult to understand the structure and functioning of marine ecosystems and to implement the so-called ecosystem-based management (EBM) and biodiversity conservation of marine resources. In this study we aim to classify further the Yellow Sea and the East China Sea Ecosystems into major subsystems, based on perspectives of physical, chemical and biological oceanography and fisheries biology. Through our analysis, we find that the usual geographical definition of the Yellow Sea, namely, north of a line extending from the northern shore of the Changjiang river mouth to the Cheju Island, is not a natural boundary for ecological delineation. Instead, it should be shifted about 100 km southward to offshore of the boundary between the Changjiang Estuary and the Hangzhou Bay. The boundary of the Yellow Sea ecosystem and the East China Sea ecosystem is located near 31°N from the south of the Changjiang Estuary to the south of the Cheju Island. With this understanding, the Yellow Sea ecosystem is divided into three subsystems: the Yellow Sea Cold Water Mass region, the Yellow Sea coastal water region and the region encompassing the southern Yellow Sea and the Changjiang Estuary; while for the East China Sea ecosystem two subsystems are identified: the inner shelf region and outer shelf region. The five subsystems are identified and characterised by features of ecological geography and the major features are as follows: 1) Community structure of high trophic level species in the east continental shelf off China; 2) Ecological geography related to the zooplankton functional groups in the Southern Yellow Sea and East China Sea; 3) Ecological zones of phytoplankton biomass and production in the East China Sea and Yellow Sea; 4) Subsystems of bacterioplankton distribution in the East China Sea and Yellow Sea; 5) Regimes of nutrients in the Yellow Sea and East China Sea–towards the understanding of ecological geography of continental shelf; and 6) Frontal systems and water types in the Yellow Sea and East China Sea.

Poster PS1-P30

Seasonal reproductive biology of *Oithona nana* (Copepoda: Cyclopoida): first record in temperate coastal waters off Argentina

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Oithonids are the most successful free-living cyclopoids in the marine pelagic ecosystem. *Oithona nana* (Copepoda: Cyclopoida) is a widely-distributed neritic species, which often comprises up to 90% of the zooplankton in many coastal areas. However, no detailed studies have been made so far on its reproductive biology. The objective of this study was to estimate, for the first time, the seasonal variation of *O. nana* reproductive rates, in a temperate region: coastal waters off Buenos Aires province, Argentina. Population density was low in late autumn and winter (1800–3424 ind m^{-3}), and high in early spring and summer (3709–12209 ind m^{-3}). The sex ratio was highly skewed for females. Female prosome length changed inversely with temperature ($r^2 = 0.63$; $p = 0.0011$), while egg diameter (mean = 45.01 µm) did not change throughout the year. The number of eggs contained in a pair of sac (mean = 24 ± 3.6 eggs sac^{-1}) was higher during the spring. Embryonic time was inversely related to the temperature ($r^2 = 0.98$; $p = 0.125$), while the interclutch time was independent of it (0.68 ± 0.07 days). Mean population specific egg production rate (0.129 ± 0.10 day^{-1}) and did not show a clear seasonal pattern. However, slightly higher values were observed in the warmest months. It was not significantly correlated with temperature ($r^2 = 0.08$; $p = 0.37$) or chlorophyll-*a* ($r^2 = 0.12$; $p = 0.27$).

Poster PS1-P31

Long-term zooplankton dynamics and environment in the White Sea since 1957

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Continuous observations on the zooplankton community and major hydrological parameters (temperature, salinity) have been held since 1957 at the monitoring station D-1 (65 m depth; 66°19'50''N, 33°40'06''E; Chupa Inlet, Kandalaksha Bay, the White Sea). Samples are taken with a ten day periodicity during the ice free season and monthly from ice. A Juday net (mesh size 170–200 µm, mouth diameter 36 cm) was used for zooplankton sampling and conductometers and reversing thermometers for salinity and temperature measurements. The data set of all zooplankton species abundance (for standard water layers: 0–10, 10–25 and 25–65 m) and data on temperature and salinity at standard depths (0, 5, 10, 15, 25, 50 and 65 m) were combined in one database. There were only minor breaks in observations in 1972 and in 1992–1997. The periodicity and continuity of the investigations are sufficient to analyse seasonal regularities in the zooplankton and to reconstruct life cycles of planktonic animals. The long-term changes of zooplankton abundance (year-to-year fluctuations, trends, cyclicity and correlation with environmental factors) can be also detected with great reliability. The zooplankton abundance demonstrates strong variability from year to year, reaching up to several orders of magnitude in specific cases. However, the abundance of key species usually restores rather quickly, only in some anomalous conditions (in extremely cold years 1966, 1969 and 1971) intensity of changes were so profound that it took more than one year for the community to return to the average state. The coldest year of 1966 was characterised by low air temperatures and stable eastern winds, that kept ice in inlets of Kandalaksha Bay till July, which was absolutely anomalous. Such combination of conditions caused a significant decrease of total zooplankton abundance and biomass not only in 1966, but also negatively impacted the abundance of some warm-water animals in the following year. At the same time extremely warm years had no significant effect on the zooplankton community. Smoothing (5-year moving average) of time series revealed rather prolonged fluctuations of abundance, biomass, temperature and salinity with a period length of five to ten years. The long-term trends of the hydrological parameters were also observed. Thus, yearly temperatures in the 0–65 m layer in the decade of 1998–2007 increased by 1°C (from 1.5 to 2.5°C) and salinity decreased by 1‰ (from 27.4 to 26.6‰) compared to the period 1964–1976; all changes were significant (Mann-Witney U-test, $p = 0.05$). Abundance of different species of planktonic animals also demonstrates various trends, but only in a few cases this parameter correlates significantly to temperature and salinity dynamics. Thus, zooplankton community structure in the White Sea is quite sensitive to anomalous environmental events, but not sensitive to the same extent to long-term trends in hydrological variables. However, the zooplankton community demonstrates the ability to return to its normal state in a few years even in extreme conditions.

Poster PS1-P32

Compound-specific isotope analysis of fatty acids as indicators of trophic interactions in East China Sea ecosystem

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Understanding feeding history is important for evaluating ecosystem performance since material and energetic relationships within marine ecosystems could have important implications for fisheries resources, especially in the period of global climate change. Some traditional techniques, such as stomach content analysis, have been used to examine feeding habits. Fatty acid analysis is an alternative approach to evaluate the trophic interactions in long-term. Composition and compound-specific isotopes of fatty acids were studied within food webs in the East China Sea. The polyunsaturated fatty acid (PUFA) content was in the range of 9–55%. PUFAs are often used as dietary indicators since they can not be created *de novo*. By comparison the composition of compound-specific isotopes demonstrated the close trophic interaction between copepods and *Sagitta*. The different diet structure could be traced from molecular isotopes of *Matapenaeus joyneri* Miers and *Solenocera crassiocornis* with *Acetea chinensis*, the former are mainly benthos feeders while the later is a floating species, although they have a similar composition of fatty acids. Since the feeding habit becomes more complex with increasing trophic level, the examination of the larger size fishes is a challenge. There are many factors can be related to the variation of compound-specific isotopes within same species, such as size and gender.

Poster PS1-P33

Functional groups of fish assemblages and their major species at a high trophic level in the East China Sea

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Fish samples, which accounted for 90% of the total biomass, were collected during two bottom trawl surveys in the East China Sea in autumn of 2000 and spring of 2001 which covered the range of 120°–126.75°E and 25.75°–31°N. Diet trophic guild was used to analyse the functional groups of fish assemblages at high trophic levels in the East China Sea. In cluster analysis, a 60% similarity level was used as the criterion to divide diet trophic guilds of fish assemblages. According to majority rule, prey species of each diet trophic guild were defined as a major predatory item when the mean percentage was greater than 60% of total prey, then each diet trophic guild of fish assemblages were divided into functional groups. Functional groups of two fish assemblages in spring and autumn (including inshore fish assemblages SG3 in spring and AG3 in autumn, offshore fish assemblages SG4 in spring and AG4 in autumn) in the East China Sea were analysed.

Seven functional groups were investigated among fish assemblages at high trophic levels in the East China Sea, including piscivores, shrimp/fish predators, shrimp predators, shrimp/crab predators, generalist predators, benthivores and zooplanktivores. SG3 consisted of four functional groups: zooplanktivores, shrimp predators, benthivores and piscivores, whose dominant species were firefly-fish (*Acropoma japonicum*) and anchovy (*Engraulis japonicus*), small yellow croaker (*Pseudosciaena polyactis*), cardinal fish (*Apogonichthys lineatus*), and brushtooth lizardfish (*Saurida undosquamis*), respectively. AG3 included zooplanktivores, shrimp/fish predators, shrimp predators, shrimp/crab predators, generalist predators and piscivores, whose dominant species were cardinal fish, largehead hailtail (*Trichiurus haumela*), white croaker (*Argyrosomus argentatus*), spearnose grenadier (*Coelorhynchus multispinulosus*), pinkgrey goby (*Chaeturichthys hexanema*), bombay duck (*Harpadon nehereus*) and small yellow croaker in each functional groups, respectively. Functional groups in SG4 included zooplanktivores, shrimp predators, benthivores and piscivores, whose major species were horse mackerel (*Trachurus japonicus*) and firefly-fish, redwing searobin (*Lepidotrigla microptera*), *Thamnaconus hypargyreus*, yellowtail kingfish (*Seriola ialandi*), respectively. AG4 included zooplanktivores, shrimp/fish predators, shrimp predators, benthivores and piscivores, whose major species were largehead hailtail, redwing searobin, fin-striped goatfish (*Upeneus bensasi*), *T. hypargyreus*, horse mackerel in each functional group, respectively.

The composition of functional groups in each fish assemblages of the East China Sea showed remarkable seasonal and spatial differences. According to the biomass, zooplanktivorous fish were the major functional group in the East China Sea in spring, and piscivorous fish were the major functional group in the autumn. Different habits and seasonal migration were the major reasons for the difference in dominant species composition, and different composition of functional groups. Therefore, it is concluded that the difference in species composition of fish assemblages, the difference in size distribution of the same species, the spatial and temporal changes of prey were the main reasons causing the difference in composition of functional groups in each fish assemblage of the East China Sea.

Poster PS1-P34

Large jellyfish assemblage in the Yellow Sea and East China Sea

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Large jellyfish have increasingly tended to form blooms in the southern Yellow Sea and northern East China Sea since the end of the 1990s, which have caused enormous damage to fisheries. However, the baseline knowledge of large jellyfish assemblages is still far from clear in the Yellow Sea and East China Sea. Semi-quantification of the seasonal geographical distribution of biomass of large jellyfish in the Yellow Sea and East China Sea are studied based on swept area method by bottom trawl surveys from 2006–2008. 11 taxa are mainly identified, among them *Nemopilema nomurai*, *Aequorea* spp. and *Ulmaridae* sp. are dominant taxa in the Yellow Sea, and correspondingly, *N. nomurai* and *Cyanea* spp. are dominant in the East China Sea. They display distinct species-specific preference distributions for studied areas. The seasonal pattern of total biomass shows that they are lowest (4.6 ± 9.4 kg km^{-2}) in March when the surface temperature is also lowest during the year, and they increase with the increasing temperature. The biomass is highest (22891 ± 25888 kg km^{-2}) in summer, and then decreases with the drop of temperature. *N. nomurai* and *Cyanea* spp., two bloom forming jellyfish taxa present different geographical patterns: 1) the occurrence of *N. nomurai* mainly in the Yellow Sea (May–December), 2) the appearance of Cyanea spp. mainly in the East China Sea (March or April–October). As for *Ulmaridae* sp., they prefer cold temperature and distribute in the middle part of the Yellow Sea, and their biomass are up to the highest in October; while *Aequorea* spp. is distributed north of 30°N, and their biomass is highest in May. In addition, the potential feeding pressure of collective *N. nomurai* on standing stock and production of zooplankton per day are preliminarily estimated during the bloom period based on several hypotheses, and results show that the potential depletion of *N. nomurai* is very large, even destructive when they are in bloom.

Poster PS1-P35

The seasonal and geographical distribution of hydromedusae, siphonophores and ctenophores in the China Seas

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In recent years, the ecological role of gelatinous zooplankton within coastal marine ecosystems with high production has been of increasing concern globally. This attention is largely a result of the formation of jellyfish and ctenophore blooms which may be intrinsically linked to over-fishing, eutrophication, climate change and species invasions. Therefore, ecological studies of gelatinous zooplankton are significant to fisheries sustainability, biogeochemical cycles and regime shifts due to eutrophication or global warming. Ecological studies on small medusae in the China Seas are very weak partly due to the characteristics of small medusae (not foraging, slimy, fragile), compared with other foraging zooplankton functional groups. Here, we explored the seasonal and geographical distribution, species/taxa composition and abundance of hydromedusae, siphonophores and ctenophores using samples collected vertically by zooplankton nets in Jiaozhou Bay, the Yellow Sea and the East China Sea from 2003–2008. We found that 1) the total abundance of small medusae was 26.4 ± 34.2 ind. m^{-3}, 14.0 ± 17.3 ind. m^{-3} and 0.8 ± 0.66 ind. m^{-3} in the Jiaozhou Bay, coastal area of the East China Sea and Southern Yellow Sea, respectively; 2) the percentage of small medusae occupying the total zooplankton abundance was larger in Jiaozhou Bay and the coastal area of East China Sea (7% and 5.9%, respectively), and smallest in the Yellow Sea (<0.5%); 3) the dominant species such as *Clytia hemisphaericum*, *Obelia* spp., *Muggiaea atlantica*, and *Rathkea octopunctata* appeared in Jiaozhou Bay, by comparison, *Diphyes chamissonis*, *Euphysora bigelowi* and *Pleurobrachia globosa* occurred in the Yellow Sea as well as the species found in Jiaozhou Bay, and *Liriope tetraphylla*, *Solmundella bitentaculata*, *Aglaura hemistoma*, *M. atlantica* and *D. chamissonis* dominated in East China Sea; 4) seasonal replacement of medusae taxa (i.e. hydromedusae, siphonophores and ctenophores) and dominant species were extremely apparent with the temperature and salinity synchronously investigated, the replacement pattern was different but associated from south to north sea area; 5) small medusae were mainly distributed waters shallower than 50 m in the Yellow Sea during all investigated periods. Based on these results and previous studies, the geographical distribution, diversity and abundance of small medusae in the China Seas were compared, reviewed and discussed.

Poster PS1-P36

Seasonal hypoxia off the Changjiang Estuary and in the inner shelf of East China Sea

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Coastal hypoxia off the Changjiang (Yangtze River) Estuary was firstly reported in Chinese literature in 1959. It has become a seasonal phenomenon in the region off the Changjiang Estuary and adjacent inner shelf of the East China Sea in summer, in 2006 the near-bottom hypoxic waters (i.e. DO<2 mg/l) covered an area of >15000 km^2, almost an order of magnitude higher than that observed in 1959. Although the surface area affected by seasonal coastal hypoxia off the Changjiang Estuary and adjacent East China Sea has dramatically increased over last 50 years, the minimum level of hypoxia (i.e. DO = 0.5–1.0 mg/l) does not show any apparent trend. Five cruises were carried out in 2005–2007 from region off the Changjiang Estuary and adjacent East China Sea shelf. Water samples were collected using CTD rosettes, sediment samples were taken by box sampler, multi-corer and gravity corers. On board, seawater samples were analysed for dissolved oxygen (DO) and pH. In the laboratory, water and sediment samples were analysed for nutrients, DOC/POC, trace elements (e.g. Al, As and Se), gaseous species (e.g. CH_4 and N_2O), biomarkers (e.g. pigments, lignin, amino acids and fatty acids), stable (i.e. C-13 and N-15) and radio active (e.g. Ra, Be, Pb, and Th) isotopes. Seawater was also sampled for flow cytometric analysis. DO in near bottom waters was found to be 2–3 mg/l in June and October 2006, but DO dropped to 0.5–1.0 mg/l in the region to the northeast of the Changjiang Estuary in August 2006 with an area of hypoxia of 15000–20000 km^2. Pigment concentrations can be 10 mg/m^3 in the coastal area, which can be 5–10 fold higher than samples collected further offshore. In this region pigment data showed the biomass domination by diatoms followed by dinoflagellates. Moreover, the biomass ratio between autotrophic to heterotrophic species for microbiology increases with higher levels of apparent oxygen utilisation, showing the study area becomes a heterotrophic driven system when hypoxia prevails in the near shore waters, while in oligotrophic waters further offshore in the East China Sea autotrophic processes dominate ($r^2 = 0.47$, $p<0.01$). Such a hypoxic situation has a dramatic influence on the function of ecosystem and biogeochemical cycles in the East China Sea as well. For example, the difference in Ra-226 activity between surface and near-bottom waters tends to increase when the difference in DO between surface and near-bottom waters is higher in coastal areas affected by hypoxia. Other trace elements can also be remobilised by a reduction of DO, particularly for those elements with a high particulate affinity and/or different redox forms in the water column.

Poster PS1-P37

Biomass size-spectra of plankton in the Yellow Sea

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Biomass size spectra (BSS) of net plankton were analysed based on the samples collected seasonally in the southern part of the Yellow Sea. Results showed a constant size distribution of plankton individuals including phytoplankton (100 pg C.ind^{-1}~70ng C.ind^{-1}) and zooplankton (70 ng C ind^{-1}~62 mg C ind^{-1}). The seasonal normalised biomass spectra were linear on a double log plot with the slopes which strongly deviated from the ideal value (slope = –1.22) of a steady pelagic ecosystem. The slope was less negative in autumn and winter than in spring and summer. According to the statistical analysis, plankton functional diversity had more influence on the characteristics of normalised biomass size spectra. Based on the BSS, the trophic pagoda trees of plankton in the Yellow Sea were depicted showing seasonal functional groups compositions of different individual size class.

P2 Ecosystem observation, modelling and prediction

Poster PS2-P1

Modelling physical processes in the northeast Pacific: model-data comparisons for assessing when model skill is sufficient as a basis for ecosystem simulation

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Ecosystem models coupled to physical models have become routine tools in exploring complex interdisciplinary dynamics. Worldwide, coupled physical-ecosystem models are being used to examine how present climate variability and future scenarios of climate change may impact ocean physics and ecosystem function. However, biological and ecological processes and rates that provide pattern in the oceans are very sensitive to the finescale details of the physical domain. If the physical domain of a model is not accurately representing “ocean truth”, it is unlikely that ecological processes that are sensitive to the physics will be accurately simulated. For instance, slight inaccuracies in stratification intensity, mixed-layer depth (MLD), or timing of seasonal mixed layer development can have significant impacts on the timing of spring blooms, and the availability and replenishment of nutrients to surface phytoplankton. All of these in turn, significantly impact phytoplankton-grazer interactions, reproductive rates and secondary production, and ultimately higher trophic level predator-prey dynamics. In this presentation, we evaluate how well a 10 km horizontal resolution ROMS regional model of the northeast Pacific reproduces spatial patterns, and seasonal and interannual signals known from observation. We use approaches that range from the “eyeball” norm to quantitative skill assessment. Evaluation of physical model fields need to include both strong constraint subsurface and gradient features (e.g. stratification intensity) as well as weaker constraint surface features such as sea surface height anomaly and sea surface temperature anomaly patterns.

Poster PS2-P2

Satellite oceanography near the seabird colony on Triangle Island, BC, Canada

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At the largest seabird colony on the British Columbia coast, found at Triangle Island in the Scott Island group off northern Vancouver Island, the growth rate and survival of Rhinoceros Auklet (*Cerorhinca monocerata*) offspring has varied dramatically among years during the past decade, with variability attributed to ocean temperatures at shore stations in spring and possibly to upwelling conditions and availability of sandlance, their preferred prey. In this analysis, we used satellite imagery to examine the ocean conditions within the foraging range of the birds. We mapped the correlation between annual auklet reproductive success and satellite-derived SST and chlorophyll concentration, as seen in 11 years of monthly composite satellite imagery for the period 1998–2008. We show that the annual fledgling production, a season-long measure of reproductive success that integrates events from egg-laying to fledgling, correlates well with the timing of the spring phytoplankton bloom, with the average April chlorophyll near the colony, and with the geographic variance of monthly chlorophyll (as an indicator of broad semi-permanent frontal zones) near the colony. Perhaps more importantly, we found extremely high correlations (R^2 =0.85) between fledgling production and cumulative chlorophyll in the vicinity of the colony that peaked in April, when most females are producing and laying eggs. All of these relationships are improvements on the correlation with SST. These newly discovered relationships should be valuable predictive tools for seabird managers. In an attempt to explain the relationships observed, we also examined winds, cloud cover, sea level height, and the timing of the spring transition as seen in current meter data and cloud cover. All time series reveal April to be the month in which chlorophyll measures best predict fledgling production. We propose that elevated chlorophyll concentration around Triangle Island is in response to seasonal changes in the physical regime as measured by winds, along with the spring transition and sea level height. These changes might be related to changes in flow in southern Queen Charlotte Sound that transport prey toward Triangle Island. Chlorophyll concentration seems to be a robust indicator of a more productive ecosystem at many trophic levels including food for adult Auklets, and perhaps especially egg-laying females. The very close relationship with accumulated chlorophyll up to the time of egg laying suggests a powerful oceanographic effect on the condition of the female, mediated through links to zooplankton and 0-class sandlance.

Poster PS2-P3

Overview of the French GLOBEC activities

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French GLOBEC-related activities started in 1984 with the National Program of Recruitment (PNDR 1984–1998) stimulated by Jean-Paul Troadec. Although without an official GLOBEC programme, numerous GLOBEC-type research projects in France have been realised under the umbrella of national and international funding sources. This poster will give an overview of the major projects and achievements realised by the French scientific community, and its potential for future IMBER activities.

Poster PS2-P4

A synthesis of observation and modelling of zooplankton spatio-temporal distributions in the northwestern Mediterranean Sea

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This poster will present a synthesis of zooplankton data compilation, Lagrangian transport simulations and coupled population models to synthesise our present knowledge of zooplankton dynamics in the north western Mediterranean Sea and to highlight future research in the framework of IMBER.

Poster PS2-P5

Mechanisms of sustained primary productivity in the Portlock Bank region: modelling and observations

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We use a spatially nested implementation of the Regional Ocean Model System (ROMS) and ocean observations to explore mechanisms responsible for the high primary productivity in the Coastal Gulf of Alaska (CGOA) near Portlock Bank in spring and summer, with a focus on the relationship between mixing, residence time, and productivity. Our CGOA model uses tidal forcing, daily atmospheric forcing, and boundary and initial conditions derived from a larger domain model of the Northeast Pacific. Hydrographic data were collected as part of six surveys undertaken by the GLOBEC/North-East Pacific programme. Modelling results suggest that primary productivity over the bank in the spring season is dominated by advective losses due to atmospheric conditions; in the summer, high productivity is maintained by tidal mixing, which pumps nutrients onto the bank from the troughs on either side, and from the top of the bank to the sea surface. These modelling results are corroborated by the observational data. It is also found that stronger mixing atop the bank in spring can lead to light limitation and decrease productivity locally. We consider possible implications of these results as they affect fish survival.

Poster PS2-P6

Marine ecosystem models: strategies, applications, and future directions

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An ecosystem approach to understanding large-scale patterns in exploited systems caused by both climate change and human activity increasingly relies on the use of numerical models. In the past, physical, lower and higher trophic level models were developed, tested and implemented independently of each other. As part of the GLOBEC programme, progress was made in coupling physics and lower trophic level models. The next step is to extend this work towards a comprehensive (end-to-end) ecosystem model including humans where all models are tightly integrated. Despite the fact that the subject of the coupling ecosystem models has received

considerable world-wide attention, there are few examples which demonstrate tightly coupled systems and its practical implementation. This is partly due to the perception that blending separate yet complex sub-models is impractical because of demanding computational requirements and partly due to the respective communities working independently. In this presentation, we compare past and present modelling strategies and applications to a new modelling framework where the widely-used ROMS (Regional Ocean Modelling System) circulation model, the NEMURO Nutrient-Phytoplankton-Zooplankton (NPZ) model, and a multi-species individual-based spatially-explicit fish population dynamics model that includes fishing fleets as a "predator species" are tightly coupled. All of these models exist in various forms, but the individual sub-models have never been harmonized together into one integrated analysis tool useful for synthesis, integration, and prediction. This model framework was designed to investigate the effects of climate and fishing on marine ecosystems within one model that includes dynamical feedbacks between the different systems. We describe the conceptual and technical challenges involved in assembling and implementing such a model and we will present some early results of this effort.

Poster PS2-P7

Near-real time monitoring of plankton in the Belgian coastal zone using Zoo/PhytoImage and the FlowCAM

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Spring *Phaeocystis globosa* blooms in the Belgian Coastal Zone (BCZ) are now recognised to be related with both North Atlantic Oscillation and anthropogenic eutrophication. In this dynamic coastal zone, mechanisms causing such blooms are not totally understood yet, especially variabilities in diatoms–*Phaeocystis* successions. The choice of monitoring stations is thus very important for studying eutrophication impacts in areas like the BCZ where the geographical extent of river loads is highly variable but, manual processing of discrete samples is time consuming and limits the number of stations sampled. This traditional method is not suitable for rapid analysis of the high temporal and spatial distribution variability of plankton communities as required to calibrate numerical models. We propose a method of near-real time monitoring of plankton assemblages which combines automatic recognition by machine learning algorithms using the Zoo/PhytoImage software (http://www.sciviews.org/zooimage/index.html) and the FlowCAM (Flow Cytometer And Microscope). This method is currently developed for the AMORE III project (Advanced Modelling and Research on Eutrophication, http://www.ulb.ac.be/assoc/esa/AMORE/objectives.htm) and ultimately aims to detect and understand plankton successions and their spatial and temporal variations along continuous transects. The method provides abundances and size spectra of the entire sample or for each group in near-real time aboard the RV *Belgica* oceanographic ship.

Poster PS2-P8

Overview of oceanographic features in the Canary Basin

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Hydrographic and nutrient data from the GyroScope 0302 cruise, carried out during March 2002, in the southern part of the Canary Basin are analysed, with respect to the different factors that affect their distribution, paying special attention to the horizontal and vertical movements that dominate in the Eastern North Atlantic. The data consists of two transects (southern and longitudinal) between the Canaries (S/C Tenerife) and the Mid-Atlantic Ridge, and between the latitudes 24.5°N and 30°N, for temperature, salinity, dissolved oxygen, nitrate, phosphate and silica measurements. The results are summarised in vertical profiles, vertical sections and property-property plots. The distribution of nutrients in the upper ocean of the Canary Basin seems to be dominated by biological activity, mesoscale oceanographic features (warm wakes, lees, eddies, etc.), originated by the Canary Islands, that act as a barrier for the winds and currents, and by the strong influence of the coastal upwelling region of northwest Africa. During the GyroScope 0302 cruise, seawater samples were collected with a 24 Niskin bottles (10 l) SBE 32 carousel combined with a CTD SeaBird 911, equipped with a pressure sensor and conductivity and temperature sensors. Nutrients were determined by CFA (Continuous Flow Analysis) using a six channels Technicon-Bran Luebbe AA II AutoAnalyser. Parameters were nitrate-nitrogen ($N\text{-}NO_3$), silicate-silica ($Si\text{-}SiO_4$) and phosphate-phosphorus ($P\text{-}PO_4$). The methodologies employed for the analysis were those described by Grasshoff (1976). Hydrographic structure in the southern Canary Basin is dominated by NACW, AAIW, MW,

NADW, with some cores of LSW and AABW. However, some of the thermohaline and chemical properties found for these waters masses differ from earlier observations, being reasonable to think that this is due to regional differences. MW seems to be highly diluted with AAIW, the high nutrient concentrations found for the MW can only be raised by the AAIW, at the depth range at which it is found. LSW is somewhat mixed with the NADW, rising the silica values found for this water. We can conclude from the analysis that there are three major source regions that are feeding into the area studied here. First is the Antarctic region, which provides waters that are fresh and rich in nutrients. These waters invade the North Atlantic as the Antarctic Intermediate and Bottom Waters, the former appearing at mid-depths. Second there is the Mediterranean Sea, which provides saline waters. The Mediterranean Sea imports the nutrient-poor surface waters of the Atlantic and exports waters with salinity increased through an excess of evaporation. Hence the Mediterranean Outflow Water is poor in nutrients. Last, there are outcrops and deep water formation regions in the northern North Atlantic, which includes the Labrador, Norwegian and Greenland Seas and whose waters are intermediate in salinity and poor in nutrients.

Poster PS2-P9

Is prey abundance important for growth and survival in larval cod?

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How sensitive are growth and survival of larval fish to prey abundance? Some studies have found weak links between prey abundance and growth in larval cod, while others have found strong links between recruitment and prey abundance. Here we model the connections between a larval fish in a realistic vertical column characterised by gradients in predation risk, growth and feeding potentials. A larva is followed from a size of 5 mm and maximizes the chance of reaching 15 mm by optimal foraging behaviour and habitat selection. The model suggests that the larva will increase its foraging activity and risk acceptance to keep up the growth rate with diminishing prey availability. Consequently, reduced prey availability will not be seen in growth rates, but in survival probabilities. This may complicate our ability to detect food limitation in larval fish, but it reconciles the lack of growth limitations seen in the field while prey still plays a role in recruitment variability.

Poster PS2-P10

Development of an empirical model to estimate phytoplankton size structure using in-water optical properties in the Chukchi and Bering shelf region

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The wide spread continental shelf from the southern Chukchi Sea to northeastern Bering Sea is known as one of the most productive areas in the world oceans. Organic carbon produced at the surface and the sub-surface layers is exported efficiently to the bottom, where it supports high benthic biomass in the region. Large, high trophic level benthic feeders such as grey whales or walruses also aggregate in the region for feeding. It has been suggested that the recent ocean warming and subsequent decline of sea ice in the area, resulting from climate change has, forced the northward shift in the ecosystem structure. To understand the underlying mechanisms of such changes and future implications, comprehension of spatio-temporal distribution of phytoplankton, the primary producers, is needed. Although satellite ocean colour remote sensing is a useful method to observe spatio-temporal distribution of phytoplankton, it has mainly been useful in detecting the biomass index, chlorophyll-*a* concentration (chl-*a*). Here we propose a new ocean colour algorithm to derive another index of algal information, which is phytoplankton size composition using in-water optical properties. A model to estimate phytoplankton size ratio (PSR) was developed using *in situ* water optical properties, light absorption coefficient of phytoplankton $a_{ph}(\lambda)$ and backscattering coefficient of suspended particles $b_{bp}(\lambda)$ including algae, and size fractionated chl-*a*. These data were collected in the Chukchi and Bering Sea shelf during summer 2007 with ship observation. We defined the PSR as the ratio of >5 µm algae to total algae. PSR was quantified by analysing the correlation between PSR and $a_{ph}(\lambda)$ ratio R*a* (= $a_{ph}(443)/a_{ph}(667)$), which varies with phytoplankton pigment composition, and spectral slope of $b_{bp}(\lambda)\gamma$, which can be an index of the mean size of suspended particles. We regarded these two optical parameters as independent variables for a PSR model. Both R*a* and γ were significantly and linearly correlated with PSR. Due to weak correlations between Ra and γ, and PSR, estimation of PSR from each of these parameters independently resulted in low accuracy. To improve the accuracy of PSR estimation, we propose a two variable model using both Ra and γ. PSR were plotted as dependent variables and the two optical parameters as independent variables in three dimensional space. Multiple logistic regression model was fitted as a response surface model of PSR with R*a* and γ, because PSR should have convergences in 100% for maximum and 0% for minimum. A multiple PSR

model suggests it can discriminate at least the size dominant classes for the study region, larger or smaller than 5 µm. R*a* can be an index of large size algal groups such as diatoms or dinoflagellates, but it does not indicate "true" cell size. On the other hand, γ is an index of mean particulate materials, but is also optically influenced by non-algal particles. Despite these challenges, the multiple PSR model is an effective method to detect true algal size classes. By applying the PSR model to satellite ocean colour remote sensing, we suggest that we can detect not only chl-*a* but also the spatio-temporal distribution of algal size classes from satellite observations in the near future. Thus satellite derived PSR can contribute to advanced understanding of ecosystem structure changes in the shelf region of the Chukchi and Bering seas.

Poster PS2-P11

Kleiber's Law works because biomass packages the respiratory ETS

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Kleiber's Law relating biomass (M) with metabolic rates (R) follows the allometric equations, $R = aM^b$, where $b = 0.75$ over 20 orders of magnitude. This law has gained increasing importance in recent years, because it is the basis for the Metabolic Theory of Ecology. Here we investigate whether or not it holds for potential respiration in marine zooplankton. Because the potential respiration is the V_{max} of respiration one would assume that it would also follow Kleiber's Law. Recently we showed that respiration and electron transport system activity did follow Kleiber's Law over five phyla of marine zooplankton. The allometric equation for respiration, in this case, was $R = 1.5M^{0.76}$ and the equivalent equation for a potential respiration was $\dot{O} = 3.3M^{0.79}$ indicating that the potential respiration was actually more closely related to biomass than it was to respiration. However, it is not known whether potential respiration follows Kleiber's Law in natural zooplankton assemblages. To investigate this question, samples of ETS activity and protein in the zooplankton from the northwest African upwelling system were taken in March of 2006 (CONAFRICA 0603). These samples included both offshore oceanic zooplankton, nearshore upwelling zooplankton, and zooplankton from ten different depths until 200 metres. These samples were analysed by depth, for the two different regions, and for the complete sample pool for agreement with Kleiber's Law. Our results show that in the upwelling area and stations related with the cyclonic eddy, zooplankton are growing at a high metabolic rate. In this area ETS activity is better correlated with biomass than with respiration ($b = 0.89–0.98$). In coastal stations this relationship diminishes somewhat ($b = 0.79$) and is closer to Kleiber's Law ($b = 0.75$). In offshore stations ETS–biomass relationship is weaker than Kleiber's Law ($b = 0.64$). In general, regardless of the depth, the upwelling zone samples follow Kleiber's law better than the samples offshore or inshore. However, when we analyse the total number of samples (672), we find a slope of 1 between ETS and biomass, showing that the biomass is a very good package for the ETS. We propose this is the principal reason why Kleiber's Law works so well. Respiration is correlated with biomass, because biomass packages the ETS.

Poster PS2-P12

Relative contribution of oceanographic conditions and spawning aggregations to cod larvae and 0-group seascape in the Barents Sea under different climatic scenarios

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Ocean current patterns, hydrographic conditions and variability in the spawning aggregations have been identified as influential parameters for survival of early life stages of Arcto-Norwegian cod in both modelling and field studies. In the present study we aim to investigate the relative contribution of temperature, salinity, current patterns and convergence/divergence activity on the seascape of cod larvae and 0-group in the Barents Sea, taking into account the spatial information available for the spawning aggregations in the Lofoten Islands. Moreover, we aim to study changes in the relative contribution of factors under different climatic scenarios (i.e. high and low values of the North Atlantic Oscillation (NAO). To do that, we combine a particle tracking model with non-parametric regressions (general additive models, GAM) to analyse the cod larvae seascape for the period 1986–1991.

The modelling approach was split into two life stage-based steps: 1) cod larvae distribution is modelled using eggs drifting information, and 2) 0-group distribution is modelled using larvae drifting information. We found that inter-annual variability in the spatial aggregations of the spawners could influence the seascape of larvae drifted. In 1987, a high concentration of spawners in the northern area of Lofoten Islands (compared with other years) facilitated a higher spreading of particles in the Barents Sea. Our results also show a clear change in the effect of all the covariate analyses for two periods–from 1986 to 1988 with low NAO regimes, and from 1989 to 1991 with high NAO regimes. The two best models were obtained looking at the different effects of spatial location and temperature over the two regimes. The change in the effect of temperature and salinity could be related to a change in the spatial location of the front between the North Atlantic Current (NAC) and the Norwegian Coastal Current (NCC) (water masses in the NAC and NCC have different correlations between salinity and temperature). The models show a southern concentration of cod larvae during low NAO regimes. Convergence/divergence activity over the shallow bank areas (Tromsøflaket) could produce retention and slow down the northward transport and add to the existing lower current transport during low NAO regimes, thus causing such southern distribution.

Poster PS2-P13

Modelling the effect of temperature and chlorophyll-*a* on dissolved oxygen in two contrasting estuaries of the Bay of Biscay

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The effect of temperature and chlorophyll-*a* on variations of dissolved oxygen concentration was assessed in two estuaries of contrasting hydrographical characteristics and anthropogenic impact (estuary of Bilbao and of Urdaibai, both draining to the Bay of Biscay) for the period 1997–2006, using generalised additive models (GAMs) and generalised additive mixed models (GAMMs). There were clear axial differences in the dominant way in which temperature affects dissolved oxygen in both estuaries. In the inner estuary of Bilbao (30 salinity) the main factor explaining dissolved oxygen variations was temperature (negative relationship), showing that the dominant effect of temperature was on oxygen consumption processes, which could be explained by the high concentration of organic matter, the strong stratification of the water column and high residence time during the summer. In contrast, in the outer estuary of Bilbao (≥34 salinity) the main factor explaining variations in dissolved oxygen was chlorophyll-*a* and the relationship was positive. This can be taken as an indication of the stronger effect of oxygen production through photosynthesis on the variability of dissolved oxygen concentration, relative to oxygen consumption processes. In the euhaline zone of the estuary of Urdaibai dissolved oxygen (DO) levels are higher and vary over a narrower range than in the estuary of Bilbao, because of the lower organic waste loadings, stronger water column mixing and shorter residence time. In the 30 salinity zone both a negative relationship with temperature and a positive relationship with chlorophyll-*a* have been detected, but both are non-linear relationships. It seems that the negative effect of temperature on DO is marked in an intermediate range of temperatures, but is less appreciable at high temperatures, presumably because of the higher impact of temperature on phytoplankton growth and dissolved oxygen production. The ≥34 salinity zone in the estuary of Urdaibai showed strong water column mixing and very high tidal flushing, and oxygen levels were generally near saturation. Thus it is likely that ventilation processes were more important than oxygen production or consumption processes in this outer zone.

Poster PS2-P14

Pacific saury response to climate change and its improvements by considering the influence of Japanese sardine and laboratory experimental approaches

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An ecosystem based bioenergetics model NEMURO.FISH (North Pacific Ecosystem Model for Understanding Regional Oceanography. For Including Saury and Herring) was developed and successfully reproduced realistic growth of Pacific saury with parameters mainly determined based on field observations. This model was

forced by observed sea surface temperature (SST) from 1950 to 2002 to elucidate the interannual response of Pacific saury growth to climate variability. The observed condition factor of Pacific saury showed large decadal variability with significant year-to-year variability. In the model, wet weight of Pacific saury also showed decadal and year-to-year variability, however the amplitude of decadal variability was much smaller than observed. The cause of the model failure is suggested to be the absence of a multi-species fish formulation in the model. The Japanese sardine population, which has a large biomass that exhibits great decadal fluctuations, is proposed as potentially affecting zooplankton density in the saury migration region. We also investigated differences of interannual growth variability between spawning seasons. Since Pacific saury spawns from autumn to the following spring, we consider three seasonal (autumn, winter and spring) cohorts in the model. The amplitude of growth variability is largest for the spring-spawned cohort and smallest in the winter-spawned cohort. This difference is caused by the difference of life history of each spawned cohort. The spring-spawned cohort spawns only once in their life-cycle, however other cohorts spawn twice. During the (autumn) fishery season, the age 1 spring-spawned cohort has not yet spawned, while the other cohorts have spawned once. As a result, the spring-spawned cohorts retain the memory of the environmental influence during the early life stages while the other cohorts, through their spawning, have erased that memory. Hence, the spring-spawned cohort shows a larger fluctuation in wet weight than other cohorts.

NEMURO.FISH was also used to investigate responses of Pacific saury to global warming using the SST of current climatology and a global warming condition generated by CCSR/NIES/FRCGC coupled atmospheric-ocean model output with the A2 scenario. The saury showed a decrease in both wet weight and body length under global warming. Also the migration pattern was modified by increased SST. Higher SST in the mixed water region under global warming prevented southern migration of saury in the first winter. As a result, the egg production was enhanced by higher availability of prey zooplankton. However, while a lot of parameters were determined based on field observations, several parameters are still unknown and the values of those parameters were borrowed from herring ones. Sometimes this kind of immature estimation of parameters brings misunderstandings of saury response to climate or anthropogenic forcing. To minimise uncertainty of the bioenergetics model, rearing experiments of Pacific saury were conducted. The results of rearing experiments showed higher consumption rate and lower feed conversion efficiency (28%) compared with those estimated from observations. This big gap between rearing experiments and field observations seems to be caused by the difference of quality of food. Rearing experiments with natural food are expected to improve the model.

Poster PS2-P15

Effect of large-scale long-line mariculture on ecosystem of Sungo Bay: results of numerical model simulation

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A numerical ecosystem model expressing phosphorus and nitrogen cycling and chlorophyll-*a* concentration in the pelagic system of Sungo Bay, China, was developed in order to investigate the seasonal variations of these elements and to study the impacts of mariculture on nutrients and phytoplankton. The model was also used to estimate the carrying capacity for the scallops, oysters and kelp in the system and the harvest potential for different seeding and harvesting scenarios. Sungo Bay (37°01'–37°09'N, 122°24'–122°35'E) located in Shandong province of China has been used for large-scale long-line cultivation of kelp *Laminaria laminaria*, oysters *Crassostrea gigas* and Chinese scallops *Chlamys farreri* for over 20 years. Sungo Bay is a small bay with a mean depth of 7.5 m and total area of about 133 km^2. Therefore, the total bay was considered as a box in the model. The model consists of equations representing almost all relevant physical and biological processes. The response of the concentration of chl-*a*, dissolved inorganic nitrogen and dissolved reactive phosphorus to the change of scallop and kelp cultivated biomass were simulated by the model. Results revealed that sediment release was an important source of nutrients. The concentration of chlorophyll-*a* decreased significantly with a five times increase in the scallop biomass. With scallop biomass increasing, the concentration of nitrogen declined, and the concentration of phosphorus declined during April to September. Ecological carrying capacity for the scallop in Sungo Bay was assessed. With the scallop at the primary cultivation density, the cultivation area for the scallop could increase from 1037 ha to 4100 ha without a significant change on the concentration of chlorophyll-*a*.

Poster PS2-P16

The National Investigation of Marine Ecosystem and some results in the seas adjacent to the Korean peninsula

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The National Investigation of Marine Ecosystem (NIMO) project was started in 2006 to evaluate the status of marine ecosystems in the seas adjacent to the Korean peninsula, providing strategic guidelines to decision makers for conservation and management of ecosystems. A multidisciplinary approach was adopted to comprehend the whole structure and function of ecosystems by regular surveys during February, May, August and November. In 2007, water quality indicators and the abundance/biomass of phytoplankton, zooplankton, benthos, ichthyoplankton and fishes were measured in one sub-region of the Yellow Sea adjacent to Korea. Tentative results showed that the sub-region could be classified into four sub-ecosystems based on physical and biological characteristics. Among 1,411 species collected and identified, 23 species were categorised as harmful marine organisms and one species as invasive species. Data produced from this survey are managed by the data centre and available on the website.

Poster PS2-P17

The effect of climate change on the growth of Japanese chum salmon (*Oncorhynchus keta*) and other pelagic fish using a bioenergetics model coupled with a three-dimensional lower trophic ecosystem model, NEMURO

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In the 1970s, a reduction in the body size of Japanese chum salmon (*Oncorhynchus keta*) was observed. To investigate this body size reduction in the North Pacific, we developed a bioenergetics model for chum salmon coupled with the results from a lower trophic ecosystem model embedded into a three-dimensional global model. In the bioenergetics model, respiration and consumption terms are assumed to be functions of water temperature and prey zooplankton density, which are the determining factors of the reduction of body size. The model reproduced the body size of the 1972 and 1991 year classes of chum salmon. The reproduced body size of the 1972 year class was larger than that of the 1991 year class, and this result agrees with observations from the Bering Sea. Our model also reproduced the body size trend from l970 to 2000. The prey density, especially in the eastern North Pacific, had a greater influence on the change of body size than did the SST. This suggests that the size reduction of Japanese chum salmon in the 1990s was partly affected by changes in zooplankton prey density. In the context of the global warming scenario, we discuss changes in the migration route of chum salmon. We conclude that Japanese chum salmon cannot survive past 2100.

Poster PS2-P18

Empirical evidence for meso-scale forcing in Gulf of Alaska based upon the variability in the stable carbon isotopic composition of northern lampfish, *Stenobrachius leucopsarus* (Myctophidae) in relation to copepods and marine survival rate of salmon

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Northern lampfish (NLF), *Stenobrachius leucopsarus* (Myctophidae), the dominant pelagic fish taxon of the subarctic North Pacific Ocean, were sampled opportunistically in MOCNESS tows made on continental slope waters of the Gulf of Alaska (GOA; N = 376) as well as in deep areas of Prince William Sound (PWS: N = 38) during 1997 to 2005. The overall mean whole-body lipid-corrected stable carbon isotope value of NLF from the GOA was -21.4 (SE = 0.03) whereas that from PWS was -19.6 (SE = 0.14). This pattern is similar to that observed for late feeding stage *Neocalanus cristatus* copepods thus confirming a mean cross-shelf carbon stable isotope gradient and the diagnosis that 13C depleted carbon reflects GOA origin carbon.

As well, there was a statistically significant positive correlation between the considerable temporal variation in the monthly mean stable isotope composition of GOA *Neocalanus* and GOA NLF ($R^2 = 0.46$, $P < 0.001$). However, because NLF were sampled more commonly than *Neocalanus* early (March and April) and late (August to December) in the calendar year, assessment of temporal isotopic variation is more extensive. NLF stable carbon

isotope shifts were protracted over longer periods than what was observable for *Neocalanus*. For example, NLF had very low values (<-22) from April through August 2001, then increased to ~-21 from December 2001 to April 2003. Values were again <-22 from May to June 2003 rebounding to more positive values beginning in August 2003, peaking at -20.5 in May 2004. There was relatively little fluctuation from July 2004 through May 2005 when monthly mean values ranged from -21 to -22.

The stable carbon isotope values of NLF, measured in May, were positively correlated to marine survival rate of PWS hatchery salmon cohorts entering the marine environment in the same year ($R^2 = 0.76$, $P < 0.011$). The stable carbon isotope values *Neocalanus* in May were also positively correlated to salmon marine survival ($R^2 = 0.71$, $P < 0.017$). Due to small sample size the correlations between stable carbon isotope values of NLP in other months were not significant ($P > 0.05$). However, qualitatively, there were positive relationships in July and August and a negative relationship in October. The stable carbon isotope values of NLF may also be negatively correlated to those of early marine salmon sampled during the same month but on the inner continental shelf ($R^2 = 0.42$, $P < 0.086$). These relationship parameters are similar to that reported for the stable carbon isotope values of the salmon and their marine survival rate (negative and weak). Thus processes manifested through the stable carbon isotope value of biota from the continental slope more closely predicted marine survival rate than that of the salmon themselves. The observed ^{13}C variation at the slope is posited to depend on whether or not the primary producers comprising the food web base are diatoms or not. The incipient inverse relationships suggested by negative correlations as well as the positive correlations are consistent with the hypotheses that exchange between coastal and oceanic waters in the study area are driven by meso-scale eddies and that these eddies facilitate the occurrence of slope diatom blooms as well as drive oceanic zooplankton subsidies into coastal waters. The stronger as well as more significant correlations of salmon marine survival rate to NLF as well as slope *Neocalanus* stable carbon isotope values point to processes taking place at the slope (i.e. interactions driven by meso-scale eddies when at the edge of the shelf) as being the driving force to inter-annual variability in the coastal Gulf of Alaska study area.

Poster PS2-P19

Long-term dynamics of the megabenthic assemblage in Tokyo Bay, Japan: possible linkage to environmental variations

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Tokyo Bay is a heavily eutrophicated area in Japan and has experienced great changes in both environment and biota in response to consequences of human activities in metropolitan areas and/or changes in meteorological and oceanographic conditions. To assess the effects on the ecosystem, we have to monitor the long-term changes in the biocoenosis. We have conducted bottom trawl surveys at 20 sampling stations covering the whole bay area twice a year from 1977 to 1995 and from 2003 to 2008. Fishes, crustaceans, mollusks and echinoderms were identified to species level. Abundance and biomass were standardised, as catch per unit effort (CPUE), by dividing by tow numbers. During the sampling period, substantial changes in both the species composition and CPUE were observed. Six periods were delineated by cluster analyses using the Bray-Curtis similarity index for the biomass-based CPUE (1977–1978, 1979–1986, 1987–1988, 1989–1995, 2003–2005 and 2006–2008), reflecting changes in CPUE as well as species composition. CPUE increased from the late 1970s and peaked in 1987, followed by drastic declines in the late 1980s. In the 1990s, CPUE remained low, at less than half the 1987 level. The changes between the late 1970s and mid 1990s were mainly due to drastic changes in CPUE of dominant species (mantis shrimp *Oratosquilla oratoria*, whipfin dragonet *Repomucenus valenciennei*, and marbled sole *Pseudopleuronectes yokohamae*). In the mid-2000s, biomass-based CPUE markedly increased, although abundance-based CPUE was as low as that of the 1990s, which was due to an increase in large-sized fishes (Japanese sea bass *Lateolabrax japonicus* and elasmobranchs). In the late 2000s, however, CPUE of the large-sized fishes showed a decreasing trend except for stingray *Dasyatis akajei*. To explore environmental factors showing a similar temporal trend to the megabenthic assemblage, we carried out stepwise multiple-discriminant analysis (SMDA). We collected data of precipitation, water temperature, chemical oxygen demand, dissolved oxygen concentration, concentrations of dissolved inorganic nitrogen (DIN) and phosphorus (DIP), chlorophyll-*a* concentration, and copepod density in the bay between 1987 and 2005 from published database for SMDA. In the

SMDA, the 2000s were separated from the 1980s and 1990s, which was a result of decreases in chlorophyll-*a* concentration and copepod density as well as increase in DIN/DIP in 2000s. This result suggests that changes in the megabenthic assemblage between 1990s and 2000s were coincidental with those in the nutrient concentrations and productivity in lower trophic levels in the bay, although the causal mechanisms remain unclear. Meanwhile, we could not discriminate periods between the 1980s and 1990s by the SMDA, suggesting that other anthropogenic, environmental and/or biological factors were involved in the drastic decrease in CPUE in the late 1980s.

Poster PS2-P20

Seasonal and spatial variations in the limiting factor regulating phytoplankton growth in the Yangtze River estuary and adjacent East China Sea

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The Yangtze River Estuary (YRE) and the adjacent East China Sea (ECS) is one of the most important ecosystem in continental shelf margin sea studies. Four cruises were carried out in summer in 2006 and spring, summer and autumn in 2007. Nutrients and related ecological parameters were determined in more than 150 stations each cruise in the Yangtze River Estuary and adjacent water (121°E–128°E, 30°N–32.33°N) and along nutrient enrichment bioassays in summer and winter cruises in order to examine spatial and temporal variations in the limiting factor regulating the phytoplankton growth in the YRE and ECS.

Nitrate, phosphate and silicate were generally coupled with salinity distribution and followed the typical gradient distribution along the estuarine fresh water to open waters. Industry and agriculture produced nitrate and phosphate were higher in the YRE than those in the Hangzhou Bay, this might be attributed to longer residence time of water in the Hangzhou Bay, while terrestrial weathering derived silicate was relatively higher in YRE than that in Hangzhou Bay. In the river channel near Shanghai city high nitrite and ammonium were detected, which indicated city sewage outfalls might also be considered as a nutrient source.

Nutrient ratios and nutrient enrichment bioassays indicated spatial and seasonal variations in the limiting factors regulating phytoplankton growth in the Yangtze River Estuary and East China Sea. Light limitation occurred in the nearshore areas due to the high suspend solid concentrations (up to 598 mg/L in summer) and vertical mixing. Low temperatures (13.5°C on average) might be the key factor controlling the phytoplankton production during winter. In both summer and spring, at the inner river channel and nearshore estuary, a high N/P ratio (>100:1) indicated the potential phosphate limitation. In summer, enrichment experiments indicated nitrogen and phosphorus were potentially co-limited in the freshwater-influenced high salinity areas outside the front, coincident with the results from the N/P and N/Si ratios. In contrast, DIN was the most likely limiting nutrient at the surface in the shelf open water of the ECS during the four seasons. Particulate inorganic phosphate, dissolved organic phosphate and particulate organic phosphorus contributed 50%–80% of total phosphorus which suggested that those forms might provide potential phosphorus support for the primary production in the phosphate limitation areas.

Poster PS2-P21

Diel-vertical migration behaviour of *Euphausia pacifica* in a dynamic coastal upwelling environment: 2-D modelling at the Oregon coast

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Like many zooplankton species, *Euphausia pacifica*, the most abundant krill species near the Oregon coast, migrates vertically in the water column over a daily cycle. This diel-vertical migration varies based on the development stage of the zooplankter, resulting in a range of migration depths during daylight for the population. In a region such as the Oregon coast upwelling zone, different depths in the water column may have different cross-shelf velocities, with deeper velocities potentially being slower (or directionally opposite) those found near the surface during upwelling. We couple an individual-based model of development to a 2-D physical circulation model for the northern California Current to estimate how important individual behaviour may be to overall patterns of distribution across the shelf. We examine the effect of vertical migration on cross-shelf distribution by comparing patterns created by both migrating and non-migrating *E. pacifica* individuals under upwelling and non-upwelling conditions and compare our model results to field data collected during upwelling seasons between 2000 and 2002.

Poster PS2-P22

Process study of spring phytoplankton bloom in the Yellow Sea

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The Yellow Sea is one of the world's 50 so-called "large marine ecosystems", and one of the most important fishing areas of the East China. Since it exhibits oligotrophic and low phytoplankton biomass properties during the majority of the year, the spring phytoplankton bloom, is very important to growth and development of zooplankton and fish stocks, leading to food production. The objective of this study is to understand the features and mechanisms of the phytoplankton bloom process, and the significance to the food production of the Yellow Sea ecosystem. Multidisciplinary investigations of phytoplankton spring bloom were carried out in the Yellow Sea from 30 March to 23 April 2007. By means of satellite remote sensing and sea surface mapping, large scale spring blooms were observed in the central region of the Yellow Sea. In the centre of bloom area, chl-*a* concentration was over 10 mg/m^3, with a maximum up to 20 mg/m^3. The dominant phytoplankton species was *Skeletonema costatum*, with cell abundances being 97.98% of the total phytoplankton. During the cruise, there was no significant stratification in the water column, while the spring bloom had already started. In the bloom zone, difference between the upper and bottom water was very small, and temperature inversion could be observed at some stations during the night. Therefore this bloom can not be explained by "critical depth" theory. It may belong to non-stratification spring blooms which are rarely reported. Another important feature of this bloom is the dramatic decline rate. After the climax stage of bloom, the chl-*a* concentration decreased rapidly dropping from 20 mg/m^3 to below 4 mg/m^3 in one day. From the chl-*a* fluorescence profiles, it could be observed that the termination of the bloom was exhibited by the strong sinking of aggregated phytoplankton. Results of microcosm culture experiments also suggested that the bloom was not terminated by nutrient exhaustion, since high biomass of phytoplankton in the microcosm system could be maintained for a fairly long period without nutrient addition. The bacterial community was studied using 16S rDNA clone libraries and by PCR-Denaturing Gradient Gel Electrophoresis (PCR-DGGE) analysis. The predominant bacterial communities examined during a 24 h period by PCR-DGGE were Alphaproteobacteria, Gammaproteobacteria, and the Cytophaga-Flavobacteria-Bacteroides group, which were also the most dominant in other researches, such as in the southern ocean and the mesocosm diatom bloom. However, the predominant bacterial communities during non-bloom period, which were Gammaproteobacteria, Deltaproteobacteria and Bacteroides, were different from the bloom period. The clustering results of DGGE profile analysis showed that the bacterial community composition changed between the period of bloom and 10 d after the bloom during the first diatom bloom (BM1), while the bacterial communities were almost the same during the second diatom bloom (BM3). Four libraries of BM1 were dominated by Alphaproteobacteria, Gammaproteobacteria, and the Cytophaga-Flavobacteria-Bacteroides group, while three libraries of BM3 were dominated by Alphaproteobacteria, Gammaproteobacteria, and unidentified bacteria. However, the dominant operational taxonomic units (OTUs) was the Roseobacter group in the two diatom blooms. The results implied that the Roseobacter group was responsible for a major part in the cycling of carbon. The sedimentation brings abundant organic matter to the sea floor, and provides a rich diet to zooplankton and benthic fauna. Meanwhile, the dissolved oxygen concentration within the whole water column was relatively high, even in the bottom water, and the minimum oxygen saturations observed during this cruise were over 70%. With adequate dissolved oxygen and a plentiful diet, the zooplankton and benthic organisms possess a favourable condition to develop their population, and consequently promote the ecosystem food production of the Yellow Sea.

Poster PS2-P23

The inherent and apparent optical properties of the Strait of Georgia, British Columbia, Canada

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Optical and bio-physical data were measured in the waters of the Strait of Georgia within the euphotic zone in late spring and early summer of 2006. From the *in situ* hyperspectral optical measurements of beam attenuation and absorption (inherent optical properties), and chromophoric dissolved organic matter (CDOM) absorption, particulate absorption and scattering were derived. The concentration of CDOM was measured with a fluorometer and water samples were collected for total suspended material (TSM) and chlorophyll-*a* (chl-*a*). Waters closer to the Fraser discharge showed the highest concentrations of TSM and CDOM, whereas in deeper waters and waters further from the plume, both TSM and CDOM were relatively lower, and chl-*a* relatively higher, reaching the lowest values at the bottom of the euphotic layer. Upwelling radiance and downwelling irradiance were also measured and were used to derive the apparent optical properties of these waters. Together, inherent and apparent optical properties were then modelled in Hydrolight to simulate the attenuation of light in the waters of the strait. Overall, these waters had a well-defined attenuation gradient, which allowed for the optical classification of waters under strong (OM1),

medium (OM2), and low (OM3) influence of the riverine waters. Particulate scattering dominated the attenuation of light reaching values of around 16.00 m^{-1} at 411 nm, for waters under the strongest influence of the river; these values decreased up to two orders of magnitude in deeper waters. However, for deeper water masses and waters under low influence of the Fraser River discharge, absorption and scattering at short wavelengths showed a similar contribution to the total attenuation of light; for some waters, absorption was even higher. Particulate scattering was mostly influenced by inorganic particles, especially in OM1. High loads of inorganic particulate scatterers possibly increased the diffuse light into OM2, thus increasing chl-*a* concentrations. Conversely, in deeper waters the relative increase of absorption by CDOM indicates the possibility of competition with phytoplankton for short wavelength radiation. Relevance: Attenuation of light in the water column is caused by particles and dissolved substances in the water. Each of these attenuate light differently thus having an impact on the physical and biological properties of a water body. This research will contribute to the understanding of light attenuation and the impact of the many optical constituents on the distribution of light in the waters of the Strait of Georgia under the influence of the Fraser River plume. Consequently, variations in light attenuation can potentially be linked to variations in primary productivity and help us understand the impact of the Fraser River on the waters of the Strait of Georgia.

Poster PS2-P24

Modelling the potential impacts of aquaculture expansion and climate fluctuations on global reduction fisheries and fishmeal markets

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The stability of reduction fisheries and the global fishmeal market they support is explored using a bioeconomic model under two interactive drivers: climate-driven changes in the biological production of regional fish stocks and the potential expansion of aquaculture markets. The model describes an *El Niño*-type perturbation altering the productivity of Peruvian and Chilean stocks and its effects are faced by two alternative aquaculture expansion and fishmeal demand hypotheses. The model uses data from 1997-2004 and considers twelve national production systems, including fish resources, fishing fleets and reduction industries, and 21 markets. The model captures *ca*. 85% of the global fishmeal trade, although the results are aggregated into four regional fishmeal producing regions and four generic markets. The model concludes that impacts of regional climatic fluctuations, whilst reducing the short-term productivity of regional stocks, are not sufficient to endanger the global fishmeal production system unless they are combined with an expansion in fishmeal demand. In this case, results suggest that drastic management at both markets and fisheries are needed, including measures to substitute fishmeal in aquaculture, to avoid the risk of collapse in small pelagic fisheries. It is argued that the dynamics of the fishmeal price since the early 1990s responds to this balance between climatic variability in production and market developments. It is concluded that the way climate impacts are managed, both at regional ecosystem and global markets level, will determine the sustainability of the world's reduction fisheries, a conclusion that could be extended to other, similarly affected, natural resources.

Poster PS2-P25

Integrating Climate and Ecosystem Dynamics: circumpolar analyses of Southern Ocean ecosystems

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Integrating Climate and Ecosystem Dynamics (ICED) is a new multidisciplinary international programme, recently launched to address the challenges of integrating Southern Ocean ecosystem, biogeochemistry and climate research at the circumpolar scale. Understanding the processes driving ecosystem responses to climate change and harvesting is critical to developing management strategies for the Southern Ocean, and elucidating its role in the earth system. ICED has been developed as part of IMBER and GLOBEC and provides the scientific framework for major national and international integration activities, with a focus on cross-disciplinary science. This decade-long programme will initiate, coordinate and integrate three main areas of activity: historical data synthesis, fieldwork and model development. The ultimate goal of ICED is to improve predictions of ecosystem dynamics, including responses to climate change and harvesting. This will be achieved by developing a hierarchical set of models of ocean circulation, biogeochemical cycles and the end-to-end operation of food webs with different spatial, temporal and trophic resolutions. 2009 sees the implementation phase of ICED with an initial focus on synthesis activities and planning for major new field activities.

Poster PS2-P26

Timing of spring phytoplankton bloom before development of the thermocline in the central southern Yellow Sea

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The spring phytoplankton bloom in central southern Yellow Sea was observed through real time satellite remote sensing combining *in situ* tracking in April 2007, when the thermocline had not developed. The spatial coverage of the bloom was larger than 20000 km^2, with several high phytoplankton abundance patches, possessing the key species with chain and spines which help the phytoplankton to float at the upper layer of the euphotic zone. The highest chlorophyll-*a* value reached up to more than 20 $mg\ m^{-3}$. The results of the analysis of ten years data revealed that before mid-March no bloom happened, which was probably due to light limitation, confirmed by P-I relation experiments. In addition, the quiet weather without winds larger than Class 2 for three days encouraged the bloom to form. The fact that high phytoplankton biomass and abundance easily appeared in the upper layer of the Yellow Sea Warm Water suggested that the water temperature was another factor to induce the bloom formation. The nutrient enrichment from the dry precipitation carried by storm during the observation period strengthened the bloom and prolonged the period.

Poster PS2-P27

Impacts of climate change on growth and migration of Japanese sardine (*Sardinops melanostictus*) in the western North Pacific

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We developed a multi-trophic level ecosystem model including Japanese sardine (*Sardinops melanostictus*) by coupling to a fish bioenergetics model to a lower trophic level. This model includes physical and biochemical processes, plankton dynamics, and additionally behavioural ecology of Japanese sardine. The model is composed mainly of three models; 1) a climate model (coupled atmosphere-ocean model), 2) a lower trophic level ecosystem model, 3) a fish migration model of Japanese sardine. The climate model is a high-resolution setup of the MIROC ver. 3.2 (Model for Interdisciplinary Research on Climate; K-1 Model Developers, 2004). An oceanic general circulation model coupled with lower trophic level ecosystem model: NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) developed by PICES (the North Pacific Marine Science Organization). Simulated plankton density fields by NEMURO are used for prey density conditions in the fish migration model. The fish migration model has used individual-based modelling techniques, which is applied to Japanese sardine in the western North Pacific (Okunishi *et al*., in press). The individual-based model is composed of a bioenergetics sub-model and a Lagrangian transport sub-model. The bioenergetics sub-model estimates growth of sardine and decides swimming directions. The Lagrangian transport sub-model simulates the position of sardine by using the ocean current and predicted swimming directions by the bioenergetics model. To investigate the effect of global warming on the pelagic fish ecosystem, such as Japanese sardine which is one of the commercially important species in the western North Pacific, we conducted present day and global warming experiments using predicted physical fields by a high-resolution climate model. As physical fields, we used results of pre-industrial condition (hereafter Control-RUN) and global warming conditions (hereafter CO_2-RUN) from this climate model (Sakamoto *et al*., 2005). The Control-RUN were carried out by fixing the external forcing at the year 1990 by the climate model. The CO_2-RUN is a global warming experiment, where the atmospheric CO_2 concentration is increased at the rate of 1% per year from pre-industrial conditions. The atmospheric CO_2 concentration during the analysis periods in the CO_2-RUN is about doubled by the pre-industrial condition. The model results demonstrated possible impacts of global warming on migration pattern and growth of Japanese sardine. Sardine will move the spawning ground towards the northern regions, and succeed in recruitment themselves. During the northward migration period in spring and summer, the geographical distribution of fish will move from one to two degrees northward under global warming conditions. However, in the CO_2-RUN, the acceleration of the Oyashio, which is the western boundary current of the subarctic gyres in the North Pacific, prevents the increase in sea surface temperature in the downstream site of the Oyashio, which is a fishing ground in summer in the current state. Therefore, the impact of global warming on geographical distributions of sardine around Japan seems to be not so pronounced.

Poster PS2-P28

Metabolic theory of ecology cannot predict respiration during nutrient limitation in marine bacteria

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Respiratory oxygen consumption is caused by enzymatic activity of the respiratory electron transfer system (ETS). However, in spite of this understanding, respiration models continue to be based on allometric equations relating respiration to body size, body surface, or biomass. The Metabolic Theory of Ecology (MTE) is a recent example. It is based on Kleiber's Law relating respiration (R) and biomass (M) in the form, $R = K_1 M^{3/4}$, where K1 is a constant. This law holds because biomass packages the ETS. Consequently, we have been proposing to bypass biomass and model respiration directly from its causal relationship with the ETS activity (R = f(ETS)).

Here we present an enzyme kinetic model (EKM) of respiratory oxygen consumption based on the substrate control of the ETS. It argues that R is controlled by the maximum velocity, V_{max}, of the enzyme reactions that controls the process (i.e. the ETS), the temperature, and the substrate availability, S. Kinetics of this thermal-substrate regulation are described by the Arrhenius and Michaelis-Menten equations. The EKM equation takes the form:

$$R_1 = \frac{V_{max}\, S\, e^{\left(\frac{-E_a}{R_g (T_1 - T_0)}\right)}}{(K_m + S)}$$

where E_a is the molar Arrhenius activation energy, R_g is the molar gas constant, K_m is the Michaelis-Menten constant, and T is temperature.

In this work we apply the EKM and the MTE to predict a respiration times-profile throughout the exponential, steady state, and nutrient-limited phases of the marine bacterium *Vibrio natriegens* in an acetate-based culture. Both models were tested by comparing their output with the measured R_{O2} time-profile. They were evaluated quantitatively by least-square regression analysis. When the predictive capability of both models was compared, serious flaws in the MTE rendered it inaccurate during nutrient limitation. In contrast, the EKM worked well throughout the entire period of the experiment. Results suggest that respiratory control is achieved through changes in the *in vivo* activity of the ETS by substrate modulation of the *in vitro* ETS (V_{max}). We conclude that EKM holds promise for predicting respiration at the different physiological states and time-scales important to microbiological studies.

Poster PS2-P29

Modelling zooplankton respiration from ETS activity

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Oxygen consumption (R) results from the activity the respiratory electron transfer system (ETS). It has no causal relationship to biomass. ETS is ubiquitous in zooplankton, determines the level of potential respiration (Φ), and is the enzyme system that ultimately oxidizes the products of food digestion, makes ATP, and reduces O_2 to water ($O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$). As measured, it reflects the maximum velocity (V_{max}, *sensu* Michaelis-Menten) of the rate-limiting step of the ETS. Furthermore, from zooplankton to bacteria, over a range of 11 orders of magnitude, ETS activity and respiration are tightly coupled ($r^2 = 0.856$). However, current respiration hypotheses ignore the enzymatic basis of respiration and instead are based on allometric relationships between R and biomass. The most accepted version from the Metabolic Theory of Ecology (MTE) is $R = i_0 M^{¾}$, where i_0 and temperature (T) are constants and the biomass term is from Kleiber's Law. We argue that, for zooplankton, a V_{max}-based O_2 consuming algorithm is more consistent with the cause of respiration. Our point: although biomass is related to respiration, the first-principles-cause of respiration is the ETS because it controls O_2 consumption. Biomass is related to respiration because it packages the ETS. Consequently, we propose here to bypass the packaging and model respiration from ETS and hence V_{max}. This V_{max} is regulated by T according to Arrhenius theory and by specific reactants (S) that sustain the redox reactions of O_2 consumption according to Michaelis-Menten kinetics. Our enzyme kinetic model (EKM) not only describes respiration over a large range of body sizes but also explains and accurately predicts respiration on the short time scales.

The EKM equation takes the form:

$R_1 = V_{max} S\, e^{-E_a/(R_g(T_1-T_0))} / (K_m + S)$

where E_a is the molar Arrhenius activation energy, R_g is the molar gas constant, K_m is the Michaelis-Menten constant, and T is temperature (Kelvin).

Poster PS2-P30

Determinism of seabird foraging trajectories – a modelling approach

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As most predators, seabirds adopt efficient foraging strategies despite an *a priori* poor knowledge of resource distribution and availability. When seabirds breed, foraging decisions are even more challenging since they need to reach a high foraging success on a daily basis. In the case of South African Cape gannets, the main prey are small pelagic fish (sardine and anchovy) characterised by high patchiness and potential rapid re-distribution. To cope with this spatial-temporal unpredictability, seabirds may have learnt and may exchange knowledge on areas of relatively high prey predictability. Seabirds may also rely on fishing boats by exploiting fishing discards. Here we propose to test the importance of *a priori* knowledge on fish predictability and of the scavenging behaviour in the movements adopted by Cape gannets while breeding. For that purpose, we use 259 gannet GPS tracks recorded between 2002 and 2008 and the simultaneous pelagic prey distribution derived from hydroacoustic surveys. Based on this data set, we set up a conceptual model within the framework of state-space Bayesian modelling to test the role of learning and communication as well as the interaction with fishing boats in the foraging strategy of the Cape gannet. The objective is to compare simulated trajectories of this model to empirical data.

Poster PS2-P31

A multi- ecological models analysis of effects of global changes on fishing and aquaculture activities in coastal area

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The demand for reliable predictions of impacts of global change on ecosystem functioning, and the cascading effects on the human dimension (ecosystem services, human health) is continuously increasing. However, the reliability of model predictions generally decreases with increasing model complexity and number of trophic levels considered, so that predictions of local scale response of ecosystem and/or of higher trophic level organisms to global changes might be not very accurate. The possibility of organism acclimatisation to new conditions introduces an additional source of uncertainty. A possible way forward to increase robustness of results is the application of different ecological models to the same problem. In this paper we forecast impacts of changes in precipitation pattern over the drainage basin of the lagoon of Venice – as predicted by a regional climatic model on biogeochemistry of the lagoon, and in turn on habitat suitability for Manila clam, which represents an important economic resource in the area. Clam suitability is assessed by using three different ecological model approaches: a) an end-to-end food web dynamic model, which describe both direct and indirect effects on clam in a 0D representation; b) a spatially resolved habitat suitability model and c) a 3D integrated dynamic model obtained by coupling a transport biogeochemical model to a bioenergetic and to a dynamic population models for clams. Results agree in indicating a reduction in clam suitability under A2 and B2 IPCC scenarios and point to the need for implementation of adaptive management.

Poster PS2-P32

Simulation of zooplankton prey fields in the German Bight to study sprat growth variability in time and space

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The present study connects the investigation of lower and higher trophic levels, which are both influenced by their physical and biological environment. Copepods were focused due to their key role within the ecosystem acting simultaneously as a predator and prey item within the food web. The three-dimensional ecosystem model ECOHAM was used to simulate the North Sea ecosystem and to study the temporal development and spatial variability of zooplankton biomass and abundance. The zooplankton was divided into a stage-structured populations representing *Pseudocalanus elongatus* and the rest of the zooplankton biomass. Simulated copepod fields were analysed to investigate the regional distribution of primary and secondary production in relation to the locally different stratification and circulation characteristics and their influence on population dynamics and total zooplankton biomass. Using reported weight-length relationships we gained a size-resolved spectrum of food items, which served as an input for a coupled transport and an individual-based growth model (IBM) for fish larvae. The IBM predicts growth and survival conditions of larval sprat (*Sprattus sprattus*) depending on local prey availability and hydrodynamical conditions in the German Bight. The ecosystem model determined high variability of the different size classes due to the succession of copepod stages resulting in alternating match/mismatch patterns of prey for the sprat larvae, which could not be resolved using bulk zooplankton biomass only. The larval development exhibits a corresponding variability depending on available food concentration and size-class composition of prey.

Poster PS2-P33

The influence of interannual variations in euphausiid population productivity on the production of herring and salmon along the west coast of Vancouver Island, Canada, with implications for understanding ecosystem function

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Data from a long-term euphausiid monitoring programme, and biological and commercial catch sampling of herring (*Clupea pallasi*) and salmon (*Oncorhynchus* sp.) populations were used, to test if variations in euphausiid productivity affected fish production along the west coast of Vancouver Island (WCVI). Results indicated that variations in herring recruitment, growth, and mortality, and sockeye (*O. nerka*) and coho (*O. kisutch*) recruitment are explained by variations in euphausiid biomass. There are critical periods when predators select very specific, and different, fractions of the euphausiid biomass. Subsequent analyses show that median annual euphausiid biomass, and various physical oceanographic measures and indices, do not correlate with the biomass of important euphausiids. This suggests that these indirect measures provide no information on variations in prey that are important for herring and salmon production. Currently, there appears to be no substitute for direct field observations when trying to ascertain how the coastal upwelling ecosystem along the WCVI functions. These results have fundamental implications for predicting the effects of ecosystem change on fish production.

Poster PS2-P34

Modelling the circumpolar distribution of Antarctic krill

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Antarctic krill has a heterogeneous distribution through the Southern Ocean. Key breeding grounds, generally close to the Antarctic continent, are believed to sustain open ocean populations. Here we present a modelling study of the connections between these populations together with a look forward to the coupled life cycle model that we are developing. Sea ice is an important habitat for Antarctic krill, supplying both a winter food source and shelter from predators. Advection simulations run with and without the sea ice habitat show that the association of krill with sea ice can greatly affect the population connections in particular locations, either by increasing retention or dispersal depending on locality. The modelling results also highlight the potential importance of

the westward-flowing Antarctic Coastal Current for maintaining the observed krill distribution. We are currently working towards embedding a closed life cycle model of krill into the advection simulations using functions of egg development, growth and spawning. This will allow us to identify key regions in the circumpolar Southern Ocean for the life stages of krill and provide further insight into the importance of advection on the distribution of the species.

Poster PS2-P35

Biomass fluxes and biomass spectra in an ecosystem model

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Organisms in an aquatic system have been sorted by their body biomass (size) into discrete size classes or into a continuous biomass spectrum. As individuals grow by either assimilating inorganic carbon by photosynthesis or consuming organic carbon, carbon biomass propagates from small to large organisms or sinks to detritus and dissolved organic carbon (DOC) which represents the biomass flux between lower and higher trophic organisms, and bio-carbon burial. Because prey-predator relationships are transient and opportunistic related to random micro-scale encounters, the linkages and fluxes between species and functional groups in an ecosystem are highly variable and stochastic which has challenged any deterministic approach with specified flux rates. Are there any invariables in an ecosystem representing the mean biomass flow efficiency of the system, or any macro-scale variables representing statistical means of micro-scale phenomena? Many literatures have explored the slopes of biomass spectra in global oceans, shown the similarity and variations, and explored theories and empirical explanations of biological processes determining a biomass spectrum. We are continuing to explore the regional and seasonal variations of biomass spectra from equatorial, mid-latitude to polar regions and from coastal to open oceans in terms of biomass fluxes, productivity and burial of an ecosystem. Our findings indicate the slope in an equatorial region is nearly invariable while the biomass varies seasonally. But in a polar region, the slope varies seasonally from a herbivorous dominated community in spring to a carnivorous dominated community in autumn-winter. We also found an offshore gradient from a steeper slope in coastal upwelling areas to a flatter slope in offshore permanently stratified areas. The biomass spectrum balance equation is applied to analyse biomass propagation and productivity associated with individual growth and biomass recycling. Mathematical equations have also been developed for estimating biomass export to DOC and detritus. Biomass spectra provide integrated biomass values and also slopes as two integrative indices to verify model results for biomass, productivity, biomass fluxes between trophic levels and carbon burial.

P3 Ecosystem approach to management

Poster PS3-P1

Advances in ecosystem assessments in Alaska: responding to recent and predicted future interactions between climate and fisheries

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Numerous guidelines and definitions have emerged world-wide with respect to an ecosystem-based approach to fisheries management. These are now being implemented at international, national, and regional levels. the US federal fishery management recognises that an ecosystem approach to management of marine fisheries in the US needs to: 1) be adaptive, 2) be regionally directed, 3) take account of ecosystem knowledge, 4) take account of uncertainty, 5) consider multiple external influences, and 6) strive to balance diverse societal objectives. US marine fisheries management in Alaska has been used world-wide as an example to highlight successful management that incorporates ecosystem considerations. This system is presently dominated by groundfish fisheries that are providing relatively stable sources of production. Ecosystem-based management measures implemented in the past include precautionary single-species harvest levels, by-catch monitoring and restrictions, habitat and food-web protection measures, and endangered species considerations. Here, we provide here a history of US ecosystem based fishery management and advice in Alaska, highlight some of the current pressures and indicators of ecosystem status, describe ongoing scientific research and progress in understanding ecosystem processes, resilience, and thresholds, and discuss the challenges for translating ecosystem research into management advice. In particular, a great deal of uncertainty in predicting management outcomes may arise from our uncertainty in the future climate states. Are we accurately reporting expectations of recovery and our uncertainty? To do so, we must develop quantitative ecosystem level decision rules and thresholds while maintaining flexibility. For example, between 2001 and 2005, the unprecedented lack of southeast Bering Sea ice and warmer climate conditions may have reduced production in key groundfish stocks such as walleye pollock (*Theragra chalcogramma*)–in the management system, this has led to *ad-hoc* pollock quota reductions based in part on ecosystem considerations. In this presentation, we describe progress in formalising such ecosystem considerations into decision rules while describing a system that remains willing and sufficiently flexible to, if necessary, include *ad-hoc* information based on the best available science surrounding such unexpected events: any management system must keep in mind that the ecosystem can always surprise us.

Poster PS3-P2

Length-based inter-cohort growth variability in common sardine (*Strangomera bentincki*) off central Chile (1990-2007)

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It has been postulated that interannual variability in the length-at-age growth of different cohorts of common sardine (*Strangomera bentincki*) is very low. Nevertheless, residuals of length-at-age seem to be related to interannual changes in sea surface temperature, and probably with cohort-specific changes in growth. In this contribution we studied the variability in the von Bertalanffy (VB) growth parameters of different cohorts of common sardine from 1990 to 2007. Time series of monthly length-frequency data were used to study the growth of the species. The MIX software was used to separate normal component from the length-frequency data set, and modal progression analysis was used to identify cohorts that have recruited each year. The growth parameters were estimated by using nonlinear mixed-effects model (NLME) and considering that population growth parameters have a common distribution, and that some cohort-specific parameters can be treated as random effects. This approach was compared with standard nonlinear methods (SNL) applied separately for each cohort.

The growth in length of common sardine exhibited seasonal oscillation in the growth rate, with the slowest length growth rate occurring between April and May, just before the austral winter. According to the Akaike Information Criterion, a model that considered both L_∞ (VB asymptotic length) and K (VB growth coefficient) as random effects was better in explaining inter-cohort changes in growth. This model performed better than the SNL model, and exhibited less fluctuating growth parameters. Indeed, the SNL growth parameters estimates were more variable, with important deviations because incomplete and noisy data of some cohorts.

Although in this work we did not attempt to relate changes in the growth to some environmental variable, the NLME estimates revealed higher *K* in 1993, 1997–1998, and 2003 (warm years), and lower *K* values for 1991, 1995, 2000–2001, and 2005 (cold years). It must be mentioned that the main objective of this work was how to estimate inter-cohort variability in von Bertalanffy growth parameters and how to estimate them when data are incomplete or noisy for some cohorts. Clearly, the NLME have an advantage over the SNL method because we are assuming that the growth process comes from a common distribution. In this way, we recommended that NLME growth parameters should be used to study the effects of environmental changes on the growth of this small pelagic fish.

Poster PS3-P3

A multi-fleet cost analysis of industrial fishing in São Paulo, Brazil

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Unprecedented information from a brief fishery socio-economic survey of different industrial fleets in São Paulo, Brazil, will be presented. An assessment of the different kinds of fishery economics attributes such as investment, fixed costs, effort, labour, sailing costs and profits showed both an inter and intra-fleet comparison. Costs vary between fleets, but in general, fuel is the main cost for all fleets representing almost 40% of total costs, followed by labour costs (~30%), repairs (13% and taxes 8%). The pink-shrimp fleet showed the greatest values for fixed costs per fishing trip (70%) and the surface gill-netters fleet, the lowest, being the most profitable of all fleets. Cluster analysis of fishing boats showed that the two main factors of explaining similarities between fleets were fuel and catch price. The worst economic performance was detected in both the shrimp-trawl fleets, possibly due to the high variable cost values. The undertaken cost-benefit analysis will be explored and discussed under a management perspective. Results appeared to be valuable also as input values for the assessment of different fishing policies scenarios for the South Brazil Bight ecosystem through Ecopath with Ecosim optimisation policies routines and analysis.

Poster PS3-P4

GIS and ecosystem assessment for sustainable fisheries management: a case of the Tamil Nadu coastal region, India, during pre- and post-tsunami

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Rapid scientific, technological and socioeconomic changes have fuelled as explosive growth in marine fish harvests. Scientific methods like GIS and ecosystem science approach will be helpful for improving marine fishery resources in a sustainable manner (socially and environmentally). The ecosystem approach aims at managing fish species and fishing activity within the context of the ecosystem and examines fisheries within a larger context of households, communities and the socioeconomic environment. Effective resource and environmental management has the potential to yield socioeconomic benefits in the longer-term for fisheries management. The present study utilises GIS and the ecosystem approach to analyse the spatial and temporal variations in the uses of the ecosystem resources in the coastal region. It also assesses restoration of ecosystem resources like habitats and assess the socio-economic parameters in each sector of the study area for better management and governance in the marine social-ecological system. The study area, Tamil Nadu plays a vital role in the fishing industry in India. The study area covers nearly 1076 km, which touches both the west coast and the east coast of India and constitute about 15% of the Indian coastal length and also contributes about 19% of marine product of India. The study area has been divided in to four zones 1) Coramandal coast 2) Palk Bay 3) Gulf of Mannar and 4) West coast. According to Fishery Survey of India the coast has been divided into latitudinal extension i.e 10°N latitude to 12°N latitude. These zones cover 13 coastal districts of Tamil Nadu in which the number of fishing villages are 591. The unpredictable tsunami which hit the coastal region of Indian Ocean on 26 December 04 was one of the biggest disasters the world has ever experienced. This havoc has brought massive damage to socio-economic life of the people in the region. Tamil Nadu (India) is also one of the regions which have been affected by the killer waves of the tsunami. The area between10°N to 12°N latitude to 80°E to 84°E longitude was most affected. The study assesses the impact of the tsunami on marine fishery resources and spatio-temporal variations of fish landings during pre- and post-tsunami period. The result shows the decline of fish landings of certain species or groups of fishes in the area of 10°N and 11°N in the depth zone of 50-100 m, where as in 12°N has shown an increase in catch rate during the post-tsunami period. The post-tsunami has shown a 1% increase of marine fishery product in Tamil Nadu. This hike cannot be considered as a growth of fishery

product in the region because the number of fishing gears and crafts has improved and increased comparatively to the pre-tsunami period. It was also found that the social and economic system of the study area changed dramatically. An integrated GIS approach has been used to map the spatial and temporal changes of fishery resources, the coastal community and socio-economic dimensions. The present paper examines the social and physical vulnerabilities through mapping techniques. GIS based ecosystem mapping has been developed for each zone of the study area, based on environment, physiography and social economic parameters. Assessment has been made and GIS based maps have been prepared (for each zone) for good fisheries governance.

Poster PS3-P5

Modelling regime shifts in the Southern Benguela: a frame-based approach

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Small pelagic populations in productive upwelling systems are characterised by long-term patterns of alternating dominance. Sardine and anchovy are the most important small pelagic species in the southern Benguela ecosystem, which has been shown to have undergone regime shifts during the past 50 years. Modelling regime shifts at an ecosystem scale can be of great importance in fisheries management, to aid in long-term planning and fishing strategy evaluation. Frame-based modelling has been successfully applied to regime shift dynamics in terrestrial ecosystems. The pattern of abrupt shifts between quasi-stable regimes suggests the usefulness of a frame-based approach in the southern Benguela, with separate frames describing each small pelagic dominance pattern. Frame-based modelling is applied to sardine/anchovy dynamics under the influence of climate variability involving interaction with the small pelagic fishery. Four frames are used in the model: both species high; sardine high/anchovy low; anchovy high/sardine low; and both species low. Switching rules for transition between the frames are described. Rapid prototyping is used to construct and test first- and second-generation prototypes of a frame-based model. A sensitivity analysis of the model is performed. The model is found to be reasonably sensitive to the sardine population model parameters, and the influence of juvenile sardine bycatch is noticeable in the “Sardine Low” frames. The model behaviour is relatively insensitive to climate variability, but the inherent degree of stochasticity in the sardine recruitment calls for continuous population monitoring and adjustment of fishing levels to avoid crashing the modelled sardine stock. The model is exercised in a variety of scenario analyses, and confidence in the model is strengthened by the observed parallels to the real world. The potential use of the model as an educational “test platform” for improving understanding of fishing impact on the dynamics of small pelagic populations is explored. The advantages of the frame-based modelling technique include their particular usefulness in inter-disciplinary teams and the ease with which a frame-based model can be expanded and modified, and the experiences of this project support these findings. Frame-based modelling is also found to be an approach well-suited to the development and maintenance of the computer software which encapsulates the model, and as a common interface between programmers and biologists. Suggested uses of the model include deriving ecosystem “probabilities of change” based on various management options for use in an expert system for detecting and predicting ecosystem change.

Poster PS3-P6

Development of Integrated Multi-trophic Aquaculture in Sungo Bay, China

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Integrated Multi-trophic Aquaculture (IMTA) is a form of marine farming that utilises the ecosystem services provided by organisms of low trophic levels (e.g. shellfish and seaweed) raised in appropriate ratio to mitigate the effects of organisms of high trophic levels (e.g. fish). Because the contribution of IMTA is to recycle food and energy for increased sustainability and profitability of the aquaculture industry, therefore, the IMTA has rapidly developed in the world, especially in Sanggou Bay, China since last several years the best approaches for China.

Long-line culture of IMTA has being well developed in Sungo Bay, which is located in the east of the Shandong Peninsula, China, with the total area of 13,300 ha. With the annual production of 2,100 tons of scallop *Chlamys farreri* in fresh weight, 110,000 tons of oysters *Crassostrea gigas* in fresh weight, 80,000 tons of kelp *Laminaria japonica* in dry weight, and about 100 tons of finfish respectively, Sungo Bay has becoming one of the most famous IMTA area in the world.

The feeding rate and absorption rate and excretion rate by the mainly cultivated scallop *Chlamys farreri* and oyster *Crassostrea gigas* were measured. And the seasonal variations in oxygen consumption rate and ammonia excretion rate of different size of scallops and oysters were studied. The experiment on the co-culture of scallop and kelp was made to get he optimised ratio of co-culture.

The process of sediment resuspension to the nutrient supply, the Results showed that wind-waves and currents were the dominant driving force for sediment resuspension in Sanggou Bay. The correlation between SSC and turbidity (NTU) is $SSC = 15.908 \times \ln(NTU) + 7.0888 (n = 33,\ R^2 = 0.7209)$. The critical shear stress for sediment resuspension in Sanggou Bay is about 0.059 N/m^2. The maximal stress depth is about 8.81 cm, the magnitude of sediment resuspension flux is 10^{-5}–10^{-6} kg m^{-2} s^{-1}. The suspended sediment concentration by resuspension can be predicted by.

$$SSC = \frac{25.23W^{0.92}}{2.67} + SSC(0) - \frac{25.23W^{0.92}}{2.67}\ e^{-(2.67\,t/h)}$$

The equilibrium mass concentration of nitrogen and phosphate is 5.72 μmol/L and 0.903 μmol/L, respectively. Combined with the concentration in different seasons in water column, it can be estimated that the function of resuspended sediment is as follows: nitrogen and phosphate source in Spring; nitrogen sink and phosphate source in Summer and Autumn; nitrogen and phosphate sink in Winter.

A numerical ecosystem model expressing phosphorus and nitrogen cycling and chlorophyll-*a* concentration in the pelagic system of Sungo Bay, China, was developed in order to investigate the seasonal variations of these elements and to study the impacts of mariculture on nutrients and phytoplankton. And the model also used to estimate the carrying capacity for the scallops, oysters and kelp in the system, the harvest potential for different seeding and harvesting scenarios.

Poster PS3-P7

Forecasting returns of coho and chinook salmon in the northern California Current: a role for high-frequency long term observations

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Successful weather forecasting is based on a basic understanding of the underlying physics and physical mechanisms that determine the weather. Similarly, forecasting of ecological phenomena in ocean requires a basic understanding of the physical and ecological mechanisms that determine the outcomes which one hopes to predict. Successful prediction of fishery yields for example will require a modicum of knowledge of where in the ocean the given species lives during all parts of its life cycle, and of processes that determine the key recruitment bottlenecks. Towards this end, we have measured hydrography and plankton and juvenile salmonid abundance in coastal waters of the northern California Current along eight transects off Washington and Oregon, in June and September for the past 11 years (since 1998). We have also been monitoring since 1996 hydrography, zooplankton and krill along a single transect off Newport at biweekly intervals to provide more frequent tracking of changes in ocean conditions at the event-to-seasonal and seasonal-to-interannual scales. We have had some success with qualitative forecasts of coho and spring Chinook salmon (e.g. we provide outlooks on the expectations of either good, fair, or poor returns, one to two years in advance of the fish returning to their natal streams to spawn). Recruitment and return rates are best predicted by biological oceanographic conditions derived from our monitoring programmes: date of biological spring transition, biomass anomalies of northern lipid-rich copepods, copepod community structure, and catches of juvenile Chinooks during June surveys and juvenile coho in September surveys. All of this information is available on the world-wide web at http://www.nwfsc.noaa.gov under “Ocean Index Tools”. The forecasts and outlooks presented on this web page have received acceptance by the NOAA Fisheries Regional Offices, by coastal watershed managers, by the tribes, and by power and water managers for the Columbia River system. Our ability to forecast the success or failure of salmon runs in the future will depend in part on our ability to forecast the impact of global climate change on ocean conditions in coastal waters. Models along with ecosystem observations may become a requirement to understand how variations in physical climate forcing will affect fisheries and marine ecosystem productivity. We have recently begun working with a Geophysical Fluid Dynamics Laboratory climate model that is coupled with an ecosystem model to determine if this type of model can be used to provide useful outlooks as to the salmon response to future climate change.

Poster PS3-P8

Ranking ecological relative status of exploited ecosystems using multiple indicators

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In this work we provide an example of how, in the context of the Ecosystem Approach to Fisheries, a previously agreed suite of indicators can be used to rank and assess the relative status of exploited marine ecosystems, taking into account their peculiarities and ecological histories. We used a set of simple and data-based indicators established under the work developed by the EUR-OCEANS IndiSeas WG, a follow-up to the SCOR/IOC Working Group on “Quantitative Ecosystem Indicators”. Drawing from these readily available ecological indicators, ranking of 19 exploited ecosystems was undertaken while the state and trends of the ecosystems and ecological goals were analysed taking into account expected changes in indicators with respect to increasing fishing impacts. Ecosystems were ranked in a comparative context. Firstly, ecosystem states were compared by examining the mean values of these indicators in the last three years for which data were available. Secondly, slopes of the observed trends and their significance were assessed across ecosystems taking auto-correlation into consideration to analyse short time series of standardised data. The ecosystems were then ranked across all indicators and by sub-categories of indicators weighting the selected indicators by four ecological goals: conservation of biodiversity, 2) ecosystem stability and resistance to perturbations, 3) preservation of trophic structure and resource quality, and 4) biomass potential. Subsequently, ecosystems were group into “desired” or “undesired” status due to fishing impacts cross-comparing observed states and recent trends. Further similarities and differences between ecosystems were explored using multivariate analyses to compare the ranking of ecosystems and testing environmental and socio-economic explanatory factors.

Poster PS3-P9

Comparing indicators across fished marine ecosystems: the IndiSeas experience

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There has been a strong move worldwide towards the Ecosystem Approach to Fisheries (EAF). To make progress towards implementing the EAF, carefully selected and appropriate indicators are required to translate ecosystem impacts and changes into management measures that can be assessed for their effectiveness. The scientific community grappling with the EAF is challenged to provide a generic set of synthetic indicators to accurately reflect the effects on fisheries on marine ecosystems, to facilitate effective communication of these effects and to promote sound management practices. Building on the work of SCOR/IOC Working Group on “Quantitative Ecosystem Indicators” (2004), the working group IndiSeas was established under the auspices of the EUR-OCEANS programme, to look at “EAF Indicators: a comparative approach across ecosystems”. A suite of eight ecosystem indicators considered to be the most suitable was agreed upon with respect to several criteria and were assembled for 19 fished ecosystems. Using the comparative approach, a web-based “dashboard” comprised of these ecosystem indicators has been developed, reporting results of various statistical and analytical techniques employed to evaluate the exploitation status and trends of world’s marine ecosystems and to guide fisheries management in each ecosystem. An attempt is made at establishing reference levels for the indicator

suite, ecosystems are ranked according to exploitation status reflected by the indicator suite, a decision tree is developed to classify ecosystems into improving, stationary or deteriorating status, and the roles are assessed of non-fishery drivers in determining changes in ecosystems.

Poster PS3-P10

Population dynamics of blue whiting: density-dependent and density-independent effects

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The known history of the blue whiting (*Micromesistius poutassou rissa*) is rather short. Due to the collapse in Norwegian spring spawning herring in the late seventies a general desire to find new resources for commercial exploitation in the northeast Atlantic aroused a greater interest in the blue whiting. Surveys carried out mainly by the United Kingdom and Russia led to the discovery of commercial quantities. Later on it turned out to be one of the most numerous fish species in the northern northeast Atlantic. Many countries acquired a commercial interest in the fish and the fishery developed quickly in the seventies. Norway started experimental fishing with pelagic trawls in the spawning area in 1972. As international landings of blue whiting grew to significant quantities it became clear that an international agreement was needed on how to share this resource among the nations involved. The fishery of this stock was for the first time regulated in 2007 through a management agreement between the nations that have the species in their national economic zones; EU, Faeroe Islands, Iceland and Norway.

The blue whiting is a small oceanic and semi-pelagic gadoid. As a typical plankton feeding species its role in the Norwegian Sea could be of vital importance. It self is prayed upon by several species, among them cod (*Gadus morhua*), tusk (*Brosme brosme*), and tooth whales. The blue whiting has a high growth rate in its first year (12–15 cm). In the next few years it grows to 20–25 cm in length and becomes sexually mature at an age of two to four years. Its distribution stretches over a great part of the northeast Atlantic and the species is one of the most numerous in the Norwegian Sea ecosystem. It is found from the polar front area between Iceland, Jan Mayen and Spitzbergen and eastwards to the coast of Norway with local populations in many of the Norwegian fjords. In the north the blue whiting is found up to 82°N and in the Barents Sea eastwards to 45°E. The main spawning area, to where it migrates mainly in February–April is to the west of the British Isles, mostly at a depth of 300–400 m.

Recruitment to the blue whiting stock has varied considerably throughout time since the instrumental record started in the early 1980s. Notably it became substantially higher than earlier during the late 1990s and early 2000s despite the fishing pressure being well above that recommended by ICES. Here a masters thesis is trying to cast new light on the reasons behind the observed recruitment dynamics is presented. The two main lines of analysis are: 1) Analyses of recruitment variation: both annual variation and variation on a longer time scale have been analysed using time-series analyses, GAM, multiple regression and classical stock-recruitment models (including Ricker, Beverton-Holt, and Hockey-Stick). Analyses of climate variables, the age-composition of the stock, the presence of other species and the quantity of the spawning stock and how these factors affect the stock-recruitment relationship are presented. Using the Shannon-Wiener diversity index to describe the age diversity in the spawning stock I will show that stock-recruitment relationship is under influence of the age composition of the spawning stock and that the Beverton-Holt recruitment model describes the stock-recruitment relationship fairly well. 2) Analyses of natural mortality by age and year: using time series analyses and Leslie matrixes on age-based data I have analysed changes in the natural mortality rates in the stock since fisheries started taking both fisheries, density of other species and variation in climate in to consideration. I will present results from this age-based model and show a simulation model of the lifecycle of the blue whiting.

Poster PS3-P11

Pattern of spatial occupation of the realised spawning habitat of anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) off central Chile

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The realised spawning habitat of anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) off central Chile, defined as the region where fish actually spawn in a given year at a given time, display interannual fluctuations. Furthermore, both species co-occur in the same reproductive habitat, and have a similar reproductive

strategy. The main objective of this work is to compare the spatial structures of realised spawning habitat of anchovy and common sardine during periods of high and low egg densities, with the aim of determining whether such structures are density-dependent or density-independent. We used information of one egg survey when egg density was low (winter 2005), and another one when egg density was higher (winter 2007) off central Chile (33°00'S–40°00'S). Geostatistical techniques were used to infer structural characteristics, such as autocorrelation ranges, variogram shapes and variability, and different scales of density. Our results show that both species have very similar patterns of space occupation in the two study years. The indicator variograms for both species suggested a progressive ''destructuration'', and a decreasing radius of influence with increasing density, this is consistent with results of Barange *et al*. (2005) for anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in South African waters. Indeed, Barange *et al.* (2005) concluded that the spatial expansion of anchovy and sardine during the high density year resulted in an increment in the number and density of hotspots. The results of the variograms indicate that the autocorrelation ranges are similar in both years, even despite the egg densities were higher in 2007. This confirms that the variograms reflect intrinsic structures of realised spawning habitat. The conclusion is that an increment in anchovy and common sardine egg densities are mostly driven by an increment in the number and density of very high-density ''hotspots''. These can be explained with the theory of density-dependence as suggested MacCall's (1990) hypothesis that populations expand their geographical range with increased abundance.

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