Ocean impacts from the bottom of the food web to the top: Biological Oceanography Committee (BIO) retrospective

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As one of the four core Scientific Committees of PICES, the unique mission of the Biological Oceanography Committee (BIO) is to promote and coordinate biological oceanography and interdisciplinary research in the northern North Pacific Ocean. BIO plays a key intermediary role with respect to the other PICES Standing Committees. For example, lower trophic levels may be the most directly affected by processes considered by the Physical Oceanography and Climate Committee (POC). These lower trophic levels then, affect and are affected by the upper trophic levels. BIO interacts with the Fisheries Science Committee (FIS) to provide scientific advice on ecological roles of lower and higher trophic level organisms on fisheries. BIO also plays a central role in defining "normal" conditions against which changes of interest to Marine Environmental Quality Committee (MEQ) can be measured. At the same time, BIO is responsible for developing scientific programs for annual and inter-session meetings, for formation of Working Groups on key areas of interest, for participation in the CCCC Implementation Panel and Task Teams, and for coordinating activities with other international and national programs. Here we summarize the 10-year record of the progress of BIO toward these goals.

Members and phases of development

The past and current BIO members are shown in Table 1. During the initial phase (1992-1995), BIO generated its own scientific programs for Annual Meetings (Table 2). In the intermediate phase (1996-1998), BIO organized joint sessions with other Scientific Committees (Table 2) and sponsored the formation of two Working Groups (Table 3). In the third phase of development (1999-2001), BIO further expanded efforts for jointly sponsored sessions with other Scientific Committees and the CCCC Program (Table 2), and developed interactions with other relevant international organizations (Table 3).

Activities of Working Groups

Working Group 11: *Consumption of marine resources by marine birds and mammals in the PICES region* (Co-Chairmen: Hidehiro Kato of Japan and George L. Hunt of U.S.A.). The Working Group was formed to tabulate available data on population sizes and diet composition of marine birds and mammals, and to calculate their seasonal and annual prey consumption to evaluate their predation effects on intermediate and lower trophic levels within the PICES region. To facilitate comparison and summarization, the PICES region (30ºN to the Bering Strait) was divided into 14 sub-regions (Introduction to this volume, Fig. 2) based on oceanographic features. While the quality and quantity of information was not uniform across the sub-regions, the Working Group revealed that at least 47 marine mammal species and 135 seabird species inhabit the PICES region. Estimates of abundance exceed 10,000,000 marine mammals and 200,000,000 seabirds. Seabirds and marine mammals are widely distributed throughout the PICES region. The mean size of individuals ranges from 28 kg to over 10,000 kg for marine mammals and from 20 g to 8,000 g for marine birds. Pooling available estimates of the western PICES sub-regions (approximately 49% of the total PICES region), total prey consumption by marine mammals is estimated to be 13 million tons during summer (June-September, 122 days) per year. Estimates for predation by seabirds are 1 million tons in sub-region BSC, 0.5 million tons in sub-region ASK, and 50 thousand tons in sub-region CAS. For the estimates covering the entire PICES region, there are still gaps of information to be filled (for details

Table 1 Biological Oceanography Committee members.

Chairmen		
M. M. Mullin (1992-1995) P. A. Wheeler (1996-1998) T. Ikeda (1999-2001)		
Members		
Canada: K. L. Denman (1992-2000) D. L. Mackas (1992-) T. R. Parsons (1992-1997) P. J. Harrison (1998-) A. Pena (2001-)	Korea: S. Y. Hong (1996-1998) J. U. Lee (1996-1997 S. K. Yi (1996-1997) J. H. Shim (1998-) S. Yoo (1998-) W. S. Kim (1999-)	China: Y. Q. Chen (1992-) R. Wang (1992-1998) B. L. Wu (1992-1995) M. Y. Zhu (1996-) S. Son (1999-)
Russia: B. N. Kotenev (1996-) V. I. Radchenko (1996-) V. V. Sapozhnikov (1996-)	Japan: T. Ikeda (1992-1995, 1997-) T. Sugimoto (1993-2000) A. Tsuda (1996-) M. Kishi (2001-)	U.S.A: L. Jones (1992-2000) M. M. Mullin (1992-2000) P. A. Wheeler (1992-) R. D. Brodeur (2001-) M. Dagg (2001-)

see PICES Scientific Report No. 14 published in 2000). With recognition that information about marine mammals and birds is important for the research on ecosystem dynamics in the PICES region, Working Group 11 was restructured and reformed as Marine Birds and Mammals (MBM) Advisory Panel since 1999 to fulfill its research objective.

Working Group 14: *Effective sampling of micronekton to estimate ecosystem carrying capacity* (Co-Chairmen: Richard D. Brodeur of U.S.A. and Orio Yamamura of Japan). The major objective of the Working Group is to obtain and tabulate data on consumption and biomass of micronekton in the PICES region, together with improvement of its sampling gears. “Micronekton” comprises adult euphausiids, mesopelagic fish, mysids, pelagic shrimps and cephalopods.

In addition to creating data inventories of micronekton in the North Pacific, topics under discussion are geographic zonation design (by adapting the sub-region system used by Working Group 11 mentioned above), reproduction, early life history and demographic rates; prey-predator relationships and rates (diet composition, food consumption rates, predators and predation rates, parasites and diseases); and sampling considerations (net towing, acoustics, visual design).

Review of BIO strategic plan

During its development, BIO set six goals for coordinating biological oceanography within PICES (Table 4). Here we state each goal and progress towards its implementation. Overall, BIO had great success in stimulating and coordinating research in biological oceanography within the PICES framework. Over the last decade, the extent of this success is highlighted by the international and interdisciplinary work summarized above, that covers physical oceanography and climate, upper and lower trophic levels of the marine ecosystem, stimulation of the long-term observational studies and modeling efforts of the PICES-GLOBEC CCCC Program, and expansion of coordinated interdisciplinary harmful algal bloom studies into the PICES region. Our recent efforts with the marine mammals and birds, and micronekton, will continue the facilitation of studies of ocean impacts from the bottom of the food web to the top in the North Pacific Ocean.

Table 2 BIO topic sessions at the PICES Annual Meetings.

Year	Sponsor	Title/Conveners
PICES II (1993)	BIO	• Paleoecological studies in the subarctic Pacific. (Convener: M. M. Mullin)
PICES III (1994)	BIO	• Structure and ecosystem dynamics of the subarctic and transition zone of the North Pacific. Is the east like the west? (Co-Conveners: A. Taniguchi and R. D. Brodeur)
PICES IV (1995)	BIO	• Factors affecting the balance between alternative food webs structures in coastal and oceanic ecosystems. (Co-Conveners: R. Wang and M. Omori)
PICES V (1996)	BIO	• Regional and interannual variations in life histories of key species. (Co-Conveners: D.L. Maskas and T. Ikeda)
PICES VI (1997)	BIO/FIS BIO/MEQ	• Mickonekton of the North Pacific: Distribution, biology and trophic linkages. (Co-Conveners: R. D. Brodeur, K. Kawaguchi and Q. S. Tang) • Harmful algal blooms: Causes and consequences. (Co-Conveners: R. Forbes and J. H. Shim)
PICES VII (1998)	BIO POC/BIO MEQ/BIO	• Controlling factors for lower trophic levels (especially phytoplankton stocks). (Co-Conveners: V. Alexander, A. Taniguchi and P. J. Harrison) • Carbon cycle in the North Pacific Ocean. (Co-Conveners: S. Tsunogai and C. S. Wang) • Contaminants in higher trophic level biota-linkages between individual and population responses. (Co-Conveners: R. F. Addison and L. Jones)
PICES VIII (1999)	BIO/CCCC MEQ/BIO	• Recent findings of GLOBEC and GLOBEC-like programs in the North Pacific. (Co-Conveners: M.D. Ohman and V.I. Radchenko) • Coastal eutrophication, phytoplankton dynamics and harmful algal blooms. (Co-Conveners: D. L. Garrison and T. Orlova)
PICES IX (2000)	BIO BIO/CCCC POC/BIO	• Prey consumption by higher trophic level predators in the PICES regions: Implications for ecosystem studies. (Co-Conveners: G. L. Hunt and H. Kato) • Recent progress in zooplankton ecology study in PICES regions. (Co-Conveners: T. Ikeda, W. S. Kim, M. M. Mullin and D. W. Welch) • North Pacific carbon cycling and ecosystem dynamics. (Co-Conveners: K. L. Denman, S. R. E. Emerson and T. Saino)
PICES X (2001)	BIO POC/BIO/FIS MEQ/BIO/POC	• Plankton size classes, functional groups and ecosystem dynamics: Causes and consequences. (Co-Conveners: A. Pena, T. Saino and P. A. Wheeler) • The physics and biology of eddies, meanders and rings in the PICES regions. (Co-Conveners: W. R. Crawford, J. J. Polonina and T. Sugimoto) • Physical, chemical and biological interactions during harmful algal blooms. (Co-Conveners: H. G. Kim, F. J. R. Taylor and V. L. Trainer)

Table 3 Summary of other annual activities.

Year	Annual activities
PICES I (1992)	• recommended the collection and dissemination of the schedules for cruises in the subarctic Pacific by major research vessels of the member nations • discussed possible coordinated research topics by member nations
PICES II (1993)	• recommended the development of straw man proposal for PICES-GLOBEC
PICES IV (1995)	• recommended WG 11: Consumption of marine resources by marine birds and mammals in the PICES region
PICES V (1996)	• recommended increased BIO representation for CCCC-IP, REX Task Team (Hunt) and MODEL Task Team (Jones) • Zhang was appointed to SCOR WG 105 as PICES representative and as rapporteur to BIO and FIS for SCOR WG 105
PICES VI (1997)	• recommended WG14: Effective sampling of micronekton to estimate ecosystem carrying capacity
PICES VII (1998)	• recommended PICES/ICES collaboration for ICES zooplankton workshop in 2000 • supported formation of Iron Fertilization Experiment Advisory Panel
PICES VIII (1999)	• recommended establishment of Advisory Panel on Marine Birds and Mammals
PICES IX (2000)	• convened BIO/MBMAP Technical Workshop "The basis for estimating the abundance of marine birds and mammals, and the impact of their predation on other organisms". (Co-Convenors: G. L. Hunt and H. Kato) • presented a proposal on ICES/PICES/GLOBEC Symposium on Comparative zooplankton ecology at ICES/PICES Zooplankton Ecology Workshop in Honolulu (approved by ICES and international GLOBEC) • published PICES Scientific Report No. 14 "Predation by marine birds and mammals in the subarctic North Pacific Ocean"

Table 4 Strategic plan and progress.

Goal	Progress
Improve cooperation with other PICES components	Accomplished by sponsoring many joint topic sessions with CCCC, POC, MBM Advisory Panel at PICES IX, and with POC, FIS, and MEQ at PICES X
Enhance interaction with relevant international organizations	BIO proposed a joint ICES/PICES/GLOBEC Symposium on Comparative zooplankton ecology to be held in May 2003
Increase involvement in specific recognized scientific issues	BIO participated in a workshop on "Designing the iron fertilization experiment in the subarctic Pacific" in Tsukuba, Japan, 2000, and plans participation in field experiments in 2001 and beyond
Improve community attendance and participation in Committees, Task Teams and Working Groups	This remains a problem area
Improve inter-sessional work via e-mail leading to shorter and more efficient Annual Meetings	This has only been partly successful. More e-mails do not necessarily lead to shorter meetings
Increase travel support for student participation at Annual Meetings	PICES is providing partial support for some students and young scientists, but BIO does not have data available to document extent or details

Scientific themes and future prospects

A distillation of BIO activities over the last decade generates three primary themes: (1) regional and basin-wide comparisons of lower and upper trophic levels, (2) importance of life histories, alternate food webs, and understudied groups of organisms for ecosystem analysis, and (3) role of trace metals and biogeochemical cycling in controlling biological production and the carbon cycle. We will not attempt to give a comprehensive overview of these themes, but provide some illustrative examples of leaps forward and remaining gaps in our understanding.

A major early success of PICES interest in basin scale comparisons is presented in the special issue of *Progress in Oceanography* on "Ecosystem dynamics in the eastern and western Gyres of the Subarctic Pacific" (Beamish *et al.* [Eds.] 1999). Harrison *et al.* (1999) noted higher nutrients and chlorophyll in the west compared to the east but similar levels of primary production (Table 5). Mackas and Tsuda (1999) concluded that there is some evidence that the western Gyre is more productive than the Alaska Gyre (Fig. 1), but noted that more research is needed to determine if there is a permanent east-west gradient. More important for ecosystem analysis is the recognition of interannual and interdecadal changes and links to climate variability. Mackas and Tsuda (1999) described evidence of long-term shifts in biological characteristics such as size structure and life history timing for subarctic zooplankton, and concluded that "Comparisons of both present ecosystem state and historical precursors among different parts of the North Pacific are likely to be essential for development of this understanding" (of changes in the pelagic ecosystem that are large in amplitude, but are widely and unevenly spaced across decades). A significant expansion of this work on the importance of nutrients in controlling the levels of primary production in the eastern and western gyres, is the application of satellite data on the distributions of nitrate (inferred from temperature) and phytoplankton (inferred from ocean color as a measure of chlorophyll). Using such data, Goes *et al.* (2001) showed how the onset of El Niño resulted in *depressed* phytoplankton production in the Gulf of Alaska, but *increased* phytoplankton production in the following spring and summer in the western North Pacific (Fig. 2).

A second theme emerging in the progress of biological oceanography of the North Pacific Ocean is variation or deviation from traditional food webs along with recognition of woefully understudied groups of organisms. A striking example of a change in food web structure is the unusual appearance of coccolithophore blooms in the Bering Sea (Fig. 3), concurrent changes in relative abundances of copepods and euphausids (Napp and Hunt 2001, Stockwell *et al.* 2001), and massive die-off of short-tailed shearwaters (*Puffinus tenuirostris*), an apex predator in the south-eastern Bering Sea (Baduini *et al.* 2001). Another example of a major change in foob web structure is the seven-fold increase in gelatinous zooplankton in the Bering Sea (Fig. 4) that may result from a competitive interaction between jellyfish and walleye pollock (Brodeur *et al.* 1999, 2002). Both of these changes in the Bering Sea appear to be related to climate changes, but the underlying causes and interactive effects remain to be determined. A special issue of *Progress in Oceanography* will cover "Variability in the Bering Sea Ecosystem" (Macklin *et al.* [Eds.] 2002).

Table 5 Comparison of primary production and phytoplankton biomass, and physical and chemical environmental factors between the Western Subarctic Gyre (WSG) and Alaskan Gyre (AG) in summer (from Shiomoto *et al*. 1998).

Parameter	WSG	AG
Primary production (mg C m^{-2} d^{-1})	663 $\pm$ 86; 751 $\pm$ 94	642 $\pm$ 55
Chl concentration (mg L^{-1})	1.03 $\pm$ 0.15; 0.82 $\pm$ 0.05	0.4
Chl standing stock (mg m^{-2})	28.6 $\pm$ 2.9	22.9 $\pm$ 1.6
Surface primary productivity (mg C mg Chl $^{-1}$ d $^{-1}$)	33.4 $\pm$ 2.5	51.3 $\pm$ 5.6
Temperature < 50 m (^{o}C)	3.0 – 9.5	6 - 12
Euphotic zone depth (m)	24 - 49	57- 82
Nitrate + nitrite concentration (μM)	10.4 – 22.9	6 - 17

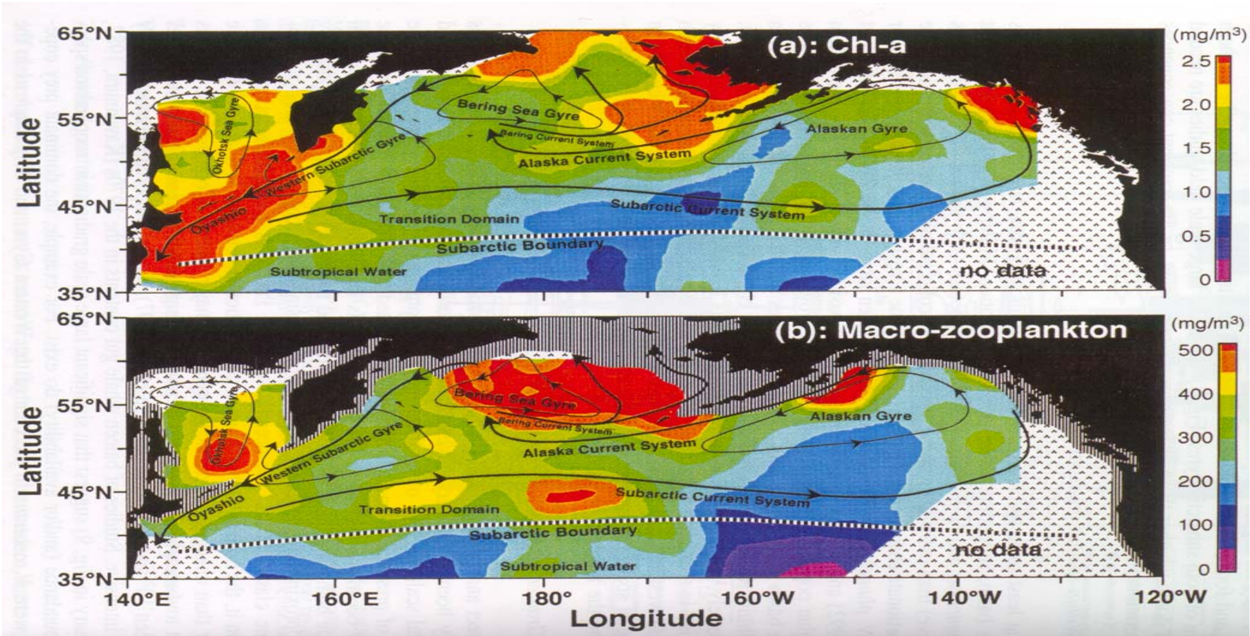

Fig. 1 Average summer season distributions of upper ocean chlorophyll concentration (upper panel), and zooplankton biomass (lower panel) in the subarctic Pacific, overlaid with the circulation pattern. Figure courtesy of K. Tadokoko, modified by colorization and addition of circulation streamlines from Sugimoto and Tadokoro, 1997. Figure 8 from Mackas and Tsuda (1999).

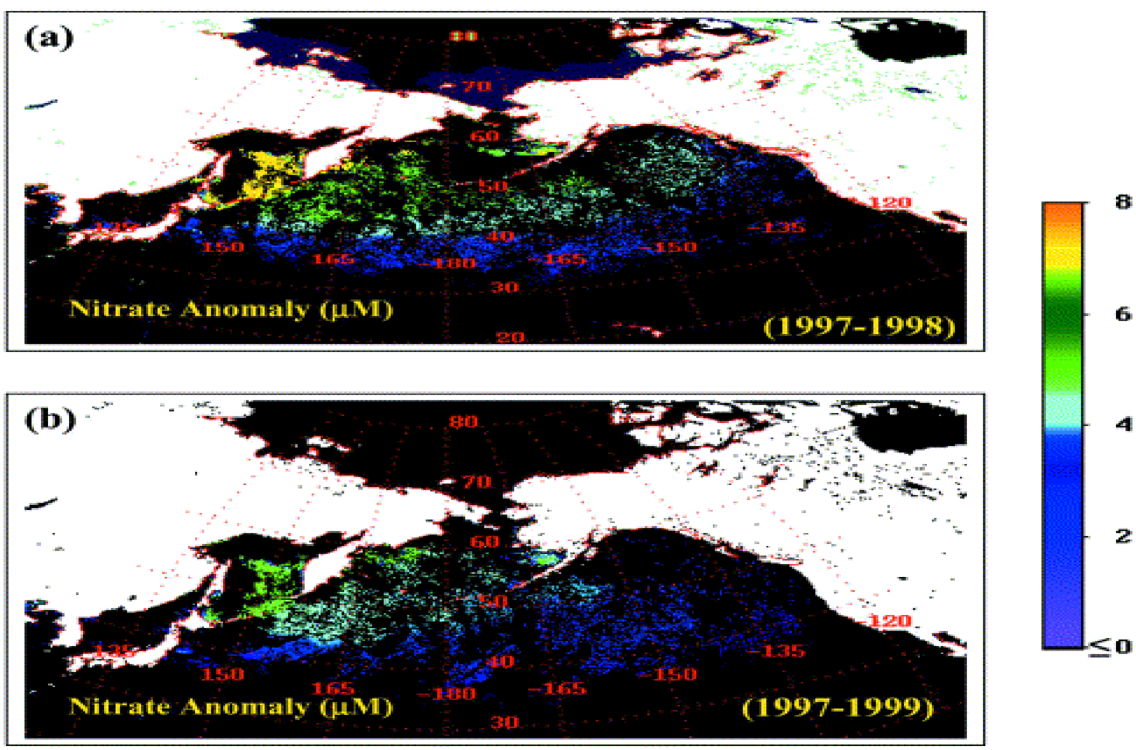

Fig. 2 Anomaly plots showing the difference in sea surface nitrate concentrations between a) 1998 and 1997 and b) 1999 and 1997. Figure 3 from Goes *et al.* (2001).

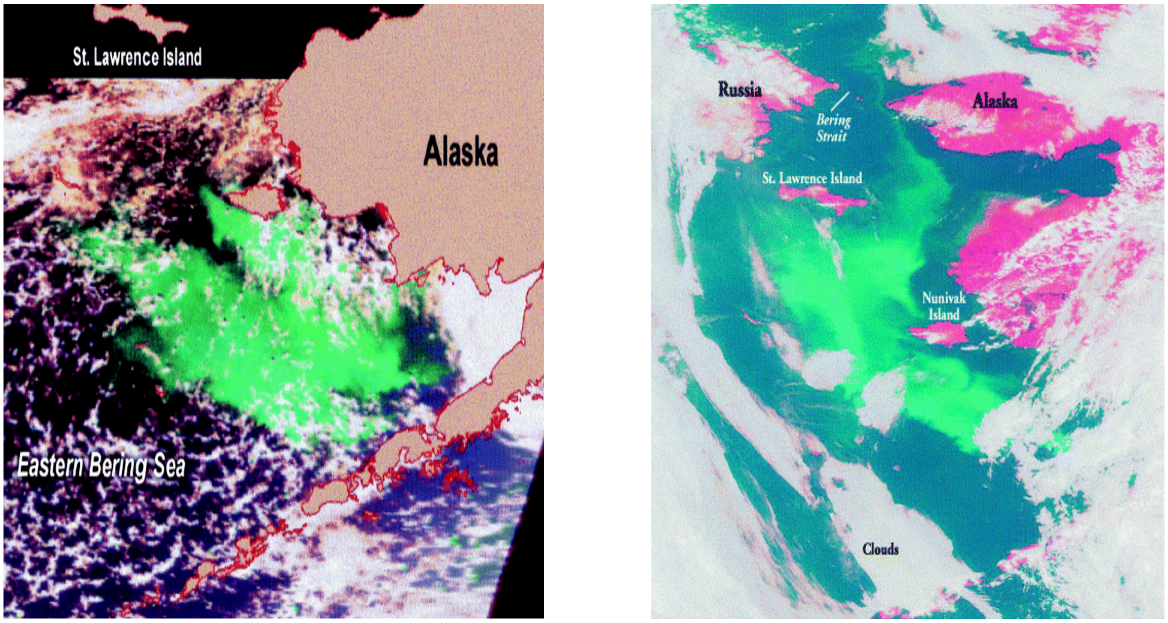

Fig. 3 SeaWIFS composite true color image of coccolithophore bloom in the eastern Bering Sea (left panel). SeaWIFS false color image showing the extension of a filament of the bloom northward to the Bering Strait (right panel). Both images are from Napp and Hunt (2001).

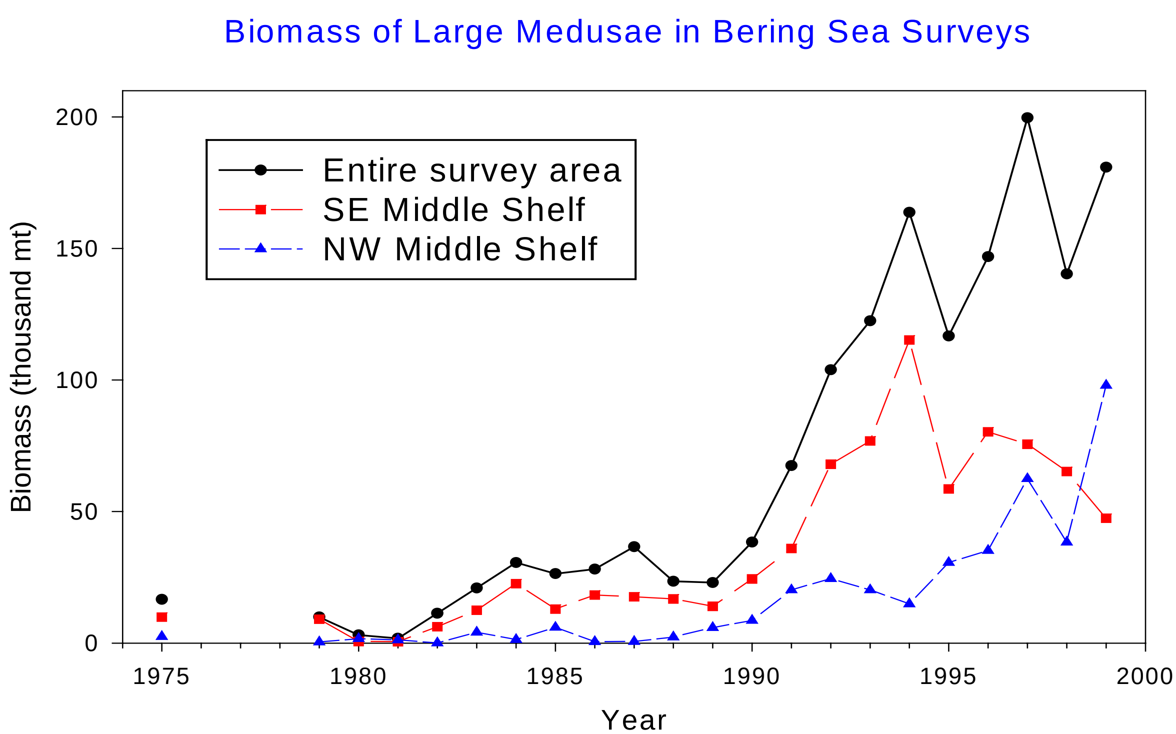

Fig. 4 Biomass of medusae collected on the eastern Bering shelf from 1975-1999. Figure 2 from Brodeur *et al.* (2002).

The understudied groups of organisms in the North Pacific Ocean include micronekton and marine birds and mammals. Micronekton include small squid, migratory midwater fish and shrimps, that are difficult to sample quantitatively. Mackas and Tsuda (1999) demonstrate the importance of micronekton by partitioning the consumption of copepod production (*Neocalanus*) in the subarctic Pacific (Fig. 5). Their analysis suggests that approximately one-third of the total predation of *Neocalanus* is likely to be due to squids, myctophids, shrimp and deep-living chaetognaths. Work is underway by WG 14 to develop and improve methods for sampling and assessing the role of microzooplankton in the North Pacific.

Marine birds and mammals comprise another major understudied group in the North Pacific ecosystem. As part of the east-west gyre comparison, Springer *et al.* (1999) reviewed the gross distribution of seabirds and certain marine mammals in the North Pacific gyres to compare their east-west distributions. The available information indicates that seabird biomass in the western gyre is three-fold greater than that in the eastern gyre. Cetaceans (prior to overharvesting) were also more abundant in the western gyre. Both of these observations suggest higher productivity in the western gyre as was also suggested by Mackas and Tsuda (1999) and by Goes *et al.* (2001). Hunt *et al.* (2000) compiled more extensive data on biomass distribution and prey consumption and identified major gaps in the survey of marine birds and mammals in the regional areas depicted in Figure 2 (Introduction to this volume). As better observational data become available it is clear that populations of marine birds and mammals fluctuate with changing climate conditions.

Current work in the southeast Bering Sea demonstrates major changes in the importance of large whales in the 1990s in terms of predation and carbon cycling (Tynan 2001). Combinations of long-term observations of abundances and migrations with measures of consumption demonstrate dramatic changes in the roles of large whales as top predators in the southeast Bering Sea (Tynan 2001). It is only by increasing our knowledge of the abundance and activity of these important groups, that we will have sufficient information to understand and predict possible changes in the ecosystem resulting from climatic or anthropogenic changes.

Finally, the role of trace metals and biogeochemical cycling in controlling biological production and the carbon cycle has, and will, continue to receive attention in studies of the North Pacific. The role of iron as an important trace metal limiting phytoplankton production was first recognized in the subarctic Pacific by the late John Martin. Investigations in the Gulf of Alaska demonstrate an important role of iron and light in regulating diatom growth (Fig. 6, Harrison *et al.* 1999). Their results support the conclusion that iron limits the primary productivity of the large cells (especially diatoms) except in the winter when iron and light become co-limiting. The small phytoplankton do not appear to be iron limited, but are mainly controlled by microzooplankton grazers. The potential effect of iron on the subarctic ecosystem continues to be an important area of investigation with a PICES supported field program planned for 2002-2003.

Studies of carbon cycling have been jointly sponsored by BIO and POC through workshops and topic sessions, and the most recent results will be presented in a special issue of *Deep-Sea Research* II in 2002. Other examples of important aspects of biogeochemistry in the North Pacific include re-evaluation of estimates of nitrogen fixation in the Pacific Ocean and globally (Karl *et al.* 2001), and the impact of microbial food webs in both the Pacific and the Atlantic Oceans. These issues will be covered in a special issue of *Progress in Oceanography* on "Plankton size classes, functional groups, and ecosystem dynamics: Causes and consequences" (Bychkov and Pena [Eds.] 2003). We anticipate that such studies will continue to be an important part of PICES activities through the next decade.

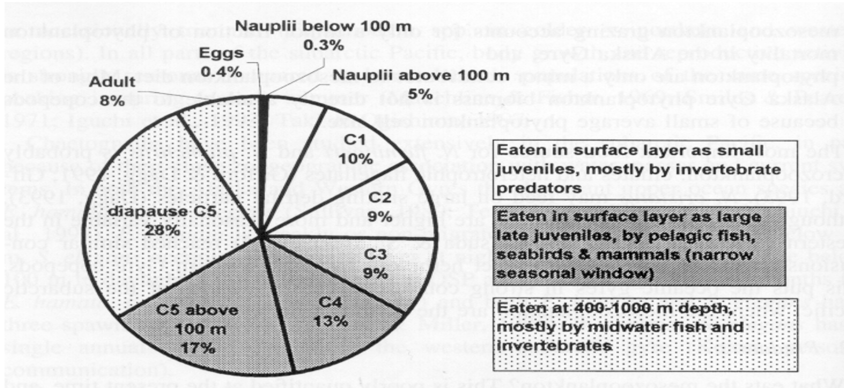

Fig. 5 Fate of *Neocalanus plumchrus* production, as estimated from a life-stage partitioning of mortality weighted by individual body size. Shading indicates degree of availability to different sets of predators. About one-third (unshaded) is in the upper layer on small nauplii and early copepodites, and is probably available mostly to invertebrate predators. Slightly over one third (sloped lines) is on larger C3-C5 copepodites during the brief time window before they leave the surface layer. This fraction is the only one likely to be directly available to the larger planktivorous pelagic fish, sea birds and marine mammals. It is also available to invertebrates and migratory micronecton. The remainder occurs below the upper 150 m, mostly on diapausing C5 and adults (stippled); this fraction is likely to be available primarily to midwater micronekton. Figure 5 from Mackas and Tsuda (1999).

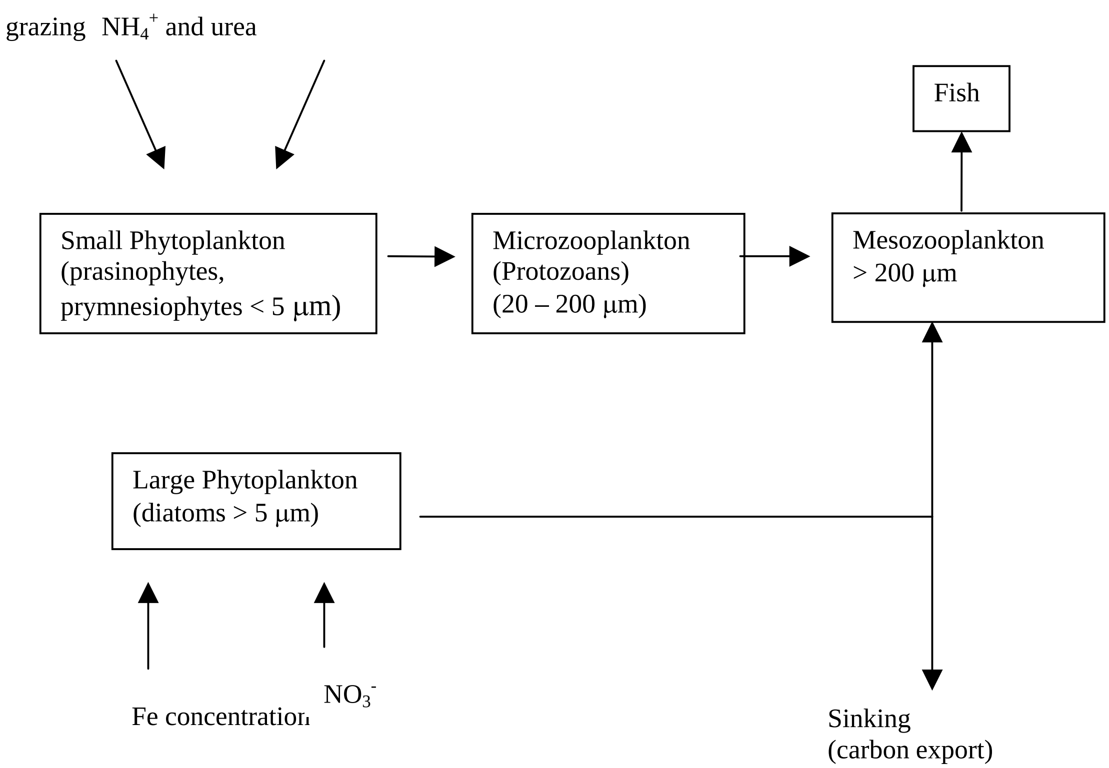

Fig. 6 Simple food change at Station P showing bottom-up control of large phytoplankton by Fe and top-down control of small phytoplankton by microzooplankton grazing. Figure 8 from Harrison *et al.* (1999).

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