July 1999 ISSN 1195-2512 Vol. 7 No. 2

PICES Press

Newsletter of the North Pacific Marine Science Organization (Published semi-annually)

Improving PICES CO_2 measurement quality

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One of the first questions asked of analytical measurements is: how reliable are they? This is the key concern of the PICES Working Group 13 on "CO_2 in the North Pacific", which requires that measurements made at different times, by different investigators, from different laboratories in the various PICES nations, are comparable and correct.

In October 1998, at the first meeting of WG 13 in Fairbanks, Alaska, it was decided that, as one of the first steps towards this goal, the Working Group would plan and carry out a series of inter-laboratory comparisons of measurement techniques for such carbonate parameters as total dissolved inorganic carbon, total alkalinity, and the $^{13}C/^{12}C$ ratio of the inorganic carbon in seawater. For our initial study, we decided to focus on the first two parameters. The plan was to conduct an inter-laboratory comparison of these measurements on some natural sea water samples, and then hold a technical workshop to discuss the results of these studies, and initiate detailed exchange regarding measurement techniques and data quality among scientists working in the North Pacific, to ensure that future CO_2 data collected in the region are of the high quality needed for biogeochemical studies.

Four separate samples based on natural seawater were used:

- A Certified Reference Material (Batch 45) supplied by Dr. A. Dickson of the Scripps Institution of Oceanography;
- An unknown surface sea water sample supplied by Dr. A. Dickson, and prepared in the same way as the Scripps Certified Reference Materials;
- An unknown surface sea water sample supplied by Dr. N. Tsurushima, and prepared in the same way as the University of Hokkaido secondary standards for total dissolved inorganic carbon; and
- An unknown deep-sea water sample supplied by Dr. A. Murata, based on water collected in November 1998 on the R/V *Mirai* from a depth of 3000 m, filtered and sterilized.

These samples were distributed in February 1999 to the various participating laboratories, and were analyzed by thirteen laboratories for total dissolved inorganic carbon and by nine laboratories for total alkalinity.

A follow-up workshop was held April 20–22, 1999, in Tsukuba, Japan, at the National Institute for Resources and Environment. About 30 scientists and technicians participated in this intercalibration exercise (*see photo and the accompanying table*). Travel for a number of the non-Japanese participants was provided by PICES, the Kansai Environment Engineering Center, and the Japan Marine Science and Technology Center. For the workshop, a conference room was paired with a laboratory so that participants could alternate between detailed technical discussions of measurement techniques and quality control, and viewing of actual analytical instruments set up in the adjoining laboratory.

Participants of the PICES CO_2 Technical Workshop held April 20–22, 1999 at the National Institute for Resources and Environment, Tsukuba, Japan.

Author of this paper Dr. Andrew G. Dickson (indicated by arrow) is an Associate Professor-in-Residence at the Scripps Institution of Oceanography of the University of California, San Diego. His research interests include the study of the oceanic carbon dioxide system as well as other aspects of ocean biogeochemistry. Andrew is a member of the joint IOC/JGOFS (Intergovernmental Oceanographic Commission/Joint Global Ocean Flux Study) Advisory Panel on Ocean Carbon Dioxide and a member of the PICES Working Group 13 on CO_2 in the North Pacific. Through these two groups he plays a major role in organizing inter-calibration and quality control for CO_2 measurements in seawater.

Participants of WG-13 CO_2 Technical Workshop

Country	Affiliation	Name
Canada	Institute of Ocean Sciences, Sidney, B.C.	W. K. Johnson
Japan	Central Research Institute of Electric Power Industry, Abiko	K. Shitashima
	Hokkaido University, Sapporo	S. Watanabe
	Japan Marine Science and Technology Center, Yokosuka	A. Murata
	Japan Science and Technology Corporation & Hokkaido University, Sapporo	N. Tsurushima
	Japan Science and Technology Corporation & National Institute for Environmental Studies, Tsukuba	T. Egashiri, F. Shimano
	Kansai Environment Engineering Center Ltd., Osaka	K. Goto, T. Harimoto K. Ishida, T. Kitao H. Ohta, H. Tsubota
	Marine Works Japan Ltd., Yokohama	J. Imai, H. Yamamoto
	Meteorological Research Institute, Tsukuba	H. Inoue, M. Ishii
	National Institute for Environmental Studies, Tsukuba	Y. Nojiri
	National Institute for Resources and Environment, Tsukuba	K. Harada, Y. Watanabe
	National Research Institute of Fisheries Science, Yokohama	T. Ono
	Research Institute of Oceano-Chemistry, Osaka	T. Kimoto
	Tokyo University of Fisheries, Tokyo	M. Aoki
Korea	Seoul National University, Seoul	D.-J. Kang
Russia	Pacific Oceanological Institute, Vladivostok	G. Pavlova
USA	NOAA Pacific Marine Environmental Laboratory, Seattle	R. A. Feely, M. F. Roberts
	Scripps Institution of Oceanography, San Diego	J. Afghan, G. C. Anderson A. G. Dickson
	University of Hawaii, Honolulu	C. Carillo, D. Hebel

Two institutions participated in the intercalibration exercise but not in the technical workshop: NOAA/AOML, Miami, U.S.A., and National Sun Yat-Sen University, Kaohsiung, China-Taipei.

(cont. on page 5)

The status of the Bering Sea: July – December 1998

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Dr. Phyllis J. Stabeno, a physical oceanographer at the Pacific Marine Environmental Laboratory (PMEL) of NOAA, conducts research focussed on understanding the dynamics of circulation of the North Pacific, Bering Sea and their adjoining shelves. She is the PMEL Director of NOAA Fishery Oceanography Coordinated Investigations (FOCI), and by applying her knowledge of physical processes to fisheries oceanography, she plays a vital role in its success. FOCI research focusses on building sustainable fishery resources in the Gulf of Alaska and Bering Sea while maintaining a healthy ecosystem. Phyllis is also a Principal Investigator on several research elements for other programs, including: Southeast Bering Sea Carrying Capacity (Coastal Ocean Program), the Bering Sea Green Belt: processes and ecosystem production (Arctice Research Initiative) and Prolonged Production and Trophic Transfer to Predators: processes at the inner front of the southeast Bering Sea (National Science Foundation). This research seeks to improve our understanding of ecosystems through the integration of physical and biological phenomena.

Observations of the eastern Bering Sea shelf continue to provide a strong example of an ecosystem undergoing significant physical and biological change. Both 1997 and 1998 showed unusual conditions in the physical oceanographic and meteorological environment. These included enhanced transport in the Bering Slope Current, above normal sea surface temperatures, strong wind mixing late May and weak summer winds. Anomalous weather conditions in spring 1997 and 1998 caused significant changes in physical and biological features of the southeastern Bering Sea. These in turn contributed to extensive die-off of seabirds, a rare coccolithophore bloom (which continues to this day) and a commercial failure of salmon runs.

Significant changes in this ecosystem are of particular concern since the eastern Bering Sea provides approximately half the fish and shellfish caught in the United States. It is also home to at least 450 species of fish, crustaceans, and mollusks; 50 species of seabirds; and 25 species of marine mammals. Major changes in one species within this ecosystem could have profound effects throughout the system. In response to the changing conditions, NOAA scientists convened an international workshop (The FOCI International Workshop on Recent Conditions in the Bering Sea). Several thematic questions served as a focus at the workshop:

- What anomalous conditions were observed in the eastern Bering Sea during 1997 and 1998 and what mechanisms caused these anomalies?
- Is there evidence that these unusual conditions will persist?
- What are the implications for the future of the ecosystem and its living marine resources?

A final report of the workshop was completed and may be found on the web at http://www.pmel.noaa.gov/foci/bs_98workshop/workshop_report.pdf. Further discussion of results in this article can be found in more detail in the report.

The Bering Sea ecosystem is a complex and highly variable environment. Atmospheric forcing occurs on a continuum of temporal scales, including interannual (ENSO), decadal (Pacific Decadal Oscillation), and longer (Global Climate Warming). These in turn effect the physical oceanographic variability of the region, which then cascades through the ecosystem. The strong El Niño of 1997 was followed by a strong La Niña in 1998. Both of these influenced the atmospheric conditions in the Bering Sea. The Pacific Decadal Oscillation (PDO) switched from a strongly negative (cold SST in the eastern Pacific Ocean) to positive (warm SST) values in 1997. Within the time series of the PDO, there is some interannual variability especially associated with ENSO events. During 1998, the PDO has been strongly negative, but this may be more a result of the La Niña, than a change in decadal patterns of the PDO. Although there has been, and continues to be, considerable speculation of a regime shift comparable to the one that occurred in 1977, it is too early to tell. Such a change could have a profound impact on salmon in the Bering Sea, since changes in the PDO appear correlated with salmon production. The sudden climate shifts that occurred in 1923, 1947 and 1976 in the North Pacific substantially altered marine ecosystem in Alaska as well as off Japan, Hawaii, California and Peru. The recent warm period of the PDO has been associated with high salmon production in Alaskan waters. In addition to decadal variability, long-term climate trends must also be considered. From paleoclimatic evidence, it appears that present conditions on the Bering Sea shelf are anomalously warm. During the last decade, the western Bering Sea has cooled while the eastern Bering Sea has warmed.

Atmospheric conditions directly influence the sea surface temperature (SST). Mooring sites (*Figure 1*) funded as part of Southeast Bering Sea Carrying Capacity (a NOAA Coastal Ocean Program) are in their fifth year of collecting data and provide important data to help unravel the changes that are occurring in this ecosystem. The following observations are from these moorings. During summer 1997, SST on the Bering Sea shelf was particularly warm (>4˚C above normal over the southeastern shelf) due to weak winds (shallow mixed layer) and fewer clouds. During 1998, extremely stormy conditions persisted into June. In July, however, winds decreased and calm conditions occurred for the next 6 to 8 weeks. This once again resulted in a shallow mixed layer. In addition, during 1998 sea ice did not intrude deeply over the southeast shelf, and was present for only a short time, which resulted in the retention of some of the heat from the previous year (1997). The weak shallow mixed layer and warm initial conditions resulted in above normal SST (2˚C above normal) for the second year in a row.

From the historical data records in the vicinity of site 2, 138 separate occupations of hydrographic stations were found from 1966-1998. From these and the mooring data from site 2, it is evident that the upper layer typically begins warming in late March or early April, and temperature continues to increase through

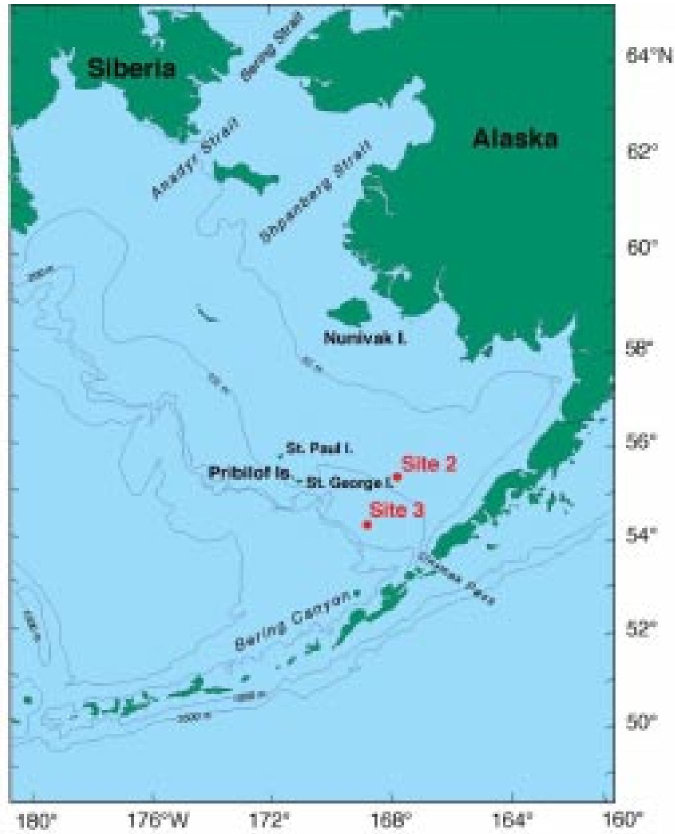

Fig. 1 Geography and place names in the eastern Bering Sea. The location of the two monitoring lists is indicated by bold numerals. The hydrographic transect is show as a solid line. Depth contours are in meters.

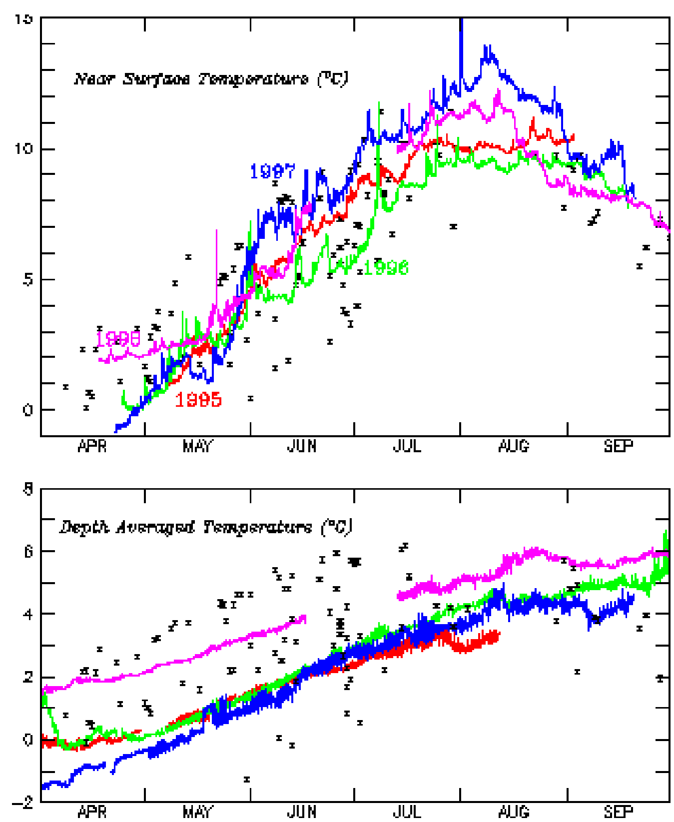

Fig. 2 (a) The seasonal sign of near surface temperature at Site 2. Data from the years when moorings were located at this location are indicated by colored lines. Data from hydrographic surveys between 1966 and 1994 are shown as Xs. (b) The depth averaged temperature for the same data shown in panel a.

early August when maximum SST typically occurs. Prior to 1997, near surface temperatures did not exceed 11.5˚C, but temperatures well above this maximum were observed in the summer of 1997 and to a lesser extent in 1998. While the warmest near-surface temperatures were observed in 1997, the water column as a whole was not particularly warm (*Figure 2b*). It is interesting to note that the warm surface temperatures during 1997 were offset by a shallow mixed layer and cool bottom temperatures so that vertically averaged temperatures were similar to those observed in 1995 and 1996, and cooler than most of the historical temperatures. In contrast the warm surface temperature of 1998 was complemented by the warmer than average bottom temperatures, resulting in the depth averaged temperatures being the warmest of those observed during the last decade. They were however cooler than the warm years of the early 1980s, when PROBES collected data in this region.

The transport in the Bering Slope Current was comparable to what it was in 1997 (~6 x 10^6 m^3 s^{-1}), which is approximately twice the expected transport. Significant cross shelf transport occurred during 1998. This was evident in the increase in salinity that was observed over the shelf, and was supported by finding of age-0 pollock and oceanic zooplankton along the 50 meter isobath about 400 km from the shelf break. Measured currents on the shelf over the southern Bering Sea were stronger in 1998 than in 1997, particularly along the 50 meter isobath which typically forms the boundary between the coastal domain and the middle shelf. The coccolithophore bloom, which began in early summer 1997 continued through 1998. Coccolithophores are small, photosynthetic cells covered by calcareous plates. Light reflects from the plates giving the water its distinctive milky white color. This bloom was farther north on the shelf during 1998 than in 1997. The flow of water through Spanburg Strait and north through Bering Strait is clearly indicated by the thin stream of coccolithophore rich water flowing northward between the two passes in *Figure 3*. Why the coccolithophore bloom has persisted for so long is not known, but it is possible that limited nitrogen over shelf favored the growth of coccolithophores over diatom species or that the warmer than normal temperatures over the shelf during the last summers provided a favorable environment.

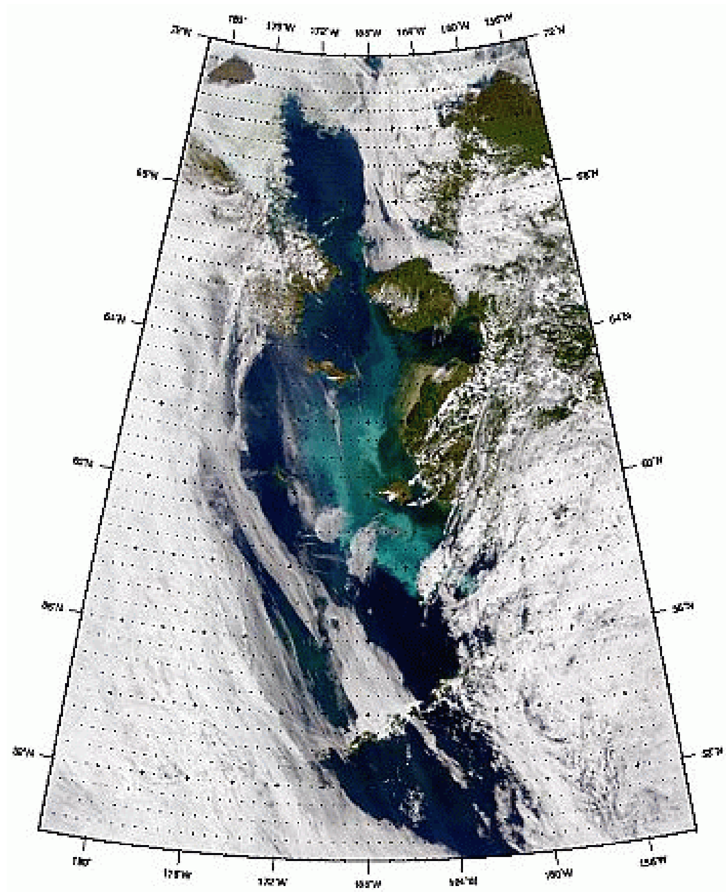

Fig. 3. SeaWiFS true color image from 19 July, 1998, showing the advection of the coccolithophore bloom northward through Bering Strait and into the Chuckchi Sea.

(cont. from page 2)

One principal focus of the meeting was to discuss in detail results obtained from the inter-laboratory comparison. The measurements of total dissolved inorganic carbon were very encouraging. Once the data had been adjusted using the measurement on CRM Batch 45 so as to allow for calibration problems, all the results from the various laboratories involved were consistent with each other. However, for the measurement of alkalinity, though a calibration adjustment improved the degree of agreement, there were still significant discrepancies between the measurements made by the various laboratories. In fact, much of the discussion at the workshop centered on techniques for improving the calibration of these measurements for the future. Results from the workshop will be presented at the WG 13 meeting at PICES VIII in Vladivostok (Oct. 8-9, 1999). A detailed report is being prepared which will be published in both English and Japanese later this year. Both the Technical Workshop, which all found stimulating and informative, and the wonderful hospitality of our hosts, Drs. Yukihiro Nojiri and Koh Harada made the visit to Tsukuba extremely enjoyable.

Our next step should be a Data Workshop (co-sponsored by PICES and JGOFS) planned for the year of 2000. It will enhance the effort to merge the various CO_2 data sets from around the North Pacific and thus lead to an improved overall understanding of the processes affecting the carbon cycle in the region.

The state of the eastern North Pacific since October 1998

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Dr. Howard J. Freeland is Head of the Ocean Science and Productivity Division of the Department of Fisheries and Oceans, Pacific Region, Science Branch, and works at the Institute of Ocean Sciences. His research interests include the climatic state of the ocean and low frequency variability, and he is the scientist accountable for the maintenance of Line-P. Howard is a member of PICES' Physical Oceanography and Climate Committee, and the newly formed Publication Committee. He also serves as an adjunct professor at the University of Victoria.

The 1997/98 El Niño event ended abruptly in May of 1998. At that time sea level off the west-coast of N. America experienced a very rapid set-down. At exactly this time a very intense eddy was generated near the border between British Columbia and Alaska, which propagated offshore and southwards against the prevailing currents. This was reported in the PICES Press Vol. 7, No. 1. William Crawford (Institute of Ocean Sciences) has continued to track this eddy, nicknamed the Haida Eddy, and in February 1999, it was at 47° 45' N, 135° 40' W. The sea-level anomaly at the centre is about 25 cm and the diameter of the 5 cm anomaly contour is about 200 km. This intense feature is carrying a distinct ocean ecosystem at its core and we hope to be able to continue to track its progress and evolution. The February Line-P trip will re-visit the eddy and seed an APEX float in the centre. The APEX float is a reengineering of the profiling ALACE, float developed by Webb Research of Falmouth, Massachusetts. This particular float is an early, prototype model supplied by Webb Research for testing purposes.

After the end of the El Niño in the equatorial Pacific, sea surface temperatures declined in the N.E. Pacific. *Figure 1* shows actual sea-surface temperature observations over the last 12 months at Amphitrite Point, a lighthouse on the west coast of Vancouver Island. The return towards normalcy is clear and the difference between conditions in February 1998, and February 1999, is dramatic. The plot shows actual sea surface temperature observations, the black curve indicates the annual cycle determined from 65 years of daily observations. Observations above the normal temperature are shaded red, and observations below normal are shaded blue.

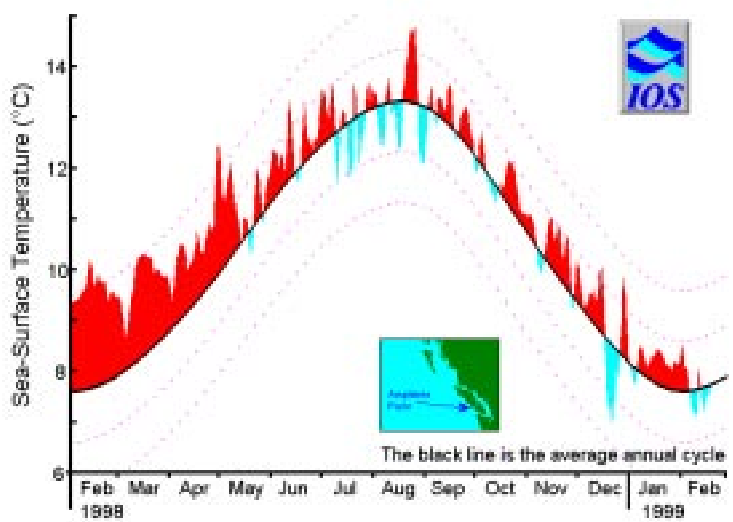

Fig. 1 *Sea surface temperature time series at Amphitrite Point, on the west coast of Vancouver Island, over the last 12 months.*

However, conditions did not return to normal on the equator. Almost immediately after El Niño conditions ended, a large pool of cold water developed in the central Pacific, and the Pacific came under the influence of the 1998/99 La Niña. On the equator La Niña conditions continued to strengthen through January 1999. Besides the cooling in the central Pacific of up to 3°C, the Tropical Atmosphere Ocean (TAO) array shows stronger-than-normal low-level easterly winds, and NOAA satellites observe a reduction in outgoing long-wave radiation, etc. These are all symptomatic of a significant La Niña event taking place.

When an El Niño occurs, there are clear manifestations of this event at high latitudes. For example, the very high temperatures seen in the early months of 1998. However, the high latitude SSTs do not correlate well with the incidence of equatorial La Niñas.

The diagrams in *Figure 2* show that despite the influence of the equatorial La Niña, sea surface temperatures in the coastal regions of the N.E. Pacific have actually remained slightly higher than average until December 1998.

Computer models designed to forecast conditions in the equatorial Pacific indicate that any return towards normalcy should take several seasons yet. If that remains the case, and we have had surprises in recent years, then no large anomalies should be expected in the N.E. Pacific over the next couple of seasons.

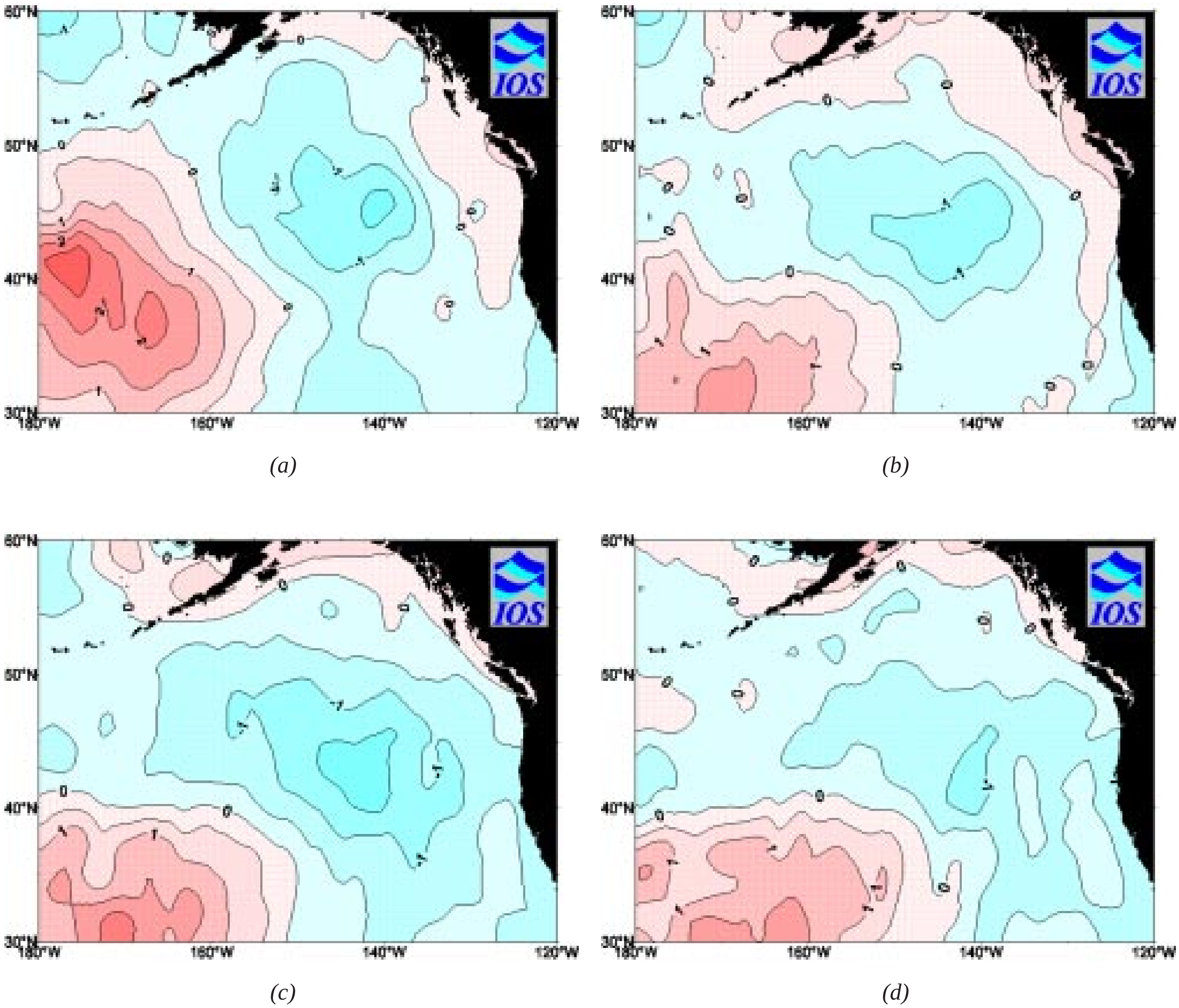

Fig. 2 Sea surface temperature anomaly field in the N.E. Pacific. (a) October 1998, (b) November 1998, (c) December 1998 and (d) January 1999.

The state of the western North Pacific in the second half of 1998

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Mr. Satoshi Sugimoto is Scientific Officer of the Oceanographical Division of the Climate and Marine Department at the Japan Meteorological Agency (JMA). He is working as a member of a group in charge of monitoring and forecasting sea surface temperature and sea surface current in the western North Pacific. Based on in situ and satellite data, this group provides various oceanographical products. One of the main products is the "Monthly Ocean Report", which is published and distributed by JMA every month. Mr. Sugimoto is now involved in developing a new analysis system for sea surface and subsurface temperature to improve sea surface temperature forecasts in the western North Pacific.

Sea surface temperature

Figure 1 shows monthly mean sea surface temperature (SST) anomalies in the western North Pacific from July to December 1998, computed with respect to JMA's 1961-90 climatology. JMA has operationally produces ten-day and monthly mean SST analysis for 1x1 degree grid points over the western North Pacific, using *in situ* observations. Another daily SST analysis has been performed in seas around Japan, between 20˚N and 50˚N from 110˚E to 160˚E. In this analysis, satellite-derived SST (NOAA/AVHRR) and *in situ* observations are both used. JMA adopts SST of this analysis for that region in the 1x1 degree SST analysis over the western North Pacific from January 1998.

It is remarkable that positive SST anomalies exceeding +1˚C were observed from 160˚E to 170˚W along 40˚N in August 1998, and anomalies exceeding +3˚C were found around 40˚N, 170˚E. These anomalies expanded and moved westward, and SST anomalies exceeding +1˚C prevailed along 30˚N in December.

In the western tropical Pacific, positive SST anomalies exceeding +0.5˚C prevailed west of 150˚E throughout 1998, exceeding +1˚C in the South China Sea and southeast of Philippines.

Time series of regional ten-day mean SST anomalies in the western North Pacific (*Figure 2*) show that SST anomaly of 1998 for region D was the highest in the last ten years. In region B and region C, SST anomalies, which had been almost always negative between 1992 and 1997 except during 1994 for region B, turned positive in July 1998 and December 1997, respectively. SST anomaly for region B exceeded +2˚C in September 1998, and dropped in November 1998, while that for region C was positive throughout 1998. In region F, SST anomaly was negative throughout 1998.

Kuroshio

Figure 3 shows the location of the Kuroshio axes from July to December 1998. The Kuroshio has kept a non-large-meander path, though a small meander of the Kuroshio has persisted near 139˚E since May 1998. Its southernmost position near 139˚E was almost 32˚N in July and in November. Near 132˚E, the Kuroshio has flowed off the coast of Japan since November 1998.

Carbon dioxide

JMA observed the distribution of carbon dioxide concentrations (partial pressure, pCO_2) in the surface water and the overlying atmosphere in the western North Pacific on board R/V *Ryofu Maru* from September 17 to November 10, 1998 (*Figure 4*).

In the area south of the Kuril Islands and north of 48˚N along 165˚E in September 1998, the CO_2 partial pressure in the surface water was lower than in the atmosphere, implying that atmospheric CO_2 was absorbed by the ocean. In the western equatorial Pacific in October 1998, the CO_2 partial pressure in the surface water was higher than in the atmosphere, indicating that oceanic CO_2 was emitted into the atmosphere. This is the first time that the CO_2 concentration in the surface sea water along the equator exceeded 30 μ-atm as compared to those in the atmosphere since November 1996.

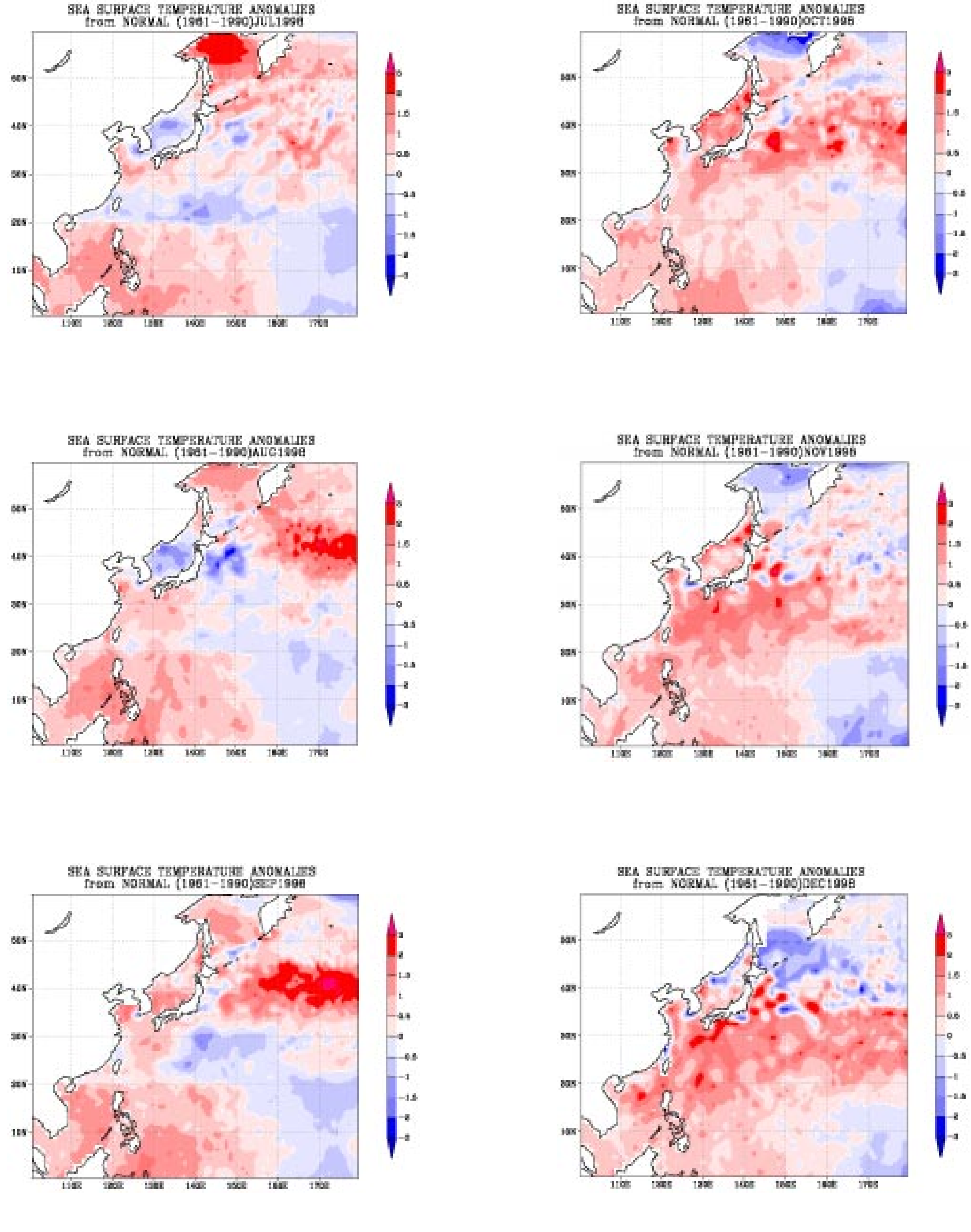

Fig. 1 Monthly mean sea surface temperature anomalies (˚C). Anomalies are departures from JMA's 1961-1990 climatology.

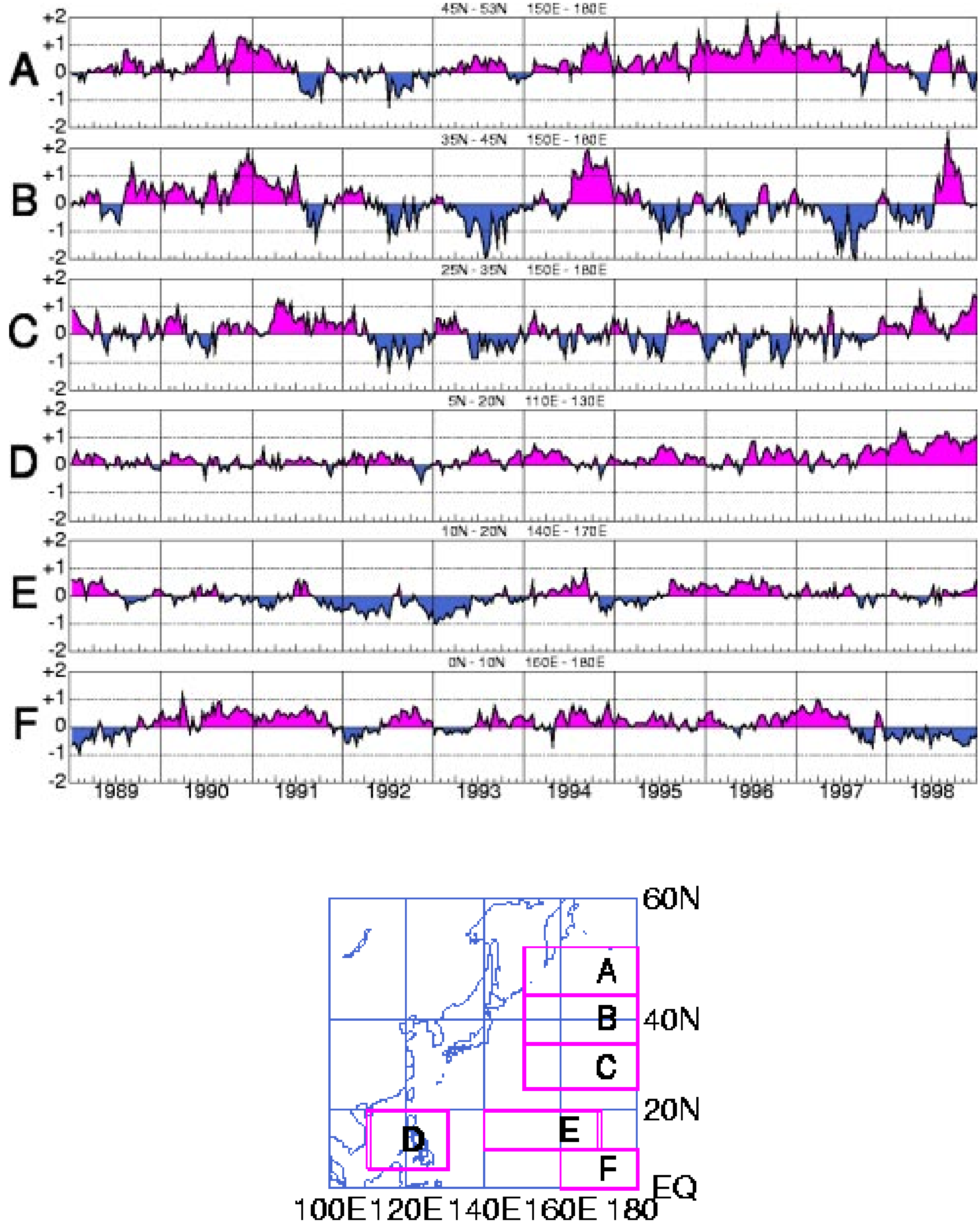

Fig. 2 Time series of the ten-day mean sea surface temperature anomalies (˚C), computed from JMA's 1961-1990 climatology for the areas shown in the bottom panel.

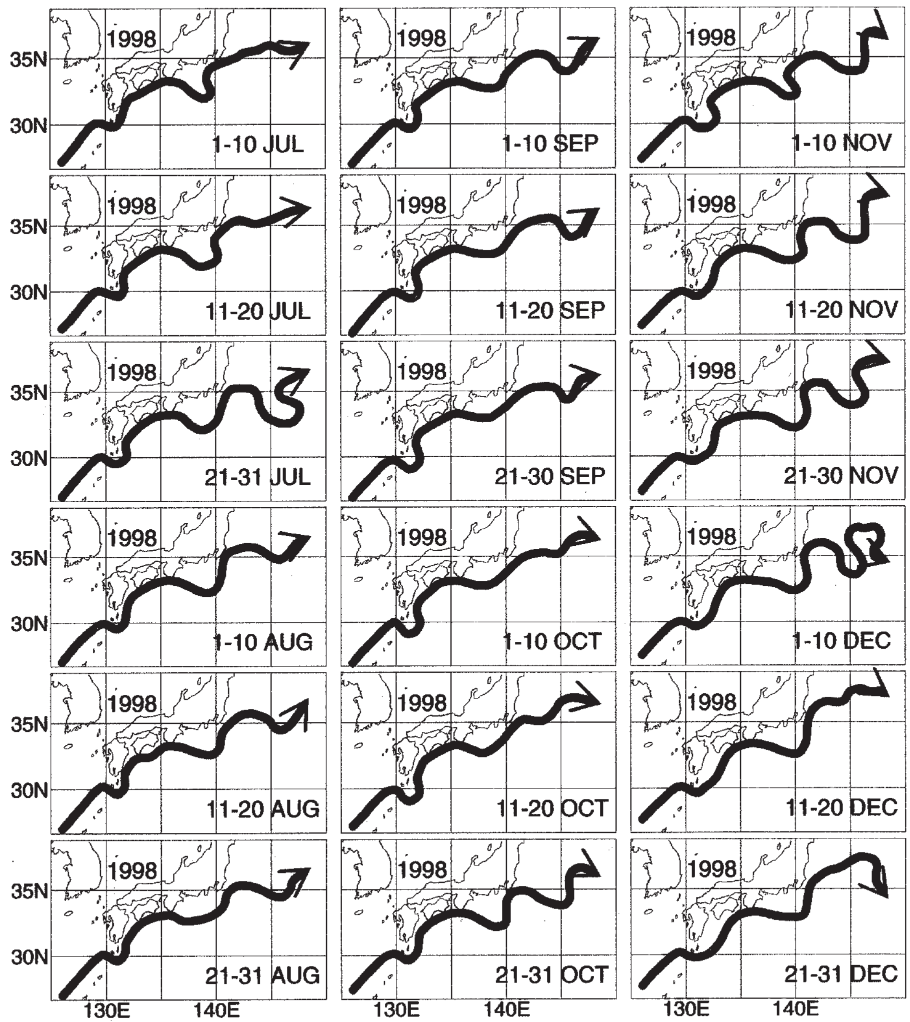

Fig. 3   *Location of the Kuroshio axis from July to December 1998.*

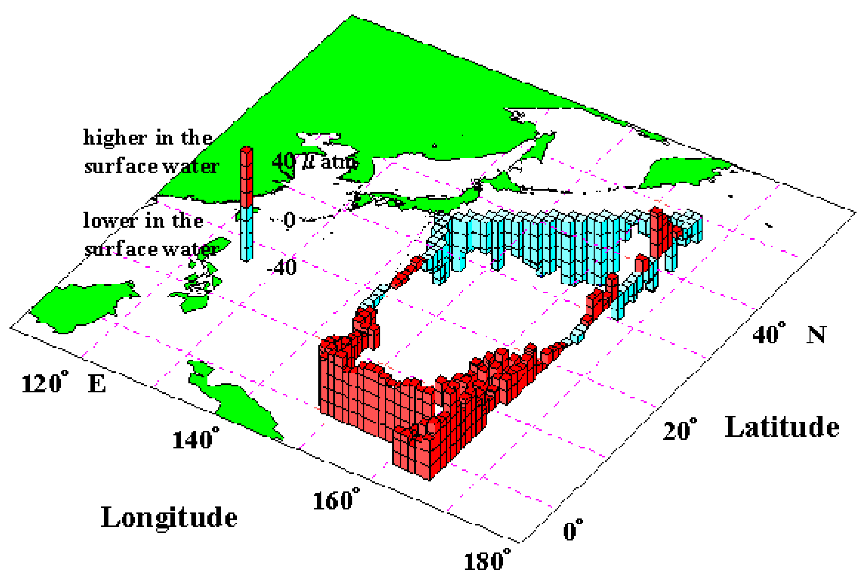

Fig. 4   *CO_2 concentration difference between the surface water and the overlying atmosphere in the western North Pacific observed by the R/V* Ryofu Maru *from September 17 to November 10, 1998. Red upward pillars indicate that the ocean emits CO_2 into the atmosphere, and blue downward pillars indicate atmospheric CO_2 is absorption by the ocean.*

Paul Henry LeBlond

The all-around scientist Paul, in different roles at various PICES meetings: presenting a paper at the scientific session, introducing the POC Best Presentation Award and leading a discussion at the POC business meeting.

Paul LeBlond has made a tremendous contribution to PICES since its inception. Besides attending every PICES annual meeting, he was a member of the Physical Oceanography and Climate Committee (POC) from the beginning and chaired that committee from 1996-1998. Paul co-chaired Working Group 7 on "Modeling the Subarctic North Pacific Circulation," which reviewed the status of physical modeling efforts in the North Pacific and identified the kinds of observations and information that would be needed to improve circulation models. This work proved valuable in providing advice and direction to the PICES Climate Change and Carrying Capacity Program's MODEL Task Team, of which Paul was also a member. He served one year on the PICES Publication Study Group, which has now evolved into a standing committee to advise Science Board on publication and translation matters. He is presently a member of the scientific steering committee for the upcoming Beyond El Niño conference that has engendered the support of many international organizations and will prove to be one of the most scientifically stimulating conferences on climate variability and ecosystem impacts to be held in recent years. Paul has been a strong leader in the PICES scientific community, stimulating productive scientific debate among its members, and giving us good directions for the future. Although PICES is losing his leadership after his retirement, we hope to gain his continued participation in PICES scientific endeavors, now and in the future.

Drs. Yutaka Nagata and Paul LeBlond, the first and the second Chairmen of POC at PICES IV in Qingdao, October 1995.

This article is published in appreciation and recognition of Paul's outstanding service to PICES over many years. We hope that the following two essays, along with a brief biography published in the previous issue of PICES Press (Vol. 7, No. 1), give our readers a reasonably complete portrait of Paul.

Dr. Richard Thomson (thomsonr@dfo-mpo.gc.ca), Head of Local Dynamics and Processes Section at the Institute of Ocean Sciences (Sidney, B.C.) was Paul's Ph.D. student at the University of British Columbia (UBC) and has considerable collaborative research experience with Paul. His essay focuses mostly on scientific achievements of Paul.

Dr. Louis Druehl (ldruehl@mail.island.net) is Professor of Marine Botany at Simon Fraser University and now works at the Bamfield Marine Station.(Vancouver Island, B.C.). Paul and Louis were Ph.D. students in Oceanography at UBC at the same time, and continue to socialize, enjoy their friendship and share common interests. Louis' notes provide a "historical view" on Paul's scientific and social life.

A tribute to the scientific accomplishments of Paul H. LeBlond

One way to describe the impact of a scientist's work is through an annotated chronology of their publications. The approach is informative, but dry and uninteresting. A less formal approach is to ask the scientist to list what he or she considers his other most salient contributions, with some indication of why these particular contributions are important. When I confronted Paul LeBlond with this question during a recent meeting we were attending, he hesitated briefly and then listed off a series of publications that he considered his "most satisfying scientific achievements". Research publications that provide a sense of satisfaction, a feeling of "eureka!", regardless of how infrequently the effort might be cited by your peers.

It is perhaps not surprising that his well-known book "Waves in the Ocean", co-authored with Lawrence Mysak, was not at the top of his list. Books are challenging, difficult to write, and help solidify a scientist's reputation internationally, but they do little to lift one's spirit or challenge the intellect in the manner of a primary journal publication. Paul's work on tidal propagation in a river (LeBlond, 1978, 1979, 1981) is near the top of his list. It took him a year of arduous perturbation analysis before he finally realized that his approach was wrong and that the advance of tides up a river channel should be viewed in terms of an elliptical *diffusion* equation rather than a hyperbolic *wave propagation* equation. Paul is equally proud of the papers he wrote (with David Griffin and me) on the estuarine exchange of heat and salt between the southern Strait of Georgia and Juan de Fuca Strait (Griffin and LeBlond, 1990; LeBlond, Griffin and Thomson, 1994). Fortnightly hydraulic control within coastal tidal channels had been studied before, but Paul's co-authored work presented the first predictive model that accounted for the effects of all dominant factors – including tidal currents, winds, and runoff - that control the estuary/ocean. Paul also likes the work he did on the formation of spiral beaches (LeBlond, 1973, 1979, 1980; Bremner and LeBlond, 1974). "What I like about this is the interaction between waves and sedimentology in shaping the coastline. Waves shape the coastline which in turn affects wave propagation through refraction and diffraction..."

After some prodding, Paul acknowledged the widespread use that has been made of his theoretical work with Lin Jiang on tsunami generation by viscous underwater landslides (Jiang and LeBlond, 1992, 1994) and on other aspects of tsunami generation (King and LeBlond, 1982; Dunbar, LeBlond and Murty, 1989; Ng, LeBlond, and Murty, 1990). Tsunami generation and run-up are serious subjects of ongoing research and Paul's series of papers form a cornerstone of much of the modern research being conducted on landslide-generated tsunamis in vulnerable coastal communities in Norway, Alaska and British Columbia. A relatively little known corner of Paul's considerable investigative ability was his study of gas bubbles "where I was pleased to find some general formulation which related gas and fluid properties to the fate of rising bubbles". Finally, I have the honour of having worked with Paul LeBlond on his last major project, the Canadian WOCE drifter program, prior to his retirement from Earth and Ocean Sciences at UBC, a department that he was instrumental in launching. The WOCE field program ended more than 5 years ago but we are still analyzing and interpreting the data from that program for publication. Although Paul no longer writes science-funding proposals, he remains a highly active member of the scientific community, a strong proponent for the rationale use of our diminishing coastal heritage, and an advocate for the more serious aspects of cryptozoology.

In closing, I would like to emphasize that Paul was foremost an educator who treated his students as equals, despite the sometimes obvious differences in intellect and ability. Paul may be the last of the renaissance men. He is fully bilingual in English and French. When he was going to work with Russian scientists, he learned Russian. Before going to visit Cuba, he learned Spanish. He learned German during his sabbatical year to Germany. Paul is also a damn good athlete. I may be a superior soccer player but Paul could skate circles around me on the hockey rink. He was a great person to have as a graduate supervisor and continues to contribute unselfishly at several levels of community participation. The last word goes to Paul: "The greatest enjoyment of a research career for me has been the interaction with graduate students. In some cases, they worked on my ideas. In many others, they brought their own ideas and I learned as much from them as they from me."

Richard Thomson

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Notes on Paul

Paul Henry LeBlond attended McGill University where he studied physics with a subliminal inclination to meteorology. During this period he was active in the Reserve Officers Training Corps (ROTC), specializing in radar and managing to get grounded for sneaking a lady friend (later to become his wife) into the officers' mess.

Paul's passage through University of British Columbia graduate studies was smooth and swift. Like many physical oceanographers before him, he was able to cope with the tricky quirks of nature by applying standard assumptions (such as friction-less, bottom-less, and boundary-less) to resolve the physical nature of the Arctic Ocean. His graduate career did have some interruptions, such as a broken pencil during a particularly profitable cognitive period or a desperate call to his stock broker to bail out his National Research Council scholarship from some moose pastures mine stock.

A loose-knit floppy sweater, pulled up over forearms, glasses floating somewhere between nose and forehead, and a thoughtful smile are an unpretentious but authoritative Paul. Whence evolved this charming professor? Paul has always been friendly, good-natured, and easy-going; all characteristics shared with his father. The quaint milieu of his graduate studies and earlier academic years influenced him as well. The UBC Institute of Oceanography was housed in freezing/boiling, rat infested W.W.II army barracks that cuddled and cozied preening academics and at the same time herded them to unconventional (for the 1960's) sociability. Faculty (including physical oceanographers Robert Stewart, Ronald Burling and George Pickard) and graduate students took coffee together (a big deal then!), went-a-beering Fridays, and soccered and hockeyed to crutches and revenge.

The 1960's and 70's were challenging times for aspiring academics. There were the temptations of the hippie culture and the oppression of a work ethic, inherited from parents who survived the Great Depression. Paul skirted this period with a friendly authoritative smile or a slightly more indulgent participation. He and his partner Josee hosted chicken dinners on Fridays. Always a different chicken dish followed by a large green salad. Numerous guests, academic or not, milled throughout the house on these occasions. You did not know if you were talking to a professor, a student, an artist, or just someone who walked into the wrong party. You did know Paul and Josee's kids, Michael, Philippe, and Anne, they played the music?!

Paul is well known for his contributions to national and international oceanographic committees (e.g. Pacific Fisheries Resource Conservation Council, the Science Advisory Council of the Department of Fisheries and Oceans, Canadian Ocean Frontier Research Initiative (as President) and to numerous local boards (e.g. the Museum Society, the Access to Media Education Society). He has also taken on more onerous and politically charged tasks. In one instance, he investigated why Canada was unable to find a group of First Nation fishers, including one child, who drifted off Vancouver Island in a herring skiff for over one month. Later, Paul reviewed the functions of west coast lightkeeps. Whatever his findings were, the political decision and indecision continue to reverberate on our shores. With increasing responsibilities come increasing rewards (air miles) and honours (Fellow Royal Society of Canada).

Paul's research interests have evolved from the "pure" physical study of phenomena such as internal waves to interdisciplinary topics. For example, the influence of oceanographic conditions on fish migrations. His academic "branching out" culminated in his plunge into cryptozoology, the scientific investigation of mythical-beasts-demanding-respect. He was instrumental in forming the International Society of Cryptozoology and published in the first issue of its scholarly journal (LeBlond, P.H., 1982. An estimate of the dimensions of the Lake Champlain Monster from the length of adjacent wind waves in the Mansi photograph. Cryptozoology 1: 54-61).

Paul's contributions are many and varied, and Canada's place in ocean science is advanced, thanks to his efforts. To me his greatest contribution is his living demonstration of good science by a *bon vivant* with grace and humility. We expect to see much more from Paul.

Louis Druehl

Paul dressed up for the ROTC Ball, Montreal, 1960.

Paul, the graduate student, Vancouver, Christmas 1961.

*Paul, the young professor, and family
(Josee, Anne, Phylippe), Vancouver, 1969.*

Paul on a trycicle in Quebec City, age 3.5 years.

*Paul marrying off his daughter Anne in Yelapa, near
Puerto Vallarta, Mexico, Nov. 5, 1997.*

*Grandfather Paul with first grandchild Mika,
Vancouver, April 1998.*

Report on the ICES/SCOR Symposium on Ecosystem Effects of Fishing

In 1996, the Scientific Committee on Oceanic Research (SCOR) initiated a Working Group on the Impact of World Fisheries Harvests on the Stability and Diversity of Marine Ecosystems. At the PICES Fifth Annual Meeting (October 1996), the Governing Council named myself, then the Chairman-elect of the Fishery Science Committee, to officially represent PICES in this Working Group. The SCOR WG 105 activities compliment work being carried out in the North Atlantic under the auspices of the International Council for the Exploration of the Sea (ICES) by the Working Group on the Ecosystem Effects of Fishing, which has been active since 1990. A summary of the first meeting of the SCOR WG 105, held in November 1996 in Halifax, Canada, was published in PICES Press Vol. 6, No. 1. At this meeting, ICES and SCOR agreed to plan a joint symposium in order to facilitate a global synthesis of what is known about the impacts of fishing on marine ecosystem, and to provide a forum for discussions on how this information can be used for formulations of management strategy and tactic.

The ICES/SCOR Symposium on "Ecosystem Effect of Fishing" was held in France, March 15-19, 1999. About 350 scientists and managers attended the meeting. "PICES participants" include Anne B. Hollowed (U.S.A), Warren S. Wooster (U.S.A), Patricia Livingston (U.S.A), Chang-Ik Zhang (Korea) and Qi-Sheng Tang (China) (*see photo*).

A major part of the meeting was taken up with invited keynote papers covering three topics:

The first topic "*Fisheries impacts in different ecosystems*" provided a global overview of the effects of fishing on different marine ecosystems and on specific species groups. The focus was on differences and similarities in the responses in various parts of the world. The ecosystems addressed included coastal and estuarine system, semi-enclosed seas, continental shelves, upwelling systems, boreal ecosystems, the deep seas and the Antarctic. The species groups involved benthos, demersal fish, large pelagics, sharks and rays, seabirds, marine mammals and turtles. The evidence for cascading effects on primary production and zooplankton was also reviewed.

The second topic "*Quantification of ecosystem impacts*" presented methods for quantifying fisheries impacts at the species and ecosystem levels. The definition of overfishing in an ecosystem perspective, the quantification of the vulnerability of individual species to fishing, selection and phenotypic evolution caused by fishing, and the risk of species extinction were discussed. At the community and ecosystem level, the usefulness of trophodynamic models, multispecies models, and indices of community structure were summarized. Experience in the use of sustainability indicators and measures of ecosystem health was reviewed.

The development of integrated approach to fisheries and environmental management requires a selection of indices of ecosystem change, which are perceived to be scientifically sound, important to society and operational in a management context. The third topic "*Integrating fisheries and environmental management*" reviewed management objectives and expectations from the respective points of view of representatives of the fishing industry, NGOs, and fisheries and environmental managers. This was followed by the presentation of a framework for designing operational ecosystem management strategies, after which some of the legal, economic, and technical tools that might be used to achieve the objectives were described. The current experience with integrating environmental and fisheries objectives was summarized by reviewing the approaches developed within ICES, CCAMLR, US fisheries management, Philippine coastal zone management, and Australian multiple-use management. The future trends and constraints in the development of an integrated approach to fisheries management were outlined.

Additional contributions were as posters presenting specific case studies. A total of 140 posters were displayed throughout the symposium and presented at three special afternoon sessions.

All invited papers and a limited number of papers based on poster presentations will be considered for publication, following peer review, in a special issue of the ICES Journal of Marine Science, produced by Academic Press in March 2000.

The final summary report on the ICES/SCOR symposium, drafted by Dr. M. Sinclaire (Chairman of SCOR WG 105), will be available within a few months. The SCOR WG 105 will close its activity after the final summary report with a concluding paper presented at the coming SCOR annual meeting.

(cont. on page 23)

What is the carrying capacity of the North Pacific Ocean for salmonids?

To understand the interannual and interdecadal variations in marine fish production, researchers must identify factors related to growth and survival. These factors can include nutrient dynamics, food-web processes, and physiological processes, all of which may be affected by both local and large-scale physical processes. In this paper, we review evidence for changing ocean conditions in the oceanic domain of salmon. We give examples of estimates of forage demand of salmonids and their relation to available food resources, as well as the impact predators have on limiting salmon production.

Dramatic changes have occurred in the North Pacific Ocean in recent years. After the now widely accepted regime shift of the late 1970s, salmon catches from subarctic waters of the northern North Pacific increased markedly. Some of the changes in the North Pacific that have recently been documented include:

- Significant warming of the ocean during the 1990s, with record setting temperatures during 1994, 1997 and 1998. Warming and freshening of surface waters resulted in a shallower winter mixed-layer depth, and reduction of nutrients entrained into the euphotic zone (Freeland et al. 1997).
- Changes in the seasonal maxima of *Neocalanus plumuchus*, a dominant subarctic copepod, with peak biomass occurring two months earlier in the upper water column between 1956 and 1997 (Mackas et al. 1998).
- In the Bering Sea, unusual coccolithophore blooms have been reported in 1997 and 1998, which may have been related to the severe declines in the Bristol Bay sockeye runs during both summers and a drastic reduction in the runs of Yukon chinook and chum salmon in 1998 (Kruse 1998).
- Decreased nitrate during the winter and regions of depleted nitrate off British Columbia during the 1990s (Whitney et al. 1998).

All of these changes may affect the carrying capacity of the North Pacific Ocean for salmon and other higher trophic levels.

What is carrying capacity?

Carrying capacity is a measure of the biomass of a given population that can be supported by the ecosystem. It changes over time with the abundance of predators and resources. Resources are a function of the productivity of prey populations and competition (U.S. GLOBEC 1996).

Carrying capacity is determined by both bottom-up and top-down processes. Bottom-up processes include: primary productivity, food web structure, number of trophic links, ecological efficiencies and fraction of production consumed by salmon competitors.

Top-down controls on carrying capacity are mediated through predation. In addition, the total carrying capacity of a species is modulated by the size of region inhabited, which, in turn, is influenced by temperature and availability of food (Crowder and Magnuson 1983). All of these factors are dynamic and fluctuate among seasons, years, decades and millennia.

Several investigators have estimated the carrying capacity of the North Pacific Ocean for salmonids based on calculations of production and food consumption of salmon. LeBrasseur (1972) concluded that maturing salmon in the oceanic water of the Northeast Pacific consumed only about 10% herbivores, the remaining 90% was fishes and squids which were considered primary or secondary carnivores, one or two trophic levels higher than copepods and euphausiids. He calculated that salmon consumed about one-fifth of the spring production of herbivores, either directly or indirectly. Sanger (1972) estimated that only about 3.4% of the annual zooplankton production in the North Pacific was consumed by salmon, again either directly or indirectly, through higher trophic levels. Similarly, Favorite and Laevastu (1979) estimated that salmon consumed only a few percent of the zooplankton, and concluded that “apparent salmon production can be increased significantly above the present mean runs *if they are competitive for available food* (emphasis added)”.

Since these early studies, several salient estimates have changed. Firstly, primary production was probably underestimated in earlier studies and is now believed to be several times higher using advanced techniques (Wong et al. 1995). Secondly, large copepods and euphausiids, which were thought to be herbivores, are now believed to be mainly primary carnivores, with microzooplankton being the primary consumer of the small phytoplankton cells that fix most of the carbon in the subarctic Pacific (Booth 1988; Miller 1993). As a result, all trophic levels above these including herbivores, carnivores and salmon, are believed to be one trophic level higher than assumed in early studies. Thirdly, the catches and production (catch + escapement + mortality) are now about twice as large as they were in the 1960s and early 1970s.

Table 1 shows three estimates of salmon production per unit area and salmon production as a percentage of primary production. The percentage of primary production that is incorporated into salmon is only 0.025-0.034%. This seems very low. But a simple, salmo-centric food chain shows that salmon occupy the 4^{th} or 5^{th} trophic level (*Figure 1*; Welch and Parsons 1993; Brodeur et al. in press). Only about 0.8% of primary production is available to the salmon guild, and the production of this guild of fishes and squids is roughly 0.16 g C/m^2/y. The percentage of primary production (0.16/140 = 0.1%) is about 3-4 times the estimate of salmon production/primary production in Table 1. This leaves the remainder of the production at this trophic level (65-75%) for a wide variety of other fishes, squids, birds, and mammals.

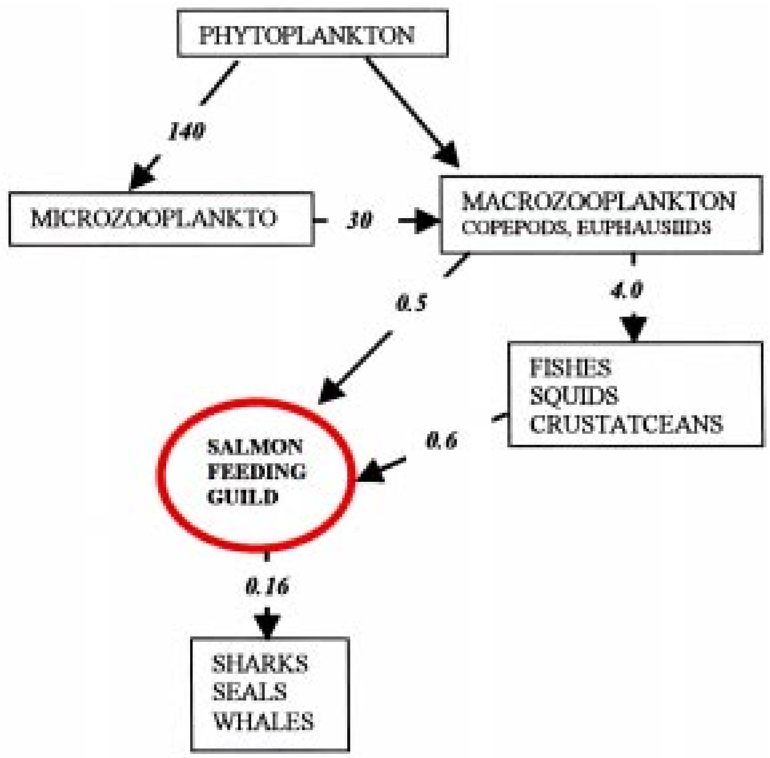

Fig. 1 Simplified food web emphasizing the salmon guild. Ecological efficiencies of 22% are assumed from phytoplankton to microzooplankton and 15% for higher trophic levels.

In addition, much of the production of macrozooplankton is consumed by planktivores that are not prey of salmon.

The food web that includes salmonids is complex and reticulated with many other species that compete directly or indirectly with salmon (*Figure 2*). Some fishes, such as Pacific pomfret and Pacific saury, migrate into subarctic waters during the spring and summer when their distributions overlap with salmon. Moreover, most of the primary production that ends up in gelatinous zooplankton, such as scyphozoans, ctenophores and salps, is probably not utilized intensively by salmon (except chum salmon) or by higher trophic levels of the salmon food web. Vertically migrating micronekton, such as myctophids, are also important consumers of macrozooplankton, as are baleen whales. Even though only a fraction of the primary production or zooplankton biomass is utilized by salmon, as recognized by earlier reports, the high trophic level of salmon and the complex food web with many other consumers and competitors suggest that substantial increases in the production of salmon in oceanic waters of the subarctic Pacific are unlikely.

Density-dependent growth and survival

The present catches of North Pacific salmonids during the 1980s and 1990s were about 600,000 to over 900,000 T and represent historic maxima (Beamish et al. 1997). Declines in both the size of salmon harvested and their size at age, and increases in the age of maturity have been well-documented over the past 20 years around the Pacific Rim (Bigler et al. 1996; Cox and Hinch 1997; Helle and Hoffman 1998; Kaeriyama 1998). This is cogent evidence for density-dependent growth, and suggests that we have approached the carrying capacity of oceanic waters of the North Pacific for salmonids.

Intraspecific and interspecific competition for food of salmon have also been shown. The diets of pink salmon may change between years of strong and weak year classes, with a shift from zooplankton to more nutritious prey, such as gonatid squids, when pink salmon abundance is low, resulting in faster growth (*Figures 3 and 4*). These micronektonic squid compete with immature salmon for zooplankton, while providing a food source for maturing salmon (Aydin unpublished). This type of food-web interaction, known as "intraguild predation" creates complex dynamics which are parameter-sensitive and difficult to predict (Rice 1995). Some gonatid squid such as *Berryteuthis anonychus*, with a life cycle of 1- 2 years, may fluctuate greatly on annual, ENSO, or decadal time scales, and thus represent a significant source of variation within the system. However,

Table 1. Some estimates of salmon production, area of salmon, and primary production (PP) in the North Pacific.

	Salmon production (10^6 mt) / Area (10^6 km^2)	mt/km^2 / g/m^2	g C salmon [1] / g C PP	%PP
This estimate	2.4/9.0[2]	0.27	0.045/140	0.032
Sanger 1972	1.2/10.42	0.12	0.02/85	0.034
Ware & McFarlane 1989	0.482/3.14	0.15	0.025/100	0.025

Footnotes: [1] *wet weight x 0.165 = g C*
[2] *area based on distribution of pink salmon in the North Pacific summed over 10 yrs (K. Nagasawa, Japan High Seas Fisheries Research Laboratory, Shimizu, Japan, unpubl. data)*

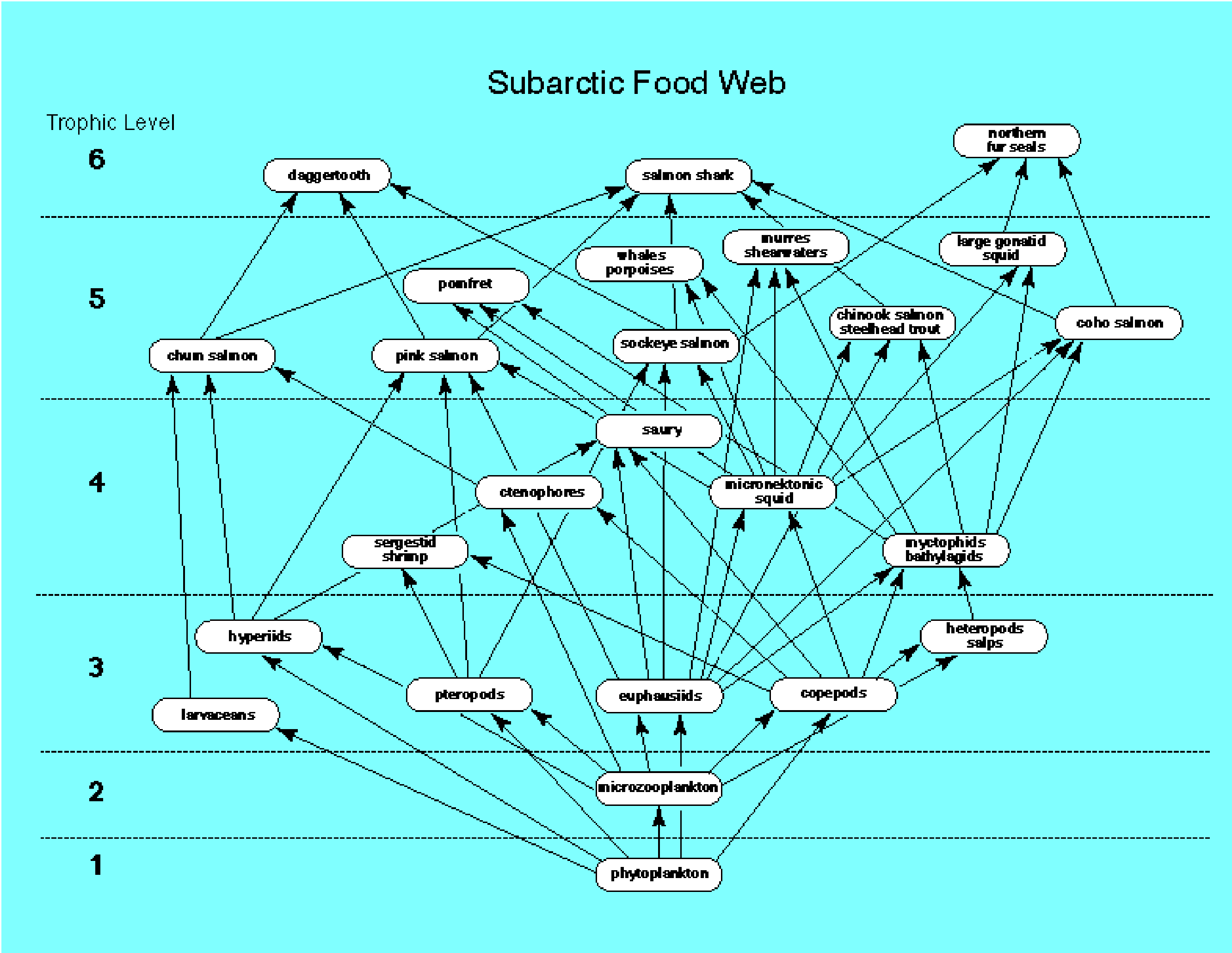

Fig. 2 Food web of the subarctic Pacific Ocean (from Brodeur et al. in press).

few surveys to date have studied the distribution, abundance or variation of squid and other micronekton in pelagic ecosystems.

The existence of a trophic triangle among zooplankton, micronekton and some salmon species (*Figure 3*) may create positive feedback, in which a salmon's growth early in a season accelerates its growth later in the season. When this feedback is included in bioenergetics models of maturing pink salmon growth, a small change in an individual's body size in April leads to a large difference in body size in August, as a smaller initial body size delays a salmon from switching to more nutritious, higher trophic level prey (*Figure 5*; Aydin unpublished). Density-dependent food limitation during the fall or winter may slow growth throughout the spring and summer, regardless of food supply during these later seasons. Applying these two growth curves to salmon abundance reveals possible cascading interactions in

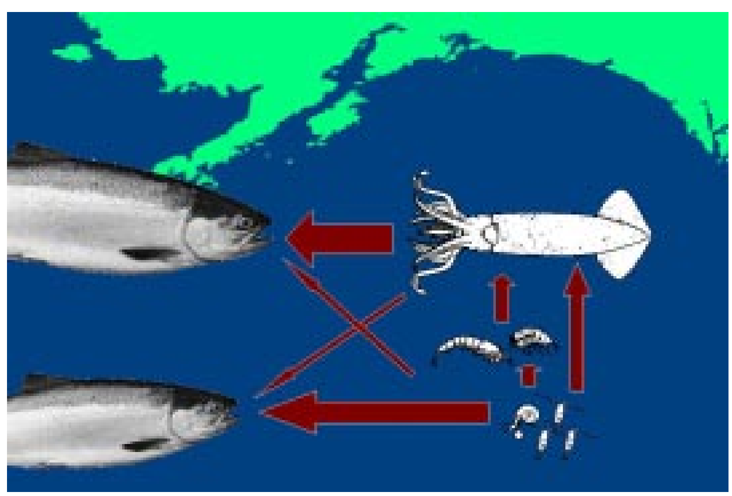

Fig. 3 Schematic diagram of pink salmon feeding during summer in the Alaskan Gyre. Smaller salmon feed primarily on macrozooplankton, while larger salmon feed primarily on micronekton, especially squid.

the food web. Modeling shows that if overall zooplankton biomass doubles, and returning salmon biomass almost doubles, the demand placed on zooplankton by salmon triples. Because predation on squid decreases (as the salmon are less able to catch squid) squid production will increase, further increasing predation on zooplankton and further decreasing the growth potential for salmon.

Both the growth and diet of chum salmon have also been correlated with the abundance of pink salmon (Walker et al. 1998). When pink salmon are not common, chum salmon may shift their diets from gelatinous zooplankton to more nutritious prey (Tadokoro et al. 1996). There is evidence for a negative correlation between Asian pink salmon catches and zooplankton biomass (Shimoto et al. 1997). These examples suggest competition for available prey and top-down control of prey by salmon.

This competition and the resulting slower growth of maturing salmon have been related to increased ocean survival and increased hatchery production of young salmon (Bigler et al. 1996). Releases of hatchery salmon increased rapidly after the mid-1960s and are presently between 5 and 6 billion a year, about one-fifth to one-fourth the total number of juvenile salmon entering the ocean (Heard 1998). According to Beamish et al. (1997), about 84% of the chum, 23% of the pink, and 5% of the sockeye salmon are produced from hatcheries.

Estimates of the forage demand placed on coastal and oceanic feeding areas by wild and ocean-ranched pink salmon originating from Prince William Sound, Alaska, were derived from a bioenergetic model by Cooney and Brodeur (1998). Annual food consumption for these stocks rose from less than 100,000 mt prior to 1976, to more than 300,000 mt after 1988 when hatchery production began dominating adult returns. Most of the food consumption occurred in the oceanic rather than coastal environments. On average, every metric ton of fry generates the need for about 1200 mt of food to support survivors and non-survivors in coastal and ocean feeding regimes every year. These results suggest that recent levels of wild and hatchery production in the North Pacific Ocean have placed substantial forage demands on coastal and oceanic feeding domains.

The evidence for density-dependent survival is not as strong as that for density-dependent growth (Pearcy 1992 for review). Ocean survival of salmon is thought to be high and variable during early marine life while they inhabit coastal waters and then decreases as fish increase in size and move offshore. During the 1980s and 1990s young salmon apparently experienced highly favorable conditions in the coastal ocean before migrating into oceanic waters. High survival of juvenile salmon was correlated with the increased zooplankton standing stocks in coastal waters of the Northeast Pacific after the regime shift, suggesting that the carrying capacity for juvenile salmon increased substantially. However, the high survival of juvenile salmon appears to be straining the carrying capacity of the central subarctic Pacific, where zooplankton stocks increased only slightly, thereby limiting the growth of maturing salmon.

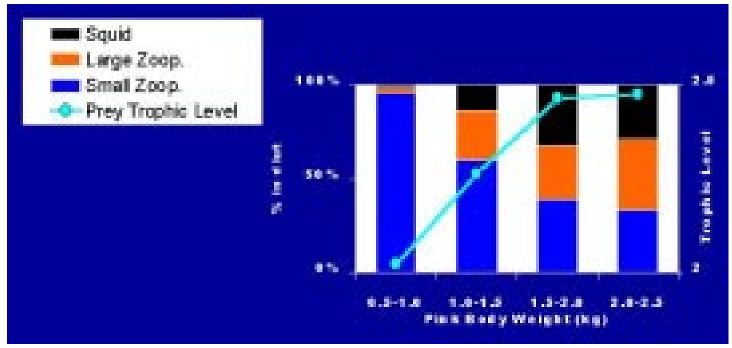

Fig. 4 *Proportion of three types of prey in July pink salmon diet in the Alaskan Gyre: micronektonic squid; large zooplankton (primarily large amphipods and polychaetes); and small zooplankton (primarily pteropods, copepods, and juvenile euphausiids).*

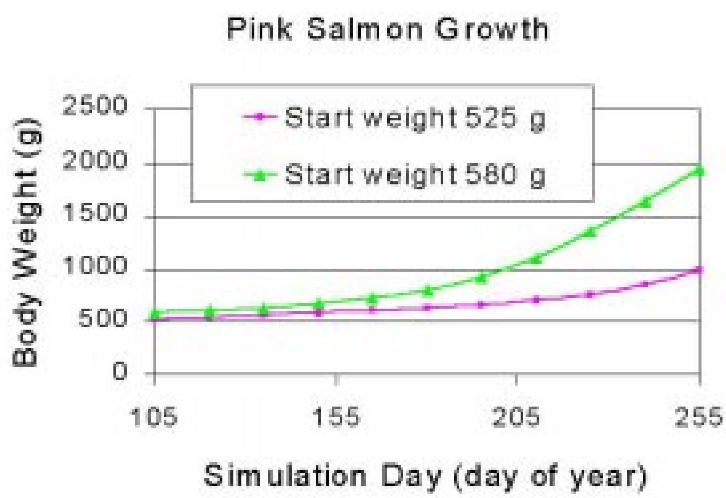

Fig. 5 *Body weights of pink salmon during April-August based on a bioenergetics growth model. The only difference is a 10% difference in initial (April) body weight.*

Area and temperature

Fish integrate both food and temperature to maximize growth rates. As ration declines, they achieve better growth at cooler temperatures. As food availability increases, they can occupy warmer waters until limited by metabolic constraints (Brett 1979; Crowder and Magnuson 1983; Davis and Myers 1998). Hence temperature directly influences the foraging area, and hence potential carrying capacity. After the regime shift of the late 1970s, sea surface temperatures (SST) in the eastern subarctic Pacific increased, as did zooplankton biomass.

Nevertheless, growth rates generally declined. Hinch et al. (1995) found a negative relationship between SST and the size of returning Fraser River sockeye, suggesting that because of high metabolic costs in warm water these fish were not able to obtain enough food for maximal growth.

Recent declines of salmon

Catches and survival of some stocks of salmon and steelhead along the west coast have declined sharply. Catches of sockeye, chum, coho, chinook and odd-year pink salmon all dropped during the 1990s, indicating a sudden change in the productivity of some stocks from southern British Columbia. Catches and marine survival of steelhead have also declined, especially from the south coast of British Columbia. Survival of hatchery coho salmon from the Strait of Georgia, Puget Sound and Oregon all decreased after 1989 and have remained low. These significant declines all occurred during the prolonged, unprecedented series of El Niño events from 1990-1995. They reversed the trends of high survival for most of these stocks during the 1980s. The 1997-98 El Niño was accompanied by very warm ocean temperatures and low ocean productivity off British Columbia (Whitney et al. 1998). Severe declines in the returns of Bristol Bay sockeye salmon in 1997 and 1998, and dismal returns of both chum and chinook salmon to the Yukon River, were reported by Kruse (1998).

Future trends and climate change

What does the future portend for salmon production? Since we have just experienced record salmon production, a continuation of recent warm conditions or a regime shift to cooler conditions will likely result in lower production in the northern North Pacific. If the warm sea temperatures of the early 1990s and 1997-98 continue, increased buoyancy of the mixed layer may decrease nutrients and lower productivity (Whitney et al. 1998). If the 1998 La Niña triggers a shift to cold conditions, similar to the period of 1945-1976, salmon production will probably decline in the Alaska region but may increase along the West Coast of North America (Hare et al. 1999).

Projections of global warming from greenhouse gases suggest that with present increases of CO_2, the area of the North Pacific Ocean suitable for salmon will progressively shrink (Welch et al. 1998). Higher metabolic costs in warm water along with lower food production and availability could cause further decreases in the size and fitness of salmon (Hinch et al. 1995; Cox and Hinch 1997). In any event, we can be assured that the environment and climate of the North Pacific Ocean will change, and that these changes may not be necessarily favorable for salmonids.

Future climate changes could affect the carrying capacities of both the coastal rearing and migratory habitats for juvenile salmonids and the oceanic feeding grounds for maturing salmon. If the carrying capacity of the oceanic subarctic Pacific continues to decline while survival of juvenile fish remains high, growth rates of maturing fish may be even lower. If the carrying capacities of both habitats decline and fewer juveniles are produced, growth rates of maturing fish in oceanic waters may not change and could even increase.

Can we enhance the future viability of salmon?

Short of reducing anthropogenic releases of greenhouse gases, we can do little to influence world climate. But we can enhance the resiliency and fitness of salmon by conserving the genetic diversity of Pacific Rim stocks, thus facilitating adaptations to future climatic changes.

Most genetic diversity is found in the multitude of wild salmon stocks. This genetic diversity is essential to sustain the productivity of both wild and hatchery stocks in the future. Hatchery fish have negative effects on the growth and survival of wild fish through mixed-stock fisheries, competition in freshwater and the ocean, and interbreeding. Decreases in the size of wild fish cause reduced fecundity, egg size, survival of young and decreased energy stores for in-river migrations. Adverse interactions between wild and hatchery fish are probably most severe during periods of unfavorable regimes when the ocean carrying capacity is low (Beamish et al. 1997; Heard 1998). This is because hatcheries can produce juveniles at high rates even during these periods of low productivity when wild stocks are declining or at low levels. Hatchery fish may place enormous demands on the food resources of the ocean (Cooney and Brodeur 1998).

This raises doubts about the need for massive releases of hatchery fish during periods of low ocean productivity and poor survival of wild salmon. We need a better understanding of the interactions between hatchery and wild salmon and how hatchery fish affect the growth, reproduction, and survival of wild fish in the ocean, especially during unfavorable conditions. Such knowledge may be critical to sustaining the productivity of salmon in the North Pacific Ocean during climatic regimes with different conditions and ocean carrying capacities. As Cooney and Brodeur (1998) state; "To ignore the signals manifested in diminished size of Pacific salmon is to invite potential disaster for these and other resources." In the future we should promote management for genetic diversity to ensure future productivity and sustainability of our salmon.

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[*] Many citations to the literature in the original text were deleted to conform with the editorial policy of PICES Press.

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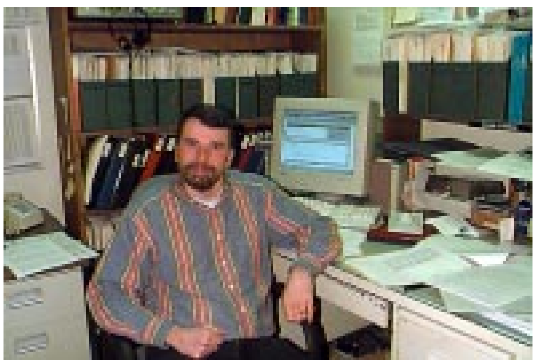

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(cont. from page 16)

The symposium showed clear evidence that some ecosystems have been altered by fishing. In other cases, the evidence was not so clear because of lack of data at the appropriate time and space scales, inadequate knowledge of pristine conditions, and insufficient data on certain ecosystem components. The scientific community is now challenged to develop and apply ecosystem indicators of the effects of fishing for their regions and to establish standards that can be related to ecosystem management objectives. The whole PICES scientific community can certainly play a role in these activities. PICES, which has focused primarily on the climate-related changes on ecosystems, needs to begin investigations and comparative studies that can help separate human- and climate-related impacts. We have the interdisciplinary scientific expertise that is necessary to take such an ecosystem perspective, which might be lacking in other intergovernmental organizations that may focus on only one species or group of species. The ways in which we can begin this work could include:

- starting a working group that develops and compares ecosystem change indicators among PICES regions,
- promoting ecosystem monitoring programs that would allow the detection of change in presently unmonitored ecosystem components,
- conducting symposia that summarize present knowledge of community structure and diversity changes in North Pacific ecosystems, and
- promoting data exchange on climate factors, fishing removals, and ecosystem components that could assist in comparative studies.

All PICES committees and the PICES Climate Change and Carrying Capacity Program can have a role in making progress in this area.

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Southeast Bering Sea Carrying Capacity (SEBSCC)

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The southeastern Bering Sea is a major ecosystem supporting bountiful economic resources. It boasts an abundance of high-latitude marine life and some of the busiest fishing ports in the United States. This ecosystem responds to changing conditions in ways that can be observed as fluctuations in abundance of commercial fish and shellfish, sea birds and marine mammals. At present, the southeastern Bering Sea ecosystem has a dominant pelagic species: the commercially fished walleye pollock (*Theragra chalcogramms*). Pollock is a nodal species, constituting an integral part of the region's food chain as both prey and predator. Understanding the ecology of this fish in the context of the overall ecosystem is a useful approach to developing methods to better manage living marine resources of the southeastern Bering Sea.

Southeast Bering Sea Carrying Capacity (SEBSCC), a project of the U.S. National Oceanic and Atmospheric Administration (NOAA) Coastal Ocean Program, is a six-year, interdisciplinary, regional ecosystem study. The study's goal is to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile pollock and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) pollock abundance. SEBSCC builds on earlier research in the Bering Sea by programs such as the Outer Continental Shelf Environmental Assessment Program (OCSEAP), Processes and Resources of the Bering Sea Shelf (PROBES), and Bering Sea Fisheries-Oceanography Coordinated Investigations (BS FOCI). PROBES defined specific hydrographic regimes for the region: the coastal or inner shelf domain, the middle shelf domain, the outer shelf domain, the continental slope, and the transitional areas (fronts) between them. Each of these domains is also a different marine habitat. SEBSCC research is focused on the middle shelf, outer shelf, and slope domains. By cooperating with other agencies, groups, and investigators with broad ecological interest in the southeastern Bering Sea, SEBSCC shares knowledge pertaining to the areas of the shelf that it studies and obtains information relating to other areas. In particular, the National Science Foundation project "Prolonged Production and Trophic Transfer to Predators: Processes at the Inner Front of the Southeastern Bering Sea" (Inner Front Project) complements SEBSCC research by examining the inner shelf domain and the front separating it from the middle shelf domain.

SEBSCC is divided into monitoring, process, modeling, and retrospective and synthesis components focused on four central scientific issues:

1. How does climate variability influence the Bering Sea ecosystem? Is there historical evidence for a biophysical regime shift on the Bering Sea shelf? How is this reflected in ecological relationships and species mix? Are there "top-down" ecosystem effects associated with climate variations as well as "bottom-up" effects?
2. What limits population growth on the Bering Sea shelf? Is there evidence of a single species carrying capacity, e.g., for pollock, or a more complex structure?
3. How are pollock, forage fish, and apex species linked through energetics and life history? How important is cannibalism in the dynamics of pollock?
4. How do oceanographic conditions on the shelf influence biological distributions? How do the separate hydrographic domains, sea ice, and the cold pool influence the overlap or separation between predators and prey?
5. What influences primary and secondary production regimes? What are the sources of nutrients to the southeastern Bering Sea shelf, and what processes affect their availability? Is the variability in sea ice extent and timing the primary factor

influencing productivity? What determines the relative allocation of organic carbon going to the benthos versus that remaining in the pelagic system? What are the lower trophic level structure and energetics on the shelf in summer and winter, especially regarding euphausiids? What is the role of gelatinous organisms?

These broad issues support SEBSCC's narrower goal of understanding the ecosystem in terms of pollock and provide a basis for selection of proposed research. Funded research also needs to provide information that supports industry and management of the region. For example, results from SEBSCC research related to short-term forecast of pollock recruitment will improve stock assessments used to recommend "allowable biological catch" estimates to the North Pacific Fishery Management Council. Research results pertaining to the availability of juvenile pollock to apex predators will assist Council decisions regarding restriction of fishing around marine mammal rookery areas. The project's focus on ecosystem response to changes in environmental conditions provides a context for resource management in a changing environment.

As described in the SEBSCC Home Page (http://www.pmel.noaa.gov/sebscc/), the project is managed by a partnership between NOAA and the University of Alaska Fairbanks, with an advisory panel of technical experts from science and industry offering programmatic guidance. Research for SEBSCC is determined through an open, competitive process. The project's first research cycle was from August 1996 through September 1998, and included scientists from two NOAA laboratories and five universities. A second, two-year research cycle is just beginning. Funded research for each cycle is identified in *Table 1*.

Monitoring

SEBSCC's monitoring program consists of broad-scale field surveys using ships, multi-disciplinary moorings, drifting buoys, and analysis of satellite data. Cruises are conducted from late winter through fall using principally the NOAA Ship *Miller Freeman* and the University-National Oceanographic Laboratory System (UNOLS) Research Vessel *Wecoma.* Generally, cruises occur in February, to deploy moorings and measure late winter conditions; in April, to monitor the progress of the spring bloom; in June, to measure post-bloom conditions; and in September, to survey habitats of pollock near the Pribilof Islands and to recover moorings. SEBSCC has been fortunate to cooperate on July cruises to the southeastern Bering Sea shelf aboard the Japanese Fisheries Research and Training Vessel *Oshoru Maru.* An areal survey of the southeastern Bering Sea shelf for age-0 pollock is conducted during this cruise. *Figure 1* locates study areas, mooring sites and the cruise track for hydrographic, nutrient, phytoplankton, and zooplankton collections that are performed three or four times during the field year.

Figure 2 contains a schematic of a biophysical mooring. Observations from mooring site 2 form the longest historical oceanographic time series in the southeastern Bering Sea, as the site has been occupied nearly continuously since 1995. For example, *Figure 3* presents near-surface seawater temperatures from 1995 to 1998 from site 2. Note that August 1997 brought the highest-ever-recorded temperature in the region. Other

Table 1. SEBSCC research components: 1996-1998 and 1999-2000.

1996-1998

Monitoring
- Monitoring and development of biophysical indices
- Altimetric census of mesoscale eddy-like features

Process studies
- Origin and dynamics of nutrients on the shelf in relation to dominant physical and biological processes
- Isotopic and biomarker composition of sinking organic matter: indicators of food web structure
- Using optical measurements to explore the influence of mesoscale eddies on interaction of trophic levels
- Low-temperature incubation of walleye pollock eggs
- Habitat differences in frontal regions around the Pribilof Islands and their importance to juvenile pollock growth and survival

Modeling
- Circulation modeling
- Individual-based modeling of walleye pollock
- Spatial model of upper-trophic level interactions

Retrospective studies and synthesis
- High-resolution acoustic and juvenile pollock retrospective data analysis
- Retrospective study of the role of atmospheric forcing on the "cold pool" and ecosystem dynamics of the shelf
- Historical trends in the number of foraging trips made by lactating northern fur seals
- Retrospective relationships between Southeast Bering Sea pollock recruitment and biophysical correlates

1999-2000

Monitoring
- Monitoring and use of biophysical indices: phase II
- Currents and transfer processes between shelf and slope: a Lagrangian perspective

Process studies
- In situ monitoring of nitrate concentrations
- Origin of nutrients on the shelf in relation to physical processes and biological uptake
- Sinking organic matter and pelagic food webs
- Proximity of age-0 pollock, jellyfish, predators, and prey
- Habitat differences in frontal regions around the Pribilof Islands with respect to juvenile pollock growth and survival: phase II

Modeling
- Circulation modeling

Retrospective studies and synthesis
- Environmental influences on early life stages of walleye pollock during the late 1970's climate regime shift
- Climate regime shift of the 1970s: air-sea interactions crucial to walleye pollock
- Measures of ecosystem trends: an approach for synthesis and understanding

measurements from the mooring include salinity, chlorophyll absorbance and fluorescence, current speed and direction, and, during the ice-free part of the season, surface atmospheric variables. Sedimenting particles have also been collected using traps moored near mooring 2 for the past two years.

Future monitoring efforts will continue occupation of site 2 with subsurface and surface moorings, site 6 with subsurface moorings, and transects as shown in *Figure 1*. Sediment traps will be maintained at site 2, and a nitrate sensor has been added to the biophysical mooring there.

Process-oriented studies

Nested within the broad-scale observations, SEBSCC conducts studies to investigate specific biological and physical processes. These include indicators of food web structure through the collection and stable isotope analysis of organisms and sinking organic matter, investigation of the origin and dynamics of nutrients, and exploration of the influence of mesoscale eddies on biological interactions. At higher trophic levels, the project has studied the effect of water temperature on the incubation of pollock eggs, and habitat differences for juvenile pollock in structural fronts around the Pribilof Islands.

The Pribilof survey occurs in the fall and has been conducted since 1994, having been started by BS FOCI. The region is a very informative site as all three shelf domains, with their respective stratification regimes, occur there. The hypothesis of this study is that unique physical and biological conditions associated with the frontal region between the coastal and middle shelf domains around the Pribilof Islands provide an exceptionally good nursery habitat for juvenile (age-0) pollock. In particular, the occupation of Transect A, a survey line extending about 45 km north-northeastward from St. Paul Island, the northernmost of the Pribilofs, has been repeated annually since 1994. Hydrographic, chemical, and biological (juvenile pollock, their predators and prey) observations and samples are collected there.

Figure 4 shows the distribution of nutrients and chlorophyll-*a* along the transect during 1995 and 1996. Nitrogenous nutrients (nitrate plus nitrite) were >1 μM below the thermocline in the stratified waters and throughout the water column in the transition and inner front area in both 1995 and 1996. Maximum chlorophyll-*a* concentrations (>4 $\mu g\ l^{-1}$) were found in surface waters just offshore of the region where nutrients were >1 μM. Moderate chlorophyll concentrations were measured in the stratified waters where nitrogenous concentrations were low. Some general conclusions may be inferred from the overall results of these surveys. There is high interannual variability. In general, the highest densities of juvenile pollock are at the front or inshore, but food density is highest offshore. The diet of juvenile pollock is highly variable, with copepods and euphausiids being the main prey at the front. The condition of juveniles (as measured by Fulton's K) is significantly higher offshore than in the coastal or frontal regions. This work will continue during SEBSCC's second research cycle.

Modeling

Modeling is a useful approach for understanding specific elements of the ecosystem, especially when models incorporate details of realistic biological/physical interaction and allow for data assimilation. Models also assist in the formulation and interpretation of field studies and provide context for integration of results. SEBSCC has three modeling components. One is a 3-dimensional, eddy-resolving circulation model of the southeastern Bering Sea. The circulation model is implemented as a free-surface, primitive equation, eddy-resolving model at 4-kilometer resolution with wind, heat flux, tidal, and subtidal forcing. The model reproduces the observed tidal residual circulation around the Pribilof Islands, while replicating the Aleutian North Slope Current, the Bering Slope Current, and the shallow inflow through Unimak Pass. The model has simulated conditions through mid-May during 1995 and 1997. Simulations show considerable eddy activity in the Bering Sea basin, more so in 1995 than in 1997; abundance of eddies and strongest mixing near the shelf break and along the 100-m isobath; and a cold pool (an annual spring and summer feature of the bottom layer of the shelf having variable extent and duration) on the shelf in both years.

SEBSCC's two biological models are a spatially explicit individual-based model (IBM) of the early life stages of pollock and a spatial model of upper-trophic level interactions focused on pollock, their prey and predators. The IBM model tracks fish separately through space and time. It is probabilistic and mechanistic, adapted from a similar effort developed for the Gulf of Alaska, and includes detailed descriptions of processes that

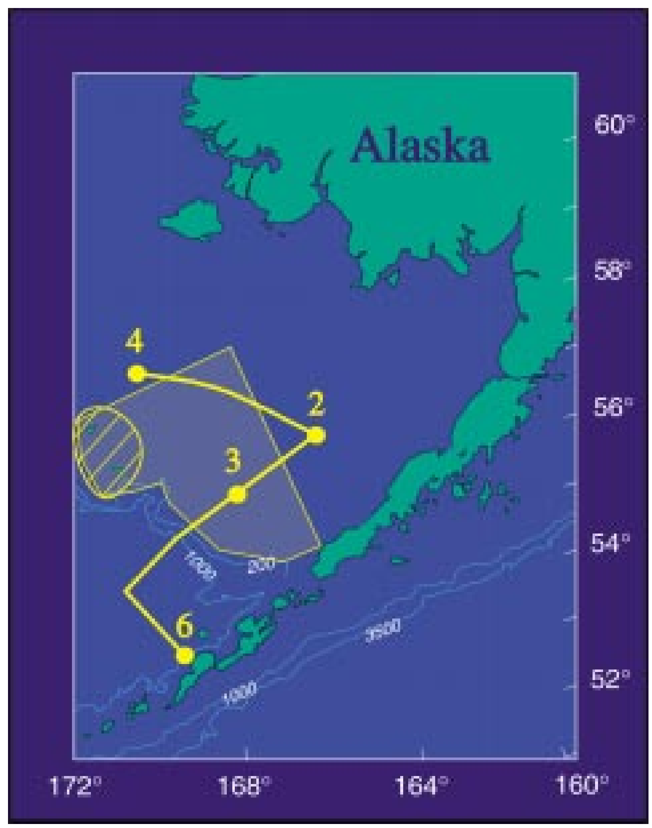

Fig. 1 The southeastern Bering Sea. The SEBSCC study area includes mooring sites 2, 3, 4, and 6; hydrographic, chemical, and biological sampling transects between moorings; a juvenile walleye pollock habitat (hatched area) around the Pribilof Islands; and a juvenile pollock survey area (shaded). Depths shown are in meters.

differ by life stage and affect survival. Some of its attributes are specification of habitat to set spawning depth and date and average food densities, depth distribution by life stage, and fish behavior. SEBSCC's spatial model of upper-trophic level interactions that spatial processes affecting the overlap and availability of juvenile pollock to predators, particularly, adult pollock, are important determinants of juvenile pollock survival. An intermediate product of the model's development is parameterization of a multispecies virtual population analysis (MSVPA) model. It characterizes the predation interactions between major groundfish populations and one marine mammal predator, northern fur seal, in the eastern Bering Sea for the time period 1979-1995. This model will provide starting values of juvenile pollock abundance and estimates of prey suitability for the full spatial model.

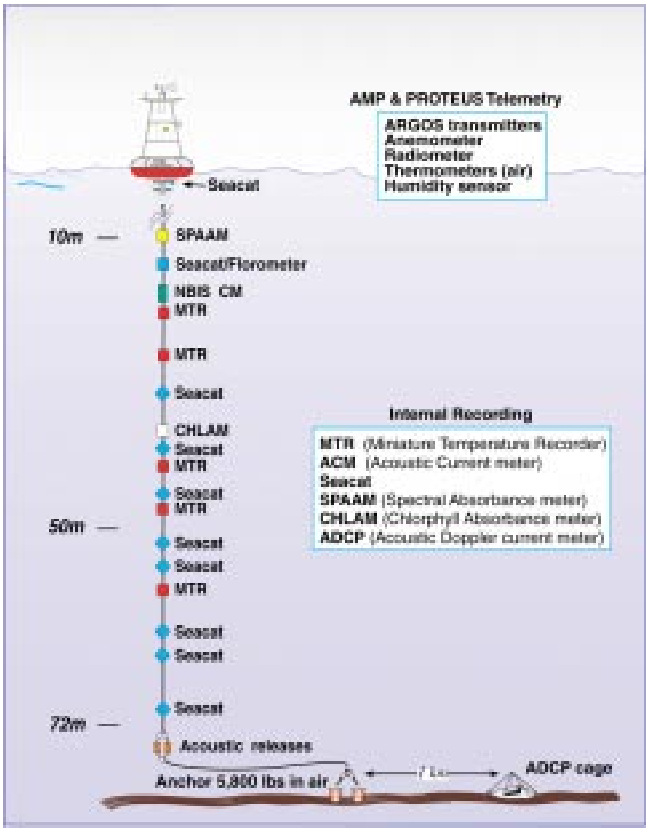

Fig. 2. The biophysical mooring deployed by SEBSCC at mooring site 2.

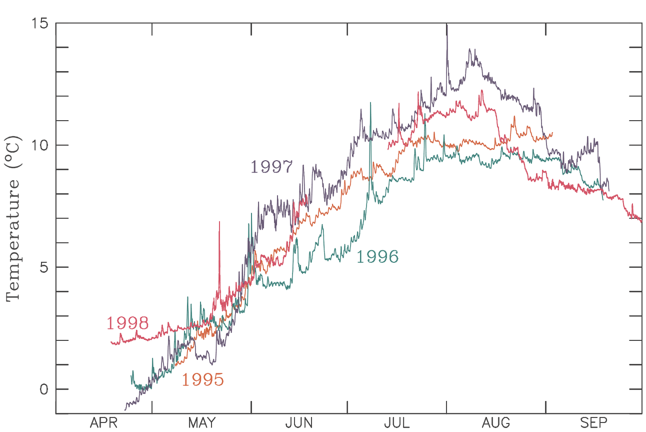

Fig. 3. Near-surface sea water temperatures (°C) measured at mooring site 2 from 1995 to 1998.

Future refinements to circulation model forcing include specification of daily heat flux estimates and derivation of freshwater flux estimates from satellite-observed ice coverage. SEBSCC will couple the circulation, IBM, and spatial interactions models to allow numerical experiments examining the role of pollock in an ecosystem context and the role of the physical and biological environment in shaping trophic interactions involving pollock.

Retrospective analysis and synthesis

With this research technique, historical databases are used to investigate the biological and physical consequences of different biophysical domains and climate variability and to develop semi-quantitative conceptual models. SEBSCC has used hydroacoustic data to determine the distribution of juvenile pollock with respect to their predators and prey in frontal regions of the Pribilof Islands. Examination of spatial proximity between pollock and prey (plankton) patches suggests that when plankton biomass is low, fish tend to cluster around plankton patches. At high plankton densities, there is no consistent association. A small-scale spatial association was found between seabirds (murres and puffins) and their prey, large shoals of age-0 pollock. This association appears to depend on the size of the bird clusters, with larger clusters (>10-50 birds) always associated with food, and smaller clusters

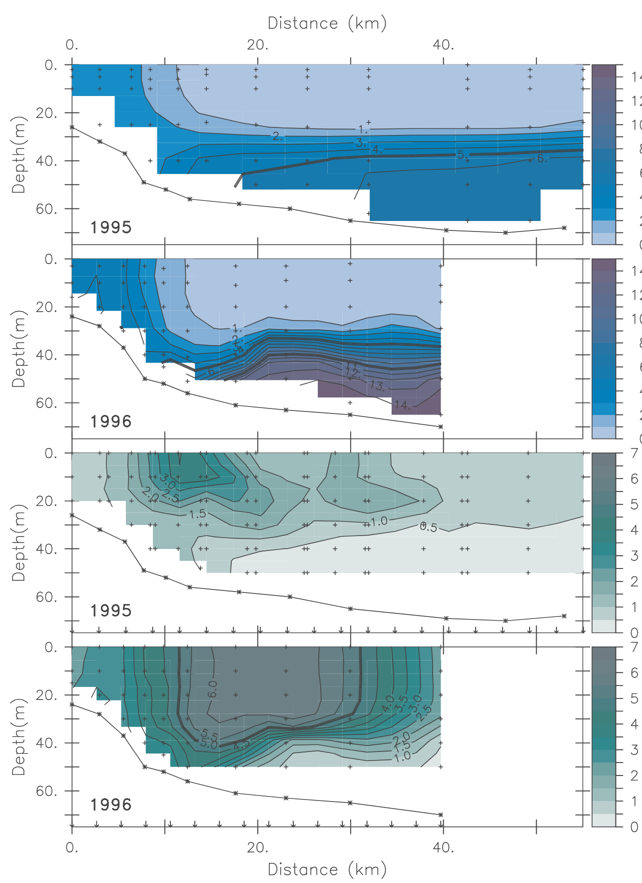

Fig. 4. Distribution of nitrogenous nutrients (µM of NO_2 and NO_3 combined) and chlorophyll-a (µg l^{-1}) along transect A.

not dependably so. In another study, historical trends in the number of foraging trips made by lactating northern fur seals did not correlate significantly with the abundance of their prey, pollock. An examination of biophysical correlates has led to the development of a conceptual model for pollock survival in the southeastern Bering Sea. Because pollock eggs and larvae over the southeastern Bering Sea shelf are found in the upper 20 m, the trajectory of their wind-driven transport during spring and early summer is important to their survival. Also, climate fluctuations and their role in the extent of seasonal sea ice and the resulting cold pool have been shown to affect the distribution of pollock on the shelf. Fishery surveys have shown that pollock tend to avoid the cold pool. An extensive cold pool forces juvenile pollock to share territory with cannibalistic adult pollock, and this is thought to reduce juvenile survival.

In the next research cycle, SEBSCC researchers will explore linkages between environmental influences, particularly air-sea interactions, and the early life stages of pollock during the regime shift of the 1970s. Also, the project will synthesize research results from SEBSCC and other studies using the guiding hypothesis that climate variability influences survival of young pollock by several interdependent biophysical processes. Features of the ecosystem that are candidate indices for the survival of juvenile pollock in the southeastern Bering Sea include:

- extent of sea ice and its influence on the timing of the phytoplankton bloom and hence the succession of bottom-up mechanisms that must match in time and space the needs of first-feeding pollock larvae;
- wind which influences the ecosystem through mixing and by advection as direct wind-driven flow;
- timing of storms that affect the intensity of stratification over the middle shelf and the depletion of nutrients in the cold pool;
- concentration of nutrients retained in the bottom layer of the middle shelf that are essential for prolonged production at the inner front;
- species composition of phytoplankton (e.g., rare coccolithophorid blooms);
- location, strength and stability of the Aleutian North Slope Current and Bering Slope Current system that influence advection of nutrients and pollock larvae onto the shelf; and
- increased presence of previously low abundance biota (e.g., jellyfish and coccolithophores).

Conclusions

SEBSCC has investigated with success the interannual variability in the southeastern Bering Sea from 1996 to 1998. SEBSCC's results coupled with information from the Inner Front Project allow some conclusions to be drawn about conditions over the slope and shelf. Extreme variation was observed in the climatology, physical oceanography and biology of the region during this period. Aspects of the environment in which variation of particular note occurred included: ice extent; storminess; insolation; sea surface temperature; thermal stratification; timing of the spring bloom; changes in phytoplankton community; blooms of the coccolithophore *Emiliania huxleyi*; abundance of euphausiids; timing of euphausiid mating on the inner shelf; and distribution, mortality, and shifts in reproductive success of seabirds. Contrasts between 1997 and 1998 are especially revealing. For more detailed information on some of the events mentioned below, see related articles on the status of the Bering Sea in *PICES Press* *6*(1), *6*(2), *7*(1), and this edition.

In 1997, atmospheric conditions over the eastern Bering Sea during spring and summer included uncharacteristically light winds, warm temperatures and clear skies. These conditions resulted from forcing on multiple time scales: intra-seasonal, El Niño, Pacific Decadal Oscillation, and global climate warming. The atmosphere produced a strong effect on the physical oceanography, which in turn cascaded through the ecosystem, although the exact mechanisms are not well understood. An early spring diatom bloom was associated with sea ice. By the end of April 1997, chlorophyll concentrations had decreased to pre-bloom values, and nutrients were depleted in the upper layer. Despite the generally weak wind conditions, one strong wind mixing event did occur in mid-May. The impact of this storm was to mix the upper 45-50 m, thereby making nutrients from the lower layer available in the upper water column. This, and net phytoplankton production below the shallow mixed layer, reduced the reservoir of nutrients typically found throughout the summer in the lower layer, setting the stage for the switch from diatoms to a coccolithophore bloom. The coccolithophore bloom dominated productivity, and a shortage of adult euphausiids at the inner front, compared to other years, is indicated in the mass mortality of seabirds.

By contrast, 1998 was very different in forcing, yet it produced a similar coccolithophore bloom. From measurements in February 1998, the water over the shelf failed to mix to the bottom when sea ice was present. This lack of mixing allowed retention of some of the heat accumulated in the bottom layer from the previous year. Additionally, stronger than average atmospheric heat flux in late winter and early spring contributed to the warming of the shelf. The seasonal ice pack arrived and retreated early, spring temperatures in the southeastern Bering Sea were warmer than 1997, and there was much more storm activity. Storms that followed ice retreat mixed stored heat from the bottom layer to the surface. Although high nitrate uptake was observed near the surface, wind mixing was so strong that it prevented a recognizable spring phytoplankton bloom. Anomalous conditions prevailed again during summer 1998, with a second year's coccolithophore bloom over the shelf from Bering Strait to the Pribilof Islands. Circulation was abnormal as evidenced by detection of oceanic copepods, normally native to slope and outer shelf waters, in the coastal domain. During mid-August, shelf water was still warm, but by early September, storm winds had deepened the mixed layer, and the surface water was colder than at the same time in 1997. Seabird abundance was low, those sampled were under weight, and there were signs of reproductive failure in Pribilof Island colonies. Shelf waters were rich in nutrients, and zooplankton were in greater abundance, as opposed to 1997 when

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The Whole Earth System: The role of regional programs

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Patricia A. Livingston has been a fishery research biologist at the U.S. National Marine Fisheries Service (NMFS) - Alaska Fisheries Science Center since 1977. Presently she is serving as leader of the Resource Ecology and Ecosystem Modelling Program. Pat has been involved in several aspects of PICES in the last few years, at first as a member of the Bering Sea Working Group and a member of Model Task Team for the PICES-GLOBEC Climate Change and Carrying Capacity (CCCC) Program and since 1996 as Co-chairman of the Implementation Panel of the CCCC Program. At PICES VII she was elected the new Chairman of Science Board. A detailed biography of Pat Livingston can be found in PICES Press Vol. 7, No.1, (January 1999).

The International Geosphere-Biosphere Program's (IGBP) study of Global Change has taken on a tremendous task. It has mobilized scientists from a broad spectrum of disciplines, organized them into eight discipline-oriented projects, and brought them all together at its second International Congress to discuss how to integrate the research findings of the disciplines and produce a synthesis of program results.

The disciplines involved in understanding how our earth system works and how it responds to human actions include atmospheric science, terrestrial ecology, oceanography, hydrology, and links between the natural and the social sciences. One of the key interactions being studied is the global carbon cycle. Understanding of this cycle and what is needed to balance the carbon budget is crucial to reach international consensus on safe policies for human emissions of carbon. Such a scientific understanding at this global scale can only be reached through an international research effort.

The second IGBP Congress, held May 7-14, 1999, at Shonan Village in Japan, brought these groups together to discuss their progress in understanding the earth system and to find ways to integrate results across the scientific disciplines. It was clear that this integration is crucial to advance our understanding. For example, we heard about the importance of land surface descriptions in weather and climate models and it became evident that we need to improve the descriptions of land-use changes to improve the predictions of our global climate models. Also, the interfaces between the ocean and atmosphere and the land and ocean were shown to be important areas where we need to provide more integration.

Where will IGBP go in the 21st century? Some ideas of the way forward were discussed. It was apparent that there should be a core activity that would do earth system modeling and that there should be cross-cutting activities on the carbon cycle, the global water cycle, and food and fiber. The need to increase emphasis on activities at the interfaces such as air-ocean and land-ocean was also expressed.

How will all this be accomplished? Regional studies were seen as an important way to move forward in understanding how the full system works in an area. Such studies will help identify the specific human activities and economics in a region that may be influencing change and will help connect the global with the local. One of the biggest challenges in this area will be to reconcile the social sciences with the hard sciences. It is clear that we need to better integrate the human dimension into our understanding of the earth system dynamics.

Similar challenges face PICES in the future. We are challenged to integrate our understanding across the disciplines represented by our scientific committees: physical oceanography and climate (POC), biological oceanography (BIO), fisheries science (FIS), and marine environmental quality (MEQ). Some integration is provided through the PICES-GLOBEC Climate Change and Carrying Capacity Program, but more is needed if we are to advance the PICES goals of advancing scientific knowledge about the ocean environment, global weather and climate change, living resources and their ecosystems, and the impacts of human activities. We should also consider whether the disciplines we have represented are sufficient. Do we need more representation of the atmospheric and social sciences? How should we integrate the human dimension? These are the scientific challenges of the future and we need to address them soon if we are to provide a regional contribution to understanding global change and to move towards a sustainable earth system.

Sub-Arctic Gyre Experiment in the North Pacific Ocean (SAGE)

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Dr. Nobuo Suginohara is Professor at the Center of Climate System Research (CCSR), University of Tokyo. He is a modeler leading the CCSR Ocean Modeling Group and develops an ocean model as part of a climate model useful for predicting climate changes of decadal through centennial time scales. At the same time, he has been organizing inter-agency programs related to the World Ocean Circulation Experiment (WOCE) in Japan, and is now Chairman of the Subarctic Gyre Experiment (SAGE) program, a research program for the Research Promotion Fund by the Science and Technology Agency. Dr. Suginohara is a member of PICES' Physical Oceanography and Climate Committee.

1. Introduction

1.1 Why does the subarctic gyre in the North Pacific need to be studied?

Almost two decades have passed since the role played by the ocean in determining climate changes was recognized: TOGA (Tropical Ocean and Global Atmosphere) led to deeper understanding of El Niño-Southern Oscillation of several years' time scales; WOCE (World Ocean Circulation Experiment) has increased our knowledge on the deep ocean which controls climate changes of decadal to centennial time scales.

There is evidence of the importance of the subarctic gyre in the North Pacific in understanding climate changes. According to results of a recent climate model (Tokioka et al., 1995), the subarctic North Pacific as well as the tropical Pacific is very sensitive to climate change. In fact, the observed sea surface temperature exhibits a significant decadal signal in the subarctic North Pacific (e.g., Zhang et al., 1997). Also, the subarctic North Pacific is considered to be an area for anthropogenic CO_2 absorption (Tsunogai et al., 1993). At intermediate depths in the subtropical region, there is a water mass called North Pacific Intermediate Water (NPIW), which is characterized by its low salinity. NPIW is formed in the subarctic North Pacific, and flows into the subtropical region, thus playing an important role in transporting the anthropogenic CO_2 to the whole North Pacific intermediate depths. Therefore, the subarctic North Pacific is a key area to be understood for accurately predicting climate change. We need to understand the subarctic region from the sea surface to the bottom for developing and validating climate models, for understanding oceanic response to changes in atmosphere, and for estimating the absorption rate of anthropogenic CO_2.

However, the subarctic North Pacific is an area where the weather, particularly winter weather, is very severe. This severe weather has hindered observations. Now, we have a big research vessel "*Mirai*", which enables us to obtain data even in wintertime. Data for all seasons will contribute to the development of climate models, which is one of the major objectives of WOCE and CLIVAR (Climate Variability and Predictability), and will also provide important information necessary for setting up the monitoring system of GOOS (Global Ocean Observing System). In addition, circulation fields in the subarctic North Pacific obtained from data will provide an environment for GLOBEC (Global Ocean Ecosystem Dynamics) and JGOFS (Joint Global Ocean Flux Study).

1.2 What do we know about the subarctic North Pacific?

Figure 1 shows salinity sections along 165 ˚E and 30˚N obtained by Japanese ships under one-time WOCE Hydrographic Program (WHP). We can clearly see that the water of salinity minimum occupies the intermediate depths of almost all of the subtropical North Pacific, although characteristics of the water along the eastern and the southern perimeter of the subtropical gyre look different. This water called NPIW is formed in the subarctic gyre and transported into the subtropical gyre near the western boundary (Talley, 1993; Yasuda, 1997) and also near the eastern boundary (You et al., 1999).

Figure 2 shows results of a numerical model for the North Pacific by Tsujino and Suginohara (1998). On the surface, σ_q= 26.6, where the core of NPIW exists in their model, we can see a cross-gyre flow both near the western boundary and the eastern boundary. The water introduced into the subtropical gyre near the western boundary flows eastward to the eastern boundary. There it mixes with the water from the north, and turns first southward and then westward, crossing the Pacific again. Along the western boundary, part of it flows into the tropical gyre forming a southward western boundary undercurrent. Note that state-of-the-art models are

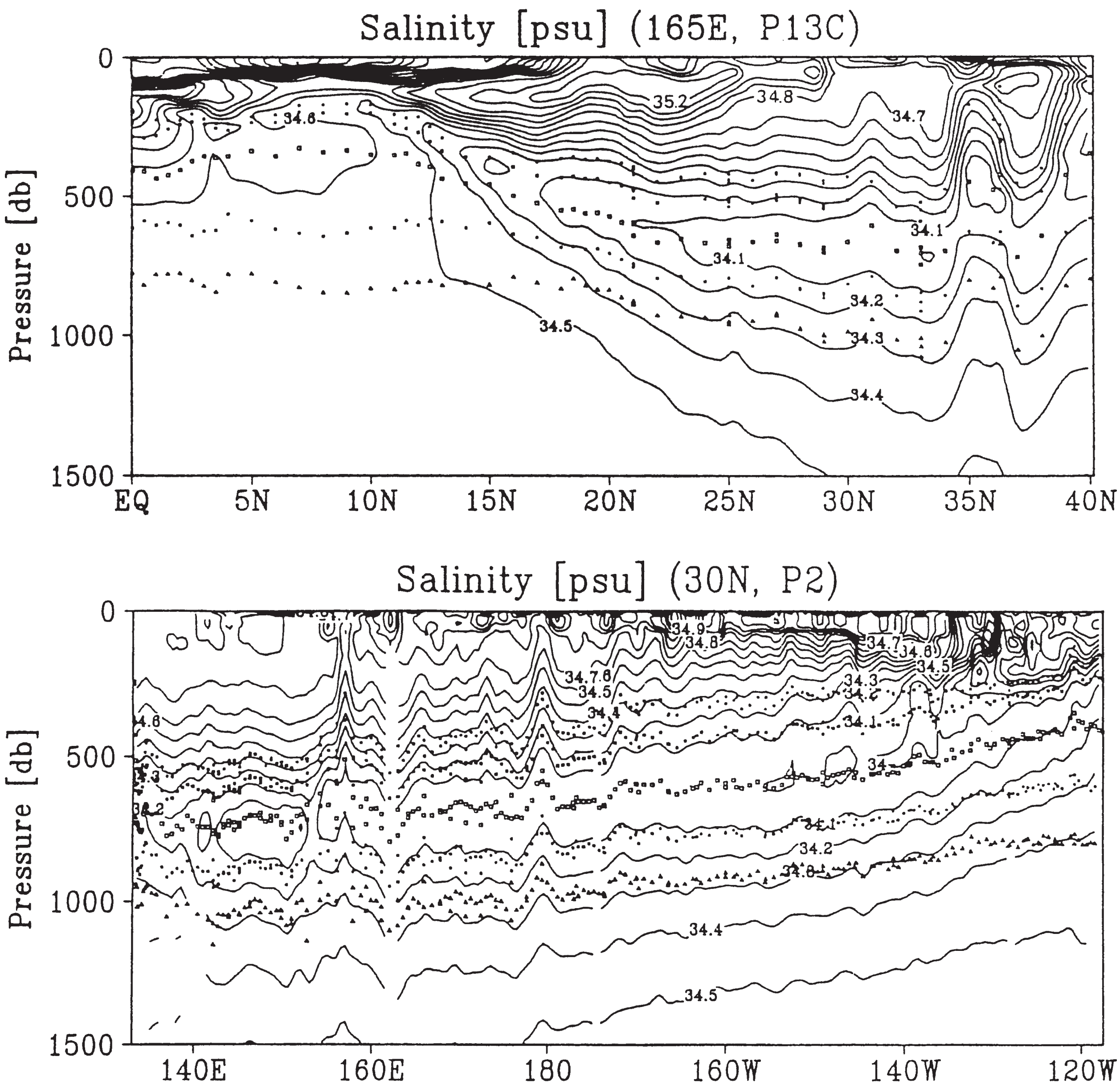

Fig. 1 Meridional salinity section along P13 (165˚E) (upper panel) and zonal salinity section along P2 (30˚N) (lower panel) with the depths of five neutral density surfaces σ_N = 26.2 (o), 26.5 (■), 26.9 (□), 27.2 (•) and 27.4 (∆) (after You et al., 1999).

not good enough to reproduce the separation of the Kuroshio from the coast of Japan.

According to the model, in the density range of σ_q=26.6 - 26.8 the net cross-gyre transport is about 1.5 Sv (see *Figure 3*). There are a few of observational estimates for this transport. For example, Talley (1994) obtained about 3 Sv for the density range of σ_q=26.64-27.4 in the mixed water region, but this value includes a lot of uncertainties. Therefore, we still do not know how much NPIW is formed in the subarctic North Pacific and transported into the subtropical gyre. Furthermore, we do not know their temporal variability at all.

2. *Outline of the program*

Major objectives of the SAGE program are to estimate the formation rate of North Pacific intermediate waters such as NPIW, and to clarify their distribution processes and decadal/interdecadal variability. To accomplish the objectives, the following four core projects (CP) are set up.

CP1: *Observational study on the structure and variability of the subarctic gyre*

- Surface layer circulation (Thermal structure and current field)

Sea surface topography measured with satellite altimetry will be analyzed. We will keep a network of XBT and XCTD observation including TRANSPAC-XBT, and conduct Lagrangian measurements of the current field using surface and subsurface drifters.

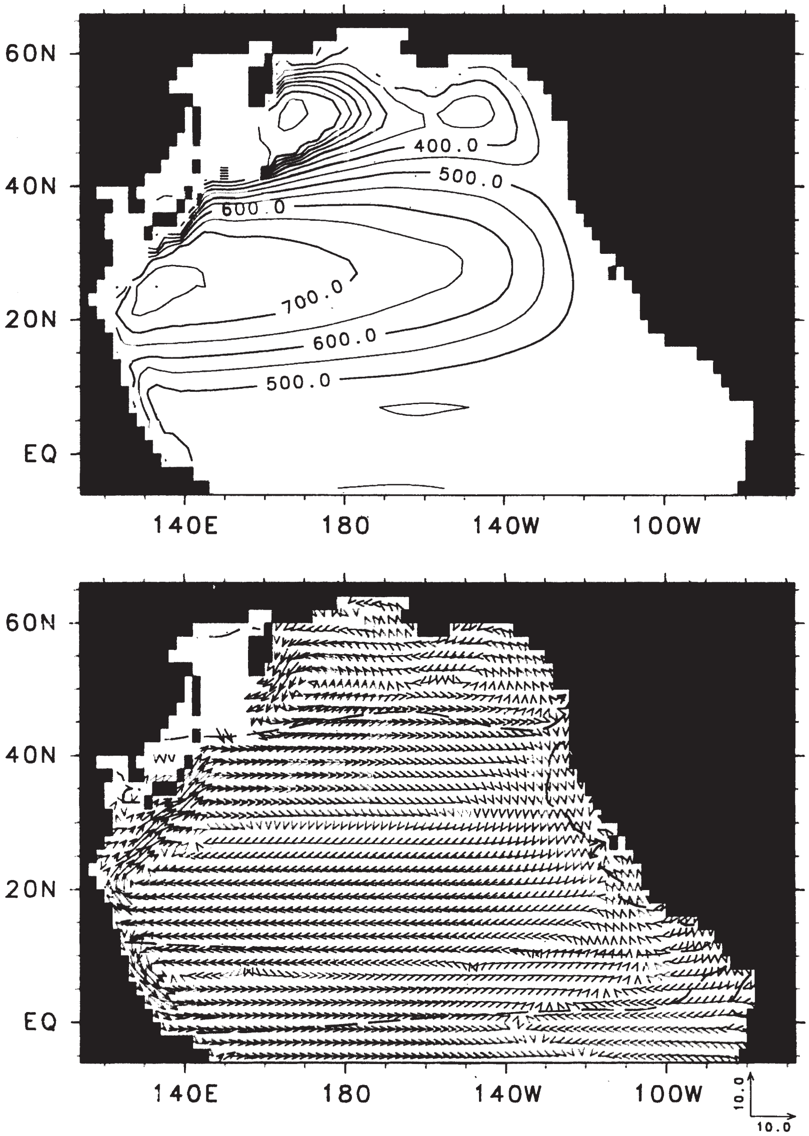

Fig. 2 *Depth in meters and horizontal velocity on the* σ_θ *=26.6 surface modeled by Tsujino and Suginohara (1998).*

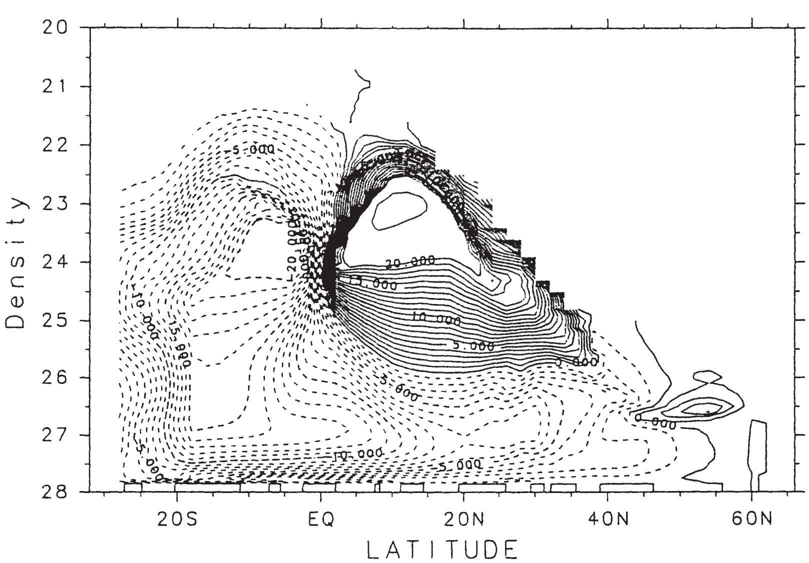

Fig. 3 *Meridional stream function in Sv against potential density modeled by Tsujino and Suginohara (1998).*

- Hydrographic structure of the subarctic gyre (temperature, salinity, and tracers)

We will revisit one-time WHP lines such as P1 (47˚N), P16N (152˚W), and P13 (165˚E) to detect decadal changes of the subarctic North Pacific.

CP2: *Research on the interaction between the subarctic and the subtropical circulation*

- Formation and distribution of NPIW in the western North Pacific -

We will try to identify the formation processes of the origin water of NPIW in the Okhotsk Sea, interaction between the Okhotsk Sea and the subarctic gyre, and advection process of NPIW including cross-gyre flow.

CP3: *Behavior of* CO_2 *in the subarctic circulation system*

We will map air-sea exchange of CO_2 in the subarctic North Pacific and estimate seasonal variations of TCO_2, pH, pCO_2, etc. in the mixed water region.

CP4: *Modeling of the subarctic gyre*

We will develop inverse models for the intermediate and deep layer circulation, assimilation models, and an eddy resolving model for the North Pacific. For an eddy resolving model, we try to reproduce the Kuroshio separation at a realistic latitude.

Participating institutes and organizations are listed in *Table 1*. They own many ships, which we will make full use of to accomplish the objectives of the SAGE program.

3. Preliminary results

The program is in progress according to plan. Here are some of the results obtained so far.

Figure 4 plots observation lines occupied in April to July 1998. This multiple-ship survey is for identifying the formation and transformation processes of NPIW in the mixed water region. *Figure 5* shows one of the preliminary results. The cold and fresh water around 34˚N, 145˚E is thought to be transported from the Oyashio region. It is expected that the exact amount of the cross-gyre transport be obtained and the formation and transformation processes of NPIW be clarified.

Table 1. List of participating institutes and organizations.

Fisheries Agency
- Hokkaido
- Tohoku
- Central
- Far Seas

Agency of Industrial Science and Technology
- National Research Institute of Resources and Environment

Maritime Safety Agency
- Hydrographic Department

Meteorological Agency
- Climate and Marine Department
- Meteorological Research Institute

Japan Marine Science and Technology Center

Universities
- Tohoku University
- University of Tokyo
- Kyoto University
- Tokai University

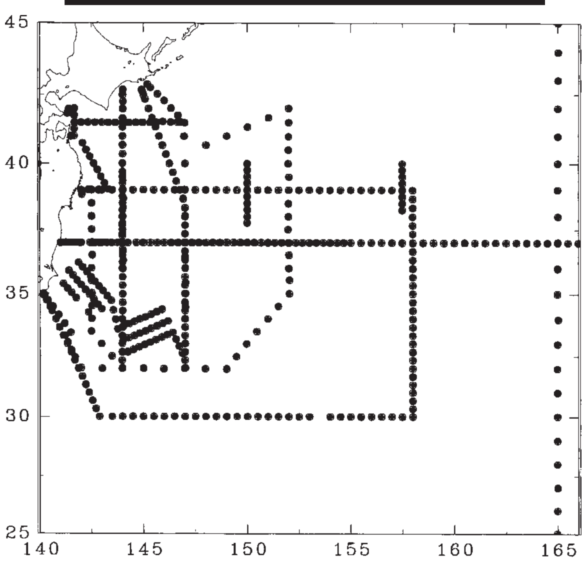

Fig. 4 Observation lines occupied by the R/V's Soyo-Maru, Kofu-Maru, Ryofu-Maru, and Wakataka-Maru in April to July 1998.

Figure 6 shows the temperature and salinity in the western part of P1 along 47˚N for two periods, 1985 and 1997. The observation in 1997 was preliminary for the revisit of P1 in 1999. There were no tracer observations in 1997. The comparison clearly shows that the deep layer in 1997 became colder by 0.01-0.05˚C and saltier by 0.005-0.01 psu in the west of 165˚E, while it was warmer by 0.01-0.05˚C in the east

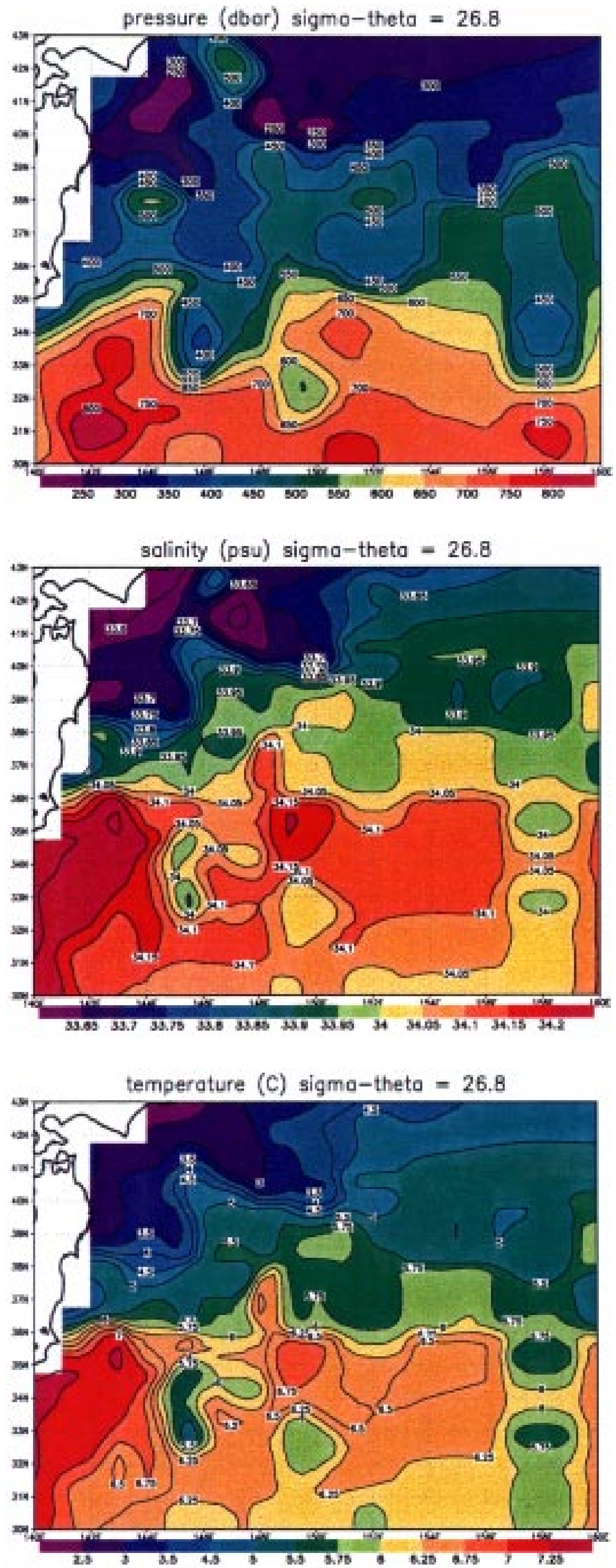

Fig. 5 Depth, temperature, and salinity on the σ_q=26.8 surface from the multiple-ship survey in Fig. 4.

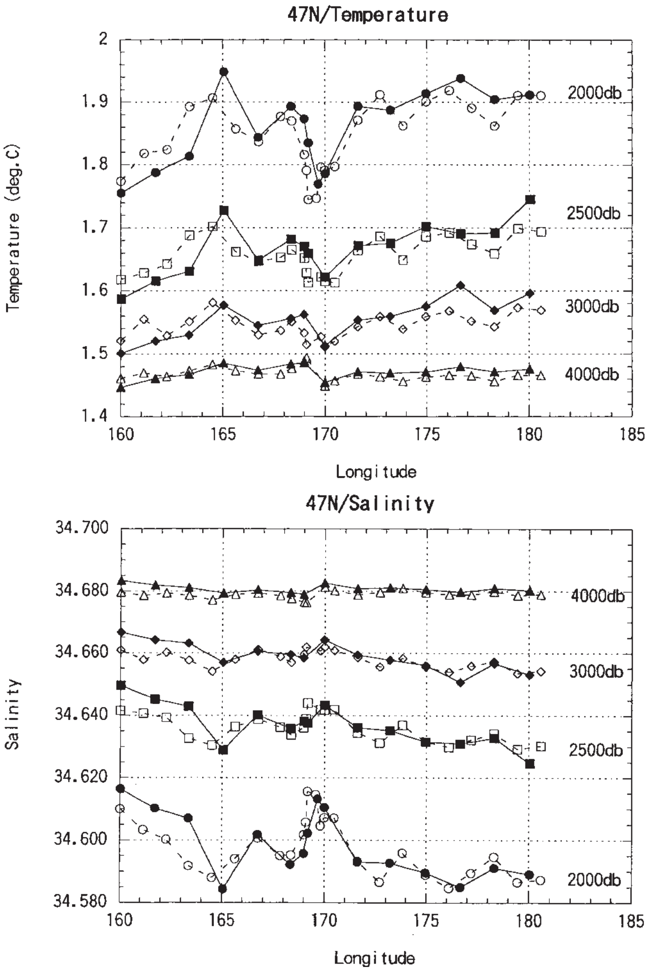

Fig. 6 Temperature (upper panel) and salinity (lower panel) along 47˚N at different depths. Solid lines with solid symbols are for R/V Shoyo's *observations in August 1997, and dashed lines with open symbols are for R/V* Thompson's *observations in August 1985.*

of 165˚E. Detailed analyses of the 1997 data are still being made. The whole P1 line will be revisited in June to September 1999, by the R/V *Kaiyo-Maru* of Japan Fisheries Agency and the R/V *Mirai* of JAMSTEC. Details of the changes will be learned soon by using observations of temperature, salinity, nutrients, and various tracers such as freons and ^{14}C.

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You, Y., N. Suginohara, M. Fukasawa, I. Yasusda, I. Kaneko, H. Yoritaka, and M. Kawamiya (1999). Roles of the Okhotsk Sea and Alaskan gyre in forming the North Pacific Intermediate Water. submitted to J. Geophys. Res.

Zhang, Y., J.M. Wallace, and D.S. Battisti (1997). ENSO-like interdecadal variability: 1900-93. J. Climate, 10: 1004-1020.

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coccolithophores dominated. During mid-September the coccolithophore bloom was still prevalent.

Although these unusual conditions did not seem to have an immediate effect on the groundfish of the area, they may impact future abundance. NOAA fishery surveys in 1997 and 1998 located fewer young-of-the-year pollock than in previous years. Participants on the July 1998 *Oshoro Maru* cruise reported that the abundance of age-0 pollock seemed low relative to the previous four years. However, observations from the Inner Front Project in August 1998 suggest that young pollock, in fact, were quite abundant but located further onto the shelf than usual. This displacement could derive from wind-driven transport of pollock larvae northeastward from their spawning area during the stormy spring. Ramifications of these recent changes will not be known for several years until the young pollock mature into adult fish and are harvested.

SEBSCC has extended the knowledge base of the southeastern Bering Sea at a critical moment. More and more attention is focused on the Bering Sea. Just a few years ago, as other fisheries of the United States were suffering serious declines, the eastern Bering Sea fishery was considered stable. In the past two years there have been indications that this may not be the case.

Commercial salmon failures, curtailment of fishing areas and times because of declining marine mammal populations, massive deaths of seabirds, and indications that a major shift in Bering Sea climate may be occurring, all suggest that the Bering Sea ecosystem is changing in a significant way. It is clear that we must understand this change in order to manage responsibly the bountiful resources that this region provides. SEBSCC contributes measurements and results that are vital to a more complete understanding of the Bering Sea ecosystem.

The Alaska Predator Ecosystem Experiment (APEX): An integrated seabird and forage fish investigation sponsored by the *Exxon Valdez* Oil Spill Trustee Council

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Mr. Bruce Wright has been the Alaska Predator Ecosystem Experiment (APEX) Project Manager since its inception in 1994. At the time he was the Damage Assessment Program Manager for the Office of Oil Spill Damage Assessment and Restoration with the National Oceanic and Atmospheric Administration (NOAA), a position he accepted in 1991. Mr. Wright is now the Chief of that office, which works closely with the Exxon Valdez Oil Spill Trustee Council, and in 1997, he was assigned as the NOAA agency liaison to this Council. In 1998, he was selected as vice-chairman of the Jay Hammond Bald Eagle Research Institute, and was named the chairman in 1999. Having many years of teaching experience, he has helped develop six Wildlife Series correspondence courses on whales, eagles, and bears (1987), and continues to teach those courses as part-time visiting faculty at the University of Alaska Southeast. Bruce graduated from San Diego State University where he earned a B.S. degree in biological sciences (1975) and a M.S. degree in ecology (1977).

The Alaska Predator Ecosystem Experiment (APEX) project began in 1994, and arose as an effort to determine why some seabirds showed no sign of recovery from the *Exxon Valdez* oil spill. Such knowledge was seen as essential to undertaking biologically realistic recovery. The basic hypothesis of APEX, that food limits recovery, appears to have been confirmed by multiple approaches within APEX (www.uaa.alaska.edu/enri/apex/index.html). Historical data from long-running sampling of the Gulf of Alaska (GOA) indicate a major change in the marine ecosystem associated with increased water temperatures in the late 1970s. This led to a change from capelin *(Mallotus villosus)* and shrimp to flatfish and pollock *(Theragra chalcogramma)*. Seabird diets reflect this change: capelin and sand lance *(Ammodytes hexapterus)* were replaced by pollock. At-sea studies in Prince William Sound during APEX have demonstrated an abundance of pollock offshore, with schooling species such as herring *(Clupea harengus)* and sand lance inshore. Most seabird foraging has been concentrated inshore on these species. Capelin have been rare and limited to certain areas. APEX field studies in PWS and the GOA of Black-legged Kittiwake (*Rissa tridactyla)*, Marbled Murrelet (*Brachyramphus marmoratum*), and Pigeon Guillemot (*Cepphus columba*) have shown that they have better reproductive success when consuming high lipid schooling species: forage fish abundance and seabird breeding success have been positively linked. According to laboratory studies seabirds grow better and have heavier masses at fledging when fed high lipid schooling species. Nutritional studies have revealed that herring, sand lance, and capelin have higher lipid (and energy) levels than do pollock. Finally, models of populations and foraging have shown that certain colonies contribute disproportionately to the dynamics of a species.

Retrospective studies

Declines of APEX predator populations, murres, kittiwakes, harbor seals *(Phoca viyulina phocoena*), and Steller sea lions (*Eumetopias jubatus*), have occurred in the GOA since the 1970s. Changes in composition and abundance of forage species may be related to the decline of these predator populations and their chronic low population levels. A trophic regime shift resulting from a climatic forcing event in the last half of the 1970s was suggested as the driving mechanism for these observed trends. These data were collected in a similar manner, over widely dispersed regions of the GOA, and show massive reorganization of the marine ecosystem following the extreme environmental change, (*Figure 1*) as evidenced in long-term (1953-1998) small-mesh trawl surveys

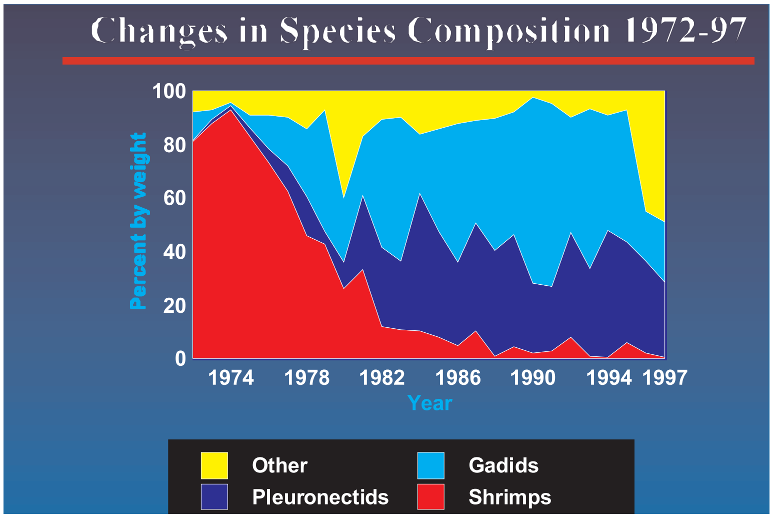

Fig. 1 Changes in species composition in the Gulf of Alaska, 1972-1997, from small-mesh mid-water trawl surveys (from Anderson, P. J., J. E. Blackburn, and B. A. Johnson. 1997. Forage Fish and Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program No. 97-01. University of Alaska Fairbanks, 1997.)

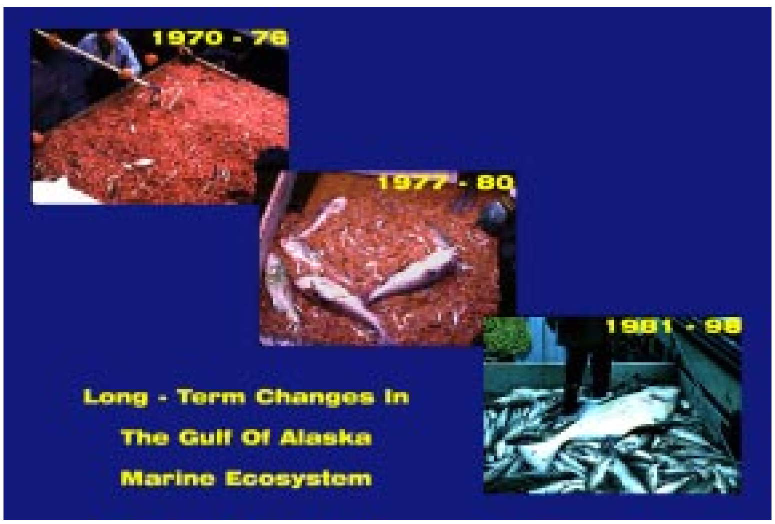

Fig. 2 Long-term changes in the Gulf of Alaska Marine Ecosystem (from Botsford, L. W., J. C. Castilla, and C. H. Peterson. 1997. The Management of Fisheries and Marine Ecosystems. Science 277: pp 509-515)

(www.fakr.noaa.gov/trawl/index.htm). Nearly 10,000 individual sampling tows are in the current project database. Recent analysis of the 1996-1998 survey data has indicated that the groundfish-dominant trophic structure still exists with no signs of reversal (*Figure 2*). Thus, the current system exhibits a high degree of stability. Long-term monitoring is needed to determine what drives and maintains these GOA marine ecosystem changes, particularly the effects on APEX predators.

Scale

Factors affecting food availability of seabirds occur at many spatial scales ranging from tens of meters to thousands of kilometers. While broad-scale oceanic processes (e.g., circulation and temperature) may affect general food abundance, it is often small-scale events (e.g., local currents and upwelling) that have an impact on how and where individual seabirds choose to forage. By observing individual seabirds and schools of fishes the APEX study has found several factors that influence how seabirds forage. In summer, the waters of PWS are stratified with little mixing and the near-surface fish schools (herring, sand lance, and capelin) are small, occur in low density, and are located close to shore. Seabirds in PWS respond by foraging singly or in small flocks close to shore. This is in contrast to lower Cook Inlet where there is strong tidal mixing of the water column, the fish are in larger and more dense schools than in PWS, and the fish occur offshore (capelin and pollock) as well as near shore (capelin and sand lance). When prey are predictable, seabirds learn and remember where prey can be found and individual birds return to the same area repeatedly. In this case, they do not always forage on fish that are closest to the colony; rather, they pass by fish schools to return to the area where they have successfully foraged in the past. When prey availability changes daily due to tidal cycles, birds respond by adjusting their foraging activities. Seabirds also change their foraging strategy in respect to prey abundance: when prey are scarce seabirds generally forage in flocks, but when prey are abundant they often forage alone. This behavior change likely increases their efficiency by using other birds to find food when it is scarce, and decreasing risk of kleptoparasitism by foraging alone when prey are abundant. At intermediate spatial scales of tens to thousands of km, the distribution of seabirds at colonies and at sea in the northern GOA reflects regional patterns of productivity and forage fish abundance. Seabird productivity varies with overall forage fish abundance in a nonlinear fashion, and in some areas and years, productivity is clearly limited by food availability. Decadal changes in forage fish stocks have altered the diets of many seabirds in the GOA, and influenced trends in productivity and population dynamics.

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ICES and GOOS: A progress report

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Background

Since the oceanic processes know no national boundaries, monitoring and detecting climate change and variability, predicting the impacts of such changes, and advising the national policy makers on how to respond and adapt to these impacts, require strong global coordination and collaboration. The International Council for the Exploration of the Seas (ICES) was established to provide such a forum for collaboration in the north Atlantic and the adjacent seas. In the last few decades, the need for expanding the regional coordination into a global one has been growing because of the technology revolution and global utilization of such technologies. Clearly, the technological revolution of this century has drastically changed the way each of the world's nations manages and exploits the natural resources, and as a result potentially increasing the human-induced component of global warming and climate change. Thus the concept of a Global Ocean Observing System (GOOS) was born under the Intergovernmental Oceanographic Commission (IOC). Over 10 years after its inception it has now been accepted by most nations and many are in the process of defining their national contributions.

The basic premise of GOOS is to build on existing strengths (http://ioc.unesco.org/goos). Contributions to GOOS are expected to be long-term (measurements, once begun, should continue into the foreseeable future), systematic (measurements should be made with the precision, accuracy, and care in calibration required to provide continuity in the quality of data in space and time even though different methodology may be used), and subject to continuing examination. It was also recognized right from the start that not every monitoring belongs to an integrated observation system. In order to make it easier for the national Governments to separate their GOOS contributions from the rest, and also to ensure that the observations designated as GOOS will surely contribute to our knowledge of global ocean variability, the international GOOS planning team has drawn up a set of 9 design principles for GOOS (The Global Ocean Observing System, GOOS, Prospectus 1998, GOOS Publication no: 42, UNESCO).

Since many aspects of the ocean need to be monitored, GOOS planning was carried out under four components (modules): climate, coastal, health of the ocean and living marine resources. The overall direction is provided by a scientific steering committee. Understandably, planning of the climate module is the most advanced, since it was able to take advantage of the scientific understanding of the climate system advanced by programs such as the Tropical Ocean and Global Atmosphere Programme (TOGA), the World Ocean Circulation Experiment (WOCE), the Global Energy and Water Cycle Experiment (GEWEX), Climate Variability (CLIVAR), etc. The original design of an ocean climate observing system for climate was completed by the Ocean Observing System Development Panel (OOSDP) in late 1994, published in early 1995 (OOSDP, 1995) and endorsed soon afterwards. Planning of the other modules is at varying stages of development.

A comparison of the ICES mandate and its activities, with the GOOS principles, the GOOS Climate module design and the preliminary plans of the other GOOS modules, clearly highlights the fact that ICES may be considered as the first phase of the north Atlantic GOOS even if it is not designated as such until now (http://www.ices.dk). Recognizing this, ICES established in 1997, a Steering Group on the Global Ocean Observing System consisting of the chairmen of the Working Groups under the Oceanography, Marine Habitat, and Living Resources Committees. Based on the report of this Working Group, and to further develop a strategy for ICES-GOOS collaboration, a workshop, co-sponsored by ICES and IOC, was planned, and held in Bergen, Norway

(cont. on page 40)

Report on GOOS Living Marine Resource Panel Meeting

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Dr. Warren S. Wooster is an oceanographer who studies interactions between climate variations and marine ecosystems. He is a professor emeritus at the School of Marine Affairs, University of Washington, in Seattle, and Co-Chairmam of the Living Marine Resource Panel of the Global Ocean Observing System. His earlier academic appointments were at the Scripps Institution of Oceanography (1947-1973) and the University of Miami, and he has been at the University of Washington since 1976. Dr. Wooster was Secretary of the Intergovernmental Oceanographic Commission (1961-1963), President of the Scientific Committee on Oceanic Research (1968-1972) and of the International Council for the Exploration of the Sea (1982-1985), and the first Chairman of PICES (1992-1996). Warren continues to be involved in PICES activities serving as the interim Chaiman for the Publication Committee, member of the MONITOR Task Team and the National representative for the CCCC Implementation Panel. A detailed biography of Dr. Wooster can be found in PICES Press Vol.5, No.1 (January 1997).

The second meeting of the Living Marine Resource Panel of the Global Ocean Observing System (LMR-GOOS) was held in Montpellier, France, on March 22 - 24, 1999. (Reports on the first meeting can be found in PICES Press, volumes 6(2) and 7(1).) Some of the problems faced by the Panel, in moving toward an operational monitoring plan that could yield useful products, are described in the following text from the draft report:

> The Panel must consider how to proceed to the development of a strategic, and eventually an implementation, plan. The problems in achieving a firm design for the LMR component of an operating system include the heterogeneity of present observing systems for biological elements, and the lack of agreement on which observations would benefit potential users. Although it is now generally accepted that variability in the physical and biological environment has an important role in determining the abundance and availability of living marine resources, there are no generally accepted models whereby observations of the relevant physical and biological variables can be used in forecasting such abundance and availability. With no present observing system on which to build and no agreed linkage between measurable variables and desired products, the optimal route to the desired outcome remains obscure.

At its first meeting, the Panel identified in generic form the ecosystem components and conditions for which information is required, and it now must further specify the measurements of these components and conditions that should be incorporated in an operating system. It must also consider how such data can be applied to desired end products. For example, one might propose a scheme for monitoring phytoplankton abundance and primary production, but there is as yet no agreed way to use such data to predict abundance of some fish stock of commercial importance. On the other hand, such information could be useful in determining changes in the condition (health) of an ecosystem.

In Montpellier, the Panel spent much of its time in developing a more specific table of desired observables and useful products that could be derived therefrom. Derivation of these products was dependent on the use of various models, and an attempt was made to suggest how the observables and products might be linked through analysis using identified models. This effort also led to consideration of capacity building in user countries whereby this work could be accomplished.

Two on-going monitoring projects, the Sir Alistair Hardy Foundation's Continuous Plankton Recorder (CPR) survey, and the ICES International Bottom Trawl Survey, both in the North Atlantic, were recommended for incorporation in the GOOS Initial Observing System (IOS). PICES may wish to identify some North Pacific monitoring projects to be included in the IOS.

Reports were made on several retrospective experiments in which the use of available monitoring information was tested to see if major ecosystem changes could have been predicted. Particular attention was given to such an experiment on the eastern Scotian Shelf where major changes in cod stocks occurred. Other experiments in progress were described, and the possibility of additional experiments, for example in the Gulf of Alaska, was considered.

The Panel was informed of the development of the FAO Fisheries Global Information System, FIGIS, which could do much to answer the Panel's concern about the need to bring together national and regional analyses of fisheries data in order to assess population changes in the upper trophic levels of marine ecosystems.

Pilot experiments have been proposed in order to demonstrate the concept of monitoring from the living marine resource point of view. Those in connection with the GEF-funded Large Marine Ecosystem (LME) monitoring and assessment projects and with large-scale GLOBEC projects, such as those concerned with small pelagics and with the Southern Ocean, seemed promising. In the PICES region, Professor Takashige Sugimoto (Japan) described work in the northwest Pacific that could constitute an LMR pilot project, and Professor Warren Wooster (USA) proposed that a northeast Pacific plan for use of the Continuous Plankton Recorder (CPR) be adopted.

The full report of the meeting should be completed in the next month and distributed in early summer. Comments and suggestions from the PICES community will be welcome. These can be considered at a third meeting, anticipated by the end of 1999, when an implementation plan should be completed.

(cont. from page 36)

APEX mesoscale studies of seabird populations in the northern GOA reveal a high degree of local, short-term variability in population parameters, but a pervasive influence of mesoscale phenomena on populations in discrete oceanographic domains.

Energetics

APEX research also addresses whether shifts in diet quality may constrain reproduction of Pigeon Guillemots, Black-legged Kittiwakes, and other piscivorous seabirds nesting within the *Exxon Valdez* oil spill area. Researchers measured lipid content of forage fishes because it is the primary factor determining energy density. Lipid content of seabird prey ranged from 2% to 61% of dry mass, resulting in a fivefold difference in energy density (2.0 to 10.8 kJ/g wet mass). Most of this variation was due to among-species differences, but intraspecific variation in lipid content was related to age, sex, location, and reproductive status of fish. Of the main fishes consumed by seabirds, juvenile herring, pre-spawning capelin, and sand lance had the highest energy densities. Kittiwake diets were dominated by these high-lipid forage fishes at all study sites, and the dates of energy provisioning to nests were correlated with nestling growth and survival. The trend established in the earlier part of this decade of higher kittiwake productivity associated with increasing availability of sand lance, capelin, and herring was broken in 1997, a poor year at most kittiwake study colonies. For guillemots, the proportion of high-lipid schooling fish (sand lance, herring) in the diet was associated with higher growth rates, and productivity, compared with those consuming mostly nearshore demersal fishes or gadids. These results support the hypothesis that productivity of kittiwakes and guillemots in the northeast Pacific area is strongly linked to the availability of three species of forage fishes: Pacific sand lance, Pacific herring, and capelin. These three species form schools near shore and have high energy densities compared with most other forage fishes. Recovery of seabird populations injured by the *Exxon Valdez* oil spill will depend on recovery of these key fish stocks.

Modeling

The population dynamics of kittiwakes and other seabirds in PWS are usually in a state of flux. At any given time, some colonies are growing and some are declining. Although there is strong evidence that variation in food supply underlies much of the fluctuation in colony size, the mechanism by which food supply influences colony dynamics needs to be more clearly defined. Analysis of demographic data indicates that the rate of population change for a given colony is closely related to the breeding success of that colony. Breeding success in turn is related to the rate at which food is delivered to chicks and the quality of that food. Using detailed data on the movement patterns and foraging behavior of radio-tagged kittiwakes coupled with extensive concurrent aerial surveys of fish schools, APEX researchers have constructed a computer model designed to mimic the behavior of a foraging kittiwake. This model can be used to simulate the response of a foraging kittiwake to various patterns of food distribution and abundance. These simulated foraging behaviors can then be used to predict the distance that adults must travel in order to forage, and the rate and nature of food deliveries to the chicks. Since chick survivorship is known to be strongly influenced by these factors, we believe that it will be possible to make predictions about the performance of individual colonies based on hypothetical fluctuations in the distribution and abundance of the forage fish.

Summary

Changes in the marine ecosystem of the GOA led to a low-fat "lean cuisine" on which seabirds had difficulty raising young. APEX researchers are still exploring why this shift occurred and the mechanism through which it affects seabirds. The main implication for management is that recovery will continue to be inhibited as long as present ecological conditions exist. APEX studies have also identified key colonies and foraging areas that should be protected during future oil spills and during development of infrastructure in the GOA.

(cont. from page 37)

from March 22–24, 1999, under the Co-Chairmanship of Mr. Roald Sætre (Norway), Prof. Christopher N.K. Mooers (U.S.A.) and Dr. Hans Dahlin (Sweden). Participants at the meeting included individuals from ICES, IOC and EuroGOOS, and from many of ICES member countries on both sides of the Atlantic.

The workshop objectives were to:

- identify existing ocean observing activities within the ICES area that are relevant to GOOS;
- investigate how observations already being made routinely, could be combined and enhanced and incorporated within a common plan;
- propose a possible design for an ICES regional GOOS component;
- develop a draft implementation plan for ICES-GOOS;
- advise the Bureau on the policy role of ICES.

The first day was used for several presentations setting the frame for further work by reviewing the status of GOOS in relation to ICES as well as to relevant international organizations and programmes, such as IOC-GOOS, EuroGOOS, the North Sea Conferences, and the SeaNet co-operation. Additionally, there were short reports from the participants, national or institutional, as well as from some national representatives who were unable to attend the meeting, on observation systems relevant to ICES-GOOS and on regular products based on these systems.

ICES-GOOS links

The ICES member countries have all signed up to the Rio declaration and Agenda 21, the Climate convention and the Convention of Sustainable development. GOOS is the system for ocean information which is being implemented to support Agenda 21 and the conventions. All work co-ordinated by ICES and carried out through its member states are of relevance and of value for GOOS. For both the member states and for GOOS it is important that the ICES co-ordinated efforts also will be available for GOOS.

It was very clear to all participants that ICES encompass activities of relevance to all GOOS modules; for example

Living Marine Resources (LMR): - repeated surveys of physical, chemical, ecological and fisheries variables;

Climate - North Atlantic standard sections and stations repeated at least annually over several decades;

Coastal - seasonal sampling (and synoptic modelling of physical and ecological variables in the Baltic, the North Sea and the Nordic Seas;

Health of the Ocean (HOTO) - sampling of contaminants in the Baltic and the North Sea

Most of the ICES countries operate national monitoring and reporting systems for the marine environment where the end products could contain elements of hind-casting, now-casting or forecasting. With its long-term activities in monitoring and detecting climate variability, assessing the impacts of climate change on marine resources, participating in international research programs, and generating and providing information for public consumption (such as the annual North Atlantic Ocean Climate Summary), ICES offers historical context and expertise. In selected areas, such as the North Sea, there is some co-ordination of the data collection and assessment reports have been worked out within the framework of the North Sea Conferences.

Conclusion

The workshop concluded that ICES has much to offer GOOS in terms of historical databases, observing system expertise, and interpretative expertise. Of course, as identified in the GOOS Plan, all monitoring systems need to be reviewed and revised as necessary, and ICES programs need them as well. However, such changes in the existing ICES programs can only be made in consultation with other relevant programs and agencies. To facilitate such collaboration at the administrative, operational and scientific levels, a suite of recommendations was drawn up at the workshop. ICES will discuss these in the upcoming months, and if time permits, the ICES-GOOS plan will be developed for the I-GOOS meeting in June.

News from the PICES Secretariat

Congratulations to *Dr. Alexander S. Bychkov* who has been selected as the new Executive Secretary of PICES, effective June 1, 1999.

Applications are invited for a three-year appointment to the position of the Assistant Executive Secretary, which is now open. A description of the position and the application procedure can be found on the PICES Home Page (http://pices.ios.bc.ca). Applications should be submitted to Dr. Alexander S. Bychkov, PICES Secretariat, c/o Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2.

PICES PRESS

Published and produced by
PICES Secretariat
c/o Institute of Ocean Sciences,
P.O. Box 6000,
Sidney, B.C.,
Canada. V8L 4B2
Tel.: (1-250) 363-6366
Fax: (1-250) 363-6827
E-mail: pices@ios.bc.ca
http://pices.ios.bc.ca
ISSN 1195-2512