Phase 1

Summary of the PICES/NPRB Workshop on
Forecasting Climate Impacts
on Future Production of Commercially Exploited Fish and Shellfish

July 19–20, 2007
Seattle, Washington, U.S.A.

Background

The North Pacific Marine Science Organization (PICES) and the North Pacific Research Board (NPRB) co-sponsored a workshop on *Forecasting Climate Impacts on Future Production of Commercially Exploited Fish and Shellfish* on July 19–20, 2007, in Seattle, U.S.A. The workshop provided a forum for 38 participants from six countries (Appendix 1.1), including a significant number with expertise on the effects of climate on North Pacific fisheries and representatives from PICES' Biological Oceanography, Fishery Science, and Physical Oceanography and Climate Committees (BIO, FIS, and POC) and Climate Forcing and Marine Ecosystem Response (CFAME) Task Team of the Climate Change and Carrying Capacity Program (CCCC). This workshop was a follow-up to an earlier workshop on *Linking Climate to Trends in Productivity of Key Commercial Species in the Sub-arctic Pacific* that was held October 13–14, 2006, at the PICES Fifteenth Annual Meeting in Yokohama, Japan. The goal of the endeavour was to develop a coordinated international effort to provide quantitative estimates of the impacts of climate change on major fish populations. Workshop participants representing each of the PICES member countries agreed that they would be interested in participating in this effort. One outcome of the workshop was a concept for a PICES Panel on Fisheries and Climate Change (PPFCC) to continue this work.

Participants discussed how these forecasting activities might differ from other national or international research programs that are focused on climate change impacts. In summary, they will complement several ongoing research activities within the PICES region and the sub-arctic as a whole, and several features of the concept make it unique. First, it will provide quantitative estimates of the impacts of climate change on fisheries in the North Pacific. Second, it will produce a coordinated interdisciplinary and multi-national effort involving the application of similar methods and forecasting approaches to compare responses of fish and shellfish species across their ranges. Third, it will focus on species of significant commercial interest and not on entire ecosystem responses. Forecasting tools will be developed to allow the inclusion of environmental impacts on fish and shellfish production, distribution and growth.

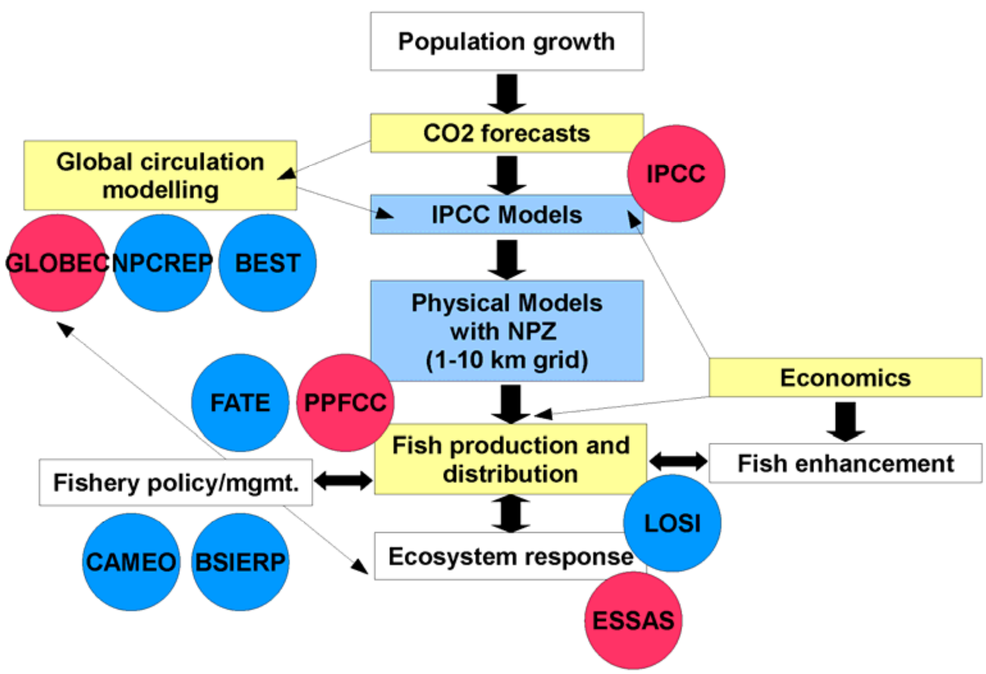

Fig. 1.1 Schematic showing linkages between U.S. national (dark blue) and international (red) research programs in the PICES region (see text for description of acronyms). National programs are expected to continue to fund research within the boxes.

Results of the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (IPCC AR4) will be used to develop scenarios of regional oceanographic changes that will, in turn, be linked to changes in ocean forcing of upper trophic level species (see discussion below). This builds on a history of research on mechanisms underlying fisheries production, setting the stage for the development of quantitative climate change impacts on fisheries. Participants at the workshop recognized the importance of ocean and climate effects on recruitment and accepted the concept of decadal-scale variation – a very important advancement and key result of the workshop.

Links to Other Programs

FIS-sponsored activities like the proposed PPFCC could provide a critical link to other national and international research programs that are expected to be active within the region during the next decade (Fig. 1.1). These would build on the work of the IPCC that has provided scenarios for modelling climate change impacts on fisheries. Examples of bio-physical models that are being developed by national programs include the U.S. National Science Foundation's Bering Sea Ecosystem Study (BEST), the U.S. Global Ocean Ecosystem Dynamics Program (GLOBEC) Northeast Pacific Program (NEP), and the U.S. North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) program as well as international programs such as GLOBEC International. PICES scientists can coordinate their activities with on-going research on upper trophic level responses to environmental forcing that are taking place in most national research institutions. In particular, the results will be first-order forecasts for use in developing more complex, process-oriented studies that seek to predict the responses of whole ecosystems such as is being attempted in the NPRB-funded Bering Sea Integrated Ecosystem Research Program (BSIERP) and the U.S. National Oceanic and Atmospheric Administration's (NOAA's) Loss of Sea Ice (LOSI) program.

The regional forecasting approach can be used to guide comparative research across the northern hemisphere, some of which is sponsored by GLOBEC's Ecosystem Study of Sub-Arctic Seas (ESSAS), and by the U.S. Comparative Analysis of Marine Ecosystem Organization (CAMEO) program. The goals of this initiative are consistent with the climate forecasting element of the proposed PICES science program, FUTURE (Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Ecosystems), and the U.S. Fisheries and the Environment (FATE) program.

The results of the coordinated research effort can be used by a wide range of individuals who are normally outside of the research community. Stakeholders who rely on fish and shellfish resources are expected to use the results to anticipate changes that may affect their businesses and communities. Fisheries managers will utilize the forecasts to evaluate whether actions are needed to sustain fisheries in their regions. Conservation groups will be interested in order to better understand the regional and species-specific risks and challenges that climate change poses for species of interest.

Forecasts developed through this effort will help to identify research gaps that could be the focus of interdisciplinary research programs involving field work. Just as the recognition of regime shifts was used to promote the development of large national and international interdisciplinary research programs, participants at the workshop thought that the international research effort to investigate the impacts of climate change on marine fish populations may promote the expansion of national and international research programs on climate change and marine ecosystems.

Workshop Format

The workshop provided a forum for discussion of four components needed to complete the forecasts in a timely and coordinated fashion, including: IPCC scenarios, predictions of oceanographic impacts, modeling approaches, and scenarios for natural resource use and enhancement. The key outcomes of these discussions are included in this report.

Session I. Status of climate change scenarios in the PICES region

Drs. James Overland (U.S.A.) and Vladimir Kattsov (Russia) reported on the IPCC climate change scenarios arising from the 4th Assessment Report. A major conclusion from Session I was that most model projections involve large natural variability (including decadal variability) as well as persistent trends from anthropogenic climate change. These effects are expected to include persistent trends, shifts in the timing of seasonal events, such as the spring transition, and an increased frequency of extreme events, such as the number of warm or cold days. From a spatial perspective, models differ markedly in the intensity of change across the North Pacific and its adjacent seas. Session leaders noted that the major challenge facing climatologists is to assess whether models give a reasonable representation of the large-scale response of the Pacific to anthropogenic greenhouse gas and aerosol emissions, relative to natural variability. Some progress on this issue was anticipated by the POC/CFAME workshop that was held during the PICES 2007 Annual Meeting, where climatologists were encouraged to exchange ideas on techniques to link the IPCC climate change scenarios with oceanographic change scenarios of the North Pacific.

Session II. What are the expected impacts of climate change on regional oceanography and what are some scenarios for these drivers for the next 10 years?

Dr. Nathan Mantua (U.S.A.), who led the discussion for this session, noted that the IPCC scenarios exhibit a wide range of possible outcomes (Fig. 1.2) associated with different assumptions regarding emissions build-up and climate sensitivity to a given change in emissions (geophysics). The oceanographic response to climate change is also uncertain and can give potentially conflicting results (Snyder *et al.*, 2003). It was also recognized that trends in ocean conditions at the regional scale may not be easy to detect in the next few decades because shorter-term variations can mask them. The group discussed the possibility that different techniques may be needed to forecast ocean responses over the near-term period of 0–10 years and the longer-term period of 10–30 years. Participants were reminded that the PPFCC effort is challenging because operational climate forecasts at lead times greater than one year are simply not available at this time. In the U.S., only a few major centers routinely offer climate forecasts, and these centers (NCEP/CPC, IRI, ECMWF, *etc*.) only project climate conditions from one to four seasons into the future. There have been a handful of research studies that highlight the potential for making skillful multi-year forecasts for aspects of Pacific climate, most notably predictions for sea surface temperature (SST) variations in the Kuroshio Extension region (Schneider and Miller, 2001; Seager *et al.*, 2001).

Dr. Nicholas Bond (U.S.A.) provided an example of how an IPCC scenario can be tied to a quantitative scenario for rock sole production in the Bering Sea. He used IPCC scenarios to estimate cross-shelf transport in the Bering Sea, and described how this index could be incorporated into a spawner-recruit relationship for rock sole to predict future run strength of this species in the Bering Sea.

The major recommendations from this session were as follows:

- Oceanographers and climatologists need to be encouraged to exchange ideas on techniques for evaluating oceanographic responses to climate change.
- Oceanographers need to be made aware of detailed information on physical or bio-physical drivers that can be used to make projections of future fish distribution or production, particularly if there are critical environmental thresholds that govern competition for prey, predation or advection to suitable habitats.
- Fisheries biologists were encouraged to provide detailed information on the physical or bio-physical drivers or environmental thresholds that are needed to make a projection by the 2007 PICES Annual Meeting (*e.g.*, Table 1.2).

Session III. Recruitment forecasting

Dr. Richard Beamish (Canada) led the discussion during this session. Several participants provided examples of the influence of climate on local oceanography and fish production. Dr. Xianshi Jin (China) presented evidence that decadal changes in climate conditions may have influenced the fecundity of northern anchovy. He also demonstrated important regional differences in the production of small yellow croaker. Time trends in the annual catch of small yellow croaker and largehead hairtail in the Yellow Sea show a marked increase in abundance since 2000. Dr. Kazuaki Tadokoro (Japan) provided evidence that decadal shifts in the location of the transition between the Oyashio Current and the Kuroshio Current may influence the salinity and mixed layer depth which is strongly correlated to the production of the copepod *Neocalanus plumchrus*. Dr. Vladimir Radchenko (Russia) presented some recent work by Dr. Gennady Kantakov (Sakhalin Research Institute of Fisheries and Oceanography) which showed how climate linkages influence circulation patterns in the Sea of Okhotsk. The resulting changes may alter the distribution and survival of juvenile salmon in the region. Ms. Teresa A'mar (U.S.A.) described a technique for forecasting Gulf of Alaska walleye pollock. Her projection incorporated environmental forcing on recruitment by modifying the mean age–1 abundance with environmental factors that had been previously linked to recruitment.

There was insufficient time for participants to deal with recruitment mechanisms for all species, but from the limited discussion it was clear that understanding of the mechanisms that affect recruitment ranges from poor to good. Dr. Suam Kim (Korea) noted that retrospective studies have shown that environmental forcing accounts for a significant fraction of the variance in recruitment, and some improvement could be made by directed research on mechanisms.

Participants were encouraged to examine the species listed in Table 1.1 to assess the current state of knowledge regarding mechanisms linking climate forcing and fish production, and the uncertainty associated with these mechanisms (see Table 1.2 for an example; however, requests for output by latitude, longitude, and month were preferred). A few participants noted that some fraction of the recruitment of managed species may be random so there may be a threshold to predictability. Different views were also expressed on what percentage of explained variability constitutes a "good" forecast. One useful exercise would be for scientists across the Pacific Rim to report on the amount of variance explained in existing studies in order to determine if there is a common level of random variance associated with models of environmental links to recruitment.

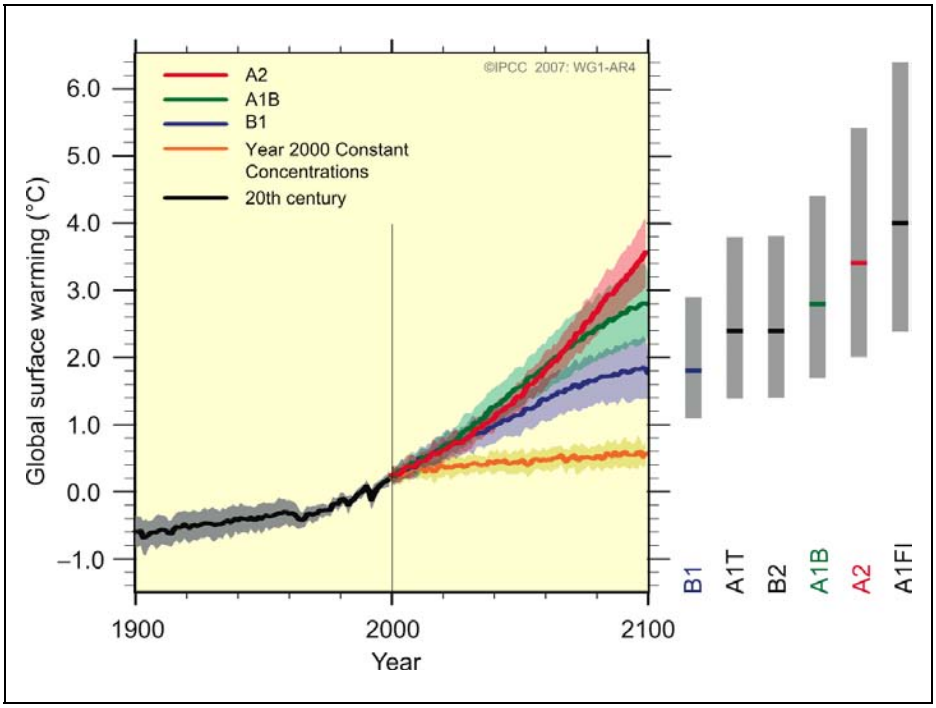

Fig. 1.2 Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the Atmosphere–Ocean Global Climate Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. (Reprinted from http://www.ipcc.ch/graphics/ gr-ar4-wg1.htm).[1]

[1] Note that the IPCC did not make anthropogenic carbon emission forecasts. Instead, they developed a suite of future greenhouse gas and sulfate aerosol emissions scenarios, each of which is based on a story-line that includes scenarios for economic development, international cooperation, and technological change. These are termed "scenarios" because it is accepted that the political, socio-economic, and technological factors required for making true "greenhouse gas emissions forecasts" are essentially unknowable.

Table 1.1 Preliminary list of species across regions showing opportunities for comparative studies.

Taxon		Region							
Common name	**Scientific name**	**U.S.A. WC**	**Canada**	**U.S.A. GOA**	**U.S.A. BSAI**	**Japan K-O**	**Japan/East Sea**	**Russia**	**Yellow Sea/ East China Sea TWC**
Walleye pollock	*Theragra chalcogramma*	–	X	X	X	X	X	X	–
Pacific cod	*Gadus macrocephalus*	–	X	X	X	–	–	X	–
Pacific hake	*Merluccius productus*	X	X	–	–	–	–	–	–
Pacific halibut	*Hippoglossus stenolepis*	X	X	X	X	–	–	X	–
Arrowtooth flounder	*Atheresthes stomias*	X	–	X	X	–	–	X	–
Northern rock sole	*Lepidopsetta polyxystra*	–	–	–	X	–	–	–	–
Sablefish	*Anoplopoma fimbria*	X	X	X	X	–	–	–	–
Rockfishes (POP)	*Sebastes* spp.	X	X	X	X	–	–	–	–
Pacific herring	*Clupea pallasi*	–	X	X	X	X	X	X	–
Sardine	*Sardinops sagax, S. melanostictus*	X	–	–	–	X	X	X	–
Anchovy	*Engraulis japonicus, E. mordax*	X	–	–	–	X	X	–	X
Chub mackerel	*Scomber japnicus*	X	–	–	–	X	X	–	X
Jack mackerel	*Trachurus japonicus*	X	–	–	–	X	X	–	X
Pacific saury	*Cololabis saira*	–	–	–	–	X	X	–	–
Yellow croaker	*Pseudosciaena polyactis*	–	–	–	–	–	–	–	X
Largehead hairtail	*Trichiurus lepturus*	–	–	–	–	–	–	–	X
Saffron cod	*Eleginus gracilis*	–	–	–	–	–	X	–	–
Pink salmon	*Oncorhynchus gorbuscha*	–	X	X	X	–	X	X	–
Chum salmon	*O. keta*	–	X	X	X	X	X	X	–
Sockeye salmon	*O. nerka*	–	X	X	X	–	–	X	–
Chinook salmon	*O. tshawytscha*	X	X	X	X	–	–	–	–
Coho salmon	*O. kisutch*	X	X	X	–	–	–	–	–
Common squid	*Todarodes pacificus*	–	–	–	–	X	X	–	X
Market squid	*Loligo opalescens*	X	–	–	–	–	–	–	–
Ocean shrimp	*Pandalus jordani*	X	X	X	–	–	–	–	–
Red king crab	*Paralithodes camtschaticus*	–	–	–	X	–	–	–	–
Tanner crab	*Chionoecetes bairdi*	–	–	–	X	–	–	–	–
Snow crab	*Chionoecetes opilio*	–	–	–	X	–	–	–	–

WC – West Coast, GOA – Gulf of Alaska, BSAI – Bering Sea/Aleutian Islands, K-O – Kuroshio–Oyashio, TWC – Tsushima Warm Current, POP – Pacific ocean perch

Table 1.2 Example of a mechanism/climate/production table for Bering Sea salmon stocks.

Index	Mechanism	Season	Citation
Spring temperature, out-migration timing, timing of spring bloom	Ice breakup affects timing of out-migration	Spring	Rogers (1988); Burgner (1991); Shotwell *et al.* (2006)
Timing of spring bloom, apparent growth effect	Match/mismatch; Critical period	Spring	Cushing (1972); Beamish and Mahnken (2001); Mackas *et al.* (2001)
Temperature effect on predation, diet composition and spatial distribution of predators, including young-of-the-year pollock recruitment.	Alternative prey for predators and daily ration for predators	Spring – Summer	Pearcy (1992); Farley *et al.* (2007)
Timing of spring transition	Match/mismatch; Critical period	Spring– Summer	Logerwell *et al.* (2003); Peterson and Schwing (2003)
Prey availability for post-smolts, zooplankton abundance and composition	Growth, foraging success	Summer	Cushing (1972); Willette *et al.* (1997); Cooney (1993); Beamish and Mahnken (2001); Peterson and Schwing (2003)
Oceanic habitat volume–mixed layer depth and fronts	Competition for prey – partitioning predators and prey	Summer	Coachman (1986); McRoy *et al.* (1986)
Euphausiid abundance	Reduced predation risk when alternative prey abundant – high prey availability leads to accelerated growth; critical size	Summer	Cooney (1993); Willette *et al.* (1997); Beamish and Mahnken (2001)
Diet composition of predators, abundance of predators	Predation	Summer – Fall	Pearcy (1992)
Winter survival	Critical size/critical period; winter survival of larvae and juveniles	Winter	Beamish and Mahnken (2001)

Session IV. What models are out there? How is climate linked to the model?

Dr. Michael Schirripa (U.S.A.) led this discussion and identified eight types of models:

1. PICES North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO): light intensity + SST;
2. PICES NEMURO.FISH: Input from NEMURO;
3. NOAA Fisheries SS2: Generalized framework;
4. Single Species Management Strategy Evaluations;
5. ATLANTIS: ROMS output, flow, SST, salinity;
6. Ecopath-Ecosim;
7. Multi-species forecasting models;
8. Modularized models as building blocks.

Dr. Yasuhiro Yamanaka (Japan) provided an overview of a collaborative research effort to couple a 3-D circulation model to NEMURO and a multi-species model that includes interactions between anchovy, saury and sardine. The sardine model includes migration estimated by an artificial network approach and a bio-energetic model to incorporate changes in growth of fish associated with local environmental conditions.

Dr. Bernard Megrey (U.S.A.) discussed the international research effort to develop common software to couple fish bio-energetics to NEMURO (NEMURO.FISH). Dr. Richard Methot (U.S.A.) provided examples where single species stock assessment models could be adapted to incorporate environmental forcing on recruitment, growth, or distribution of fish. This type of single species forecasting tool could be readily applied, and it was suggested that current forecasting tools could be shared among nations.

Participants discussed the feasibility of utilizing NEMURO.FISH type models to develop forecasts. Japanese scientists reported that they have been working to embed bio-energetic models in regional climate–ocean models. U.S. participants noted that a NEMURO model had been linked to a salmon bio-energetics model to assess climate impacts on pink salmon in the sub-arctic Pacific. They pointed out that BEST recently provided funding to develop similar models for the Bering Sea. They also reported linking a Nutrient-Phytoplankton-Zooplankton (NPZ) model to a climate–ocean model for the California Current system (CCS) which could be used to assess climate impacts on small pelagic fishes in the CCS and in the Asian region. It was noted that the base model for the CCS is a 10-km grid model that may not adequately resolve coastal oceanography. U.S. scientists also remarked that applications of the ATLANTIS model have been attempted in the CCS. ATLANTIS provides a spatially explicit consideration of the amount of production as a function of temperature or other physical variables. In preparation for the October 2007 workshop, scientists were asked to be prepared to report on the types of forecasting models that are available, by species, to allow for an analysis of the opportunities for comparisons across regions.

It was recognized that for several species, proposed mechanisms underlying recruitment variability included measures of prey availability and the volume of suitable habitat. For volumetric estimates of habitat suitability, NEMURO.FISH type models with imbedded climate–ocean models would be preferred; however, environmental proxies could be used to estimate prey volume.

Participants discussed several techniques for using environmental proxies in forecasting models. Fisheries biologists were asked to create tables with detailed information on the required physical or biological variables (by latitude, longitude, and month) used to forecast processes underlying recruitment growth and distribution of fish stocks. This task was to be completed prior to the 2007 PICES Annual Meeting in Victoria. It was agreed that the tables would be distributed to oceanographers as soon as they were finished.

Session V. Assumptions regarding future fishing scenarios and enhancement activities

Dr. Anne Hollowed (U.S.A.) led this discussion. She acknowledged that developing scenarios to forecast future fishing mortality rates and impacts of marine enhancement activities will be important. The Management Strategy Evaluation modeling approach explicitly calls for this type of effort. To stimulate discussion, members from each nation were asked their opinion on the:

- future demand for fish and shellfish,
- expected trends in management of marine resources,
- future of fisheries enhancement activities,
- implications of increased fuel prices on the choice of target species by fisheries.

There was insufficient time for a thorough discussion of this issue. However, the need for a serious treatment of these factors in models was highlighted. The following is a brief summary of the responses.

Canada

- A modest increase in demand is expected, driven mostly by world markets. Eco-labelling is a new trend and poses a threat to the demand of some fisheries.
- There will be a trend toward science that supports ecosystem-based management, objectives-based fishery management plans (more precautionary), new “ocean to plate” (economics, eco-labelling) initiative.
- Substantial changes will take place for salmon management, including reduced commercial harvests by non-indigenous fishermen in most areas. The remaining fisheries will shift to quota management. Fisheries are curtailed by the Species at Risk Act (SARA).
- Hatcheries will not be expanding. However, there will be some expansion of ocean ranching, but not in large areas. Fish farming in British Columbia will continue to expand, but probably slowly in the first 10 years.
- No big changes in groundfish management are expected. There will be some interest in groundfish fish farming and enhancement. SARA constrains some groundfish fisheries.

- Active shellfish mariculture and enhancement programs (*e.g.*, geoduck, abalone) are taking place.
- There is a need for more conservative catch quotas for Pacific hake in the U.S. (shared stock with Canada).

China

- The demand for seafood is expected to increase.
- Aquaculture production has been higher than ocean capture fisheries, and it is likely that aquaculture programs will expand.
- Fleet reduction (buy-back) programs will reduce the fishery effort and will provide fishermen training for alternative employment.
- Enhancement programs have been used for more than 20 years to rebuild fish, shrimp, shellfish, and jellyfish populations. These programs will continue or expand.
- A ban on fishing during summer months, used to manage fisheries since 1995, will continue.

Japan

- There will be a decrease in demand (consumption per person) for seafood as diets shift to other meats, except that the demand for high-grade species, like tuna, is increasing.
- No big changes in management are expected for the next 10 years.
- Stock rebuilding for salmon is taking place, and hatcheries are releasing larvae of coastal fishes like flatfish, shellfish and others.
- Fish farming is important, particularly in the northern part of Japan.

Korea

- Fisheries demand is increasing.
- Rebuilding plans have been implemented for blue crab and some other species.
- Salmon enhancement programs will be developed.
- Managers will adopt a more precautionary approach to resources, including bycatch reduction.
- The current open access to the fishery system may be replaced by a license limitation and quota system over the long term. A new fishery management act may be passed by the government this year.

Russia

- Demand is growing. The Russian Far East exports to Japan and is exploring markets in Korea, China and other Asian countries. A large increase in domestic demand could be realized if transportation systems are improved.
- New fishery rules are established for all areas. There are some new restrictions on the crab fishery and some revision to the quota system. There is a plan to establish total allowable catches for all fished stocks. Changes are likely, perhaps with a shift in focus to the most commercially important fisheries.
- Enhancement programs for salmon are likely to continue or expand, with a focus on the Sakhalin–Kuril Islands region where 24 new hatcheries will be built. Enhancement is also done in some areas for clams and sea cucumbers.
- Fuel is an issue for Russian fisheries. It constrains current fisheries to the Exclusive Economic Zone.
- In the Russian Far East, oil and gas extraction on the shelf is being developed in the Sakhalin region. Further development of oil and gas in the Kamtchatka region may cause conflicts in this important fishery region.

U.S. Alaskan coast

- Market demand for Alaskan fish and shellfish is likely to continue to increase in Alaska. New markets for Arctic fish species may develop as access to new fishing grounds is improved by loss of sea ice.
- Fisheries management strategies will continue to employ the precautionary approach and multi-species management through target species and limit reference points. New constraints associated with the adoption of these measures are designed to sustain non-target species.
- Fish hatcheries are used for salmon in the Gulf of Alaska. It is unlikely that they will expand in Alaska in the near term. However, in the long term this approach may be considered. It is likely that efforts to rebuild Alaskan crab stocks will intensify in the next decade due to the combined interest of the fishing industry and the conservation community.
- Increases in fuel prices will have a great impact on Alaskan fisheries where many fishing grounds are located in remote regions.
- Several regions of the Bering Sea, Aleutian Islands and Gulf of Alaska have already been set aside as marine protected areas or marine reserves. The most recent action by the North Pacific Fishery Management Council to close the northern regions

of the Bering Sea to commercial trawling is likely to curtail (but not prohibit) expansion to the north.

U.S. West Coast

- International markets are increasing, so demand will be driven by markets in the Far East. The demand for some products are increasing in China, but decreasing in Japan. Local markets are expected to increase.
- Management changes are similar to Alaska because they are driven at the national level.
- Fishing opportunities are constrained for rockfish owing to strict rebuilding plans. Some overfished stocks may take 50 years to recover. Bycatch will constrain future fisheries.
- Enhancement will not be important, except for salmon.
- Fuel and other considerations are similar to Alaska.
- Incorporation of ecosystem-based management is increasing.
- There is a national initiative to develop offshore aquaculture, but there is some resistance in certain areas, particularly Alaska. It is uncertain if this will develop.

Workshop participants agreed that temporal trends in anthropogenic activities should be included in the forecast. At a minimum, this information should include scenarios regarding expected levels of fishing mortality. Fisheries enhancement efforts are likely to expand, which may mask the impact of climate on survival during the early life history period. The impact of fishery enhancement could be modeled by changing the expected mean recruitment, by changing the carrying capacity of the system, or both. A useful suggestion was that each nation should prepare a document describing the future of fisheries management in 10–20 years.

Session VI. Where do we go from here?

It was decided to continue with a multi-national interdisciplinary research team approach that includes representatives from each PICES member country, as well as a broad spectrum of experts in climatology, oceanography, fisheries biology and modeling. For some nations, experts have to be identified to join the research effort. Participants recognized the need for discussions within disciplines to resolve technical issues, and it was decided that some of these issues could be resolved through e-mail prior to the 2007 PICES Annual Meeting. It was also noted that Asian scientists could discuss some of these issues at the 3rd Japan/China/Korea GLOBEC symposium scheduled for December 2007, in Hokkaido, Japan.

The list of target species was reviewed and several were dropped from the list developed in October 2006. After careful deliberation, 28 species were selected for further consideration (Table 1.1). Participants also reviewed the regional partitions proposed in October 2006, but no change was recommended.

Participants agreed to project implications of climate change at 10- and 30-year time horizons. To ensure that the forthcoming PICES Scientific Report adequately represents the opinions of participants, each scientist was requested to write a short statement describing the feasibility of implementing a program like PPFCC and the feasibility of completing the forecasts within the next 2–3 years.

References

Beamish, R.J. and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Prog. Oceanogr.* **49**: 423–438.

Burgner, R.L. 1991. Life history of sockeye salmon (*Onchorhynchus nerka*). pp. 3–117, *in* Pacific Salmon Life Histories, *edited by* C. Groot, and L. Margolis, UBC Press, Vancouver.

Coachman, L.K. 1986. Circulation, water masses, and fluxes on the southeastern Bering Sea shelf. *Cont. Shelf Res.* **5**: 23–108.

Cooney, R.T. 1993. A theoretical evaluation of the carrying capacity of Prince William Sound, Alaska, for juvenile Pacific salmon. *Fish. Res.* **18**: 77–87.

Cushing, D.H. 1972. The production cycle and the numbers of marine fish. *Symp. Zoo. Soc. Lond.* **29**: 213–232.

Farley, E., Murphy, J., Adkison, M., Eisner, L. 2007. Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea shelf. *J. Fish Biol.* **71**: 1145–1158.

Logerwell, E.A, Mantua, N., Lawson, P.W., Francis, R.C. and Agostini, V.N. 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. *Fish. Oceanogr.* **12**: 554–568.

Mackas, D., Thomson, R., Galbraith, M. 2001. Changes in the zooplankton community of the British Columbia continental margin, 1984–1999, and their covariation with oceanographic conditions. *Can. J. Fish. Aquat. Sci.* **58**: 685–702.

McRoy, C.P., Hood, D.W., Coachman, L.K., Walsh, J.J. and Goering, J.J. 1986. Processes and resources of the Bering Sea shelf (PROBES): The development and accomplishments of the project. *Cont. Shelf Res.* **5**: 5–22.

Pearcy, W.G. 1992. Ocean Ecology of North Pacific Salmonids. Books in Recruitment Fishery Oceanography. Washington Sea Grant Program, University of Washington, Seattle, 176 pp.

Peterson, W.T. and Schwing, F.B. 2003. A new climate regime in northeast Pacific ecosystems. *Geophys. Res. Lett*. **30**: 1896, doi:10.1029/2003GL017528

Rogers, D.E. 1988. Bristol Bay smolt migrations: timing and size composition and the effects on distribution and survival at sea. pp. 87–101 *in* Salmon Production, Management, and Allocation, *edited by* W.J. McNeil, Oregon State University Press, Corvallis, OR.

Schneider, N. and Miller, A.J. 2001. Predicting western North Pacific Ocean climate. *J. Climate* **14**: 3997–4002.

Seager, R., Kushnir, Y., Naik, N.H., Cane M.A. and Miller, J. 2001. Wind-driven shifts in the latitude of the Kuroshio-Oyashio Extension and generation of SST anomalies on decadal time scales. *J. Climate* **14**: 4249–4265.

Shotwell, S.K., Adkison, M.D. and Hanselman, D.H. 2006. Accounting for climate variability in forecasting Pacific salmon in data – limited situations. pp. 871–900, *in* Fisheries Assessment and Management in Data Limited Situations, *edited by* G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, and D. Woodby, Alaska Sea Grant College Program, AK-SG-05-02, 958 pp.

Snyder, M.A., Sloan, L.C., Diffenbaugh, N.S. and Bell, J.L. 2003. Future climate change and upwelling in the California Current. *Geophys. Res. Lett.* **30**: 1823.

Willette, M., Sturdevant, M. and Jewett, S. 1997. Prey resource partitioning among several species of forage fishes in Prince William Sound, Alaska. pp. 11–29, *in* Forage Fishes in Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems, Alaska Sea Grant College Program Report No. 97-01, University of Alaska Fairbanks, AK.

Appendix 1.1

List of Participants

Seattle, Washington, U.S.A.
July 19–20, 2007

CANADA

Richard J. Beamish
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC, V9T 6N7
Canada
Richard.Beamish@dfo-mpo.gc.ca
Stock assessment

Brian Riddell
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC, V9T 6N7
Canada
Brian.E.Riddell@dfo-mpo.gc.ca
Stock assessment

Donald Noakes
Thompson Rivers University
Main Campus Box 3010
900 McGill Road
Kamloops, BC, V2C 5N3
Canada
dnoakes@tru.ca
Statistics

Richard E. Thomson
Fisheries and Oceans Canada
Institute of Ocean Sciences
P.O. Box 6000
Sidney, BC, V8l 4B2
Canada
Richard.Thomson@dfo-mpo.gc.ca
Oceanography

JAPAN

Kazuaki Tadokoro
Tohoku National Fisheries Research Institute
Fisheries Research Agency
3-27-5 Shinhama-cho
Shiogama, Miyagi 985-0001
Japan
den@affrc.go.jp
Lower trophic level response

Yasuhiro Yamanaka
Hokkaido University
N10W5, Kita-ku
Sapporo, Hokkaido 060-0810
Japan
galapen@ees.hokudai.ac.jp
Coupled models

PEOPLE’S REPUBLIC OF CHINA

Xianshi Jin
Yellow Sea Fisheries Research Institute, CAFS
106 Nanjing Road
Qingdao, Shandong 266071
People’s Republic of China
jin@ysfri.ac.cn
Fisheries science

Hao Wei
Ocean University of China
5 Yushan Road
Qingdao, Shandong 266003
weihao@ouc.edu.cn
People’s Republic of China
Climate modeling/dynamics

Republic of Korea

In-Sook Heo
Republic of Korea
currently at:
Daniel J. Evans School of Public Affairs
University of Washington
Seattle, WA 98195
U.S.A.
heioi@u.washington.edu
Policy

Sukyung Kang
National Fisheries Research and Development Institute
408-1 Sirang-ri, Gijang-eup, Gijang-gun
Busan 215-821
Republic of Korea
kangsk@nfrdi.go.kr
Fisheries oceanography/Salmon ecology

Suam Kim
Pukyong National University
559-1 Daeyeon-3-dong, Nam-gu
Busan 608-737
Republic of Korea
suamkim@pknu.ac.kr
Oceanography

Sung-Tae Kim
National Fisheries Research and Development Institute
408-1 Shirang-ri, Gijang-eup, Gijang-gun
Busan 619-902
Republic of Korea
kste1362@nfrdi.go.kr
Stock assessment

Jae Bong Lee
National Fisheries Research and Development Institute
408-1 Sirang-ri, Gijang-eup, Gijang-gun
Busan 619-905
Republic of Korea
leejb@nfrdi.go.kr
Stock assessment

Chang-Ik Zhang
Pukyong National University
559-1 Daeyeon-3-dong, Nam-gu
Busan 608-737
Republic of Korea
cizhang@pknu.ac.kr
Ecosystem models

Russia

Vladimir M. Kattsov
Voeikov Main Geophysical Observatory
7 Karbyshev Street
St. Petersburg 194021
Russia
kattsov@main.mgo.rssi.ru
Climatology

Vladimir I. Radchenko
Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO)
196 Komsomolskaya Street
Yuzhno-Sakhalinsk 693023
Russia
vlrad@sakhniro.ru
Stock assessment

U.S.A.

Z. Teresa A’mar
University of Washington
Box 355020
SAFS
Seattle, WA 98195-5020
U.S.A.
zta@u.washington.edu
GOA AK, Stock assessment models

Kerim Y. Aydin
Alaska Fisheries Science Center
NMFS, NOAA
7600 Sand Point Way NE
Seattle, WA 98115-0070
U.S.A.
Kerim.Aydin@noaa.gov
BSAI AK, Ecosystem models

Nicholas A. Bond
NOAA/PMEL, JISAO
7600 Sand Point Way, NE
Seattle, WA 98115-6349
U.S.A.
Nicholas.Bond@noaa.gov
AK, Climatology/Oceanography

Martin Dorn
Alaska Fisheries Science Center
NMFS, NOAA
7600 Sand Point Way NE
Seattle WA 98115
U.S.A.
Martin.Dorn@noaa.gov
GOA AK, Stock assessment models

Carrie Eischens
North Pacific Research Board
1007 West Third Avenue, Suite 100
Anchorage, AK 99501
U.S.A.
carrie.eischens@nprb.org
Ecology

Melissa Haltuch
Northwest Fisheries Science Center
NMFS, NOAA
2725 Montlake Boulevard E
Seattle, WA 98112
U.S.A.
mhaltuch@u.washington.edu
Stock assessment

Christopher J. Harvey
Northwest Fisheries Science Center
NMFS, NOAA
2725 Montlake Boulevard E
Seattle, WA 98112
U.S.A.
Chris.Harvey@noaa.gov
North CC, Ecosystem models

Alan Haynie
Alaska Fisheries Science Center
NOAA
7600 Sand Point Way NE
Seattle, WA 98115
U.S.A.
Alan.Haynie@noaa.gov
Economics

Albert J. Hermann
Joint Institute for the Study of the Atmosphere and Ocean, PMEL
7600 Sand Point Way NE
Seattle, WA 98115
U.S.A.
Albert.J.Hermann@noaa.gov
CC and AK, Circulation models

Anne B. Hollowed
Alaska Fisheries Science Center
NMFS, NOAA
7600 Sand Point Way NE
Seattle, WA 98115-6349
U.S.A.
Anne.Hollowed@noaa.gov
AK, Stock assessment models

Gordon H. Kruse
University of Alaska Fairbanks
11120 Glacier Highway
Juneau, AK 99801-8677
U.S.A.
Gordon.Kruse@uaf.edu
BSAI AK, Stock assessment models

Nathan J. Mantua
University of Washington
Box 55020
Seattle, WA 98195-5020
U.S.A.
nmantua@u.washington.edu
North CC, Climatology/Oceanography

Bernard A. Megrey
Alaska Fisheries Science Center
NOAA
7600 Sand Point Way NE
Seattle, WA 98115-6349
U.S.A.
Bern.Megrey@noaa.gov
GOA AK, Stock assessment models

Richard Methot
Northwest Fisheries Science Center
NMFS, NOAA
2725 Montlake Boulevard E
Seattle, WA 98112
U.S.A.
Richard.Methot@noaa.gov
Stock assessment models

Sam McClatchie
Southwest Fisheries Science Center NOAA
8604 La Jolla Shores Drive
La Jolla, CA 92037-1508
U.S.A.
Sam.McClatchie@noaa.gov
South CC, Fisheries oceanography

James E. Overland
Alaska Fisheries Science Center
NMFS, NOAA
7600 Sand Point Way NE
Seattle, WA 98115-6349
U.S.A.
James.E.Overland@noaa.gov
AK, Climatology

Clarence Pautzke
North Pacific Research Board
1107 W 3rd Avenue, Suite 100
Anchorage, AK 99501
U.S.A.
cpautzke@nprb.org
AK, Fisheries management

Michael J. Schirripa
Northwest Fisheries Science Center
NMFS, NOAA
Hatfield Marine Science Center
2032 SE OSU Drive
Newport, OR 97365
U.S.A.
Michael.Schirripa@noaa.gov
North CC, Stock assessment models

Frank Schwing
NOAA Fisheries Environmental Laboratory
1352 Lighthouse Avenue
Pacific Grove, CA 93950
U.S.A.
Franklin.Schwing@noaa.gov
South CC, Oceanography

Phyllis J. Stabeno
NOAA/Pacific Marine Environmental Laboratory
7600 Sand Point Way NE
Seattle, WA 98115-0070
U.S.A.
Phyllis.Stabeno@noaa.gov
AK, Oceanography

William Stockhausen
Alaska Fisheries Science Center
NMFS, NOAA
7600 Sand Point Way NE
Seattle, WA 98115-0070
U.S.A.
William Stockhausen@noaa.gov
BSAI AK, Individual based models

Tom K. Wilderbuer
Alaska Fisheries Science Center
NOAA
7600 Sand Point Way NE
Seattle, WA 98115
tom.wilderbuer@noaa.gov
BSAI AK, Stock assessment models