INTRODUCTION

Project scope

The PICES Carrying Capacity and Climate Change (CCCC) BAsin Scale Studies (BASS) Task Team was established to facilitate studies of the impacts of climate change and climate variability on the physical and biological processes in the gyres of the western and eastern subarctic Pacific Ocean.

In general, the oceanography and ecology of the eastern (ESA) and western (WSA) basins of the subarctic Pacific (Fig. 1) are poorly understood relative to the coastal areas. It is known that the central subarctic Pacific is productive as indicated by the large abundance of Pacific salmon, squid and other important fishes. Recent studies also suggest that the oceanography of the gyres is closely linked to the decadal scale changes in climate. Therefore, it is important that there is a co-ordinated effort to focus on the priority research issues, and to exchange scientific information on a timely basis.

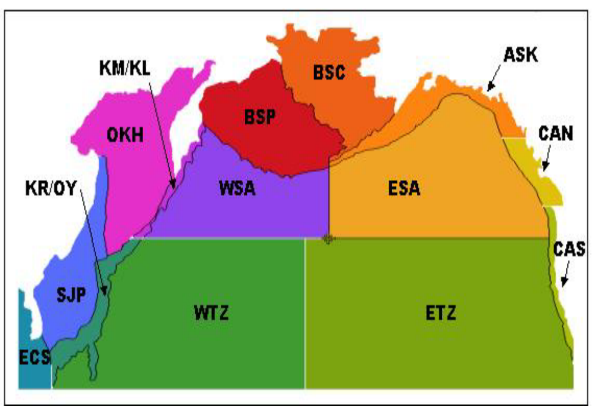

Fig. 1 Sub-regions in the PICES area (north of 30°N and including the marginal seas) of the N. Pacific Ocean. ASK - Gulf of Alaska Continental Shelf; BSC - Bering Sea Continental Shelf; BSP - Bering Sea Pelagic; CAN – California Current North; CAS – California Current South; ECS - East China Sea; ESA - Eastern Subarctic; ETZ - Eastern Tropical Zone; KM/KL - Kurile Islands Region; KR/OY - Kuroshio/Oyashio Region; OKH - Sea of Okhotsk; JP - Sea of Japan; WSA - Western Subarctic; WTZ - Western Tropical Zone.

At the PICES Sixth Annual Meeting, the BASS Task Team sponsored a symposium on the *Ecosystem dynamics of the Eastern and Western Gyres of the Subarctic Pacific*. The purpose was to bring together available information on the two gyres in a comparative framework. Topics included:

1. ocean responses to climate forcing,
2. nutrients and primary production,
3. structure of the lower trophic levels, the mesozooplankton communities, and the epipelagic nekton,
4. the role of midwater fishes, and
5. the importance of these areas to marine birds and mammals.

Papers presented at the meeting were published in a special issue (Beamish *et al.* 1999a) of *Progress in Oceanography* (Guest Editors: R.J. Beamish, S. Kim, M. Terazaki and W.S. Wooster).

A follow-up workshop was convened in Hakodate, Japan (October 2000), to identify potential models which might have utility for examining gyre systems (McFarlane *et al.* 2001). Trophodynamic linkages that were likely to be common, as well as those that were model-specific, were identified, and shortcomings were highlighted. Discussions included identifying data groups and potential data sources, incorporating climate and oceanographic change in models, and linking models of the oceanic gyre to models of coastal regions.

Participants recognized that modelling would play an increasingly prominent role in examining the dynamics of the gyres, and recommended the BASS and MODEL Task Teams examine the feasibility of using the ECOPATH/ECOSIM modelling approach as a means to organize our understanding of ecosystems of the subarctic gyres. Specific objectives were to: (a) synthesize all trophic level data in a common format, (b) examine trophic relations in both gyres using ECOPATH/ECOSIM, and (c) examine methods of incorporating the PICES NEMURO lower trophic level model into the analysis.

Three workshops followed in Honolulu, U.S.A. (March 2001), then Victoria, Canada (October 2001), and finally in La Paz, Mexico (April 2002), where the ECOPATH/ECOSIM baseline models were developed, linked to the NEMURO model, and a number of hypotheses tested (see Appendices C to F for workshop reports).

The purpose of this approach was to provide a "picture" of the two subarctic gyres, and to facilitate our understanding of how these systems respond to natural and anthropogenic change. This report presents our current understanding of the dynamics of these systems. Further, this report should serve as an outline for data availability and more critically, gaps in upper trophic level biological data as they affect our understanding of the function and variation in the subarctic gyres' food webs. Finally, it is hoped that the report will form the basis of future work to link the subarctic gyre system to coastal systems.

Climate change, carrying capacity and food web models of the subarctic Pacific Ocean

The subarctic Pacific consists of a major cyclonic gyre surrounded on the north by coastline and boundary currents, and on the south by the Subarctic Current, which isolates the gyres from subtropical waters. The main gyre is pinched at its longitudinal center by the Aleutian Islands, which causes re-circulation of its waters into two sub-gyres: the Western Subarctic and Eastern (Alaskan) Subarctic Gyres (Fig. 2). The two subarctic gyres are biologically distinct, supporting different species and production patterns from plankton through predatory marine mammals (Beamish 1999). As such, the two separate ecosystems are the primary subjects for comparison in this report.

The biological production, carrying capacity, and food webs of the Eastern and Western Gyres have been subjects of considerable speculation, especially given difficulty of access, and the relatively limited data collection performed in these high seas areas (Pearcy *et al.* 1999). This interest has been driven in part by the fact that the gyres are a "rearing and growth" area for Pacific salmon (*Oncorhynchus* spp.), and are therefore production areas for important commercial fisheries. Additionally, the link between climate and fisheries on decadal (regime shift) scales points to important ecosystem interactions occurring within the gyres and in synchrony with Pacific-wide events (*e.g.*, the Pacific Decadal Oscillation, Mantua *et al.* 1997).

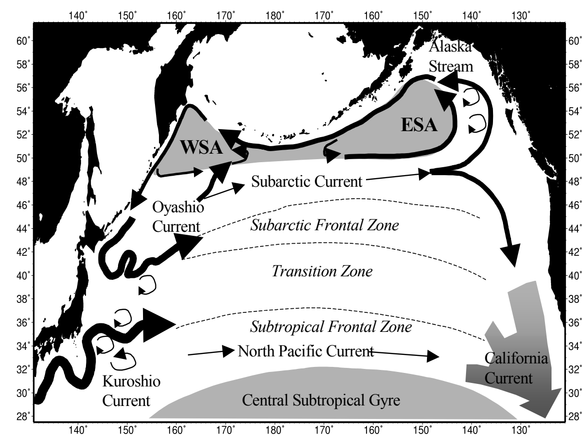

Fig. 2 Western and Eastern Subarctic Gyres (WSA and ESA, shaded gray areas), boundary currents (arrows), and subarctic/subtropical frontal zones (dotted lines). Oceanographic features are approximate and may change on interannual time scales.

Attempts to quantify the carrying capacity and/or maximum production rates of fish in the gyres have revealed a fundamental paradox. Calculations of zooplankton biomass and production, when compared to demands made by foraging salmon, the dominant fish, invariably indicated a surplus of available food. Models constructed in the 1970s (Favorite and Laevastu 1979) concluded that the North Pacific could sustain ten times the 1970s standing stock of salmon.

Yet during the 1980s and 1990s, when the system contained only twice the total salmon biomass examined by Favorite and Laevastu, salmon sizes declined (Bigler *et al*. 1996, Ishida *et al.* 1993, Ricker *et al.* 1995). Conservative production estimates, using observed 1980s and 1990s zooplankton and salmon biomass, indicate that adult salmon consume between 0.04% and 0.10% of available annual zooplankton production (Brodeur *et al.* 1999). Since salmon are a dominant pelagic nekton in the region, it seems at a first glance unlikely that this level of consumption would lead to competition for prey, and thus represent an ecosystem at its carrying capacity for salmon. However, as suggested by Pearcy *et al.* (1999), trophic and seasonal compression of salmon foraging opportunities may reveal more specific foraging limitations: calculations of the forage available for salmon and other large nekton in the gyres is re-examined here.

Further, it is clear that environmental forcing on multi-year scales, for example through the PDO and ENSO, affects the biology of higher trophic levels in these ecosystems and across the globe (Beamish 1993; Brodeur and Ware 1995; Hollowed *et al.* 1998; Francis *et al.* 1998; Beamish *et al.* 1999b). The effects of climate are not limited to the direct increase or decrease of the biomass of the entire system. Animals with longer-than-annual life histories integrate short term changes, and their biomass may not respond immediately to changes in ocean conditions. In order to move from correlative to mechanistic relationships linking climate and biology, it is necessary to construct models, either conceptual or quantitative, which account for appropriate time scales of interaction through the food web. Links may not be linear or direct, and scale is critical.

For example, the shoaling mixed layer is used by Polovina *et al.* (1995) to predict increases in zooplankton production based on the increased concentration of nutrients within the mixed layer. However, as Freeland *et al.* (1998) point out, while the mixed layer may concentrate nutrients during the spring growth of zooplankton, it may also limit resupply of nutrients later in the season. Thus, while the overall quantity of zooplankton production averaged annually may increase, the extent of the bloom throughout a season, and the resulting zooplankton community structure and transfer of energy to other portions of the food web, may increase for some species but decrease for others.

To examine such indirect and possibly unexpected interactions, food web models are a useful tool, and must be scaled to account for differences in rates across trophic levels on both seasonal and interannual scales. To accomplish this, multiple models should be examined in concert, with some models covering small or short scale dynamics (such as those associated with plankton dynamics), and some covering the annual scales of fisheries models. Finally, migration models linking gyres with coastal areas should be used to expand the view to examining synchronous changes that have been reported in marine populations across the widest possible area of the North Pacific.

Purposes of these models

The ECOPATH models presented here are based on the pooling of available data from both sides of the Pacific Ocean. Data from these ecosystems has been brought together and discussed in previous international workshop settings (Beamish *et al.* 1999a): the present work represents the first steps in an ongoing quantitative synthesis. These models provide a quantitative framework for cataloging these data and a guide for directing future data collection.

Various conceptual food web models of the gyres have been constructed (Sanger 1972; Pauly and Christensen 1996; Brodeur *et al.* 1999), usually with a combination of quantitative and qualitative data. These previous models have begun to address and assess the “carrying capacity” of the subarctic Pacific for many important species, especially Pacific salmon: this work is continued here.

More critically, in view of regime- or longer-term climatic change, and the acknowledged importance of links between climate and the production of Pacific salmon and other species, it is desirable to focus research priorities based on quantitative assessments of current notions of subarctic ecosystem sensitivities and interactions. Due to the difficulty of data collection in the open ocean, the ecological links with coastal ecosystems, and the necessity of strong international collaboration in future research of these ecosystems, it is useful to have a quantitative framework for pooling information.

ECOPATH, as a tool, is a relatively straightforward method for constructing a quantitative food web for the purposes of hypothesis exploration and data synthesis. The food webs created are similar to those created through other synthetic methods: the resulting models represent a "snapshot" of what is essentially a moving target, a changing ecosystem. By providing the snapshot as a step in continuing workshops and collaborations, we examine our view of the ecosystem's sensitivities to change as viewed and modeled through the data currently available. Moreover, we are able to use this framework as a guide to data synthesis, by providing foci for continued international collaboration and collective research.

By simultaneously presenting two models built on a similar framework for two different systems (Eastern and Western Gyres), we stress a comparative approach in examining the underlying biology and climate interactions: these comparisons are emphasized in the results of this work. This comparative approach is crucial to understanding the synchronous interactions (simultaneous species rises and collapses) reported in coastal and oceanic ecosystems throughout the world.

The dynamic simulations presented here using ECOSIM include attempts to fit or model changes in biomass as they might occur given certain types of physical forcing. In these models we attempt to take into account the dynamic nature of multiple pathways available in the food webs, and through the examination of simplified interannual patterns, to begin stretching from the correlative to the mechanistic relationship. Finally, we report on the first stages of linking a smaller-scale nutrient-phytoplankton-zooplankton model (NEMURO) with ECOSIM to partially bridge the gap between the seasonal production cycle and the longer time periods associated with regime shifts.