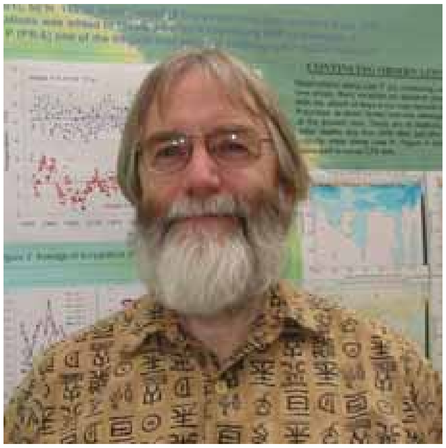
Recent trends in waters of the subarctic NE Pacific



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Frank A. Whitney has led the Line P program for the past 14 years, carrying out repeat oceanographic sections for WOCE (1991-97) and hosting the Canadian JGOFS program (1992-97) on these cruises. Through this time, his main research interest has been in understanding processes which control nutrient supply to the upper ocean. He has also surveyed meso-scale eddies several times in an attempt to estimate offshore transport of coastal waters in the Gulf of Alaska. Frank has been working in oceanography on the British Columbia coast since 1969.

Nutrient supply to the upper ocean

Several recent publications, when their results are combined, present a compelling argument for “bottom-up” controls on fish production (especially in non-migratory species) in the NE Pacific.

Ware and Thomson (*Science*, May 20, 2005) show strong correlations between annual chlorophyll concentrations, using satellite data, and long-term yield of resident fish in a region extending from southern California to the Aleutian Islands. Iverson (*Limnol. Oceanogr.* 35, 1990) had previously demonstrated a direct relationship between primary productivity (PP) and fish production (FP) over a broad range of world fisheries. One of his figures I have found enlightening, shows that there is essentially no FP when PP is less than ~50 g C m^{-2} y^{-1}; above this there is a linear correlation suggesting ~10% carbon transfer between phytoplankton and carnivorous fish/squid. Low PP regions tend to reprocess nutrients within small plankton, producing very little exportable production (*i.e.*, production available for higher trophic levels).

In the NE Pacific, the Ware and Thomson correlation between chlorophyll and fish catch reveals some surprising results. For example, they show that the most productive regions are at the north end of the upwelling domain in northern Washington and southern British Columbia (Fig. 1). They suggest that this is due to the broad shelf and additional nutrient inputs from rivers. Whitney *et al.* (*DSR II* 52, 2005) have reviewed nutrient supply to shelf regions in the NE Pacific and found that high nutrient supply in this region is also due to tidal mixing in Juan de Fuca Strait and onshore transport through canyons. Ware and Thomson identify rich fish yields in other tidally mixed areas on the British Columbia coast.

Another intriguing finding from the Ware and Thomson paper is that there appears to be an equally efficient transfer of energy from phytoplankton to fish in both the downwelling and upwelling domains. The higher yield where upwelling is weak may be due to a stronger off-shelf transport of PP where upwelling is strong.

Since I have been focusing much of my research on nutrient supply in open and coastal oceans, I extend the Ware and Thomson results to indicate a direct link between physical mixing processes that supply nutrients to the upper ocean (Table 1), and fish production. Recent publications arising from a PICES session in 2003 and the U.S. GLOBEC program provide new insights to nutrient transport in coastal waters of the NE Pacific (*e.g.*, Wheeler *et al.*, *GRL* 30, 2003; Stabeno *et al.*, *CSR* 24, 2004; Whitney *et al.*, *DSR II* 52, 2005; Childers *et al.*, *DSR II* 52, 2005; Ladd *et al.*, *DSR II* 52, 2005). Ware and Thomson identify the richest fisheries in regions where strong tidal mixing and estuarine circulation are coupled. Crawford and Dewey (*Atmosphere-Ocean* 27, 1989) showed that these mixing processes provided more nutrients to the southern British Columbia coast than either upwelling or coastal tidal mixing.

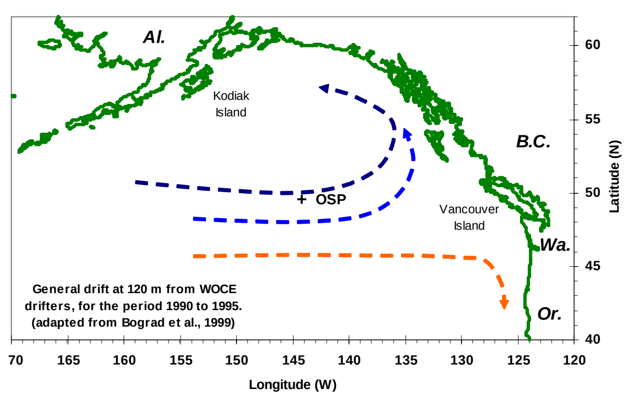

Fig. 1 *Map of the NE Pacific Ocean showing general flow in the Subarctic Current past Ocean Station Papa (OSP) to the coasts of Oregon (Or.), Washington (Wa.), British Columbia (B.C.) and Alaska (Al.).*

Table 1. Processes providing nutrients to the upper ocean in the NE Pacific.

Process	Region	Importance
Winter mixing	universal	Varies over region and interannually depending on wind intensity
Upwelling	South of ~51ºN	Summer event
Downwelling	North of ~51ºN	Relaxation during summer transports deep waters onto shelf
Rivers	N of ~46ºN	Silicate and iron additions
Tidal mixing	S BC, S Alaska	Nutrients from depth mixed to surface
Estuarine circulation	Coastal inlets and basins	Fresh water outflow draws nutrient rich waters into inlets and straits
Mesoscale eddies	N of ~52ºN	Exchange of nutrients and biota between coastal and open oceans
Bathymetric steering	Vicinity of Vancouver and Kodiak Islands	Directs coastal currents onshore through canyons
Summer winds	Alaska coast	Bursts of increased mixing, upwelling
Changes in subarctic circulation	Oregon coast	High nutrient, low oxygen waters upwelled onto the coast, resulting in hypoxia (fish and crab kills)

Winter conditions along Line P

Briefly, our February 2005 Line P survey [south British Columbia coast to Ocean Station Papa (OSP)] shows that surface waters stay warm compared with our 1956-1991 climatology (Fig. 2).

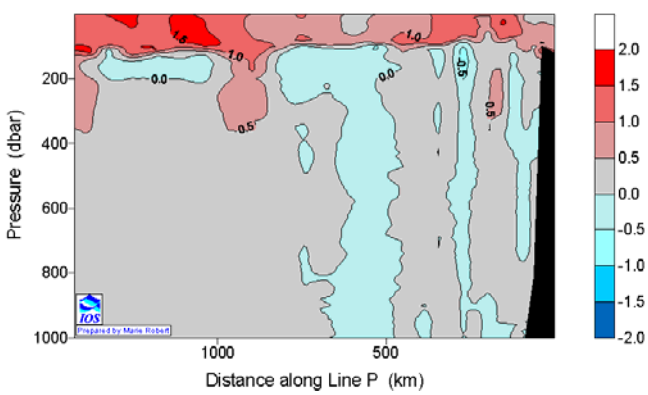

Fig. 2 Temperature anomalies along Line P in February 2005 (courtesy, M. Robert).

Even though the surface waters remained warm, the mixed layer depth at OSP deepened to ~110 m following 2 years of abnormally shallow winter mixed layer (<90 m). Mixed layer nitrate is typical for winter, concentrations lying between the minimum levels seen in 1998, and the highs observed in cool years (1989, 1999). However, silicate concentrations are lower than those measured in winter 1998, from about 500 to 1200 km along Line P. Silicate is a crucial nutrient for diatom growth and export production, and can become limiting in the subarctic NE Pacific when iron supply to the open ocean increases (Wong and Matear, *DSR II* 46, 1999; Whitney *et al.*, *DSR II* in press).

A reasonable prediction for the coming summer would be to see silicate limitation along much of Line P (not the coastal waters) and decreased particulate flux to the deep ocean. A more tentative prediction would be for coccolithophores to be more abundant than usual in spring or early summer. I base this speculation on the tendency of plankton along Line P to be either siliceous or carbonaceous.

(cont. from page 17)

Break-out groups were formed during the second day of the workshop to better facilitate in-depth discussions. Groups considered phytoplankton, water column physics and chemistry (including iron), microzooplankton and mesozooplankton. Each group developed scientific questions/hypotheses, and then discussed appropriate methods, measurements and time scales for studies. They considered how to accomplish comparisons and contrasts between the eastern and western gyre systems.

Discussions in Corvallis showed that interests of the eastern and western groups differ because the systems to be studied differ, not only in production dynamics but also in physical oceanography. Moreover, the groups will have different requirements for developing a consensus for support in their respective national oceanographic programs. Each group must work out the justifications for funding the necessary long cruises in its region and develop enthusiasm in rather different scientific cultures, while at the same time sustaining the comparability of measurements in the two OECOS areas. It was resolved to try to do that.

As organizers of the OECOS workshop, we want to thank the participants for coming and for their vigorous discussion of the oceanographic issues. We also thank PICES and OSU for the generous support that made it possible for us to meet and talk.