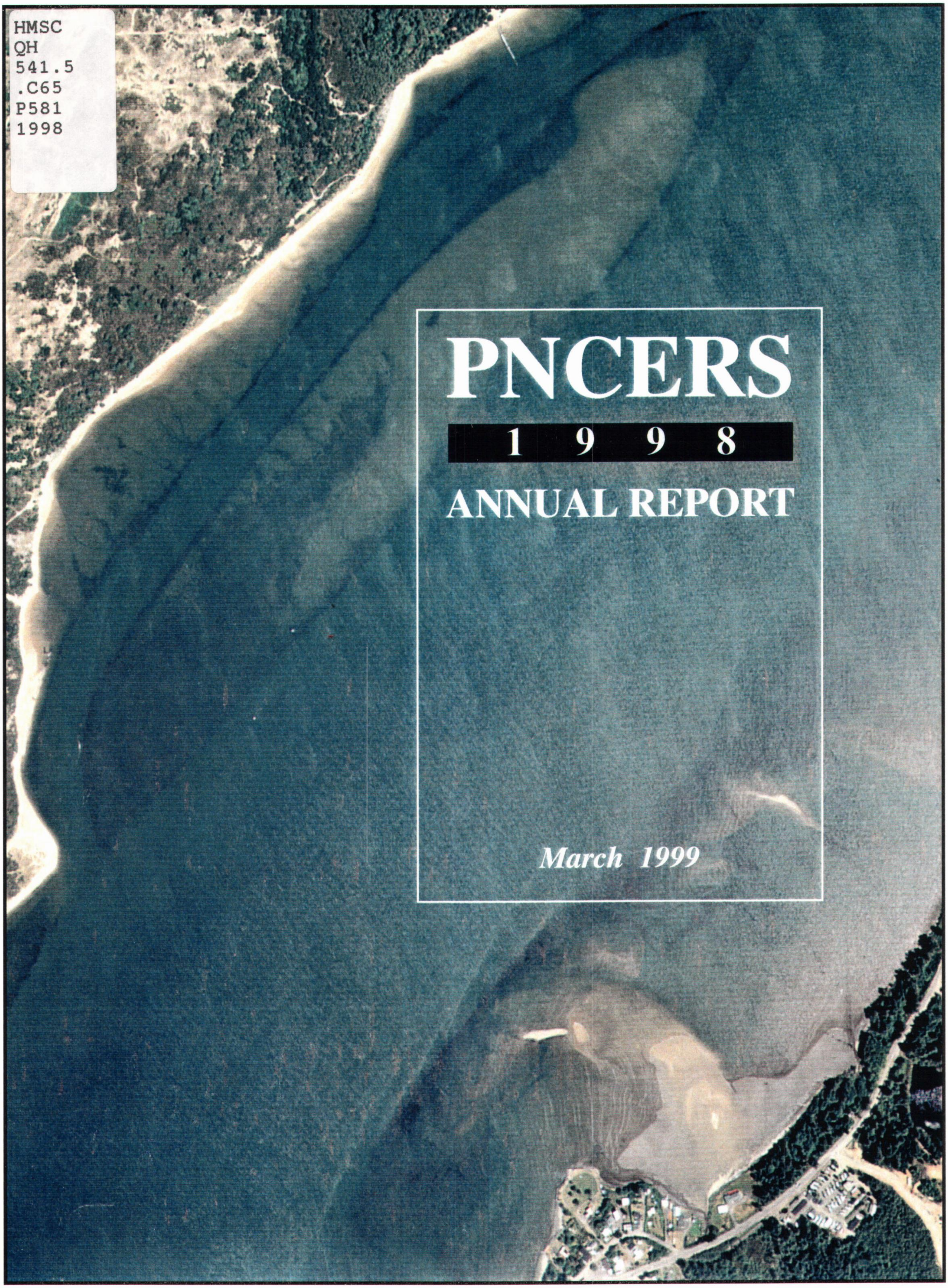
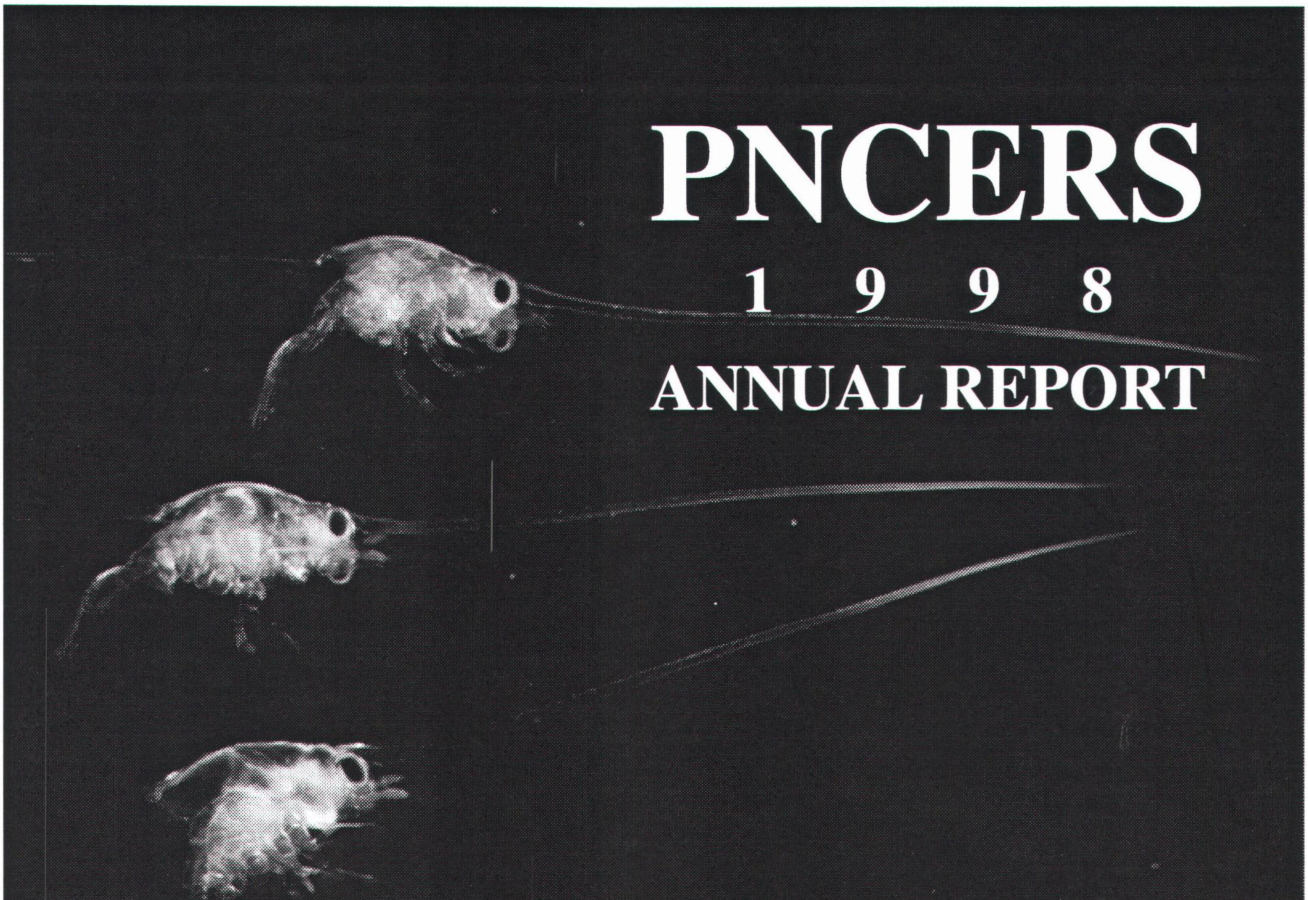


PNCERS

1998

ANNUAL REPORT

March 1999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Cover: Coos Bay, near location of PNCERS/Eelgrass study site at Fossil Point. 1997 BLM.
Title Page: *Petrolisthes cinctipes* zoeae, photographed at Bamfield, British Columbia in 1991. © Gregory C. Jensen.

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Group photo taken at the annual PNCERS All-Hands Meeting, held January 22-23, 1999, at the Washington Park Arboretum Visitors Center in Seattle, Washington.

Back row, left to right: Andy Bennett, Don Gunderson, Kristine Feldman, Andrea Copping, Jan Newton, Alan Shanks, Barbara Hickey, Curtis Roegner, Grace Tsai, Rebecca Johnson, Ron Thom, Amy Borde, Sue Banahan, Arni Magnusson, Michelle Pico, David Marmorek, Dan Huppert, Steve Rumrill, Tom Leschine, Ian Parnell, Kathleen Bell.
Front row, left to right: Sara Breslow, Julia Parrish, Robert Bailey, John Stein, Greg McMurray, Clint Alexander

Photo by Andy Bennett, 1999

SUMMARY OF RESEARCH

Executive Summary
Julia K. Parrish

The Pacific Northwest Coastal Ecosystems Regional Study (PNCERS) is a five year, multi-investigator, interdisciplinary approach to identifying the physical and human-mediating factors affecting the estuarine and nearshore ecosystems along the outer coast of Oregon and Washington. PNCERS has chosen to focus on five coastal estuaries: Willapa Bay and Gray's Harbor in Washington, and Tillamook Bay, Yaquina Bay, and Coos Bay in Oregon (Figure 1: Summary Map). In addition, several studies examine bio-physial interactions in the nearshore environment over the entire coastal region encompassed by Washington and Oregon (Figure 1). An overview of all projects' measurements, information sources, instruments used and target organisms is provided in the Summary Table, pages xi-xiv.

Rather than exhaustively inventory ecosystems, PNCERS has provisionally chosen to focus on several valuable ecosystem components (VEC's), relevant to both the continued ecosystem structure and function, as well as to commercial, recreation, and aesthetic values of the human community. VECs include Pacific salmon, Dungeness crab, Pacific oyster, and tourism. PNCERS seeks to develop a conceptual model of the physical factors important in determining the distribution, abundance, and survival of key ecosystem indicators, and the more pointed human impacts altering the system's ability to sustainably produce these indicators (Plates 1 and 2). Our approach is to investigate various aspects of the complex ecological and economic fabric affecting any one VEC with a set of semi-independent research projects which pass information across disciplinary boundaries (Plates 1 and 2).

In the first full research year of PNCERS, the research team has begun to create an integrated, interdisciplinary program simultaneously functioning on several levels. Each project, of which there are currently nine, has begun data collection and analysis.

In the nearshore environment, physcial oceanographic factors appear to have had a dramatic effect on a range of marine organisms, from upper trophic level species such as seabirds to larval Dungeness crab. Many species are also affected by regional and local forces such as storm events triggering a change in the seasonal pattern of upwelling and downwelling, the depth of the thermocline, and the tidal cycle. However, these bio-physical relationships are complex, often species specific, and occasionally anomalous. In general, we are finding that water movement and water properties are very significant forces affecting transport of larvae (including commercially important species such as Dungeness crab), coastal productivity, and presumably the future production of commercially of species such as salmon.

In the estuarine environment, physical forces also play a key role in determining the distribution and abundance of species. Unlike the nearshore, estuaries are more dynamic, subject to atmospheric heating and cooling, and remarkably concurrent in response to storm events inducing temperature change. Estuaries have also suffered dramatic changes in habitat availability over time, most often the loss of wetlands and marsh habitat as a consequence of increased agricultural use. In Willapa Bay, salt marsh has actually increased; however, this effect is a consequence of *Spartina* introduction to the system. Changes in habitat availability likely has dramatic consequences for total, and perhaps sustainable, production of VECs such as salmon, crab, and oysters, as there are distinct habitat-species linkages. Production of VECs such as crab is also a function of larger associations of habitat mosaics, or sectors. Identification of these sectors, in both the estuarine and nearshore environments, may lead to increased ability to determine how future habitat change will affect VEC production.

The human communities using these systems have also been changing over time. Economies based primarily on resource extraction (forestry and fisheries) have been changing to tourism and recreation. This change has been accompanied by an aging of the communities, as retirees move in and young people leave. VECs such as tourism are apt to become evermore important as this demographic trend continues.

Management of these systems is complex. There are a bewildering array of laws at the local, state, and federal level which direct use of land and water, indicate stewardship, regulate pollutants, and protect commercial uses such as navigation. Many communities appear to have little knowledge of the relationships between ecosystem change and the loss of system structure and function, and consequent downturns in the local economy.

In the next few years of PNCERS research, we will be expanding on our simple conceptual models (Plates 1 and 2) by testing sets of impact hypotheses represented by the arrows (see also Appendix B: All-Hands Meeting Report). In addition to further defining key physical and human-mediating

SUMMARY MAP

factors affecting ecosystem production, we will be attempting to determine how the human communities living in the system believe the system is working (or not), as a bridge to developing useful tools for future ecosystem management.

#	PROJECT TITLE
1	Coastal Ocean Coupling: A Physical Baseline for PNCERS
2	Demographic and Economic Trends: A Socioeconomic Baseline for PNCERS
3	Plankton Patchiness and Environmental Correlates
4	Seabirds as Reflectors of Environmental Change
5	Estuarine Bioindicators: Dungeness Crabs and English Sole
6	Links Between Estuaries: Larval Transport and Recruitment
7	Salmon Coded Wire Tag Current and Retrospective Analysis
8	Mapping Estuarine Habitat
9	Assessing Existing Decision Processes: Institutional Mapping and Ecosystem Management

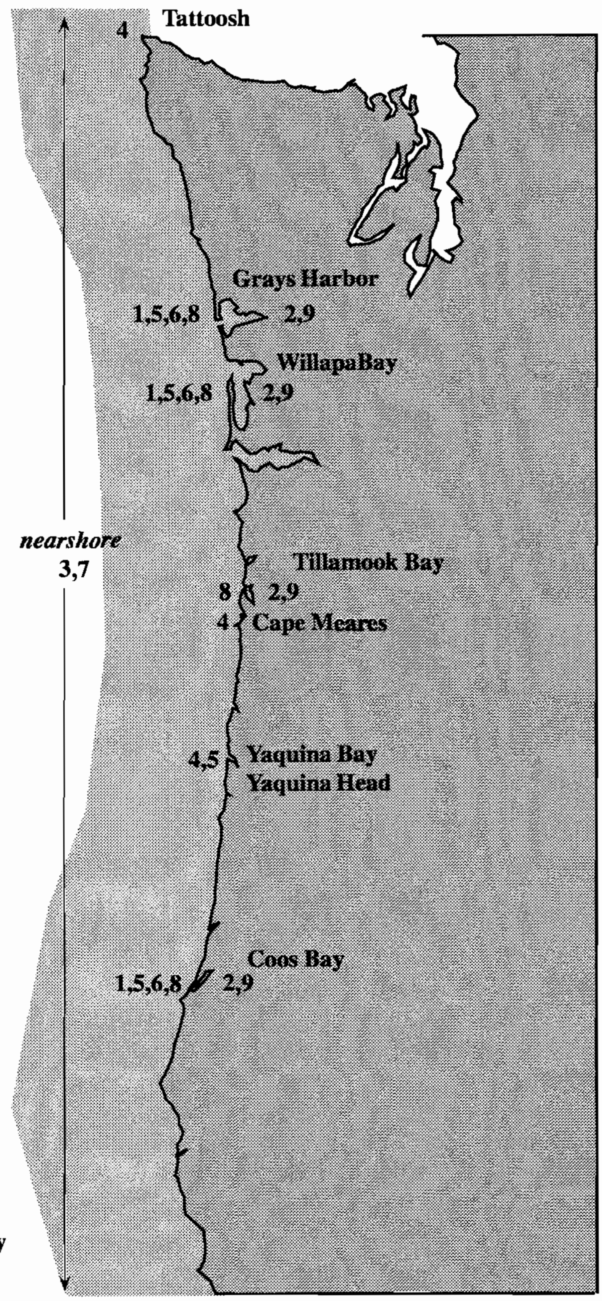


Figure 1. Summary Map. Locations of data collection by PNCERS researchers. Numbers refer to project titles.

Table 1. Summary Table (facing page). A comprehensive list of the kinds of data collected, instrumentation used and target organisms in PNCERS' twelve research projects. Projects have been categorized as either: Physical, Biological, Economic, or Social. Within each project information is also presented about data type: Direct (that is, collected by the researchers) and Derived (that is, collected previously and used by the researcher, as in a database). Finally, information is presented about how data are gathered, either source or instrument; and the target organisms of study. Numbers refer to project titles, listed above.

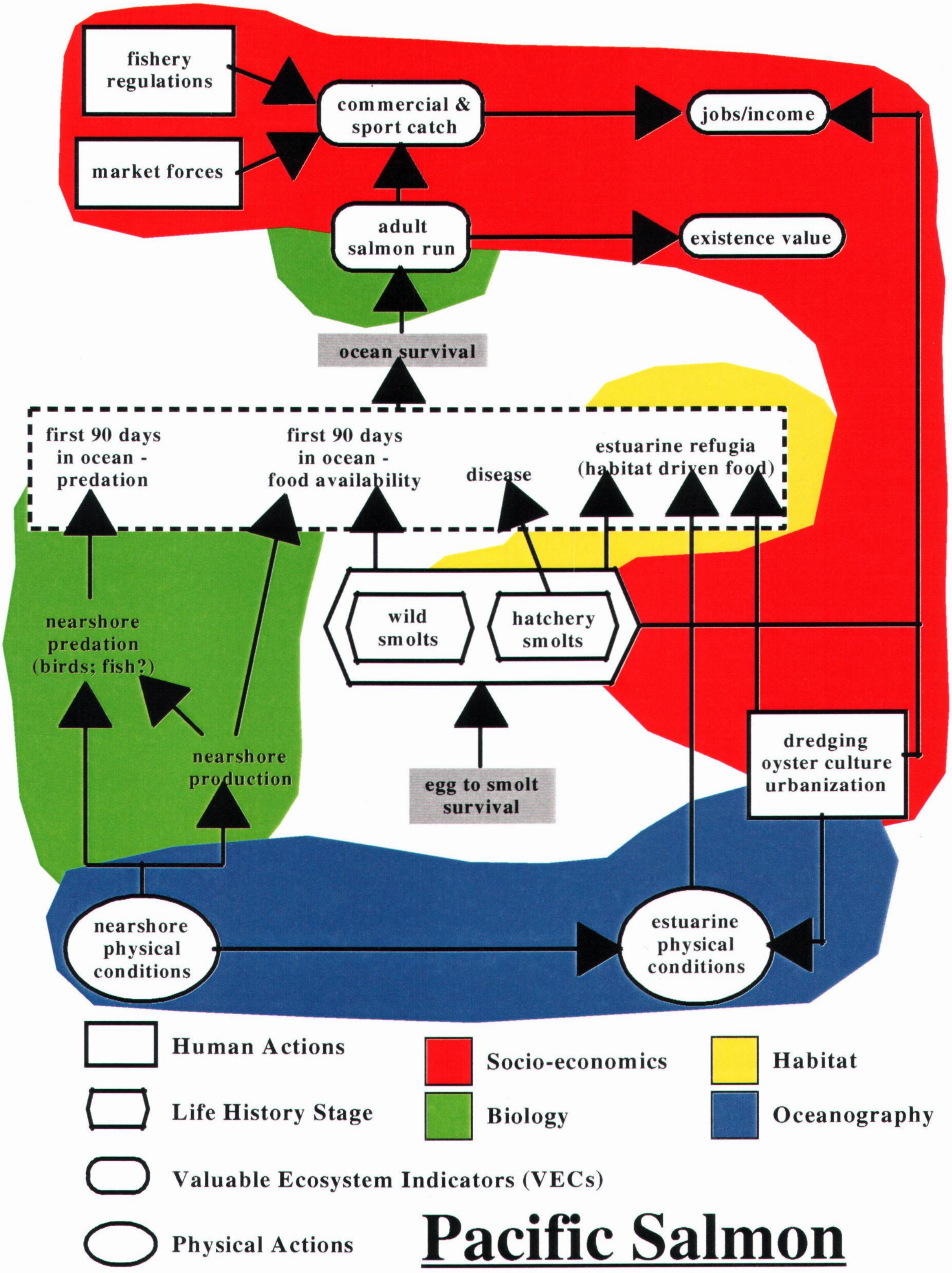


Plate 1. Conceptual model for salmon as a Valued Ecosystem Component (VEC). Colors distinguish disciplinary groups. Shapes distinguish action types, life history stages and valued ecosytem components.

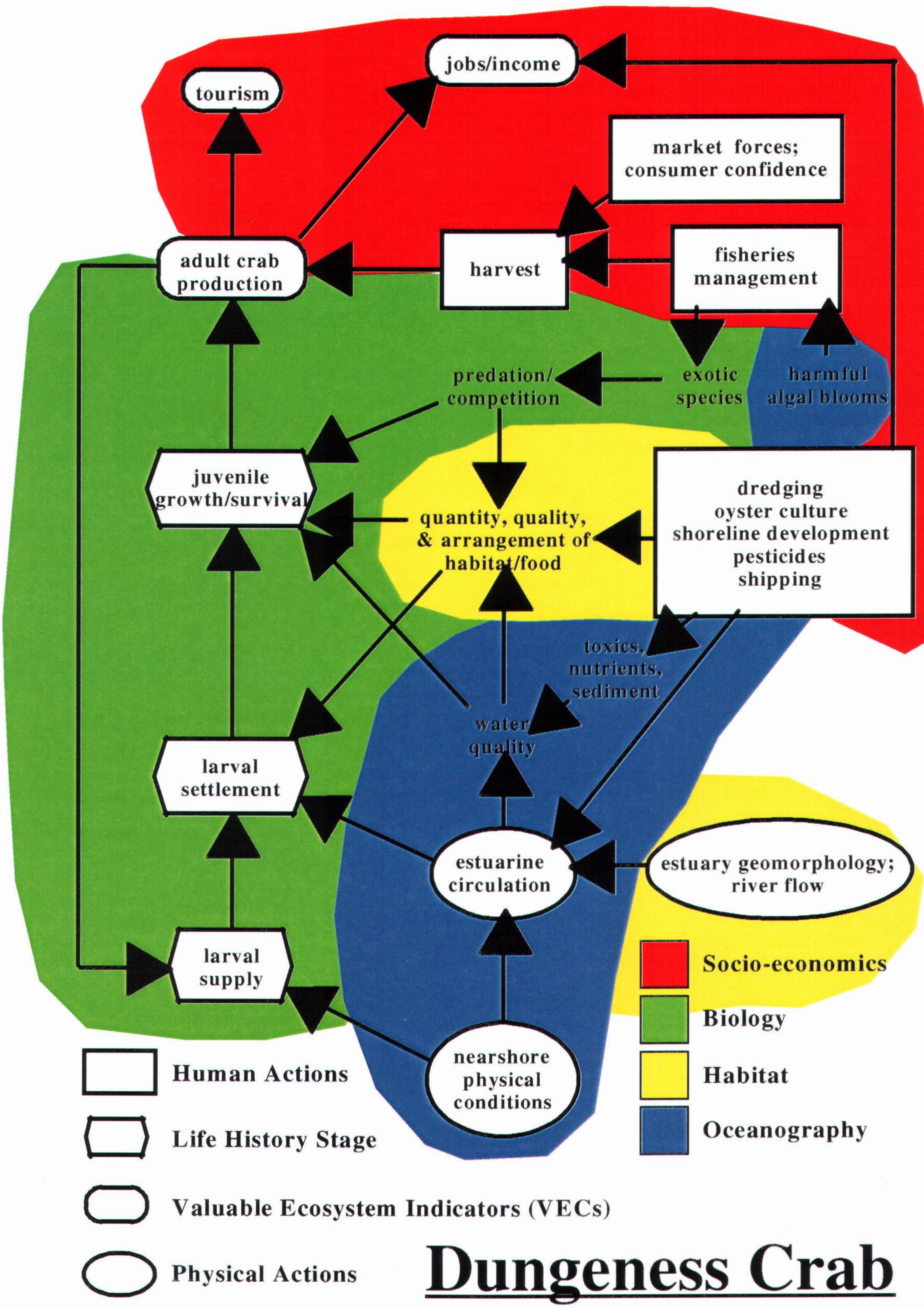


Plate 2. Conceptual model for crab as a Valued Ecosystem Component (VEC). Colors distinguish disciplinary groups. Shapes distinguish action types, life history stages and valued ecosytem components.

SUMMARY TABLE

	ESTUARINE		NEAR SHORE	
DIRECT MEASUREMENTS		#		#
Physical	◆ land characteristics	9	◆ acoustic backscatter (38, 120 KHz)	3
	◆ current speed and direction	1,6	◆ fluorescence	3,6
	◆ water temperature	1,5,6,8	◆ current speed and direction	3,1,6
	◆ wind speed and direction	1,6	◆ water temperature	3,1,6
	◆ accretion/erosion	8	◆ salinity	3,1,6
	◆ sediment elevation	8		
	◆ lower depth limit	8		
	◆ secchi depth	8,5		
	◆ salinity	1,5,6,8		
	◆ PAR (photosynthetically active radiation)	8		
	◆ sediment grain size	5		
	◆ distribution of substrate type	5		
Biological	◆ vegetated habitat distribution (current and historical)	8	◆ plankton and juvenile fish distribution	3
	◆ eelgrass habitat transects shoot density percent cover above ground biomass below ground biomass epiphyte biomass	8	◆ seabird breeding phenology reproductive success population size diet	4
	◆ demersal invertebrate and select fish abundance size-frequency wet-weight	5	◆ abundance and distribution of crustacean and fish larvae	6
	◆ distribution of crustacean and fish larvae	6		
Economic	◆ economic values of alternative land use	9		
	◆ land use regulation	9		
Social	◆ interviews environmental issues of concern	9		

	ESTUARINE		NEAR SHORE	
	role of agencies in land/resource management role of science in decision-making science sources			
DERIVED MEASUREMENTS				
Physical	◆ benthic habitat change (geomorphological)	8		
	◆ shoreline location (current and historical)	8		
	◆ bathymetry (current and historical)	8		
Biological	◆ correlation between habitat change and species change	8	◆ plankton spatial distribution relative to environmental conditions	3
	◆ hydrographic amd atmospheric features influencing larval transport of Dungeness crab megalopae	6	◆ relationship between spatio-temporal distribution of plankton and salmon smolts	3
	◆ correspondence between larval supply and initial post-settlement abundance of juvenile crabs	5	◆ physical oceanographic correlates with seabird demography and diet	4
	◆ correlation between substrate type and larval settlement	5,6	◆ physical oceanographic correlates with larval abundance and transport	6
	◆ temporal and spatial scales of variability in larval supply	6	◆ correlation between larval supply and year class strength	6
	◆ correlation between larval supply and year class strength	6		
Economic	◆ detailed data on fisheries, tourism, and recreational industries	2	◆ detailed data on fisheries, tourism, and recreational industries	2
	◆ location of salmon fishing and crabbing areas and other fish and wildlife information	2	◆ location of salmon fishing and crabbing areas and other fish and wildlife information	2
	◆ land ownership and use	2	◆ land ownership and use	2

	ESTUARINE		NEAR SHORE	
	◆ input-output models of ecosystem-related industrial sectors	2		
	◆ land use model	9		
	◆ instiutional mapping	9		
	fishing			
	logging			
	shellfish			
	agriculture			
Social	◆ review and assessment of Ecosystem Management as a concept	9		
	◆ history of regional land management	9		
INFORMATION SOURCES / INSTRUMENTATION				
Physical	◆ moored sensor arrays	1	◆ SIMRAD EK-500 system	3
	◆ CTD	1	◆ ADCP	3,1
	transmissometer		◆ moored sensor arrays	1
	fluorometer		◆ CTD	1, 6
	oxygen sensor		transmissometer	
	◆ MicroCats	1	fluorometer	
	◆ navigation charts	8	oxygen sensor	
	◆ habitat maps	8	◆ MicroCats	1
	◆ photographs	8		
	◆ GIS	8		
	◆ GPS system	8		
	◆ sediment-erosion table stations	8		
	◆ beam-trawl surveys	5		
	◆ Van-Veen grab	5		
	◆ YSI meter	5		
	◆ secchi disk	5		
Biological	◆ navigation charts	8	◆ MOCNESS	3
	◆ habitat maps	8	◆ Methot trawls	3
	◆ photographs	8	◆ anchovy trawls	3
	◆ GIS	8	◆ direct observation	4
	◆ beam-trawl surveys	5	◆ light traps	6
	◆ light traps	6	◆ 500 μm neuston net	6
	◆ 500 μm neuston net	6		
	◆ Tucker trawl	6		

	ESTUARINE		NEAR SHORE	
Economic	◆ Regional Economic Information System	2		
	◆ US Forest Service IMPLAN System	2		
	◆ US Census GIS data	2		
	◆ US Geological Surveys	2		
	◆ County assessments	9		
	◆ state agencies			
Social	◆ literature reviews	9		
	◆ in person interviews	9		
	◆ telephone interviews	9		
	◆ worldwide web	9		
TARGET ORGANISMS				
Biological	◆ English sole	5	◆ plankton	3
	◆ demersal invertebrates	5	◆ euphausiids	3
	◆ demersal fishes	5	◆ other marine fishes	3
	◆ Dungeness crab (*Cancer magister*) (adults, juveniles and megalopae)	5,6	◆ glaucous-winged gulls	4
	◆ Crustacean larvae (megalopae and zoea)	6	◆ pelagic cormorants	4
	Cancrids	6	◆ Brandt's cormorants	4
	Thalassinids	6	◆ common murres	4
	Xanthids	6	◆ Crustacean larvae (megalopae and zoea)	6
	Grapsids	6	Cancrids	6
	Pinnotherids	6	Thalassinids	6
	Porcellanids	6	Xanthids	6
	Pagurids	6	Grapsids	6
	◆ Cirripeds (cyprids)	6	Pinnotherids	6
	◆ Eelgrass (*Zostera marina* L.)	8	Porcellanids	6
			Pagurids	6
			◆ Cirripeds (cyprids)	6
Economic	◆ people (tourism/recreational)	2,9		
	◆ shellfish	2,9		
	◆ salmon	2		
	◆ crabs	2		
	◆ groundfish	2		
Social	◆ people	9		
	◆ eelgrass	9		

RESEARCH PROJECTS

Coastal Ocean Coupling: A Physical Baseline for PNCERS .... Project 1

Barbara M. Hickey

Introduction

Time series of oyster condition at different sites within Willapa Bay demonstrate significant interannual variability as well as a significant downward long term trend (B. Dumbauld, pers. comm. to BMH). Multi-year time series of Dungeness crab populations for the Washington coast as well as for Willapa Bay and Grays Harbor estuaries demonstrate strong interannual variability in both 0+ (newly settled crab less than a year old) and 1+ (crab less than two years old) crabs, both off the open coast and in the estuary (see, e.g. Gunderson et al., 1990; Jamieson and Armstrong, 1991; Iribarne et al., 1994, 1995; Armstrong et al., 1994). In all but the El Niño year sampled (1985), the data suggest that 1+ crab densities are much higher in estuaries than along the open coast. Moreover, offshore size data suggest that the estuaries serve as a nursery for young crab: a significant number of crab emigrate from the estuary to the coast, producing a jump in offshore mean size distribution when emigration occurs.

At the present time environmental data are insufficient to determine the link between productivity in our coastal estuaries and variability in the species that use it as either a nursery or a home. Estuaries on the U. S. Pacific Northwest coast have not received the attention of east coast estuaries that have been more heavily impacted by development. For the most part, variability in these estuaries is directly related to changes in the physical environment, in particular, due to changes in the adjacent coastal ocean.

Our component of PNCERS was designed to address the physical variability in several Pacific Northwest estuaries and the relationship between variability in the coastal ocean and these estuaries and, in concert with fisheries components of PNCERS, to determine factors that cause variability in year class strength in several important species. Measurements in three estuaries allow comparative studies in both fishery success and environmental variability.

Results & Discussion

During the first year of PNCERS we have made substantial progress toward our goal of understanding water property variability in coastal estuaries of the Pacific Northwest. Major accomplishments include the following:

- We have successfully acquired simultaneous data on currents and water properties in each of three estuaries and over the shelf adjacent to those estuaries.

- We have demonstrated that water properties in all three estuaries have dramatic variability on scales of 3-10 days and that during summer, water property changes occur nearly simultaneously in three estuaries separated by a distance of 400 km.

- We have demonstrated that atmospheric cooling events dramatically lower estu-

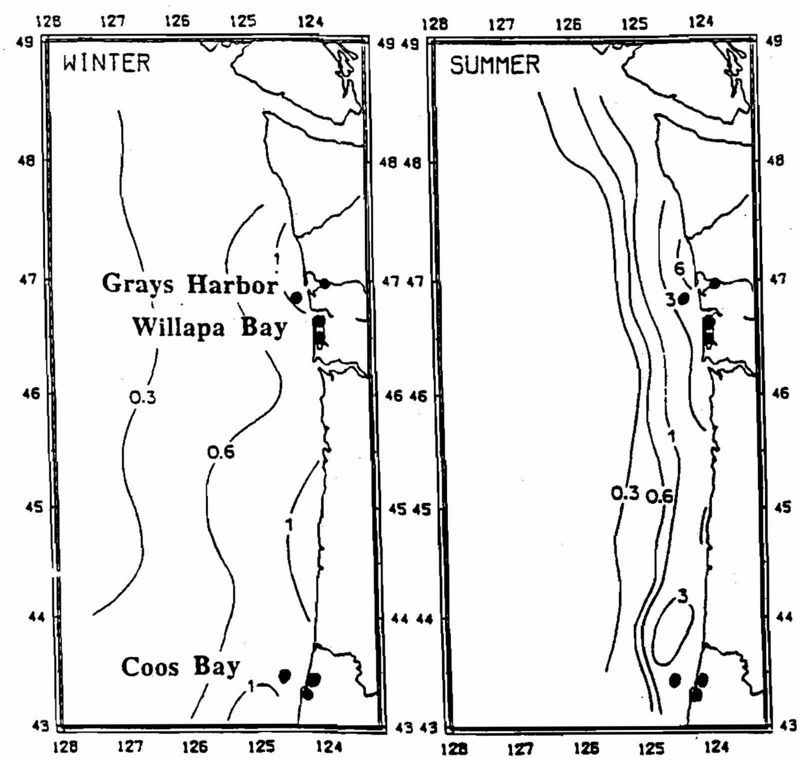


Figure 1.1. Locations of PNCERS sensor arrays measuring currents and water properties at hourly intervals for a two year period. Contours illustrate the seasonal distribution of chlorophyll a (mg m^{-3}) along the coast.

ary water temperature for extended periods during winter.

- For one of the estuaries we have developed a simple conceptual model for low frequency (3-10 d) processes that effect estuary water properties.

Each of these results is discussed in more detail below.

Data Collection Effort

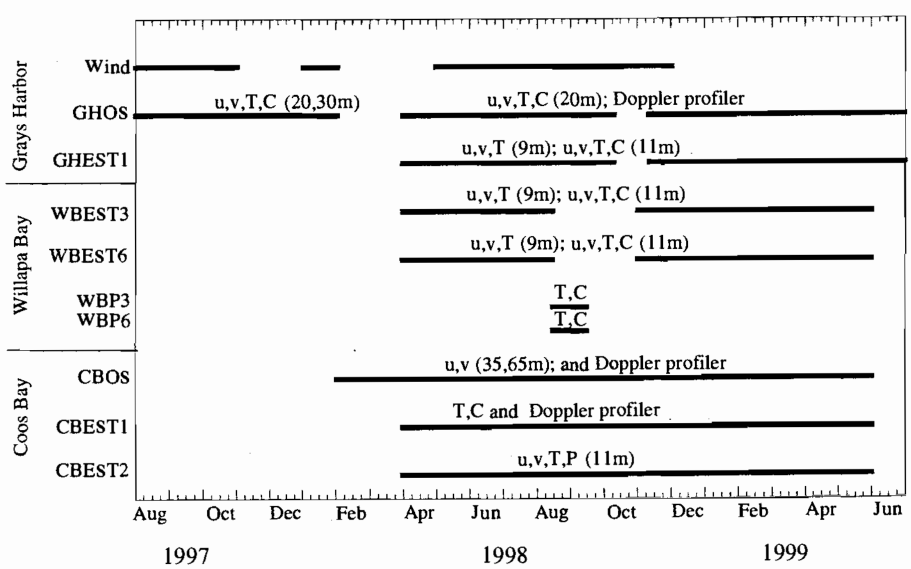
Measurements of ocean currents and water properties have been initiated in three coastal estuaries, Willapa Bay and Grays Harbor, Washington and Coos Bay, Oregon, as well as on the continental shelf off Grays Harbor and off Coos Bay. Data include time series of current speed and direction, water temperature and conductivity (to calculate salinity). Locations of moored sensor arrays are shown in Figure 1.1. Shelf arrays each support a 300 kHz RDI Workhorse profiling current meter as well as at least two conventional current meters for backup and to measure water conductivity (to obtain salinity). The Workhorses have 20 degree beam angles so that only 6% of the water column above the sensor cannot be used. With the shallow deployment depths, we are able to measure to within 3 meters of the surface off Grays harbor and 11 m off Coos Bay. In-estuary sensors include electromagnetic current meters (InterOcean S4s) as well as mechanical current meters (Aanderaas). Wind measurements have been made in selected periods on a tower in Willapa Bay. Wind data have also been acquired from NDBC buoys. A timeline and summary of moored sensor measurements to date is given in Table 1.1.

Some modifications to the arrays as originally proposed were required. In Grays Harbor, the active shipping and shallow depths off the channel axis made deployment possible in only one site instead of two. The second mooring scheduled for Grays Harbor was deployed in Willapa instead. The shallow depths in Coos Bay prevented deployment of conventional moorings as were proposed. Instead, we refurbished two bottom cages designed as sensor mounts. We also supplied an acoustic Doppler profiling current meter to be mounted on one cage, replacing the individual current meter proposed for that site. Thus, measurements in Coos Bay have been considerably upgraded beyond the scope of work contained in the proposal.

The measurement collection is proceeding on schedule. Moreover, we were able to deploy moorings several months in advance of the proposed timeline (in August 1997 offshore of Grays Harbor and in January 1998 offshore of Coos Bay, rather than the scheduled April 1998 deployment) to catch the El Niño. In general, the moored sensor arrays in the estuaries were deployed in March 1998, cleaned in June 1998, redeployed in November 1998 and will be cleaned in April 1999. The arrays will be redeployed in June 1999 to begin a second year of measurements. Some problems arose due to biofouling; for example, the Grays Harbor array was sunk by mussel infestation requiring a separate vessel trip to drag for the instruments and another trip to redeploy the array. Also, the Doppler current meter at Coos Bay failed to pass predeployment tests after retrieving it in October, requiring a new electronics board before a second trip to Coos Bay for redeployment in February. A transponder being used to locate bottom cages in Coos Bay leaked beyond repair. Two other current meters have leaked beyond repair, likely a result of the extremely energetic environment and the biological fouling.

Data return has been good with the exception of conductivity measurements. Biological fouling is significant in summer; in winter, the ranges on the sensors were set too high to capture much of the signal. Consequently, we purchased three Sea-Bird MicroCats for salinity measurements. These sensors have a much larger range and greater accuracy. They are also equipped with anti-fouling cylinders which will extend

Table 1.1. Time line and variables measured in the PNCERS study. U and V represent east-west and north-south velocity, respectively; T, C and P represent temperature, conductivity and pressure; "Doppler Profiler" indicates velocity measurements at 1-2 m intervals. Measurement depth in meters is given next to each set of sensors.



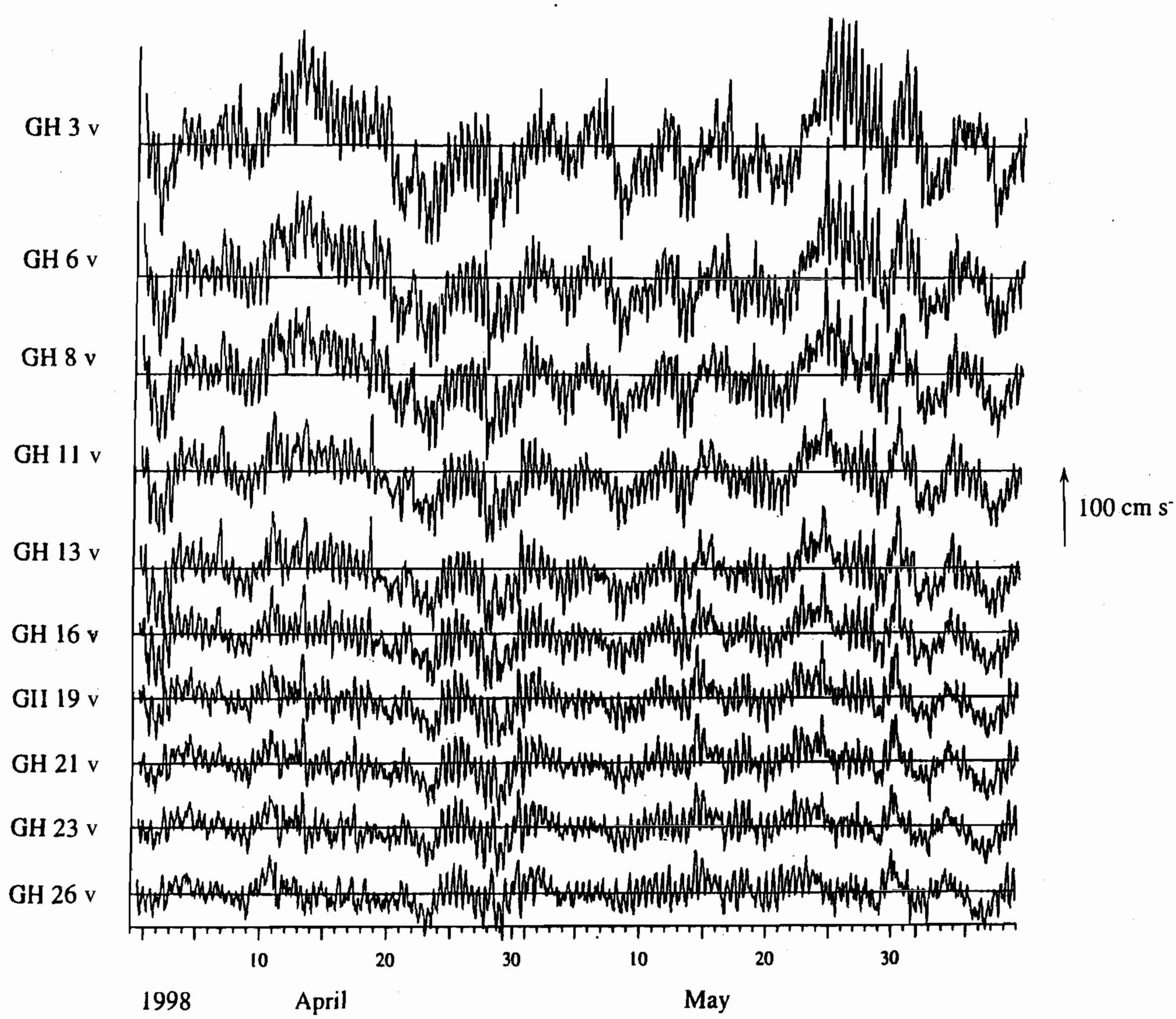


Figure 1.2a. Time series of alongshelf component of velocity (v) at selected depths (given in meters) at a location on the shelf off Grays Harbor, Washington during April-May, 1998. Bottom depth is about 38 m.

the duration of time series obtained. We also have adjusted the ranges on our in-estuary current meters.

Examples of data collected simultaneously at two sites on the shelf separated by about 400 km are shown in Figures 1.2a and 1.2b. The figures illustrate that at both sites, variability includes significant fluctuations at tidal and inertial frequencies as well as lower frequency fluctuations. The lower frequency fluctuations are a result of changes in wind direction along the coast with the passage of weather systems (e.g., Hickey, 1989). During this winter period, the low frequency fluctuations are sometimes coincident at the two sites and sometimes not, a reflection of the fact that winter storms in the Pacific Northwest are more vigorous and occur more frequently at more northern latitudes. For example, a period of northward flow (downwelling favorable or storm conditions) on about May 25 is observed only at the more northern site (Figure 1.2a). Conversely, the period of southward flow (upwelling-favorable or fair weather conditions) beginning about April 20 is much more prolonged at the southern site (Figure 1.2b). On the other hand, the storm of April 12 is observed at both sites. These data are important to PNCERS because they show the extent of the movement to which species in larval form are subjected in a given period. Information such as this will be used to help understand variability in year class strength of important species that spend at least part of their lifetime in the open ocean.

Water property surveys have been made on several occasions in each estuary, generally upon deployment, cleaning or recovery of moored sensors. A summary of data collected is given in Table 1.2. Examples of processed survey data ob-

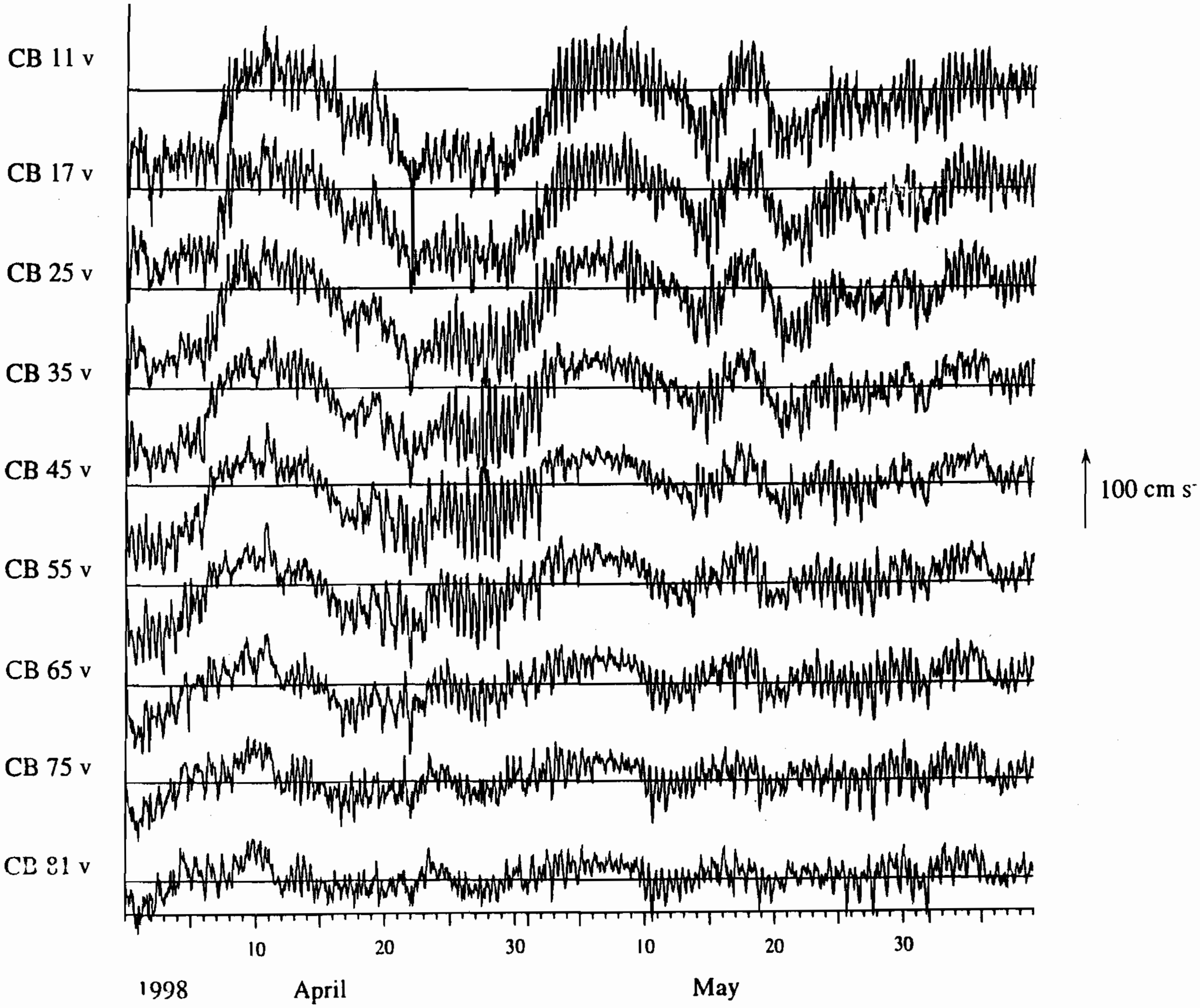


Figure 1.2b. Time series of alongshelf component of velocity (v) at selected depths (given in meters) at a location on the shelf off Coos Bay, Oregon during April-May, 1998. Bottom depth is about 97 m.

tained in each of the three estuaries are shown in Plate 3 and Plate 4. Salinity in Willapa and Grays Harbor estuaries (Plate 3) are remarkably similar in spite of the three month difference in timing and in spite of morphological differences between the two estuaries. Comparison of corresponding temperatures (Plate 4) shows the influence of cooler riverflow and wintertime cooling in the earlier section. Although salinity in Coos Bay (Plate 3) looks dramatically different from those in the other two estuaries, the difference is a result of a difference in river discharge rather than morphological differences. A major storm (hence high river discharge) occurred in the Pacific Northwest several days prior to this section. The data in the other estuaries were obtained during relatively low runoff conditions. Other salinity sections in Coos Bay (not shown) have shown the same weak stratification (partial mixed conditions) as Grays Harbor and Willapa Bay during low riverflow periods. Temperature data from Coos Bay (Plate 4) is much warmer than Grays Harbor, sampled just a week later. The warmer temperatures are consistent with the major downwelling event that preceded the Coos Bay section. In general, we suspect that site to site differences are weaker than differences due to environmental conditions, which are frequently of sufficiently large scale to effect all estuaries simultaneously.

The CTD data are important to PNCERS in setting ranges of temperature and salinity conditions encountered by marine species when in the estuaries. For example, strong surface stratification may inhibit vertical transfer of nutrients. The CTD data also allow us to interpret and extrapolate information obtained by our moored sensors at individual sites.

Large Scale Nature of Estuarine Water Properties

Hourly measurements of temperature within each of the three

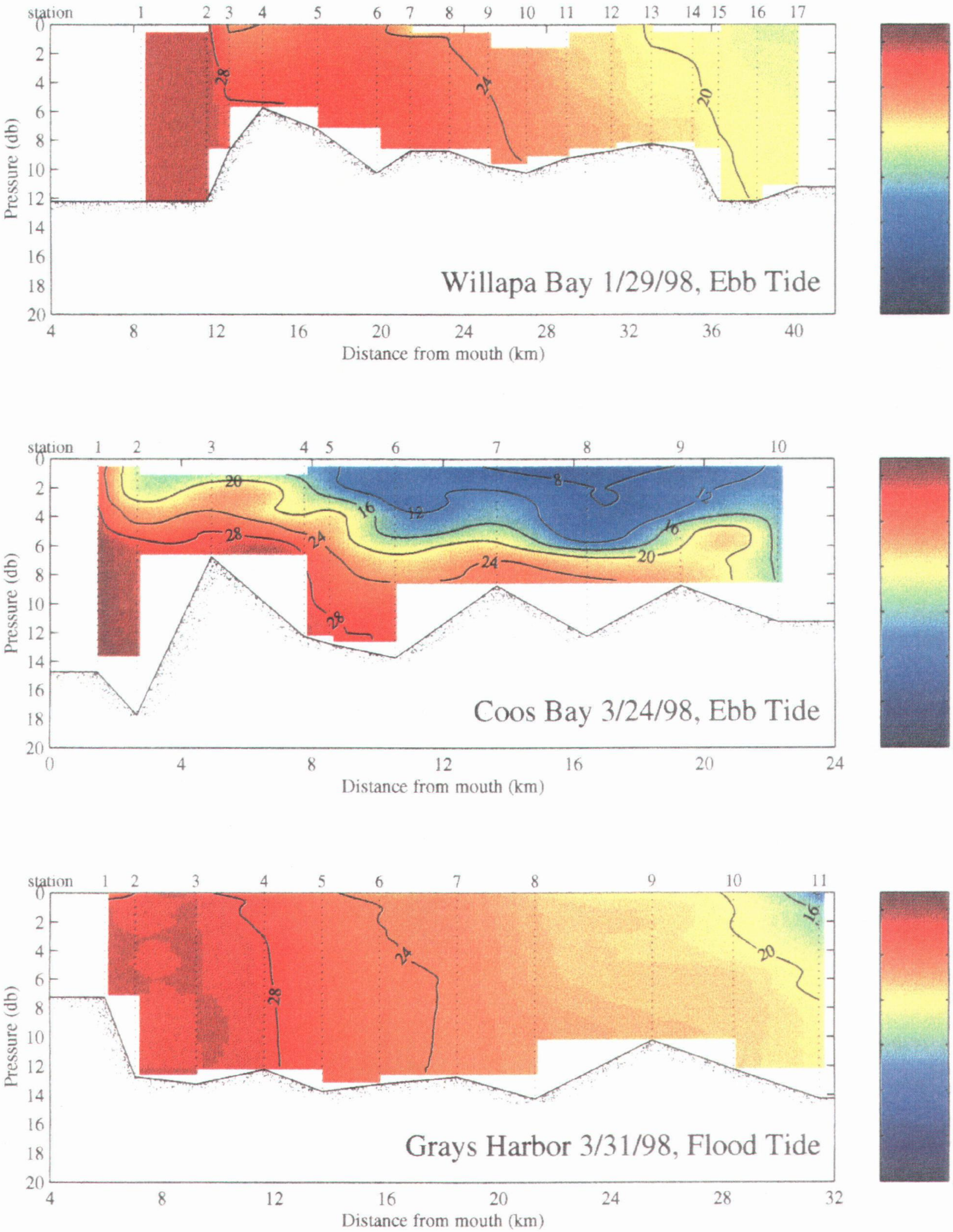


Plate 3. Contoured sections of salinity in winter-spring, 1998 along the main channels of three coastal estuaries. Contour intervals are the same in each panel.

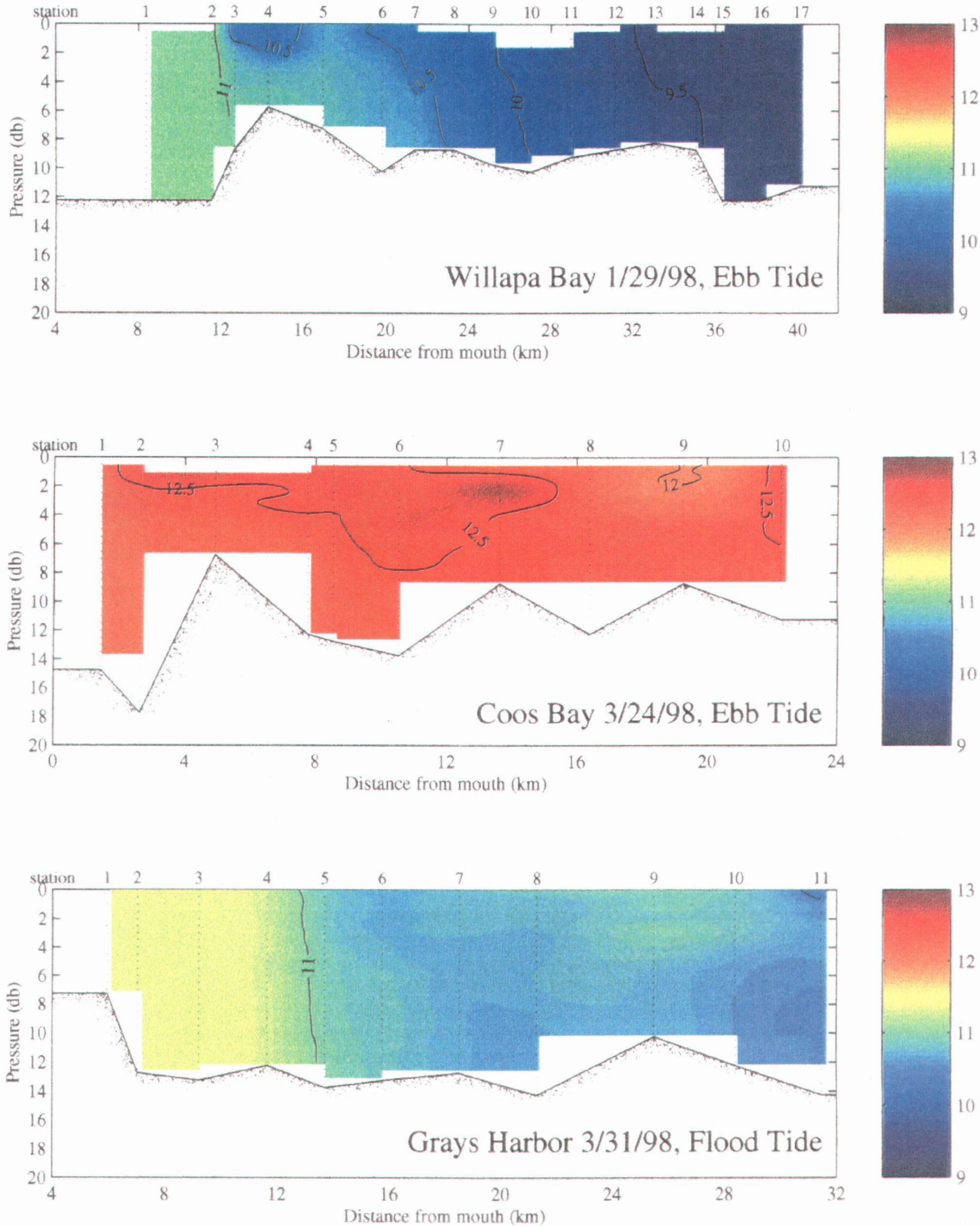


Plate 4. Contoured sections of temperature in winter-spring, 1998 along the main channels of three coastal estuaries. Contour intervals are the same in each panel.

Table 1.2. Summary of CTD data collected in three coastal estuaries since the start of PNCERS.

Date	Location	# CTD Stations	Instrument S/N
7/29/97	Willapa	16	SB19-165
12/2/97	Willapa	8	SB19-229
1/29/98	Willapa	17	SB19-510
2/19/98	Willapa	4	SB19-229
3/24/98	Coos Bay	16	SB19-510
3/31/98	Grays Harbor	11	SB19-510
4/2/98	Willapa	2	SB19-510
6/1/98	Grays Harbor	8	SB25-37
6/7/98	Coos Bay	15	SB19-2041
6/7/98	Coos Bay	28	SB25-37
7/30/98	Willapa	1	SB19-510
9/10/98	Willapa	14	SB19-510
10/4/98	Coos Bay	13	SB19-510
10/9/98	Grays Harbor	6	SB19-510
10/14/98	Grays Harbor	10	SB19-510
11/5/98	Willapa	13	SB19-2163
11/11/98	Grays Harbor	7	SB19-2163

estuaries in a low riverflow, summer period show that dramatic fluctuations in temperature (several degrees) occur on tidal scales (Figure 1.3). Fluctuations are also observed on longer scales (3-10 d) in each of the estuaries and these fluctuations are similar in all three estuaries. The discussion below demonstrates that these fluctuations are largely driven by coastal processes of upwelling and downwelling. With partial support from PNCERS, a paper on the nature of these fluctuations in the summer, low river discharge period (Hickey et al., 1999) has been submitted for publication. The upwelling and downwelling is large scale because the wind that drives them is large scale (Halliwell and Allen, 1987; see summary in Hickey, 1998). The large scale nature of the physical forcing has several important consequences on ambient biology; e.g., patchiness in larval distributions cannot be attributed to patchiness of the physical environment on a similar scale.

Atmospheric Cooling in Pacific Northwest Estuaries

An example of a striking atmospheric cooling event is shown with time series at several channel sites in Willapa Bay in winter, 1997 (Figure 1.4). Temperature at some locations in the estuary drops as low as 4°C. Lower than average water temperatures persist for several days. The coldest temperatures occur at locations farthest from the estuary mouth, indicating that the cooling is a result of local forces rather than advection from another cooled region, for example, from the Columbia River plume. In a "cold" weather year in the Pacific Northwest, such events may occur several times during that year. It seems likely that organisms in the estuary will experience stress during such periods and, over a season, may grow more slowly than during a warmer winter. Such events may have to be taken into effect in biological models for various trophic levels and may play a role in interannual variability of species of interest. In general, temperature extremes (and their duration) at both warm and cold limits for particular species (and both their food and predators) are likely important, particularly if such extremes occur at critical life history phases.

A Conceptual Model for Willapa Bay

Our conceptual model for dominant physical processes affecting one of the three coastal estuaries being studied is shown in Figure 1.5. The model is based primarily on measurements in Willapa Bay (hence the shape), where data were collected prior to PNCERS. Although the relative importance of the various processes will differ between estuaries, we have collected sufficient data to date in Grays Harbor and Coos Bay to at least be able to say that each of the processes discussed below is expected to occur in each of the estuaries.

Processes are shown in the conceptual model as transport vectors and nonlinear interactions between them are ignored (Figure 1.5). The model is derived from analysis of measurements to date and will be further refined as our analysis proceeds. The model has two scenarios, one applicable to downwelling wind conditions in winter; a second applicable to upwelling wind conditions in summer. During downwelling conditions, winds are to the north along the coast; coastal transport is to the north and warmer, lighter water is moved onshore, where it can downwell. During upwelling conditions, winds are to the south; coastal transport is to the south and offshore; colder, nutrient rich water is moved onshore at mid and near bottom depths and upwells to surface layers nearshore (within a Rossby radius of the coast). Nutrients are also affected by riverflow into estuaries and by biological processes.

In both scenarios shown in Figure 1.5, important low frequency processes include the alongshelf geostrophic currents (V_g), Ekman transport into or out of the estuary (V_E), the gravitational circulation in the estuary (V_g), and local wind-driven flow within the estuary (V_τ). "Geostrophic" flow is the shelf current that occurs throughout the water column in response to local wind accelerating the water column; Ekman flow is the current that occurs only near the surface in response to that same wind; gravitational flow is the mean current caused by river discharge into the estuary at one end—it has outflow near the surface and inflow below to replace any lost water; and local wind-driven flow in the estuary is the current forced by the stress of the wind in the estuary—it is generally in the direction of the wind over the estuary.

In the downwelling scenario, alongshelf geostrophic flow is toward the north, Ekman transport is toward shore, local wind-driven flow in the estuary is toward the north (and out of the

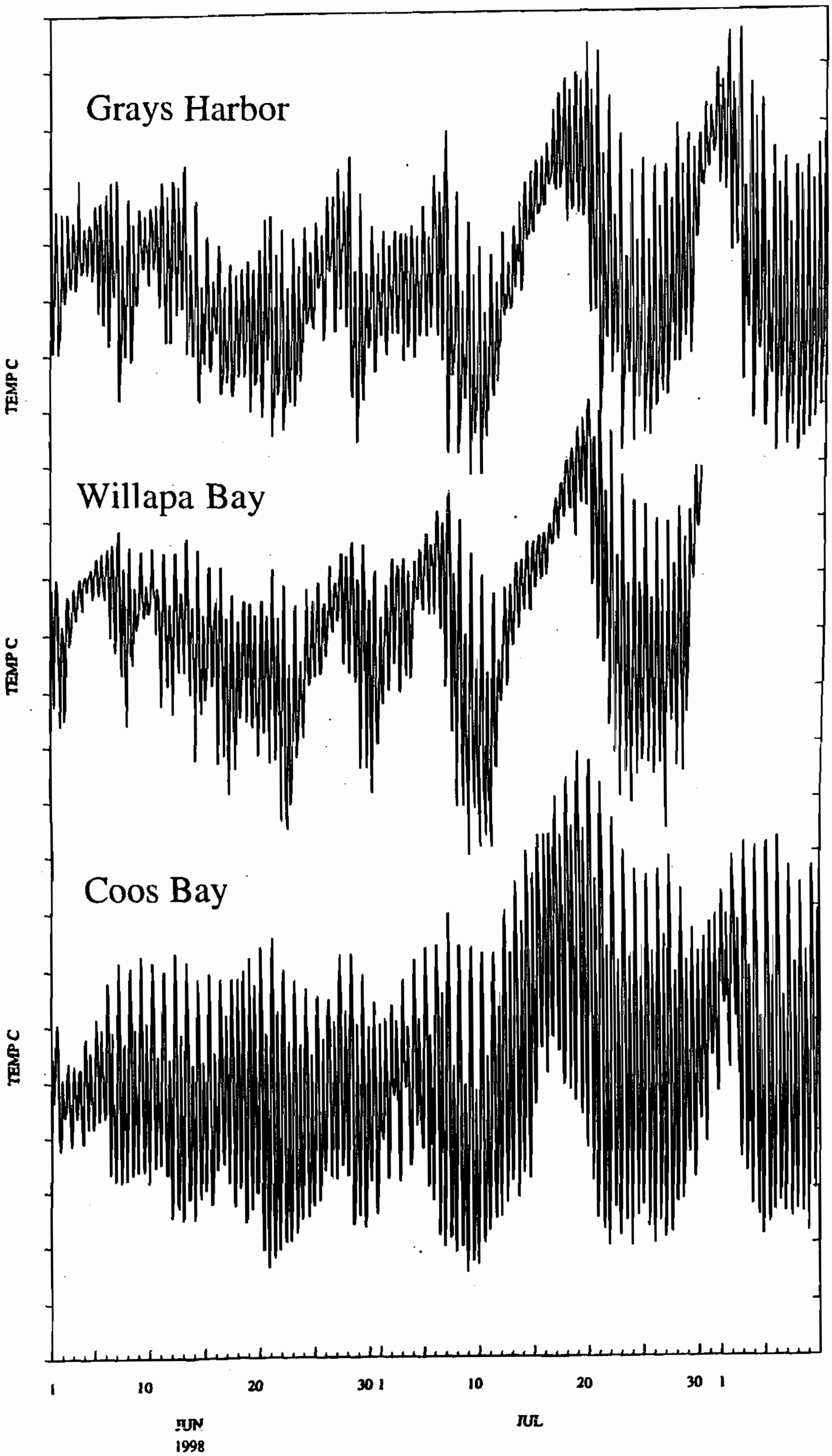


Figure 1.3. Hourly temperature time series in three coastal estuaries in summer, 1998. The data illustrate the site to site similarity in 3-20 day fluctuations in water properties. The data also illustrate the dramatic fluctuations in a given day in each estuary due to tidal changes. Tick marks along the y-axis indicate one degree intervals.

estuary; Hickey et al., 1999). In the upwelling scenario, the directions of each of these wind-related processes reverse. Tidal processes are dominant within the estuary at diurnal and higher frequencies. In general, tidal currents are dominant within the estuary, whereas subtidal currents are dominant over the shelf except within a tidal excursion of the estuary mouth. Wind driven flow within the estuary is dominant over tidal residuals and shows a strong direction reversal with depth. Measured subtidal flows do not necessarily illustrate a simple gravitational circulation with surface outflow and near bottom inflow. Our measurements of subtidal flows have indicated that flow patterns must be highly three dimensional.

In terms of water properties, our conceptual model shows warmer water offshore in winter during downwelling conditions and colder water in the estuary (Figure 1.5). This situation reverses in summer during upwelling conditions. Water in the estuary has a much larger seasonal variation (~16°C vs. ~4°C) than that offshore due to the heating and cooling of shallow waters. We suspect that the water over the banks of Willapa Bay and possibly the muds on those banks also affect the temperature changes within the Bay.

Integration & Interaction

- We recently organized a mini-workshop for PNCERS field components. PIs and students met for a half day, sharing data from last May's joint measurement period and preparing a plan for next year's work. Attendees included Barbara Hickey and Neil Banas (UW Oceanography),

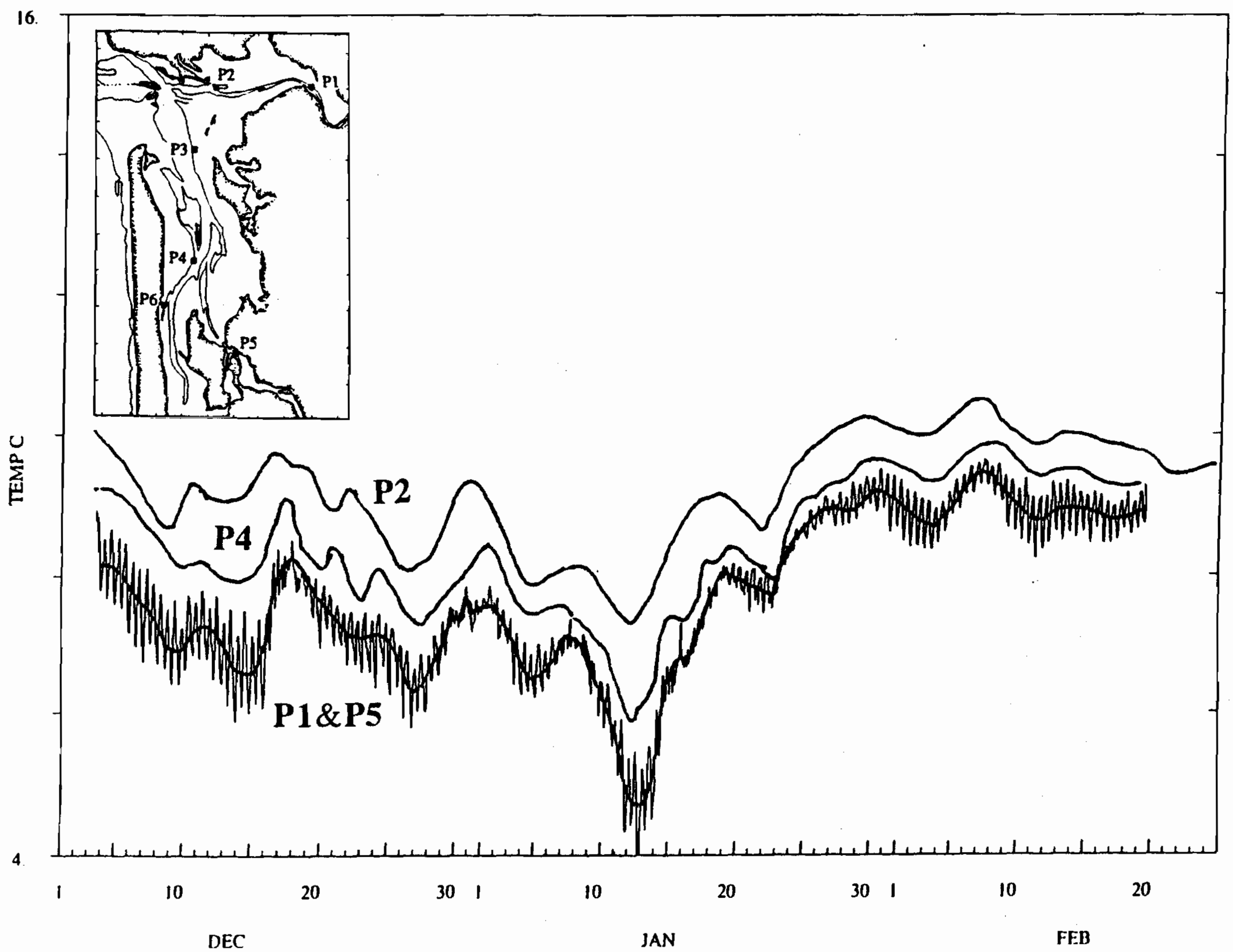


Figure 1.4. Time series of hourly temperature at a site in the southern portion of Willapa estuary, with subtidal temperature at several other sites. The data illustrate a dramatic cooling event in response to atmospheric temperatures of about 20°F, with more intensive cooling in the extremities of the estuary.

Grace Tsai (UW Fisheries), Curtis Roegner (Oregon Institute for Marine Biology), Jan Newton and Schudlich (Washington State Department of Ecology).

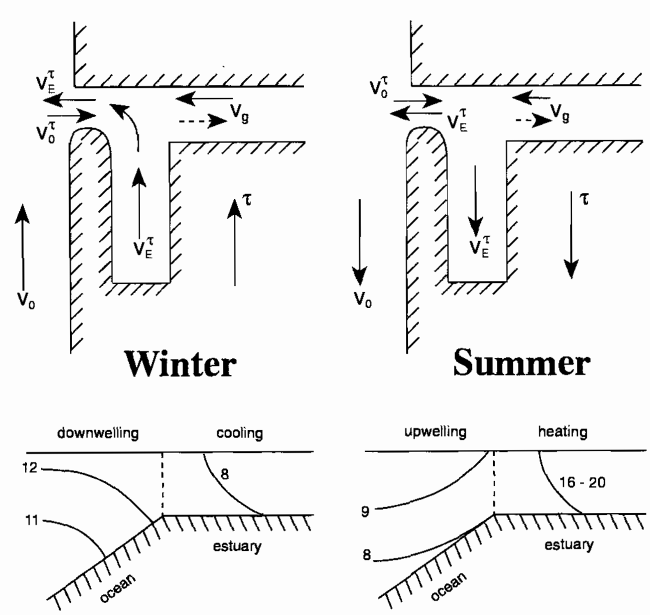


Figure 1.5. Schematic showing dominant subtidal scale ("residual") processes for currents (upper panels) and water properties (lower panels) for Willapa Bay during summer (right panels) and winter (left panels) conditions. Processes include the along-shelf geostrophic currents (V_0), Ekman transport into or out of the estuary ($V_0\tau$), gravitational circulation in the estuary (V_g), and locally driven wind-driven flow within the estuary ($V_E\tau$). Wind stress is indicated by "τ". Return flow into the estuary is indicated by a dashed line. Relative magnitudes are derived from the available data. In the bottom panels, typical isotherms are represented in a shelf-estuary cross-sectional view. Note that, in any season, winds (and hence upwelling or downwelling) can occur in any season, but occur more typically in the seasons shown.

• We participated with PNCERS investigators in both Willapa and Coos Bay surveys in June 1998. Our interaction with the Coos Bay PIs has been particularly fruitful: they have provided lodging and small boats. In June we traded CTDs with them and provided the Coos Bay group with offshore ship time. Our CTD was equipped with a transmissometer, a fluorometer and an oxygen sensor, making it particularly useful for the effort on larval recruitment studies. We surveyed the estuary with their more portable CTD while they surveyed the shelf offshore.

• Brett Dumbauld (Washington State Department of Fisheries) has been providing a small boat for many of our Willapa trips to clean or refurbish sensors and collect CTD data.

• We recently sent our new student (Neil Banas) to Coos Bay with Dave Armstrong's fisheries group. Neil, who is being supported partially by PNCERS and partially by Washington Sea Grant, has a strong interest in interdisciplinary work. His Ph.D. thesis project will be to develop a numerical model for Willapa Bay. He is helping Armstrong's students learn to process CTD data and assisted them in interpreting their larval crab data from offshore surveys. He spent several hours this month assisting Curtis Roegner with Matlab routines. He has also spent a week in Willapa with Jan Newton, learning about phytoplankton and nutrients.

• We have interacted with GLOBEC (P.I. Bob Smith), with GLOBEC providing the ship and assisting personnel (Wecoma) to deploy the offshore mooring near Coos Bay in February 1998.

• As part of PNCERS we are providing physical oceanographic data to help understand a bloom of harmful algae that took place in Willapa and Grays Harbor last fall at the start of the El Niño. The interaction includes Vera Trainer (National Marine Fisheries), Jan Newton (Department of Ecology and PNCERS), and Rita Horner (UW).

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Jamieson, G. and D.A. Armstrong. 1991. Spatial and temporal recruitment patterns of Dungeness crab in the northeastern Pacific. Memoirs Queensland Museum 31: 365-381.

Applications

Publications:

Hickey, B.M. Subtidal processes in Willapa Bay estuary during summer, 1995. Continental Shelf Research (submitted).

Banas, N. and B.M. Hickey. CTD data in Grays Harbor, Willapa Bay and Coos Bay during 1997-1998. This report has been distributed to PNCERS colleagues and is available for other interested parties. Data will be available on the Web.

Presentations:

Barbara Hickey, "Ocean-estuary coupling in the Pacific Northwest." Eastern Pacific Oceanographic Congress (EPOC) conference, September, 1998, Mt. Hood.

Barbara Hickey gave an invited lecture on coastal estuaries for School of Marine Affairs (SMA) course 511, Coastal Environmental Management, November, 1998, University of Washington. The class was studying the invasive green crab problem.

Dr. Hickey gave an interdisciplinary school-wide seminar highlighting her PNCERS work at the School of Oceanography, October 1998, University of Washington.

Barbara Hickey, "Water properties and currents in coastal estuaries of the Pacific Northwest." PNCERS Eat and Learn Seminar Series, January 29, 1999, University of Washington.

Barbara Hickey will make an invited presentation on her PNCERS results and prepare a paper for the Pacific Northwest Estuaries Conference, April, 1999, Portland, Oregon.

Workshops:
As a member of the NSF supported COOP (Coastal Ocean Program) steering committee Barbara Hickey has represented PNCERS at two semi-annual meetings. At these meetings, members of other groups (NSF, ONR and NOAA) are interested in PNCERS efforts to assist in planning their own programs.

Barbara Hickey attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
We are providing physical oceanographic data to help understand a bloom of harmful algae that took place in Willapa and Grays Harbor last fall at the start of the El Niño. The interaction includes Vera Trainer (National Marine Fisheries), Jan Newton (Department of Ecology and PNCERS collaborator), and Rita Horner (UW).

We have interacted with GLOBEC (P.I. Bob Smith) in that GLOBEC provided the ship and assisting personnel (R/V *Wecoma*) to deploy the offshore mooring near Coos Bay. As mentioned above, we have encouraged our Sea Grant funded student to interact with PNCERS investigators by sending him on two field trips to date.

Personnel

Barbara M. Hickey, Professor, University of Washington
Sue Geier, Research Engineer, University of Washington
Nancy Kachel, Oceanographer, University of Washington
Bill Fredericks, Scientific Programmer, University of Washington
Jim Johnson, Field Engineer, University of Washington
Neil Banas, Graduate student, University of Washington

Demographic and Economic Trends: A Socioeconomic Baseline for PNCERS .... Project 2

Rebecca Johnson and Laurie Houston

Introduction

This report provides socioeconomic background information for the four case study areas of PNCERS: Coos Bay, Tillamook Bay, Willapa Bay, and Grays Harbor. This overview will address three questions:

- How have populations in these areas been changing?
- How are people employed and what are they earning?
- How are the natural resource industries contributing to the economy?

The next step will be to explore linkages between the human system and the natural system.

Results & Discussion

Coastal communities in Oregon and Washington, as elsewhere, are undergoing significant economic and demographic transitions. Traditional resource-based industries like fishing and wood products have declined and have been supplemented by tourism and in-migration of retirees.

Population growth rates in the coastal counties tend to fluctuate more than overall state changes. Periods of negative growth (out-migration) are also more pronounced in the coastal counties, as they are generally harder hit by downturns in the economy. Overall, the coastal counties show slower growth rates than state averages, although Tillamook and Pacific Counties have recently been similar to the state averages (Figures 2.1a and 2.1b).

Age distribution in the coastal counties is significantly different than that of the state or U.S., with relatively more people in the older age groups, and relatively fewer people in the 18-29 age group. Pacific and Tillamook Counties are attracting the most "retirees" and retaining the fewest 18-29 year olds. In terms of educational attainment, the four coastal counties have more people with high school and less-than-high school

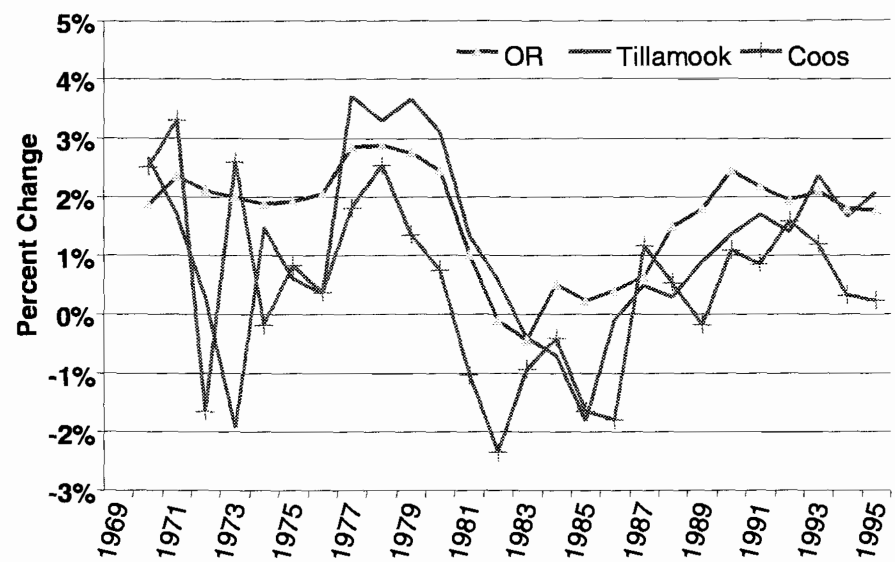


Figure 2.1a. Percentage change in population of Coos and Tillamook counties compared to Oregon, 1969 - 1995.

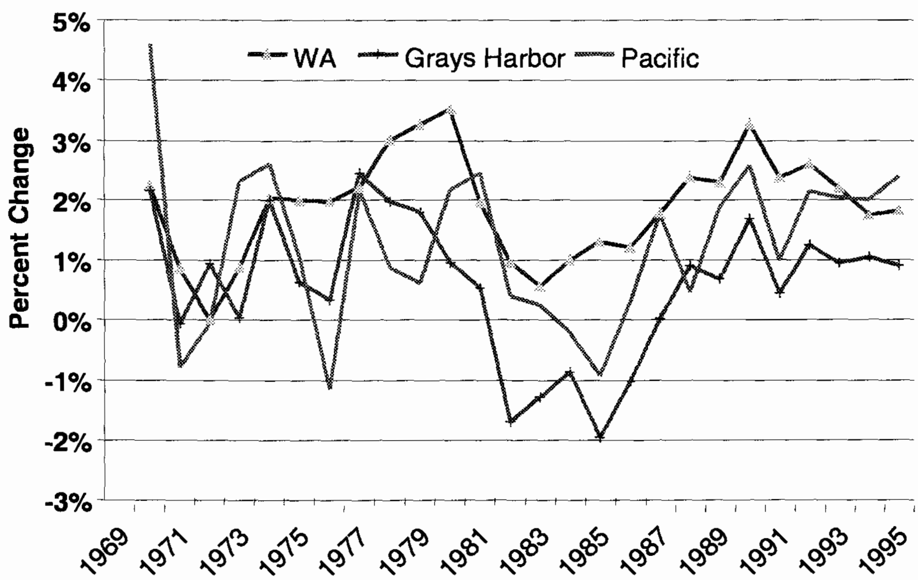


Figure 2.1b. Percentage change in population of Grays Harbor and Pacific counties compared to Washington, 1969 - 1995.

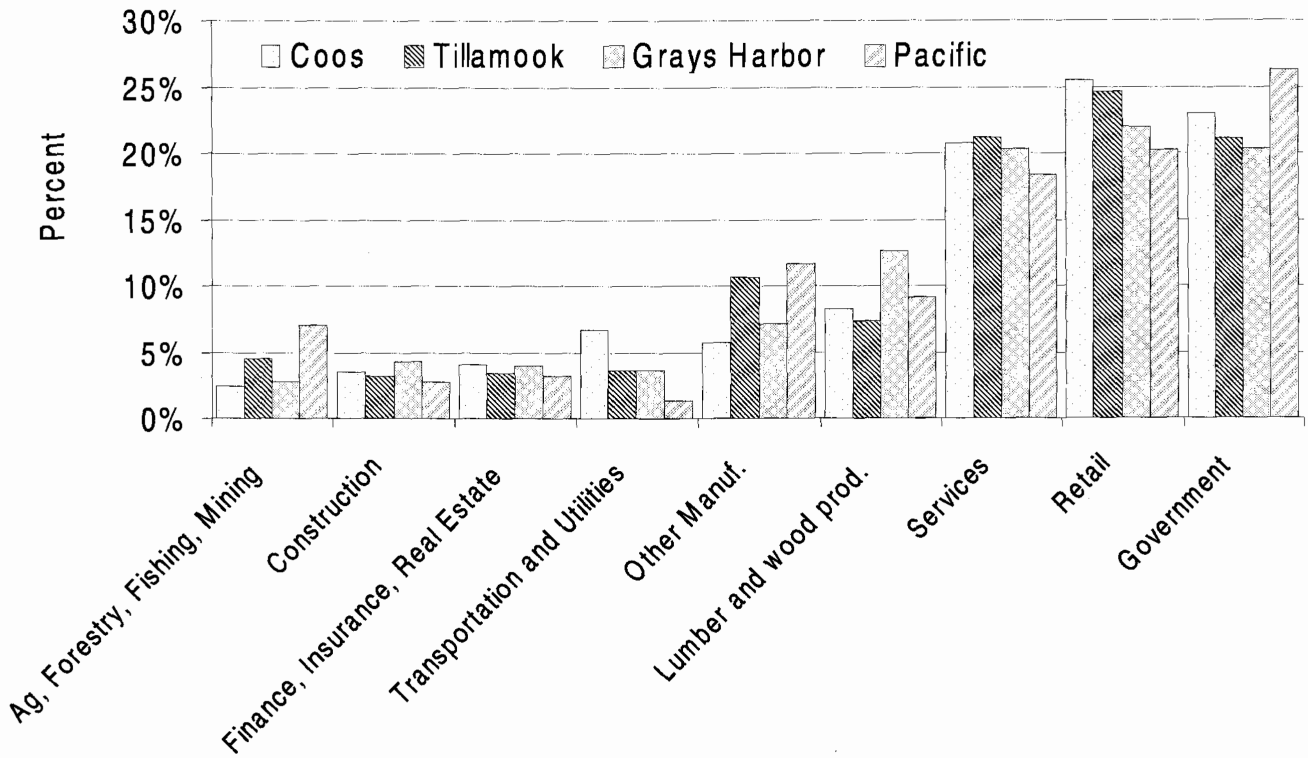


Figure 2.2. Percent of covered employment, by sector in Coos, Tillamook, Grays Harbor and Pacific counties, 1995.

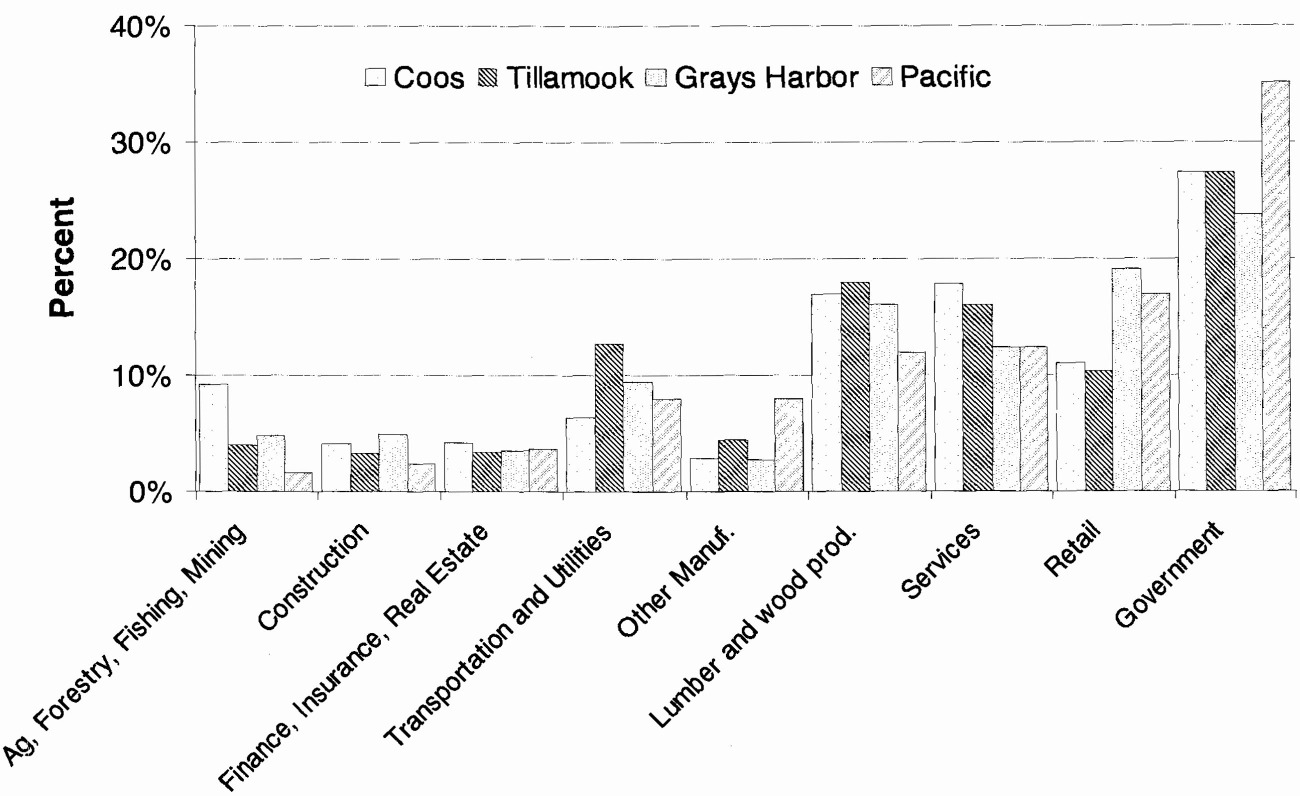


Figure 2.3. Percent of payroll, by sector in Coos, Tillamook, Grays Harbor and Pacific counties, 1995.

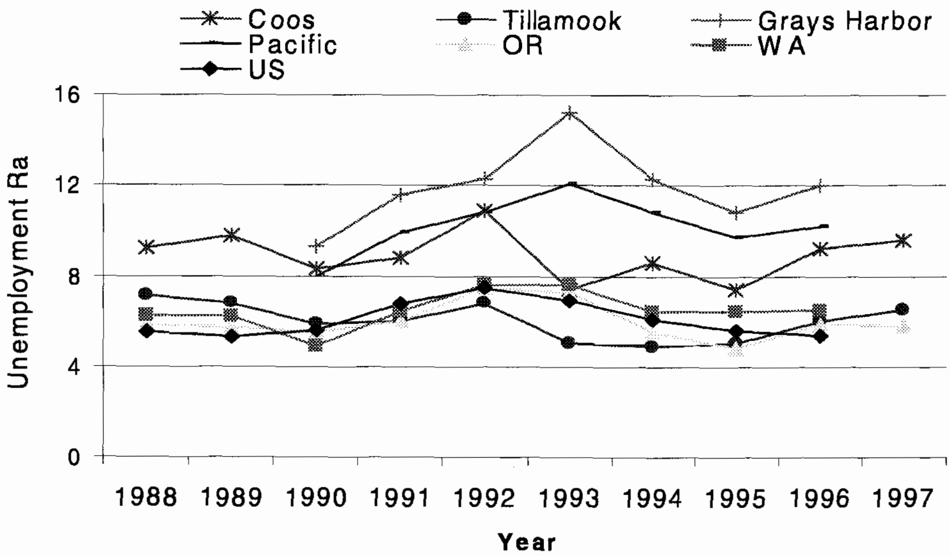


Figure 2.4. Unemployment in Coos, Pacific, Tillamook and Grays Harbor counties, Oregon, Washington and the United States, 1988 - 1997.

The flip side of employment is unemployment, and there are some dramatic differences between these four counties over time. Tillamook unemployment has remained fairly low, similar to state and U.S. averages in recent years (Figure 2.4). Pacific County has lower unemployment levels than Grays Harbor, but both are higher than the Oregon counties. The Oregon counties were less affected by the recession of the early 90's than the Washington counties, and recovered much quicker.

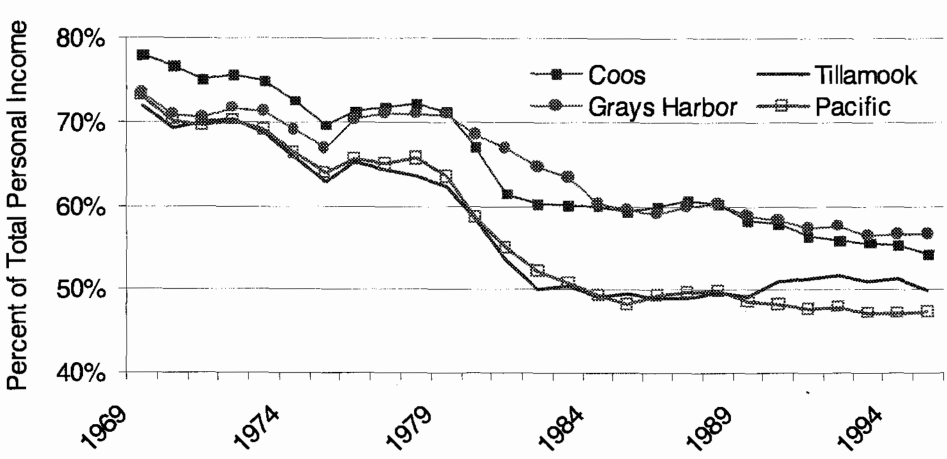


Figure 2.5. Net earnings (earned income) as a percent of total personal income in Coos, Grays Harbor, Tillamook, and Pacific counties, 1989 - 1994.

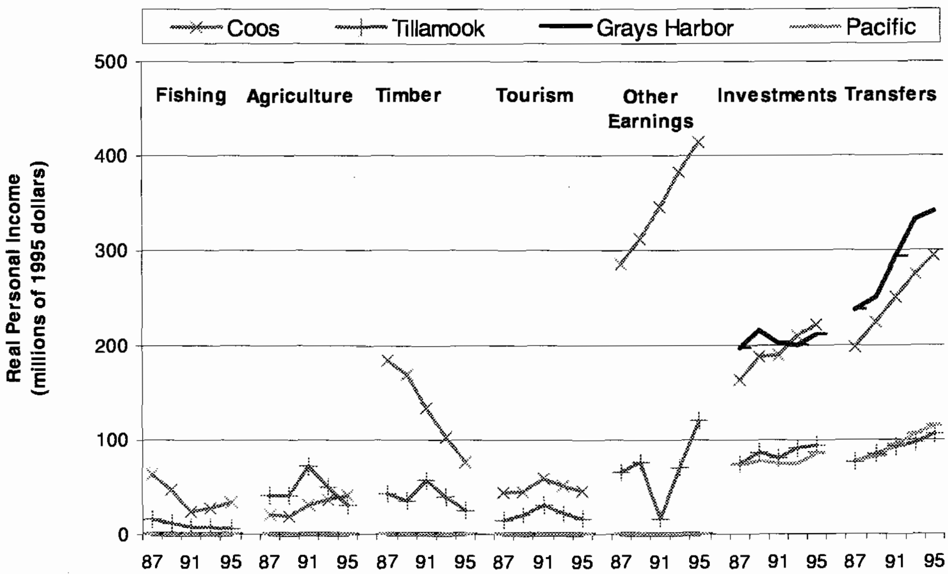
An interesting trend over time is the dramatic increase in transfer payments as a percent of total personal income. This is at least partially a function of the increase in retirees collecting Social Security payments in these areas. As transfer payments have gone up, the percent of total personal income that is "earned" (i.e., employee compensation and proprietor income) has fallen. Tillamook and Pacific Counties now have only about 50% of total income that is earned, which means that there is a lot of wealth in these counties that is not tied to the local businesses or industries (Figure 2.5).

levels, and fewer with college or graduate degrees.

Coastal sectors with the highest proportion of employment are services, retail trade, and government. A comparison of Coos and Tillamook Counties shows the influence of agriculture and dairy on Tillamook County (Figure 2.2). Pacific County also has more agricultural employment than Grays Harbor, as well as more government and other manufacturing employment (Figure 2.3). In terms of payroll, services and retail trade take a lesser role due to part-time employment and lower paying jobs, but government is still by far the highest. Lumber and wood products, which had much lower employment than services, has a payroll nearly as high in Tillamook and Coos Counties.

A focus on the natural resource industries (agriculture, fishing, timber, and tourism) in the Oregon counties shows that timber has declined in relative importance, while agriculture, fishing, and tourism have remained fairly constant. The major change, however, has been the increase in all other industries in these counties, reducing the relative importance of the natural resource industries (Figure 2.6). The income analysis for the two Washington counties is still in progress.

There are other indicators of this declining importance, such as the dramatic decline in commercial troll caught coho salmon in Oregon and Washington. On the recreational side, salmon and steelhead catch rates and tag sales have also declined in recent years.



Note: Income for 1993 in the fishing, agriculture, timber, tourism, and other sectors were interpolated by averaging the values for 1991 and 1995. Personal income values for fishing, agriculture, timber, tourism, and other earnings for Grays Harbor and Pacific counties have not been estimated yet.

Figure 2.6. Real personal income sources for Coos, Tillamook, Grays Harbor and Pacific counties, 1987 - 1995.

Applications

Publications:

Johnson, R. 1999. Human Systems and Estuaries in Oregon and Washington. Speaker summary in: G. McMurray, ed., *Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, Workshop Report* (in press).

Presentations:

Becky Johnson, "Human systems and estuaries in Oregon and Washington." PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Workshops:

Becky Johnson and Laurie Houston attended the PNCERS Workshop on Linking Social and Ecological System Models, May 29-30, 1998, University of Washington.

Both also attended the PNCERS Social Science Workshop, July 27, 1998, Corvallis, Oregon.

Becky Johnson attended the PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Becky Johnson attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:

Hans Radtke and Shannon Davis of The Research Group, Corvallis OR

Nancy Bockstael, University of Maryland.

Personnel

Rebecca Johnson, Associate Professor, Oregon State University

Laurie Houston, Faculty Research Assistant, Oregon State University

Integration & Interaction

Now that we have some of the socioeconomic background information on our four areas, we want to focus on the interactions between the human system and the natural system, i.e., how does the natural system impact the human system, and how does the human system impact the natural system? One of the major impacts of the natural system on people is that it serves as an attraction for both residents and tourists. Previous surveys have shown that one of the most often stated reasons for people to move to the coast is the natural environment and the associated recreation opportunities. Those same features draw recreational visitors. In the case of estuaries, opportunities for fishing, crabbing, boating and wildlife watching are major attractions for recreational visitors.

Impacts of humans on the natural system of estuaries include site hardening (impervious surfaces) which can affect water quality and quantity, marina development which can affect water quality and habitat, and recreation use which can impact species abundance and health.

The focus of the social scientists in PNCERS will be to develop models that will predict or explain the human component of the systems, e.g., explain residential development processes and recreational development processes. Other scientists will then supply the linkages between these changes in the development and natural system indicators.

Plankton Patchiness and Environmental Correlates ....Project 3

Gordon Swartzman

Introduction

The aim of this project is to improve our understanding of the spatial distribution of fish and plankton in the coastal near-shelf region, based on analysis of multi-frequency acoustic data and supporting environmental data.

The data were collected by the National Marine Fisheries Service Alaska Fisheries Science Center during July and August 1995 and 1998. Acoustic data were taken using a Simrad EK500 split beam echosounder system at 38 and 120 kHz. Surface temperature, salinity and fluorescence were sampled as well as occasional CTD's, and ocean current information with depth is available from an Acoustic Doppler Current Profiler (ADCP).

Using image processing algorithms on the acoustic images we locate shoals of fish and patches of plankton in the water column. The resultant 3-D spatial map of the spatial distribution of fish and plankton allows us to examine how the patchiness changes with changes in front features, bottom depth and latitude. The zooplankton patch distribution will provide a model for food resources in the nearshore ocean environment, that hopefully, can, by relating it to ocean features, be extended to predict zooplankton distributions under different ocean conditions.

Results & Discussion

Most of our effort this year has involved obtaining and processing the acoustic survey data for 1995. The data are extensive and have stressed our disk systems. The full data set consisted of 24 CD's, each with about 600 megabytes of

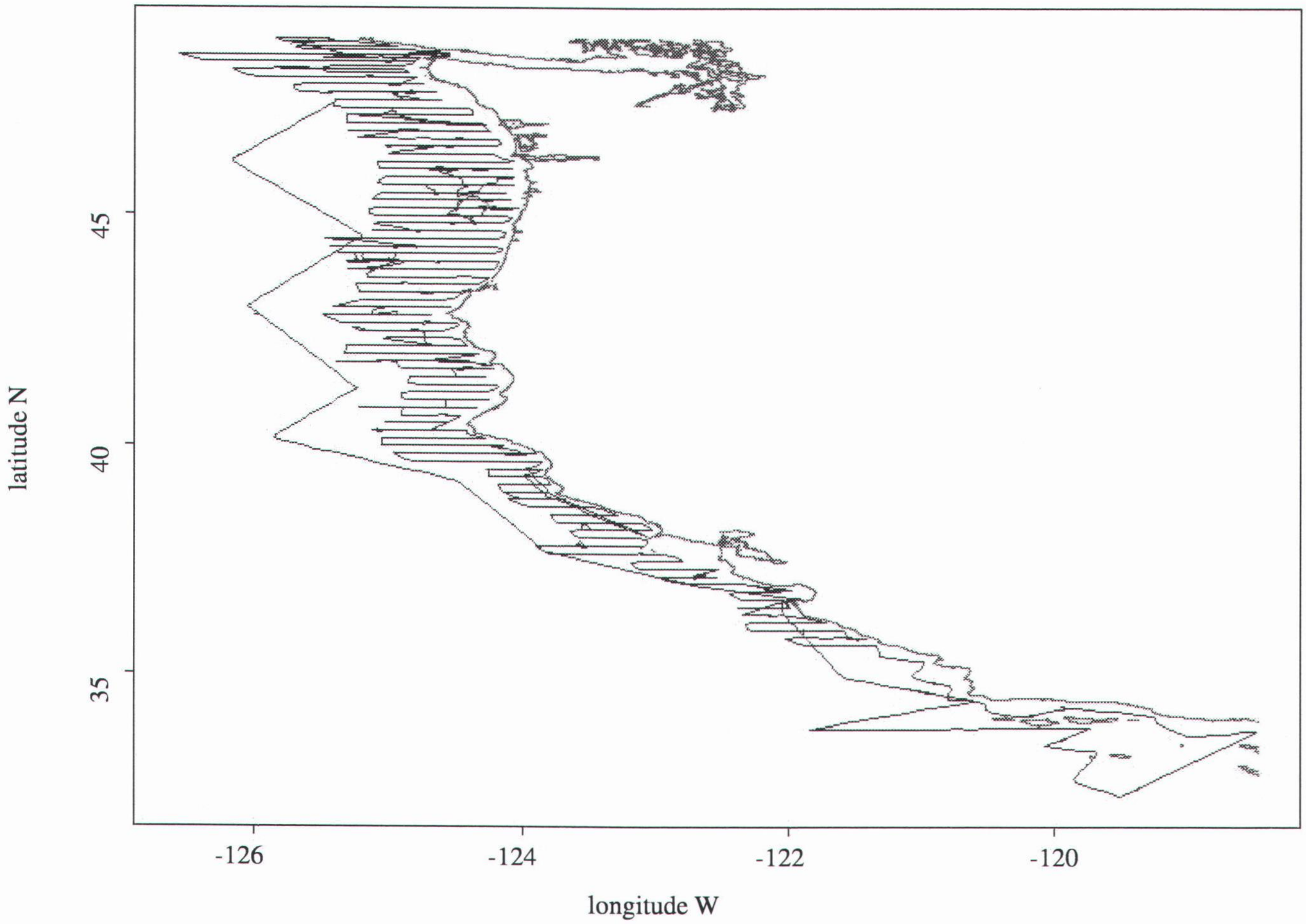


Figure 3.1. Transect lines for 1995 NMFS acoustic survey off the U.S. west coast. Survey transects are shown as straight lines and coastline as irregular line. The survey began in Seattle, zigzagging south offshore and then began regular, parallel east-west transects moving north.

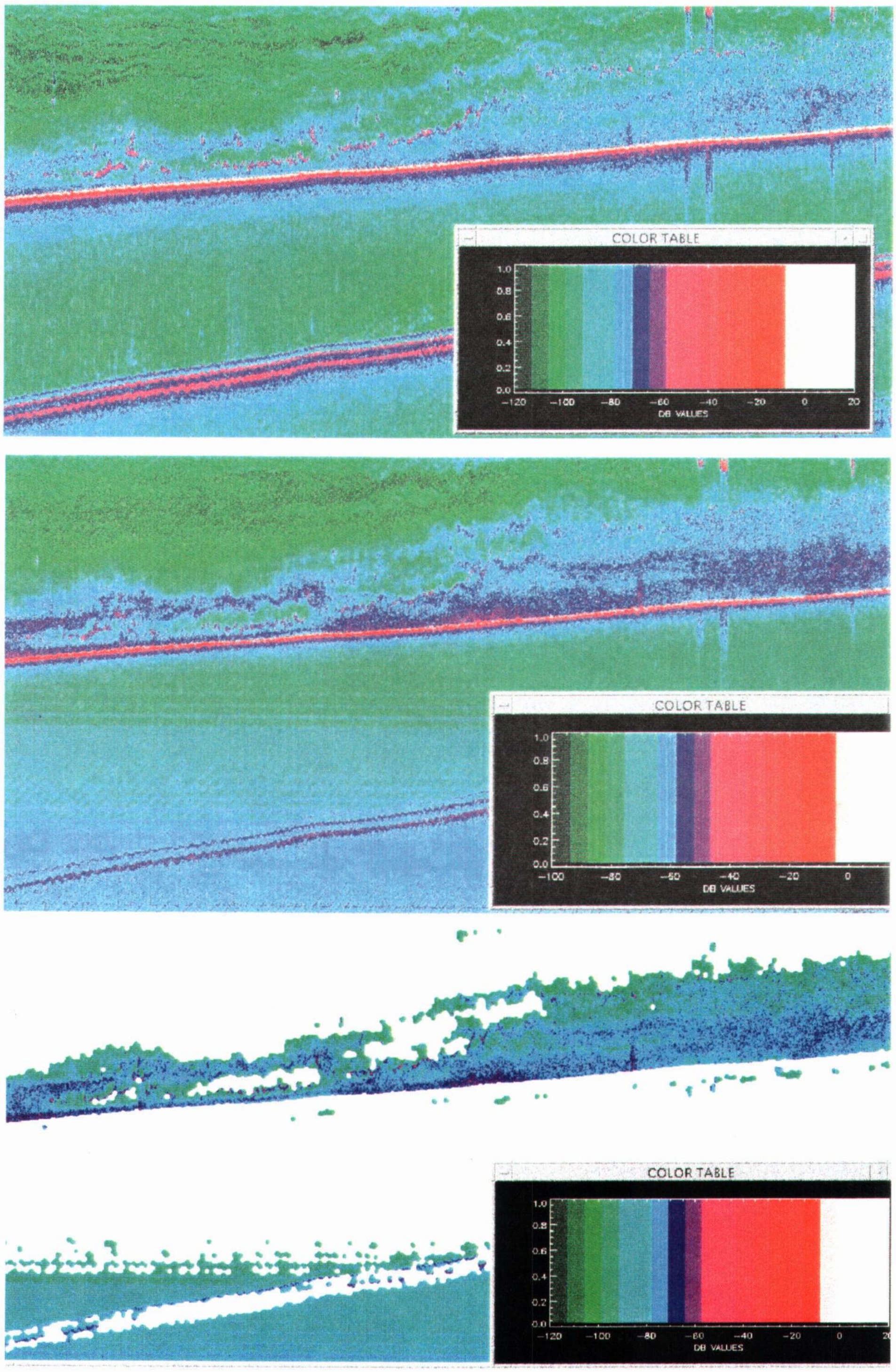


Plate 5. Three panels showing identical acoustic backscatter images at 38 kHz (top panel), 120 kHz (middle panel) and their difference (120 – 38 kHz; bottom panel) after morphological processing. Color tables in dB are on each figure. The difference image shows 0 dB difference within fish shoals and positive differences in the patch around the fish shoals, indicative that the plankton were, at this time, surrounding the fish shoals.

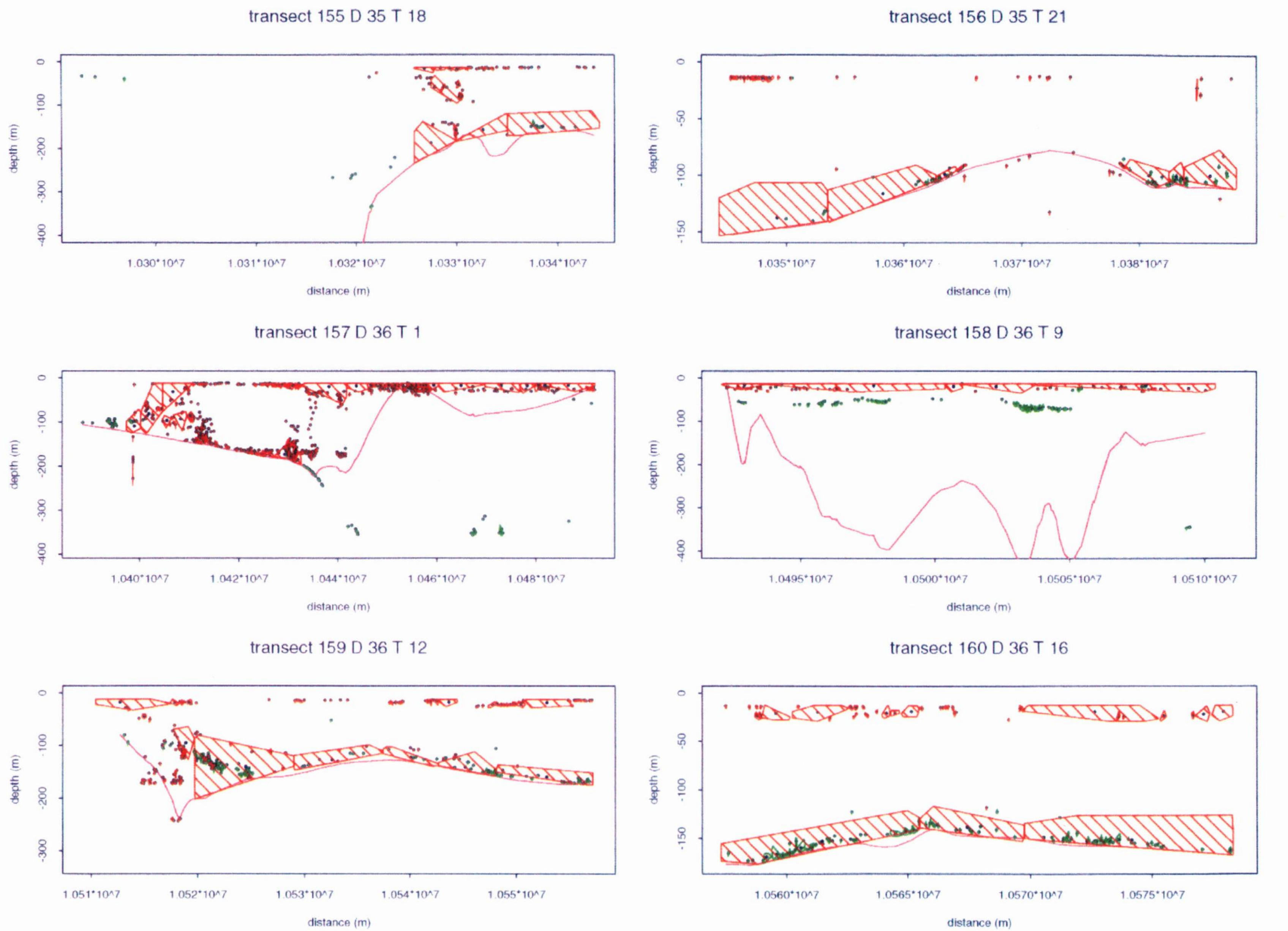


Plate 6. Plot of several transects. Plankton (larger patches) are cross hatched diagonal to the lower right. These plots show many fish shoals inside of plankton patches.

data. After initial processing the data were reduced to 1700 images for each frequency. Each image covers a 5 nautical mile transect segment. Each image is 1000 pixels horizontal and 500 pixels vertical, resulting in pixel resolution of 8m horizontal x 0.5 to 2 m vertical (depending on the depth of the water column). Figure 3.1 shows coverage from the 1995 NMFS survey.

To further reduce the size of the data file in order to allow us to map the spatial distribution of fish and plankton patches and to statistically examine their spatial distribution and proximity, morphological image processing algorithms were applied to the backscatter images.

A single frequency (38 kHz) algorithm was used for locating fish shoals and a two-frequency algorithm (38 and 120 kHz) for plankton patches.

The two-frequency algorithm is based on the relationship between sound reflection and wavelength. Because zooplankton are in a size range close to the wavelength used in the echosounders their "visibility" is greater at higher frequency. This is not true for fish, which, being significantly larger, reflect sound of both frequencies about equally. Plate 5 shows backscatter images at 38 and 120 kHz and an image of the difference between the 120 and 38 kHz images.

Small, high backscatter (red) patches that are visible at both frequencies, but have 0 dB difference in backscatter are fish shoals. Larger patches surrounding the shoals have higher backscatter at 120 than 38 kHz and are likely plankton patches.

After processing we produced distribution plots for fish shoals and plankton patches for each transect in the survey (Plate 6).

At higher orders of organization we have begun a search for biological signals such as vertical migration or bio-physical interaction (e.g. attraction to surface or thermocline.)) For this analysis we combine all survey transects and look at average subtracted backscatter as a function of time of day and depth. Figure 3.2 shows one such pattern -- a band of plankton at 175 m which disaggregates at night.

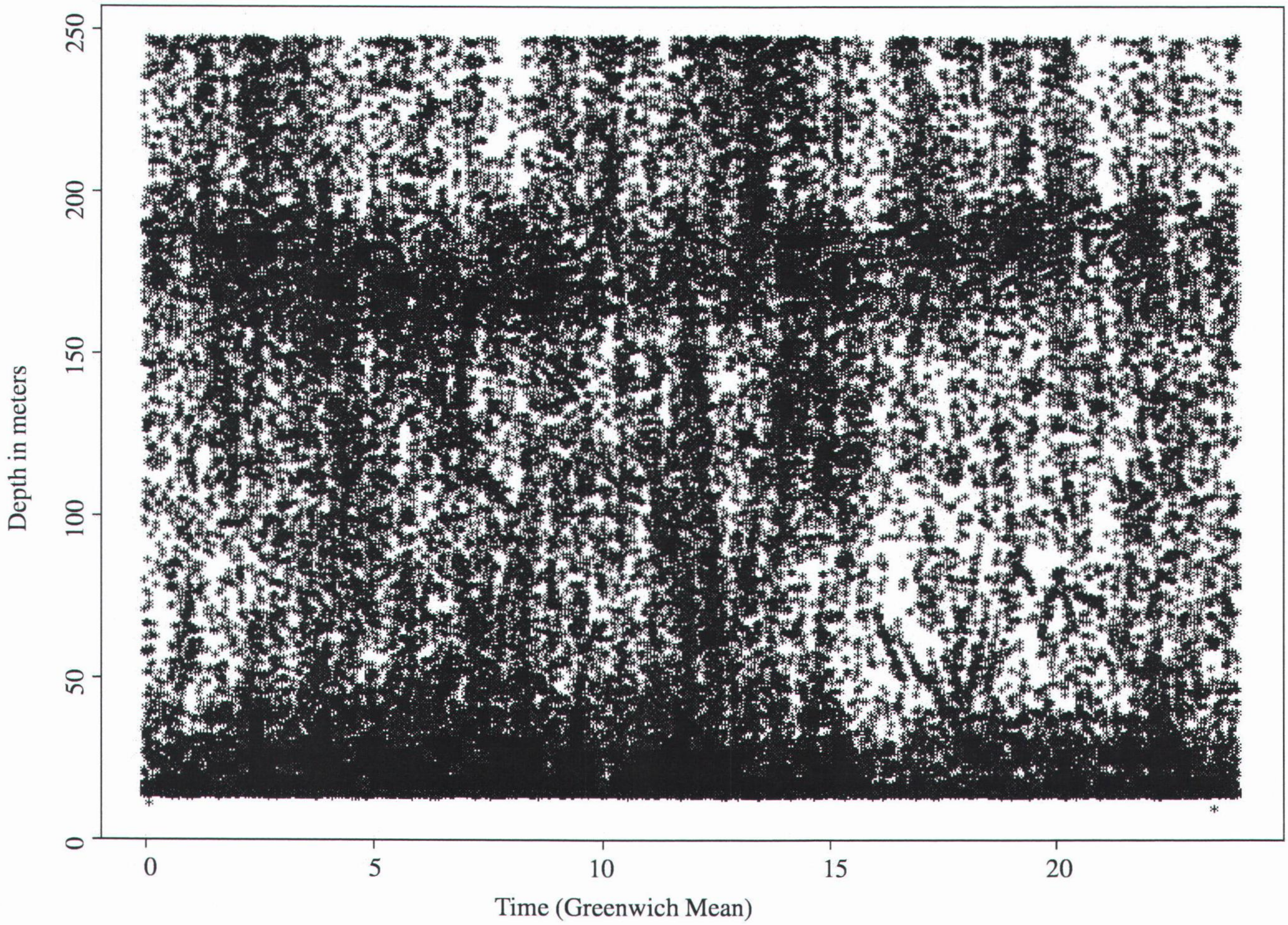


Figure 3.2 Average subtracted backscatter for all surveyed transects as a function of time of day and depth.

Ongoing Analysis
To relate the distribution of fish shoals and plankton patches to environmental conditions several analysis approaches are being used. They involve either 1) binning the data into small (e.g. 100-250 m) bins and using either nonparametric regression or correlation (e.g. spectral analysis) methods to test for the relationship of patch density to such environmental variables as bottom depth, temperature, latitude, and current flow, or 2) examining the distribution of distance from plankton patches to fish shoals for evidence of clustering (e.g. proximity). In the first method we look for scales of association between the fish or plankton and environmental conditions (spectral analysis) or test for possible association between high density regions of fish or plankton and ocean features such as fronts or eddies or upwelling regions, which are identified by their physical properties. In the second approach we look at distances between fish shoals and their nearest neighbor plankton patch and test whether these distances are random (Poisson) or whether there appear to be more plankton patches close to fish shoals than would occur if the patches were randomly distributed.

Integration & Interaction

This project will interact closely with the coded wire tag project of Ray Hilborn. Our idea is to relate ocean survival from different river systems to the nearshore zooplankton patchiness in the neighborhood of these river system. Because the surveys were made in July-August, they transect nearshore regions during the period that smolts have just entered the nearshore environment and thus should give a fair picture of what food resources various smolt populations encounter.

We also will interact with Curtis Roegner and Alan Shanks' larval distribution project. Our collaboration will involve comparing the distribution of larval patches with zooplankton patches that may either serve as food or help to examine the relationship between larval patches and ocean features.

A third interaction will be with Julia Parrish's bird colony project. We will be able to look at the distribution of plankton around each of the studies colonies and examine the relationship of plankton density to distance from the colony, providing a food potential map for these colonies during the survey period.

Applications

Publications:
None.

Presentations:
"Near-shore fish and plankton distribution: How to see the plankton through the noise." PNCERS Eat and Learn Seminar Series, February 5, 1999, University of Washington.

Workshops:
PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
Jeff Napp, Chief Scientist, Alaska Fisheries Science Center

Personnel

Gordon Swartzman, Professor, University of Washington

Seabirds As Reflectors of Environmental Change .... Project 4

Julia K. Parrish

Introduction

In the coastal environment, it is often difficult to determine the degree to which human factors (e.g., harvest, development, pollution, disturbance) affect natural resource populations relative to physical factors (e.g., upwelling, temperature, storm severity, ENSO). This difficulty is compounded because many of the commercially important species are subtidal, making sampling a problem. Finally, species such as salmon - although thought to be highly sensitive to the nearshore environment in the first 90 days of life - are not sampled until they return as adults years later. As upper trophic level predators, seabirds are excellent indicators of marine environmental condition, because they range widely over the nearshore environment while remaining bound to a single site - the colony - during the breeding season. Thus, unlike other upper trophic level marine organisms (e.g., large finfish, marine mammals), seabirds can be easily and repeatedly sampled. The PNCERS program is using seabirds as a stand-in for commercially and culturally important species such as salmon to gain insight into how annual change in the nearshore environment "trickles up" through the food web to affect the demography of upper trophic level species.

At the same time, seabirds are also predators on salmon smolts and other nearshore upper water column fishes. In the lower Columbia, seabird predation may account for as many as 26 million out-migrating salmon smolts. Thus, studying the food habits of seabirds can provide indirect information on the predation risks salmon smolts experience.

How seabirds reflect integrated environmental conditions in the coastal nearshore environment is a function of where and what they eat. PNCERS has chosen a set of piscivorous species respectively confined to the most upper portions of the water column (glaucous-winged gulls), nearshore habitats such as kelp beds (cormorants), and upper water column to deep water (100 m, common murres). The bulk of our re-

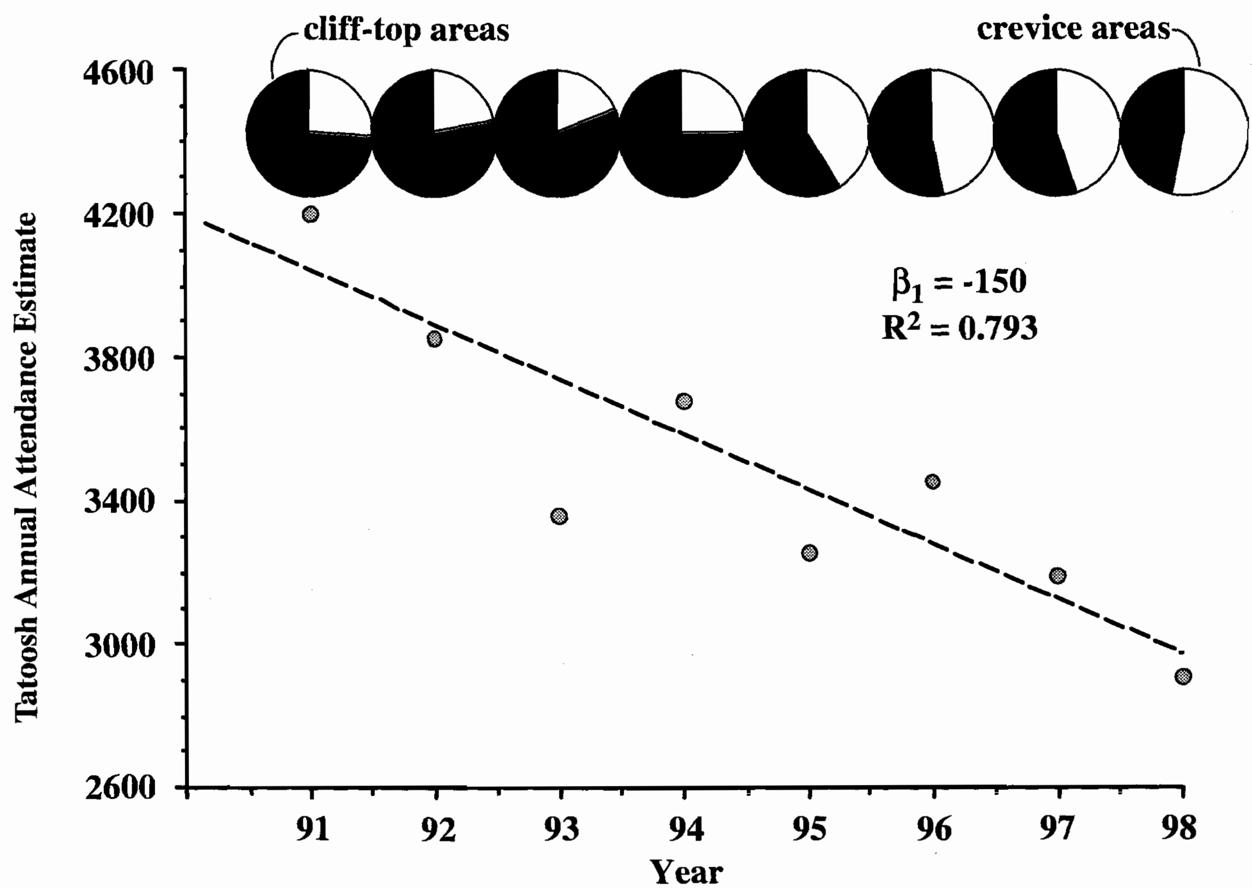


Figure 4.1. The annual population index (attendance equals number of birds present on the colony at any one time) from 1991 through 1998. Pie charts above each year indicate the division between cliff-top nesters and crevice nesters.

search focuses on murres, as this species "sees" the same foraging environment as do large finfish.

PNCERS has two main seabird field sites: Yaquina Head in Newport, Oregon and Tatoosh Island in Neah Bay, Washington. For the former colony there is population information on common murres and cormorants collected by USFWS personnel. For the latter colony we have population information on common murres, cormorants, and glaucous-winged gulls dating back to 1991, and dietary information on murres dating back to 1996.

Results & Discussion

To date, we have concentrated our analysis efforts on common murres, our main species of interest. On this species, we collect data on breeding population size, the timing and success of breeding, diet, and the factors affecting reproduction and mortality.

Tatoosh Island

Seabird data on Tatoosh Island were collected by Julia Parrish (PI) and Tim Brown (technician), with occasional assistance by Todd Hass (postdoctoral fellow), Karen Jensen (technician), and Sara Breslow (technician). Tatoosh is the last remaining stable breeding colony in Washington. In 1998, murre numbers continued to drop, accompanied by a concomitant rearrangement of breeding from predominantly cliff-top areas prior to 1998 to predominantly crevice locations in 1998 (Figure 4.1). Within the State as a whole, murre numbers are currently a third to a fifth of their peak in the late 1970s (over 30,000 birds). The reasons for these declines are unclear, but may include:

1. Changes in the physical environment at a basin-wide and/or regional scale which precipitate changes in the amount and/or type of food available.

2. Changes in the amount of predatory pressure experienced, particularly as threatened populations of bald eagles recover.

3. Impacts of human-mediated mortality from oil spills, fishery interactions, and

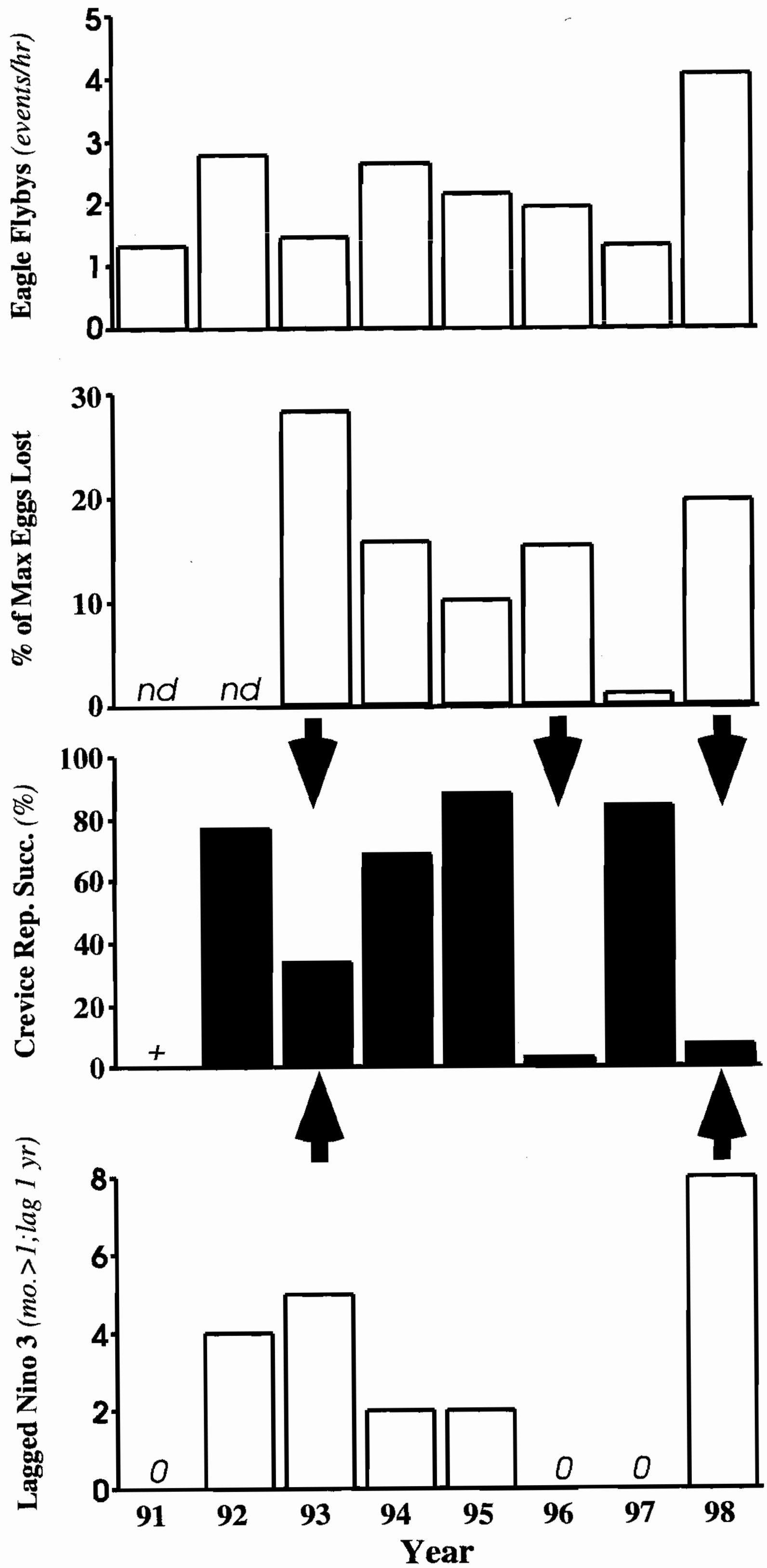
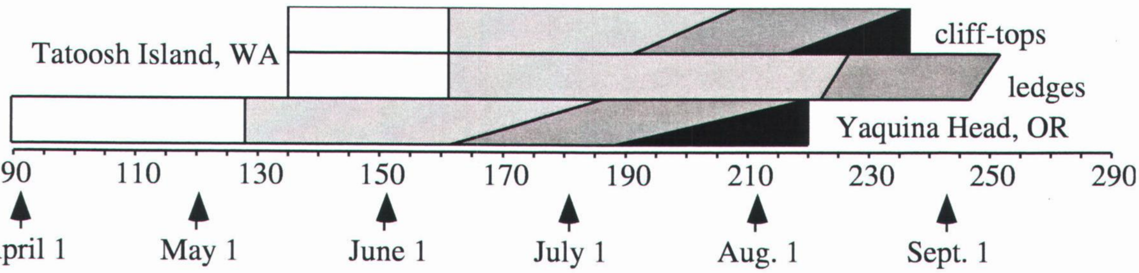


Figure 4.2. The relative effects of bald eagles and physical forcing factors on common murre reproductive success on Tatoosh Island, WA. Arrows denote disproportionate effects.

Table 4.1. Reproductive success and timing of breeding at monitored common murre colonies in Washington and Oregon. Open bar = adults on colony. Light gray = eggs present. Dark gray = chicks present. Black = chicks fledging.

	Pairs Followed	% Eggs Lost or Abandoned	% Chicks Died	Reproductive Success (%)
WA crevices	45	93	?	0 - 7
WA cliff-tops	116	47	46	27 - 29
OR cliff-tops	122	61	28	20 - 28



disturbance when humans deliberately visit a colony or inadvertently come too close (e.g., aircraft, boats).

Colony attendance (a stand-in for population size) may decline because birds are dying, emigrating, or because reproduction is not high enough to replace mortality. On Tatoosh, the murre population has experienced tremendous variation in reproductive success (calculated as the number of chicks leaving the colony divided by the number of pairs attempting to reproduce; Figure 4.2, Table 4.1). In 1998, an El Niño year, we predicted that reproductive success would be low, and it was. However, although there was a clear climate signal (Figure 4.2 and 4.3), there was also a significant increase in the number of eagles visiting the island (Figure 4.2, top panel) which translated into a large amount of disturbance causing an estimated 20% of all laid eggs to be lost in eagle-related panics (Figure 4.2, second panel).

What is clear is that murre reproduction is subject to both predatory pressure and physical changes in the environment (e.g., temperature changes signaling change in nearshore productivity; arrows in Figure 4.2). We are investigating the diet data as a second source of information on the degree to which ocean change resulted in "bottom-up" stresses on these birds. The assumption behind this ongoing work is that environmental change which would cause reproductive failure, and perhaps even emigration, of common murres would also create foraging bottlenecks for large finfish, including salmon.

Yaquina Head

In Oregon, we started field work at two sites - Yaquina Head in Newport and Cape Meares near Tillamook. Julia Parrish (PI), Jennifer Seavey (graduate student), and Karen Jensen (technician) collected the majority of the data from 1 April to 15 July 1998. After reviewing the data, we have decided to concentrate our future efforts at the Yaquina colony, allowing us to maximize data collection, as well as develop collaborative interactions with researchers at the Hatfield Institute of Marine Science, the NMFS Science Center, the USFWS refuge office, and the EPA laboratory.

Prior to our efforts in 1998, no on-colony data had been collected on Oregon murres, although the USFWS refuge biologists routinely make colony attendance counts of murres over a wide range of Oregon colonies. In contrast to Washington, murre numbers in Oregon have steadily risen, and now top 700,000 birds in colonies all along the coast. The Yaquina colony supports perhaps 10,000 murres. Thus, if physically-mediated environmental change was the primary driving factor affecting seabird population size in coastal Oregon and Washington, we would have to speculate that the signals are reversed (positive for Oregon and negative for Washington). To date we are unaware of any oceanographic signal showing this pattern (Figure 4.3).

In 1998, reproductive success on Yaquina Head was also extremely low (Table 1), supporting the theory that murres were responding to a regional-to-basin-wide physical signal (e.g., Figure 4.3). We are continuing to analyze diet data from this colony as well.

Integration & Interaction

Using the basic demographic and diet data from Yaquina and Tatoosh, we are pursuing several avenues of integrated data analysis, both within and without of PNCERS. In general, we are attempting to use these data to examine two broad areas of interest:

1. Do seabirds, specifically common murres, reflect physical changes in nearshore oceanography? If so,

at what spatio-temporal scales?

2. Are seabirds significant predators of nearshore fishes, including salmon?

Seabirds as Reflectors
We are pursuing collection of a variety of physical oceanographic datasets from which we will be able to glean an environmental signal at local, regional, or basin-wide scales. Ilia Halatchev (undergraduate) and Nathalie Hamel (technician) have been working off the web and with NODC personnel to collate monthly anomaly and index data, including:

Local scale - weather station data, buoy data, upwelling index

Regional scale - COADS data, PNW index

Basin scale - PDO index, Niño 3, 3.4 index, SOI

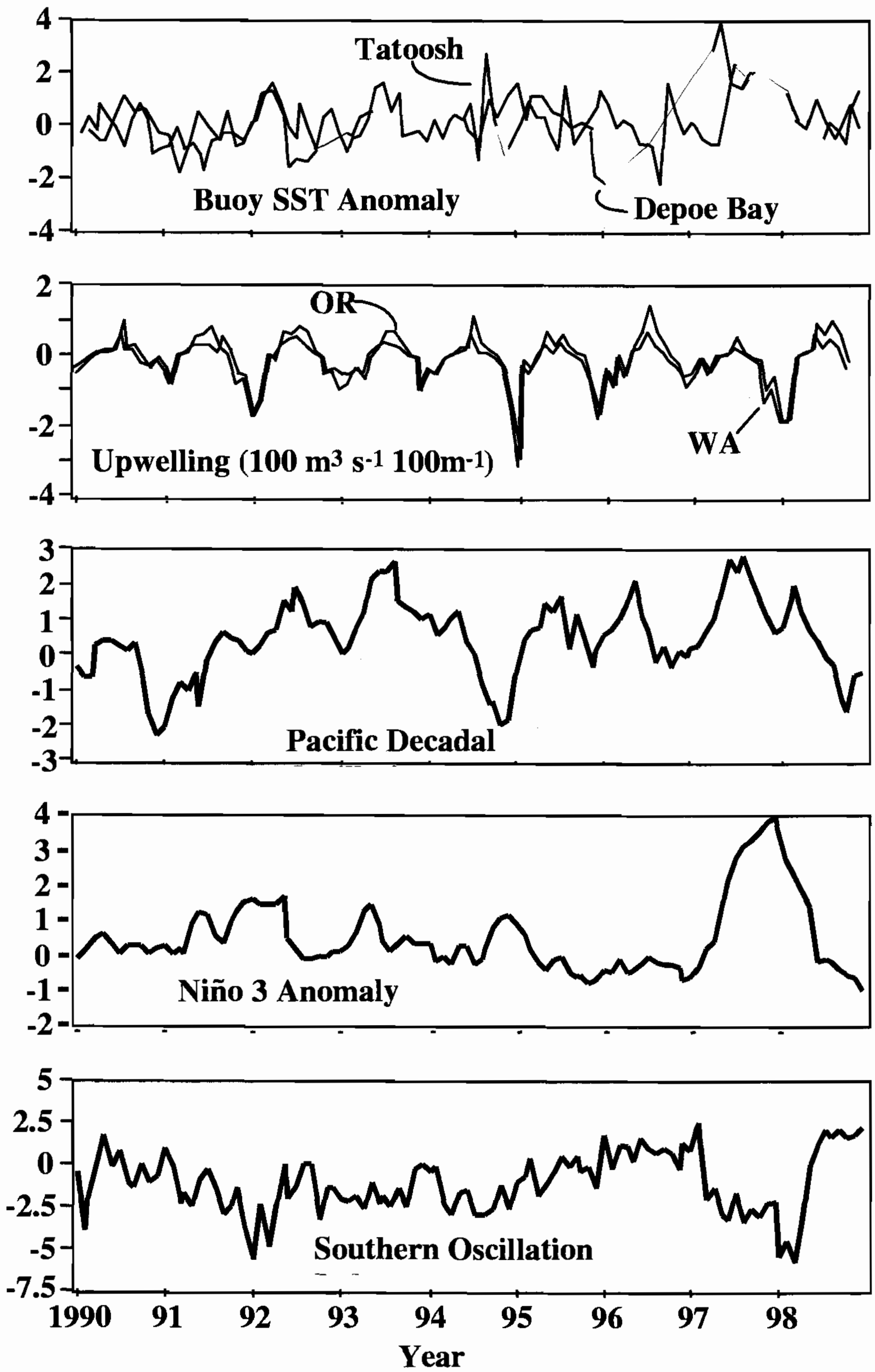


Figure 4.3. Some oceanographic indices at local (first 2 panels), regional (third panel) and basinwide (bottom 2 panels) scales.

We intend to consult and potentially collaborate with PNCERS PI Barbara Hickey and PNCERS collaborator Bob Francis in these efforts.

Our demographic and diet data are also being used as part of a regional study (11 sites from central California to the Bering Sea) of whether and how seabirds reflect environmental change. Although this effort is centered principally on how seabirds responded to the 1997-98 El Niño event, it will also provide a context within which we can place our local scale results. This effort is being spearheaded by Bill Sydeman, Point Reyes Bird Observatory.

Blythe Peterson (undergraduate) has been working with University of Washington archivists, authors of the Washington and Oregon seabird colony catalogs, and the Region 10 Office of the US Coast Guard, to amass historical information on seabird presence along the outer coast of Washington and Oregon. We hope to be able to use these data in future to assess which locations in the nearshore environment have provided upper trophic level species with the most stable sources of food (i.e., been productive enough to sustain a reproducing seabird colony). Eventually, we will marry the historical data with current data from our monitored colonies, as well as with other PNCERS efforts to find stable production signals in the nearshore environment (e.g., NOAA triennial survey data analysis of Gordon Swartzman).

Seabirds as Predators
We are also using our diet data to begin to calculate the food requirements of seabird populations along the outer coast of Washington and Oregon. Our on-colony data provides us with *in situ* boundaries, which will be combined with a set of ongoing studies of seabird diet and growth being conducted by Dan Roby at Oregon State University. Eventually, we hope to collaborate with PNCERS PI's Ray Hilborn and Gordie Swartzman to build an *EcoPath* model of salmon smolt survival in the first 90 days of ocean life.

Applications

Publications:
Parrish, J. K. 1999. Animal Life-Histories and Variability in Pacific Northwest Estuaries. Speaker summary in: G. McMurray, ed., *Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, Workshop Report* (in press).

Presentations:
"Seabird By-catch and the Conservation Trap: Blind Allies and Crying Wolf." Invited Speaker, Pacific Seabird Group Annual Meeting, Blaine, Washington.

"Animal Life-Histories and Variability in Pacific Northwest Estuaries." PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

"Seabird Conservation: Bandaids, Roadblocks, and Reality Checks." Invited Seminar, University of Puget Sound, Washington.

"Saving Seabirds in Washington: Conservation, Conversation, and Education." Invited Speaker, ARCS Foundation, Seattle, Washington.

"Factors Affecting Common Murre Conservation." Invited Seminar, Oregon Institute of Marine Biology, Coos Bay, Oregon.

"Top Down versus Bottom Up: What Affects Common Murres the Most?" Invited Seminar, Monterey Bay Aquarium Research Institute (MBARI), Moss Landing, California.

"Avian Influences: Seabird-Fish Interactions." Invited Speaker, American Fisheries Society North Pacific International Chapter Meeting, Union, Washington.

Olympic Coast Marine Research Workshop Plenary Speaker on the topic of Seabirds. Co-Organizer of the Workshop with Ed Bowlby, Seattle, Washington.

Workshops:
PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
Additional data on reproductive success and foraging parameters were collected on Common Murres as part of a NOAA grant "El Niño 1997-1998 and Spatio-Temporal Patterns of Productivity for the California Current, Gulf of Alaska, and Bering Sea Coastal Marine Ecosystems". This grant focuses on comparisons across eco-region and year. Results from this larger study will be used to compare the degree to which Oregon and Washington seabird field sites are indicative of general region-wide linkages between oceanographic change and upper trophic-level response.

Personnel

Julia K. Parrish, Research Assistant Professor, University of Washington
Todd Hass, Postdoctoral fellow, University of Washington
Tim Brown, Research Technician, University of Washington
Nathalie Hamel, Research Technician, University of Washington
Karen Jensen, Research Technician, University of Washington
Sara Breslow, Research Technician, University of Washington
Jennifer Seavey, Non-matriculated Graduate student, University of Washington
Blythe Peterson, Undergraduate student, University of Washington
Ilia Halatchev, Undergraduate student, University of Washington

Estuarine Bioindicators: Dungeness Crab and English Sole .... Project 5

David Armstrong, Don Gunderson and Kris Feldman

Introduction

This aspect of the PNCERS program is intended to provide a sense of spatial/temporal distribution and abundance of certain macrofauna in OR and WA coastal estuaries. Several objectives guide the focus of this work and its relationship to other PNCERS programs: 1) Evidence that coastal species like Dungeness crab and English sole use estuaries as "nursery" grounds during early life history; 2) the physical processes by which they enter the systems from the open coast; 3) type and quality of nursery habitat (refugia) required by small post-settlement stages of crab and sole; 4) sub-regions of the estuaries where such habitat is most extensive and resultant density and/or biomass of target species highest and; 5) means of communicating such biological/ecological information to colleagues addressing economic, demographic, and decision processes.

Our project is closely associated with the Mapping and Assessing Estuarine Habitat Quality project as further basis to describe the spatial distribution of certain fauna with respect to habitat types and major physical/chemical features and processes. Important in this regard is information about historic anthropogenic changes in landscape within the estuary (e.g. dredging, diking, land-fill, decline in water quality) and how these actions may have curtailed estuarine production of certain fauna. From the larval transport perspective, we are joined in efforts with other PNCERS investigators to study nearshore distribution of advanced larval stages, measure the timing and magnitude of entry into estuaries, and describe physical/behavioral means by which this occurs. We have made good progress this last year in beginning some of the work that addresses objectives above, including our own retrospective analyses of past historic faunal data from Grays Harbor (GH) and Willapa Bay (WB).

Results & Discussion

Larval Dungeness Crab Dynamics

We participated with Alan Shanks and Curtis Roegner to examine physical processes by which Dungeness crab megalopae are transported onshore from the outer Washington coast and into estuaries. Key to this ongoing study is collaboration with Barbara Hickey and Neil Banas to link the biological data we collect to coastal physical data. Neil particularly was instrumental in analyzing the CTD data from the May/June survey in '98. Sampling stations for this component of the study were located 0, 2, and 4 nautical miles (NM) along each of three transect lines radiating out from the mouths of GH and WB (Plate 7). The shoreward stations were labeled "0" NM although, as shown, they actually occur 1-2 NM from shore. During a spring tide series in late May 1998, neuston tows were taken and CTD casts made at each set of stations during an alternating time-series between the two locations divided into four periods: GH1 (5/25-5/26), WB1 (5/27-5/28), GH2 (5/28-5/29), and WB2 (5/29-5/30). Due to logistical reasons and time constraints imposed by the tides, neuston tows were taken only at stations on the outer two transects off each estuary, whereas CTD casts were made at stations on all three transects. In total, each station was sampled twice with respect to combinations of diel and tidal phases – day flood, day ebb, night flood, night ebb. Dungeness megalopae counts per tow were divided by volume filtered to generate numbers of megalopae/100m^3.

CTD data

Temperature-salinity (T-S) graphs generated from the CTD data show that vertical T-S structure did not differ substantially across the GH –WB regions (about 15 km apart), nor between ebb-flood tidal phases within a region. Current and wind time series data (B. Hickey, this report) show that coastal oceanographic conditions along Washington during these 5 days were relatively quiescent, providing only weak and unsustained upwelling and downwelling events scattered across time. Interestingly, the two diel-tidal phases in which the highest station-specific densities of megalopae off Willapa Bay were found (5/27 night ebb and 5/30 night flood) corresponded to northward-flow, downwelling events (see B. Hickey, this report). The most conspicuous features of the nearshore during this period was evidence of 1) a northward flowing low salinity water in the Columbia River plume (Plate 7; 2m salinity contour) and, 2) rather high surface temperature indicative of downwelling events. Salinity was about 22-24 ppt and 25-28 ppt off WB and GH, respectively, in accord with northerly flow and thus lower salinities nearer the freshwater Columbia River source towards WB. While some surface temperature profiles were about 12°C during the first 2 days of the cruise, temperatures warmed to about 13.5°C, reflecting a downwelling trend (Plate 7).

Megalopae distribution and abundance

Larval crab density (#/100m^3) averaged across all diel-tidal combinations for all stations and all four sampling periods show that, in general, megalopae were much more abundant off WB than GH (Figure 5.1). Across sampling periods for both GH and WB, the number of megalopae caught during night was much higher than that caught during the day (Figure 5.1a). However, megalopal density did not differ between ebb and flood tidal stages, between diel-tidal combi-

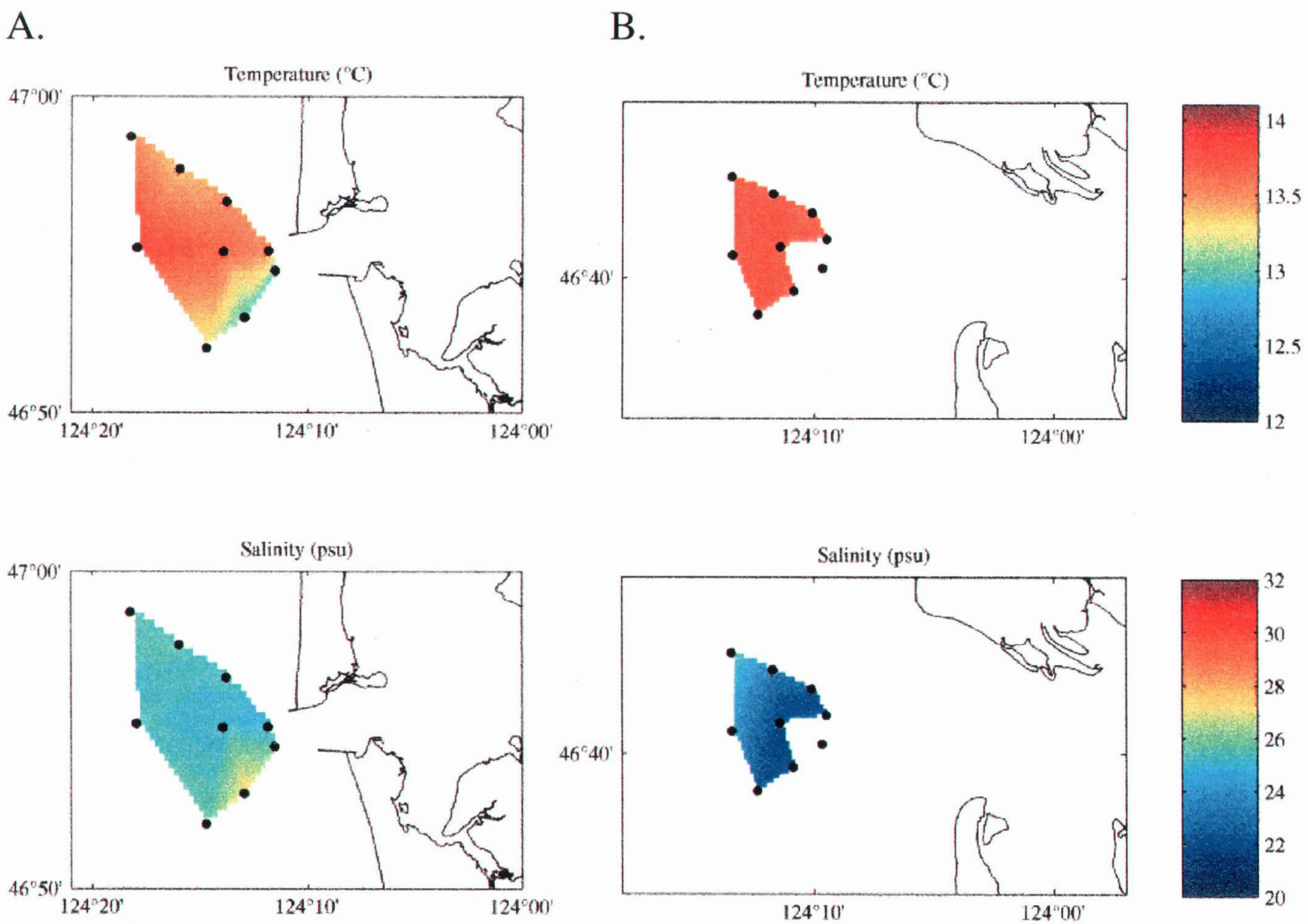


Plate 7. Temperature and salinity contour graphs generated from CTD data taken at 2m depth at stations off A) Grays Harbor during the 5/28/98 day flood and B) Willapa Bay during the 5/30/98 night flood. Relatively low salinities recorded during these periods suggest northward flowing low salinity water from the Columbia River plume while relatively high surface temperatures are indicative of downwelling events.

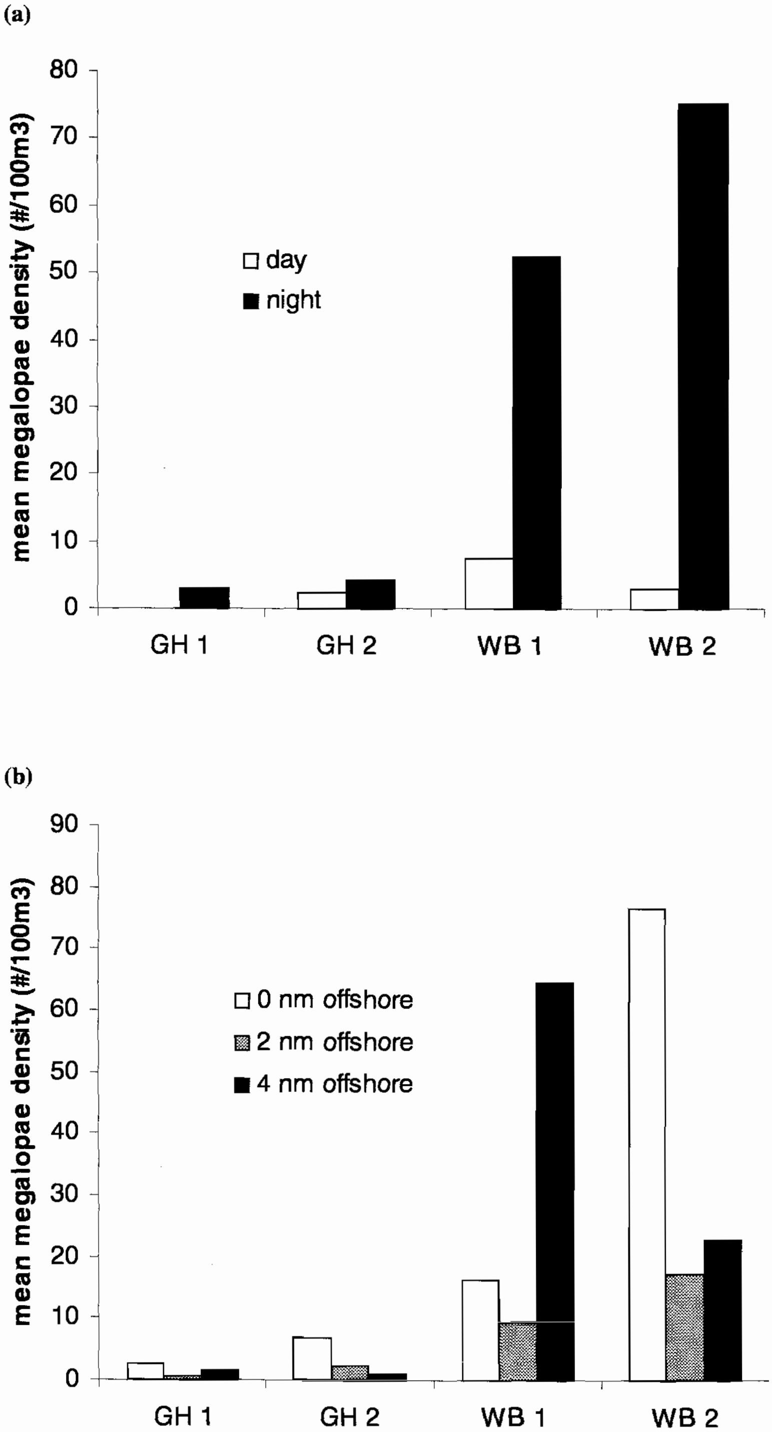


Figure 5.1. Mean density of Dungeness crab megalopae collected from neuston tow samples collected off of Grays Harbor and Willapa Bay. Data from four sampling periods (5/25-5/26/98 and 5/28-5/20/98 off Grays Harbor [GH 1 and GH 2, respectively] and 5/27-5/28/98 and 5/29-5/30/98 off Willapa Bay [WB 1 and WB 2, respectively]) were pooled by A) day and night and B) distance offshore. Note that, in general, megalopae were more abundant off Willapa Bay than Grays Harbor and more abundant at night than during the day, but no consistent trends were observed with respect to distance offshore.

nations, nor with distances offshore in any consistent way across the sampling periods.

Time-series of megalopae caught at GH and WB stations indicate that abundance and distribution varied greatly at several different spatial and spatial-temporal scales. The overall regional difference in megalops abundance between GH and WB, with higher abundance in the latter, is evident. However, even within both regions, the distribution of megalopae across the stations was very patchy and changed dramatically with time. Off Willapa Bay, for example, the two highest values of megalops density measured for the stations at different diel-tidal phases were 371/100m^3 (5/25 night ebb) and 548/100m^3 (5/30 night flood). Yet, the densities at their neighboring stations, 2 NM away, were 9/100m^3 and 31/100m^3, respectively. In terms of distance offshore, the spatial-temporal trend may be seen in the WB data. During the first sampling event off that estuary (WB1), highest density was among the 4NM stations, but 48 hours later (WB2) density was highest at the "0" NM stations closest to the entrance (Figure 5.1b).

Large concentrations of megalopae off WB were found during downwelling events supporting the hypothesis that planktonic larvae would be advected onshore with the surface layer of coastal water during northward flow. Lower salinity surface water found during WB2 (5/29-30 flood-ebb) may be the result of Columbia River outflow and northward direction of the plume along the coast. Low-resolution satellite image of chlorophyll concentration along the Oregon-Washington coast during this period shows chlorophyll concentrated along the coast slightly north of the mouth of the Columbia River, in contrast to its general spread south of the River during the summer resulting from southward flow. High megalops abundance off WB may have originated to the south as a large patch entrained in the Columbia River plume, perhaps later to reach GH to the north. Although larval abundance was low off GH during this 5-day survey, estuarine settlement was extremely high at some time during the late spring-early summer period. Ongoing work for the Corps of Engineers to monitor crab settlement in shell habitat mitigation plots (Visser and Armstrong, unpublished data) indicated some of the highest post-settlement densities of juvenile instars (J1) ever measured in samples taken in May 1998 (over 800/m^2 in some habitat; more typically 100-200/m^2, e.g. 1990).

That Dungeness megalopae were not associated with water of certain temperature and salinity in any consistent way during our study suggests that simple, local water properties alone are not likely to serve as predictors of megalopae abundance and distribution. Large-scale coastal oceanographic processes clearly play a major role in the coastal transport dynamics of megalopae. The utilization of current and wind time series data and close collaboration with Barbara Hickey's group will be crucial in the continued study of physical processes by which Dungeness megalopae are transported onshore and into estuaries.

Subtidal Trawl Surveys 1998

A series of subtidal trawl surveys were conducted in June and August in GH and WB (WA), and Yaquina Bay (YB) and Coos Bay (CB), Oregon. Survey protocol was followed as developed during Sea Grant research in the mid 1980s in which estuaries were stratified based on properties such as summer temperature-salinity regimes, sediment type, and distance from the mouth. A small mesh beam trawl developed by Gunderson was used to target 0+ and 1+ juvenile Dungeness crab, English sole, and a variety of other fishes and invertebrates including staghorn sculpin (a

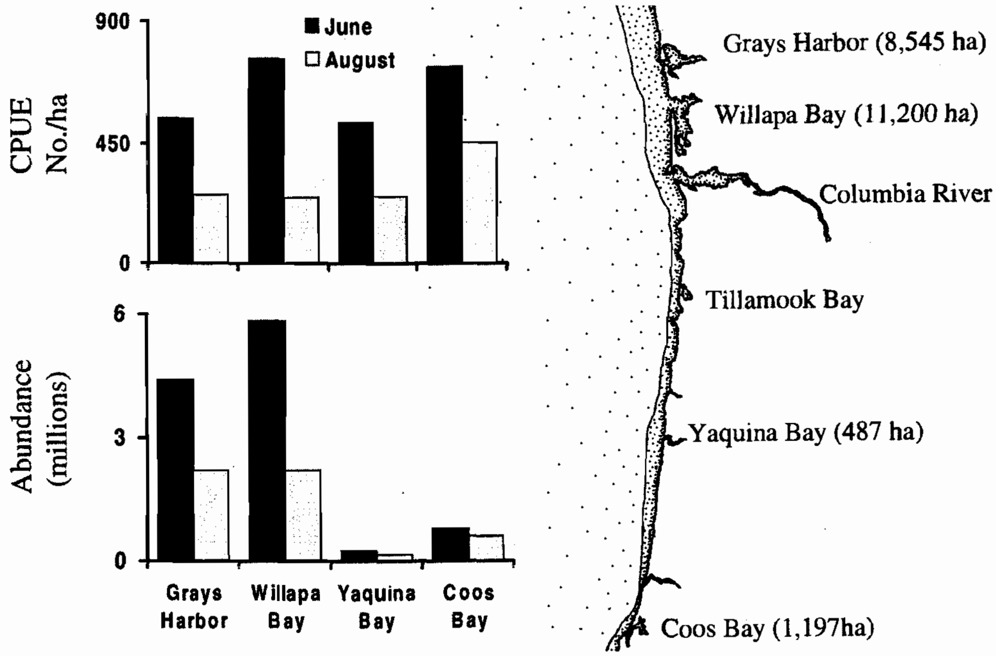


Figure 5.2. Average 1+ Dungeness crab CPUE (catch per unit effort) and abundance based on subtidal trawl surveys in Grays Harbor and Willapa Bay (WA) and Yaquina Bay and Coos Bay (OR), during June and August 1998. Note that mean density (CPUE) was comparable across all four estuaries, including a pattern of decline from June to August, while overall abundance was much greater in Grays Harbor and Willapa Bay due to the greater size of these estuaries relative to Oregon estuaries.

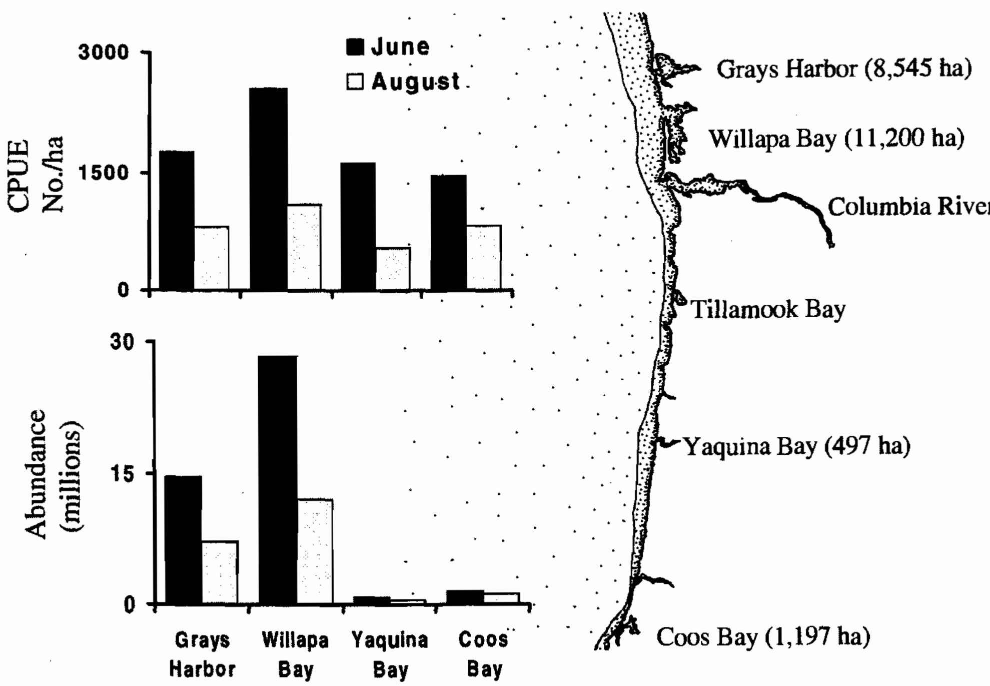


Figure 5.3. Average English sole CPUE and abundance based on subtidal trawl surveys in Grays Harbor and Willapa Bay (WA) and Yaquina Bay and Coos Bay (OR), during June and August 1998. Note that, similar to 1+ Dungeness crabs, mean density (CPUE) of English sole was comparable across all four estuaries, including a pattern of decline from June to August, while overall abundance was much greater in Grays Harbor and Willapa Bay due to the greater size of these estuaries relative to Oregon estuaries.

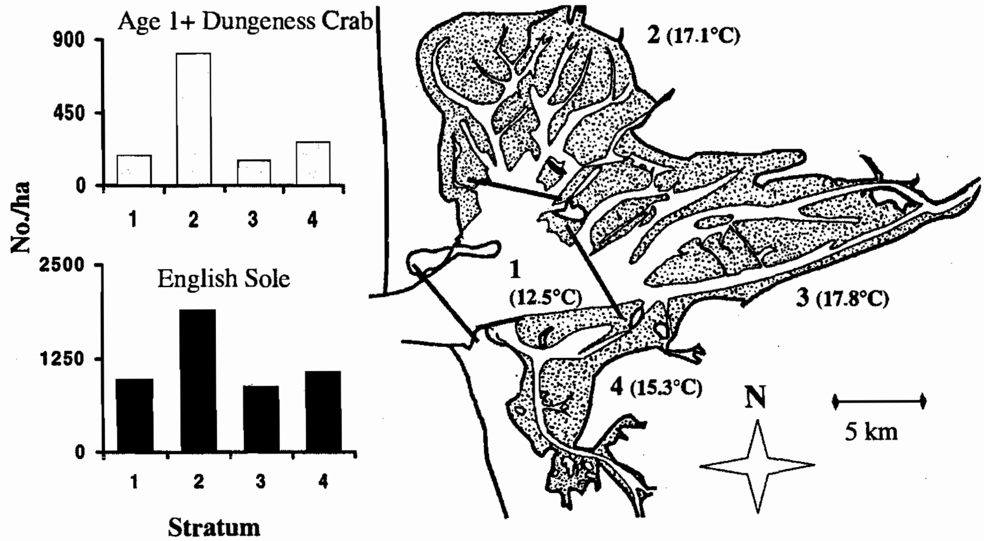


Figure 5.4. Average CPUE for 1+ Dungeness crab and English sole across subtidal strata in Grays Harbor (WA) during 1998 (months June and August, pooled). Note that density differed substantially across sub-regions, with the highest density of Dungeness crabs and English sole present in strata 2. Map of Grays Harbor shows strata boundaries and corresponding mean summer surface water temperatures recorded over the sampling period.

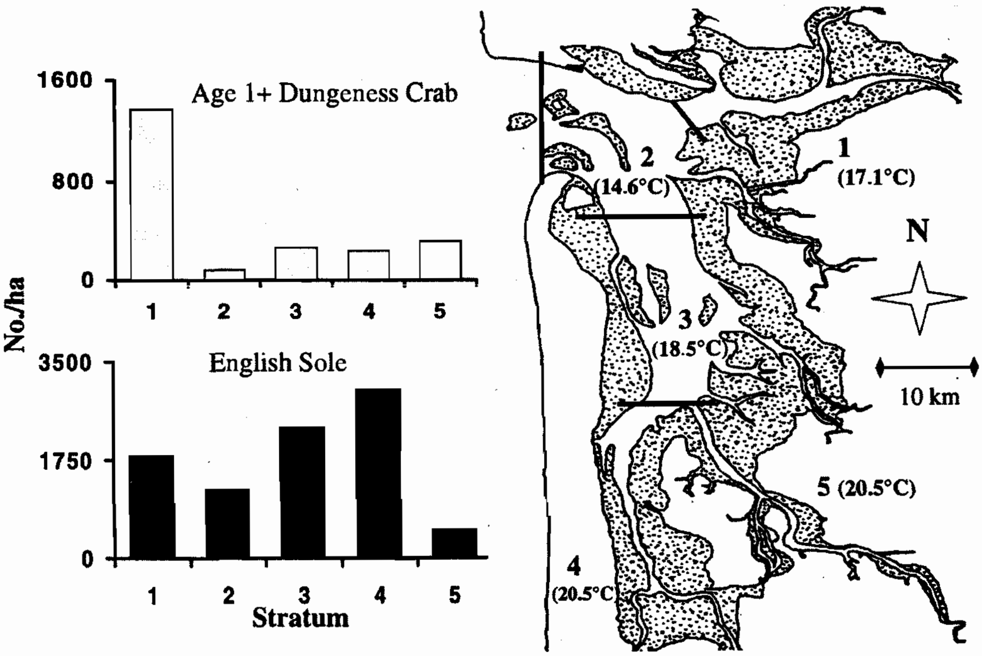


Figure 5.5. Average CPUE for 1+ Dungeness crab and English sole across subtidal strata in Willapa Bay (WA) during 1998 (months June and August, pooled). Map of Willapa Bay shows strata boundaries and mean summer surface water temperatures recorded over the sampling period.

significant crab predator) and crangonid shrimps. While we had previously done these quantitative surveys in GH and WB between 1983-88, this was the first opportunity to measure abundance and distribution of the same fauna in the much smaller Oregon systems, all during the strong El Niño of last year. Each system was stratified into 4-5 sub-regions of 4-5 randomly selected, fixed stations and sampled using GPS to measure distance fished for conversion of animal numbers to density based on area swept. All target species were sorted, counted, measured (mm carapace width for crab; total length for fish), sexed (crab only) and weighed (fishes; crab weights later determined from size-weight regressions). In addition to animal data, catches were sorted when possible to describe and weigh other epibenthic material as partial basis to later classify habitat. Most common materials sorted were bivalve shell (and sorted to common species), allocthanous sticks, woody debris, detrital eelgrass, and macroalgae. Material was weighed wet to 0.1 kg and entered with other station data.

Size of estuarine subtidal area digitized for abundance estimates differs by 20x between WB (11,200 ha) and YB (500 ha), which obviously affects estimated abundance in the systems. Surprisingly however, the mean density (CPUE [catch per unit effort] as #/ha) of both Dungeness crab and English sole was very comparable across the four estuaries, including a pattern of decline from June to August (Figures 5.2, 5.3). Density of 1+ crab was about 500-700/ha in June and 200-300/ha in August in all four estuaries. Estimated abundance, however, was substantially higher in the WA estuaries at about 4-6 million, declining to 2 million in GH and WB during June and August, respectively (Figure 5.2). Density of English sole was about 1550

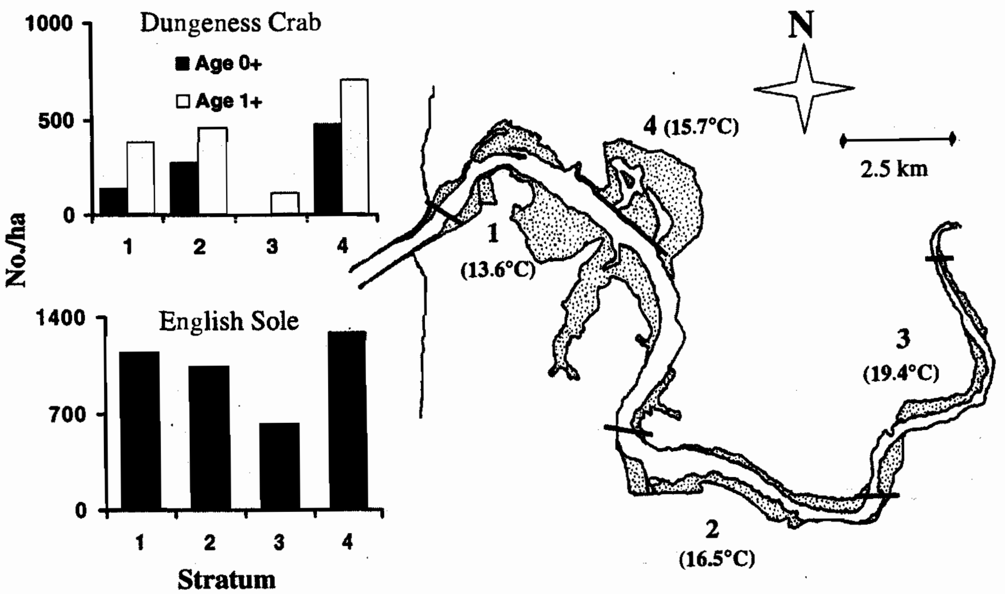


Figure 5.6. Average CPUE for 0+ and 1+ Dungeness crab and English sole across subtidal strata in Yaquina Bay (OR) during 1998 (months June and August, pooled). Note the relatively lower density of crab and sole in strata 3 compared to other strata. Map of Yaquina Bay shows strata boundaries and mean summer surface water temperatures recorded over the sampling period.

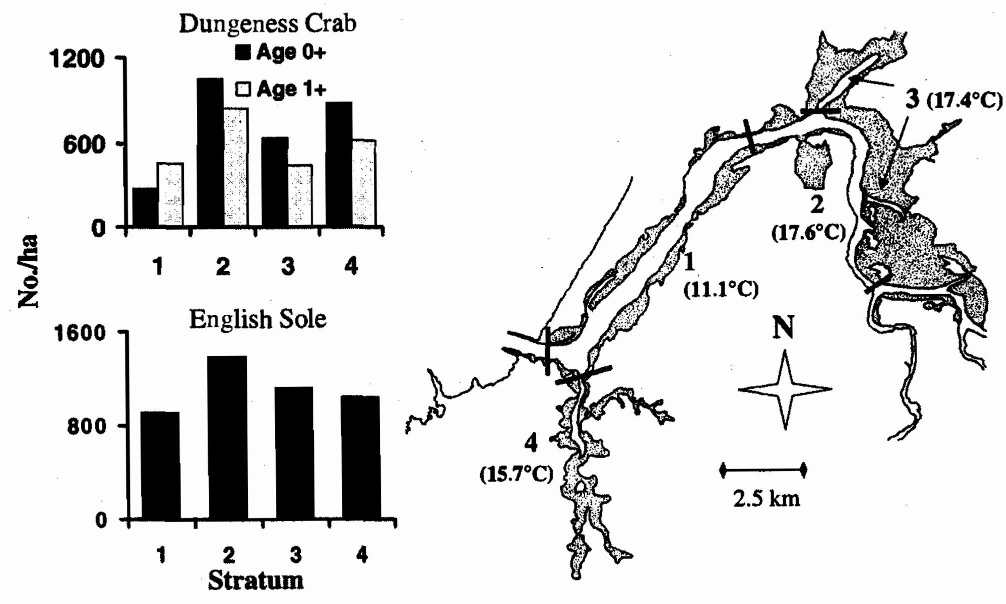


Figure 5.7. Average CPUE for 0+ and 1+ Dungeness crab and English sole across subtidal strata in Coos Bay (OR) during 1998 (months June and August, pooled). Map of Coos Bay shows strata boundaries and mean summer surface water temperatures recorded over the sampling period.

and 700/ha in June and August, respectively, in all estuaries but, again, abundance was 10-30 million in GH and WB and only several 100,000s in YB and CB (Figure 5.3).

While the mean density of crab was comparable among the four estuaries, density and estimated abundance differed substantially across sub-regions of each system. In GH, for example, 1+ crab density was about 4x higher in Stratum 2 (STR2; 900/ha) than in the other three sub-regions (about 200/ha; Figure 5.4). In general, sub-regions with highest crab density tend to: 1) have fairly warm summer bottom water temperatures (about 17°C in '98; see Figures 5.4 - 5.7); 2) are farther into the systems and never adjacent to the estuarine mouths; 3) have more numerous shallow subtidal channels (e.g. see GH STR2, WB STR1, YB STR4, CB STR 2,4 in respective figures) and; 4) have higher quantities of epibenthic shell material and other "structure" indicative of refuge.

English sole appeared to be more uniformly distributed and were at high density within strata at those stations that seemed to occur on a sand substrate (i.e. low quantities of epibenthic material). The only noticeable attributes that seemed to limit sole distribution were in those areas where strong freshwater input was evident, and resultant bottom water salinity fairly low (> 20 ppt). In a system like YB which is essentially defined by the geomorphology of the river channel, upriver stations in STR 3 (Figure 5.6) had relatively few English sole, as did STR 5 in WB (Figure 5.5) which is fed directly by the Naselle River. Also in such areas, the quantity of epibenthic material (e.g. woody debris) is high and may work against this type of fish that commonly buries in sand.

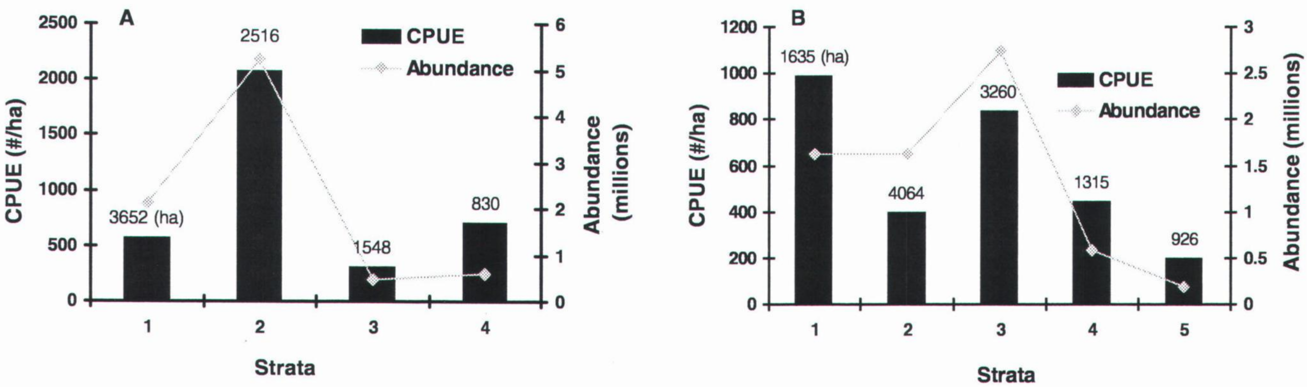


Figure 5.8. Production (CPUE and abundance) of 1+ Dungeness crabs by strata for (A) Grays Harbor and (B) Willapa Bay, Washington. The area of each stratum (number of hectares) is given above each data column. Data were compiled and pooled from beam-trawl surveys conducted from June through August, 1983-88. Note the high abundance and CPUE of crabs in strata 2 in Grays Harbor and the relatively higher production of crabs in the northern regions of Willapa Bay (strata 1-3) compared to more southern regions of the bay (stratas 4 and 5).

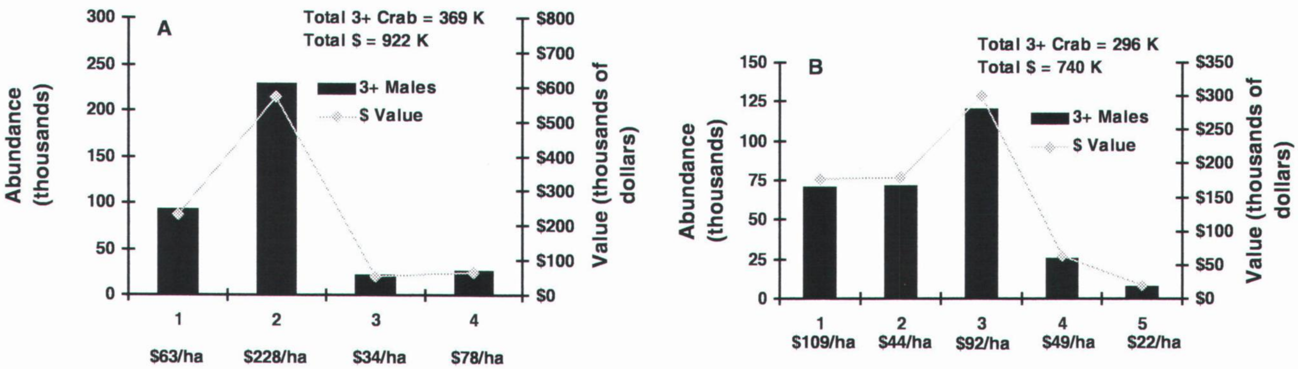


Figure 5.9. Production (abundance and dollar value) of 3+ male Dungeness crabs by strata for (A) Grays Harbor and (B) Willapa Bay, Washington. Dollar values per hectare also are listed under each stratum. Data were compiled and pooled from beam-trawl surveys of 1+ crabs conducted from June through August, 1983-88. Population estimates of 1+ crabs were subjected to published mortality rates and ex-vessel values to derive numbers of 3+ male crabs and total value to the commercial fishery.

Retrospective Analyses

Benthic beam-trawl surveys conducted in subtidal channels of GH and WB from 1983-88 were analyzed to describe the distribution and abundance of 1+ Dungeness crabs. Given the high variability in 0+ density and abundance following settlement as driven by high mortality and patchy survival spatially, 1+ abundance seems a better metric of crab production in estuaries. Population estimates of 1+ crabs were calculated by pooling data collected from June through August, 1983-88, to show long-term trends in mean abundance and catch-per-unit-effort (CPUE; no./ha) by location (strata) within each estuary.

Total 1+ crab abundance during summer in Grays Harbor was 8.4 million crabs averaged over the six-year period. Over 60% of the population (5.2 million crab) was concentrated in STR 2 (Figure 5.8a), which is the northern region of the estuary and is characterized by broad expanses of intertidal habitat intersected by numerous subtidal channels. The importance of production in this area is magnified when viewed spatially since the subtidal of this stratum is about 29% of the estuarine total. STR 1 produced the second highest number of crabs (2.1 million crabs) followed by STR 4 and 3 (0.6 and 0.5 million crabs, respectively; Figure 5.8a). CPUE exhibited a pattern similar to that of abundance, with the highest catch per hectare occurring in STR 2 (2,076 crabs/ha), and the lowest catch per hectare occurring in STR 3 (314 crabs/ha); Figure 5.8a).

Total 1+ crab abundance for WB was 6.7 million crabs averaged over the six-year period. Over 40% of the population (2.7 million crabs) was concentrated in STR 3 (Figure 5.8b), which is located in the middle portion of the estuary (see Figure 5.5). In general, southern regions of the bay (STR 4 and 5) produced fewer crabs (0.6 and 0.2 million crabs, respectively) than mid to northern regions of the bay. Although abundance was highest in STR 3, CPUE was highest in STR 1 (992 crabs/ha), located in the northeastern portion of the estuary, followed by STR 3 (839 crabs/ha; Figure 5.8b).

To estimate how many 1+ crabs would survive to enter and support the commercial offshore fishery, we applied published mortality rates to 1+ populations (Wainwright et al. 1992) to derive numbers of 3+ male crabs. We also assigned dollar values to 3+ crab populations using an average weight of 2 pounds/male and an ex-vessel value of $1.25/lb to estimate the value associated with different regions of the bays. Based upon these calculations, GH would have contributed on average 369,000 3+ male crabs to the fishery each year representing a total ex-vessel value worth of $922,000. STR 2 is the most productive region of the bay with a value of $572,900 based on production of 229,156 3+ male crabs (Figure 5.9a). When values were compared on a per-hectare basis, STR 2 again was the most productive region ($228/ha), followed by STR 4 ($78/ha; Figure 5.9a). These preliminary estimates will be done again with other mortality data if available to construct a range of such production and value/ha.

Willapa Bay would have contributed approximately 296,000 3+ male crabs to the fishery each year representing a total ex-vessel value worth $740,000. The northern regions of the estuary (STR 1, 2, and 3) were more productive in terms of abundance and value than the southern regions (STR 4 and 5; Figure 5.9b). STR 1 contains the highest per hectare value ($109/ha) followed by STR 3 ($92/ha; Figure 5.9b).

These data indicate that Dungeness crab production varies greatly among different regions of each estuary, most likely due to a combination of factors such as benthic prey production, quality and availability of habitat, predator concentrations, and environmental factors such as salinity and temperature. Accordingly, because some areas appear to be of greater importance to estuarine crab production than others, both natural and human-mediated environmental stressors could have differential effects on crab production depending on where and when they occur and the resulting impact to the environment.

Integration & Interaction

As noted in the Introduction, we are fortunate to have strong, productive links to several other PNCERS programs at present. We are providing a sample-link for the Larval Transport and Recruitment program with Shanks and Roegner. Beyond the neuston and CTD data collected this past spring, Dave Eggleston continued studies of larval transport within GH as a function of water properties and wind, and Eileen Visser measured settlement and survival in shell mitigation habitat constructed by the Corps. This activity will continue in summer, 1999. All these studies of larval transport and settlement continue to benefit from work by Hickey et al. on coastal ocean coupling, and we are confident that mechanistic explanations will become more integrated with biological data over time. Integration of our work with that by Ron Thom and Steve Rumrill is important to the overall success of the Mapping and Assessing Estuarine Habitat Quality themes, but the degree of contact was limited last year. We believe that emphasis should be given to this partnership, especially since we have other associated programs pending through Sea Grant and WRAC. The collaboration with Ted DeWitt of the Newport EPA lab was tremendous as opportunity to build our benthic trawl survey around their extensive ecological field program in that estuary. Tom Wainwright of NMFS in Newport continues to interact concerning hypotheses related to crab life history in these systems and alongshore. We view our attempts to equate juvenile crab production with eventual coastal fishery value as a preliminary exploration of ways in which we can better portray our biological data for use in the socio-economic research projects of Dan Huppert, Tom Leschine and Rebecca Johnson. Suggestions and interaction as to how we might proceed further are most welcome.

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Applications

Publications:

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Dumbauld, B., E. Visser, D. Armstrong, L. Cole-Warner, K. Feldman, and B. Kauffman. 1999. Use of oystcr shell to create habitat for juvenile Dungencss crab in Washington coastal estuaries: status and prospects. J. Shellfish Res. (in rcview).

Presentations:
David Armstrong, "Do coastal cstuarics in the Pacific NW support offshore fisheries?" AAAS spccial symposium. Anaheim, January, 1999.

Don Gunderson, "Dcsign Criteria for a Network of West Coast Groundfish Refugia." PNCERS Eat and Learn Seminar Series, February 26, 1999, University of Washington.

David Armstrong, "Entrained but not forgotten: The Geopolitics of Dungcness crab in Coastal Estuaries." PNCERS Eat and Learn Seminar Scrics, March 5, 1999, University of Washington.

Workshops:
David Armstrong attended the PNCERS Workshop on Linking Social and Ecological System Models, May 29-30, 1998, University of Washington.

David Armstrong, Don Gunderson, Kristine Feldman and Grace Tsai attended the PNCERS All-Hands Mceting, January 22-23, 1999, Seattlc, Washington.

Partnerships:
Ted DeWitt. EPA Lab, Newport, OR
David Eggleston. NCSU, North Carolina
Tom Wainwright. NMFS, Newport, OR
Brett Dumbauld. WDFW, Willapa Bay, WA

Personnel

David Armstrong, Professor/Director, School of Fisheries, UW
Don Gunderson, Professor, School of Fisheries, University of Washington
Kristine Feldman, Graduatc student, School of Fisheries, University of Washington
Gracc Tsai, Graduate student, School of Fisheries, University of Washington
Joe Miller, Graduate student, School of Fisheries, University of Washington

Links Between Estuaries: Larval Transport and Recruitment ....Project 6

Alan Shanks, Curtis Roegner and David Armstrong

Introduction

Variation in the supply of larval invertebrates to estuarine habitats is likely a primary determinant of population structure. Larval dispersal is in turn affected by the interaction of larval swimming behavior and hydrodynamic processes. This study seeks to understand the temporal and spatial scales of variability in the transport and dispersal of marine invertebrate larvae to Pacific Northwest estuaries. A primary goal is to determine physical oceanographic correlates with larval abundance. We are therefore measuring larval abundance in two ways: 1) as time series (daily samples) collected with light traps located at various estuarine stations, and 2) as surveys of the coastal ocean during oceanographic cruises. In both cases, abundance of organisms is to be related to physical data acquired from ship-borne and moored instruments.

Light trap samples

We are using light traps to measure temporal and spatial variation in the abundance of crustacean larvae within the Coos Bay, Grays Harbor, and Willipa Bay estuaries. Plankton are collected from the traps on a daily frequency. In Coos Bay, we are nearing one year of continuous measurements (initiated 17 February 1998) from the main sampling site near the mouth of the bay, and we have made shorter time series from two other sites. Another long time series has been collected by Brett Dumbauld from Willipa Bay, while a process study in Grays Harbor was hampered by trap malfunction. More information on the light trap design and operation can be found on the Internet at http://darkwing.uoregon.edu/~croegner/lt.html. Sorting and analysis of the many samples is presently underway. We are concentrating on 11 species of brachyuran crab larvae, with lower effort devoted to barnacle cyprids and fish larvae.

Each of the study estuaries has a data base of physical measurements we will use to categorize the oceanographic processes effecting larval transport. Oceanic and estuarine instrument moorings measuring velocity, salinity, and temperature are being maintained by Barbara Hickey and Jan Newton. We access wind vectors and sea surface temperature from NOAA weather buoys located on Stonewell Bank off Newport and St.Georges Bank near Eureka, CA. Wind vectors are also measured at Cape Arago near Coos Bay. Water level, temperature, and light intensity are recorded at Charleston, Coos Bay, and Grays Harbor light trap sites. During periodic estuarine cruises, CTD and velocity measurements are made at selected stations. These time series data will be used to determine spatio-temporal variation in physical transport events.

Cruises

We have conducted several cruises to the coastal ocean to investigate the spatial distribution of marine invertebrate larvae. Four cruises were on R/V *Wecoma* in support of GLOBEC long term observation (LTO) investigations (February, April, August, November 1998), when we made large scale, regional (Newport, OR to San Francisco, CA) surveys of ocean conditions and biotic distributions. These trips are scheduled to continue at least through autumn 1999. We also coordinated with Steve Rumrill through the South Slough National Research Reserve during June 1998 to conduct an intensive survey of the upper ocean between 43.4 and 44.0° N on the NOAA ship *McArthur.* We can now compare these data collected during the 1998 El Niño with similar cruises made from 1995 to1997. Additionally, we made surveys of the Coos Bay estuarine plume and nearshore frontal features on the trawler *Olympia* in June 1998. Finally, we have conducted numerous cruises in the Coos Estuary on University of Oregon vessels. Note that light traps were operating during all but the first of these cruises in 1998, allowing a comparison on the coastal distribution of organisms to the delivery of larvae to the Coos estuary.

Results & Discussion

Light traps

While the majority of the light trap samples have yet to be counted, we have sufficient data for a preliminary view of recruitment patterns for the Charleston, Coos Bay site during Spring-Summer 1998. The light traps very efficiently sample crustacean larvae. Time series for five groups of larvae are shown in Figure 6.1; some of the physical variables are shown in Figure 6.2. In general, larval abundance was pulsed, with abundance peaking over a 2 to 5 day period. We interpret these pulses as individual transport events. A formal analysis of the data is underway, but a few noteworthy observations are presented below:

• Temporal distribution of cancer crab megalopae: There were coincident pulses of *Cancer magister* and *C. spp.* around day of year (DOY) 118 and 130, but note that peak distributions are offset by several days. There was a large peak of *C. magister* near DOY 140 that was not seen in the *C. spp.* group. These variations in abundance may relate to patchiness in the offshore larval distributions (see below). Overall, *C. magister* recruited over a 30 d period centered in May, with the bulk of the megalopae entering the estuary over a 10 d

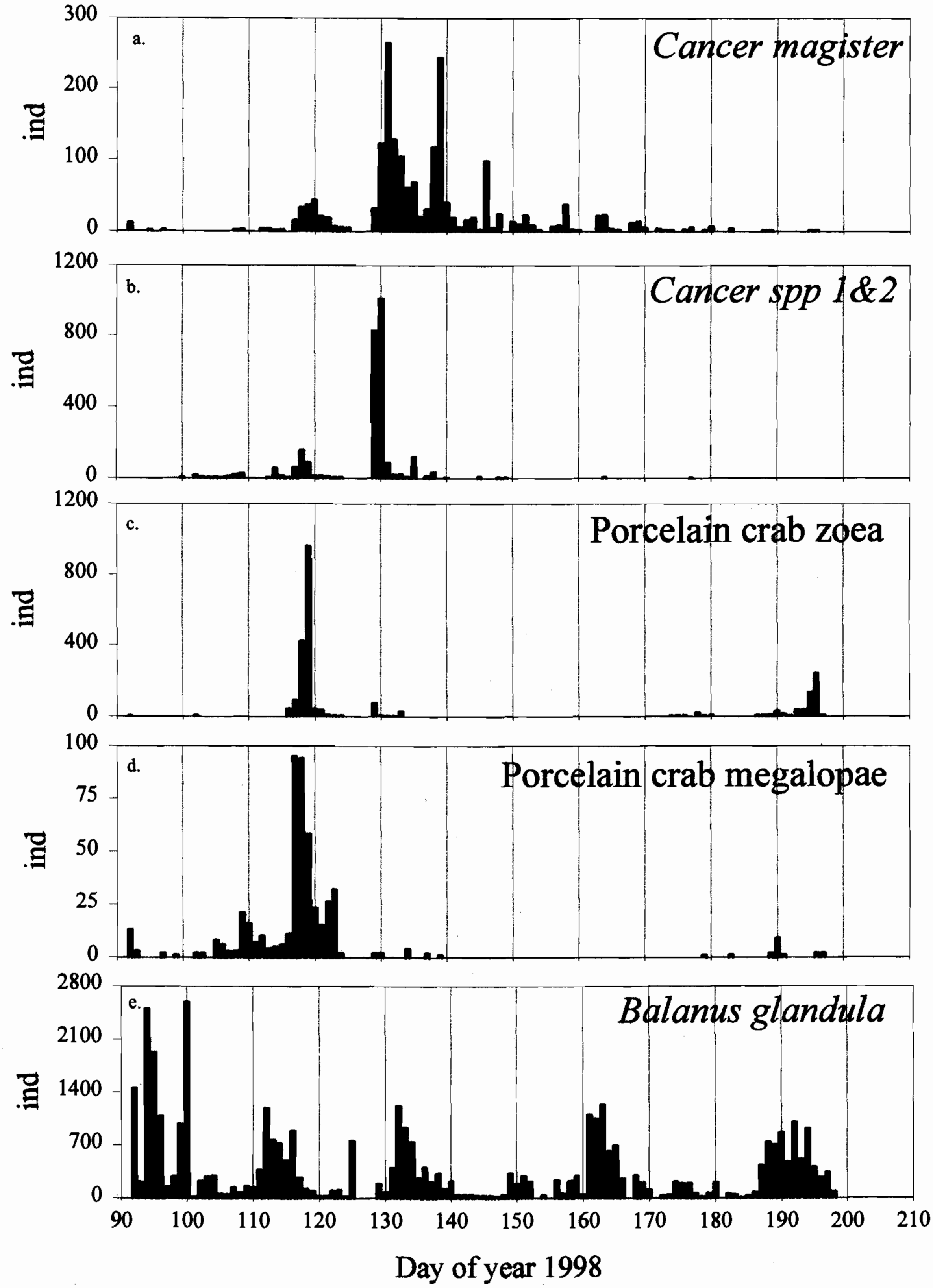


Figure 6.1. Time series of larval abundance from light traps located in Charleston Marina at the mouth of Coos Bay. a., Dungeness crab (*Cancer magister*) megalopae; b. *Cancer* spp. 1 and 2 megalopae; c., Porcelain crab zoea I and II; d., Porcelain crab megalopae; e., barnacle (*Balanus glandula*) cyprids.

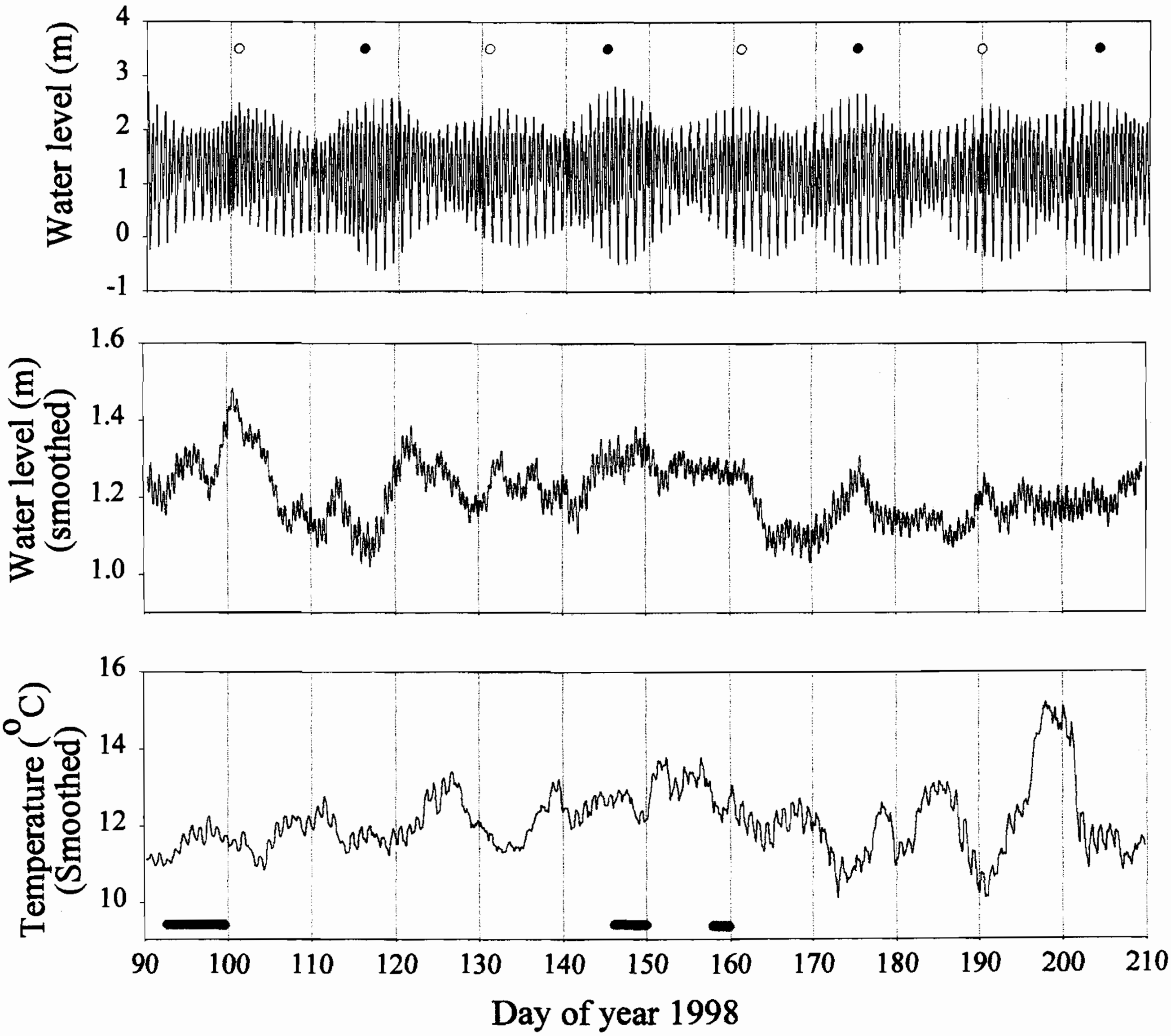


Figure 6.2. Time series of physical variables measured from the Charleston Coast Guard station, Coos Bay from 30 March (DOY 90) to 29 July 1998. a., Water level, with full and new moon periods indicated by white and black circles, respectively. b., Water level smoothed with a 24-h moving average to remove the tidal signal. c., temperature smoothed with a 24-h moving average. Dark bars in c. indicate cruise periods of *Wecoma* (W9804a), *McArthur* (AR9806), and *Olympia*, from left to right.

period. In contrast, nearly all the *C. spp.* entered during just 2 d. These results emphasize the importance of daily measurements.

• Porcelain crabs: There were coincident peaks of both zoea and megalopae around DOY 118; this was a major transport event for all these groups of crabs. A smaller pulse of zoea occurred later in the season, and was not associated with coincident peaks of either porcelain or cancer megalopae. As with *C. magister*, porcelain crab megalopae were abundant for about a 20 d period.

• Barnacle cyprids: *Balanus glandula* cyprids exhibited a cyclical abundance pattern. This pattern is in contrast with other barnacle species, which were more episodic (data not shown).

Relation to the physical variables

No formal analysis has been made to date, but several general conclusions are evident.

• Spring-neap cycle. The abundance of barnacle cyprids appears related to spring tides, but no other organisms show consistent patterns with the spring-neap lunar cycle (Figures 6.1 and 6.2). The synchronous transport event at DOY 118 occurred near the new moon, but *C. magister* shows

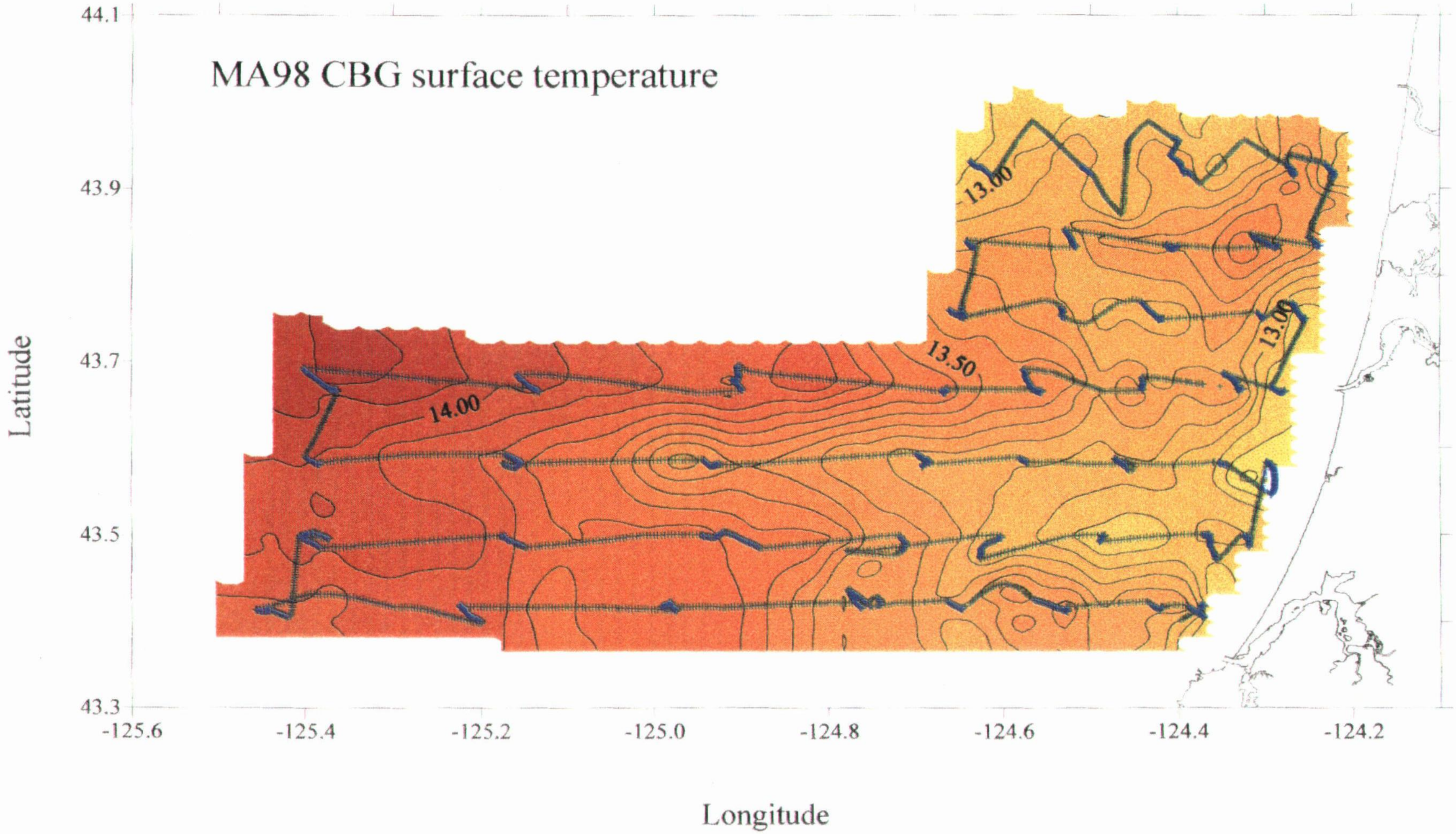


Plate 8. Cruise track (green line) and surface temperature over the Coos Bay Grid site measured from *McArthur* during 26 May to 1 June 1998.

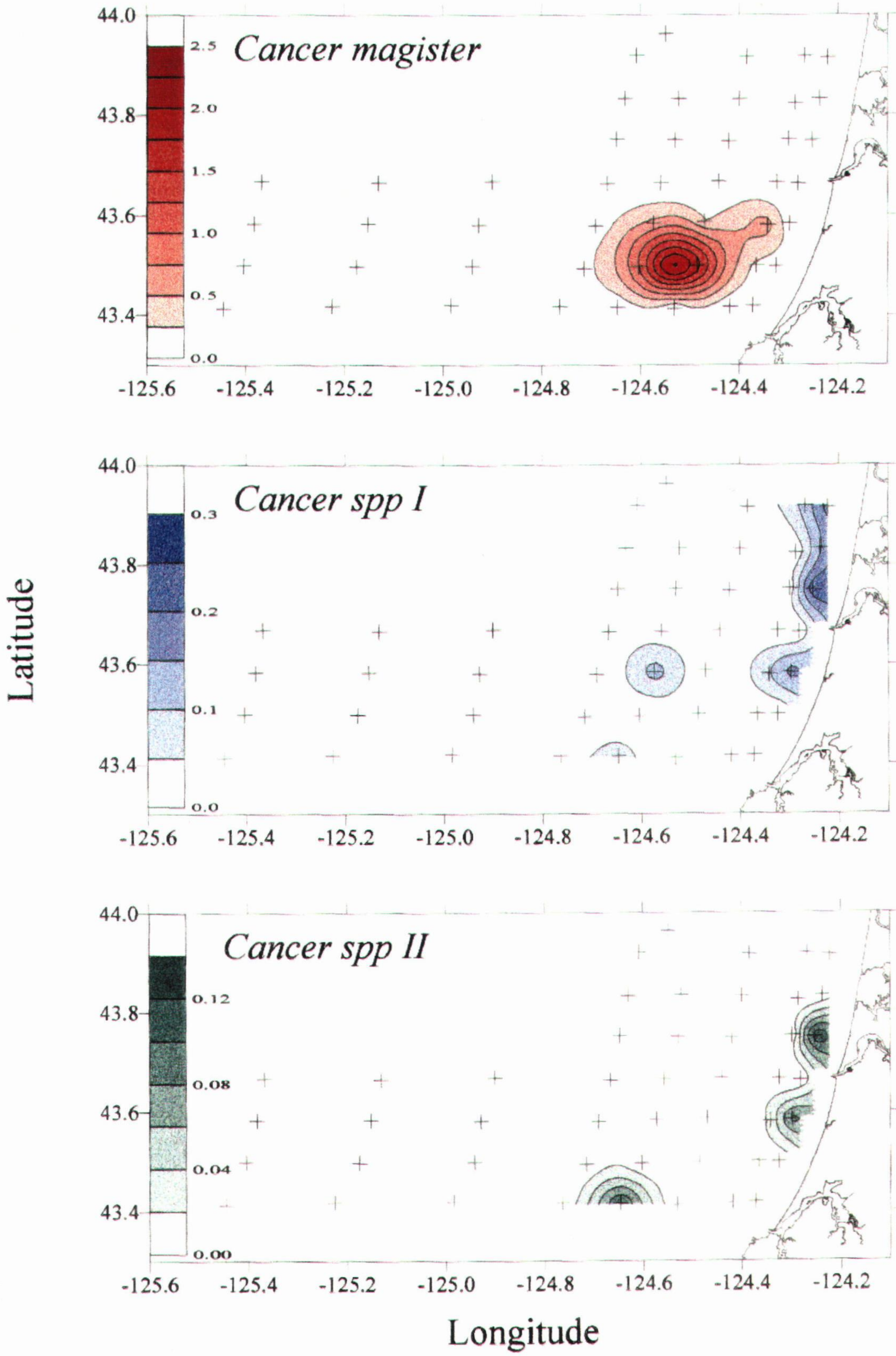


Plate 9. Surface distribution of megalopae of the crabs *Cancer magister* (a.) *C. productus* and *C. oregonensis* (b.), and *C. gracilis* and *C. antennarius* (c.) within the Coos Bay Grid, 26 May to 1 June 1998. "+" designates sample locations.

nearly equal large peaks at both 130 and 140, spring (full moon) and neap tides, respectively. Porcelain crab zoea seem unrelated to spring-neap cycle.

• Temperature and water level data measured from the Charleston Coast Guard station were smoothed to reduce the tidal signal and discern temporal variation that may signal advective events (Plate 8). There are no obvious relations among the abundance of any organism with the temperature signal. In fact, there are no significant correlations between the smoothed temperature and water level time series at any lag (in contrast to highly significant cross-correlations of the unsmoothed data at lags of 3 h). But there are interesting trends to the smoothed water level signal. For the crabs, peaks of abundance at DOY 120 and 130 and 140 coincide with a switch from upwelling to downwelling "events" (as determined by decreasing to increasing water level). The *C. magister* peak at DOY 140, however, occurs during a relatively small "event", and the single peak in *C. magister* abundance at DOY 148 is anomalous. These tentative observations will be reevaluated when the full biological and physical data sets become available.

Cruises

The 1998 *McArthur* cruise was designed to examine the spatial distribution of larval invertebrates off the Oregon coast. The cruise track and sea surface temperatures of the Coos Bay Grid are shown in Plate 8. We sampled stations both on and off the shelf, and biological samples were collected from surface, 0 to 20 and 20 to 40 m depth intervals.

Surface distributions of three groups of cancer crab megalopae are shown in Plate 9. All distributions are patchy, and in contrast to previous years, megalopae are concentrated on the shelf rather than further off shore. There is no diurnal signal in abundance. Virtually all *Cancer magister* megalopae occur in a single aggregation of approximately 20 x 30 km dimensions located near the shelf break. The other species of *Cancer* megalopae are concentrated in the nearshore, but there are additional offshore patches. Megalopae are rare below the neuston. Results from the other cruises off Oregon await further analysis.

Integration & Interaction

We have had extensive interaction with Barbara Hickey and her associates. Members of her group have come to Coos Bay repeatedly to deploy and service moored instrument arrays and conduct surveys of the estuary. Our groups have consulted extensively toward evaluating the physical oceanographic data in light of the daily light trap measurements. Our group has also interacted with David Armstrong's project examining the benthic distributions of young of the year crab in Coos Bay. Brett Dumbauld has been collecting light trap samples for us in Willapa Bay, and we are planning to establish a light trap site in Yaquina Bay under the supervision of Ted Dewitt. We anticipate these interactions to strengthen with the implementation of the Year 2 research plan.

Applications

Publications:
None.

Presentations:
None.

Workshops:
Curtis Roegner attended the PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Alan Shanks and Curtis Roegner attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
GLOBEC (PI Bob Smith) provided shiptime and assisting personnel. South Slough NERR provided *McArthur* shiptime.

Personnel

Curtis Roegner, Research Associate, University of Oregon
Allan Shanks, Assistant Professor, University of Oregon
Amy Pils, Masters student, University of Oregon
David Armstrong, Professor, University of Washington

Salmon Coded Wire Tag Current and Retrospective Analysis .... Project 7

Ray Hilborn

Introduction

The basis of this project is the extensive Pacific salmon coded-wire-tag (CWT) data base that provides estimates of survival from either hatchery release, or downstream migration (for wild fish). This data base will provide us with estimates of estuarine and ocean survival for approximately 90,000 release groups, providing broad spatial and temporal coverage. We will use this data base to examine the impact of natural and anthropogenic factors on salmon survival.

Results & Discussion

The beginning of this part of the project was delayed until September 1998 and the arrival of Mr. Arni Magnusson, the graduate student who is compiling CWT data and estimating survival rates. Our initial objective (phase I) was to update our previous data base on coded-wire-tag data to provide estimates of the survival rates of all CWT tagged groups of salmon on the west coast. As of 1 February we have: 1) downloaded all of the CWT data from the Pacific States Marine Fisheries Commission (PSMFC) to our computers, 2) completed the extensive formatting and structuring required to calculate survival rates from the raw data, and 3) developed an ACCESS data base to hold the release and recovery data. We are just beginning the second (analysis) phase of the project which involves estimation of survival rates.

We anticipate that we will have the survival rate analysis completed by 15 March, and can then begin phase III - exploration of the hypotheses regarding the impact of biophysical factors on survival. These hypotheses are discussed below.

Tables 7.1 and 7.2 provide an overview of the data available up to brood year 1990 for coho. Note that data are also available for chinook, steelhead and chum. As noted above we have not yet completed rebuilding the data to include recent releases. Table 7.1 shows the number of CWT release groups available by year for the north Oregon coast and south Or-

Table 7.1. Number of coho CWT release groups available by year for the north and south coasts of Oregon.

Brood Year	North	South	Total
73	2		2
74	6		6
75	27		27
76	65	2	67
77	145	4	149
78	142	4	146
79	189	5	194
80	203	8	211
81	117	5	122
82	93	5	98
83	102	4	106
84	143	5	148
85	38	7	45
86	35	8	43
87	27	8	35
88	43	7	50
89	31	8	39
90	15	5	22
91	17	8	27
Grand Total	1440	93	1537

Table 7.2. Number of CWT release groups available by year for Washington coast coho split into north, south, and Willapa Bay groups.

Brood Year	North	South	Willapa	Total
71	3	2	2	7
72	3	6	2	11
73	1	4		5
74	8	3	2	13
75	9	3	1	13
76	9			9
77	6			6
78	8			8
79	4			4
80	14	6	3	23
81	10	4	3	17
82	9	10	5	24
83	21	35	13	69
84	33	9	5	47
85	29	6	3	38
86	26	2	1	29
87	39	4		43
88	55	5		60
89	28	4		32
90	26	4		30
91	22	7	1	30
92	8			8
Grand Total	371	114	41	526

egon coast. Here we see excellent coverage for the northern oregon coast, but poorer coverage of southern areas. Table 7.2 provides the same information for Washington CWT coho. Although the north coast data are fairly complete, south coast and especially Willapa Bay coverage is poor. Figure 7.1 show the trend in coho survival rates estimated for Oregon and Washington.

Hypotheses

We will begin with testing of the following hypotheses. The discussion below considers each hypothesis independently. However in our statistical analysis we will need to consider interaction between hypotheses, as well as internally correct for other factors such as size at release, hatchery treatments etc.

Estuarine quality hypothesis: survival rate is related to estuarine size/quality.

It has been observed by a number of researchers that salmon released into estuarine and protected waters have considerably higher survival than those released on the open coasts of Oregon, Washington, British Columbia, and Alaska. For instance, coho salmon released in Puget Sound typically have three times higher survival than fish released into Washington coastal streams. We will examine this hypothesis in detail, and test whether the fish released into estuaries on the coast that are the focus of the PNCERS study, show higher survival than fish released into nearby streams that drain into the coast outside of the major estuaries. We will work with the PNCERS estuarine researchers to develop quantitative measures of estuarine condition, and see if these covariates explain any of the variation in survival.

Estuarine plume hypothesis: intensity and direction of the estuarine plume during seaward migration is a significant factor in affecting smolt survival.

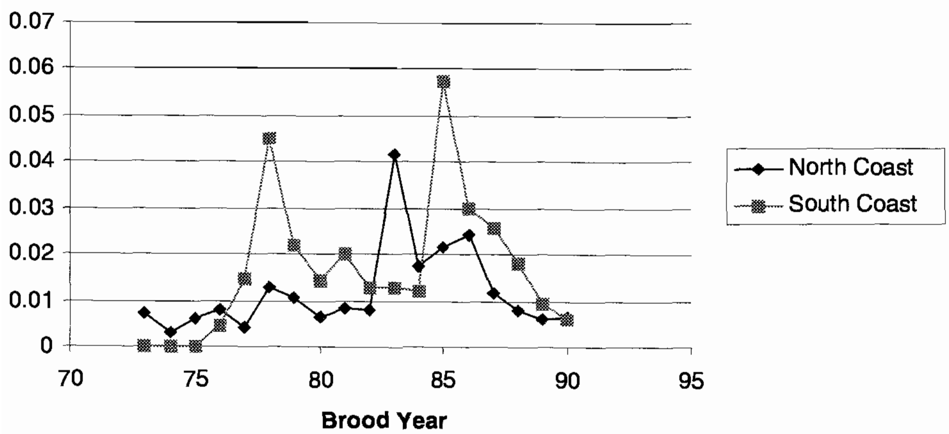


Figure 7.1. Survival of coho salmon released from the north and south coast of Oregon, 1973 - 1990.

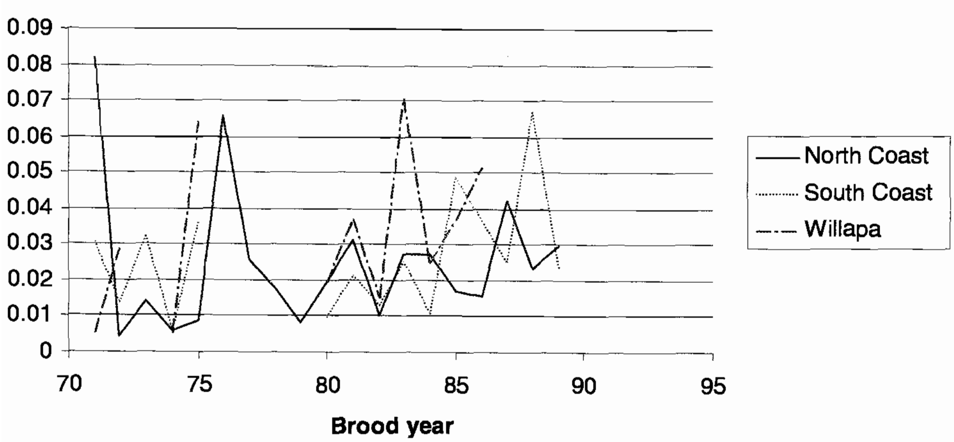


Figure 7.2. Survival of coho salmon released from the north and south coast of Washington and Willapa Bay, 1971 - 1989.

The plume of water from estuaries, water that is less saline, more turbid, and a different temperature, is a major physical feature of the coastal ecosystem and the subject of a major part of the PNCERS effort in physical oceanography. From the measurements made by Barbara Hickey we anticipate being able to reconstruct the historical pattern in ocean plume at the time of seaward migration for CWT tagged fish. This will rely on historical data on wind direction and force, freshwater discharge, etc. We can then compare the survival rates observed to reconstruction of direction and intensity of the plume.

Upwelling hypothesis: intensity of upwelling during seaward migration is a significant factor in affecting smolt survival

There are a number of measures of upwelling that rely on reconstruction from wind data to generate space time maps of upwelling. We plan on superimposing our estimated salmon smolt distribution upon these maps to look for relationships between timing and intensity of upwelling to explain variation in survival.

Zooplankton and fish hypothesis: survival is related to the distribution of fish and zooplankton during seaward migration

The PNCERS project examining spatial/temporal patterns in fish and zooplankton from hydroacoustic data (Gordon Swartzman) will provide snapshots of the distribution of fish and zooplankton taken during NMFS surveys. We hope that these snapshots can be used to develop relationships between physical events such as winds, and the anticipated distribution of zooplankton and fish, both in space and time. We will then take our estimates of survival and migration path during early ocean entry and see if there appear to be significant relationships between the zooplankton/fish and salmon survival.

Integration & Interaction

As mentioned above we hope to have estimates of survival from all CWT groups within the next few months. The analysis of survival in relation to estuarine size and presence/absence requires no intimate connection with other researchers and we will begin that analysis first. However, beyond that step almost all of our analyses require close interaction with other researchers, especially Barbara Hickey for physical factors, Gordon Swartzman for fish/zooplankton distribution, and Ron Thom and Steve Rumrill for estuarine habitat quality. We will participate in a series of mini-workshops where we all put our data and knowledge on the table, refine the above mentioned hypotheses, and see to what extent we can develop "data bases" on plume intensity and direction, upwelling, and zooplankton/fish distribution to statistically test hypotheses regarding these various factors.

In collaboration with PNCERS PI's Gordon Swartzman and Julia Parrish, we hope to build an *EcoPath* model of smolt survival as a function of food availability and predator pressure during the first fifty days of nearshore coastal life.

Applications

Publications:
None.

Presentations:
None.

Workshops:
Ray Hilborn and Arni Magnusson attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
None.

Personnel

Ray Hilborn, Professor, Fisheries, University of Washington
Arni Magnusson, Graduate student, Fisheries, University of Washington

Mapping and Assessing Estuarine Habitat Quality .... Project 8

Ronald M. Thom and Steven Rumrill

Introduction

The focus of this project is on benthic estuarine habitats. The overall goal is to provide resource managers and decision makers with information about habitats that are useful in making management decisions in coastal estuaries of the Pacific Northwest. To achieve this goal, the habitat/bioindicator study is addressing two broad objectives:

- through a retrospective analysis, understand and document large scale changes in the primary benthic habitats that have taken place in the target estuaries

- through directed field and laboratory studies, understand and document the factors responsible for spatial and interannual dynamics of selected habitats.

By accomplishing these two objectives, we will be able to provide managers with credible indicators of the types and relative impacts of stressors affecting estuarine habitats. Within PNCERS, the habitat studies form a key link between geophysical conditions in the system and quality of the estuarine system for a variety of fisheries resources. Because of these close linkages, the habitat studies rely heavily on data gathered by other PNCERS program components especially investigations of Dungeness crab, English sole, salmonid populations, and physical/chemical processes.

Results & Discussion

Retrospective Analysis

We assessed historical changes in the spatial extent of major benthic habitats in the four coastal estuaries including Grays Harbor, Willapa Bay, Tillamook Bay and Coos Bay. The primary data sources were historical navigation charts, but also included other maps containing habitat distribution data. The original goal was to assess changes at several points in time beginning with the earliest records available. To date, we have been able to acquire and analyze at least two sets of relatively complete data for all four estuaries. All estuaries had maps dating from the late 1800's, but most were incomplete with regard to the three major parameters we were interested in: bathymetry, shoreline position and habitat distribution. The recent information is more complete except for bathymetry. In some cases we relied on navigation charts with bathymetry data that is more than two decades old. Using a geographic information system (GIS), we developed layers for each of these parameters for the years where data were available.

The results of the analysis to date for three of the estuaries are shown in Table 8.1. In general, we were able to resolve the identity of most habitats. However, in Willapa Bay and Coos Bay, there are areas where mapping is not complete in the historical record. We included the unresolved areas for book keeping purposes. It is evident that there have been large changes in the aerial extent of habitats since early records. In Willapa, the most striking changes are for salt marshes (Plate 10). The invasion of smooth cordgrass (*Spartina alterniflora*) into this estuary is largely responsible for this increase in salt marsh. In concordance with *Spartina* invasion has been the decline in mudflat habitat between mean high water (MHW) and mean lower low water (MLLW). The area below MLLW appears to have increased. The elevation range where eelgrass (*Zostera marina*) is presently found in greatest abundance (i.e., MLLW-ELLW),was not resolvable in the historical records, but now occupies an estimated 5,887 ha. The increase in area below MLLW could be explained by enhanced scouring of shallows, expansion of the elevations where eelgrass flourishes, and/or a higher sea level.

Tillamook Bay has seen large changes in forested wetland and subtidal habitat (Table 8.1). The Bay has been subjected to agriculture activity for more than a century and much of the loss of forested wetlands can be attributed to conversion of forests to farmlands. Diking of tidal marshes has been carried out to some extent also. The increase in the upper intertidal flats may be attributed to increased sedimentation from forest practices and periodic catastrophic forest fires in the steep and extensive watersheds tributary to the estuary.

In Coos Bay, marsh habitats were classified historically and recently into low and high marsh. High marsh has shown a very small decrease, whereas low marsh has declined substantially. Changes in low marsh appear to be associated with diking and filling, especially in the Coos Bay harbor area (Plates 11 and 12). High intertidal area has decreased as has the region between MLLW and subtidal. Coos Bay is a long relatively narrow estuary, with a navigation channel in the center that is actively maintained. This suggests that loss of intertidal flats may be due to slumping and scouring, especially at the edges of the navigation channel. We will investigate this hypothesis further in subsequent years.

The general conclusion regarding historical changes is that tidal wetland area has declined in coastal estuaries, and flats may have increased in Tillamook Bay, and decreased in Willapa and Coos bays. The high intertidal flats in Willapa have been converted to salt marsh. The implications for fish-

Table 8.1. Comparison of habitat areas between historical and recent records. nd = no data; subtidal = below extreme lower low water; unresolved = areas where habitat is undetermined but are within the estuary; MHW = mean high water; ELLW = extreme lower low water; MLLW = mean lower low water.

Estuary and Habitat Type	Historical Area (ha)	Present Area (ha)	Change (ha)
Willapa			
Salt Marsh	1,188	3,801	+2,613
Tidal Forested	nd	8	--
MHW-MLLW	18,644	16,139	-2,505
MLLW-ELLW	nd	5,887	--
MLLW-Subtidal	14,290	20,852	+6,562
unresolved	1,380	0	-1,380
Tillamook			
Salt Marsh	428	369	-59
Tidal Forested	771	5	-766
MHW-MLLW	1,437	1,715	+278
MLLW-ELLW	824	842	+18
Subtidal	1,171	792	-379
unresolved	485	4	-481
Coos			
Low Marsh	1,050	391	-659
High Marsh	134	127	-7
MHW-MLLW	2,338	2,029	-309
MLLW-ELLW	nd	1,112	--
MLLW-Subtidal	2,315	2,108	-207

eries resources awaits future analysis, but we can conclude that key resources that are the target of PNCERS, such as Dungeness crab and juvenile salmon have probably suffered some impact from loss of key estuarine habitats. The losses are explained by development of agriculture and forest practices in the watershed and tidal wetland portions of the systems. Dredging of navigation channels, such as Coos Bay (and Grays Harbor, yet to be finalized), has deepened channels which has changed circulation, physical processes and the bathymetry in the systems. We will attempt to provide more quantitative indications of the impact of these actions in our future reports.

Field Studies

The field studies this summer were directed at establishing permanent study sites, and collecting initial data. We are focusing on eelgrass meadows because eelgrass occurs in abundance in all systems, is very important habitat for a variety of fish (including juvenile salmon) and wildlife species, has likely undergone changes due to human and non-human caused changes in the systems, has a well-established literature, and can be repeatedly quantitatively sampled using minimally-destructive methods. It occurs in the shallow subtidal zone where it is susceptible to changes in water clarity (i.e., changes in turbidity), temperature, salinity, and nutrients. Increasing turbidity, nutrients and temperature are key stressors in coastal estuaries that were identified during the first phase of the PNCERS program. Hence, eelgrass is an excellent indicator of linkages between major fisheries resources and physical and chemical processes.

A total of 10 study sites, six in Willapa Bay and four in Coos Bay (Plates 10 and 12), were established in the very low intertidal zone. Data on a variety of eelgrass parameters were collected near all sites, along with water column data on secchi depth, salinity, photosynthetically active radiation (PAR), and temperature. Water column data from the physical/chemical processes task will supplement our data set.

The eelgrass data from summer indicated both strong differences among sites within each estuary as well as between estuaries. In general, Coos Bay sites contained greater densities of eelgrass than did Willapa Bay sites (Figure 8.1). Within Willapa Bay, densities varied considerably among the sites. The combined biomass estimate, which incorporates belowground, aboveground and epiphyte biomass, showed considerable variability among all sites sampled in both estuaries (Figure 8.2). Fossil Point, Coos Bay, had by far the greatest biomass. This site is the most marine site in Coos Bay, is very well flushed, and is located in a region of

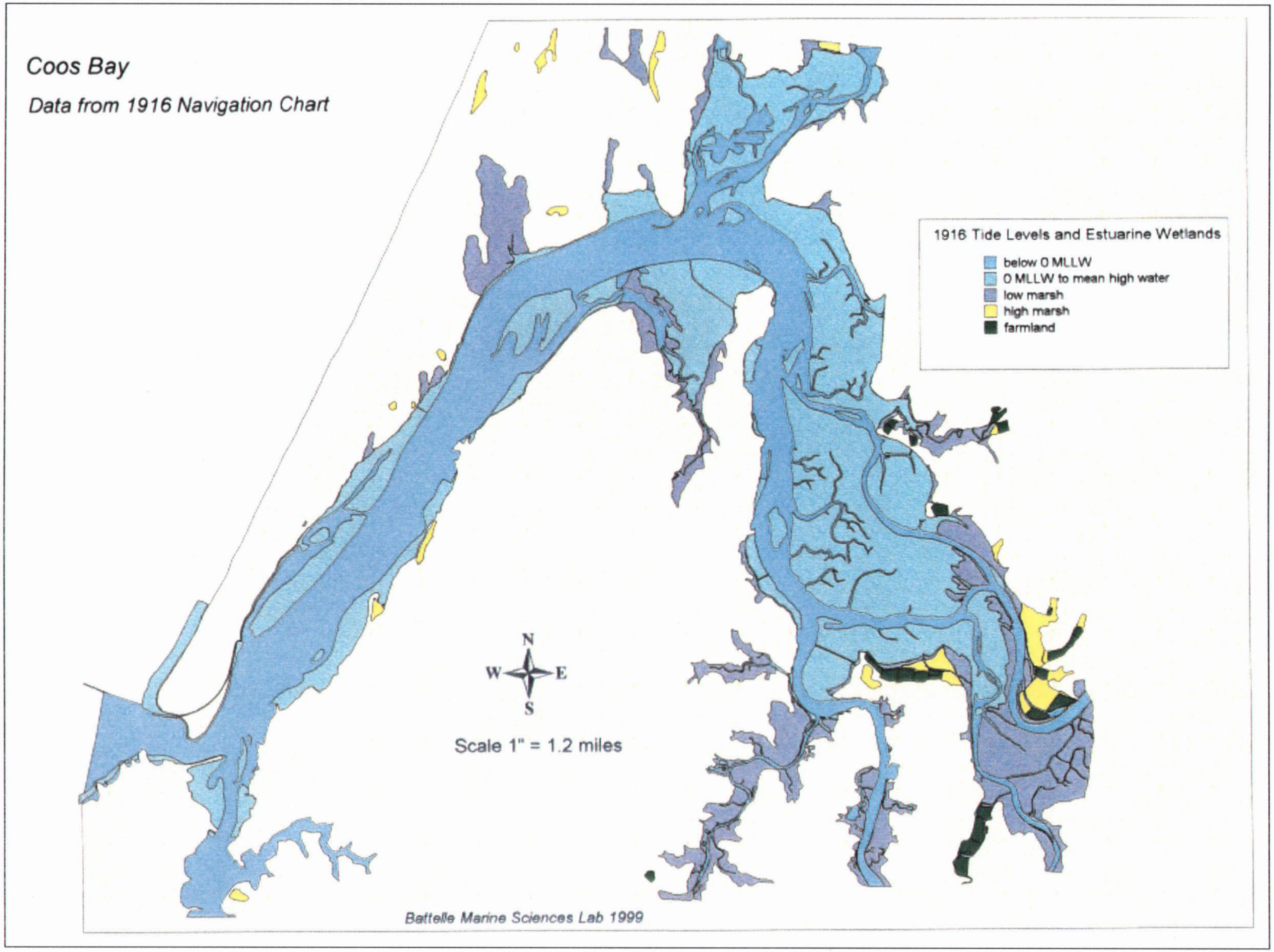


Plate 10. Historical habitat map for Coos Bay.

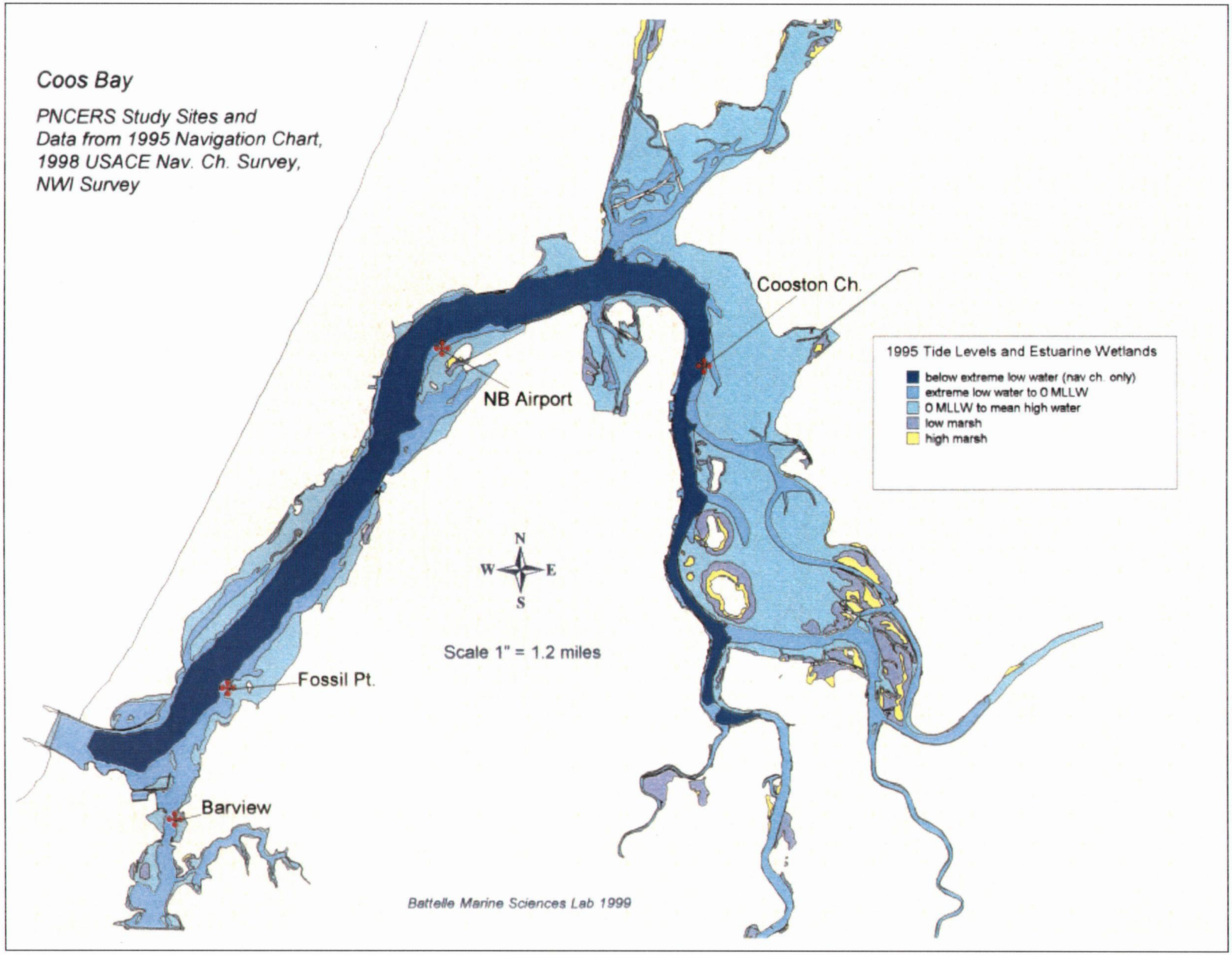


Plate 11. Study site locations in Coos Bay.

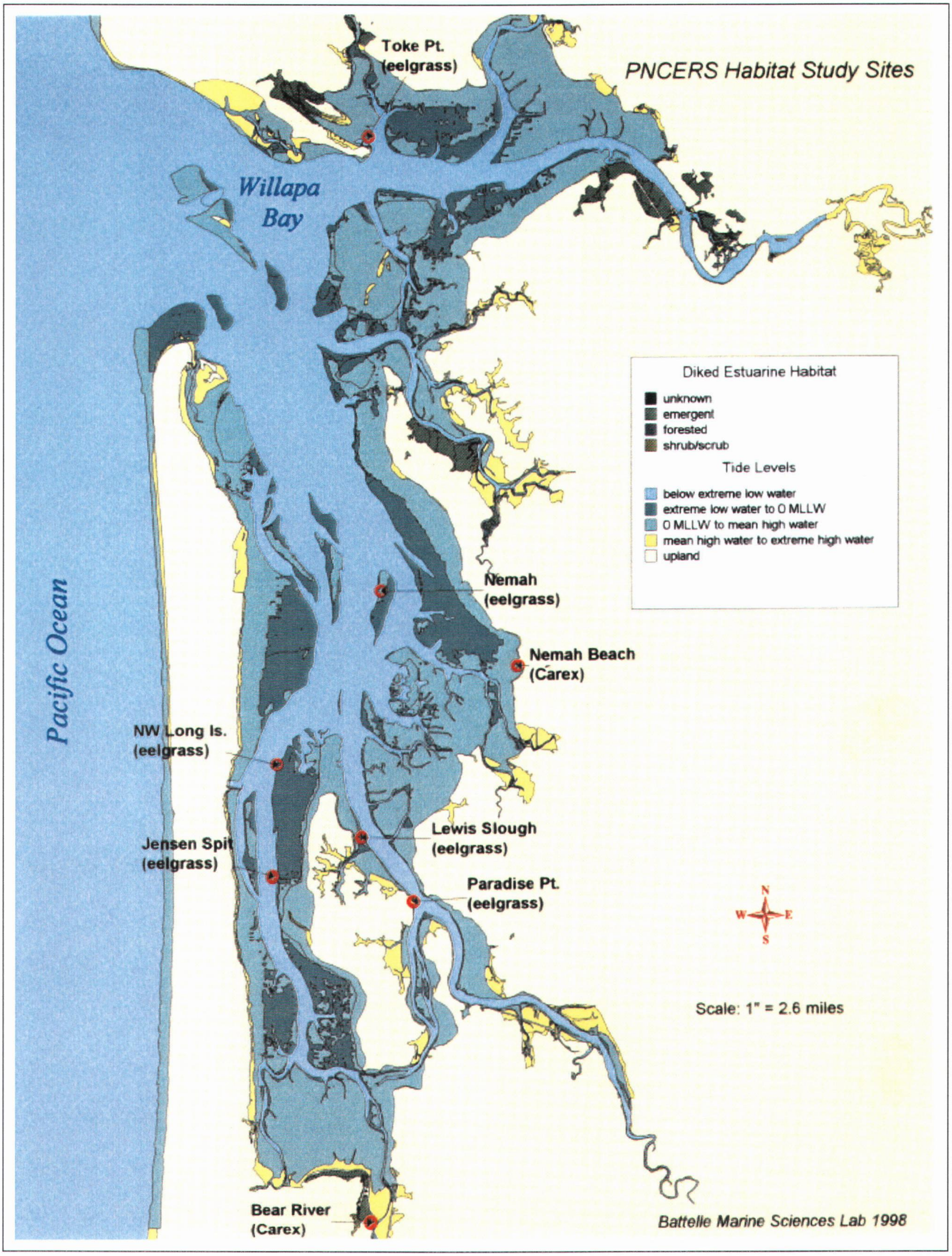


Plate 12. Study site locations in Willapa Bay.

the system where ocean-derived nutrients are abundant. Water temperatures recorded at Fossil Point and Bar View were 12.0 and 10.0 °C, respectively; which were by far the coldest recorded during our field visits. Temperatures at all other sites ranged from 15.5 to 17.0 °C. Belowground biomass comprised 40% or greater of the total biomass, except at the NW Long Island site in Willapa Bay. We cannot explain this result with the present data set, but will see if the trend holds during the next annual sampling.

Epiphytes are a good indicator of water quality, with larger quantities of epiphytes indicating potential eutrophic conditions. The data indicate both very high and very low epiphyte loads in both estuaries (Figure 8.3). Again, Fossil Point shows very high epiphyte biomass, which may indicate greater nutrient levels. Nemah and NW Long Island sites in Willapa Bay also had very high epiphyte loads, and these sites are generally more exposed to currents and mixing as compared with the other sites in the Bay. Drift seaweed also can indicate nutrient conditions. The cover of green sea lettuce (*Ulva* spp.) was notably greater in Coos Bay as compared to Willapa Bay. Sea lettuce cover averaged about 10.7% in Coos Bay and 0.01% in Willapa Bay. Data on nutrients, gathered by the Physical/Chemical component of PNCERS are critical to sorting out potential differences among these sites.

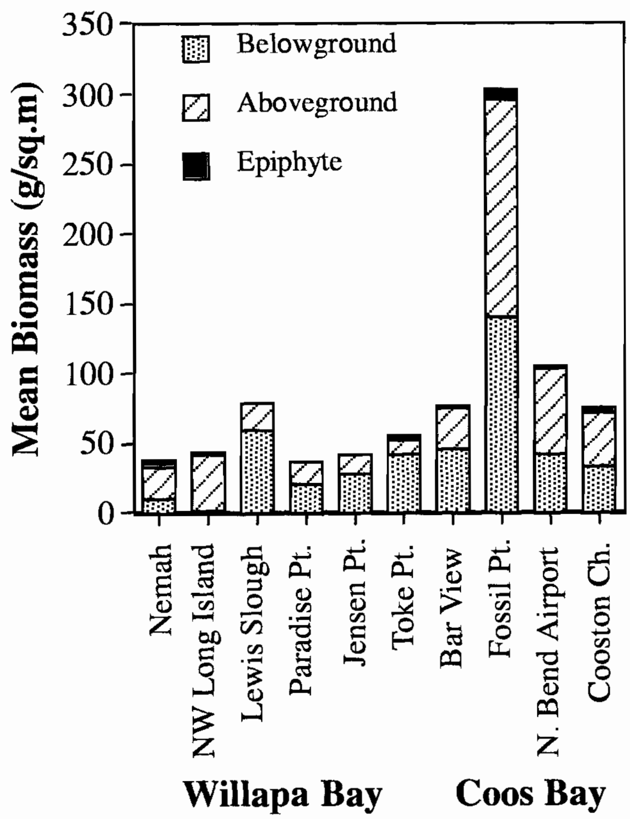


Figure 8.2. Mean total biomass at the study sites.

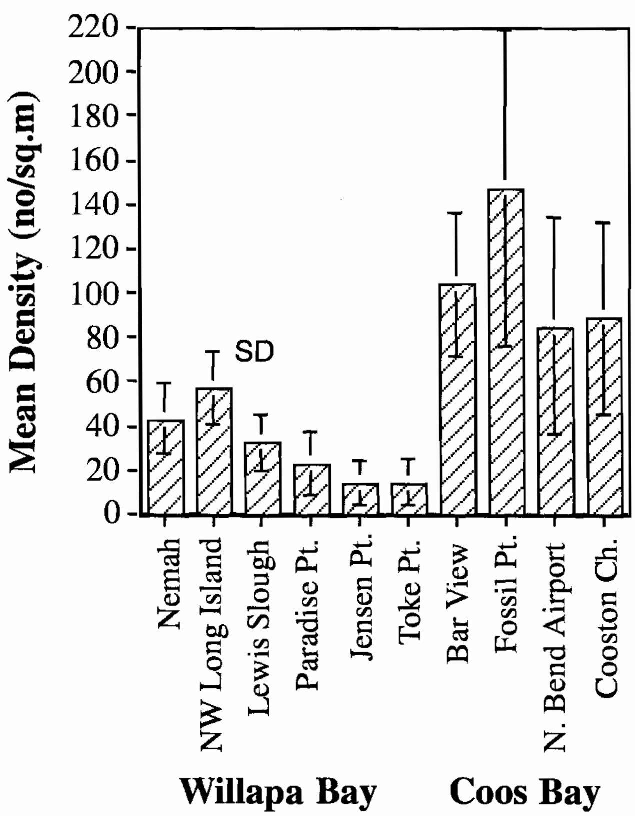


Figure 8.1. Mean eelgrass density at the ten study sites.

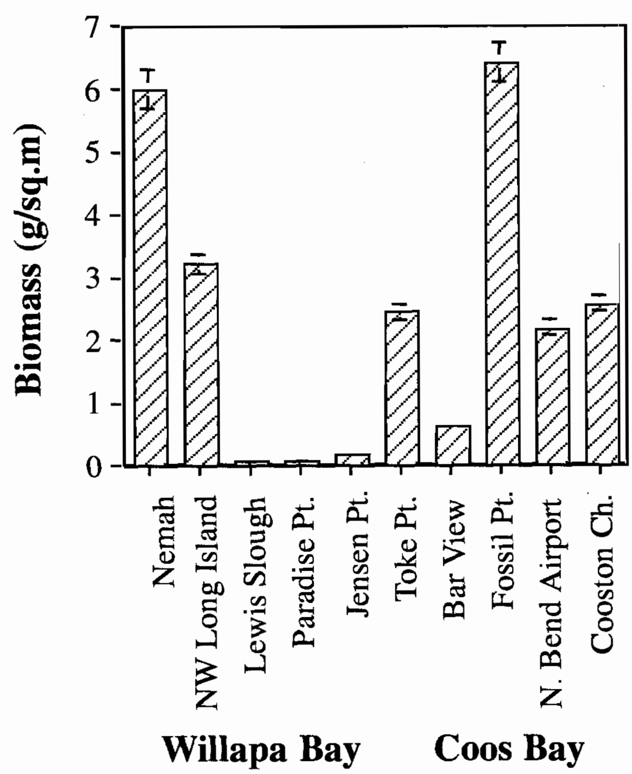


Figure 8.3. Mean epiphyte biomass at the study sites.

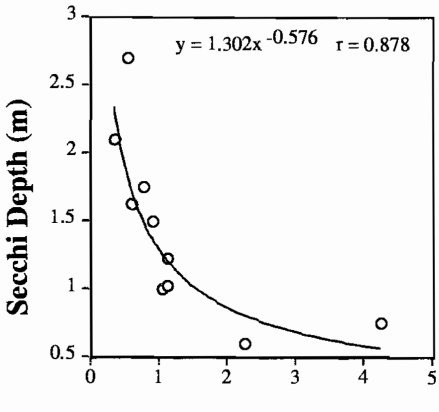


Figure 8.4. PAR attenuation coefficient versus secchi depth at the study sites.

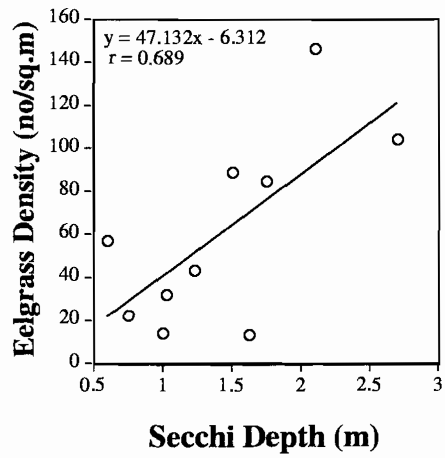


Figure 8.5. Secchi depth versus mean eelgrass density at the study sites.

An indicator of water clarity used in Chesapeake Bay and other areas, is the lower depth limit of seagrass. It has been shown that the lower depth limit is very close to the secchi depth near the sites. We are evaluating this relationship in PNCERS, by sampling the depth limit at our sites along with the secchi depth and PAR attenuation (Figure 8.4). At present, we see no correlation between these latter parameters and lower depth limit. This suggests that either there is no clear relationship in our region, or that other factors, such as scouring (see discussion above regarding navigation channel dredging) at the lower edge of the meadows is responsible for limiting further expansion of the eelgrass into deeper water.

There was a good correlation between eelgrass density and secchi depth (Figure 8.5). This indicates that water clarity may be one relatively important controlling factor, and that measurement of secchi depth and attenuation, which is being done by us as well as the Physical/Chemical component of PNCERS may yield a strong data set that can be used for management of turbidity in the systems. However, linear correlation shows many interactions among physical, chemical and biological parameters in this first data set (Table 8.2). We will use this information to help formulate hypotheses that can be evaluated in field and laboratory experiments to sort out the factors primarily responsible for spatial and temporal patterns in the eelgrass meadows in the coastal estuaries. In our field design, we located study sites so that some of these factors might be resolved. For example, there are two sites on either site of Long Island in southern Willapa Bay. The eastern sites are located in an area influenced by the Neselle River, and should have lower salinities, greater turbidities, and different temperature regimes as compared to the sites on the west side of the Island. Similarly, other sites were established with consideration of trying to resolve the most important factors affecting eelgrass abundance and dynamics. This field design, coupled with experimental studies as well as strong water properties data set, should allow us to refine the effects of various controlling factors on eelgrass.

Integration & Interaction

The Mapping and Assessing Estuarine Habitat Quality project has direct links to several PNCERS study units. We have been actively discussing these linkages with the parts of PNCERS studying crab and juvenile English sole, physical processes, and chemical processes. These discussions have been conducted to assure that data collected will be of maximum use to us as well as to the other components. We have tried to position our study sites as close as possible to those sampled for water properties in the estuary. In most cases, the sites are in very close proximity. The sites utilized by the crab and English sole group are within the general vicinity of our sites. We are evaluating oyster aquaculture as a stressor through a related program conducted in Tillamook Bay for the EPA's National Estuary Program. We are coordinating with Brett Dumbauld, leader of the PNCERS oyster study. Dr. Dumbauld has provided critical logistical support for our studies in Willapa Bay, as well as important information on oyster-eelgrass interactions.

Table 8.2. Linear correlation coefficients between some measured parameters.

	Temperature	Salinity	Secchi depth	Eelgrass density	*Ulva* cover
Temperature	--	-.76	-.86	-.75	-.96
Salinity	-.76	--	+.90	+.82	+.74
Secchi depth	-.86	+.90	--	+.69	+.83

Although not directly tied to our study, we formed a better understanding of the approach that the salmon population component is taking. Based on our discussions at the recent PNCERS annual meeting, we believe that we can provide an energetic analysis of juvenile salmonids relative to estuarine habitat, that will be useful in determining the energetic support salmon receive from estuarine habitats. This relationship was determined at the annual meeting to be an important link to develop. Finally, we have collaborated with the economic and social component of PNCERS through a workshop that they held and through discussions at the annual meeting. The discussions helped us provide meaningful data to better assess the economic and social effects associated with changes in estuarine habitat.

Applications

Publications:
Rumrill, S. 1999. Habitat Variability and Function in Pacific Northwest Estuaries. Speaker summary in: G. McMurray, ed., *Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, Workshop Report* (in press).

Thom, R. 1999. A Systematic Approach to Restoring Pacific Northwest Estuaries. Speaker summary in: G. McMurray, ed., *Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, Workshop Report* (in press).

Presentations:
Steve Rumrill, "Habitat Variability and Function in Pacific Northwest Estuaries." PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Ron Thom, "A Systematic Approach to Restoring Pacific Northwest Estuaries." PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Ron Thom, "Justification and refinement of eelgrass (*Zostera marina*) as an indicator of environmental conditions in coastal estuaries of Oregon and Washington." PNCERS Eat and Learn Seminar Series, February 12, 1999, University of Washington.

Workshops:
Ron Thom attended the PNCERS Workshop on Linking Social and Ecological System Models, May 29-30, 1998, University of Washington.

Steve Rumrill and Ron Thom attended the PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Steve Rumrill, Ron Thom, and Amy Borde attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
Dr. Ted DeWitt, EPA Environmental Research Laboratory, Newport OR - assisted us in field work; coordinated sampling protocols for eelgrass with his study in Yaquina Estuary.

Tillamook Bay National Estuary program - conducting experimental study of the interaction of oysters, eelgrass and burrowing shrimp.

Dr. David Armstrong and Dr. Dan Cheney of the Pacific Shellfish Institute - propose study to study interaction of oyster aquaculture and effects on eelgrass in Pacific Northwest.

Dr. Dan Cheney - submitted preproposal to CICEET program to investigate effects of shellfish aquaculture on eelgrass enhancement.

Washington State Department of Transportation - ongoing studies on eelgrass requirements in Puget Sound, and the effects of various stressors on eelgrass populations, as well as fish behavior.

Personnel

Ronald M. Thom, Staff Scientist, Battelle Marine Sciences Laboratory
Steven Rumrill, Research Coordinator, South Slough Estuarine Research Reserve
Amy B. Borde, Scientist, Battelle Marine Sciences Laboratory
Gregg Petrie, Senior Scientist, Remote Sensing Group, Battelle Pacific Northwest Laboratory
David K. Shreffler, Research Scientist, Battelle Marine Sciences Laboratory
Paul Farley, Senior Technician, Battelle Marine Sciences Laboratory
Blythe Barbo, Administrative Assistant, Battelle Marine Sciences Laboratory

Assessing Existing Decision Processes: Institutional Mapping and Ecosystem Management .... Project 9

Dan Huppert, Tom Leschine and Andy Bennett

Introduction

This portion of the social and economic research in PNCERS during 1997-98 included (1) investigation of the structure, legal basis, and regulatory processes of the institutions currently involved in managing the estuarine and nearshore ecosystems and (2) investigation of concepts and applicability of "ecosystem management" to the coastal ecosystems of the Pacific Northwest. In addition, the researchers devoted significant effort to (3) developing the integrative concepts and models that will ultimately tie the social-economic information to the physical and biological information being developed in PNCERS. The following summary of research to date is divided into the following sections:

- Institutional Analysis
- Ecosystem Management
- Integration of social-economic with physical/biological research

Results and Discussion

Institutional Analysis for PNCERS

During the first year of PNCERS research efforts focused on developing an analytically useful conception of the institutional analysis. As noted in the original proposal and subsequent documents, our view of the research on social/economic research emphasizes how institutions focus and channel resources and shape decision processes that affect activities in the coastal ecosystems. We view the policy processes as embedded within unique institutional environments in each coastal area, guided by state and national law, but responding to specific problems and challenges inherent to each area. Further, the institutional structure that channels and guides the decision processes evolves over time in response to changing public values, to specific legislation, to new scientific information, and to emergencies that disrupt the accustomed decision processes.

The institutional analysis is organized in five sequential components. The first two components are to: (1) identify the underlying social units (agencies and non-governmental organizations) and (2) describe the resources and authority that support these units (funding and legal basis). One could think of these two research foci as analogues of species identification and life history studies. The first simply identifies and documents what is there; the second attempts to explain narrowly how the observed units maintain their existence. The next research component (3) seeks to explain how the numerous agencies and groups coordinate or compete to exercise their authorities and to formulate policies. This does not include an in-depth explanation of the policy or decision process, but rather focuses on the hierarchical or parallel authority structures in which the agencies and groups are embedded. To what extent is joint action required, and to what extent do the agencies compete for resources and authority? These first three components are grouped under the heading of "institutional mapping" because they are predominantly descriptive and focused on structure and orientation.

The final research components are concerned with (4) the decision processes used by the multiple agencies and groups to reach decisions concerning policy; and (5) the broader evolutionary processes that drive change in the institutions and policy issues over time. While decision processes are somewhat constrained by legislation and government structure, the actual processes used in specific geographic areas in response to specific policy issues can vary in important ways. Hence, the decision process is not simply a function of law and bureaucratic organization, but involves adaptation to specific conditions, the strengths of local interest groups, and the capabilities of specific policy entrepreneurs. These two research components involve interpretation, theory, and models of dynamic processes. We have not yet delved deeply into these two components, but we expect to make progress on these during the coming year.

Institutional Mapping

Institutional mapping was originally developed to systematically describe the formal institutional framework for coastal management and for watershed planning in the Puget Sound region. First, a comprehensive survey is conducted of the programs, the implementing agencies, and their sources of legal authority in the policy arena in which elements of coastal ecosystems are managed. The geographic scope, problems addressed, actions taken (or authorized), and the legal foundation are summarized. Next, jurisdictional constraints such as duplication, conflicts, and gaps are identified by inspection of legal documents and interviews with agency personnel. This approach has been employed in comparing different regional planning approaches.

During 1998, the PNCERS socio-economic research group (principally research assistant Julie Nelson) collected and reviewed dozens of documents pertaining to laws, institutions, and planning and permitting processes for Washington State coastal areas. Nelson also conducted interviews with

Table 9.1. A summary of legislation and enforceable regulations that affect various land uses.

General Use	Legal Authorities	Key Enforceable Policies
Agriculture	Shoreline Management Act - **SMA** (RCW 90.58) State Environmental Protection Act - **SEPA** (RCW 43.21C)	SMA: Use Activities (WAC 173-16-060) Shoreline Master Programs (WAC-173-19) SEPA: Rules (WAC 197-11)
Aquaculture	SMA SEPA Water Quality Laws (33 USC 1251 *et seq.* and RCW 90.48)	SMA: Use Activities (WAC 173-16-060) Shoreline Master Programs (WAC-173-19) SEPA: Rules (WAC 197-11) Water Quality Laws: Water Quality Standards (WAC 173-201)
Commercial Development	SMA SEPA	SMA: see above SEPA: See above
Energy Development or Facilities (oil and gas development, etc.)	Energy Facility Site Evaluation Council Act - **EFSEC** Act (RCW 80.50) SMA SEPA Ocean Resources Management Act - **ORMA** (RCW 43.143) Clean Water Acts - **CWA** (33 USC 1251 *et seq.* and RCW 90.48) Clean Air Acts - **CAA** (42 USC 7401 *et seq.* and RCW 70.94) Petroleum Transport Laws - **PTL** Spill Prevention and Response Acts - **SPRA**	EFSEC Act: Regulations (Title 463 WAC part) SMA: see above SEPA: see above ORMA : Rules (WAC 173-16-064) CWA: Water Pollution Control Regulations (Title 173 WAC part) CAA: Clean Air Act Regulations (Title 173 WAC part) PTL SPRA Regulations (WAC 173-180A- D and Title 317 WAC)
Forest Practices	SMA SEPA CWA	SMA: see above SEPA: See above CWA: Forest Practices Rules to Protect Water Quality (WAC 173-010)

key state and local agencies and organizations to develop the information concerning institutions. For example, we identified the overlapping authorities of national, state, and local laws pertaining to regulation of shoreline development. The overall authority of Federal law as manifested in the Rivers and Harbors Act of 1899 (Section 10), the Federal Water Pollution Control act of 1972 (Section 404), the National Environmental Policy Act, the Clean Water Act of 1977 (and numerous amendments and related water quality legislation), and the Coastal Zone Management Act. These Acts set environmental standards, require public notice and information processes, assign authority over permits affecting navigable

Table 9.3. Agencies and organizations influential in bivalve mollusk aquaculture related ecosystem management

Willapa Bay	Grays Harbor
WA Department of Fish and Wildlife (WDFW)	WA Department of Fish and Wildlife (WDFW)
Tribes: Shoalwater	Tribes: Chehalis Quinault
WA Department of Ecology- US Environmental Protection Agency	WA Department of Ecology- US Environmental Protection Agency
WA Department of Health- US Food and Drug Administration	WA Department of Health- US Food and Drug Administration
WA Department of Natural Resources	WA Department of Natural Resources
U.S. Department of Agriculture	U.S. Department of Agriculture
U.S. Army Corps of Engineers	U.S. Army Corps of Engineers
NOAA/National Marine Fisheries Service	NOAA/National Marine Fisheries Service
Pacific Coast Oyster Growers Assoc.	Pacific Coast Oyster Growers Assoc.
Willapa/ Grays Harbor Growers Assoc.	Willapa/Grays Harbor Growers Assoc.
Willapa Alliance	Gray's Harbor Regional Planning Commission

ues regarding marine and estuarine ecosystems and their management is now under development. This plan is anticipated to result in survey work which will be conducted this coming summer, following refinement and coordination with other members of the PNCERS socio-economic study group. Residents of coastal counties in both Oregon and Washington will likely be surveyed under a combined effort by the UW and OSU teams.

Finally, a companion study of how ecosystem and other resource protection issues are dealt with in community and regional planning in communities surrounding PNCERS study sites, in the form of masters thesis work by PNCERS research assistant Andrew Bennett, is now under development.

Integration & Interaction

Based on the socioeconomic baseline, the institutional analysis, and the ecosystem management concepts, the research is focusing on the interactions between the human system and the natural system, i.e., how does the natural system impact the human system, and how does the human system impact the natural system? The social scientists in PNCERS are developing models that will predict or explain the chain of events from policy or regulatory change to human effects on the ecosystem, to ecosystem response, to human disturbance, to change in human components of the systems. For example, the model will explain the size, trends in, and location of residential developments and recreational facilities, industrial and aquaculture facilities, etc. One approach to linking economics with ecosystem effects is to focus on land use and land use changes as an economically-driven process that responds to normal economic incentives. We have developed a conceptual model, based upon the work of Bockstael, et al. for the Patuxent watershed in Maryland. The Patuxent model explains economic and other factors motivating land use. The decision to build on undeveloped land, for example, is assumed to involve selecting the highest valued use. This selection is influenced by policy variables (e.g. zoning restrictions), population trends, level of development in neighboring tracts, cost of building, location relative infrastructure (roads, schools, shopping), distance from Washington, D.C., etc. For given land uses, the ecosystem effects are related to septic systems, impervious surfaces, fertilizer applications, pet droppings, and erosion. The model includes no feedback from ecosystem change to land use. The direction of causation is depicted as:

Table 9.4. Key considerations for implementation of ecologically-based environmental management.

Ecological Concepts	Management Concepts
Uncertainty	Stakeholder Involvement
System Boundaries	Adaptive Management
Scale (Spatial & Temporal)	Capacity for Institutional Change
Functional Relationships among Components	

Table 9.5. Challenges and opportunities for ecosystem management applied to marine and estuarine areas.

Challenges to EM	Opportunities for EM
Large number of stakeholder groups	Regional planning efforts work at appropriate spatial scales
Large number of governments involved	Restoration efforts "increase the size of the pie"
Complicated regulatory & legislative structure, with jurisdictional overlap	Visible resource depletion spurs demands for management change
Citizen apathy or over-zealousness	

POLICY ⇨ HUMAN DECISIONS ⇨ ECOLOGICAL EFFECTS ⇨ BENEFITS

We are currently exploring the available property use and value information that has been digitized by county property tax assessors in Gray's Harbor and Pacific Counties of Washington State. To further develop and modify this research strategy we are recruiting a full-time research associate (Post-Doc) who would be responsible for developing the model of causal linkages between regulatory actions and ecosystem functions and conditions. A first attempt to depict the areas of needed linkages between the research fields is displayed in Table 6 which identifies habitat conditions important to specific valued ecosystem components. Currently, we are developing a map of regionally important actions that affect the habitats that in turn affect the valued ecosystem components.

Finally, one of the major impacts of the natural system on people is that some elements of the environment attract both residents and tourists. Previous surveys have shown that one of the most often stated reasons for people to move to the coast is the natural environment and the associated recreation opportunities. Those same features draw recreational visitors. In the case of estuaries, opportunities for fishing, crabbing, boating and wildlife watching are major attractions for recreational visitors. Impacts of humans on the natural system of estuaries include site hardening (impervious surfaces) which can affect water quality and quantity, marina development which can affect water quality and habitat, preparation of sites for bivalve aquaculture, dredging of shipping channels and recreation use which can impact species abundance and health. This will require direct connections between the physical/biological research components of PNCERS and the socio-economic research effort.

Further, after the departure of Dr. Susan Hanna for the Heinz Foundation in Washington, D.C., PNCERS funded Courtland Smith of Oregon State University's Department of Anthropology to examine the coastal management institutions in Oregon. His draft report entitled "Stuck on Planning: Institutional Mapping of Approaches to Maintain and Restore Northwest Coastal Ecosystems" is currently under review and revision.

Applications

Publications:

Huppert, D. and A. Bennet. 1999. Human Systems and Estuaries in Washington. Speaker Summary in: G. McMurray, ed., *Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, Workshop Report* (in press).

Table 9.6. Effects of habitat conditions on economically important ecosystem components.

	Affected Ecosystem Components						
Habitat Conditions	**Submerged Aquatic Vegetation**	**Crabs**	**Sole**	**Razor clams**	**Salmon**	**Birds**	**Oysters**
Turbidity	X	?	?	?	?	X	X
Temperature	X	?	?	?	X	?	X
Nutrients	X	?	?	X	?	?	
Substrate	X	X	X	X	?	?	X
Salinity	X	?	?	?	?	X	X
Harvest		X	X	X	X		X

Presentations:
Andy Bennett presented the Bennett/Leschine paper on ecosystem management at the Society for Ecological Restoration, Northwest Chapter's annual conference, October 1998, Tacoma, Washington.

Andy Bennett, "Human Systems and Estuaries in Washington." PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Tom Leschine and Andy Bennett, "A systems view of environmental management in Grays Harbor." PNCERS Eat and Learn Seminar Series, March 12, 1999, University of Washington.

Workshops:
Dan Huppert, Tom Leschine, Rebecca Johnson, Sue Hanna, Julie Nelson and Laurie Houston held a meeting December 1997, Portland, Oregon.

Dan Huppert and Andy Bennett attended The Southwest Washington Coastal Erosion Conference, March, 1998, Ocean Shores, Washington.

Dan Huppert, Andy Bennett, Tom Leschine, Julie Nelson, Robert Pavia, and Katherine Wellman attended the PNCERS Workshop on Linking Social and Ecological System Models, May 29-30, 1998, University of Washington.

Andy Bennett, Dan Huppert, Tom Leschine, Court Smith and Hans Radtke attended the PNCERS Social Science Workshop, July 27, 1998, Oregon State University, Corvallis, Oregon.

Dan Huppert, Michelle Pico, and Andy Bennett attended the PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Dan Huppert, Tom Leschine, Andy Bennett, and Michelle Pico attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington

Partnerships:
Courtland Smith, Department of Anthropology, Oregon State University
Nancy Bockstael, University of Maryland
Hans Radtke, The Research Group, Corvallis, Oregon

Personnel

Dan Huppert, Professor, University of Washington
Tom Leschine, Professor, University of Washington
Andy Bennett, Graduate student, University of Washington
Michelle Pico, Graduate student, University of Washington

Research Program Management

Julia K. Parrish, Research Program Manager, and Sara Breslow

Introduction

The PNCERS Research Program is managed quarter time by Julia Parrish, with 80% time technical assistance by Sara Breslow. Primary management duties include:

- Oversee day-to-day programmatic and budgeting issues.
- Call and coordinate PNCERS Research Steering Committee meetings. The Steering Committee is composed of Julia Parrish, David Armstrong, Ray Hilborn, Steven Rumrill, and Dan Huppert, and is tasked with programmatic and budgetary decision-making.
- Organize the PNCERS Research Annual Meeting, attended by all PNCERS researchers, collaborators, and PNCERS management personnel including the Program Coordinator and PMT.
- Facilitate smaller workshops in which PNCERS Principal Investigators and collaborators can meet to coordinate research activities. Facilitate other interaction activities, such as the Eat & Learn seminar series.
- Prepare a yearly Progress Report (October) and Annual Report (March).
- Prepare the annual research budget.
- Meet and coordinate with PNCERS Program Coordinator and PMT.
- Make presentations to groups and organizations potentially or actually collaborating with PNCERS (e.g., GLOBEC-NEP).
- Develop a data management plan.
- Develop the PNCERS metadatabase.

Adaptive Environmental Assessment and Management (AEAM)

As outlined in the original 5 year proposal, the PNCERS research team began to explore avenues of research project integration using the Adaptive Environmental Assessment and Management (AEAM) technique. The premise of this effort is to provide a general framework within which coordination and collaboration among PNCERS research projects, as well as with Collaborators outside PNCERS, can be facilitated. The goal is to create a network of projects which produce research and management products at several levels so that PNCERS becomes more than simply the sum of the parts:

- *Within each research project* (e.g., peer-reviewed papers, presentations at scientific meetings and management-oriented workshops, findings for dissemination to the lay public).
- *Across two or more research projects* (e.g., estuarine circulation models tied to future crab production, an ECOPATH model relating spatially-based nearshore production and seabird predation to salmon smolt survival in the first 90 days of ocean life).
- *From the entire research team* (e.g., identification of the principle human actions and physical forces affecting natural resources of interest and the limitations of current management frameworks).

To that end, we hired David Marmorek of ESSA Technologies. David was one of the original participants in the development of AEAM at the University of British Columbia in the 1970s and has since become a principal at ESSA, a leading AEAM firm specializing in environmental management and multidisciplinary studies. In October 1998, David and two ESSA associates - Ian Parnell and Clint Alexander - met with the PNCERS Steering Committee, Program Management Team, and Program Coordinator, to outline the AEAM process as adapted to PNCERS, and begin to develop a framework for a larger 2 day meeting in January 1999. At this scoping meeting, we ran through two exercises central to AEAM - the Looking Outward Matrix (LOM) and the Impact Hypothesis (IH). An extensive discussion of these techniques is provided in the ESSA Technologies AEAM meeting report (Appendix B: All-Hands Meeting Report).

In an LOM researchers and research projects are first binned into a few relevant categories, according to the major discipline/approach involved. In the case of PNCERS, these were:

- *Physical Forces-Oceanography* - Barbara Hickey (PI), Alan Shanks (PI), Bob Francis (Collaborator), Jan Newton (Collaborator)

- *Biota-Resident Species* - David Armstrong (PI), Alan Shanks (PI), Don Gunderson (PI), Walt Nelson and Ted DeWitt (Collaborators), Dave Eggleston (Collaborator)

- *Biota-Transient Species* - Ray Hilborn (PI), Gordon Swartzman (PI), Julia Parrish (PI)

- *Habitat* - Steve Rumrill (PI), Ron Thom (PI)

- *Socio-Economics* - Dan Huppert (PI), Tom Leschine (PI), Becky Johnson (PI)

For the purposes of simplification, resident and transient species categories were lumped into "Biota." Once these categories had been chosen, an LOM was constructed showing how data and information passed from one group to another. This process highlights not only what each group needs in terms of data from each other group, but more importantly, whether there are gaps in data collection.

The second exercise, construction of Impact Hypotheses, takes a set of related indicators (usually a natural resource and the socio-economic values relevant to that resource) relevant to the larger program (i.e., PNCERS) as well as the ecological and human communities, and constructs a set of interconnected pathways through which human actions might affect the ecosystem to the extent that sustainable production of the indicator was impaired. In the case of PNCERS, a second set of actions - physical forces - was added to each hypothesis, as physical forces not only affect ecosystem production, but knowledge of the way(s) these forces interact with human actions is central to PNCERS research. Within the AEAM terminology, IH indicators are referred to as Valued Ecosystem Components or VECs. At the conclusion of the scoping meeting, four preliminary VECs had been chosen:

- Dungeness Crab
- Pacific Salmon
- Pacific Oysters
- Tourism

On 22-23 January, all PNCERS PIs, the Program Management Team, Program Coordinator, and COP Program Officer participated in a more full scale development of an LOM and three of the four proposed IH's. Graduate students and Postdoctoral Fellows working within PNCERS were also present, as were several Collaborators. A list of attendees is provided in Appendix B, as is a detailed report on the meeting achievements.

Following the AEAM meeting, the PNCERS steering committee will meet to discuss whether the AEAM approach is likely to be fruitful and at what level of use. Several other integration frameworks are also being considered as replacements or add-ons.

PNCERS Eat-&-Learn Seminar Series

Because the scope of PNCERS research is so broad, it is difficult for researchers to keep up with all projects with only annual meetings. Therefore, in Winter Quarter 1999, the PNCERS Eat-&-Learn lunchtime seminar series was initiated (Table M.1). These seminars are designed as a way for

Table M.1. PNCERS Eat & Learn seminar series schedule

Jan 15	Jan Newton, "Physical and biological oceanographic processes in Willapa Bay"
Jan 22	No meeting
Jan 29	Barbara Hickey, "Water properties and currents in coastal estuaries of the Pacific Northwest"
Feb 5	Gordon Swartzman, "Near-shore fish and plankton distribution: How to see the plankton through the noise"
Feb 12	Dan Huppert, "Institutional mapping" (Canceled)
Feb 19	Ron Thom, "Justification and refinement of eelgrass (*Zostera marina*)as an indicator of environmental conditions in coastal estuaries of Oregon and Washington"
Feb 26	Don Gunderson, "Design criteria for a network of west coast groundfish refugia"
Mar 5	David Armstrong, "Entrained but not forgotten: The geo-politics of Dungeness crab in coastal estuaries"
Mar 12	Tom Leschine and Andy Bennett. "A systems view of environmental management in Grays Harbor"

researchers to describe their ongoing work to other colleagues, both within and without of PNCERS. In addition, it is a chance for Collaborators to show PNCERS researchers how their work could fit into the evolving PNCERS scheme. Interaction at the seminars so far presented has been lively, and several avenues of collaboration among PNCERS researchers have been identified. An example would be using physical oceanographic data on circulation patterns around coastal canyons to predict areas of most intense and stable nearshore upwelling (work by Barbara Hickey). These data could then be cross referenced to several biologically-based assessments of coastal production, including zooplankton biomass signals derived from hydroacoustic surveys (work by Gordon Swartzman), and size and location of large, stable seabird colonies (work by Julia Parrish). Should such bio-physical stable areas be found, their location could be used to predict which stocks of outmigrating smolts would encounter elevated levels of food and predators (work by Ray Hilborn), as well as where coastal marine reserves might be placed (work by Don Gunderson). Eat-&-Learn seminars will continue annually as a regular part of the PNCERS research program and may expand into additional Quarters depending on scheduling and interest.

Interaction with PNCERS Program Coordinator and Program Management Team

- Assisted the Program Coordinator in the development of the PNCERS Manager's Workshop, including assistance in securing PNCERS research speakers and developing the workshop questionnaire, as well as acting as a rapporteur during breakout sessions.
- Finalized second year budget
- Provided PMT with interim reports on Physical and Natural Science research projects
- Provided PMT with workshop updates from the Social Science Team

Data Management

The Research Manager met with the Program Coordinator and Program Management Team to discuss data management, and subsequently presented a preliminary data management plan to the Research Team during the recent AEAM meeting. The plan is based on the following facts and assumptions. First, it is valuable to have both current and future access to data collected during the PNCERS program. These data should be accessible to other researchers, natural resource managers, and the lay public. Second, redirecting funds from the existing research program to a data manager would harm more than help PNCERS as this option would necessarily subtract from direct work. In the same vein, assigning data management to the Research Manager would necessarily incur increased costs and thus a redistribution of existing funds. Third, because the PNCERS research program is extremely broad at a disciplinary level, encompassing physical oceanography through economics, housing all PNCERS data in a single database might not be useful, or findable, by the majority of interested researchers who might search for data along disciplinary rather than programmatic avenues. At the same time, individual PNCERS researchers might already have plans to post their data within discipline-based outlets (e.g., Barbara Hickey's data to NODC). Finally, PNCERS is currently in the process of developing a metadatabase to serve PNCERS researchers, the research community, resource managers, and the lay public. While not a data repository, the metadatabase could serve as a pointer to the location of all PNCERS data, ensuring that this information is catalogued and not lost.

Given the aforementioned points, PNCERS is proposing that all PIs take primary responsibility for identifying a public access location where their data will be stored. Each PI will also be responsible for identifying an implementation process by which their data will be transferred to the named location, including a timeline. By the end of PNCERS year 3, all PIs will have filed a data management plan with the Research Manager. All data storage sites will be listed in the PNCERS metadatabase, with specific program pointers to PNCERS, such that the metadata could be searched programmatically (e.g., find all "PNCERS"), by individual researcher (e.g., find all "Armstrong"), or via discipline/keyword (e.g., find all "salmon"). Should a ready access data storage location not be available for all researchers, the data management plan will be reconsidered.

Data Sharing

Following a discussion at the recent AEAM meeting, PNCERS has identified a need to develop a protocol for data sharing within the PNCERS research team. The general feeling was that PNCERS wishes to facilitate cross-project data sharing, while preserving individual researcher rights and credit. Specific points include: under what circumstances data collected by one research project may be used by another research project, determining authorship in cases where one project makes use of another's data, and final authority on data interpretation. We are proposing to use the Pacific Seabird Group (PSG) Pacific Seabird Monitoring Database rules for data use as a model. The PSG database combines seabird population data from many individual and agency sources which then become available to all. Because of concerns about data use, four categories of use codes were developed: not to be used in any publication or presentation, not to be used without specific written permission of the originator (terms to be specifically negotiated), not to be used without proper citation (provided in the database), and generally available for use. Rules are known by all, and access to the database implies that the individual agrees to these conditions. During PNCERS Year 3, the Research Manager will develop a set of data use guidelines, in conjunction with the data management program, for review by PNCERS researchers.

Metadatabase

In collaboration with PNCERS Program Coordinator Greg McMurray, Sara Breslow has been developing the PNCERS metadatabase, a centralized database catalog where PNCERS PIs and others working within the PNCERS geographic area can search for information that meets their research or management needs (See Appendix C: Metadatabase). Ultimately, the metadatabase will be posted on the PNCERS web page, fronted by a user-friendly search engine (yet to be built) that will allow the user to find information via a multitude of pathways, such as a clickable map, a browsable subject index, and various keyword queries.

Approximately 14 weeks of full time work has been devoted to the PNCERS metadatabase. Of that time, about 2 to 3 weeks have been spent on each of the following tasks:

Development
- Installing hardware and software
- Learning Microsoft Access and basic SQL
- Learning about relational databases
- Learning about metadata

Design
- Designing useful metadata fields
- Planning user-friendly search engine
- Designing easy-to-use data entry forms and reports in MS Access
- Assessing and ensuring compatibility with FGDC standards and search nodes

Research
- Researching other metadatabases, what they contain and how they work
- Collecting keywords from library and web research and input from PNCERS PIs
- Searching for databases on web and in libraries
- Assessing relevance of, and sorting databases

Data Entry
- Collecting metadata
- Composing and editing abstracts
- Establishing communication with database managers
- Updating metadata

Iteration and Troubleshooting
- Revising data formats for search engine compatibility
- Normalizing database (i.e. reorganizing tables) based on expert advice
- Programming drop-down menus
- Miscellaneous troubleshooting

Future Plans for the metadatabase include the following:

Design
- Design Search Engine
- Design Web site
- Learn SQL, Visual Basic, and HTML and/or hire expert

Research
- Interview PNCERS PIs and collaborators about databases of interest
- Continue web research

Data Entry
- Speed data entry by focusing on essential fields only
- Recruit more data entry people (i.e. undergraduate research assistants)

Outreach
- Present metadatabase to PNCERS researchers

Miscellaneous Duties

- Prepared PNCERS workplan and annual research budget for submission to NOAA-COP.
- Prepared Interim Research Report on select PNCERS research projects for the Program Management Team, July 1998.
- Met with PNCERS Collaborator Bob Francis on the issue of developing a historical database for oceanographic data in the PNCERS geographic region, and the possibility of linking PNCERS to the Joint Institute for the Study of the Atmosphere and the Ocean (JISAO) at the University of Washington.
- Met with Annette Olson, School of Marine Affairs, University of Washington, about the possibility of de-

veloping a collaborative effort to address principal vectors for introduced species across the five PNCERS estuaries.

- Worked with David Marmorek, ESSA Technologies, to develop meeting agendas and products for the AEAM scoping meeting and AEAM annual PNCERS research meeting.
- Supervised Sara Breslow, PNCERS Research Technologist
- Continued contact and information exchange with Hal Batchelder, re: ties between PNCERS and GLOBEC-NEP.

Applications

Presentations:
Julia Parrish, "Cooperation or veiled conflict: creating a greater whole from individual actions in marine conservation." Plenary speaker at the Oregon Chapter of the American Fisheries Society annual meeting, February 10, 1999, Sun River, Oregon.

Publications:
PNCERS Progress Report, October 1998.

PNCERS Annual Report, March 1999.

Julia Parrish worked with David Gordon, Washington Sea Grant Science writer, on the first in a series of PNCERS tabloids, PNCERS Update V#1.

Workshops:
Julia Parrish attended a GLOBEC-NEP meeting, July, 1998, Seattle Washington, and provided a PNCERS research program update. In addition, Parrish participated in discussions of GLOBEC-NEP monitoring and retrospective studies to facilitate points of interaction between GLOBEC-NEP and PNCERS.

Julia Parrish and Sara Breslow attended the PNCERS Workshop on Linking Social and Ecological System Models, May 29-30, 1998, University of Washington.

Sara Breslow attended the Oregon Coast Geospatial Clearinghouse meeting, September 3, 1998, Tillamook, Oregon.

Julia Parrish attended the GLOBEC Steering Committee meeting in Seattle, October 1998, and gave an overview presentation of PNCERS physical and biological research. J. Parrish and S. Breslow prepared a Summary Table of PNCERS research focus and data output by project (see beginning of this report) for dissemination to GLOBEC-NEP researchers.

Julia Parrish and Sara Breslow attended the PNCERS meeting, Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us, December 8-9, 1998, Troutdale, Oregon.

Julia Parrish and Sara Breslow organized and attended the PNCERS All-Hands Meeting, January 22-23, 1999, Seattle, Washington.

Partnerships:
Hal Batchelder, GLOBEC
Dawn Wright, Oregon Coast Geospatial Clearinghouse

Personnel

Julia K Parrish, Research Program Manager, PNCERS, University of Washington
Sara Breslow, PNCERS Research Technologist, University of Washington

APPENDIX A: SOCIAL SCIENCE WORKSHOPS

Notes from the PNCERS WORKSHOP on Linking Social and Ecological System Models

May 29 & May 30, 1998 University of Washington South Campus Center

1. The workshop opened at 8:30 AM with introductions of those in attendance:

Dave Armstrong, Prof., School of Fisheries, UW
Andy Bennett, Student, School of Marine Affairs, UW
Nancy Bockstael, Prof. , Agricultural and Resource Economics, U of Maryland
Laurie Houston, Faculty Research Assistant, Forest Resources Department, Oregon State U
Daniel D. Huppert, Assoc. Prof., School of Marine Affairs, UW
Rebecca Johnson, Assoc. Prof., Forest Resources Department, Oregon State U
Tom Leschine, Associate Professor, School of Marine Affairs, UW
Julie Nelson, Student, School of Marine Affairs, UW
Julia Parrish, Res. Prof., Dept. of Zoology, UW
Robert Pavia, NOAA-HAZMAT, Seattle
Ron Thom, Battelle Marine Sciences Lab., Sequim, WA
Katherine Wellman, Battelle, Environmental Planning and Social Research, Seattle

2. **Dan Huppert** began the presentations with a short review of the ecological-economic (ECO-ECO) research strategy contained in the original socio-economic proposal to PNCERS. The key paragraphs and the "boxes and arrows chart" which encapsulate our concept of the model are included below as attachments 1 and 2.

3. **Nancy Bockstael** devoted two hours to a presentation, questions to her from the group, and discussions provoked by the presentation and related questions.

Bockstael's research on the Patuxent river watershed (see Attachment A.1 and Figure A.1) began with an EPA project that sought to discover whether an economist and a landscape ecologist (Bob Costanza) could work together. The watershed covers all or parts of seven counties in Maryland. The focus was water quality in the river, but has since expanded to include aquatic habitats. Ecosystem conditions include nutrient loadings (nitrogen and phosphorus), stream flow, water quality, habitat quantity and fragmentation. The ecosystem models typically take economic activity as an exogenous influence (something to be regulated), whereas economic models take economic development (like land conversion) as a result of individual decisions chosen from among feasible alternatives to serve certain purposes. Hence, the economics model can contribute to understanding of the eco-eco system and to design of policies seeking to achieve better ecosystem management. The key is for the economic model to predict response to variables affected by policies.

The Patuxent model explains economic and other factors motivating land use. The decision to build on undeveloped land, for example, is assumed to involve selecting the highest valued use. This selection is influenced by policy variables (e.g. zoning restrictions), population trends, level of development in neighboring tracts, cost of building, location relative infrastructure (roads, schools, shopping), distance from Washington, D.C., etc. For given land uses, the ecosystem effects are related to septic systems, impervious surfaces, fertilizer applications, pet droppings, erosion, etc. The model includes no feedback from ecosystem change to land use. The direction of causation is depicted as:

Policy ⇨ **Human Decisions** ⇨ **Ecological Effects** ⇨ **Benefits**

The empirical method is a fancy equation-fitting technique that predicts land conversion as the independent variables change.

A key to success is a data set that reflects the effects of policy change on land use behavior.
Bockstael sought out spatially disaggregated land use data. These are annual data at best, and they do not conform to the 200m x 200m grid used in the ecosystem model. Bockstael noted the disparity between time/space scales incorporated in the ecosystem and economic models. The ecosystem models tend to use smaller space intervals and different time scales (both shorter and longer) that annual periods typically used in economic models. Bockstael recommends that economists and ecologists do not attempt to use the same scales. Each discipline must use scales appropriate to its research, but work out a mechanisms for sharing data.

Geographic domains can be a problem. In the Patuxent study there are ecological domains (watersheds), political domains (county boundaries with land use regulations by counties), and economic domains (the extent of the land market, for example). The different models have to accommodate the appropriate geographic domains for each. The economic model of land use must conform to some notion of a cohesive economy for which the economic variables are salient.
Watershed and political boundaries are often irrelevant to the economic system.
Bockstael suggests asking the following three questions in starting up an eco-eco project:
Where is the action? (what is changing, what ecosystem effects are considered important?)
What do the two research groups need from each other?
Which human decisions affect the ecosystem and what policy variables affect those decisions?

4. **Ron Thom** spoke next about his PNCERS research element which focuses on indicators of ecosystem conditions, like coastal plankton production, seabirds, salmon, and estuarine crabs, shrimp, fish, and larva transport.
The short term objective is to identify physical and human factors affecting the ecosystem. The research links spatial and temporal patterns of habitats and biological resources to changing physical and chemical conditions as well as human impacts. For example, birds depend upon nesting habitat, food supply, and predation. Measures of estuarine habitat include turbidity, substrate, depth, temperature, chemical contaminants, salinity. Habitat quality should be a predictor of species presence.

Thom illustrated the linkages between water quality and habitat type. For example, increased turbidity causes a decrease in eelgrass density. Eelgrass is important habitat for crab, so crab abundance depends upon human activities that increase water turbidity. Crab fishing also affects crab density and density of crab predators. So the linkages are numerous between people and key estuarine species.
Thom is looking to economists to model land use along the shore which affects algal blooms, fecal coliform count, turbidity.

5. **Julia Parrish** noted that PNCERS is huge and undoable. But we need to define a Goal, even if it is unlikely to be attained. She illustrated the ecosystem linkages with examples from seabird systems. Habitat is the bottom of the pyramid, fish and invertebrates are in the middle, sea birds (and humans) are on top. Humans affect the seabirds directly (gill nets, oil spills, eggs hunting, habitat modification) and indirectly (fishing for prey species). Dredging creates habitat for seabirds while decreasing habitat for salmon.
Another indirect route for human effect is illustrated by murres, who are killed by gulls and eagles whose populations in turn have increased in part due to food availability from human trash. Caspian tern is another bird which might act as an ecosystem indicator.
We need to focus on the links between seabirds, fish, other estuary organisms and humans.

6. **Julie Nelson** distributed information about the "organizational map" she is developing for the Willapa Bay and Gray's harbor areas. She divides the economy of the region into sectors, especially oyster, salmon, crab and groundfish harvest. Interested in developing framework for comparing values and perceptions of the ecosystem.

7. **Andy Bennett** is working on getting existing management input on what science should produce and is looking for convergence between what managers want and what science can provide.

8. **Dave Armstrong** is focusing on Subtidal aspects: estuarine and offshore, indicators of natural climate change, life histories and other data used to analyze Dungeness Crab. He is interested in delineating ecological links, such as whether oyster culture creates good habitat for small crabs. Dave wants to understand the economic trade-offs and the deeper linkages

between species.

9. **Bob Pavia** (NOAA) described three projects that are ongoing. The first concerns the problem of defining and measuring recovery of Prince William Sound after the 1989 oil spill. The project looks at intertidal biota. The second project is a circulation model that displays how geomorphic changes will affect circulation in a bay. It is a relatively simple model, but it may prove useful for developing scenarios which link dredging or other physical changes to habitat changes. Third, they are looking into game theory as a means of understanding choice from among alternative spill responses. NOAA can share with us some data sources and mapping capabilities.

10. **Rebecca Johnson and Laurie Houston** displayed summaries of the demographic and economic data they have collected from standard sources so far.

11. Due to time constraints (or bad planning by chair) we had little time for presentations by **Tom Leschine** and **Katherine Wellman.** Some of their views are reflected in much of the discussion that ensued during the afternoon of May 29.

Abstracts of General Discussion

We agreed that we need to place reasonable boundaries on the analysis and models attempted under PNCERS. We discussed whether and how to link the forested land management to estuarine ecosystems without including forest ecosystem research in PNCERS.

A first-cut delimitation of boundaries and elements for our eco-eco work stipulates five variables that affect habitats of important marine biota and which are driven, in part, by economic sectors prevalent in the four ecosystems of concern. The habitat conditions and economically important ecosystem components are many, but we would focus only on the few listed in Table 1 (turbidity, temperature, nutrients, substrate and salinity – intentionally leaving out chemicals for now). The human activities affecting the habitat conditions are also many, but we narrowed interest to the seven listed in Table 2.

The task is to understand what economic, social, and policy variables affect the human activities (economic sector) that affect the relevant ecosystem conditions.

To begin our work, we agreed to focus on just two main ecosystem components: eelgrass and oysters. Once we have some competence in this area we should expand to include the crabs and salmon; then the clams, birds, and sole. The eventual goal of characterizing and understanding "ecosystem management" following this strategy would be a matter of successive approximations, getting closer and closer to "comprehensive ecosystems" as we are able to incorporate more and more of the important aspects.

We discussed a number of immediate steps.
(1) Obtain and report on existing data and maps for the Willapa Bay and Gray's Harbor areas
(2) Summarize existing information about values, beliefs, policy preferences among "public" and among special interest groups
(3) Report data sources to Sara Breslow, who will enter information into meta database.

Table A.1. Effects of habitat conditions on economically important ecosystem components.

	Affected Ecosystem Components						
Habitat Conditions	Submerged Aquatic Vegetation	Crabs	Sole	Razor clams	Salmon	Birds	Oysters
Turbidity	X	?	?	?	?	X	X
Temperature	X	?	?	?	X	?	X
Nutrients	X	?	?	X	?	?	
Substrate	X	X	X	X	?	?	X
Salinity	X	?	?	?	?	X	X
Harvest		X	X	X	X		X

Table A.2. Human actions that influence habitat conditions .

	Causal Factors in Changing Habitat Conditions						
	Forestry Practices	Dredging channels or marinas	Conversion of Eelgrass to mudflat	Housing and Septic Systems	Shoreline Modifica-tion	Industrial Pollution	Pesticide Application
Turbidity	X	X	X	X	X	?	?
Temperature	X	?	?	?	X	X	?
Nutrients	X	?	?	X	?	?	?
Substrate	?	X	X	?	X	?	?
Salinity	?	?	?	X	?	X	?
Biocomplexity	X	X	X	X	X	X	X

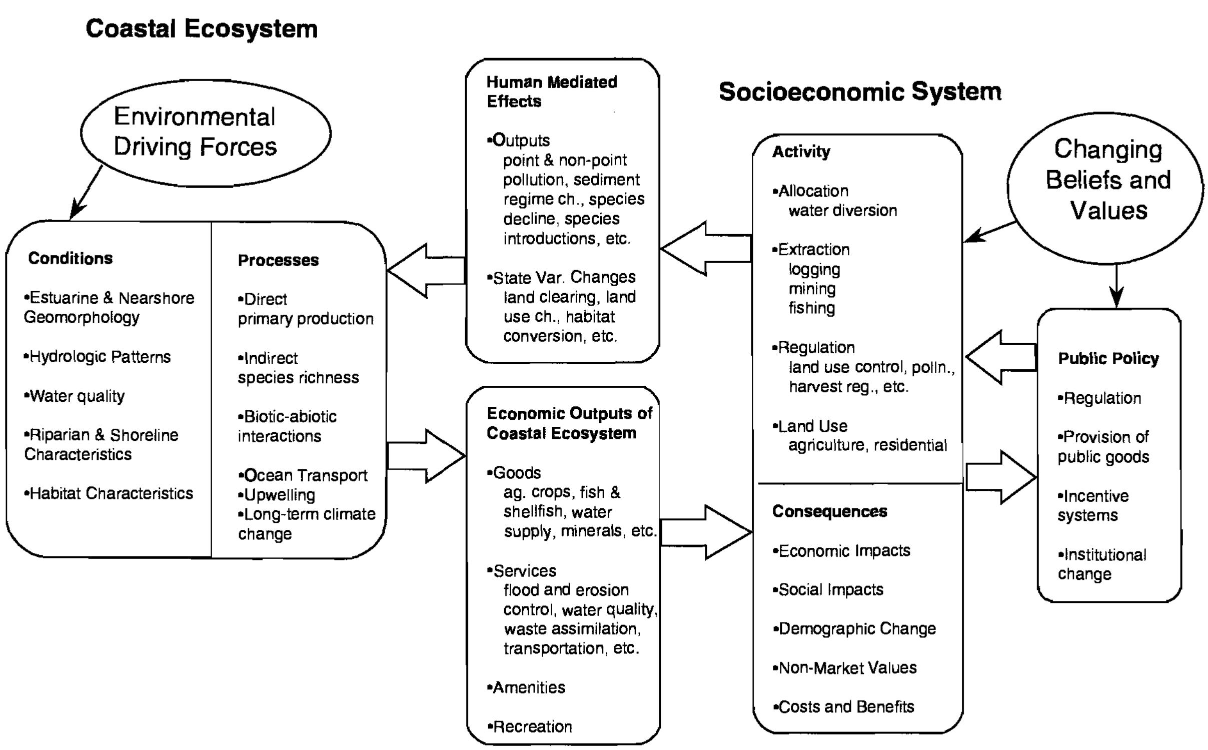
Attachment A.1. Excerpt from socio-economic proposal to PNCERS

Describing and Understanding Economic-Ecological Links

A focus for the PNCERS project is the interaction between economic activity and ecological conditions. The socio-economic group will work with the natural science team to delineate the most important sources of human influence on the four coastal ecosystems. These will then be linked to economic sectors (e.g. sedimentation and non-point source pollution to particular agricultural and forest harvest practices) and incorporated in the status of coastal ecosystems. This activity will involve workshops, such as the proposed Adaptive Environmental Assessment and Management workshop during the first year of research.

The socio-economic researchers will collaborate with the physical and biological scientists to link the social and economic consequences to predicted ecosystem conditions and to predict responses that would follow specific decisions. For example, expanded land use for vacation homes, retirement communities, and tourist facilities would have a variety of effects on sediment production and disposition, nearshore habitats, and water quality. These physical effects could influence populations of salmon, crab, and shellfish species of importance to local industries and to tourist/retirement communities. Our contribution to the combined ecosystem-economic models would be evaluations of social and economic consequences of alternative land use, fishery, pollution control and other decisions that are critically linked to understanding of ecosystem scale, function, and long-term condition.

Figure A.1. Conceptual model of ecosystem-socioeconomic system



University of Washington Correspondence
BOX 355685
Memorandum

School of Marine Affairs
Telephone: 543-7004
FAX no.: 543-1417

August 31, 1998

TO: PNCERS Group

FROM: Dan Huppert

RE : Report on Workshop at Corvallis, July 27, 1998

The workshop convened in Room 222 of Peavy Hall on the Oregon State University campus at 8:30 AM with Andy Bennett, Laurie Houston, Dan Huppert, Rebecca Johnson, Tom Leschine, and Hans Radtke in attendance.

1. The first discussion concerned progress of Laurie Houston and Hans Radtke in developing the socio-economic descriptions of the case study areas, and the question of whether Yaquina Bay would be included as a study area in place of either Tillamook or Coos Bay.

The basic data collection for Tillamook and Coos Bay is well underway, but there are still some data access issues regarding the two Washington State sites. We agreed that I, Becky and Hans would work to find a contact and source of 4-digit level economic data from Washington State. This is the so-called ES202 data collected by the State employment department which reveals numbers of employees and payrolls at a fine level of detail. The problem is that such data likely reveals confidential information (data covering 3 or fewer firms) in coastal counties. Hence, access to the data is limited and made require a formal nondisclosure agreement.

We discussed the problem of how to detect the fraction of the population that is self-employed and, hence, not documented in the usual employment statistics. In Washington State, those individuals should be identifiable from the business and occupations tax data.

We seemed to be on schedule to complete our comprehensive picture of the four estuaries by the end of September.

Regarding the choice of four study sites, the discussion was touched off in May by Dave Armstrong who made a case for studying Yaquina Bay. Support for that site apparently derived from the existence of the marine laboratory there, possible collaborators, and existing data bases. We concluded that we could not shift from Tillamook to Yaquina Bay at this time because we have already invested heavily in Tillamook. Court Smith's work (vice Hanna), for example, is really focused on Tillamook. Nor could we afford to abandon Coos Bay because of the importance of the South Slough research program, Steve Rumrill's contributions, and its importance as a timber/shipping center without significant tourism/retirement development. Our logic for the original four sites still stands and we did not decide to shift to Yaquina Bay as a site.

A discussion of Julie Nelson's research and coordination of that research with Radtke/Houston resulted in agreement that there needed to be an energetic coordination effort among the socio-economic researchers, but that also extends beyond us to include the coastal ecosystem people. The idea would be to consolidate information about land use, ecosystem condition, and economies so that each researcher would have the full picture. We also discussed ways for Nelson to complete her institutional mapping for the Washington coast. (But this became mute when Julie resigned her research assistantship in early August. I will be seeking a new student assistant to help consolidate the economic history and institutional information in Washington.)

At the end of the meeting we summarized tasks from this part of the discussion. R. Johnson was to look into the 4-digit SIC data. H. Radtke was going to contact extension agents regarding oyster production and other aquaculture production figures and attempt to quantify other marine resource uses in the estuaries. Andy Bennett was going to investigate and report on the content of the two CD ROM's currently in our possession. I am to determine what economic and other variables drive oyster production in these areas.

2. Review of May workshop notes and discussion of economic-ecological modeling.

The workshop notes were reviewed perfunctorily with little comment, and the discussion went into the content, methodology, and scope of the economic-ecological modeling effort. Three things emerged. First, we need a way to collect, consolidate, display and analyze spatial data in and around the estuaries. For Gray's Harbor and Willapa we have obtained CD ROMs containing data drawn from US Census, US Geologic surveys, some fish and wildlife information (e.g. location of salmon fishing and crabbing areas) and some land ownership and use information. The data is far from complete and lacks crucial information for the prospective economic analysis. In particular, we would require land transactions information (prices paid per unit) and more detailed information about land type (elevation, slope, soil type, cover, hard surfaces) and building types (housing characteristics that reflect real estate value, like square footage, age, etc.). With that additional data we could attempt to develop a model similar to Bockstael's land conversion model for the Patuxent river watershed. We agreed that the UW people would contact land use planning and tax assessment offices in Pacific and Gray's Harbor counties for the missing data, as well as explore further the CD ROM already received from the Gray's Harbor estuary planning office.

Second, regarding the structure of the eco-eco model, we started from the understandings reached at the May workshop that we would not be attempting to quantify human impacts on the ecosystem, but rather would be predicting levels of human inputs to the ecosystem associated with land use, economic production, and specific activities such as dredging, fishing, and preparation of mudflats for oyster culture. As a first target of research, we would seek to establish an hedonic land valuation model of the sort that Bockstael developed, probably limited to a narrow range around the two Washington Bays. The objective is to understand what economic, spatial and ecological characteristics influence land value. The second stage of that model is an equation explaining probability of land conversion based upon land value. This second stage could potentially be modified to more directly reflect policy and other variables in addition to economic value of land use.

Figure A.2 and Tables A3, A.4, A.5, and A.6 may help to explain the sequence of tasks for the Land-Use-Ecological Model. The first task (which we are still pursuing) is to compile the information about economic activities and land uses that influence both the land value and the estuarine ecosystem. For land value that includes economic infrastructural information (roads, distance to beaches, cities, other attractions), surrounding land uses, and land zoning regulations pertaining to each parcel. The hedonic land value model predicts value per acre for every land parcel included in the subject area. Land conversion is then assumed to reflect land owner decisions that maximize economic value. [We may have to modify this to account for public land holdings and private holdings in nature trusts and so forth.] The data would best be housed in a GIS data base where synthetic variables (like distance from beach, distance from shopping, percent of surrounding land in forests) can be conveniently calculated. The conversion model generates a probability of conversion from use x to use y based upon the difference in estimated value of land in use x versus use y. Last, there needs to be a source of information regarding the rates of flow of inputs or magnitudes of ecosystem changes associated with the land use changes. This would involve understanding of how land use practices are related to water quality, submerged aquatic vegetation, and other estuarine ecosystem conditions. IF those ecosystem conditions are predictive of crab and salmon population effects or the oyster condition index or the attractiveness of the estuary for recreation or residential development, THEN there could be another step in the model which reflects feedbacks from the economic impacts on ecosystems to the ecosystem condition effects on the economy. We are not promising to develop this feedback step in the model, even though it completes the loop, because we do not know whether the ecologists can make the necessary predictions. This should be discussed at the next PNCERS "all-hands" meeting.

Third, we discussed the role and content of the Wellman (Battelle) proposal for the second year budget (previously assigned to Hanna) and how it meshes with the rest of our research agenda. In general, we agreed that we should push the Battelle group to identify more clearly the relationship between land use (and conversion) and ecosystem variables important to the estuarine ecological models. This would tie the economics work more closely to the research of Thom and Armstrong and would give us a mechanism to begin predicting ecosystem effects from coastal economic activity. This would shift the emphasis of the prospective Battelle work away from a review of economic value studies to a closer collaboration with R. Thom and simple economic-ecological models for Willapa Bay and Gray's Harbor. This provides the basis for implementing the actions outlined in Table A.6. I agreed to discuss this further with Wellman.

3. Ecosystem Management. Andy Bennett and Tom Leschine summarized their review of ecosystem management concepts

and models. Six different notions of ecosystem management were found in the literature. The main objective overall is to keep ecosystems intact over the long term. Much of the past ecosystem management involved large tracts of publicly owned land. They concluded that marine ecosystem management will be much more complicated than, say, forest ecosystem management. For coastal areas there are high densities of people, very mixed land ownership patterns, and numerous overlapping regulatory authorities.

Tom Leschine explained his intention to approach the ecosystem management process using Sabatier's Advocacy Coalition Framework. He reviewed the questionnaire and summaries data used by Kent Lind in his study of sediment contamination in Puget Sound. The focus is on the use of scientific information in decision-making, especially on conditions under which science does influence decisions and under which it gets ignored.

4. Courtland Smith made a presentation regarding his "institutional mapping" work for Tillamook Bay and Coos Bay. Smith distributed an extensive bibliography regarding the Tillamook Bay estuary and a thorough summary of the history and current status of the area. Court noted that the "institutional mapping" task does not have a broadly accepted definition, and he took this as an opportunity to be creative in developing his approach. He intends to use the "adaptive management" process as a means to investigate estuarine management in the two Oregon sites. He will be documenting how the agencies are actually using adaptive management to address ecosystem issues. There seems to be a lot of money and energy available to planning and collaborating, but very little for implementing the actions. Resources for monitoring the results (a key step in adaptive management) seems to be even rarer.

He thinks that water quality regulation may be arising more forcefully in Oregon estuaries due to court challenges to the Oregon governor's salmon recovery plan. Water quality planning institutions generally establish goals and then pass on responsibility for implementing the plan to other agencies, like the Oregon Dept. of Agriculture. EPA sets Total Maximum Daily Loads (TMDLs), an important tool for water quality regulation. Water temperature is emerging as a big water quality problem along the coast. Chemical contamination seems important too, but no one is monitoring it. Bacterial pollution affects shellfish, since when water pollution exceeds the EPA standard for *E. coli* the shellfish beds are closed. In Tillamook Bay this problem links to the very important dairy industry and the powerful Tillamook Creamery Association.

Court will be working for a month or so this summer and will have a report in the fall.

5. We had little time left for discussing the coastal survey we intend to implement in the coming year. We agreed to meet in late September or October to discuss a business survey, a resident survey, and a visitor survey.

Figure A.2.

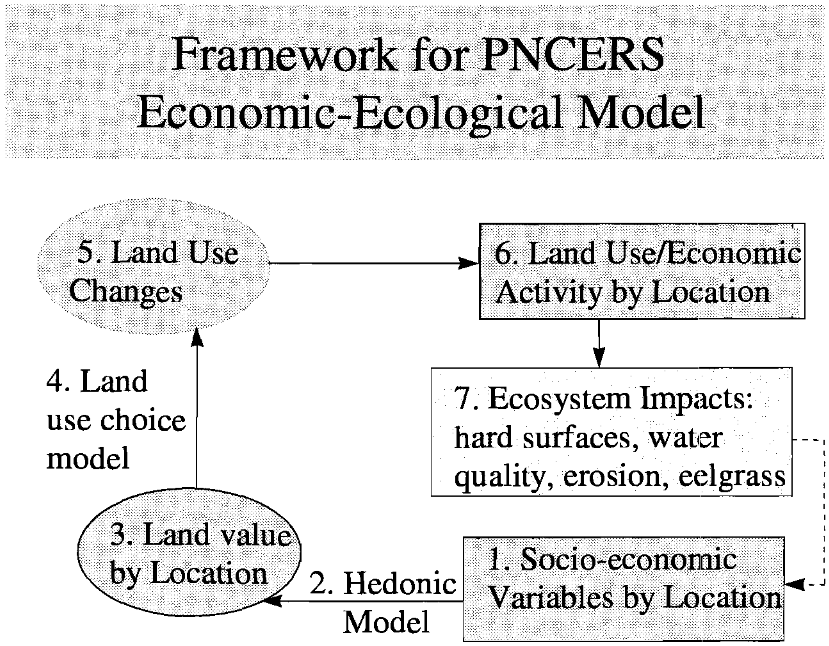


Table A.3.

Socio-economic Variables by Location

- Establish baseline economic activities and conditions for land parcels
- Include business uses, oyster growing, agriculture, residential with and without sewer, single and multi-family, timber land, road and public buildings
- Display in maps and statistical summaries

Table A.4.

Hedonic Land Value Model

- Obtain land sales price by individual lots over, say, 5 years
- Obtain land/structure characteristics by individual lots/locations and zoning type
- Add location-specific information using GIS (?); e.g. distance from metro areas, beaches, shopping
- Estimate hedonic price model

Table A.5.

Land Use Conversion Model

- Compile Information on Land use Conversions over 5 (?) years
- Calculate values of land conversion via hedonic model
- Estimate probability of conversion due to differential land values & assess changes in probabilities due to policy changes
- Estimate changes in Land Use

Table A.6.

Ecosystem Impacts Model

- Establish pertinent categories of local ecosystem effects of human activity by land use categories
- Establish rates of impact per unit of land use or activity (water quality, sediment)
- Build simple linear model linking economic uses to ecosystem effects
- Consider nonlinear effects

APPENDIX B: ALL-HANDS MEETING REPORT

Summary of the All-Hands Meeting held January 22-23, 1999

This report has been modified from the original document submitted to the PNCERS Research Program Manager by David Marmorek, Clint Alexander and Ian Parnell of ESSA Technologies following the conclusion of the All-Hands Meeting.

List of Attendees

Name	Title	Affiliation
Alexander, Clint	AEAM Facilitator	ESSA Technologies
Armstrong, Dave	PNCERS PI	University of Washington
Bailey, Bob	PNCERS Program Management Team	Oregon Coastal Management Program
Banahan, Sue	COP Program Officer	NOAA Coastal Office
Bell, Kathleen	PNCERS Prospective Post-Doc	University of Washington
Bennett, Andy	PNCERS Graduate Student	University of Washington
Borde, Amy	PNCERS Technician	Battelle Marine Sciences Lab
Breslow, Sara	PNCERS Research Technologist	University of Washington
Copping, Andrea	PNCERS Program Management Team	Washington Sea Grant Program
De Witt, Ted	Collaborator	US EPA Western Ecology Division
Dumbauld, Brett	Collaborator	Washington Department of Fish and Wildlife
Feldman, Kris	PNCERS Graduate Student	University of Washington
Francis, Bob	Collaborator	University of Washington
Gunderson, Don	PNCERS PI	University of Washington
Hickey, Barbara	PNCERS PI	University of Washington
Hilborn, Ray	PNCERS PI	University of Washington
Huppert, Dan	PNCERS PI	University of Washington
Johnson, Becky	PNCERS PI	Oregon State University
Leschine, Tom	PNCERS PI	University of Washington
Magnusson, Arni	PNCERS Graduate Student	University of Washington
Marmorek, David	AEAM Facilitator	ESSA Technologies
McMurray, Greg	PNCERS Program Coordinator	Department of Environmental Quality
Newton, Jan	Collaborator	Washington State Department of Ecology
Parnell, Ian	AEAM Facilitator	ESSA Technologies
Parrish, Julia	PNCERS PI	University of Washington
Pico, Michelle	PNCERS Graduate Student	University of Washington
Roegner, Curtis	PNCERS Post-Doc	University of Oregon
Rumrill, Steve	PNCERS PI	South Slough National Estuarine Research Reserve
Shanks, Alan	PNCERS PI	University of Oregon
Stein, John	PNCERS Program Management Team	National Marine Fisheries Service
Swartzman, Gordon	PNCERS PI	University of Washington
Thom, Ron	PNCERS PI	Battelle Marine Sciences Lab
Tsai, Grace	PNCERS Graduate Student	University of Washington
Wainwright, Tom	Collaborator	National Marine Fisheries Service

Workshop Agenda

Friday, January 22nd

8:30 a.m. Introductions: Review of Workshop Objectives and Agenda (Julia Parrish, David Marmorek)

8:50 a.m. Bounding the Problem: Build on results of scoping meeting (Oct/98) and managers meeting (Dec/98) to:
- define management **actions** or **decisions** to which PNCERS findings could potentially be applied
- define coastal zone **indicators** (or Valued Ecosystem Components) both of interest to managers, and potentially examined by PNCERS
- classify each action and indicator by **spatial scale** of interest (i.e., more appropriate to a detailed examination in *estuaries* or to a coarser examination at *coast-wide* scale for all of Washington and Oregon). Also define how far offshore the estuarine and coast-wide scales extend (e.g., up to 3 miles offshore).
- define a **temporal horizon** for PNCERS (i.e., time required to see the impacts of current management decisions in ecosystems, considering people as part of ecosystems)

10:15 a.m. BREAK

10:30 a.m. Continue Problem Bounding

11:30 a.m. Introduction to Looking Outward Exercise
- break problem into subsystems
- define information transfers required between these subsystems to predict changes in indicators in response to actions (see attached example)
- each set of specialists "looks outward" at other systems, and ignores all the nifty processes internal to their subsystem

12 noon LUNCH

1 p.m. Looking Outward Exercise
- do this exercise twice, once for estuarine scale and once for coastwide scale, with brief discussion of cross-scale linkages

3 p.m. BREAK

3:15 p.m. Continue Looking Outward Exercise

4 p.m. Introduction to Impact Hypotheses
- based on Bounding and Looking Outward exercises, define set of cause-effect linkages connecting human actions and physical forces to indicators (see attached example)
- we want to define several sets of impact hypotheses, at different spatial scales as a framework for Saturday's discussions

5 p.m. Adjourn

6 p.m. Dinner

Evening Steering Committee and ESSA meet to define draft impact hypotheses, and interdisciplinary subgroups to address them

Saturday, January 23rd

8:30 a.m. Present draft set of impact hypotheses, proposed subgroups, and schedule
- discussion of impact hypotheses
- adjust subgroup composition if necessary
- explain procedure to be followed
- break into 3 subgroups

9:30 a.m. Subgroup evaluations of impact hypotheses: Session #1 (3 subgroups). For each impact hypothesis:

1) **Clarify impact hypothesis**. Subgroup reaches consensus regarding the structure of the impact hypothesis, and if necessary, restatement of the hypothesis or its associated linkages.

2) **Documentation of existing knowledge:**
   2a) evidence for or against the overall hypothesis, or specific linkages;
   2b) key uncertainties; and
   2c) other relevant information.

3) **Conclusion.** Subgroup reaches consensus on one of three conclusions for a given impact hypothesis

and documents why:
3a) hypothesis is extremely unlikely and not worthy of PNCERS research;
3b) hypothesis is possible, but inappropriate for PNCERS research (e.g., others are already doing it, problem is outside of PNCERS focus, infeasible research topic within time available); or
3c) hypothesis is possible, and could be/is part of PNCERS research.
4) If you conclude 3c, then develop **Research Strategy**. Subgroup discusses:
4a) retrospective analyses of historic information to explore / test hypothesis;
4b) data to be collected over next 2-3 years to supplement historic data;
4c) spatial/temporal resolution of data collection / storage to allow interdisciplinary links;
4d) key data sharing responsibilities (within PNCERS, outside PNCERS (e.g., GLOBEC)); and
4e) how could proposed research contribute to tools / products to be developed for managers.

10:15	BREAK
12 noon	LUNCH (adapt schedule as required)
1 p.m.	Subgroup evaluation of impact hypotheses: Session #2 (3 – subgroups, same methods as Session #1).
3 p.m.	BREAK
3:15 p.m.	Reports from Subgroups (15 minutes presentation, 10 minutes discussion per group)
4:30 p.m.	Adjourn

Introduction

A PNCERS all-hands meeting was held 22-23 January 1999. The meeting was structured as an AEAM (Adaptive Environmental Assessment and Management) workshop, using conceptual models (impact hypotheses) to further articulate the focus of PNCERS, and interdisciplinary linkages. There were two objectives:

1. Develop an integrative framework/process for PNCERS that will promote interdisciplinary research among PNCERS scientists that is relevant to the needs of managers.

2. Generate specific ideas for applied research to fill in parts of this integrative framework (i.e., exploratory analyses, hypothesis tests, data collection, development of decision support tools).

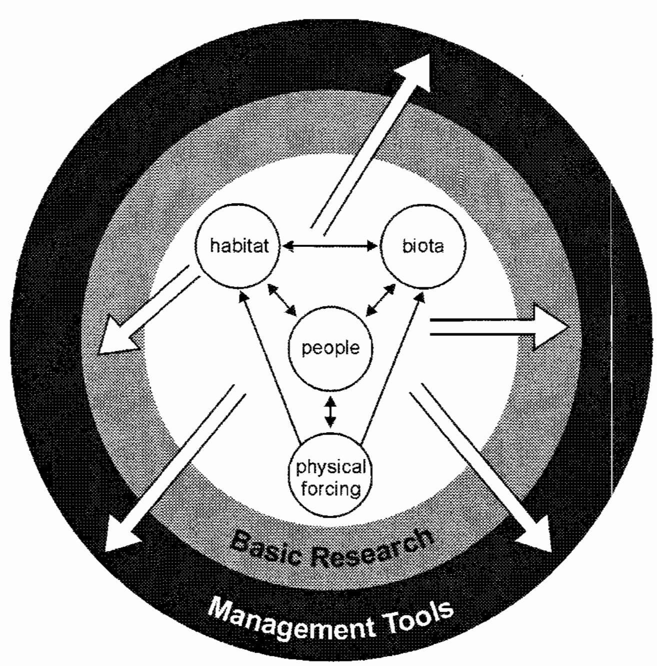


Figure B.1. A pictorial representation of the objectives of PNCERS

These objectives are visualized in Figure B.1: that is, how to maximize the integration of the components in the inner circle, so as to bring the greatest possible applied benefits of PNCERS research to managers (outer circle), in addition to advances in basic research (middle circle).

Bounding the Problem

The first day was devoted to bounding the problem: identification of key human activities or actions of interest to PNCERS (Table B.1), indicators or Valued Ecosystem Components or VECs (Table B.1), spatial bounds and resolution, temporal horizon, and a Looking Outward Matrix (Table B.2). The bounding exercise conducted on the first day was meant to illustrate the issues which must be considered, and to provide some focus for the discussion of specific impact hypotheses, but the results should be considered merely as a good start, and revisited from time to time as PNCERS evolves.

Table B.1. List of actions (or human activities) and indicators (or Valued Ecosystem Components) of potential interest to PNCERS. Valued Ecosystem Components (VECs) are resources or environmental features that: 1) are important to local human populations; or 2) have national or international profiles; and 3) if altered from their existing status, will be important in evaluating the impacts of development and in focusing management or regulatory policy. Actions and indicators are classified according to which subsystems or subgroups of researchers would logically need to consider them: B = Biota; H = Habitat; P = Physical/Chemical; S = Socio-economic.

Actions
Harvest (listing endangered species) (B)
Hatcheries (listing endangered species) (B)
Exotic species (B)
Habitat restoration (listing endangered species) (H)
Marine protected areas (H)
Ecotourism /other tourism (S)
Sea floor development (S/H)
Ocean disposal of dredge Development (S/H)
Erosion (control) (S/P)
Sewage (treatment) (S/P)
Other contaminants (S/P)
Port activity (shipping, dredging, piers, ports, jetties) (S/P)
Urban-suburban development (S/P)
Shipping / tankers (S/P)
Agriculture / Forestry (non-point source) (S/P)
Aquaculture (S/H/B)
Dams, diversions (P/H/B)
Indicators (Valued Ecosystem Components)
Catch and existence of salmon, sole, hake, rockfish, and other species (B)
Crab production; clam quantity and quality (B)
Oyster production (B)
Seabirds density / diversity (Low) (B)
Quality and quantity of specially valued habitats* (H)
Water quality for swimming (P)
Channel depth for shipping (P)
Employment (S)
Income distribution (S)
Tourism (S)
Aquaculture production (S/H/B)
* *There are many possible ways to define this VEC, including the diversity of habitats, the amount of "status quo" or original habitat, preserves, reserves, recreation areas, nursery habitats.*

Table B.2. PNCERS Looking Outward Matrix for Coos Bay. Information within a cell is passed from the row subsystem to the column subsystem. X = information that is not currently being generated from PNCERS related research, but may be available from another source, *Italics* = PNCERS nearshore scale information passed to estuary level where information also applies to other bays or areas, this is noted. WB = Willapa Bay, GH = Grays Harbor.

TO: FROM	Nearshore Physical Factors and Phys/Chem	Habitat	Biota	Socio-economic
Near shore physical factors and Phys/Chem		• Eelgrass: nutrients, temperature, turbidity, circulation, salinity (data for WB and GH). • Sea level • Storm events	• Low O2 (X?) upstream in tidal sloughs • Salinity < 18 ppt vs. > 25 ppt by month for oysters • *Coastal SST as El Nino index* • *# upwelling/ downwelling events (by day)* • Freshwater inflow in smolt migration period • [Fecal coliform] (**X,** DEQ data, WDOE data).s	• Water quality for swimming (Temp OK, coliform **X**) • Rates of shoreline erosion (**X, re:** area suitable for development) • Relative amount of estuarine flushing
Habitat		• Rate of spartina growth over time	• Crab refugia (shells, eelgrass, etc.) • Salmon refugia (chum) • Length of channels for salmon	• Distribution of different habitat types • Assimilative capacity for humans
Biota		• Existing data on burrowing shrimp	**Nearshore** • *Abundance of larvae at entrance to estuary* • *Zooplankton abundance index for ocean entry period (June-July)* • *Birds as index of offshore production*	• Harvestable edible biomass of crabs in fishing season across Coos bay (harvest within estuary, production from estuary) • CPUE of clams (static) • Length of sport fishery for salmon • Frequency of nuisance fish kills • Area and frequency of shellfish bed closures
Socio-economic		• Any development which might affect temperature, turbidity, nutrients, etc.		
Actions	• Columbia R. dams • Shoreline developments • Freshwater quality	• Harvest • Hatcheries		• Viewscape

The spatial bounds of the project vary by component, as indicated on the Summary Map (Figure 1) at the beginning of this report. The key spatial issue is to ensure that data can be aggregated or disaggregated so as to facilitate interdisciplinary linkages. With respect to the eastern boundary of PNCERS, participants agreed that upslope watershed influences were not part of PNCERS, and that habitat mapping would be confined to the estuary proper for the four PNCERS estuaries. The western bounds, at least in terms of physical oceanography, are the limit of the edge of the continental shelf. The northern and southern bounds are the border with Canada, and Cape Mendocino (respectively). Salmon, fish biomass and zooplankton would be considered coastwide. Seabird research, though concentrated in Tatoosh, Cape Meares, and Yaquina Bay, is representative of food abundance over a much larger area. Socioeconomic research is focused on the counties surrounding the four PNCERS estuaries, with other counties used for comparative purposes.

The temporal horizon of PNCERS (briefly discussed) is to provide outputs to managers that are useful today, and reflect the impacts of actions on Valued Ecosystem Components up to fifty years from now.

Impact Hypotheses

Impact hypotheses are explicit statements of the cause-effect linkages between actions and VECs. At the end of the first day, four draft impact hypotheses were developed, dealing with crab, salmon, oysters and tourism. The first three of these were addressed in detail on the second day of the workshop, and are described in the next three chapters of this report. A four-step process was used as a guideline to subgroups for the evaluation of impact hypotheses (listed below). There was some healthy variation among subgroups in how they applied and adapted this process.

1) *Clarify impact hypothesis.* Subgroup reaches consensus regarding the structure of the impact hypothesis, and if necessary, restatement of the hypothesis or its associated linkages.

2) *Documentation of existing knowledge.*
   - 2a) evidence for or against the overall hypothesis, or specific linkages
   - 2b) key uncertainties
   - 2c) other relevant information

3) *Conclusion.* Subgroup reaches consensus on one of three conclusions for a given impact hypothesis and documents why:
   - 3a) hypothesis is extremely unlikely and not worthy of PNCERS research;
   - 3b) hypothesis is possible, but inappropriate for PNCERS research (e.g., others are already doing it, problem is outside of PNCERS focus, infeasible research topic within time available); or
   - 3c) hypothesis is possible, and could be/is part of PNCERS research.

4) If you conclude 3c, then develop *Research Strategy.* Subgroup discusses:
   - 4a) retrospective analyses of historic information to explore / test hypothesis
   - 4b) data to be collected over next 2-3 years to supplement historic data
   - 4c) spatial/temporal resolution of data collection / storage to allow interdisciplinary links
   - 4d) key data sharing responsibilities (within PNCERS, outside PNCERS (e.g., GLOBEC))
   - 4e) how could proposed research contribute to tools / products to be developed for managers

The fourth impact hypothesis is listed below, but was not discussed on Saturday due to lack of time:

> Income from tourism is determined by at least five factors:
> 1) physical beauty, undisturbed by industrial uses;
> 2) wildlife viewing opportunities;
> 3) recreational harvest opportunities;
> 4) facilities that promote visits;
> 5) easy access from major population centers,
>
> which together determine the attractiveness of this site, relative to others.

It is anticipated that over the course of PNCERS other impact hypotheses will be developed, and the ones discussed here will be revised.

Crab Impact Hypothesis

Summary of discussions of the crab impact hypothesis workgroup.

Participants: John Stein, Andy Bennett, Amy Borde, Alan Shanks, Kathleen Bell, Jan Newton, Sara Breslow, Ted DeWitt, and Gordon Swartzman

Overall Hypothesis

The overall hypothesis is illustrated in Figure 2 (redrafted after the workshop to reflect subgroup discussions). The Valued Ecosystem Components (VECs) are *crab production* and derived socioeconomic benefits such as *income, employment, tourism* and *values*. The overall impact hypothesis states that these crab-related VECs are dependent on various factors that influence each of four different life history stages:

1. **Larval supply,** which is determined by physical forces in the nearshore zone that disperse and transport larvae (Link 1b), and, to a lesser extent, adult crab production within the estuary (Link 1a);

2. **Larval settlement**, which is determined by estuarine circulation (Link 2d) and the quantity/quality of settlement habitat (Link 2e). Estuarine circulation is determined primarily by three physical factors: nearshore physical forces (Link 2a), the geomorphology of the estuary (Link 2b), and the year-to-year variations in river flow (also included in Link 2b). Some human actions (i.e., dredging, shoreline development, and dams) can also affect estuarine circulation (Link 2c). The quantity/quality of habitat for larval settlement is affected by any human actions which change the amount of three-dimensional surfaces in the intertidal and subtidal zone, especially oyster culture, since oyster cultch is attractive to crab larvae for settling.

3. **Juvenile growth and survival**, which is a function of water quality (Link 3e), the quantity and quality of habitat and food (Link 4d), and predation/competition by exotic species such as green crab (Links 5a, 5b) as well as native species. Water quality is affected by nearshore physical forces (Link 3a, which can quickly alter temperature, salinity and nutrients), estuarine circulation (Link 3b), and toxics that may enter the estuary from watershed sources, shoreline developments or pesticide spraying (Links 3c and 3d). Habitat quality and quantity, and the amount of food available for crab, is affected by three factors: 1) water quality (Link 4c), particularly changes in turbidity that can affect the growth of eelgrass, or changes in nutrients that affect food availability; 2) human activities which affect the availability of refugia for juvenile crab (Link 4a); and 3) the presence of exotic plant species such as Spartina, which can replace eelgrass (Link 4b).

4. **Adult crab production**, which is a function of the level of harvest (Link 6c), as well as the number of juveniles successfully maturing into adults. Harvest is in turn affected by market forces and fisheries management (Link 6b); harmful algal blooms can influence the perceived health of harvested crab (Link 6a).

Linkages

The discussion of linkages follows a "top down" approach, first examining the overall influences on each life history stage, and then working down the causal chain.

Links 1a and 1b: *Nearshore physical forces and estuarine production of adult crabs together determine larval supply.*

There is a considerable amount of information on nearshore physical forces outside of one-mile distant from the shore. Less is known about the zone within a mile from shore, though some new information is being collected more recently by PNCERS researchers and others. Since all larval development occurs in the open ocean, it is believed that the major factor affecting larval supply are nearshore physical forces (Link 1b). The amount of crab production within an estuary (Link 1a) is expected to have less effect on larval supply than nearshore physical forces. This is because there tends to be a general

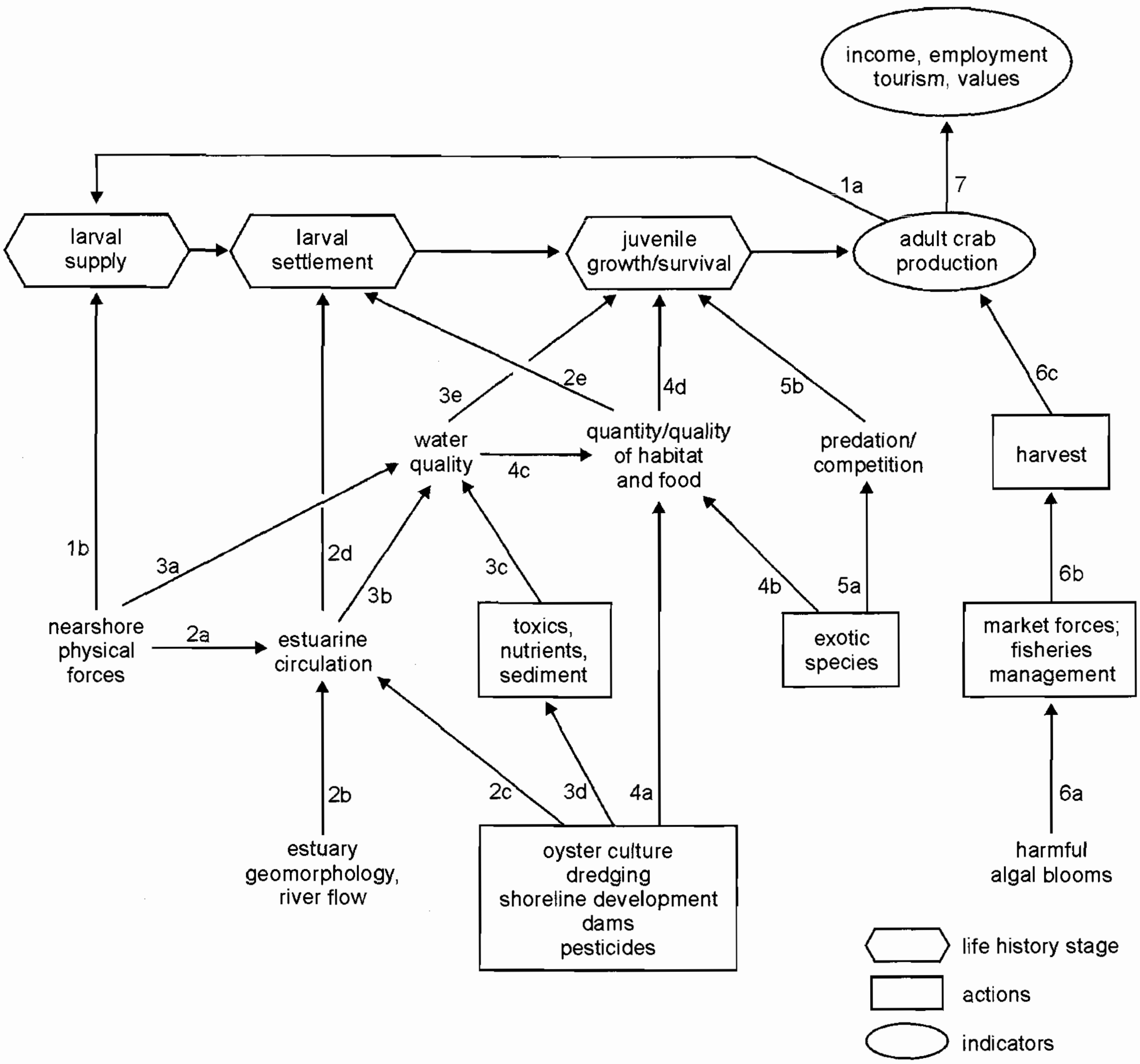


Figure B.2. Crab impact hypothesis.

synchrony in the cycles of abundance of crab all along the Pacific coast, suggesting that regional, not estuary-specific factors drive total crab production. There are considerable year-to-year variations in larval supply (age 0+) which may be due to variation in nearshore primary production, predation, or physical conditions (currents, upwellings, downwellings). Adverse physical conditions may push the planktonic forms (zoea stage) too far offshore.

There is much less variation in age 1 crab than in age 0+. This indicates some form of density dependence in age 0+ crab, which may be due to cannibalism, parasites or other factors.

Link 1b is central to PNCERS. There is lots of ongoing work in measuring transport of larvae from the nearshore zone into Coos Bay, some work in Gray's Harbor, a little bit of work in Willapa Bay, and work proposed for Yaquina Bay. It may be difficult to disentangle links 1a and 1b in that adult crab production within an estuary in a given year may have been affected by larval supply three or four years previously as a result of nearshore physical forces. It might be interesting to examine to what extent years with large larval inputs have repeated echoes in subsequent populations (i.e., peaks every three to four years after a "bumper crop" year).

Links 2d and 2e: *Larval settlement is determined by estuarine circulation (2d) and the quantity and quality of habitat (2e). These two factors are influenced by both human activities and natural forces.*

Estuarine circulation is influenced primarily by three natural phenomena: nearshore physical forces (2a), the geomorphology of the estuary (2b), and of year-to-year variations in river flow (including 2b). Certain human activities such as dredging, shoreline developments and dams can also affect circulation (2c). Larval settlement is directly affected by the amount of three dimensional habitat in the estuary, on which larvae can settle.

There has been some work on circulation models carried out in the PNCERS study area (i.e., circulation models exist for Yaquina Bay, developed by EPA; for Coos Bay, developed y the US Army Corps of Engineers; and such work has been proposed by Hickey under Sea Grant for Willapa Bay). However, these circulation models have not been developed to the extent necessary to make 3D predictions of water movement, which could potentially affect where larvae settle. Another complication is that the 0+ stage are active swimmers and therefore a circulation model would not be sufficient to predict the distribution of a non-passive organism. Though PNCERS is not likely to undertake circulation modeling, some of the existing work may suggest "circulation indices" that could be used to reflect the likelihood of larvae being transported to different parts of the estuary. The effects of estuarine circulation on water quality are discussed separately under Link 3b.

Variation across estuaries in their geomorphology may contribute to difference in circulation patterns. In addition, year to year variations in river flow may contribute to annual variations in circulation patterns. Though no one within PNCERS is focussing in detail on these two factors, it may be helpful to gather data on them to help explain some of the spatial and temporal variation in the patterns of larval settlement, both within and among estuaries.

Dredging, shoreline developments and dams can all affect estuarine circulation patterns, and therefore larval settlement. Nobody in PNCERS is focussing explicitly on the impacts of these human activities on estuarine circulation. It may be, however, that information on these factors (as for estuary geomorphology and river flow) could help to explain some of the year-to-year or spatial variation larval settlements.

Three-dimensional surfaces are used as refugia for young of year crab in the intertidal and subtidal zones. The amount of such habitat is affected by the availability of oyster cultch (a function of the amount of oyster culture), rocks, and debris. Thus, shoreline developments can also influence the quantity and quality of such habitat. Dredging is unlikely to affect the quantity of settlement habitat, since dredging generally takes place in the deeper water zones, inhabited by age 1+ crabs. However, it is possible that disposal of dredge material could take place in the intertidal and subtidal zones, though in general regulations require that such material is disposed of in deeper waters. The effects of habitat and food on the growth and survival of juvenile crab are discussed in more detail below.

The restoration work by the US Army Corps of Engineers in Gray's Harbor provides an ongoing experiment to evaluate the benefits of cultch on larval settlement. The value of three-dimensional surfaces is that they provide a refuge for young-of-year or 0+ crab in the inter-tidal and sub-tidal zones.

Links 3e, 4d and 5b: *Juvenile growth and survival is a function of water quality (link 3e), the quantity and quality of habitat and food (link 4d), and predation / competition impacts from both native and exotic species (links 5b).*

Water quality can directly affect juvenile growth and survival (Link 3e), as well as having indirect effects by influencing the quantity and quality of habitat (Link 4c). Water quality data are being collected by the United States Geological Survey, the Washington Department of Ecology (Jan Newton, Rick Edwards) and by Barbara Hickey, for the nearshore zone of Willapa Bay. Some of the data collection within the estuary is funded by the EPA through a study which is close to completion and has no further funding. There was some interest amongst the subgroup to examine these data to determine how crab production is affected by different levels of temperature, nutrients, and salinity. It was recognized that it may be very difficult to tease apart the direct effects of water quality on juvenile crab growth and survival (e.g., temperature preferences) (Link 3e) from the indirect effects of water quality changes on eelgrass production (important refugia) and primary production for both planktonic and benthic food chains that support crab (Links 4c and 4d). Gathering data on both eelgrass and water quality, or conducting experimental additions of eelgrass to areas of different water quality characteristics, may help to elucidate the relative importance of these different pathways. Understanding the water quality preferences of crab (and their importance relative to habitat requirements) might ultimately help in making decisions on where to place shoreline developments.

Dredging was thought to have only short-term direct impacts on primary productivity (i.e., a temporary increase in turbidity directly after dredging has occurred), but might have longer term effects through changes in estuarine circulation (Link 3d). The long-term effects of dredging activities on turbidity and primary production are not well understood. There is an opportunity to examine some of these effects in Willapa Bay since further dredging is imminent, and there are very detailed data (collected every 15 minutes) on turbidity levels from 1997 and 1998. There are less detailed data (monthly) available for Willapa Bay and Gray's Harbor going back to 1973, and also some data for Coos Bay and Yaquina.

Toxics (Link 3c) are less of an issue now that most pulp mills have closed in the four PNCERS estuaries. Carbaryl, used against burrowing shrimp to protect oyster culture beds, could however affect Dungeness crab. Carbaryl is applied at low tide, and kills those crustaceans and fish which remain in tide pools. The affects of carbaryl are dispersed, however, when the tide comes back in. Carbaryl is only applied one day per year, and the spring and fall seasons are avoided so as to limit potential affects on juvenile salmon. A total of 800 acres are sprayed in Willapa Bay and Gray's Harbor; roughly three-quarters of the area sprayed is in Willapa Bay. The effects of carbaryl on Dungeness crabs have been studied for about 15 years. There is no point in making this impact link a focus of PNCERS, as the effects are well known. Furthermore, the carbaryl applied to oyster beds kills crabs, but the cultch associated with oyster culture improves larval settlement sufficiently that the net result three-to-four years later is an improvement in adult crab production.

Habitat effects on juvenile crab (Link 4d) is a critical component of PNCERS. Many of the points discussed for Link 2e (i.e., effects of habitat on larval settlement) also apply to juvenile growth/survival. The main difference between these two links are in the type of habitat required: three-dimensional surfaces for larval settlement, versus refugia and feeding habitat for juvenile crab; eelgrass is believed to be extremely important for juvenile crab. The GIS work being done by PNCERS will document historical changes in the potential amount of eelgrass (as indicated by changes in depth distributions of each estuary). Together with current data on the actual distribution of eelgrass, this information should permit analyses of the correlations between crab population indices and eelgrass abundance (over space and time), as well as other habitat types. Working down the causal chain, PNCERS' researchers could then examine which human activities are most likely to influence those habitat features most strongly associated with successful growth and survival of juvenile crab. In many tropical regions, shrimp production is strongly correlated with the area of mangroves. The subgroup wondered whether crab production may show similar associations with the area of eelgrass, both along spatial gradients (within and between estuaries) and over time (in zones where there has been a substantial change in eelgrass).

Predation and competition (Link 5b) were discussed only briefly with respect to Green crab. This exotic species was recently introduced, and consumes Dungeness crab younger than age 1+. Though Green crab may affect the status of future Dungeness crab populations, it is not a factor in historical fluctuations. There are several different groups studying Green crab outside of PNCERS: Dave Armstrong (non-PNCERS funding); the Oregon Department of Fish and Wildlife (studying Green crab in Coos Bay and Yaquina Bay); the Washington Department of Fish and Wildlife (Brett Dumbald studying Green crab in Willapa Bay); an M. Sc. student at OSU (studying Green crab in Yaquina Bay); the School of Marine Affairs (policy implications); the University of Washington (feeding behavior); and several studies in San Francisco Bay. In view of all this ongoing work, it does not appear to be necessary to make this a priority for PNCERS.

Exotic plant species (Link 4b) can also affect the quantity and quality of habitat available for juvenile crab. In particular, the spread of *Spartina* into areas which formerly held eelgrass is of some concern. It would be interesting to see if retrospective analyses based on GIS mapping of *Spartina* and eelgrass distributions, or experimental changes in the relative abundance of these two groups, can elucidate the importance of this causal chain.

Links 6a, 6b, 6c and 7: *Adult crab production is a function of the level of harvest (Link 6c) and the number of juveniles successfully maturing into adults. Harvest is affected by market forces, fisheries management regulations, and harmful algal blooms (Links 6a and 6b respectively). Adult crab production affects income, employment, tourism and values.*

Along the Pacific coast, there is roughly a ten-year cycle in crab production. The harvest of crab tends to track this cycle, with fishers leaving the crab fishery during periods of very low abundance, and then reentering the fishery during periods of higher abundance. This numerical response in the fishery may contribute somewhat to the cycle, but other factors (such as cannibalism and variation in nearshore physical processes) appear to be necessary to create the observed fluctuations. Since most of the crab fishermen catch crab close to the estuary in which they grew, it may be possible to use historical harvest statistics (broken down by point-of-landing) as an indicator of the harvest pressure on adult crabs within each estuary. County statistics on historical employment levels and incomes could be examined to assess the impact of historical fluctuations in crab production, and the influence of these fluctuations (if any) on tourism (Link 7). The subgroup did not discuss how PNCERS could (or if PNCERS should) study the link between crab production and social values. Presumably a number of features which affect environmental values (e.g., viewscapes, wilderness, salmon, crab, presence/absence of industries) would be assessed concurrently.

Toxic algal blooms (containing domoic acid) can result in a moratorium on crab harvest (Link 6a). The domoic acid concentrates in the hepato-phancreas of crabs, increasing the processing costs as this organ must be removed. A harmful algal bloom in 1991 all along the Pacific coast affected crab processing activities, and high levels of harmful algal blooms were also detected in 1998. The risk to humans of domoic acid is short-term memory loss. Both the frequency of occurrence and factors causing such blooms are not well understood. Though there is a national program on harmful algal blooms (ECOHAB), these resources are focused mostly on the East coast.

Salmon Impact Hypothesis

Summary of discussions of the salmon impact hypothesis workgroup

Participants: Ray Hilborn, Tom Wainright, Becky Johnson, Tom Leschine, Dan Huppert, Barbara Hickey, Don Gunderson, and Julia Parrish

Overall Hypothesis
The survival rate of salmon smolts in estuaries and nearshore zones is a product of four key factors:

1. **Estuarine refugia** – the quality and quantity of benthic habitat specifically linked to food production, is affected by such actions as dredging, oyster culture, urbanization, and habitat restoration efforts in a manner which may exert density dependent survival effects on young ocean going salmon;

2. **Nearshore production (food availability)** – the quality and quantity of food during the first 90 days as affected by competition (e.g., competition with hatchery smolts and other fish species for food and nutrients [a density dependent survival process]);

3. **Nearshore ocean predation** – the total level of predation mortality from birds, fish, and mammals; and

4. **Disease** – increased incidence of disease due to early life history exposure to physical stressors (e.g., extreme temperature and salinity conditions) interaction with hatchery fish, exposure to estuarine contaminants (e.g., sewage).

In addition, the group recognized that egg to smolt survival is driven by mortality processes occurring within watersheds (e.g., increased/decreased inputs of large woody debris and sediment or decreased riparian function due to logging activities). Furthermore, ocean survival is driven by large-scale physical forcing factors (e.g., ENSO, PDO, and AOI). Therefore, when projecting total adult recruitment, freshwater mortality processes must also be taken into account. Nevertheless, the estuarine and nearshore zones, in combination with fishery management regulations and external market forces strongly influence the socio-economic benefits and non-market values realized from salmon resources.

The group identified four key aggregate hypotheses to describe the key estuarine and nearshore processes linking human actions and physical forcing to the socio-economic benefits of salmon resources: 1) early ocean predation; 2) early ocean food availability; 3) disease; and 4) estuarine refugia/habitat/food. In recognizing that the IH elicitation was an exercise, the workgroup pointed out that they were not attempting to build a model. More specifically, it was deemed infeasible to forecast the value of a particular indicator/valued ecosystem component (VEC) by following the full chain of linkages from each action or physical process due to sizable nearshore and open ocean data limitations (Figure 3). In particular, Ray Hilborn pointed out that the CWT data available to estimate marine survival provides a total integrated estimate of survival. In brief, independent estimates of mortality due to predation, intra-/interspecific competition, and disease in the early ocean phase of life (e.g., first 90 days) are not possible from the existing data.

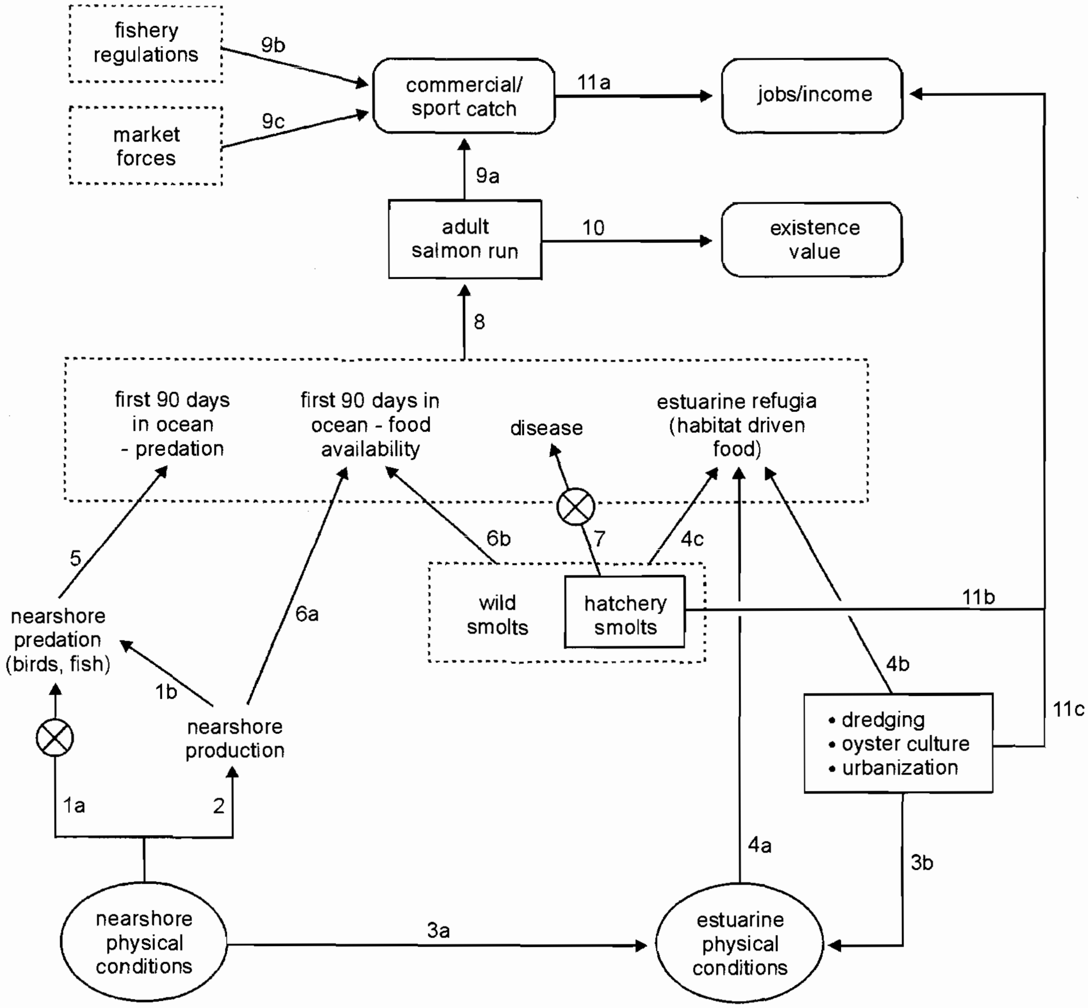


Figure B.3. Salmon impact hypothesis. Specific linkages are described in the text. ⊗ Refers to a linkage deemed outside the scope of the PNCERS research program.

Linkages

Link 1a: *Nearshore physical conditions will produce changes in the abundance of, and predation rates exerted by, seabirds and fish species on salmon.*

Julia Parrish suggested that this linkage may apply more to predators other than seabirds, and that certain seabirds rely on a relatively constant supply of fish, not episodic events. In short, Parrish believed that Link 1b represented a more significant determinant of seabird abundance than Link 1a. Also, Barbara Hickey pointed out that it would be infeasible to forecast the impacts of near shore physical conditions on birds and fish because the necessary data are extremely expensive to acquire.

In general, it was pointed out that it would be difficult to determine the relative importance of nearshore physical environment on salmon predation rates and on increased rates of mortality attributable to intra- and interspecific competition for food. For these reasons, studying this linkage was deemed inappropriate for PNCERS research.

Link 1b: *Nearshore primary production regulates total community biomass including the abundance of seabirds and fish that target young ocean-going salmon.*

The workgroup agreed that it was appropriate for PNCERS to study this linkage, because it was more likely to influence the abundance of seabirds and fish preying on salmon.

Link 2: *Nearshore physical oceanographic conditions regulate zooplankton abundance and the availability of nutrients for primary production.*

The workgroup agreed that this was an important linkage (from the point of view of the indicators in Figure 3.1), and concluded that it was appropriate for PNCERS research.

Spatial mapping and retrospective analyses (SMR) were proposed to quantify the relative importance of nearshore physical conditions on nutrient availability and zooplankton abundance. This includes exploring the relationships within a set of physical and biological measurements (upwelling indices, COADS SST maps, productivity indices, and bird abundance).

Link 3a: *Depending on their magnitude, nearshore physical oceanographic processes translate into estuarine effects, with smaller estuaries more subject (i.e., tightly coupled) to extremes.*

As demonstrated in the original proposal by PNCERS primary investigators, this hypothesis is central to PNCERS research. Without investigating this linkage, it is difficult to know the extent to which nearshore physical forcing drives change in various VECs associated with estuaries. Increased predictive capability in this area would be valuable for modifying various human actions to optimize results for a given set of VECs.

Barbara Hickey pointed out that interaction strength varies with spatial scale. As this link is the major focus of Hickey's research, she was able to identify several important physical variables, and researchers/agencies with relevant data.

Hickey, Parrish, and Hilborn also agreed to coordinate with each other for purposes of relating the effects of physical driving variables to estimates of bird abundance and marine survival rates for the stocks being investigated by Hilborn.

Links 4b and c: *Various human activities such as dredging and hatchery production limit the amount of refugia, habitat, and/or food suitable for early ocean going salmon within estuaries, thereby increasing salmon mortality rates.*

Survival of salmon smolts in estuaries may be reduced through density-dependent competition with hatchery smolts.

The workgroup proposed that habitat use studies and retrospective analyses could be used to map habitat types in estuaries and possibly the nearshore zone. Retrospective habitat studies (Steve Rumrill and Ron Thom) linked to available data on salmon smolt use of various habitats, benthic zooplankton production as a function of habitat type (potentiallyavailable from Si Simenstad), and bioenergetic models of smolt food requirements could be used to provide estimates of the number of salmon produced per unit area of a given habitat type or larger spatial aggregate. The socio-economic group could use habitat valued in salmon 'units' to contrast with the economic benefits derived from using/changing the habitat for other purposes (i.e., Link 11c, Figure 3.1).

Link 5: *Increases in the abundance of seabirds and fish in the nearshore zone will cause an increase in the total mortality on early ocean going salmon.*

The workgroup recognized that this was an important linkage in determining the values of certain VECs related to salmon. However, it was pointed out that a trophic analysis was needed to construct the list of seabirds and (especially) fish species that were important salmon predators. To this end, a study commissioned by BPA and NMFS was cited as a potential source of some of this information.

Ray Hilborn suggested that the *EcoPath* model could be used to estimate the relative significance of predation mortality on salmon by species in the nearshore zone. However, implementation of the *EcoPath* model is known to be data intensive, and the feasibility of using the model need was uncertain.

It was also pointed out that it would be more difficult to estimate the abundance of fish predators than bird predators, and that seabirds may be a sufficient surrogate. It was not known what historic data was available on the abundance of fish in the nearshore zone preying on salmon.

Link 7: *Due to various forms of artificial intervention used to lower disease rates of salmon reared in (often crowded) fish* *pens, hatchery smolts may increase the incidence of disease among wild smolts once released.*

The workgroup agreed that this was a research area outside the scope of PNCERS.

Link 8: *The abundance of returning adult salmon recruits is strongly influenced by predation, food availability and disease on early ocean going salmon.*

The workgroup agreed that the available CWT data would not permit the discrimination between mortality attributable to predation, competition, and disease. Ray Hilborn pointed out that the CWT data available to estimate marine survival provides a rather "blunt instrument" – a total integrated estimate of survival over the 2 to 4 years of a salmon's ocean life. In brief, independent estimates of mortality due to predation, intra-/interspecific competition, and disease in the early ocean phase of life (e.g., first 90 days) are not readily available.

Nevertheless, the workgroup believed that the analysis related to Links 2, 1b, and 5 would elicit the relative importance of predation vs. food.

The workgroup was not clear on the status of research in mortality attributable to disease of early ocean going salmon and its significance in regulating total adult recruitment. Nevertheless, because of the decision to drop consideration of Link 7 (a research area covered elsewhere), the workgroup did not believe it was worthwhile to pursue research related to disease induced mortality rates of wild salmon populations.

Ray Hilborn suggested comparing chum and chinook salmon survival estimates with coho salmon in both Willapa (more pristine) and Grays Harbor (heavily developed). The different marine life-history strategies between coho and chum, and coho and chinook may indicate the relative importance of estuarine habitat on the marine survival of salmon.

Link 9: *Commercial and sport catch is directly proportional to the total abundance of returning adult salmon, market forces, and fisheries regulations.*

This relationship has been well studied for a variety of fisheries. The workgroup agreed that the main issue to resolve would be the significance of market forces (e.g., salmon prices, cost of boat fuel, etc.) (Link 9c) and fisheries regulations (Link 9b) on total catches in sports and commercial fisheries.

Link 10: *The total abundance of salmon runs and the abundance of the spawning population has a variety of non-market values that are important to people.*

The workgroup agreed that this is an important element of the PNCERS research project. Dan Huppert pointed out that it would be important to consider both dollar values and these non-market values.

The Index of Sustainable Economic Welfare (ISEW) was proposed as one possible model for development of a biological and socio-economic indicator. Other measures were also to be obtained from Ron Thom and Steve Rumrill, along with a review of the primary literature.

Link 11: *Employment income and jobs in communities surrounding estuaries are affected by salmon harvests, as well as by other economic activities occurring within estuaries, such as dredging, oyster culture, hatchery operations, and urban development.*

The workgroup agreed to consider both jobs generated by fisheries as well as those generated by other human activities occurring within and directly adjacent to estuaries (e.g., dredging is not occurring for the sole purpose of harming fish).

Potential data sources and analysis methods to use to quantify the relative importance of the linkages are summarized in Tables B.3 and B.4 (respectively).

Table B.3. (Potential) data sources used as evidence for or against the various linkages in the IH.

- Bakun (sic?) upwelling/downwelling index
- COADS SST maps (sufficient spatial/temporal resolution?)
- OSCURS surface current estimates
- CZCS
- Hatchery release summaries
- NODC data for nearshore SST (as well, contact Steven Hare, PMEL)
- Hydroacoustic back-scatter data for estimating plankton and fish biomass
- Explore literature to develop appropriate early ocean salmon migration assumptions
- Environmental impact assessment reports for various management activities (e.g., dredging)

Table B.4. Proposed analyses to assess the relative importance of the various linkages in the IH.

- Trophic analysis via the *EcoPath* model
- Exploratory coded wire tag analysis (correlate survival estimates corrected for harvesting with suite of physical and biological variables) · Spatial mapping and retrospective analysis (retrospective exploratory correlation analysis)
- Bioenergetics modeling (e.g. estimates of # fish/m^2 habitat type)
- Habitat use studies
- Socio-economic analysis of the value of *all* management actions in the IH (i.e., not just the value of harvesting itself but the value of activities such as dredging, etc.)
- Non-market valuation of salmon to quantify existence value, amenity value, and other ecosystem services

Oyster Culture Hypothesis

Summary of discussions of the oyster culture hypothesis workgroup.

Participants: Andrea Copping, Kris Feldman, Tom Leschine, Arni Magnusson, Greg McMurray, Ian Parnell, Michelle Pico, Curtis Roegner, Steve Rumrill, and Grace Tsai

Overall Hypothesis

The overall hypothesis is illustrated in Figure B.4. The Valued Ecosystem Components (VECs) are *commercial oyster production* and derived socio-economic benefits such as *local employment and income*. The overall hypothesis states that commercial oyster production, which has an important economic value to the communities surrounding estuaries, is affected by six factors:

1. **The quality and quantity of appropriate sites** (stable, shallow tideflats, absence of ghost shrimp);

2. **Good water quality** (turbidity, lack of fecal coliform contamination, nutrients);

3. **Nearshore climate conditions that affect physical and chemical conditions;**

4. **Nutritious primary production** (i.e., the appropriate species of phytoplankton);

5. **Appropriate market conditions, consumer confidence, and market access** (e.g., Coos Bay airport); and

6. **Rules and regulations that affect oyster culture** (e.g., essential fish habitat, spraying, ownership – an information issue).

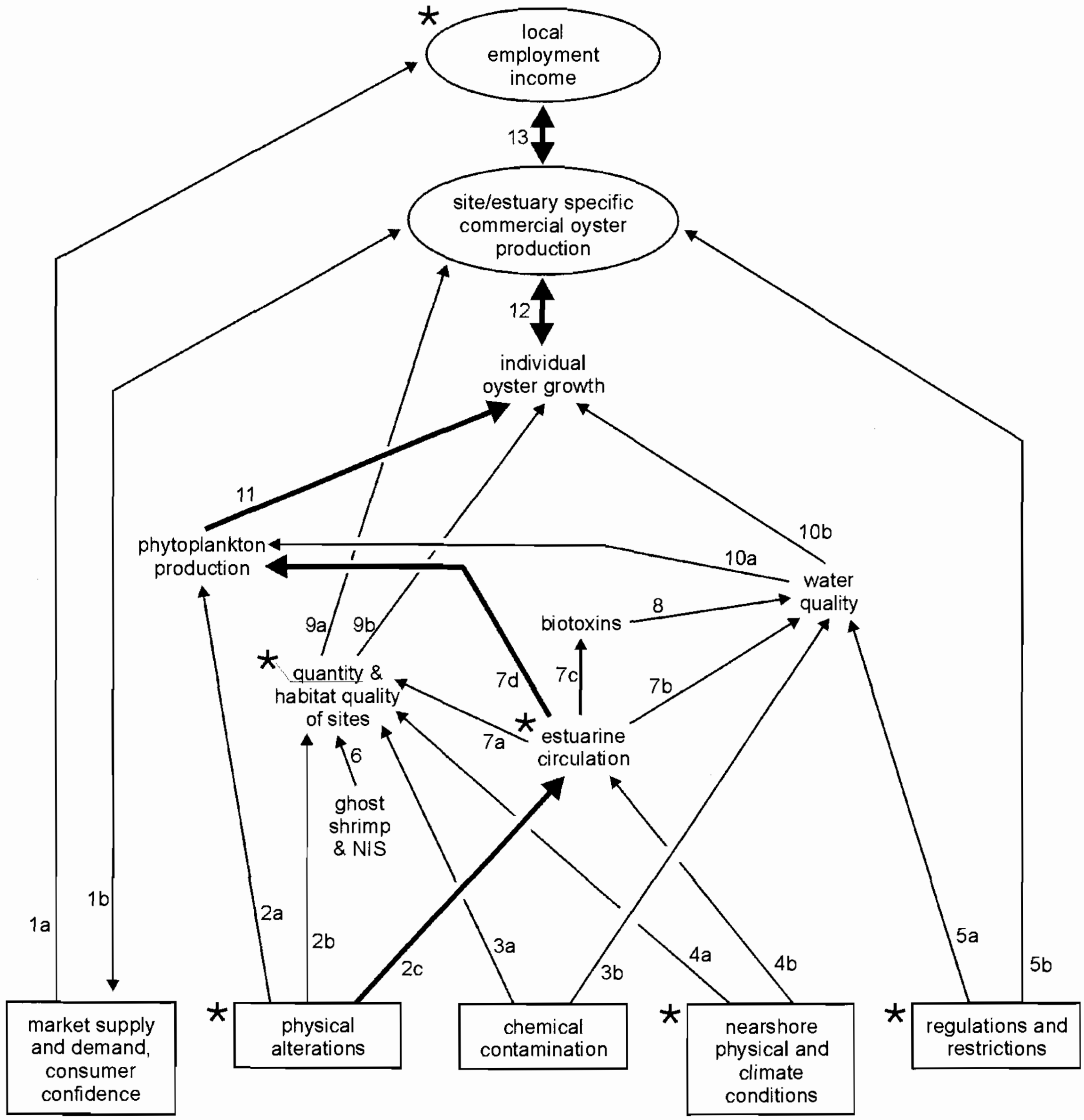


Figure B.4. Oyster culture impact hypothesis. Text in boxes indicates human actions and physical forcing factors. Text in ovals represents indicators, or valued ecosystem components (VEC). Arrows represent links between actions, ecosystem components and indicators. The bold arrows illustrate the chain of hypotheses explored in most detail during subgroup discussions (see Figure 5). Double-ended arrows indicated feedback between components. Asterisks indicate components where PNCERS research is applicable.

Subgroup discussions did not explicitly deal with the spatial and temporal resolution of issues and research relevant to oyster production, but temporal considerations are important for some components (e.g., timing of pollution events relative to oyster harvest, and timing of habitat impacts relative to the oyster production cycle).

Linkages

The Impact Hypothesis (IH) evolved throughout the subgroup discussions. The final version is shown in Figure B.4. The numbers identify the links that make up the pathways from actions to indicators. The asterisks indicate areas where PNCERS research is currently being done. As the IH evolved, two important points that arose: (1) there is feedback between some components such as commercial oyster production and market supply and demand (Link 1b in Figure B.4), and (2), human activities can be separated into two categories: 1) actions that affect water quality only (e.g., shipping, sewage); and 2) actions that affect site condition and water quality (e.g., dredging).

The complete impact hypothesis contains many pathways from actions to indicators. A composite hypothesis is a single action-to-indicator path that is simpler than the overall hypotheses illustrated in Figure B.4. The short duration of our subgroup meeting placed constraints on the number of linkages that could be explored in depth, so we decided to concentrate on the Shoreline development to Commercial oyster production composite hypothesis. The subgroup developed testable hypotheses and discussed evidence, relationship to PNCERS research, key uncertainties and other relevant information for the composite hypothesis and its linkages.

Composite hypothesis *Shoreline Development –> Commercial Oyster Production.*

Links: 2c, 7d, 11, 12 (and 13 to employment and income)

Composite hypothesis: Shoreline development (e.g., urban-suburban development, roads, causeways, physical hardening and alteration of the shoreline) affects circulation patterns in the estuary in a way that changes water quality (e.g., increased turbidity, chemical contamination, road-runoff, coliform, temperature, nutrient input) and phytoplankton production and this affects commercial oyster production. This can be linked to the higher VEC with the following phrase: "[commercial oyster production] in turn affects income and employment."

The subgroup felt that there is evidence at the process level to suggest the composite hypothesis is reasonable, but that there is no site-specific information. A key data gap is the lack of site-specific information on changes in oyster production associated with shoreline development. A possible approach to resolving this uncertainty would be an interview survey of commercial oyster growers to identify locations where shoreline development has affected oyster production. The composite hypothesis is not addressed by PNCERS research, but it is a potentially worthy PNCERS project. Information could include new data on individual oyster growth. There may be existing data on oyster production in $, but probably not at the site-specific level.

Link Hypotheses

There are several linkage paths that can be followed even within the simpler composite hypothesis stated above (Figure B.4). We further focused our subgroup discussion by extracting a single chain of linkages from within this narrower composite hypothesis (Figure B.5). This linkage chain flows from the action of Physical alteration (shoreline development) through the links of estuarine circulation, phytoplankton production, individual oyster growth and commercial oyster production to the valued ecosystem component, Employment and Income (Figure B.5). For each link, we developed an explicit hypothesis statement. The following links refer to those numbers in Figure B.5.

Link 1: *Shoreline development changes circulation patterns in the estuary and this changes estuarine flushing time*

There is some site-specific historical data on development that suggests this link is tenable (e.g., Grays Harbor airport expansion – COE, Coos Bay dredging – COE), but not lots of good quantitative data. Retrospective information on development is being collected as part of PNCERS. An information need is knowing where development will occur. Two potential sources of such information are the WA Growth Management Act, and the OR Statewide Planning Goal. Other information should include current speed and direction, sediment transport, and changes in depth. Such information is required for a whole bay in order to develop predictive models such as a future 3-D circulation model.

Link 2: *Changes in estuarine flushing time affect the supply of phytoplankton*

The relationship between estuarine circulation and phytoplankton availability is not explicitly addressed by PNCERS, but it may be possible to develop surrogate measures using data that is being collected by PNCERS researchers (e.g., Barbara Hickey). For example, temperature and salinity measures could be used to develop a proxy for advection from the nearshore environment into the estuary. Information on the flushing rate provides information about the likelihood of plankton blooms *in situ*. There is also the possibility for an interesting comparison between estuaries. PNCERS data could be combined with that of other researchers to explore relationships between flushing time and primary production. For example, Jan Newton (WDOE) has a project in Willapa Bay collecting continuous fluorometry data and primary productivity

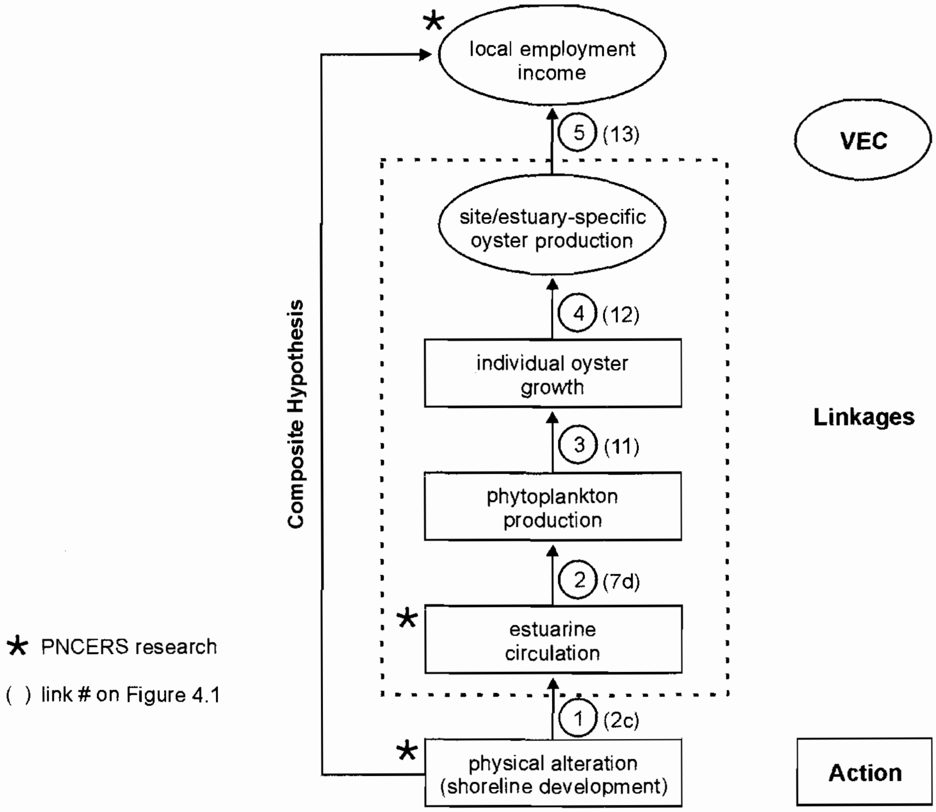


Figure B.5. A simple composite hypothesis and linkages drawn from the overall Impact Hypothesis diagram in Figure B.4. This figure represents the composite hypothesis leading from physical alterations (here shoreline development) to the VEC of local employment and income.

site measurements. B. Hickey's work also covers Willapa Bay. Steve Rumrill noted that a graduate student is collecting Chlorophyll a and nutrient measurements in South Slough, Coos Bay at two-week intervals.

Link 3: *Decreased phytoplankton availability and quality leads to lower oyster growth*

Although not explicitly addressed by PNCERS research, evidence for this link could be obtained from the shellfish industry and from applied aquaculture studies. It is important to consider not only food quantity, but also the food quality (i.e., phytoplankton species composition) that facilitates oyster growth. Greg McMurray mentioned some possible EPA data that may address this issue. (e.g., W. Breese – research in the 70s or 80s).

Link 4: *Commercial oyster production ($) is directly related to the biotic growth rate of oysters (kg/ha/yr)*

The Oyster Condition Index suggests that there is evidence for this link. Key uncertainties are market and regulatory uncertainties and the timing of closures. Oregon State University (OSU) may have a discontinuous but valuable record of oyster growth. More current data might come from oyster growers.

Link 5: *Increased commercial oyster production increases employment and income*

Although the subgroup did not have time to address this link, it was pointed out that PNCERS researchers are addressing the employment and income box.

Other Comments

Possible PNCERS research: This exercise required the subjective selection of what are believed to be the important linkages between actions and indictors. Priority was given based on the prior belief of participants about what links are important and should be explored. Arni Magnusson suggested a potential PNCERS project that would use more objective statistical methods to find the most influential links between actions and indicators. For example, in Figure B.4, Habitat, Water Quality, and Primary Production all feed into individual oyster growth. A possible PNCERS research project could be the design of an experiment where individual oyster growth is related to these three factors to look at their relative impact. The experiment would use a classical approach using controls. In this manner PNCERS researchers could work down the action-to-indicators chain looking at key linkages.

Information on another linkage: Near-shore physical and climate – estuarine circulation (Link 4b, Figure B.4):

- Addressed by current PNCERS work (Barbara Hickey).
- Nearshore – conductivity, temperature, depth, currents
- Estuary – conductivity, temperature, depth, currents, turbidity, chlorophyll
- There exists conceptual evidence for this link, specific data is part of ongoing PNCERS research.
- Key uncertainty: extrapolation from few sites (for nearshore conditions) to whole coastline, sites being monitored are not near oysters.

Common Themes

There were five common themes running through each of the three impact hypotheses covered in the workshop:

1. **Large scale oceanographic effects,** which can cause coastwide changes in the ocean phase survivals of crab, seabirds and salmon populations;

2. **Nearshore transport** of crab larvae, nutrients, and zooplankton, which can significantly affect the abundance of crab;

3. **The quality and quantity of estuarine habitat,** which can affect the growth and survival of age 0+ and 1+ crab, juvenile salmon, and commercially raised oysters;

4. **Estuarine circulation**, which can affect the productivity of food chains leading to crab, salmon and oyster production, as well as potentially affecting survival of these VECs through changes in water quality; and

5. **The response of social and economic** systems to fluctuations in VECs, on different spatial and temporal scales.

These common themes point to the need for further coordination on the information needs of different scientists. This will permit information providers (i.e., reading along the rows of the Looking Outward Matrix [Table B.2]) to better plan their work so as to efficiently serve several people's needs simultaneously. While the Looking Outward Matrix developed at the workshop provides a useful starting point for articulating these information needs, more specificity is required (e.g., what specific habitat features are of interest to each VEC, on what spatial scale, and over what historical time period). There will undoubtedly be a need for further iterations, as possible surrogate variables are uncovered for historical periods to fill data gaps in the desired data.

While estuarine circulation is an issue of importance, workshop participants agreed that PNCERS did not have the resources to undertake detailed 3D modeling of any of the five PNCERS estuaries. However, PNCERS could perhaps utilize some of the general results of existing models for Coos Bay and Yaquina Bay to suggest which areas of these estuaries have stronger or weaker connections to nearshore ocean conditions.

Finally, a common theme generally downplayed in PNCERS are *watershed* developments (e.g., dams, nutrient inputs) and processes (year to year variations in river flow). This is by design, dating back to the original RFP. Nevertheless, as PNCERS attempts to demonstrate the importance of nearshore processes and estuarine conditions on various VECs, there is a risk of confounding influences of watershed developments and processes. As with estuarine circulation, PNCERS' researchers will need to consider what methods can be used to simply represent the potential importance of such factors, without investing a lot of time in an area that is tangential to the target focus of PNCERS. Coordination with other programs that have an explicit watershed focus (e.g., CLAMS, NMFS fish habitat models) may provide PNCERS with some useful indices of watershed development.

Appendix C: Metadatabase

PNCERS Metadatabase

Sara Breslow

The PNCERS metadatabase is planned to be a user-friendly, comprehensive catalog of information on Pacific Northwest coastal ecosystems. It will serve research and information needs of scientists, policy-makers, managers, and the informed public by summarizing and describing how to access a broad range of data held in various agencies and institutions. The metadatabase is also designed to encourage creative approaches toward resource management, foster interdisciplinary dialog, and inform the public about the goals and content of PNCERS.

The metadata for each database includes information on who collected the data, where and when it was collected, what kind of data it is, and how to access the database, as well as an abstract and related information such as paper citations and internet links. The metadata is compatible with FGDC (Federal Geographic Data Committee) standards.

Created and tested in Microsoft Access, the metadatabase is structured as a relational database consisting of tables of fields linked by a unique identifier and/or contact personnel (Figure C.1). Databases and associated metadata are collected through web and library searches. Each metadata record is organized and described using keywords that were chosen in a collaborative effort by PNCERS PIs (Table C.1). User-friendly digital forms allow for intuitive data entry by multiple users (Figure C.2). Finally, a metadata report is generated (Table C.2) and a copy of the metadata is sent to the manager of the database for confirmation of accuracy. Changes and updates to the metadata are then made according to the database manager's suggestions.

So far 20 databases have been fully catalogued, ranging in subject matter from census data to remote sensing images (Table C.3). These databases were used to troubleshoot the structure of the metadatabase, testing it's versatility and efficiency. We are in the process of entering metadata on dozens more databases (Table C.4).

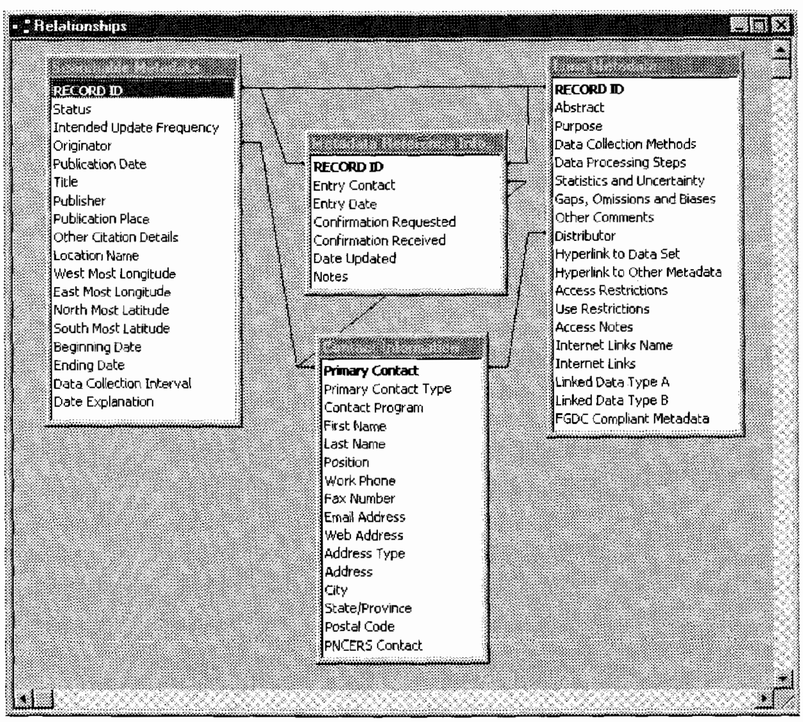


Figure C.1. Diagram of the relational database structure. Lines between tables and fields represent one-to-one or one-to many relationships. Users can search for different databases based on most of the parameters listed in the "Searchable Metadata" table. They can then retrieve "Long Metadata", including abstracts and access information, for selected records.

Table C.1. Areas of interest, categories, and subcategories used as keywords to describe and organize records in the metadatabase. The choice of words and organizational structure reflect multidisciplinary input and collaboration by PNCERS PIs.

Biology

- ALL Biology Categories
- Bacteria
  - Marine
  - Freshwater
  - Fecal Coliform Bacteria
  - Distribution and Abundance
- Benthic Microbiology
- Birds
  - Species...
- Fecal Coliform Bacteria
- Fishes
  - Species...
- Invertebrates
  - Orders...
  - Zooplankton
- Marine Mammals
  - Species...
- Marsh Plants
  - Families...
- OTHER Biology Categories
- Phytoplankton
  - Toxic (HAB-related)
  - Marine
  - Freshwater
- Protozoans
  - Marine
  - Freshwater
- Seagrasses
  - Families...
- Seaweed
  - Families...
- Viruses

Biology Parameters:

- Distribution and Abundance
- Reproduction
- Size/Growth Rate
- Diet/Nutrients
- Behavior
- Mortality/Survival
- Health
- Taxonomy
- Population Trends
- Native/Introduced
- OTHER

Economics

- Agriculture Industry
  - Crops
  - Dairy
  - Livestock
- ALL Economics Industries
- Aquaculture Industry
  - Salmon and Trout
  - Oysters
  - Manilla Clams
  - Mussels
  - Abalone
  - Seaweed/Macroalgae
- Fishing and Marine Harvest Industry
  - Salmon
  - Halibut
  - Rockfish
  - Sablefish
  - Thornyheads
  - Flatfish
  - Oysters
  - Manilla Clams
  - Crabs
  - Shrimp
  - Sea Urchins
  - Mollusks
  - Marine Kelp
- Forest Products Industry
  - Logging and Timber
  - Wood Products
  - Paper and Related Products
  - Other Forest Products
- License Fees
  - Boats
  - Fishing
- Manufacturing Industry
- Mining Industry
- OTHER Economics Industries
- Recreation/Tourism Industry
  - Hotels and Resorts
  - Transportation
  - Recreation Equipment and Supplies
  - Coastal Attractions
  - Forest Attractions
  - Marine Attractions
  - Freshwater Attractions
  - Urban/Historical Attractions
- Shipping Industry
- Subsistence

Economics Parameters:

- Location of Resource or Industry
- Condition/Quality of Resource
- Productivity
- Harvest/Use
- Income
- Employment
- Cost/Market Value
- Equipment and Supplies
- Processing and Market Distribution
- Policy/Regulation
- Environmental Impacts
- OTHER

Ecosystems

- ALL Ecosystems
- Coasts
- Estuaries
- Lakes
- Offshore
- OTHER Ecosystems
- Rivers
- Shelf
- Streams
- Watersheds
- Wetlands

Ecosystems Parameters:

- Location and Statistics
- Habitat Types
- Biology
- Chemistry
- Hydrology or Oceanography
- Geology
- Sediment and Sediment Transport
- Water Quality
- Sediment Quality
- Ecosystem Quality
- Human Impacts
- Invasive Species
- Human Uses
- Policy/Regulation
- OTHER

Human Demography

- Age
- ALL Human Demography Categories
- Education
- Employment
- Gender
- Household Income
- Language/Ethnicity
- Migration
- OTHER Human Demography Categories
- Population Density
- Population Growth
- Population Size

Land Use

- ALL Land Use Areas
- Coastal Areas
  - Beaches
  - Tidelands
- Marine Water
  - Shipping Lanes
  - Dredging
  - Estuaries
  - Aquaculture
- OTHER Land Use Areas
- Public Land
  - Parks
  - Forests
  - Preserves and Refuges

Table C.1, continued.

Rural Land
- Open Spaces
- Arable Land
- Pasture
- Cropland
- Developed Land

Urban Land
- Real Estate Development
- Undeveloped Areas
- Disturbed Areas

Water Courses
- Rivers
- Streams
- Wetlands

Land Use Parameters:

Location and Distribution
Statistics
Quality/Condition
Political and Jurisdictional Boundaries
Policy/Regulation
OTHER

Meteorology

Air-Sea Interactions
ALL Meteorology Categories
Climatology
Models
OTHER Meteorology Categories
Paleoclimatology
Weather Conditions

Oceanography

ALL Oceanography Categories
Biological Oceanography
- Primary Producers -- Primary Production
- Primary Producers -- Biomass
- Primary Producers -- Taxonomy
- Primary Producers -- Specific Growth Rates
- Consumers -- Production
- Consumers -- Biomass
- Consumers -- Taxonomy
- Consumers -- Grazing Rates
- Consumers -- Specific Growth Rates
- Organic Sedimentation -- Flux
- Organic Sedimentation -- Composition
- Food Web -- Interaction and Energetics
- Food Web -- Models
- Harmful Algal Blooms -- Species
- Harmful Algal Blooms -- Abundance
- Harmful Algal Blooms -- Distribution
- Harmful Algal Blooms -- Seafood Contamination
- Fecal Coliform Bacteria
- OTHER

Chemical Oceanography
- Dissolved Oxygen and Other Gases
- Carbonate System
- Nutrients
- Salinity
- Particulate Organic Carbon/Nitrogen
- Dissolved Organic Carbon/Nitrogen
- Organic Compounds/Toxins
- Metals
- Reduction/Oxidation Potential
- pH
- Models
- OTHER

Geological Oceanography and Marine Geophysics
- Marine Mineral Resources
- Ocean Mining
- Mineralogy
- Sedimentology
- Tectonics/Seismicity
- Geochemistry
- Hydrogeology
- Geomorphology
- Gravimetrics
- Acoustics
- Thermal
- Earth Magnetics
- Models
- OTHER

OTHER Oceanography Categories
Physical Oceanography
- Water Conditions
- Currents
- Waves
- Tides
- Acoustics and Tomography
- Paleoceanography
- Models
- OTHER

Policy and Regulation

Agriculture
ALL Policy and Regulation Categories
Development
Fishing
Forestry
OTHER Policy and Regulation Categories
Ownership/Stewardship
Recreation
Research
Shipping

Policy and Regulation Parameteters:

Federal
State
County
Tribal
Taxes
Laws
Planning
OTHER

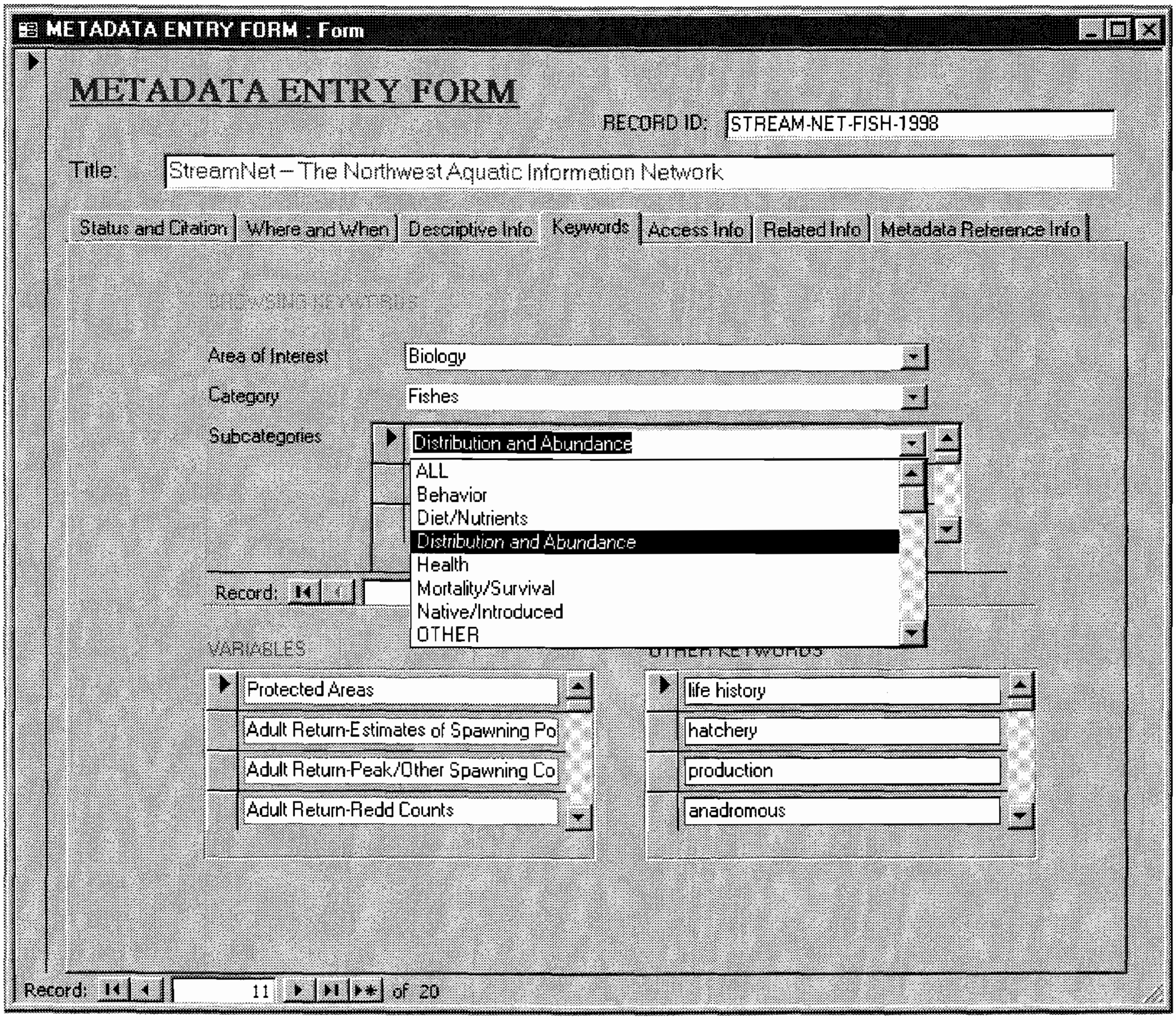


Figure C.2. One page of the data entry forms in Microsoft Access. Note the cascading drop-down menus for easy selection of browsing keywords.

Table C.2. Example of report for metadata presentation. This one is for StreamNet, a database containing all kinds of information on fish stocks in the Pacific Northwest. Reports can be tailored to the user's needs for more or less information

Database: StreamNet -- The Northwest Aquatic Information Network

Originator: StreamNet
Data - URL: http://www.streamnet.org/index.html
Metadata - URL: http://www.streamnet.org/links2.html
Datatypes: Tables, Maps, Graphs
Status: Complete
Update Frequency: Annually

Where and When

Location of Data Collection:	Pacific Northwest	**Beginning Date:**	18940000
West Longitude:	-169.323	**Ending Date:**	Present
East Longitude:	-115.617	**Data Collection Interval:**	Variable
North Latitude:	73.169	**Date Explanation:**	Earliest and latest dates of data collection.
South Latitude:	32.526		

Keywords

Browsing Keywords

Area of Interest: Biology
Category: Fishes
Subcategories:
- Distribution and Abundance
- Population Trends
- Taxonomy
- Health
- Behavior
- Mortality/Survival
- Salmon

Area of Interest: Ecosystems
Category: ALL Ecosystems
Subcategories:
- Biology
- Ecosystem Quality
- Human Impacts
- Human Uses
- Policy/Regulation

Area of Interest: Policy & Regulation
Category: Fishing
Subcategories:
- County
- Federal
- Planning
- State
- Tribal

Variables:
- Protected Areas
- Adult Return-Estimates of Spawning Population
- Adult Return-Peak/Other Spawning Counts
- Adult Return-Redd Counts
- Adult Return-Spawner/Recruit Estimates
- Dam/Weir Counts (Adult or Juvenile)
- Facilities-Dams
- Facilities-Hatcheries
- Fish & Wildlife Projects
- Harvest-Freshwater/Estuary
- Harvest-Marine
- Hatchery-Releases
- Hatchery-Returns

Other Keywords:
life history, hatchery, production, anadromous, salmonids, adult, escapement, sport, marine, harvest, hatchery, return, release, passage, spawning, rearing, migration, barriers, stock, habitat, restoration, hydropower

Abstract, Purpose, Etc.

Abstract: StreamNet is a comprehensive, easy-to-use web site on Pacific Northwest fish. It includes a large on-line database containing information on anadromous and resident fish, aquatic habitat, resource protection and restoration projects, and dams. The web site also hosts a library catalog specializing in hard-to-find "gray" material; a collection of "fish facts" including life history profiles, taxonomic and distribution information, and

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Table C.2, continued.

Database: StreamNet -- The Northwest Aquatic Information Network

glossary; and links to sources of ocean conditions information and other sites related to Pacific Northwest fish.

--SJB

Purpose: StreamNet has a two-fold mission:

1.To create, maintain, and enhance high quality, regionally consistent data on fish and related aquatic resources that is directly applicable to regional policy, planning, management, and research, and
2.To provide data and information services in an efficient and timely manner and in a format that meets the needs of users.

StreamNet supports efforts to preserve and restore the region's aquatic resources.

--Taken from StreamNet web site, with modifications by SJB

Data Collection Methods: Each year StreamNet participants prepare a data plan that guides data development for the coming year. StreamNet is involved with both adding current year data to existing datasets and acquiring new types of da StreamNet prepares data exchange standards and formats to encourage regional standardization and facilitates data compilation consistent with these protocols.

StreamNet utilizes state-of-the-art database and geographic information system technology to compile and maintain aquatic resource data. Data collection methods for datasets included in StreamNet database may be available in the literature referenced on-line and obtainable from the StreamNe library.

--Taken from StreamNet web site with modifications by SJB

Data Processing Steps: Unknown

Statistics and Uncertainty: Unknown

Gaps, Omissions and Biases: Unknown

Other Comments: None

Related Information

Internet Links: StreamNet Related Links

http://www.streamnet.org/links2.html

Related Papers: ANDERSON, Duane A. et al. Report on the Status of Salmon and Steelhead in the Columbia River Basin - 1995 [report online]. Portland (OR) : Bonneville Power Administration, 1996. [17 May 1998]. URL: <http://www.streamnet.org/Reports/crstat95.htm>. Also available as BPA report number 65130-1.

Access Information

Data Formats:

Format	Cost	Size
On-line	None	Unknown
MS Access		
ASCII		

Access Restrictions: None

Use Restrictions: Please cite materials used from this site following the instructions found at: http://www.streamnet.org/citing.html

Access Notes: StreamNet data can be provided as tables, charts, graphs, or maps and may be accessed through the Inter

Table C.2, continued.

Database: StreamNet -- The Northwest Aquatic Information Network

a Distributed Access System, FTP, the StreamNet Library, and custom products prepared by StreamNet staff. The entire StreamNet database can be downloaded.

–Taken from StreamNet web site with modifications by SJB

Distributor:	StreamNet		
Contact Person:	Douglas Burch	**Position:**	Data Manager
Work Phone:	(503) 650-5400	**Email Address:**	doug_burch@streamnet.org
Fax Number:		**Web Address:**	http://www.streamnet.org
Address:	Pacific States Marine Fisheries Commission 45 S.E. 82nd Drive, Suite 100 Gladstone, Oregon 97027-2522		

Citation Information:

Publication Date:	On-line
Publisher:	StreamNet
Publication Place:	Gladstone, Oregon
Other Citation Details:	StreamNet has a page dedicated to citing its sources at: http://www.streamnet.org/citing.html; please follow these directions as StreamNet is copyrighted.

Metadata Information

Metadata Contact:	Sara Breslow	**Confirmation Requested:**	19981201
Metadata Date:	19981015		
Date Updated:	YYYYMMDD	**Confirmation Received:**	19981208

Metadata Notes:

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Table C-3. Databases currently catalogued in the PNCERS metadatabase.

1. Advanced Very-High Resolution Radiometer Digital Images
2. Digital Orthophoto Quadrangles
3. Dynamic Estuary Management Information System (DEMIS)
4. Government Information Sharing Project
5. Hydrologic Units Maps of the Conterminous United States
6. InfoRain — Bioregional Information System for the North American Rain Forest Coast
7. Landsat MultiSpectral Scanner Imagery
8. Landsat Thematic Mapper Imagery
9. Microsoft Terraserver
10. MultiSpectral Scanner Landsat CD-ROM
11. National Environmental Data Index
12. Nonindigenous Aquatic Species Database
13. North American Breeding Bird Survey Raw Data
14. Olympic Natural Resources Center Clearinghouse for the Olympic Peninsula
15. Pacific Seabird Monitoring Database
16. Social Development Research Group Diffusion Consortium Archival Database
17. StreamNet — The Northwest Aquatic Information Network
18. Surface Observed Global Land Precipitation Variations
19. USGS Land Use and Land Cover Data
20. Willapa Watershed Information System CD-ROM and Spatial Data Catalog

Table C-4. Databases and sources of databases that are in the process of being catalogued in the PNCERS metadatabase.

Coos Bay Dynamic Estuary Management Information System (DEMIS), select databases, e.g.: Fish reaches, hatchery releases, fish landings, forest types, riparian zone canopy cover, vegetation classes and distribution, coastal sensitivity index to spilled oil, fecal coliform levels, estuary and forest ownership, historical fires, wetland extent, aquifers, and hydrographic and hydrologic surveys
Estuarine Ecology Studies, EPA
Fin fish and marine mammal data, National Marine Fisheries Service survey results,
Fisheries reporting, Oregon Department of Fish and Wildlife
Fisheries reporting, Pacific States Marine Fisheries Commission
Halibut Commission
International Whaling Commission
Joint Institute for the Study of the Atmosphere and Ocean , University of Washington Climate Data Archive,
Marine Monitoring Programs along Olympic Coast– select databasees as catalogued by the Olympic Natural Resources Center (ONRC), e.g.: baseline data for characterization of kelp, subtidal and intertidal habitats, shellfish biotoxin and harmful algal bloom assessment, seabird and raptor reproductive success and distribution, marine mammal population status
National Climatic Data Center Historical Geostationary Operational Environmental Satellite (GOES) Browse Server
National Data Buoy Center
National Weather Service
NOAA Climate Prediction Center
NOAA Pacific Marine Environmental Laboratory (PMEL)
Northwest Indian Fisheries Commission
Ocean Sciences Directorate, Office of Naval Research (ONR)
Olympic Coast National Marine Sanctuary
Optimal Interpolation Sea Surface Temperature, global data
Pacific Fisheries Management Council
Pacific Northwest Weather Records Search
Peak flows for streams in Washington and Oregon (USGS)
PFEL monthly mean pressure maps
PFEL Upwelling Indices
Sea level pressure, North Pacific (NP) Index
Sea surface temperature climatologies, derived, COADS
Surface temperature anomalies, NASA Goddard Institute for Space Studies
University of Washington Libraries Guide for Fisheries Sources and Statistics database and source listings, e.g.: international, national, regional , state and province statistics on fisheries, including data on catch, products, and aquaculture
US Corps of Engineers Monitoring
Washington Current Hydrologic Conditions (USGS)
Washington Department of Fish and Wildlife – fisheries reporting
Washington Sea Grant – Synthesis of Estuarine Life History and Ecology of Juvenile Salmon in Coastal Washington
Water Use by County and Hydrologic Unit (USGS)
Western US Climate Summaries, Western Regional Climate Center
Willapa Watershed Information System Spatial Data Catalog, select databases, e.g.: wildlife biodiversity and habitat, waste water outfall, coliform levels, geology, soils, hydrology boundaries, landcover, census data, ownership, terrain, vegetation