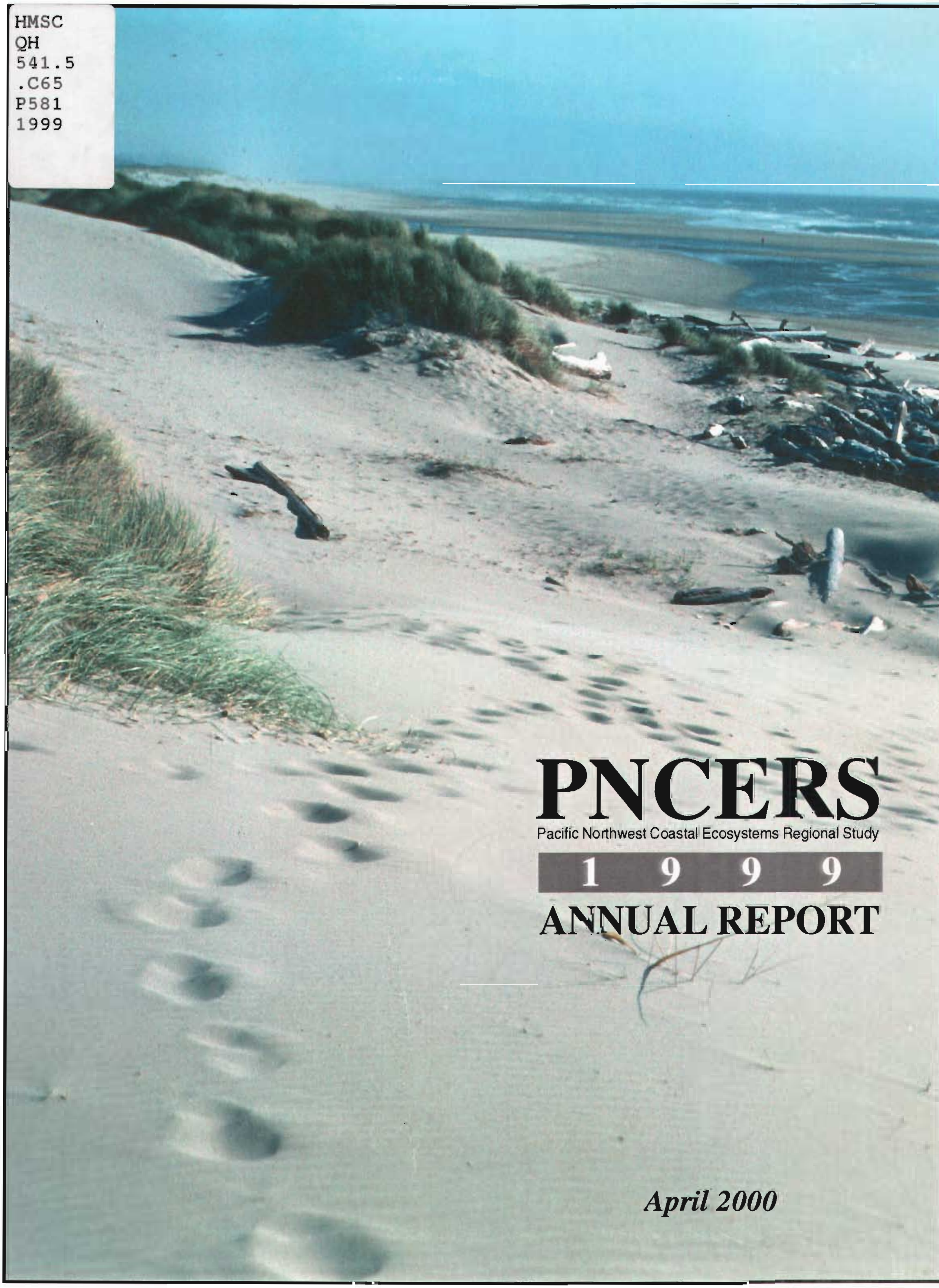


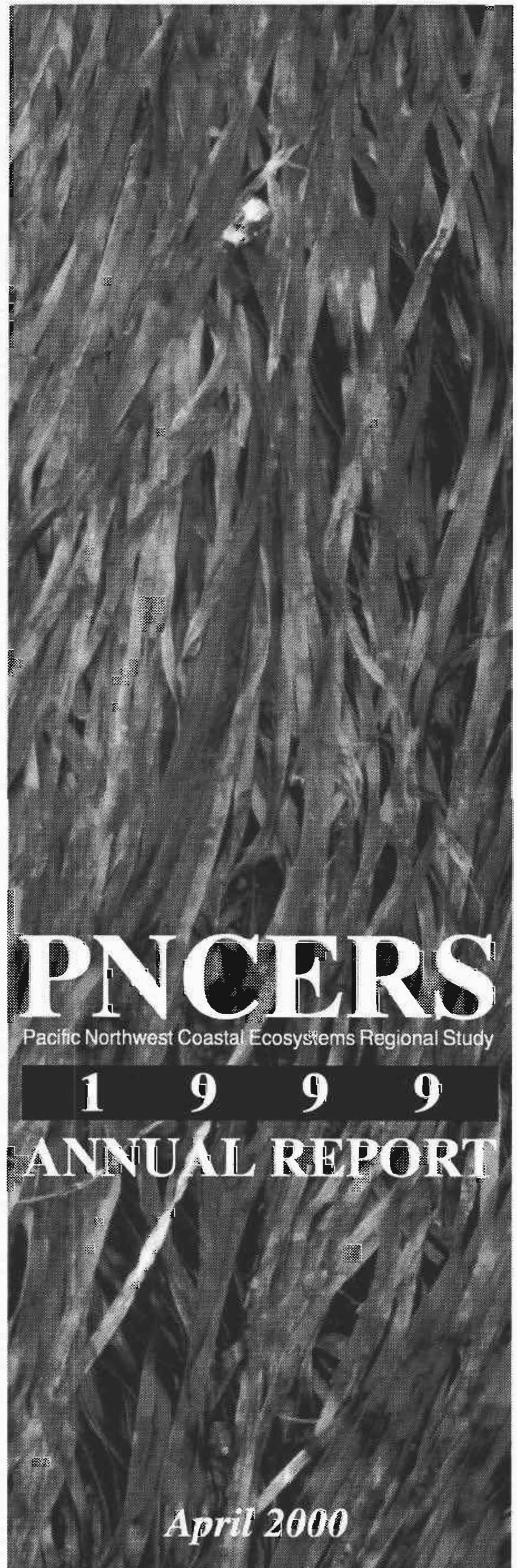
PNCERS

Pacific Northwest Coastal Ecosystems Regional Study

1 9 9 9

ANNUAL REPORT

April 2000


PNCERS
Pacific Northwest Coastal Ecosystems Regional Study
1999
ANNUAL REPORT
April 2000

Edited by Sara Breslow and Julia K. Parrish
Published by Sara Breslow

Citation:
Breslow, S. and J. K. Parrish, 2000. PNCERS 1999 Annual Report. Submitted to Coastal Ocean Programs, NOAA, April 2000.

Cover: Oregon Coast, 1984. Photo by Sara Breslow.
Title Page: Eelgrass on Washington coast, 1988. Photo by Sara Breslow.

TABLE OF CONTENTS

List of Tables and Figures

Tables

Figures

Human Resources

Principal Investigators

David Armstrong
Director/Professor, School of Fisheries, University of Washington
daa@fish.washington.edu
crabs, estuarine biota, estuarine processes, invertebrate fisheries ecology

Don Gunderson
Professor, School of Fisheries, University of Washington
dgun@u.washington.edu
biology of marine fishes, population dynamics, fisheries oceanography

Barbara Hickey
Professor, School of Oceanography, University of Washington
bhickey@u.washington.edu
physical oceanography, nearshore and estuarine circulation, the California current, river plumes, submarine canyon circulation

Ray Hilborn
Professor, School of Fisheries, University of Washington
rayh@u.washington.edu
salmon, population dynamics, modelling

Dan Huppert
Associate Professor, School of Marine Affairs, University of Washington
huppert@u.washington.edu
fisheries management, natural resource economics, public values, salmon recovery

Rebecca Johnson
Associate Professor, College of Forestry, Oregon State University
Rebecca.Johnson@.orst.edu
economic valuation and impact analysis, recreation/tourism

Julia Parrish
Assistant Professor, Departments of Fisheries and Zoology, University of Washington
jparrish@u.washington.edu
PNCERS research management, common murre ecology, animal aggregation, complexity theory

Tom Leschine
Associate Professor, School of Marine Affairs, University of Washington
tml@u.washington.edu
ecosystem management

Steve Rumrill
Research Scientist/Program Coordinator, South Slough National Estuarine Research Reserve
srumrill@harborside.com
estuarine ecology, estuarine habitats, restoration, reproductive biology, larval ecology, nearshore oceanography, estuarine resource management

Alan Shanks
Associate Professor, Oregon Institute of Marine Biology, University of Oregon
ashanks@oimb.uoregon.edu
larval transport and recruitment

Gordon Swartzman
Research Professor, Applied Physics Lab, University of Washington
gordie@apl.washington.edu
nearshore plankton and fish distribution and abundance

Ron Thom
Staff Scientist, Battelle Marine Sciences Laboratory,
ron.thom@pnl.gov
estuarine habitat, eelgrass

Post-doctoral Fellows

Kathleen Bell
School of Marine Affairs, University of Washington
bellk@u.washington.edu
environmental economics, land use modeling

Elizabeth Logerwell
School of Fisheries, University of Washington
libby@fish.washington.edu
ecology, trophic interactions, marine fish, salmon, seabirds

Curtis Roegner
School of Fisheries, University of Washington
croegner@fish.washington.edu
invertebrate recruitment, larval dispersal, estuarine ecology

Graduate Students

Neil Banas
School of Oceanography, University of Washington
neil@ocean.washington.edu
physical oceanography, models, estuarine circulation

Kristine Feldman
School of Fisheries, University of Washington
kfeldman@fish.washington.edu
burrowing shrimp, crab ecology

John Field
School of Fisheries, University of Washington
jfield@u.washington.edu
fisheries ecology, fisheries management, marine ecosystem management, climate variability, climate change

Joel Kopp
School of Marine Affairs, University of Washington
kopp@u.washington.edu
nonindigenous aquatic species, ballast water, shipping issues

Arni Magnusson
School of Fisheries, University of Washington
arnima@fish.washington.edu
coded wire tag salmon database, salmon survival, ACCESS databases

Michelle Pico
School of Marine Affairs, University of Washington
pico@u.washington.edu
institutional mapping

Amy Puls
Oregon Institute of Marine Biology, University of Oregon
apuls@oimb.uoregon.edu
larval dispersal and transport, larval ecology, zooplankton identification, estuarine ecology

Chris Rooper
School of Fisheries, University of Washington
rooper@fish.washington.edu
English sole, marine fish ecology, estuarine biota, data analysis

Technicians

Liam Antrim
Senior Research Scientist, Battelle Marine Sciences Laboratory
liam.antrim@pnl.gov
fisheries and estuarine sciences

Amy Borde
Scientist, Battelle Marine Sciences Laboratory
amy.borde@pnl.gov
estuarine habitat, GIS

Nathalie Hamel
Research Technician, Department of Zoology, University of Washington
nhamel@u.washington.edu
seabird conservation and ecology, telemetry

Laurie Houston
Faculty Research Assistant, Oregon State University, Department of Forest Resources
houstonl@ccmail.orst.edu
environmental economics, land economics, water economics

David Shreffler
Senior Scientist, Battelle Marine Sciences Laboratory
lostmtnloft@olympus.net
fisheries biology, nearshore ecology, ecological restoration

Dana Woodruff
Senior Research Scientist, , Battelle Marine Sciences Laboratory
dana.woodruff@pnl.gov
remote sensing, benthic mapping, ocean color interpretation

Research Management

Sara Breslow
Assistant Research Manager, PNCERS, University of Washington
sbreslow@u.washington.edu
PNCERS metadatabase, PNCERS research management

Julia Parrish
Assistant Professor, Departments of Fisheries and Zoology, University of Washington
jparrish@u.washington.edu
PNCERS research management, common murre ecology, animal aggregation, complexity theory

Program Management Team

Robert Bailey
Ocean Program Administrator, Oregon Coastal Management Program
bob.bailey@state.or.us
PNCERS PMT, PNCERS outreach, state ocean policy and management, coastal zone management

Andrea Copping
Assistant Director, Washington Sea Grant Program, University of Washington
acopping@u.washington.edu
PNCERS management, oceanography

John Stein
Director, Environmental Conservation Division, NFSC, NMFS
john.e.stein@noaa.gov
fisheries conservation

Program Coordinator

Greg McMurray
Project Administrator, PNCERS Program Office, Oregon Department of Environmental Quality,
mcmurray.gregory@deq.state.or.us
PNCERS administration, biological oceanography

Executive Summary

Sara Breslow and Julia K. Parrish

Introduction

Since last year, PNCERS has honed its geographic and conceptual focus, concentrating on gaining an in-depth understanding of human and natural interactions within a few major systems. The majority of our efforts are focused on three main estuaries along the Oregon-Washington coast: Grays Harbor, Willapa Bay, and Coos Bay; as well as along the length of the nearshore. Research into the natural and anthropogenic factors influencing ecosystem change in these areas takes place at several interacting levels, from detailed study on specific elements of the coastal system to broader, collaborative conceptualizations of the system as a whole.

The Collaborations Diagram (Figure 1) offers one way to visualize the collaborative dynamics within PNCERS research, with squares and circles representing research projects, and arrows indicating the direction of data flow. Square boxes represent the *independent research projects* which have always been the foundation of PNCERS research. Updates on all independent projects are reported herein. Each research project will ultimately produce a related set of primarily academic products, including graduate student theses and dissertations, peer-reviewed journal articles, and presentations to the scientific community.

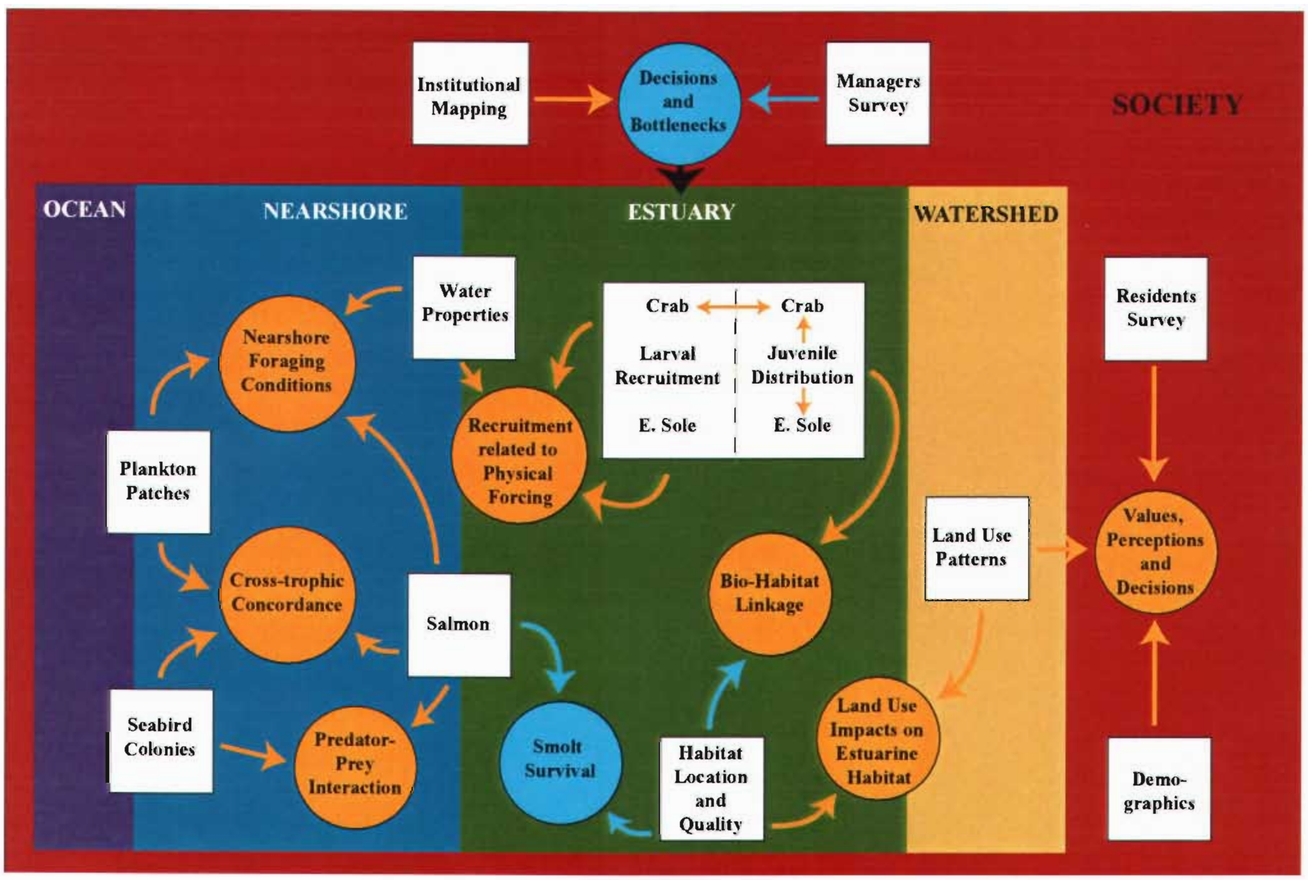


Figure 1. 1999 PNCERS Collaborations. Blocks of color indicate geographic or thematic focus areas of PNCERS. Individual research projects are shown as white squares. Collaborative projects are represented by circles, with arrows indicating the flow of data transfer. Orange circles and arrows indicate ongoing collaborations, and blue circles and arrows indicate planned collaborations.

Collaborative projects (represented by circles in the diagram) are the emerging new backbone of PNCERS. In these projects, groups of two to three Principal Investigators focus on linkages between their individual projects. One small team of researchers is investigating the physical and biological factors controlling larval recruitment to estuaries, another is characterizing nearshore foraging conditions and other factors involved in salmon smolt survival, and a third is assessing the values, perceptions and attitudes of various contingents of the coastal community. Because collaborative projects often take on a life of their own, PNCERS has hired three full-time postdoctoral fellows to spearhead these efforts in social, estuarine, and nearshore research, respectively. It is these collaborative projects upon which PNCERS will build our evolving broad scale conceptual models.

The independent and collaborative projects work together to describe trends and processes within each *primary geographic, or broad disciplinary, focus, i.e. social science, nearshore, and estuaries* (represented by large blocks of color in the diagram). Finally, projects address linkages *between* these disciplinary and regional focus areas, with questions such as:

- How do nearshore currents influence estuarine water conditions?
- How do land use patterns impact the estuarine habitat?
- How do values and perceptions influence coastal management decisions?

To facilitate data analysis at these levels, researchers are planning to combine spatial data in a PNCERS Geographic Information System, while the upcoming on-line PNCERS metadatabase will allow researchers to search for multidisciplinary data sources related to each of these categories (in addition to many other areas of interest). In addition to meeting in small research teams, PNCERS investigators have the opportunity to gather as a large group to explore these and many other integrative questions in detail at the weekly PNCERS Eat & Learn Seminars (see Research Program Management, page 71).

At the broadest level of interaction, PNCERS investigators have begun formal discussion on two emerging themes of PNCERS research:

1. the broad-scale role and consequences of physical forcing (with primary focus on the nearshore), and
2. the more local interplay between human activities and environmental change (with primary focus on estuaries).

Researchers met in two groups based on these themes at the All-Hands Meeting held in January. Discussion focused on both details of data integration and ways to weave research results into stories for outreach and educational purposes (see All-Hands Meeting report, page 75). This highest level of integration and interaction is most likely to produce meaningful results relative to natural resource management in coastal Oregon and Washington.

1999 Research Summary

PNCERS' approach to understanding natural and anthropogenic change in the Pacific Northwest coastal region is to focus attention on the major processes and key indicators that most effectively illuminate this huge and complex region. Two of the most important processes impacting this area are physical oceanographic cycles and human demographic change. Key indicators include those which primarily reflect the condition of the ecosystem (e.g. seabirds and eelgrass), those which track economic trends (e.g. property values and types of industry), and those which, perhaps most importantly, relate to both the ecology *and* economy of the region (e.g. the valued ecosystem components: salmon, oysters, crab, recreation and tourism).

Major Processes

Clearly, physical oceanographic processes are a major influence on coastal ecology. The PNCERS physical oceanographic team, led by Hickey, has been measuring and observing how upwelling and downwelling, riverflow, and seasonal and tidal cycles influence both currents and water properties near and within estuaries. In collaboration with many of the other PNCERS projects, they are helping us understand how these physical processes influence biological aspects of the system, such as the distribution and abundance of plankton patches and fish schools in the nearshore, the movement of phytoplankton (including harmful algal blooms) and larvae into and out of estuaries, and the survival of salmon smolts in both regions.

At the same time, the social science team (Huppert, Leschine, Johnson and Bell) has been documenting the human processes impacting this region, including population trends, land use, industry transitions, and the region's institutional and regulatory fabric. Bell has been hired to work with PNCERS natural scientists to understand how these human activities impact coastal ecology, primarily through an exploration of land use and land value models. The social science team is also working to explore how the coastal environment impacts community values and the local economy. Estuarine ecology is significantly impacted by humans, for example, in the form of development, invasive species, commercial oyster growing, crab harvesting, and recreation. On the other hand, the environment plays an important role in determining why people choose to live on the coast, how property is valued, and what kinds of industry develops (e.g. recreation and tourism).

Indicators
Influenced directly or indirectly by these major coastal processes are a number of species important for their ecological and/or economic value. Researchers focusing on these organisms observe and document trends in individual survival and reproductive output, and population distribution, abundance, and growth rate, as well as other factors which reflect the general health of local populations.

Nearshore indicators
In the Pacific Northwest nearshore environment, PNCERS researchers are examining links between three major biological elements of the ecosystem: common murres, fish schools, and plankton patches. They are also looking at the relationship between this rudimentary food web and physical, biological and human-associated environmental variables. Swartzman is comparing the spatial distributions of fish schools and plankton patches. Swartzman and Parrish are looking at spatial correlations between common murre colonies and prey sources, i.e. significant concentrations of schooling fish. Both are examining how population trends for these organisms respond to both spatial and temporal variability in climatological and oceanographic signals (e.g. El Niño and La Niña events, areas of upwelling and change in average sea surface temperature).

Magnusson and Hilborn have assembled a coded wire tag database with which to address questions of salmon smolt survival as a function of environmental change. In conjunction with Swartzman and Parrish, Logerwell has recently been hired to use this database to examine correlations between salmon smolt survival and plankton abundance (e.g. the prey), and smolt survival and common murre abundance (e.g. the predators). These interactions will be used to build a series of spatially explicit bioenergetics models of salmon smolt survival. In addition, Magnusson will consider estuarine parameters that may impact salmon survival. As such, the salmon serve as integrative indicators across several geographic regions.

Estuarine Indicators
PNCERS investigators conducting research in Pacific Northwest estuaries are interested in how estuarine ecosystems have changed over time, and to what degree they respond to and are impacted by both physical and anthropogenic factors. Current focus is on understanding major sources of environmental variability in order to establish a framework for understanding possible human stressors. To track how habitat and key species have changed over time, Thom and Rumrill have been mapping estuarine habitat and comparing current data to historical observations. They have also been studying eelgrass as an indicator of estuarine health, as it is responsive to changes in nearby land use, variations in water properties and water quality in the estuary, and climatological signals. To understand variation in the distribution and abundance of benthic biota, Roegner and Shanks are measuring the transport of larvae into and out of the estuaries. The patterns of abundance are being related to oceanographic variables indicative of regional water movements. Armstrong and Gunderson have been documenting changes in distribution and abundance of estuarine macrofauna (with emphasis on juvenile Dungeness crab and English sole), noting which estuarine subregions are the preferred nursery habitats. This study links the pelagic dispersal work of Shanks and Roegner with the habitat work of Thom and Rumrill. Finally, in response to the growing conviction that oysters and oyster shell habitat represent important components of coastal estuaries in Washington and Oregon, we will begin a new pilot project (headed by Jennifer Ruesink, University of Washington) to study links between oysters and a suite of native and introduced species.

RESEARCH PROJECTS

Coastal Ocean-Estuary Coupling .... Project 1

Barbara M. Hickey

Introduction

Barbara Hickey

Time series of oyster condition at different sites within Willapa Bay demonstrate significant interannual variability as well as a significant downward long term trend (Dumbauld, Pers. comm.). 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 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 1985 El Niño year the data suggest that 1+ crab densities are much higher in estuaries than along the open coast. Moreover, offshore size data demonstrate that the estuaries serve as a nursery for young crab: a significant number of crabs 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 them as either nurseries or homes. Estuaries on the U. S. Pacific Northwest coast have not received the attention of east coast estuaries that have been more

Table 1.1. Time-line for PNCERS measurements.

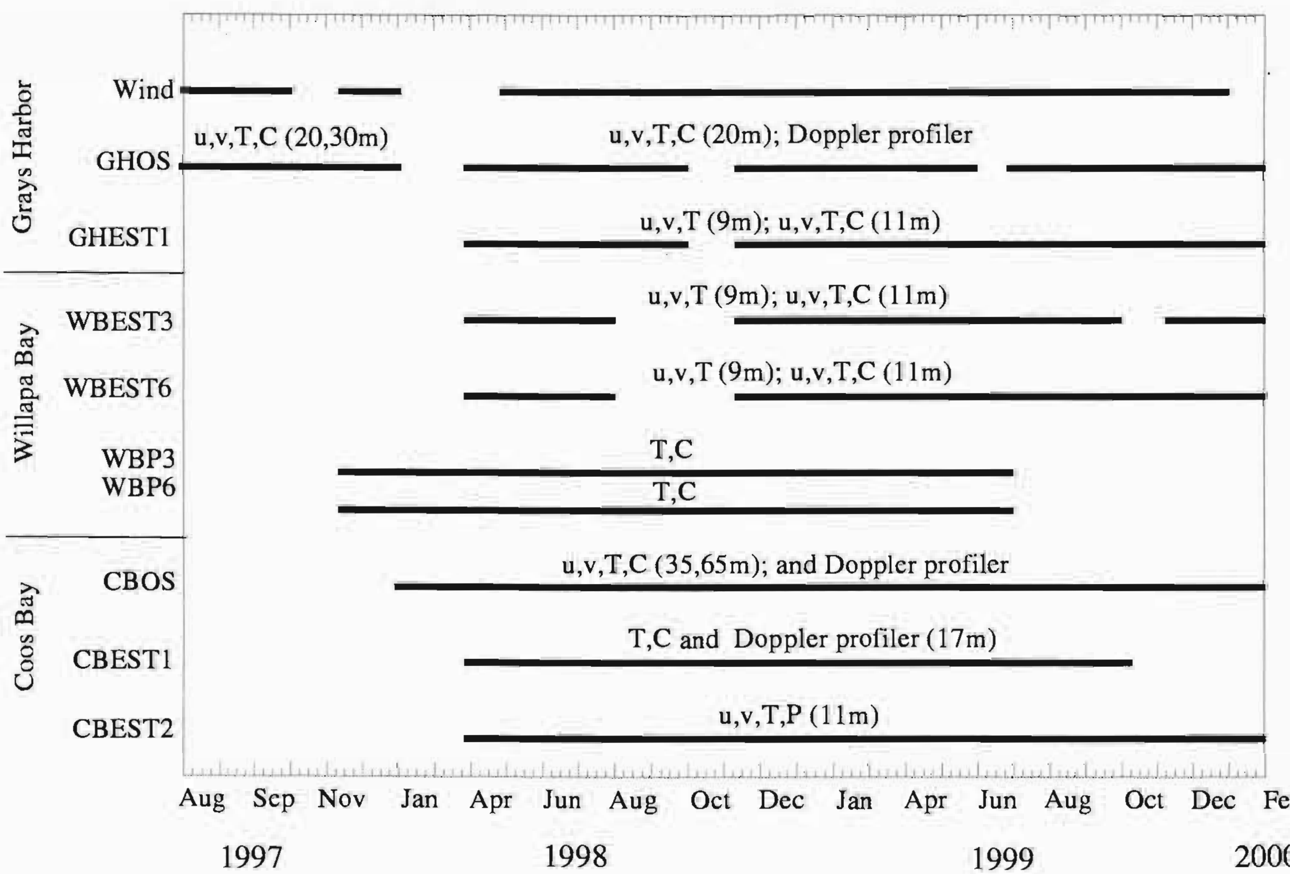


Photo facing page: Eelgrass on Washington Coast (1988). Photo by Sara Breslow.

heavily impacted by development. For the most part, variability in these estuaries is directly related to changes in the physical environment, due in particular 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 the fisheries components of PNCERS, to determine factors that cause variability in year class strength in several important species. Measurements in three estuaries (Grays Harbor and Willapa Bay, Washington; Coos Bay, Oregon) allow comparative studies in both fishery success and environmental variability.

Results & Discussion

During the past 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:

- For a second year, 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 completed analysis of water property variability in a Pacific Northwest estuary under low riverflow conditions.

- We have demonstrated that during high riverflow conditions, subtidal scale stratification is controlled by riverflow and not by tidal state.

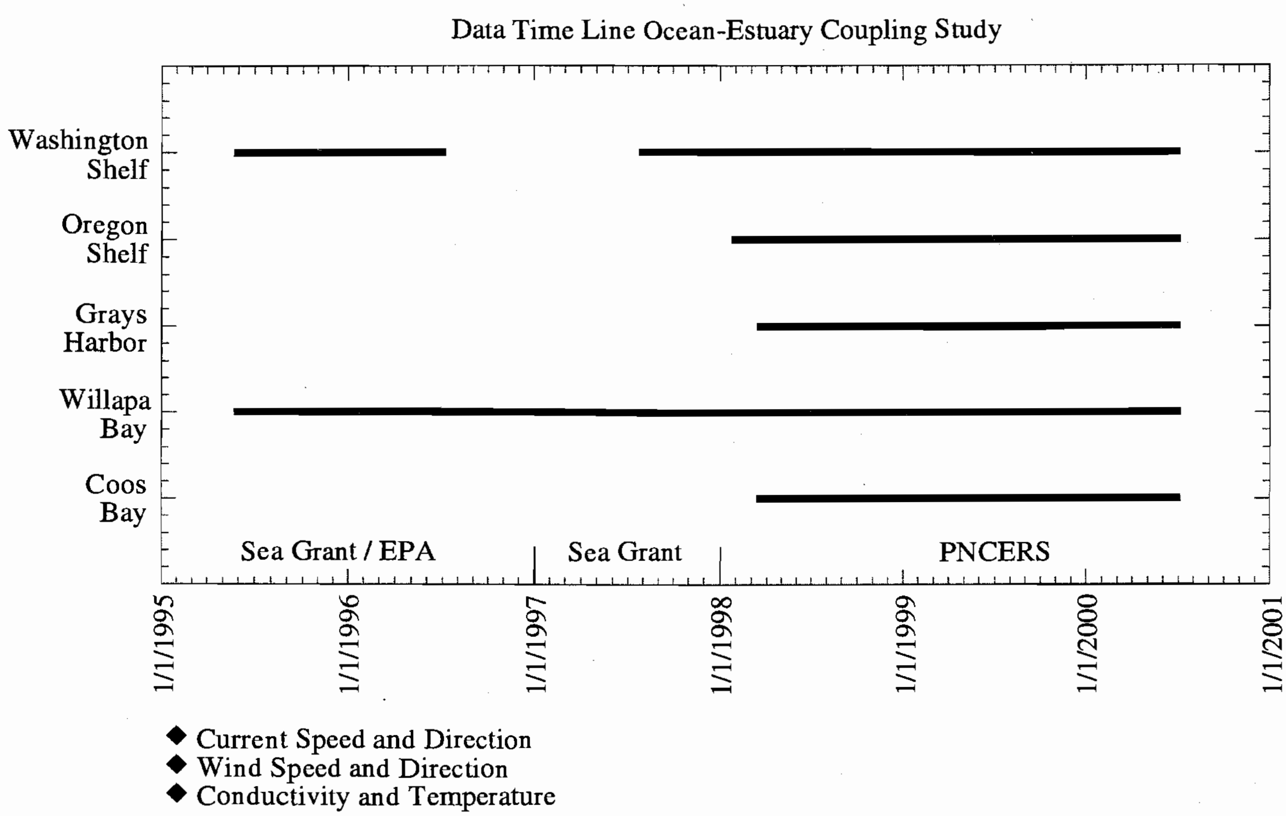
- We have demonstrated that the plume from the Columbia River dominates water properties during late spring and early summer in estuaries north of the Columbia during high snow pack years. This leads to large interannual variability in a given estuary as well as to significant differences between Oregon and Washington estuaries.

Each of these results is discussed in more detail below.

1. Data Collection and Analysis

Our primary task during the last two years has been to maintain water property and current instrumentation within three coastal estuaries and at two sites on the adjacent coast. Time

Table 1.2. Time-line for database in Pacific Northwest coastal estuaries and nearshore environment.



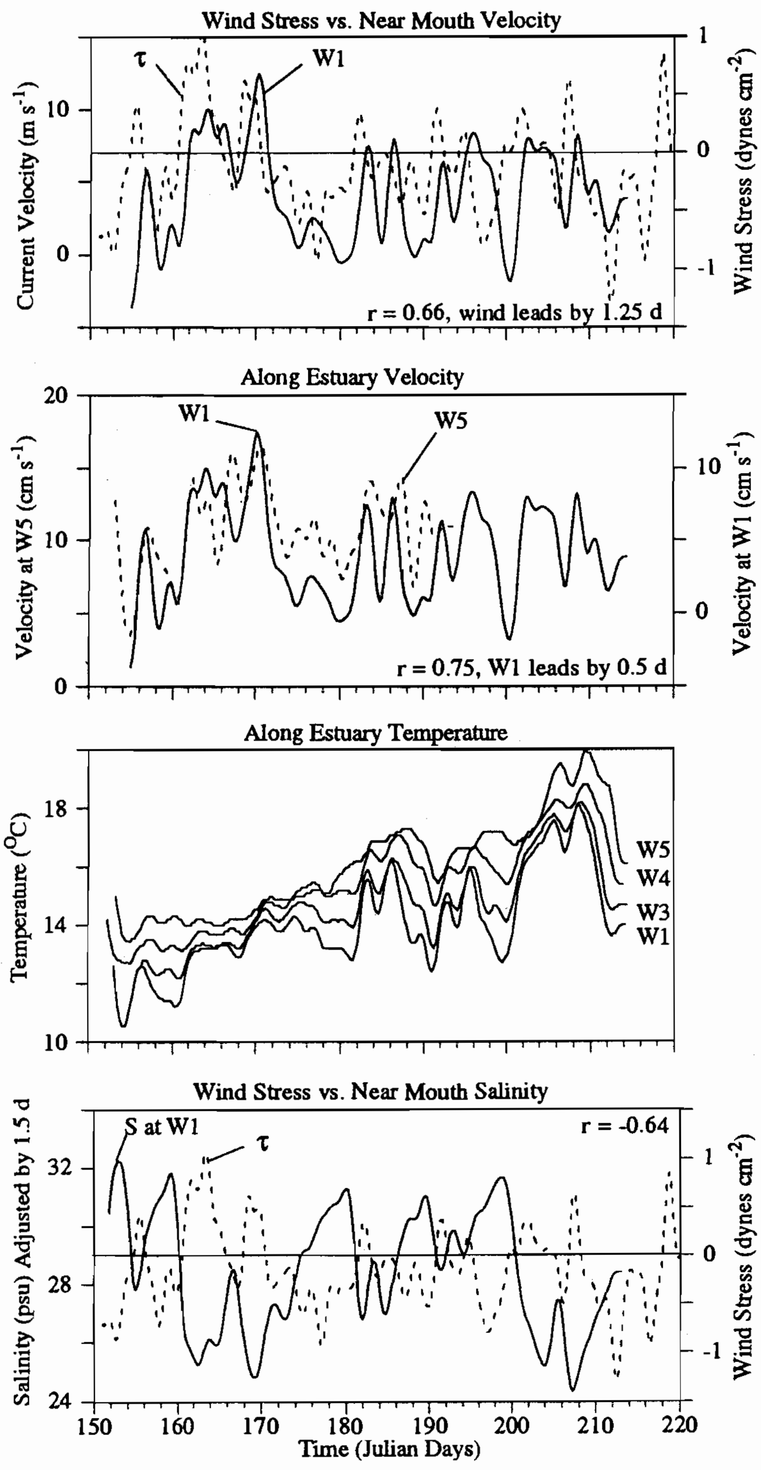


Figure 1.1. Top Panel: Alongshelf wind stress and along-estuary currents near the estuary mouth (W1). Upper Middle panel: Along-estuary currents near the mouth (W1) and halfway up the estuary (W5). Lower Middle Panel: Temperature at ~15 m at all sites (W1 at the mouth to W5 mid-way up the estuary). Bottom Panel: Alongshelf wind stress and salinity at the site nearest the estuary mouth, with salinity adjusted earlier in time by 1.5 d. From Hickey and Zhang (2000).

lines of data collected to date with PNCERS support are shown in Table 1.1. A time line showing the extensive data base acquired for Pacific Northwest coastal regions with the support of other agencies (EPA, Washington Sea Grant) as well as PNCERS is shown in Table 1.2.

In general, moorings and sensors were cleaned and refurbished at approximately quarterly intervals in estuaries and semiannually on the shelf. Seven sites are being occupied and each site requires separate ships and trips for each refurbishment. The Coos Bay estuary sites are serviced by divers using a small boat. Successful maintenance of the suite of equipment in the many locations has been challenging and arduous, utilizing much of the PNCERS-supported field effort. After a year of complete measurements it was decided to limit the Coos Bay measurement suite to water properties (only) and to the site near the mouth (only).

Because of the strenuous field effort, data processing has lagged behind collection effort. Analysis this year was primarily restricted to data from Willapa Bay. Data analysis will be emphasized in the fourth year of PNCERS.

2. Ocean-Estuary Coupling under Low Riverflow Conditions in Willapa Bay

Results from our analysis of Willapa Bay data show that water property and mid- to lower-water column current variability on scales of several days during low riverflow conditions are driven by offshore variability in coastal upwelling processes adjacent to the estuary. Density changes near the mouth of the estuary that result from upwelling or downwelling of coastal water are transmitted to the estuary as a gravity current, modifying the along-estuary density gradient and hence the gravitational circulation. New water moves up the estuary at an average rate of about 12 $cm\ s^{-1}$. These relationships (e.g., the up-estuary temperature and velocity movement and the salinity-wind stress coupling) are shown in Figure 1.1. Water properties change at a slower rate than the speed of the advancing gravity current, indicating that vertical mixing plays an important role in determining resultant water properties at a fixed location. These results are presented in detail in Hickey and Zhang (2000).

Initial comparison of water property data from all three estuaries (see the PNCERS 1999 Annual Report) shows a high degree of inter-estuary correlation during the summer growing season. This similarity is a direct result of the large scale of atmospheric forcing and hence, the occurrence of upwelling and downwelling events along the coast (Halliwell and Allen, 1987). Thus, we expect that detailed analysis of the other two estuaries during this season will yield exchange mechanisms similar to those described above, although time scales will likely differ from estuary to estuary as a result of differing morphology.

3. High-Runoff Conditions in a Pacific Northwest Estuary (Collaborative Measurements with J. Newton). Measurements of salinity and temperature near the surface and near the bottom are being made in Willapa estuary at several sites. The work is a collaboration between PNCERS (Barbara Hickey) and the Environmental Protection Agency (Jan Newton at the Department of Ecology). Comparison of time series of salinity near the surface during a high riverflow period shows that salinity at the sea surface is strongly correlated to high riverflow events (Figure 1.2). Data are from sites 6 km (W3, 12 m) or 10 km (TP, 0 m) from the ocean. High riverflow produces estuarine salinities as low as 10 psu. Comparison of salinity at the surface (TP, 0 m) with salinity in the lower water column (W3, 12 m) shows that lower water column salinity fluctuations are correlated to the surface fluctuations, although salinity during the high runoff period is rarely less than 22 psu. Note that the correlation of lower water column salinity to high riverflow events and surface salinity may be entirely fortuitous: high riverflow occurs at the same time as maxi-

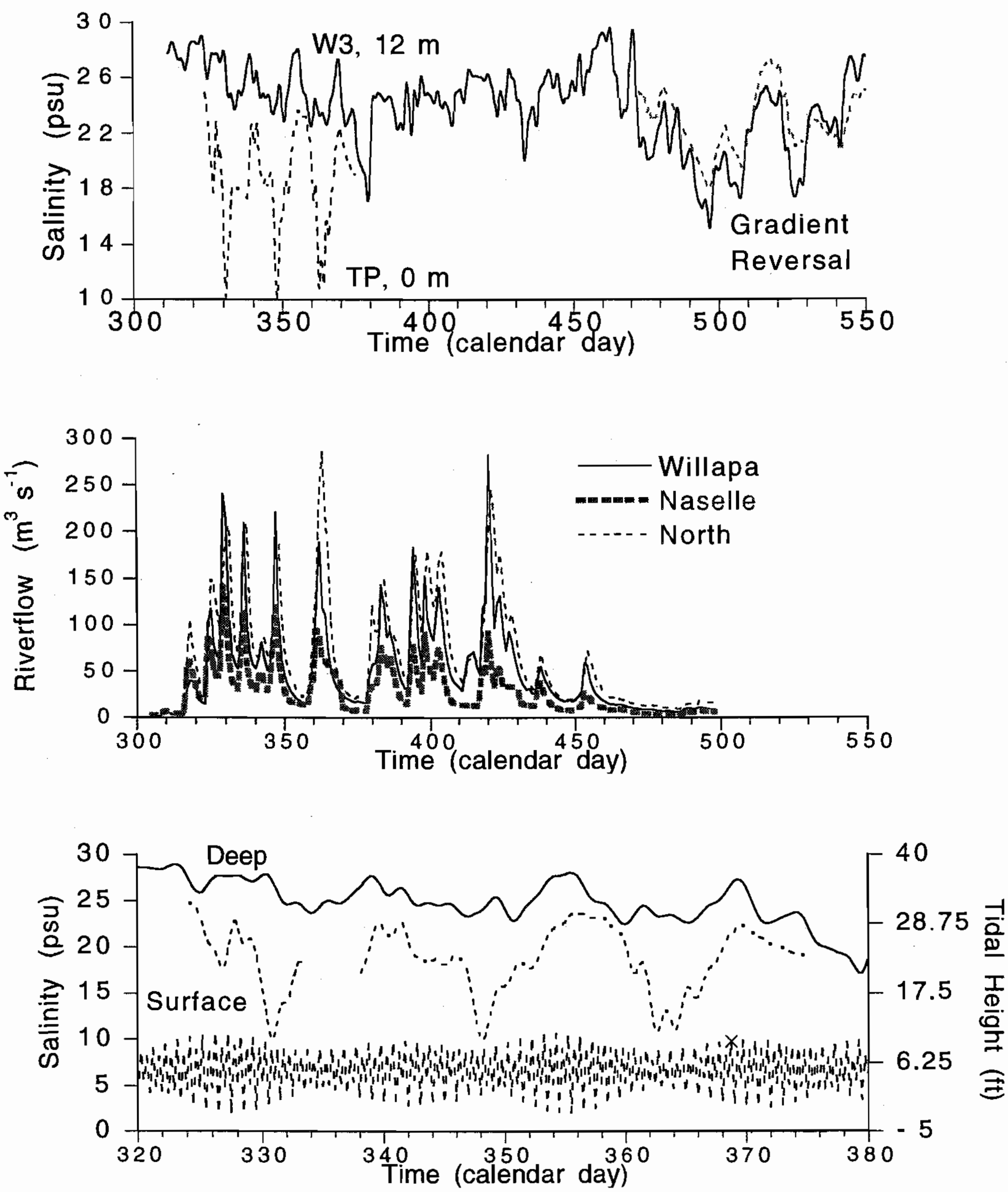


Figure 1.2. Upper Panel. Time series of salinity in Willapa Bay at the surface (TP, 0) and in the lower water column (W3, 12 m) from November 1998 through June 1999. Data are from sites 6 km (W3) and 10 km (TP) from the estuary mouth. Middle Panel. Time series of riverflow from the 3 major rivers in Willapa Bay. After day 500, riverflow is less than 25 m^3 s^{-1}. Bottom panel. Comparison of surface and deep salinity with tidal amplitude at the same sites shown in the top panel.

mum downwelling along the coast, during which processes described in (2) above come into play. The relative importance of *in situ* and remote forcing to local water properties will be examined in our future analyses.

A number of large low salinity events in the lower water column show no correlation to local riverflow. In the next section we will show that these extrema are caused by intrusions of water from the Columbia River plume into the estuary. The mouth of the Columbia River is located about 30 km south of Willapa Bay.

In many estuaries, stratification on greater-than-tidal time scales is controlled by tidal amplitude; in particular, vertical mixing is enhanced during periods of stronger tidal currents (spring tides) and diminished during periods of weaker tidal currents (neap tides). This is clearly not the case in Willapa Bay (Figure 1.2, lower panel). Maximum differences between surface and near bottom salinity (i.e., vertical stratification) are observed during high riverflow periods, and not necessarily during spring tides. The connection to tidal amplitude, if it occurs, must be of secondary importance.

4. Influence of the Columbia Plume on Pacific Northwest Estuaries (Collaborative Measurements with J. Newton)

Time series of sigma-t at a location 6 km from the ocean show dramatic density minima throughout the year (Figure 1.3). Comparison with riverflow data (Figure 1.2) shows no relationship between these dramatic minima and high riverflow conditions. Minimum salinity in the lower layers of the estuary occurs not during the high riverflow season, but

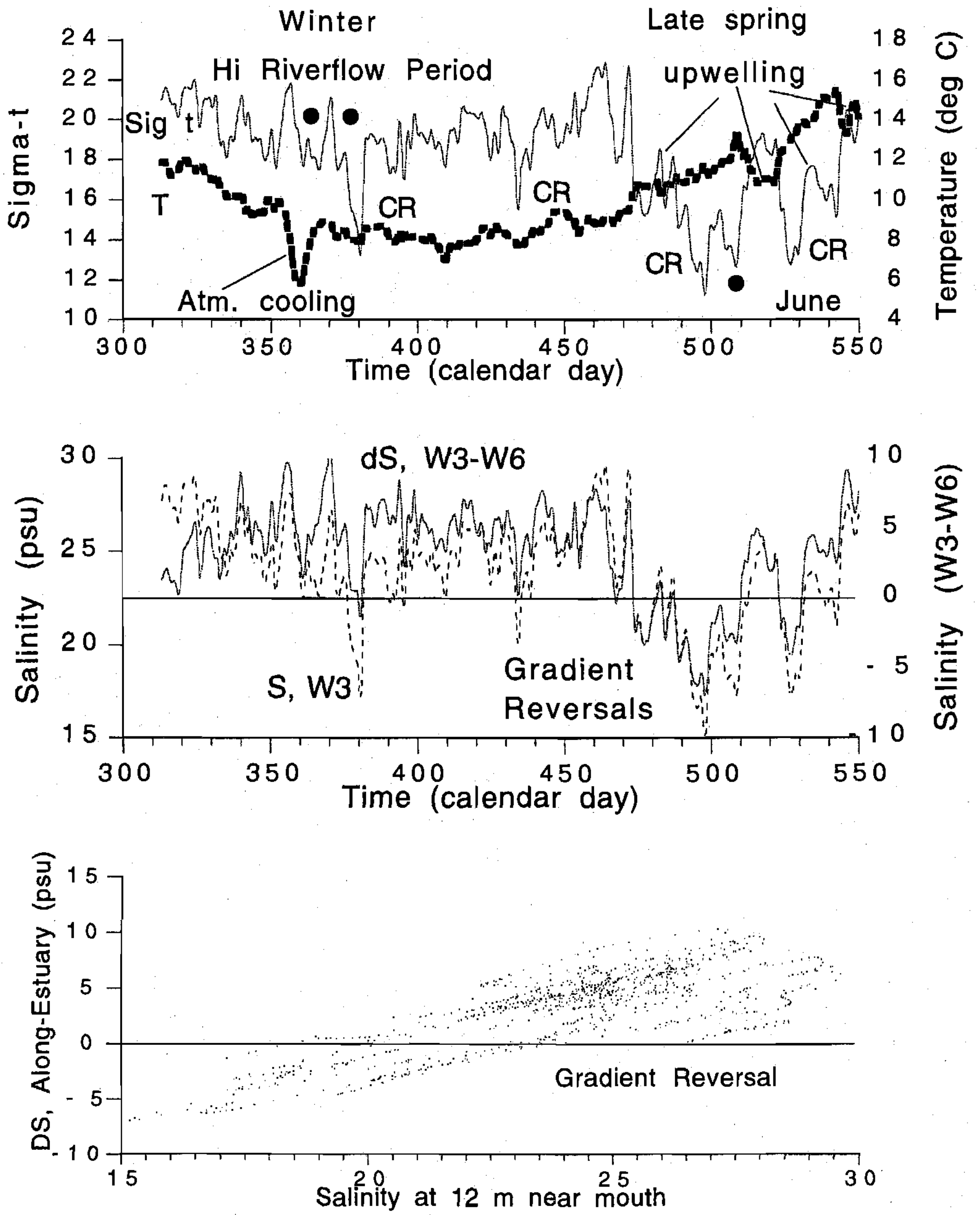


Figure 1.3. Top Panel. Time series of lower water column sigma-t and temperature from November 1998 through June 1999. The period of high riverflow and periods of upwelling are indicated. A major atmospheric cooling event is also indicated. "CR" indicates a low salinity event caused by the Columbia plume. Dates of CTD sections presented in the next 2 figures are indicated with large dots. Middle Panel. Time series of the along-estuary salinity difference over a 20 km distance along the estuary. A negative value indicates a reversal of the "normal" estuarine salinity gradient; i.e., the estuary is fresher at the ocean entrance than half way down the estuary. Bottom Panel. Along-estuary salinity difference plotted versus salinity near the estuary mouth.

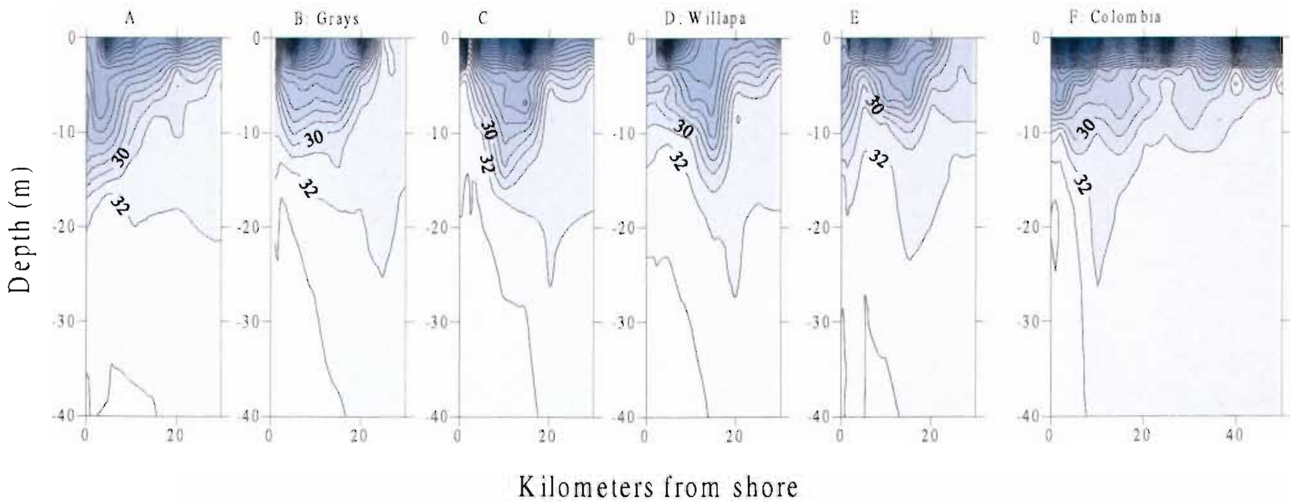


Figure 1.4. Cross-shelf salinity sections from a location near the Columbia River to north of Grays Harbor during downwelling conditions in late May 1999. Sections confirm the presence of extremely low salinity water offshore of Willapa and Grays estuaries during this high snowmelt year. Contours are drawn at 1 psu intervals.

in late spring (May-June). Salinities as low as 14-18 psu are not uncommon (see Figure 1.2). The winter of 1998-1999, in which La Niña, hence rainy, conditions prevailed in the Pacific Northwest, resulted in an extremely high snow pack in Pacific Northwest mountains. Such conditions produce anomalously high runoff conditions in the Columbia River the following spring due to melting snow. Thus, in spring 1999, the plume from the Columbia River was unusually large and unusually fresh. Hydrographic sections across the shelf offshore of Willapa from the Columbia to north of Willapa Bay confirm the presence of very low salinity water from the Columbia River plume just offshore of Willapa Bay during this period (Figure 1.4). Data were collected on a PNCERS-supported offshore survey (processed by Curtis Roegner). Data were obtained near day 500, just following an upwelling event (see survey dot in Figure 1.3).

Wind conditions in May-June, 1999 continued to reflect La Niña conditions; namely, poor weather continued to occur, with the associated northward winds that move the Columbia plume to shore (Hickey et al., 1997). Thus the time series of salinity in the estuary in May-June as seen in Figure 1.3 reflect a period of fluctuating upwelling and downwelling winds. Upwelling occurs, but the amount of freshwater over the shelf due to the Columbia freshet is apparently sufficient to inhibit upwelling of deeper, saltier, colder water. Since the Columbia River has essentially no nitrate in spring (it is utilized by indigenous phytoplankton), the lack of deep, nutrient rich water during this rather lengthy period is likely to have had major consequences on the biology of both the coastal region and the local estuaries. In addition to more direct climate effects such as increased or diminished riverflow, or changes in the amount or duration of coastal upwelling, we have thus identified another important route by which climate changes can affect both nearshore and coastal estuaries. Moreover, the effect would be limited to Washington's estuaries. Thus, comparison of crab settling rates, phytoplankton growth and other biological indicators between the estuaries during such periods could provide information on the effect of climate changes on Pacific Northwest estuaries and nearshore regions.

Time series of salinity differences over a ~20 km distance along the estuary demonstrate that during Columbia intrusions, the "normal" along-estuary density and salinity gradients (denser and more saline nearer the ocean) are near zero or reversed (Figure 1.3, middle panel). Such reversals occurred several times in the 1998-1999 winter to spring period; in particular the reversed gradient persisted for up to 2 weeks at a time in May 1999. We speculate that such gradient reversals may have important consequences for both juvenile fish and larvae in the estuaries. Gradient reversals typically were associated with lower water column salinities less than about 22 psu (Figure 1.3, lower panel). Water property surveys collected by DOE during a "normal" high winter riverflow event and a "Columbia intrusion" are shown in Figure 1.5. The survey data illustrate that in addition to elimination or reversal of along-estuary density and salinity gradients, vertical stratification is dramatically altered by intrusions of Columbia plume water; i.e. vertical stratification is eliminated completely over much of the estuary.

Integration & Interaction

Our research team is providing information on environmental conditions in three estuaries and the coastal zone. Similarities and differences of processes and environments within

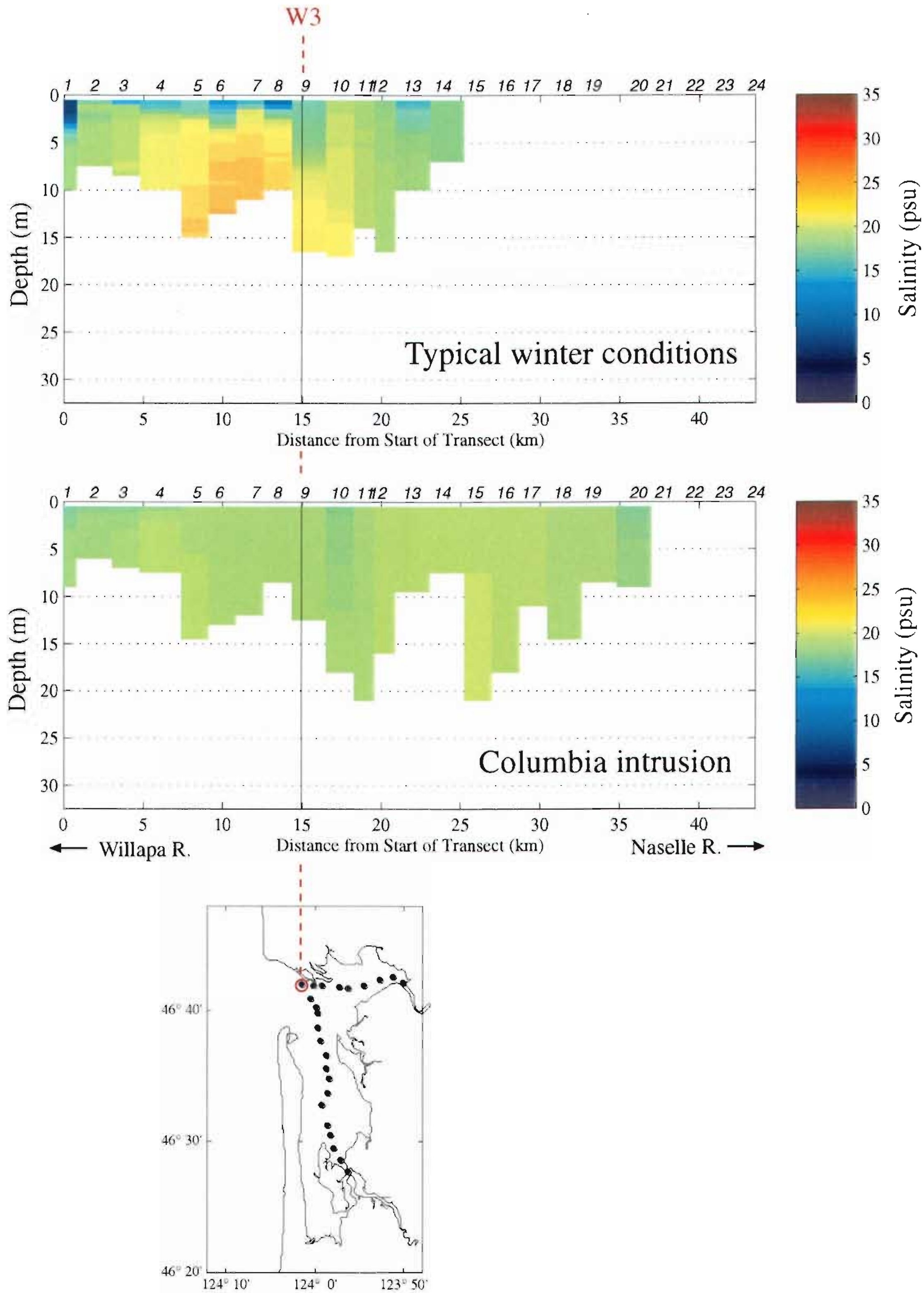


Figure 1.5. Sections showing salinity along the estuary from the Willapa River west toward the ocean and down the main axis of the estuary during "typical" winter storm conditions (upper) and during an intrusion of Columbia River water (bottom). Dates of these surveys are shown in Figure 1.3 as a pair of large dots (near days 362 and 378). The black vertical line indicates the turning point from east-west to north-south. The measurement location for data presented in Figure 1.3 (W3) is also shown. Note the transition from high stratification during normal high riverflow to low stratification during a Columbia plume intrusion.

the three estuaries and along the coast are being exploited in conjunction with PNCERS colleagues to address spatial and temporal variability in fishery year class strength, larval settling rates, fish, zooplankton, phytoplankton distributional patterns and growth rates as well as the occurrence of toxic algal blooms (HABS).

Specific examples of integrations to date in addition to those described in (3) and (4) above include the following.

1. Estuary-Ocean Biological Coupling for a Pacific Northwest Estuary, Willapa Bay: A Working Hypothesis. B. Hickey, C. Roegner and J. Newton

Research on processes affecting local estuaries has demonstrated that waters in Willapa Bay exchange with the coastal ocean on a time scale of about 5 days in the main portion of the estuary (see schematic in Figure 1.6). The type of water presented at the mouth of the estuary on flooding tides is governed by the water available near the coast at that time. The properties of that water (temperature, salinity, nutrient levels and phytoplankton content) are governed by whether upwelling or downwelling is occurring along the coast at that time. During upwelling, surface water moves offshore and cold, saltier, nutrient rich water moves upward within a few kilometers of the coast; during downwelling, surface water moves onshore and warmer, fresher, nutrient-poorer water moves inshore and downward within a few kilometers of the coast. In the Pacific Northwest, transitions between these two states occur at 2-10 day intervals. Water presented at the mouth of the estuary (for both upwelling and downwelling events) travels up the estuary at the rate of about 10 km per day, modifying the circulation in the estuary (the "gravitational "circulation) as it passes (see Figure 1.1 and discussion in text).

During a coastal upwelling event on the coast, phytoplankton seed stock are upwelled into the euphotic zone and, fueled by the high nutrient level, begin to grow. The growing phytoplankton move offshore as new seed stock is upwelled so that highest biomass typically occurs offshore rather than right at the coast. During the downwelling event that inevitably follows, the phytoplankton bloom is advected back to the coast.

Phytoplankton standing stock in coastal estuaries is of vital importance to the estuarine ecosystem and also provides the primary food source for commercial species such as oysters. We hypothesize that oceanically-derived phytoplankton can enter coastal estuaries by two routes:

1. During upwelling events, just as on the coast, seed stock are pulled into the estuary where they are fueled by the high nutrients brought in with the upwelled water. A local phytoplankton bloom may follow as this biomass moves up the estuary with the patch of water at a rate of about 10 km per day.

2. During downwelling events, just as on the coast, the phytoplankton from the upwelling-fueled bloom are pulled into the estuary and also move up the estuary. This biomass, although nutrient poor and declining rather than growing, may provide a direct food source to the estuary, particularly near the mouth of the estuary. It seems likely that HABS blooms from the coast may enter coastal estuaries via this mechanism, particularly during late fall storms. Any HABS bloom on the coast would also move to coastal beaches during these storms.

Data from a PNCERS-supported survey in June 1999 illustrate the rapid transition from downwelling to upwelling con-

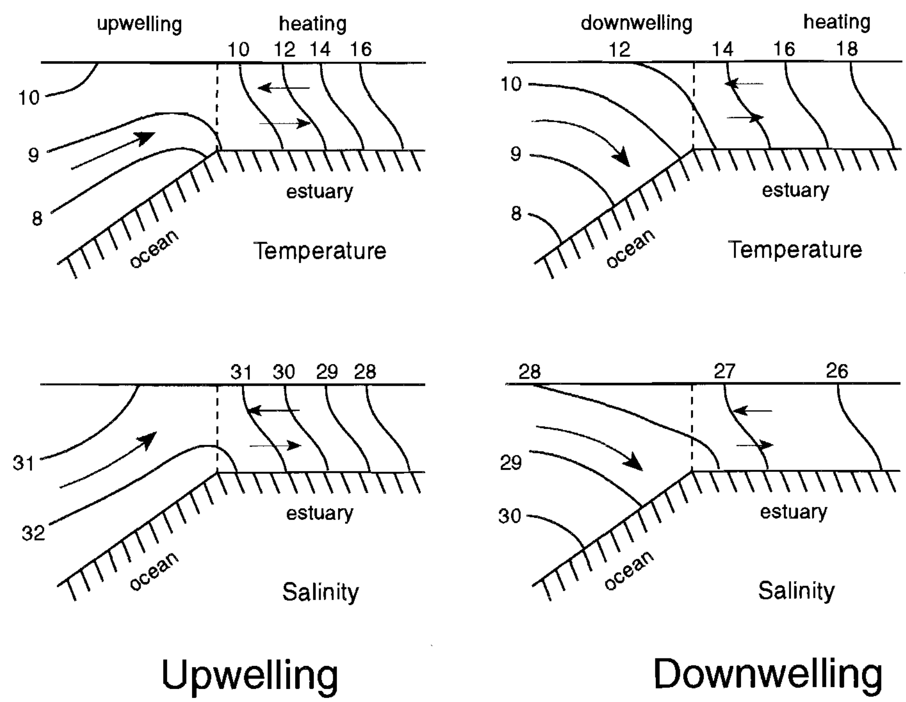


Figure 1.6. Schematic illustrating baroclinic coupling processes between the coastal ocean and a coastal plain estuary during upwelling and downwelling events for a low riverflow, summer period in an Eastern Boundary system. From Hickey and Zhang (2000).

ditions offshore of Willapa Bay. Isohalines tilt downward toward the coast during the downwelling event; just three days later, isohalines tilt upward toward the coast (compare Figures 5.4 and 5.5, upper panels, in Project 5 report). Phytoplankton distributions illustrate the rapid response (i.e., growth) of the biomass to upwelling conditions (compare Figures 5.4 and 5.5, lower panels).

Time series of sigma-t in the lower water column within the estuary during this period show the rapid change from downwelling (lower density water) to upwelling (higher density water) consistent with the change in wind direction from southward to northward (Figure 1.3). Time series of chlorophyll within the estuary, although available (from EPA-supported research) have not been processed to date. During the remaining portion of PNCERS Year 3, these data as well as information on phytoplankton species will be incorporated into the analysis and a paper prepared for publication.

The hypotheses presented here are unique. Previous work has suggested only that phytoplankton enter estuaries during "wind relaxation" events. Our results demonstrate that this conclusion is likely overly simplistic, describing only half the possibilities for biological estuary-ocean coupling in Pacific Northwest estuaries. The ongoing research suggests that multiple sources of phytoplankton may exist for the estuary (beyond indigenous species) and that these different sources may impact different subregions of the estuary.

2. Crab and Flatfish Larval Recruitment. Don Gunderson, Chris Rooper and Barbara Hickey.
We are assisting Chris Rooper in modeling transport of larval and egg stage English sole along the coast from spawning grounds to juvenile nurseries in estuaries. We are providing information on time series analysis techniques as well as a simple numerical model for alongshelf transport in late winter-spring conditions.

3. Willapa Bay Biophysical Studies. Barbara Hickey, Neil Banas, Jan Newton and Eric Siegel
A group of four interrelated abstracts were prepared for the Ocean Sciences Meeting in January, 2000. The abstracts used both physical and biological data to address issues of nutrient supply and phytoplankton growth rates and spatial patterns in Willapa Bay. At least two papers are expected to emerge from this collaboration.

4. Harmful Algal Blooms (HABS). Barbara Hickey, R. Horner and V. Trainer
Patterns and time series of data on HABS collected off the Washington coast has been analyzed to attempt to determine when and where HABS occur. Dr. Hickey has been providing expertise on movement of coastal waters. A working hypothesis with three parts has emerged: a) that HABS on at least the northern half of the Washington coast may be primarily generated in the Juan de Fuca eddy; b) that during years when intense southward advection in late summer bring this eddy (or portions of the eddy) southward to the Washington coast, c) HABS are swept to the coast if (and only if) the intense southward flow is followed by a fall storm with associated currents strong enough and/or persistent enough to move the bloom across the shelf to beaches (and, in some cases, to coastal estuaries, see above). The components of this hypothesis each require further in-depth examination and analysis. A paper presenting these ideas is in preparation.

5. Time Variability of Larval Recruitment. C. Roegner, B. Hickey, A. Shanks
We have supplied coastal current data to C. Roegner to help interpret larval light trap data at Coos Bay. This collaboration will increase this year as more of our data becomes available. In particular, the analysis will be extended to include light trap data in Willapa Bay, allowing comparison between the two estuaries.

6. Data Processing. N. Banas and D. Armstrong
CTD obtained during the Dungeness Crab trawl survey in June, 1999 were processed and interpreted by our research group.

7. Zooplankton and Fish Patches Along the U.S. West Coast. G. Swartzman and B. Hickey
Physical oceanographic expertise has been provided to assist interpretation of fish and zooplankton patterns in data from the coast-wide triennial fish surveys (processed by Swartzman). This collaboration will continue and will be extended to other years following the joint GLOBEC award to these investigators.

References

Armstrong, J., D.A. Armstrong and S. Mathews. 1994. Food habits of estuarine staghorn sculpin, *Leptocottus armatus*, with focus on consumption of juvenile Dungeness crab *Cancer magister*. Fish. Bull. 93: 456-470.

Garcia-Berdial, I., B. M. Hickey and M. Kawase. Factors Controlling the orientation of the Columbia River Plume: a numerical model study. Ocean Sciences Meeting, San Antonio, January, 2000.

Gunderson, D.R., D.A. Armstrong, Y.B. Shi and R.A. McConnaughey. 1990. Patterns of estuarine use by juvenile English Sole (*Parophrys retulus*) and Dungeness crab (*Cancer Magister*). Estuarines 13 (1): 59-71.

Halliwell, Jr., G.H. and J.S. Allen. 1987. Large-scale coastal wind field along the west coast of North America, 1981-1982. J. Geophys. Res. 92 (C2): 1861-1884.

Hickey, B.M., L. Pietrafesa, D. Jay and W.C. Boicourt. 1997.

The Columbia River Plume Study: subtidal variability of the velocity and salinity fields. J. Geophys. Res., 103(C5): 10,339-10,368.

Hickey, B.M. and M. Zhang. 2000. Baroclinic coupling between an Eastern Boundary ocean and a flood plain estuary (Willapa Bay) during low riverflow, summer conditions. Submitted to J. Geophys. Res.

Iribarne, O., D.A. Armstrong and M. Fernandez. 1995. Environmental impact of intertidal juvenile Dungeness crab habitat enhancement: Effects on bivalves and crab foraging rate. J. Exp. Mar. Biol. Ecol. 192: 173-194.

Iribarne, O., M. Fernandez and D.A. Armstrong. 1994. Does space competition regulate density of juvenile Dungeness crab *Cancer magister Dana* in sheltered habitats? J. Exp. Mar. Biol. Ecol. 183: 259-271.

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:

Banas, N. and B. M. Hickey. 1999. CTD data in Grays Harbor, Willapa Bay and Coos Bay during 1997-1998. School of Oceanography, University of Washington, Special Report.

Banas, N., B. Hickey, J. Newton and E. Siegel. 1999. Physical and biological properties of banks and channels in Willapa Bay, Washington. Abstract for Ocean Sciences meeting, January, 2000, EOS, American Geophysical Union.

Garcia-Berdial, I., B. M. Hickey and M. Kawase. Factors Controlling the orientation of the Columbia River Plume: a numerical model study. Ocean Sciences Meeting, San Antonio, January, 2000.

Hickey, B. M., J. Newton, E. Siegel and N. Banas. 1999. Event scale processes in a coastal plain estuary, Willapa Bay, Washington. Abstract for Ocean Sciences meeting, January, 2000, EOS, American Geophysical Union.

Hickey, B. M. and Xuemei Zhang. 2000. Baroclinic coupling between an eastern boundary coastal ocean and a flood plain estuary during low riverflow, summer conditions. Journal of Geophysical Research. Submitted.

Newton, J., E. Siegel and B. M. Hickey. 1999. Controls on primary production in the Pacific coastal estuary Willapa Bay: oceanic versus riverine forcing. Abstract for Ocean Sciences meeting, January, 2000, EOS, American Geophysical Union.

Siegel, E., J. Newton, B. Hickey and N. Banas. 1999. Hydrographic variability and river-estuary-ocean linkages over the seasonal time scale in Willapa Bay. Abstract for Ocean Sciences meeting, January, 2000, EOS, American Geophysical Union.

Trainer, V., R. Horner, B. Hickey, N. Adams and J. Postel. 1999. Biological and physical dynamics of domoic acid production off the Washington, USA, coast. Abstract for Ninth International Conference on Harmful Algal Blooms, February, 2000, Hobart, Tasmania.

Presentations:

Barbara M. Hickey, "Water properties and currents in coastal estuaries of the Pacific Northwest." Invited Paper. Pacific Estuarine Research Society Annual Meeting, January, 1999, Hatfield Marine Center, Newport, Oregon.

Barbara Hickey, "Physical oceanography of the Pacific Northwest." Invited Presentation, JISAO, May 1999,University of Washington.

Barbara Hickey, Jan Newton, Eric Siegel and Neil Banas, "Event scale processes in a coastal plain estuary, Willapa Bay, Washington." Ocean Sciences Meeting, January, 2000., San Antonio,

Eric Siegel, Jan Newton, Barbara Hickey and Neil Banas, "Hydrographic variability and river-estuary-ocean linkages over the seasonal time scale in Willapa Bay." Ocean Sciences Meeting, January, 2000, San Antonio.

Jan Newton, Eric Siegel and Barbara M. Hickey, "Controls on primary production in the Pacific coastal estuary Willapa Bay: oceanic versus riverine forcing." Ocean Sciences Meeting, January, 2000, San Antonio.

Neil Banas, Barbara Hickey, Jan Newton and Eric Siegel, "Physical and biological properties of banks and channels in Willapa Bay, Washington." Ocean Sciences Meeting, January, 2000, San Antonio.

Barbara M. Hickey, "Oceanography of the Pacific Northwest coast and adjacent estuaries." Physical oceanography lunch seminar, February, 2000.
University of Washington.

I. Garcia-Berdial, Barbara M. Hickey and M. Kawase, "Factors Controlling the orientation of the Columbia River Plume: a numerical model study" Ocean Sciences Meeting, January, 2000, San Antonio.

Workshops:
B. Hickey attended the PNCERS "All Hands" Meeting, January, 2000, University of Washington, Seattle, Washington.

Partnerships:
GLOBEC (NSF/NOAA supported research). Dr. Hickey has been awarded two grants, one to maintain instrumented moorings off the coast near Grays Harbor, Washington and Coos Bay, Oregon for the next four years; the other (with G. Swartzman) to provide oceanographic interpretation for zooplankton and fish patches (from hydro-acoustic data all along the west coast on two triennial surveys). With GLOBEC support, data from these moorings will extend 7-15 years, allowing interannual comparison of environmental effects on the coast and in its estuaries. Data include ocean currents, temperature and salinity at a range of depths. GLOBEC moorings will also include fluorometry and optical sensors to better examine biological variability.

COOP (Coastal Ocean Program). As a member of the NSF supported COOP steering committee Dr. Hickey has represented PNCERS at two semiannual meetings this year. At these meetings, members of other groups (NSF, ONR and other NOAA programs) are kept informed of PNCERS efforts to assist in planning their own programs.

Washington Sea Grant. N. Banas (supported by Sea Grant) and B. Hickey have prepared a data report including much of the recently collected CTD data. Title "CTD data in Grays Harbor, Willapa Bay and Coos Bay during 1997-1998". Ongoing physical oceanographic studies of biologically important intertidal areas supported by Washington Sea Grant complement the channel-oriented studies undertaken by PNCERS.

National Marine Fisheries (NMFS). We are providing oceanographic interpretations to V. Trainer (NMFS) and R. Horner (UW) to help understand HABS blooms off the Washington coast. An abstract was recently submitted for a meeting in February, 2000, Tasmania and a paper is in preparation.

University of Oregon. A. Shanks has provided small boat support and lodging for our Coos Bay surveys and mooring refurbishments.

Washington State Department of Fish and Wildlife (WSDF). B. Dumbauld has provided a small boat for many of our Willapa trips to clean or refurbish sensors and collect CTD data. We have provided Dr. Dumbauld with results from recent drifter and Doppler current surveys. We have undertaken surveys in intertidal regions of Willapa Bay of particular interest to WSDF.

Department of Ecology (DOE). We have been collaborating with J. Newton in a number of analyses [see (1), (2) above and (4), (5) in the "Results" section]. In particular we have shared CTD data as well as data from moored sensors. These data are being incorporated into several papers describing biophysical interactions between Willapa Bay and the coastal ocean.

Personnel

Dr. Barbara Hickey, Professor, University of Washington
Susan Geier, Research Engineer, University of Washington
Dr. Nancy Kachel, Oceanographer, University of Washington
William Fredericks, Scientific Programmer, University of Washington
Jim Johnson, Field Engineer, University of Washington
Neil Banas, Graduate Student, University of Washington
Samuel Sublett, Diving Safety Officer, University of Washington
Dave Thorson, Oceanographer (diver), University of Washington
Jim Postel, Oceanographer, University of Washington
Christopher Moore, Oceanographer (diver), University of Washington

Plankton patches, fish schools and environmental conditions in the nearshore ocean environment..........Project 2

Gordon Swartzman

Gordon Swartzman

Introduction

In this project we meld two-frequency acoustic data collected by the National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) during summer 1995 and 1998 along the Oregon-Washington nearshore marine environment with accompanying environmental data (depth, temperature, currents) collected during the survey. The data have been processed, using image processing methods (Swartzman et al., 1999) to produce maps of fish shoals and plankton patches along a transect curtain under the survey track. These data provide a map of the fish and plankton biota of the nearshore shelf ecosystem which can be used to:

1. characterize changes in the spatial distribution of fish and plankton between a normal (1995) and an El Niño (1998) year

2. characterize the nearshore distribution of plankton as encountered by smolt salmon when they first arrive in the ocean, and to relate this to ocean survival of various salmon stocks

3. examine the proximity of fish and their plankton prey over the study region and to relate this to bathymetric and environmental features

4. relate the distribution of fish and plankton near major bird rookeries to rookery size and breeding success; and

5. attempt to generalize the spatial distribution of nearshore fish and zooplankton to other years through examining possible relationships between the them, larger-scale environmental conditions and primary production, obtained from satellite images.

Ocean current information, collected during the surveys using an acoustic doppler current profiler (ADCP), can be used to examine the spatial variability of current conditions near the mouths of major estuary systems (e.g. Willapa Bay , Gray's Harbor, Coos Bay, Yaquina Bay) to supplement mooring data, with an eye to investigating via modeling the conditions which lead to successful transport of settling larvae into the estuaries. These nearshore data provide a synthesis of information directly relevant to the feeding conditions of regionally important biota, including salmon, crab, Pacific hake, and English Sole. They also fill a gap between the dynamics of these biota and larger-scale environmental conditions.

Results & Discussion

Comparison of Fish and Plankton Distribution Between 1995 and 1998

We extracted fish schools and plankton patches from these data using image processing methods including image thresholds, differencing and morphological image processing (Swartzman et al., 1999). The plankton patch extraction methods are based on the increase in backscatter from small organisms in the ocean (e.g. euphausiids) with increasing frequency (Swartzman et al., 1999). Plankton patches and fish schools were plotted, along with bottom depth, for East-West running transects every 10 n.mi. along the coast (Figure 2.1). The transects range from 40 to 120 km in length and cover a bottom depth range between 40 and 500 m.

In general, 1995 was a year of high fish abundance, particularly in the southern part of the survey area (South of Cape Blanco, OR), while 1998 featured an extreme northward shift in abundance, with lower fish abundance in the study area. Plankton patch density was higher in 1998, an El Niño year, particularly south of Cape Blanco. We divided the transects into a shelf area (bottom depth < 250 m) and an offshore region. We examined the relative abundance, for both survey years of fish and plankton biomass both in the shelf and offshore regions (Figure 2.2 A and B). From changes in the relative abundance of fish and plankton we divided the study area into three broad regions:

1. A southern region from Cape Mendocino, California to Cape Blanco, Oregon.

2. A middle region from Cape Blanco to Cape Lookout, Oregon (45.4N latitude, just south of the Columbia River).

3. A northern region from Cape Lookout to the US-Canada border at the Straits of Juan de Fuca (48.3 N latitude).

Results from this study have been submitted for publication in proceedings of the *Lowell Wakefield Conference on Spatial Modeling and Management in Fisheries* in Anchorage, AK in October 1999 comparing fish and plankton abundance between the 1995 and 1998 surveys. Emphasis in this paper is on changes over the three regions of the survey in relative abundance and in the proximity of fish and plankton patches.

Various methods for examining proximity of patches were used to conduct this analysis (Swartzman et al., 1999). We found that on many transects large biomass schools of fish were attracted to large biomass plankton patches near the shelf break (Figure 2.1). This co-occurrence of fish and plankton near the shelf break appeared to occur when plankton abundance was higher and there were sufficient fish in the area to exploit the plankton.

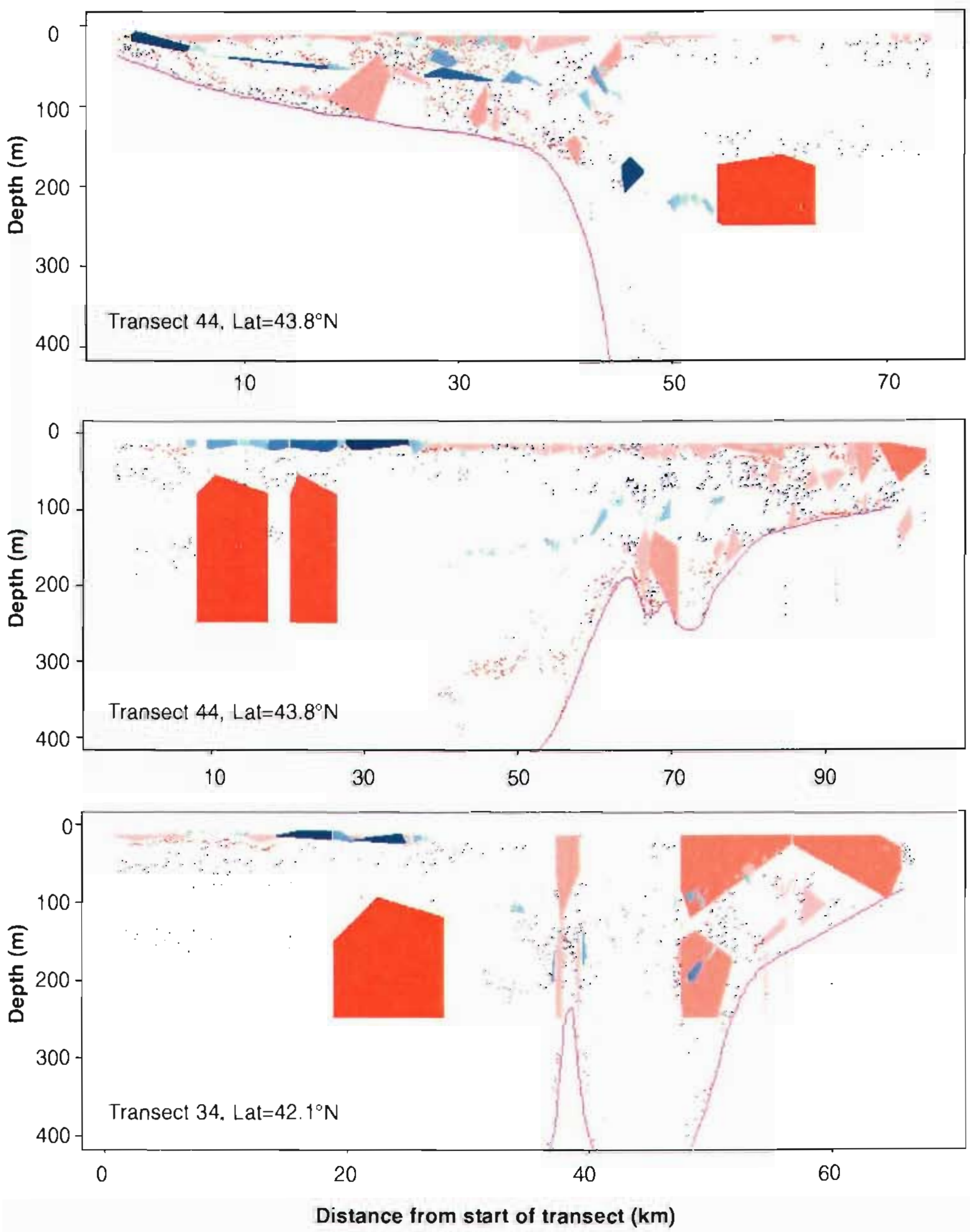


Figure 2.1. Distribution of fish schools and plankton patches for several transects in 1995. Plankton patches are in red and fish schools in blue. The intensity of color in the patch is proportional to the biomass of the patch.

Integration & Interaction

Bird-Fish and Bird-Plankton Interactions

In collaboration with Julia Parrish, we are relating the abundance and fledging success of birds on selected colonies to the plankton patch distribution in the neighborhood of the colonies. Initially, we have plotted a plan view of fish school and plankton patch biomass along the coast, for total fish and plankton and for patches and schools above the thermocline (where most piscivorous fish feeding dives are thought to be). We will use a nonparametric regression approach to model the colony size, and, if available, breeding success, as a function of available colony-specific parameters (e.g. closeness to habitation, perimeter, area) and biological parameters (e.g. index of predation or predator presence, fish biomass within 40 km of colony, median distance between fish school clusters). This will provide insight to the relative importance of physical and biological factors in influencing bird abundance. Acoustic data for 1995 and 1998 are being currently used for this, and future data acquisition of surveys in 1999, 2000 and 2001 will also be used and working with past data from 1992 and earlier (proposed).

Relating the Spatial Distribution of Fish and Plankton to Environmental Conditions

In collaboration with Barbara Hickey, we plan to develop a coast-wide picture of current flow and upwelling patterns during the summer, based on a melding of ADCP, CTD and mooring current data. We have begun examining the current velocity information and are developing a means to visualize these data along with the fish and plankton data (Figure 2.4) and to test relationships between plankton abundance and current conditions. Upwelling, cross-shelf flow and north-south flow and its change with depth are thought to strongly affect the spatial distribution and abundance of zooplankton. We will examine this relationship with an eye to developing a model of plankton abundance as a function of environmental (temperature, depth and current) conditions.

These data will also be used to:

1. develop a more general picture of the relationship between upwelling and large-scale flow patterns and plankton and fish distribution (i.e. generalize the spatial distribution of fish and plankton to other years) and;

2. model the current patterns near large estuarine systems to be used as input to models of the effect of vertical migration of larvae near the mouth of estuaries on larval transport into the estuaries. This work will be done in collaboration with Curtis Roegner (PNCERS Postdoctoral fellow) and Barbara Hickey.

Relating Salmon Survival to Nearshore Plankton Abundance During Smolt Arrival at the Ocean

Working with Ray Hilborn and graduate student Arni Magnusson we are comparing survival of salmon runs from rivers in the study area, marked with coded wire tags, with the plankton patch abundance and distribution. Our objective is to shed light on conditions that lead to successful or unsuccessful smolt survival in the nearshore ocean environment. We have extracted plankton patch data from regions near major river systems having hatcheries where the smolts were marked with coded wire tags.

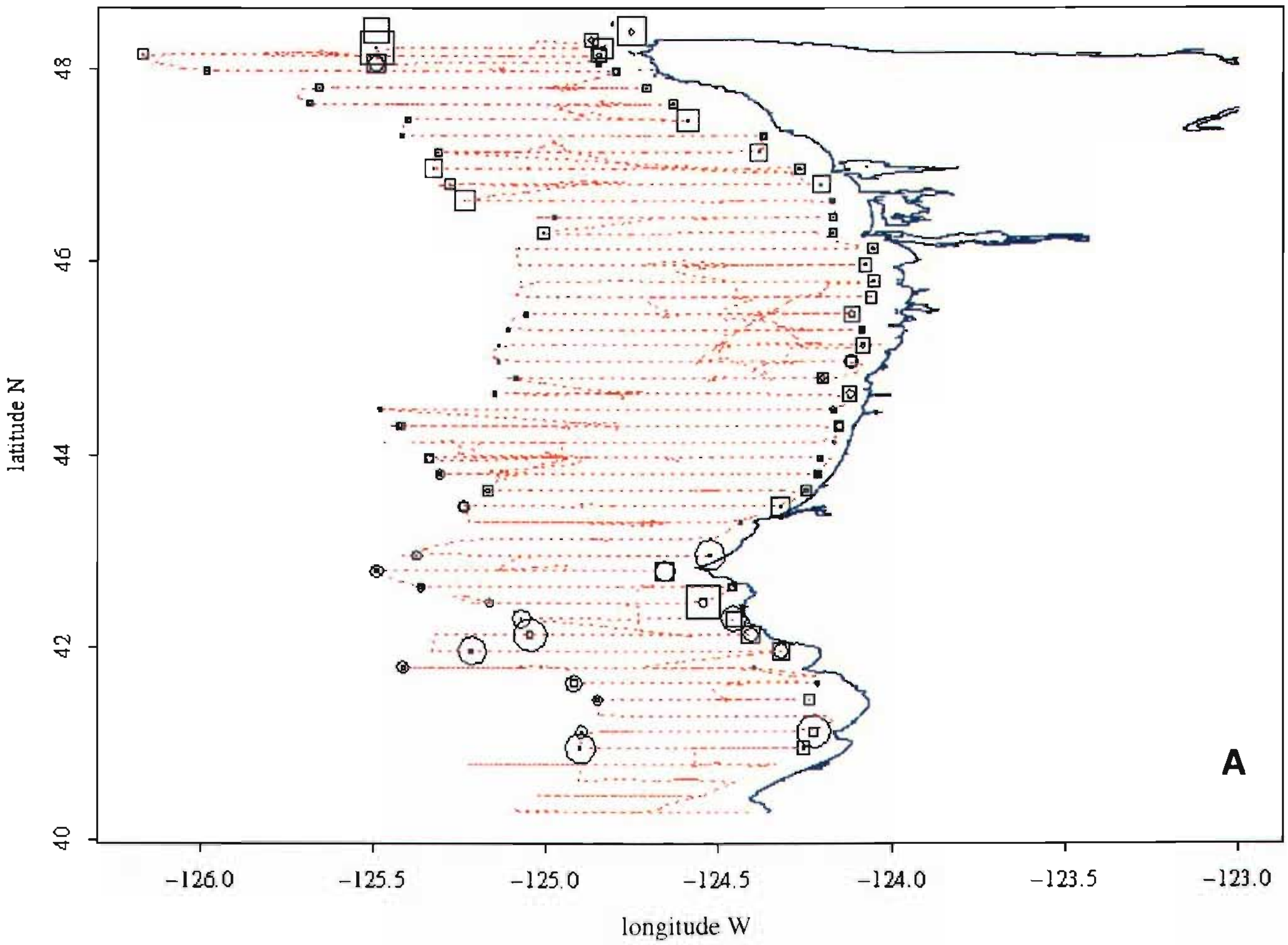


Figure 2.2. Comparison of plankton (squares) and fish (circles) biomass density for 1995 (A, above) and 1998 (B, facing page). Symbols are plotted on the land end (shelf biomass) and seaward end (offshore biomass) of each transect.

This project examines the relative importance of various large scale and local environmental and biological factors for ocean survival of salmon. It operates with the premise that the major unknown area for survival is early ocean smolt survival and therefore primarily examines factors potentially influencing this period in the salmon's life history. The factors contributed by this collaboration concern plankton patches in the near-ocean region. This includes all patches within 10 n.mi of the mouths of major river systems (those having hatcheries with coded wire tagged fish). We are looking at patches in the upper water column where salmon smolts are known to feed. Parameters extracted from the acoustic patch data include the total patch biomass (a measure of total food availability), the density of plankton patches, the median distance between patches, and the biomass distribution of patches. Parameters relative to the plankton patch density and biomass distribution are being sought through exploratory data analysis. We hope to expand our currently limited data (1995 and 1998) through addition of surveys (conducted under other projects) in 1999, 2000 and 2001. The plankton data are currently limited to 1995 and 1998, only one of these years (1995) being long enough ago that survival data are available in the coded wire tag data base. However, our major contribution may be developing and demonstrating a strategy for how to add direct biological information to more readily available physical environmental data as covariates for examining salmon ocean survival.

References

Swartzman, G, R. Brodeur, J. Napp, D. Walsh, R. Hewitt, D. Demer, G. Hunt and E. Logerwell. 1999. Relating spatial distributions of acoustically determined patches of fish and plankton: data viewing, image analysis and spatial proximity. Can. J. Fish. Aquat. Sci. 56(1):188-198.

Swartzman, G.L., R. Brodeur, J. Napp, G. Hunt, D. Demer, and R. Hewitt. 1999. Spatial proximity of age-0 walleye pollock (*Theragra chalcogramma*) to zooplankton near the Pribilof Islands, Bering Sea, Alaska. ICES Jour. Mar.

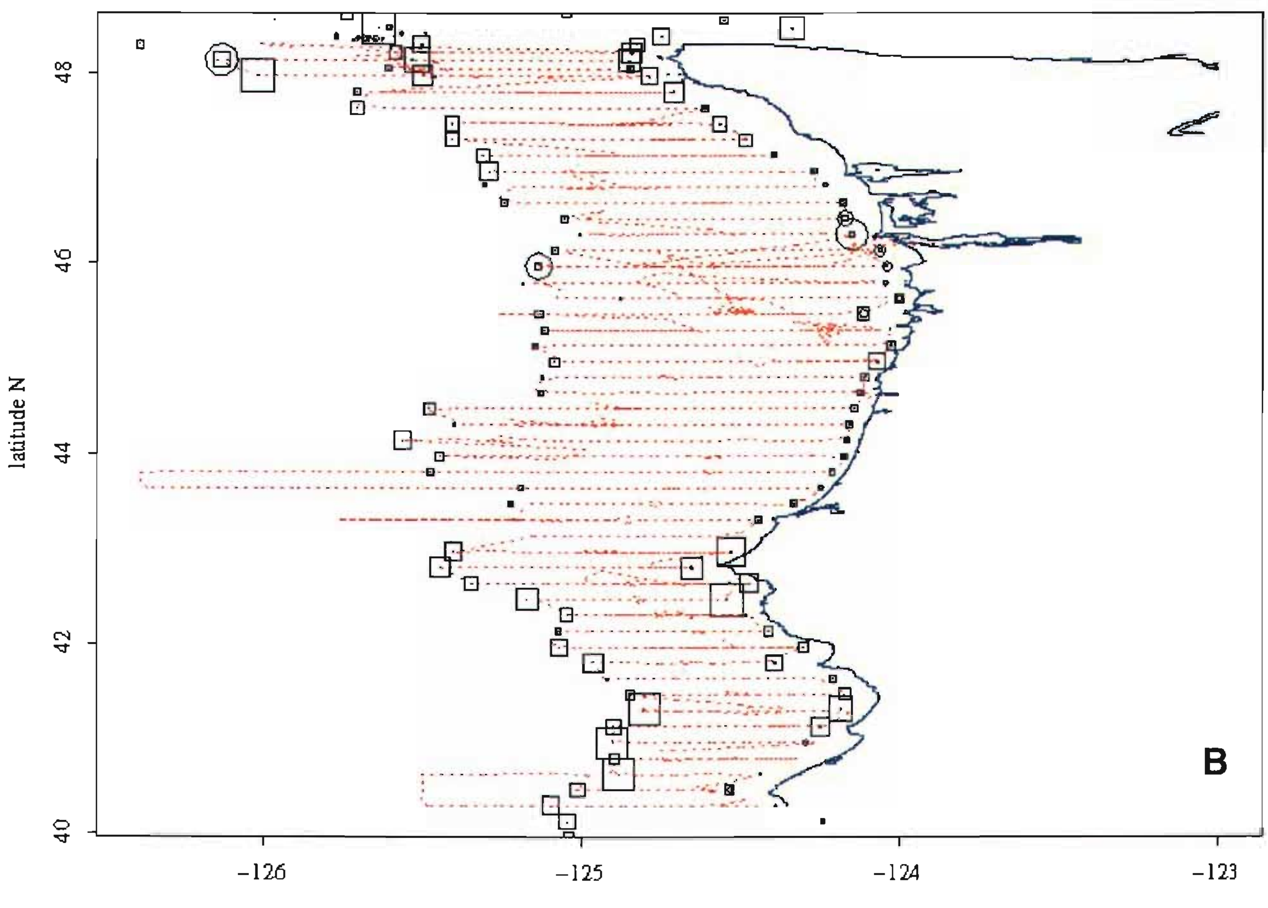


Figure 2.2, continued.

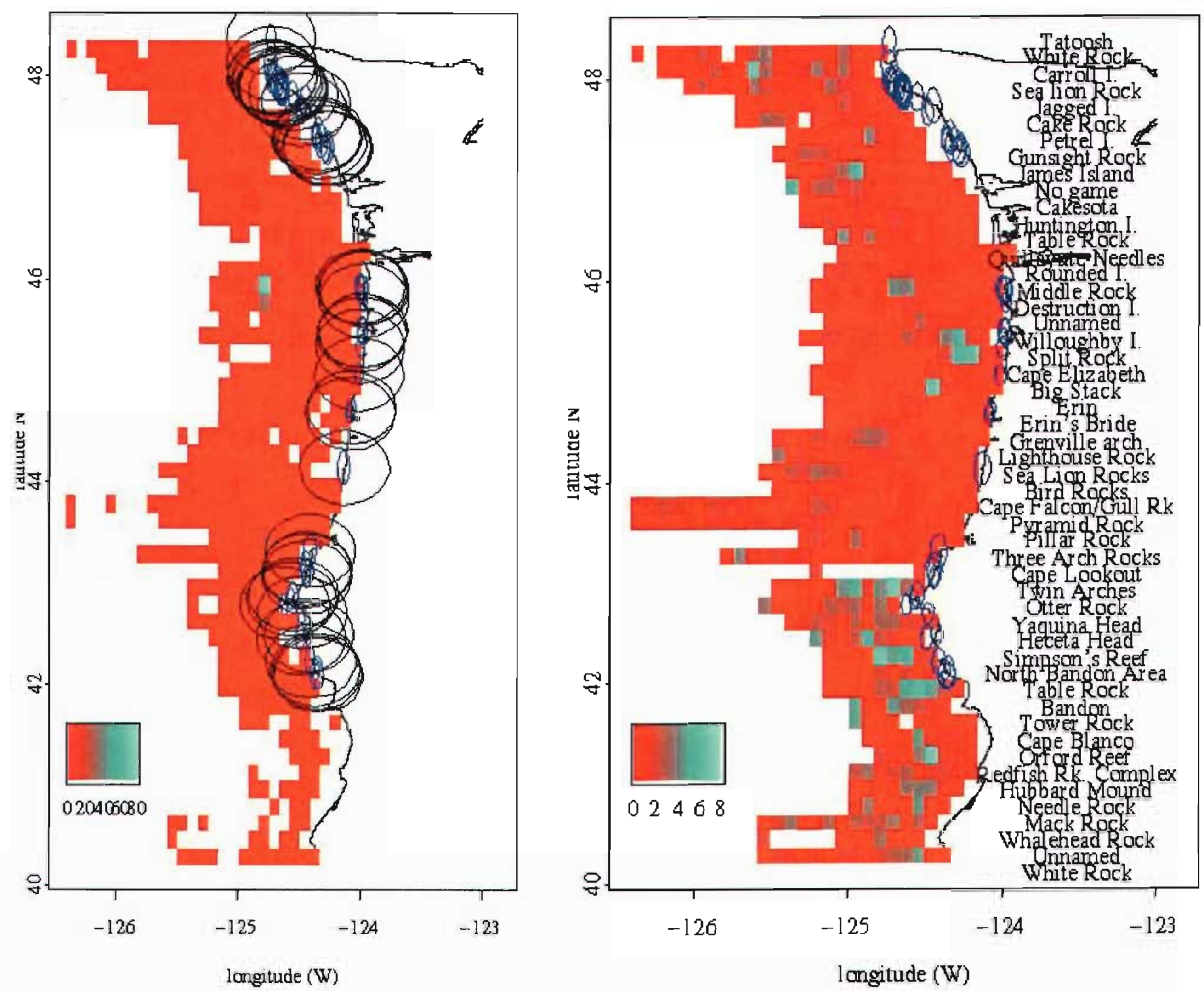


Figure 2.3. Plan view of the distribution of fish shoal biomass (left panel) and plankton patch biomass (right panel) in relation to the location of bird rookeries between Cape Mendocino and the Straits of Juan de Fuca. The left panel shows a 40 km region of foraging around each colony. The right panel names each colony (top to bottom) and shows an ellipse proportional to the population of murres at each colony.

Sci. 56:49-63.

Swartzman, G. submitted. Spatial patterns of Pacific hake (*Merluccius productus*) shoals and euphausiid patches in the California Current Ecosystem. Proceedings of *Lowell Wakefield Symposium on Spatial Modeling and Management in Fisheries*.

Applications

Publications:
None.

Presentations:

Gordon Swartzman, "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.

Gordon Swartzman, "Proximity of fish schools and plankton patches in the California Current Ecosystem" ICES working group on Fisheries Acoustics Science and Technology. April 16, 1999. St. Johns, Newfoundland.

Gordon Swartzman, "Spatial distribution of fish and plankton from an acoustic survey in summer 1995 along the California Current Ecosystem" . International Symposium on Natural Resource Modeling. June 22, 1999. Halifax, Nova

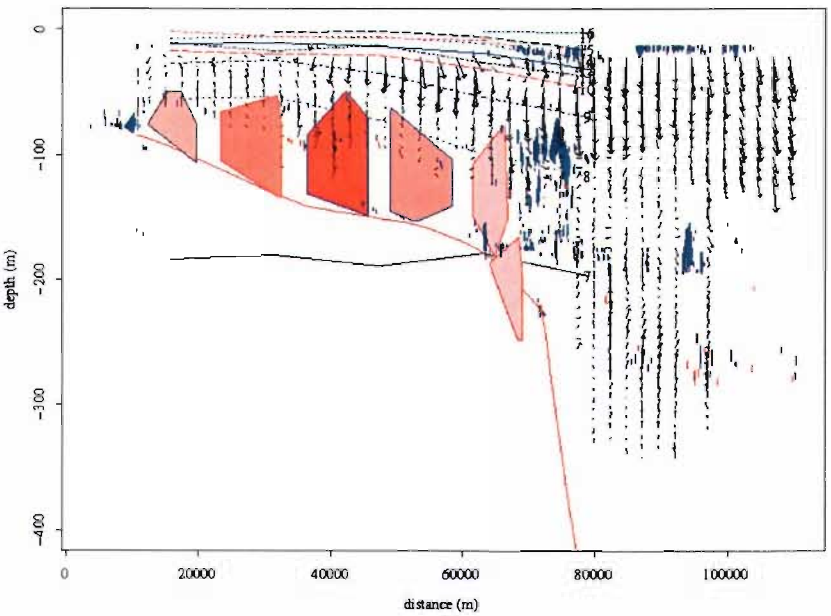


Figure 2.4. Distribution of fish schools (blue polygons) and plankton patches (red polygons) along a survey transect in 1995. The arrows denote the current velocity averaged in 5 minute bins along the transect. East and west velocities are shown by right and left respectively, while north and south are up and down on the graph. The transition with increasing depth from predominately southward to predominately northward is shown here. Also overlaid on the transect are isotherms computed from CTD data taken during the survey.

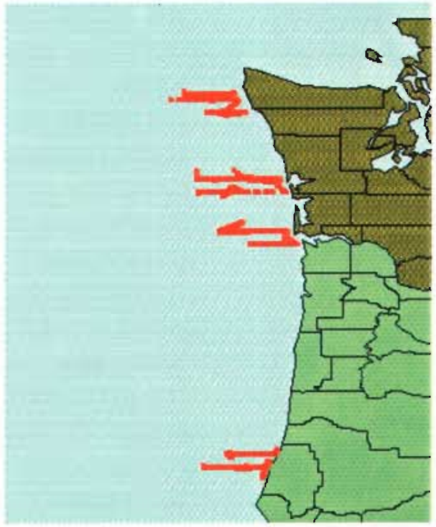


Figure 2.5. Map of coastal Washington and Oregon north of Cape Blanco showing the distribution of survey tracks and the general location of plankton patches near the mouths of major river systems where salmon smolts are likely to be feeding on first arrival in the near-ocean environment.

Scotia.

Workshops:
Gordon Swartzman attended the PNCERS All-Hands Meeting, Jan 20-21, 2000, Seattle, Washington.

Partnerships:
Chris Wilson and Steve DeBlois, NMFS AFSC Provided acoustic data for 1995 and 1998. Provided CTD data for 1995, including programs to contour and meld these data. Helped write and critique the manuscript under preparation.

Steve Pierce, Michael Kozrow, Oregon State University. Provided 1995 ADCP data in ASCII form.

Personnel

Gordon Swartzman, Research Professor, University of Washington

Seabird Indicators .... Project 3

Julia K. Parrish

Introduction


Julia Parrish

Seabirds, specifically the Common Murre, *Uria aalge*, are used in PNCERS as indicators of physical change in the coastal environment. Other studies have shown that seabird demography, specifically colony size and reproductive success, are responsive to climate and oceanographic forcing such as El Niño (Wilson 1991), changes in prey availability (Monaghan et al. 1989, Montevecchi 1993), and changes in trophic structuring as a possible consequence of regional atmospheric forcing (Aebischer et al. 1990). In general, any upper trophic level predator population exists because it is supported by the underlying trophic pyramid. Alterations in food web structure, including trophic collapse, will be reflected in upper trophic level variables. Severe change may result in a concomittant collapse of the population, as individuals starve or are forced to emigrate. Subtler changes may be reflected in a change in average annual reproductive output (as parents are forced to choose between foraging and chick provisioning) and even in diet breadth (as prey type and availability shift). In seabirds, these patterns many be exacerbated over more mobile species, because breeding restricts parents to a limited foraging environment (i.e. they can only move out of unacceptable conditions by abandoning offspring).

Why use seabirds? Many seabirds are long-lived natally philopatric species, returning to the same breeding colony year after year. Because they range widely during the off-season, measures of body condition and reproductive output are natural integrations of coastal conditions. Murres are additionally surface nesting birds, making them visually accessible from blinds, vessels, or aircraft. Censuses can be conducted remotely without disturbing the colony. Finally, murres are deep-diving piscivores, specializing on the same forage fish and euphausiid species as commercially important finfish. Diet can be easily sampled by recording the species and size of prey brought back to chicks on the colony. These features make murres an inexpensive substitute for ship-borne surveys of fish distribution, abundance, and growth (all population variable affected by environment change in space and time).

Murres are also a useful species with respect to other environmental forcing factors. Changes in predator pressure, specifically in raptor abundance, is reflected in murre colony size, attendance patterns, and reproductive success. Murres are also highly susceptible to human activities in coastal systems, including shipping and oil spills (Burger & Fry 1993), gillnet fishery bycatch (Takekawa et al. 1990, Melvin et al. 1999), and disturbance (Parrish unpub. data). In sum, murres reflect "bottom up" (i.e. climate and oceanographic), "top down" (i.e. predation), and anthropogenic forces as they alter the coastal environment. Finally, seabirds are highly visible, highly recognizable animals to the public. Because of the "charismatic megafauna" effect, using information on the factors affecting population change in seabirds to educate the public about the coastal environment and our effects on it, is a relatively easy task.

In this study, we focus on murres nesting in two colonies: Tatoosh Island, Washington and Yaquina Head, Oregon. At the former colony, we now have nine years of data on colony size and reproductive success. Oregon data collection started in 1998. Tatoosh is a relatively remote site, off limits to the public. There are no permanent inhabitants on the island. Located at the tip of Cape Flattery at the entrance to the Strait of Juan de Fuca, Tatoosh is a relatively remote site, except for its proximity to shipping lanes and fishing vessels in and around the Strait. The murre colony is small, averaging 5000-6000 birds. Yaquina Head is located immediately north of Newport, OR, a major coastal town and summer tourist resort. The seabird colony is located immediately offshore of a lighthouse and tourist facility maintained by the Bureau of Land Management. In proximity to humans, this colony is much more subject to daily human disturbance, including small vessel and aircraft disturbance. At the same time, it is relatively protected from shipping traffic and fishery effects. This colony is considerably larger than Tatoosh, averaging 20,000-23,000 birds.

During the breeding season, we collect data on patterns of colony attendance, reproductive output, sources of disturbance and mortality, and chick diet. Attendance is a census of the number of murres on the colony at any one time. Population size is then estimated by using a mutiplication factor (usually 1.67 by standard convention) to account for adults not present (foraging). Reproductive output is summarized annually in a single measure – estimated percent of pairs raising a chick to fledging age. Sources of disturbance are primarily natural – bald eagles and peregrine falcons. These predators are also the major sources of mortality. We report the estimated number of murres killed by eagles at each colony. These data are standardizations based on the actual number of kills witnessed multiplied by a time factor which accounts for the percent of total hours of observation during the portion of the season when eagles are present (Yaquina – April through June; Tatoosh – June through 20 July). Chick diet is collected by observation and is reported as percent of the total sample in each taxon category, as well as average length of fish and average foraging trip time in each year. When combined with independent data on oceanographic variables, predator presence, and human activities, these datasets begin to provide us with specifics on the degree to which murres reflect local and regional change, mediated by both human and natural forcing factors.

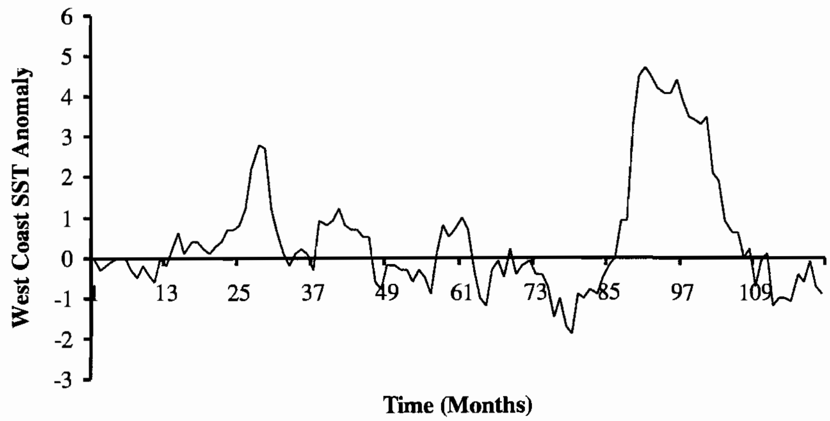


Figure 3.1. Monthly sea surface temperature anomaly calculated from the West Coast of Americas SST database (NOAA) during the 1990s.

Results & Discussion

Climate Effects

Local, regional, and global climate indices indicated that 1997-1998 were El Niño years, epitomized by warm coastal waters (Figure 3.1). For upper trophic species, this may translate into a shift in food web structure and overall prey abundance as primary productivity drops due to a subsidence of coastal upwelling. Unfortunately, there are few direct measurements of primary production, and no measurements of fish abundance to validate this suspected pattern. Seabirds would be expected to experience increased difficulty in obtaining sufficient food, perhaps leading to decreased body condition (usually weight to length ratio), smaller egg and/or clutch size, and even decreased breeding colony attendance as stressed birds abandon their reproductive effort, skip breeding altogether, or succumb to starvation. At both Tatoosh and Yaquina, colony size and breeding success was far below average annual values in 1998 (Table 3.1). In 1998, breeding was slightly delayed in both locations, and many breeders at Yaquina abandoned their eggs.

Due to the intensity of the physical signal, these population-level responses are not surprising. What is interesting is the rebound in attendance in 1999 (Figure 3.2), indicating that the birds were prob-

Table 3.1. Reproductive success (fledglings/pair) in percent of Common Murres on Tatoosh Island, WA (TI) and Yaquina Head, OR (YQ). Data from Tatoosh are reported as estimated colony-wide success and success in locations least affected by eagles, the dominant predator. Data from Yaquina are reported as success across all index plots and success in those plots least affected by eagles.

	1992	1993	1994	1995	1996	1997	1998	1999
TI	26	8	20	36	28	81	15	15
TI least	94	64	91	94	63	97	28	28
YQ							20	58
YQ least							28	72

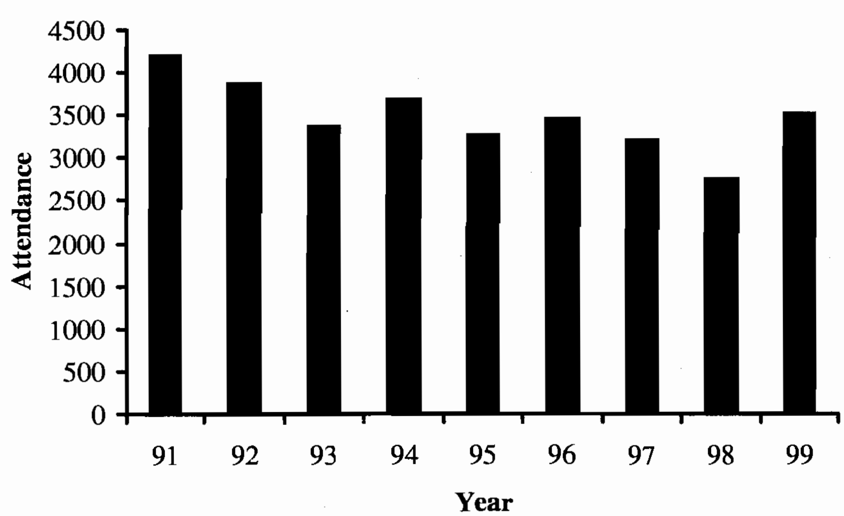


Figure 3.2. Estimated number of Common Murres attending Tatoosh Island, WA annually during the afternoon, after eggs have been laid but before chicks have begun to fledge.

ably skipping in 1998 rather than dying. Prior years data from Tatoosh shows that this dip and rebound pattern is a feature of warm water event years (eg. 1993 and 1994 Figure 3.2). In Washington, data from the coastal refuge colonies to the south of Tatoosh indicate that warm water events may precipitate dramatic change in colony size (Wilson 1991). Thus, either a change in the frequency of these events, or a more general regime may ripple up through the coastal food web, with ultimate consequences for upper trophic level populations.

Predator Effects
Both Tatoosh and Yaquina murre colonies are experiencing increasing effects of eagles (Table 3.2). On Tatoosh, where data have been collected on eagle-murre interactions for nine years, eagle pressure, measured as the first principal component score of the following three variables:

- number of eagle eyries with chicks within 25 km
- average maximum number of eagles seen simultaneously on the island
- average number of eagles flying by the observation platform each hour

has resulted in chronic reproductive depression (Table 3.2), as eagles flush murres from their eggs allowing Glaucous-winged Gulls, *Larus glaucenscens*, unimpeded access. Although eagle pressure does not appear to be depressing reproduction at Yaquina, USFWS Oregon Coastal Refuges personnel have documented repeated eagle-induced evacuation and delayed breeding at Oregon's largest murre colony – Three Arch Rocks (Lowe and Pitkin, pers. comm. to JKP). Eagle presence, the number of overflights, and the number of successful kills has also risen at the Yaquina colony (Table 3.2). Because the Yaquina colony is approximately four times the size of the Tatoosh colony, the relative effects of predators are still minor at our Oregon site. However, indications from 1998-99 Yaquina data are that this interaction, now confined mainly to a simple direct effect (i.e. mortality), may lead to more massive indirect effects (i.e. egg predator facilitation as is happening on Tatoosh) if local eagle populations continue to rise.

Table 3.2. Standardized estimate of eagle kills on Tatoosh Island, WA (TI) and Yaquina Head, OR (YQ).

	1992	1993	1994	1995	1996	1997	1998	1999
TI	24		85	71	77	30	84	121
YQ							33	83

Table 3.3. Diet of Common Murre chicks on Tatoosh Island, WA 1996-1999. All numbers are percent of total known diet items (sample size).

	1996	1997	1998	1999
Black Smelt		0.22		0.2
Cod		0.8	1.82	3.47
Eulachon	17.72	15.63	13.34	5.15
Flatfish	1.43	0.43	0.5	0.3
Hexagrammid		1.67		0.5
Larval Fish		0.51		0.59
Myctophid				1.88
Northern Ronquil			0.08	
Pacific Herring	23.63	33.72	36.37	52.08
Pacific Lamprey	0.2			
Red Brotula			0.17	
Rockfish	1.83	2.53	2.98	0.69
Salmon		0.8	1.08	7.82
Sardine	0.2		0.17	
Sculpin	0.81	0.07		
Sandlance	22.81	8.97	6.63	20.59
Smelt	0.41	1.16	4.47	
Shrimp	0.2	0.07		
Squid	0.2	1.45	0.58	1.09
Surf Smelt	30.55	30.61	31.81	5.64
Saury		0.07		
Tubesnout		1.3		
Number of Taxa	12	17	13	13
Major Taxa (>5%)	4	4	4	5
Dominant Taxa (>20%)	3	2	2	2
Mean Fish Size (MBL)	1.48	1.38	1.56	1.51
Standard Deviation	0.36	0.31	0.31	0.4
Sample Size	504	1464	1364	1070
Average Trip Time (H)	5.26	4.63	3.91	3.47

Clearly predators are an important factor structuring seabird populations. As eagles and Peregrine Falcon populations continue to rebound from depressed levels, a wide range of prey species will be effected. It is entirely possible that the coastal landscape will change as these raptors continue to depress seabird populations. Obviously, it is important to document the extent to which murre and other surface nesting species' populations are changing due to this elevated level of natural interaction, versus human-mediated effects.

Seabirds as Nearshore Predators
Just as eagles eat murres, murres eat fish. Diet studies on Tatoosh since 1996 indicate murre prefer high lipid forage fish species, including Pacific herring, surf smelt, eulachon, and sandlance. In 1999, ap-

proximately 8% of the chick diet was salmon smolts (TABLE 3.3). Both the range of species returned and average fish size appear to be fairly even among years, with the exception of 1997. In that year, murres brought back more species (17) but of lesser size. These data may indicate early effects of the El Niño altering prey abundance and distribution. Foraging rate data do not seem to echo this pattern (TABLE XX). Since 1996, the average amount of time parents are away foraging has steadily decreased from approximately 3 feeds per day in 1996 to almost 5 feeds per day in 1999. Even in 1996, the rate is comparable with other colonies, indicating that food may be plentiful around Tatoosh even in bad years.

Murres are one of the most abundant piscivorous seabirds in the Pacific Northwest. Upwards of one million murres breed along the Oregon and Washington outer coastlines, the vast majority (>950,000) in Oregon. As such, these birds can exert a tremendous effect on coastal foodwebs, both in the nearshore environment as well as in the estuary. Murres and related Alcids have been observed foraging in the large outer coast estuaries of Washington (T. Good pers. comm. to JKP) and have been caught in gillnets in these estuaries (WDFW unpub. data). Simple calculations based on foraging rates and distribution of fish species prey on Tatoosh suggest that during the breeding season, breeding murres and their chicks on the Oregon and Washington coast consume 13,000 metric tons of forage fish in a three month period.

Integration & Interaction

Seabirds as Nearshore Predators

To explore the role of murres in shaping coastal food webs, we are collaborating with two other PNCERS researchers, Gordon Swartzman and Elizabeth Logerwell, as well as with NMFS researcher Ric Brodeur. With Swartzman, we are attempting to link trends in distribution and abundance of plankton and small fish, as assessed hydroacoustically, with the numbers of seabirds nesting within a given area of the coast. This project is more fully explained in the report titled Plankton Patches, Fish Schools and Environmental Conditions in the Nearshore Ocean Environment Our contribution is to compile:

- existing colony size data for all murre colonies in Washington and Oregon
- colony location
- physical size of all island habitat suitable for nesting, whether currently housing murres or not
- predator pressure, as assessed by location of all known eagle eyries within a 20 km strip along the coast
- human pressure, as assessed by County level census data

These data will then be used to ask what types of factors might explain the unique distribution pattern of murres within the PNCERS study area.

With Logerwell and Brodeur, we are attempting to estimate the amount of food murres remove from the coastal system, using a spatially explicit bioenergetics model. Our contribution is to translate our diet and foraging rate data into usable estimates, and combine these data with estimates of total population, by area. In addition, we will attempt to estimate estuarine versus marine-derived food by conducting stable isotope analyses on fresh murre carcasses deposited by eagles. We propose to examine $^{13}C/^{12}C$ ratios because ^{13}C shows greater enrichment in inshore or benthic food webs, relative to offshore or pelagic food webs (Fry & Sherr, 1989).

References

Aebischer, N.J., Coulson, J.C., and Colebrook, J.M. (1990) Parallel long-term trends across four marine trophic levels and weather. *Nature* **347**:753-755.

Burger, A. E. and D. M. Fry 1993. Effects of oil pollution on seabirds in the northeast Pacific. The status, ecology, and conservation of marine birds of the North Pacific. K. Vermeer, K. T. Briggs, K. H. Morgan and D. Siegel-Causey. Ottawa, Canadian Wildlife Service Special Publication: 254-263.

Fry, B. and Sherr, E. 1989. $d^{13}C$ measurements as indicators of Carbon flow in marine and freshwater ecosystems *In* Stable isotopes in ecological research, pp. 196-229. Ed. by P. Rundel, J. Ehleringer, and K. Nagy. Springer-Verlag, New York.

Melvin, E, Parrish, J.K., and Conquest L. 1999. Novel tools to reduce seabird bycatch in coastal gillnet fisheries. Conserv. Biol. 13:1386-1397.

Monaghan, P., Uttley, J.D., Burns, M.D., Thane, C., and Blackwood, J. (1989) The relationship between food supply, reproductive effort and breeding success in arctic terns *Sterna paradisaea. Journal of Animal Ecology* **58**:261-274.

Montevecchi, W.A. (1993) Birds as indicators of change in marine prey stocks. In: *Birds as Monitors of Environmental Change.* R.W. Furness and J.J.D. Greenwood (eds.) New York: Chapman & Hall. pp:217-266.

Takekawa, J. E., Carter, H. R., & Harvey, T. E. 1990. Decline of the common murre in central California, 1980-1986. Studies in Avian Biology 14:149-163.

Applications

Publications:
None.

Presentations:
Julia K. Parrish, "From Fish to Birds: Circling Back on the Road to Conservation" Invited Speaker, The Hatfield Marine Science Center Distinguished Marine Scientist Colloquia, October 1999, Newport, Oregon.

Workshops:
Julia Parrish attended the PNCERS All-Hands Meeting, January 20-21, 2000, Seattle Washington.

Partnerships:
Bureau of Land Management Yaquina Head Outstanding Natural Area. Allowed us access to the Yaquina Head Lighthouse as our primary Oregon field site.

Environmental Protection Agency Laboratory in Newport, Oregon. Provided us with office space and computer facilities during our summer field season.

The Makah Tribe and the U. S. Coast Guard. Allowed us access to Tatoosh Island as our primary Washington field site.

The Olympic Coast National Marine Sanctuary. Provided us with field accommodations and computer and phone facilities in Neah Bay, Washington.

Washington Sea Grant. Provided concurrent funding to work on Common Murres in Washington and Oregon relative to fishery management issues.

Personnel

Julia K. Parrish, Research Assistant Professor, University of Washington
Sara Breslow, Technician, University of Washington
Nathalie Hamel, Technician, University of Washington
Jill Pettinger, Hourly Employee, University of California - Santa Cruz
Amy VanBuren, Undergraduate Student, University of Washington

Salmon Survival: Natural and Anthropogenic Impacts ....Project 4

Ray Hilborn and Arni Magnusson

Ray Hilborn

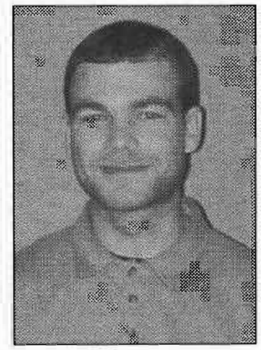
Introduction

The coded-wire-tag (CWT) data provide insight into hatchery-reared juvenile salmon survival to adulthood (Coronado 1995, Coronado and Hilborn 1998). We can safely assume that the survival rate of a CWT release group is affected by physical and biological conditions of the river, estuary and oceanic areas that they pass through before the survivors are recovered. The objective of this study is to define the variables that describe those conditions and assess their significance in affecting survival rate.

The assessment will be approached with a regression framework, using generalized linear models (GLM) and/or generalized additive models (GAM). The response variable will be survival rate, but the predictor variables will be derived from various data sources regarding physical attributes and human activities that may affect salmon survival. Hence, the study not only benefits from, but depends on integration with other studies, PNCERS or otherwise. The main restriction is that results from other studies must be able to be extrapolated over both Washington and Oregon areas. So far, connections have been made with two ongoing PNCERS studies: Gordon Swartzman's zooplankton surveys (see "Integration" section below) and Julia Parrish's seabird research (see same section).

Results & Discussion

In the 1999 research year an Access CWT database was reconstructed from data downloaded from Pacific States Marine Fisheries Commission in Portland. Numerous anomalies were clarified and filters were defined to extract the CWT release groups considered suitable for survival rate estimation. The resulting dataset (described in Table 4.1) consists of 16,638 chinook and coho tag code groups, their corresponding survival rate estimates, and various information about their release and recoveries.



Arni Magnusson

A useful way to explore temporal and spatial trends in the survival rate distribution is to stratify the CWT groups by referring to geographical attributes of the releasing hatchery. This can reveal large-scale spatial trends when the stratification is based on states/provinces, or small-scale spatial trends when based on sectors or basins. With 222 U.S/Canadian hatcheries, each with its combination of geographic attributes, there is a multitude of ways to stratify the CWT groups geographically. A comprehensive overview of the observed survival rate distribution for fall chinook, spring chinook and coho would require more space than is available here. Instead, the examples below are selected to illuminate some of the traps lurking in the survival rate data, as well as tricks for dealing with them.

Yanking Trap / Strata Trick

The average survival rate of coho CWT groups released in Washington form an interesting time series pattern when overlaid with the survival rates from Alaska, as seen in Figure 4.1. From around 1980 onward, there seems to be a dynamic negative relationship which might give rise to lofty speculations about the reasons behind it. But it's a trap, the yanking kind. Once the geographical substrata of Washington have been revealed (Figure 4.2), it becomes clear that the bumpy pattern of that state's average around 1980 was not due to great fluctuations within substrata. The average survival rate in 1980–1982 was yanked down by a sudden fivefold increase in the number of CWT groups released from the Columbia River in Washington, which brought the Washington average close to the low survival rate level of Columbia.

Brood Trap / Release Trick

Again, a negative correlation catches the eye when looking at fall chinook and coho survival rates in Columbia River in Oregon during the mid 1980s (Figure 4.3). What was it with brood year 1984, for example, that made fall chinook fare so

Table 4.1. Overview of the 16638 chinook and coho CWT groups used in this study. Other non-experimental CWT groups were filtered out on the basis of species, group size and brood year.

	Hatcheries	CWT Groups	Avg Grp Size	Brood Yrs	Avg Survival	Median Survival
Fall chinook	138	7116	38355	1971–1992	0.82%	0.33%
Spring chinook	60	2554	30836	1971–1991	1.06%	0.33%
Coho	146	6968	18938	1970–1993	1.86%	0.90%

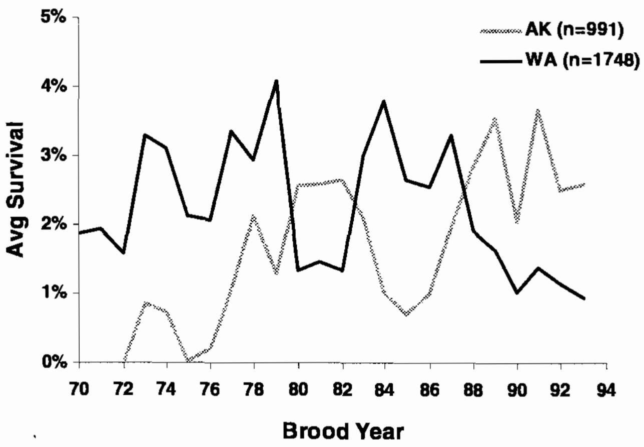


Figure 4.1. Survival rate estimates of coho released from Alaska and Washington states, plotted against brood years. Inside the brackets is the total number of tag code groups used in calculating the respective averages.

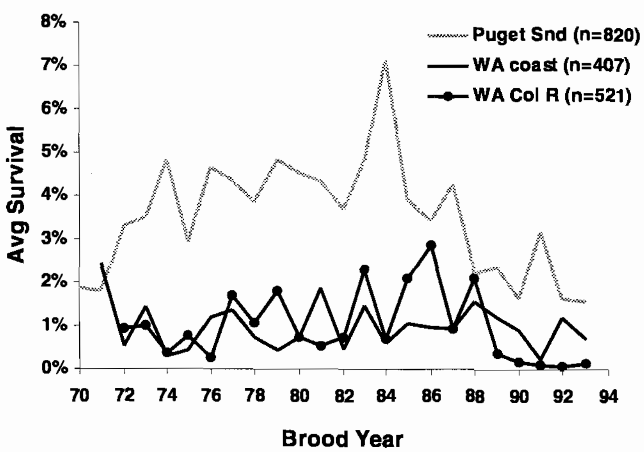


Figure 4.2. Survival rate estimates of coho released from Washington, plotted against brood years. Stratified by Puget Sound, Washington coast and Columbia River in Washington. Inside the brackets is the total number of tag code groups used in calculating the respective averages.

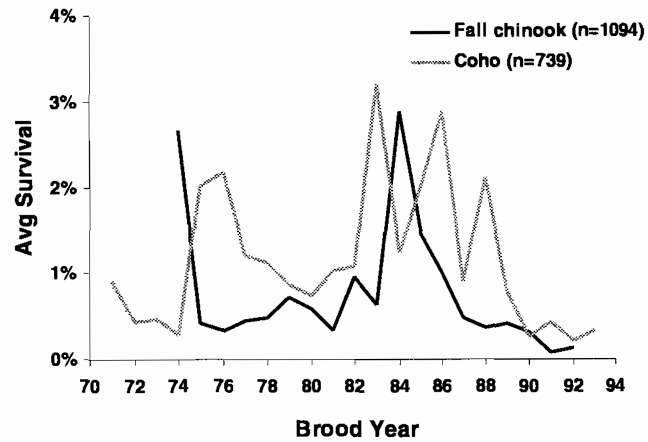


Figure 4.3. Survival rate estimates of fall chinook and coho released from Columbia River in Oregon, plotted against brood years. Inside the brackets is the total number of tag code groups used in calculating the respective averages.

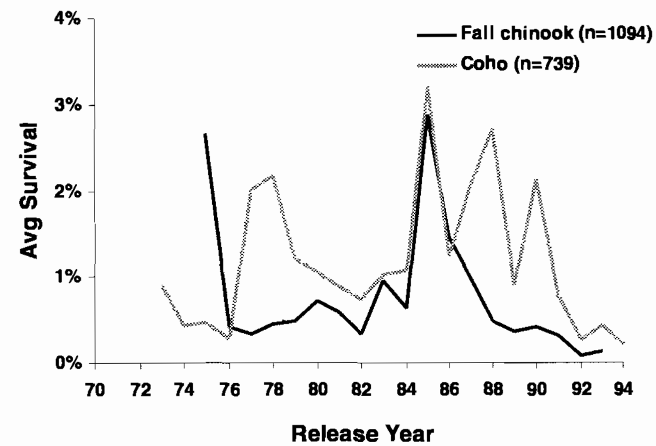


Figure 4.4. Survival rate estimates of fall chinook and coho released from Columbia River in Oregon, plotted against release year. Inside the brackets is the total number of tag code groups used in calculating the respective averages.

well and coho so badly at the same time? The picture becomes clearer when the survival rates are plotted against release year (Figure 4.4), since most of these coho CWT groups were released at age 2 while the fall chinook smolts were released at age 1. Smolts released into the Columbia River in Oregon in 1985 seem to have had a greater probability, on average, of surviving to adulthood than smolts released in 1984 or 1986. This observed trend is based on 76 CWT groups of two different salmonid species released in 1985 from 15 different hatcheries.

Modelling Consistent Trends

This high survival rate anomaly of 1985 shows up again in Figure 4.5, for coho released into Coos Bay (OR) and Willapa Bay (WA). Not only are the hatcheries different now, but these CWT groups were released into different watersheds. This might imply that the reasons behind the high survival rates of release year 1985 lie not in river or estuary habitat, but in the ocean. It is well possible, though, that the Northwest freshwater habitats were all affected by some environmental phenomenon, such as the timing of snow melting or the amount of rainfall. In the worst-case scenario, the survival rates of salmon released in 1985 were affected by some violations of the survival rate estimation. An example of this would be a sudden increase in recovery effort, either by the commercial fishing fleet or stream surveyors.

The year 1985 will play no special role in the data analysis;

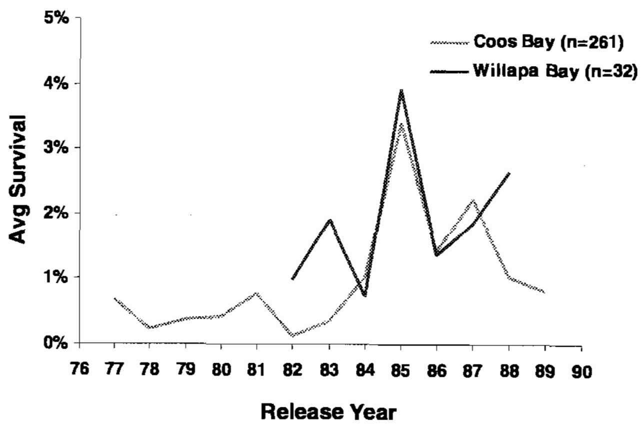


Figure 4.5. Survival rate estimates of coho released from Coos Bay (OR) and Willapa Bay (WA), plotted against release year. Inside the brackets is the total number of tag code groups used in calculating the respective averages.

this particular observation is only used as an example that touches on many important aspects of the modelling effort. Although not yet fully defined, it is clear that the planned regression is not modelling for the sake of modelling. It is very hard to describe any general trends in the data without modelling, although exploring is a vital part of any data analysis. Part of the difficulty is the sheer scope of the dataset, but so is the varying geographic resolution where trends appear and disappear by changing the "zoom level". Finally, it is possible that the data will be stratified by smaller temporal units than a year, e.g. quarters, to dampen the knife-edge importance of New Year's Day in the data analysis.

Even if the CWT data are somewhat slippery regarding the number of anomalies in the database and the assumptions on which the analysis rests, it is very clear that they carry an enormous amount of ecological information about natural and anthropogenic impacts on salmon survival. The key unit in the regression framework will be the tag code, which stands for a group of identically tagged salmon. Each tag code is a datapoint, with one survival rate estimate and many separate predictor variables, both numerical and categorical. Most of the predictor variables will be the results of other separate studies, involving research integration.

Integration & Interaction

Some collaboration has already started with four UW researchers, three of which are also PNCERS researchers: Gordon Swartzman, Julia Parrish and Elizabeth Logerwell. The fourth one is Steven Hare at IPHC, who supplied a sea surface temperature (SST) database in Access. Most likely, two separate variables will be derived from the SST data to be included as predictor variables in the regression. One would describe the SST around the respective estuary at the relevant time for that CWT group, while the other would be a more broad description of the North Pacific sea surface temperature during the CWT group's oceanic life stage.

Two variables are being extracted from Gordon Swartzman's zooplankton data, one describing the overall zooplankton abundance close to the corresponding estuary, and another based on the distances between plankton patches. Either or both of those predictors might be significant in explaining the variability of salmon survival rates in a regression framework. The problem is how recently the zooplankton data became available as a by-product from acoustic surveys off the West Coast. Only one year of zooplankton data, 1995, will be useful in the CWT data analysis. The next year in that dataset is 1998, which is too recent a release year for survival rate estimation. Nonetheless, even the single year of zooplankton data can be statistically useful, for instance in fitting the 1995 residuals of the otherwise final CWT regression model.

Salmon smolts are known to be preyed upon by common murres, which implies a negative correlation between survival rate and murre abundance close to the corresponding estuary. With rough extrapolation from Julia Parrish's seabird data, the murre abundance can be estimated as ca. 100 times higher in Oregon than it is in Washington. The exact proportional difference between the abundance in the two states is not critical for the regression, but it needs some more contrast, either in time or space, in order not to be redundant with the categorical variable *state*. Moreover, there have been a couple of meetings with Elizabeth Logerwell. Some research integration is very likely, but details have yet to be looked into.

A loose connection has been made between the CWT database and an ArcView project, copying tables to the latter and creating a point layer of estuary locations. GIS may become a useful angle from which the CWT dataset can be explored with an important geographical overview, which is not offered by the scatterplot format.

References

Coronado, C. 1995. Spatial and Temporal Factors Affecting Survival of Hatchery-Reared Chinook, Coho and Steelhead in the Pacific Northwest. Ph.D. Dissertation University of Washington. 235 p.

Coronado, C. and R. Hilborn. 1998. Spatial and temporal factors affecting survival in coho salmon (*Oncorhynchus kisutch*) in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 55: 2067-2077.

Applications

Publications:
None.

Presentations:
Arni Magnusson, "Coded-wire-tag analysis of chinook and coho survival rates in the Northwest." SOF Graduate Student Symposium, November 1999, University of Washington.

Arni Magnusson, "Coded-wire-tag analysis of Chinook and coho survival rates in the Northwest." PNCERS Eat and Learn Seminar, February 3, 2000, University of Washington.

Workshops:
Arni Magnusson attended the PNCERS All-Hands Meeting, January 20-21, 2000, Seattle, Washington.

Partnerships:
Gordon Swartzman, PNCERS
Elizabeth Logerwell, PNCERS
Julia Parrish, PNCERS
Steven Hare, IPHC

Personnel

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

Links Between Estuaries: Larval Transport and Recruitment ....Project 5

Curtis Roegner, Alan Shanks, and David Armstrong

Introduction

The population dynamics of many estuarine and coastal invertebrates varies with factors affecting the critical larval stage. In the absence of immigration, larval supply to benthic habitats sets the upper bound of recruitment. In the Pacific NW, many of the important estuarine and coastal species have pelagic larvae that spend weeks to months in the ocean before returning shoreward and metamorphosing to the benthic juvenile form. The patterns and mechanisms of dispersal in the Pacific Northwest coastal ecosystem are largely unknown. Most larvae cannot swim effectively against the horizontal currents found in the ocean, and so are not likely to propel themselves back to the coast, but they are capable of extensive vertical migrations. We therefore hypothesize that dispersal and recruitment to settlement habitats are determined by behavioral factors coupled to oceanographic processes. This project seeks to measure the patterns of larval dispersal to understand the factors and

Curtis Roegner and Alan Shanks

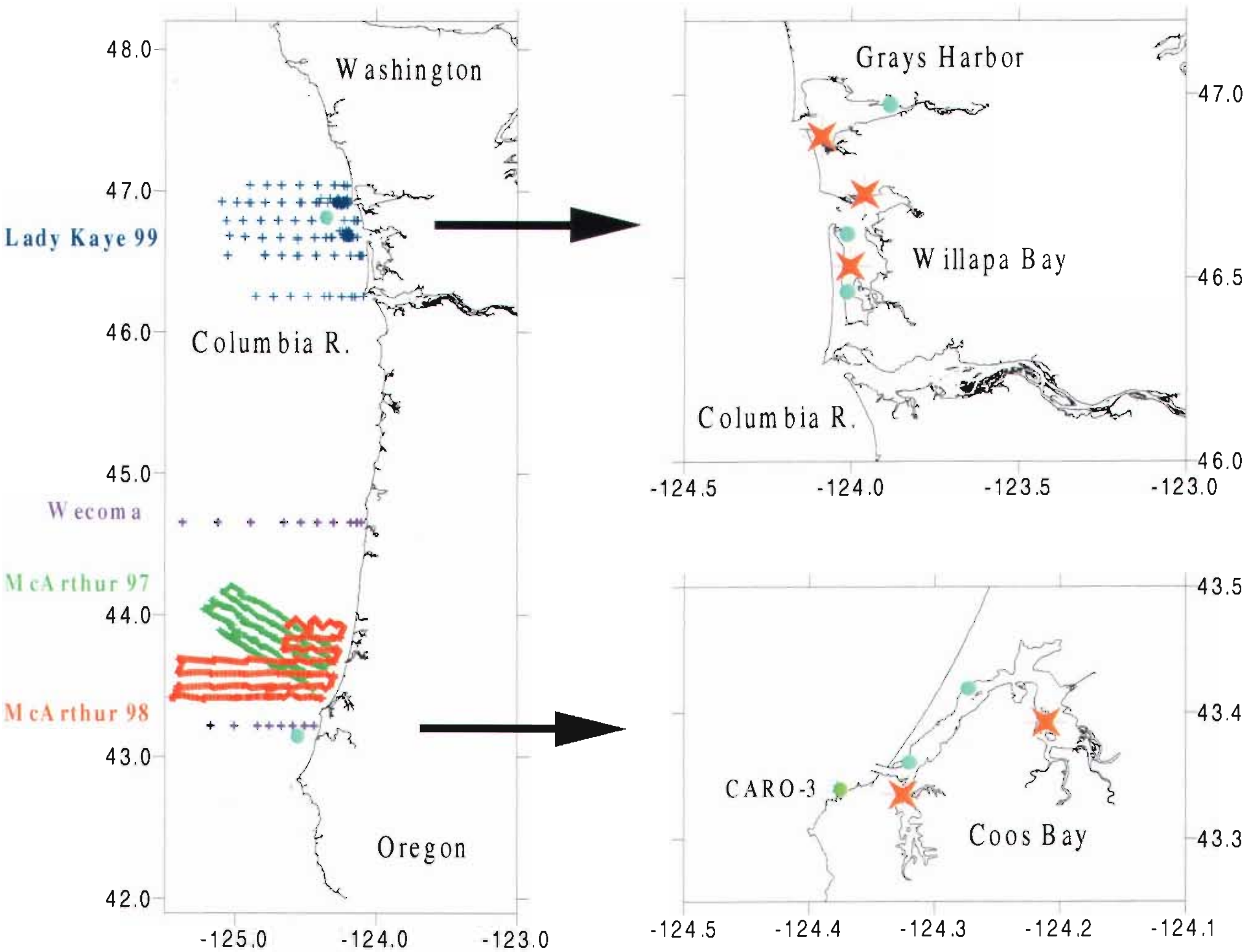


Figure 5.1. Cruise tracks and mooring sites for the larval recruitment studies. A. PNCE region showing cruise tracks for *McArthur* 1997 and 1998, the *Wecoma* NH (off Newport) and FM (off Coos Bay) transect lines, and the *Lady Kaye* 1999 cruise track. *Olympia* sampling is not shown. B. Grays Harbor and Willapa Bay. C. Coos Bay. Orange stars are the positions of light traps; blue circles designate PNCERS oceanographic moorings; green rayed circle is the CARO C-MAN station.

processes underlying recruitment variation to PNW estuaries.

We are investigating several interrelated questions:

- What is the distribution and patch size of larvae in the coastal ocean?
- What is the temporal (seasonal, interannual) and spatial (within and between estuaries) variation in the supply of larvae to estuarine sites?
- What are the physical processes that correlate to larval abundance?
- What behavioral factors facilitate dispersal and transport?

We are measuring larval abundance in two ways: 1) daily time series from fixed estuarine stations using light traps, and 2) surveys of the coastal ocean during oceanographic cruises. The abundance data is being related to physical data sets acquired from ship-borne and moored oceanographic instruments. Although many taxa have been collected in the samples, we are concentrating our analysis on brachyuran crabs. This study is fulfilling a major component of the Crab Impact Hypothesis (outlined in the PNCERS 1998 Annual Report): namely, that larval supply influences crab production.

Results & Discussion

Light Traps

The light trap deployments have continued to provide insight into the recruitment dynamics of brachyuran crabs. In Coos Bay, we now have a continuous record of over 2 years from the Charleston site (Figure 5.1), with additional sampling between March and July at the up-estuary site. In 1999 we expanded the light trap deployments to sites in Grays Harbor and Willapa Bay, in ad-

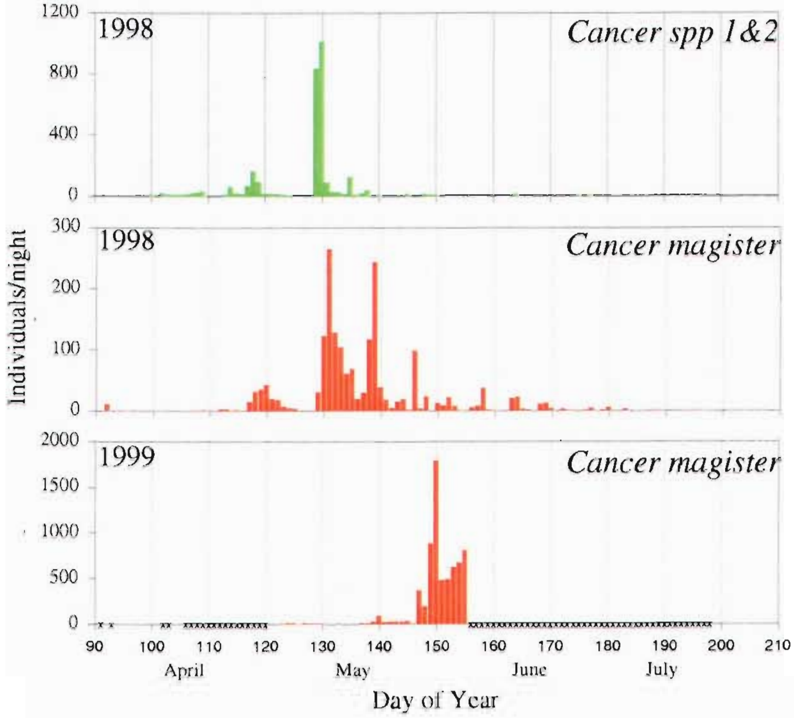


Figure 5.2. Time series of megalopae abundance from the Charleston light trap site in Coos Bay during 1998 (A and B) and 1999 (C). "x" = sample not counted.

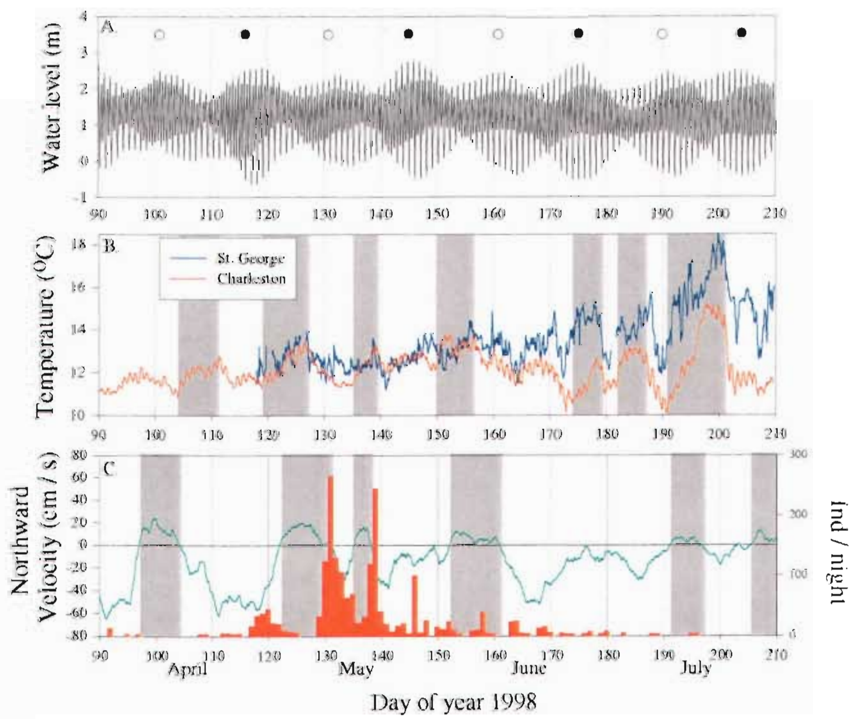


Figure 5.3. Time series of data of A., water level at Charleston and phase of moon; B., temperature at the Charleston coast guard station (red line) and St. George NOAA buoy (blue line); and C., near surface velocity from the Coos mooring site (line) and *Cancer magister* abundance (Individuals/night). In B., shaded areas designate warming periods. In C., shaded areas indicate periods of northward velocity.

dition to the up-estuary site maintained by Brett Dumbauld in Willapa Bay. The new deployments were located near the estuarine mouths, and were sampled from March to July. We now have samples that encompass 2 recruitment seasons for sites in Coos Bay and Willapa Bay. In addition, the five light trap sites were sampled coincidently between March and July 1999, during the primary Cancer crab recruitment period. When analyzed, these data will allow both regional and within-estuary patterns of recruitment to be investigated.

We are presently counting the many light trap samples, but some preliminary conclusions can be made from the data sorted to date (from the Charleston site). We are observing both species-specific and interannual variation in recruitment patterns, as illustrated by the example in Figure 5.2. Preliminary observations indicate: 1) Larval abundance is pulsed, and is often episodic. For example, annual recruitment of *Cancer* spp (*C. oregonensis* + *productus*) was confined to a 2 day window in 1998. In contrast, *C. magister* recruited over a broader period composed of 4 to 7 day periods of enhanced abundance. 2) There is interannual variation in the timing of recruitment pulses, as shown for *C. magister* in 1998 and 1999 in Figure 5.2 (although this preliminary conclusion is based upon partially completed time series). We have also discovered that, while the majority of *C. magister* megalopae recruit between April and June, several small pulses of megalopae were sampled as late as November. We do not at present know the significance of these late arriving megalopae. 3) Interestingly, the light trap time series indicate that grapsid crabs recruit predominantly in the winter, when seasonal wind patterns generate downwelling conditions. Cancer species recruitment occurs after the spring transition to upwelling conditions. Megalopae of *Pachygrapsus crassipes* are similar in size and swimming ability to *Cancer magister* megalopae, and so contrasting these patterns of abundance in relation to the seasonal variation in oceanography will be informative.

In collaboration with Barbara Hickey, we are beginning to assemble the physical oceanographic and biological time series we will use to investigate dispersal and transport processes. An example is illustrated in Figure 3, which compares time series of water level at Charleston (Figure 5.3a), temperature from Charleston and an offshore NOAA buoy (Figure 5.3b), horizontal velocity from the PNCERS ocean mooring off Coos Bay (Figure 5.3c, line), and *C. magister* abundance (Figure 5.3c, bars). The full dataset will include physical measurements of salinity, temperature and velocity from estuarine and ocean moorings, water level from tide stations, and wind and SST recordings from weather stations. The data to date indicate: 1) no strong relation with tidal period; 2) coincident temperature variations between estuary and nearshore suggesting a synoptic regional forcing; 3) occasional reversals in the mean southward surface current; and 4) pulsed *Cancer magister* abundance. Note the two largest recruitment events are associated with temperature increases in the estuary and current reversals offshore, which may indicate an advective event. These relationships will be more fully investigated this coming year.

Cruises

Previous cruises on board *McArthur* and *Wecoma* revealed information on larval patch size and distribution. We continued participation on the GLOBEC surveys in 1999 (cruises W9902 and W9904); samples consisted of neuston and subsurface Bongo net tows and CTD casts. Data from these cruises are clarifying the cross-shelf dispersal of meroplankton during different seasons, and in addition we now can compare the physical oceanography and plankton abundance and composition during El Niño (1998) and La Niña (1999) conditions. We have processed most of the 1998 samples, and found crab larvae to be widely distributed in the coastal ocean (including off the shelf) during both night and day periods (data not shown).

In May, we undertook a 10 day cruise off the coast of Grays Harbor and Willapa Bay on the trawler *Lady Kay*. We sampled a grid of cross-shelf transects, once at the beginning and again after 4 days (Figure 5.1). Fortuitously, this period captured the transition from downwelling to upwelling conditions, and we observed the initiation of a dense phytoplankton bloom. Figure 5.4 shows the first series of transects during downwelling conditions. Note the relatively flat position of the 10 and 11 °C isotherms and the low abundance of chlorophyll (time sequence goes from A to E). Just 3 days later, strong upwelling resulted in a peak algal biomass >10 mg/m^3 (Figure 5.5). Note how the 11 °C isotherm progresses offshore with time (sequence goes J to F), and that the algal bloom is concentrated between 20 and 40 km offshore. We also observed strong gradients of meroplankton abundance in relation to these oceanographic variations. This pulse of chlorophyll, and any associated meroplankton, would be expected to propagate shoreward during wind relaxation where it may then be advected into the estuary. Note that the light traps at all 5 estuarine sites were in operation during the cruise, and we will be looking closely at the relation among offshore plankton abundance, light trap time series, and physical oceanographic processes during this period.

Integration & Interaction

The light trap data is revealing that the supply of larvae to estuaries does vary both within and among years. We also have additional information revealing the patchy nature of the offshore larval distributions. It now seems clear that much of the light trap variability is due to variation in transport of patches from offshore sites to estuarine mouths, at which point

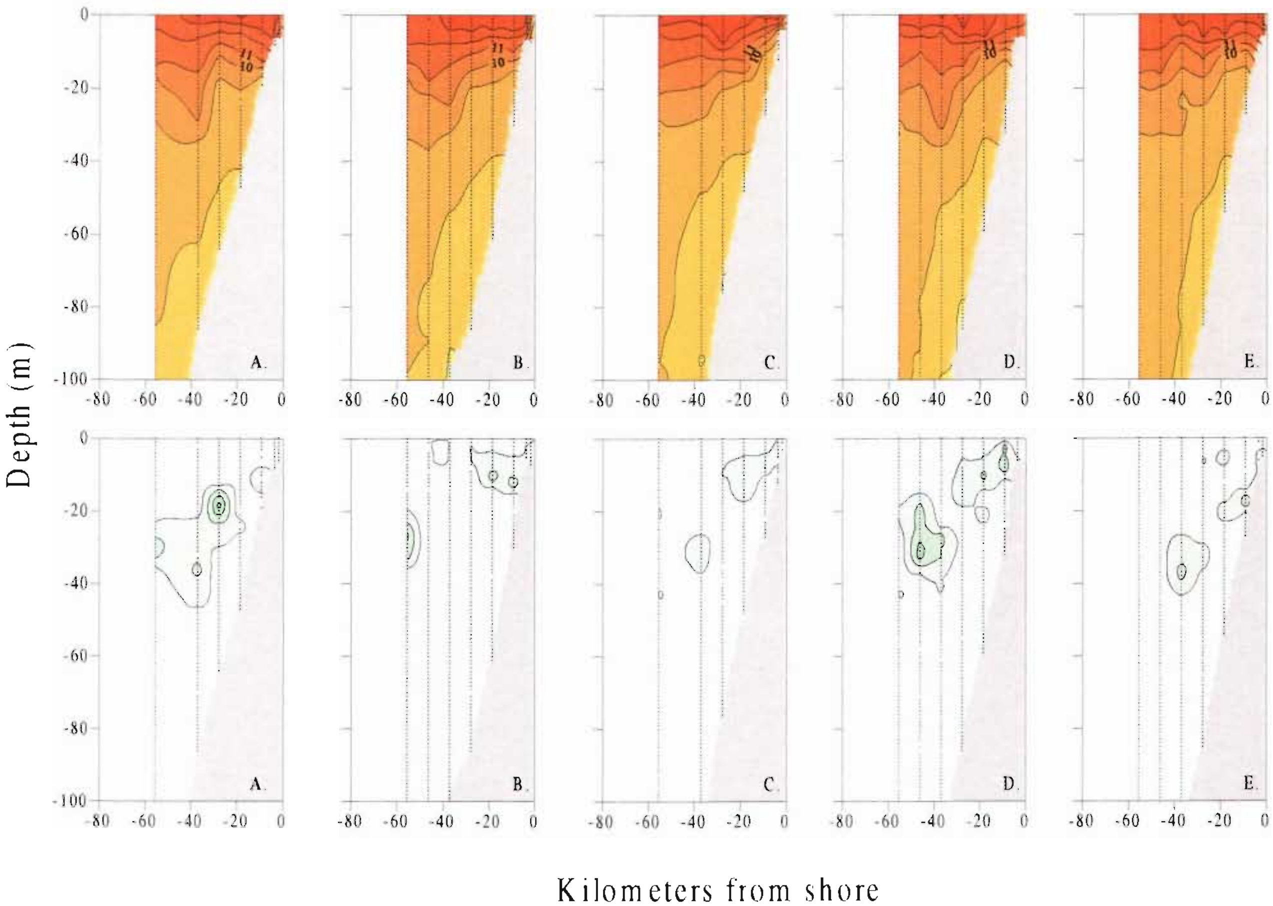


Figure 5.4. Cross-shelf transects of temperature (upper row) and chlorophyll a (lower row) during downwelling conditions. Transects were made in the order A to E (north to south). Isotherms are 1 °C intervals; chlorophyll isopleths ate 1 mg/m³; gray areas indicate the bottom.

larvae can gain access to estuarine habitats. Since transport is dependent largely on physical oceanographic events, the integration of light trap time series with advective events determined from the mooring data may yield the mechanism(s) influencing recruitment variation.

The following specific integrations are currently planned or under way:

1. In collaboration with Barbara Hickey and Jan Newton, we are collating the chlorophyll and coastal oceanography signal from the *Lady Kay* cruise with time series from the ocean and estuarine moorings in Willapa Bay. This project will evaluate the nearshore-estuarine linkage for estuarine primary production. Data analysis is presently underway.

2. Our long-term collaboration with Barbara Hickey's group continues. At present, we are assembling the physical time series with light trap time series to determine if the patterns of larval abundance can be related to advective events at the Coos Bay site. As sample processing continues, we will extend the analysis to the Washington estuaries.

3. Further oceanographic cruises on *Wecoma* and *McArthur* are planned to examine the vertical distribution of larvae.

4. Using the crab abundance data from David Armstrong, Don Gunderson, and Chris Rooper, we hope to evaluate how annual recruitment variation affects estuarine crab production levels.

5. In collaboration with Gordon Swartzman, we propose to model larval vertical swimming behavior in relation to vertical velocity shear to examine the boundaries of larval dispersal.

Applications

Publications:
None.

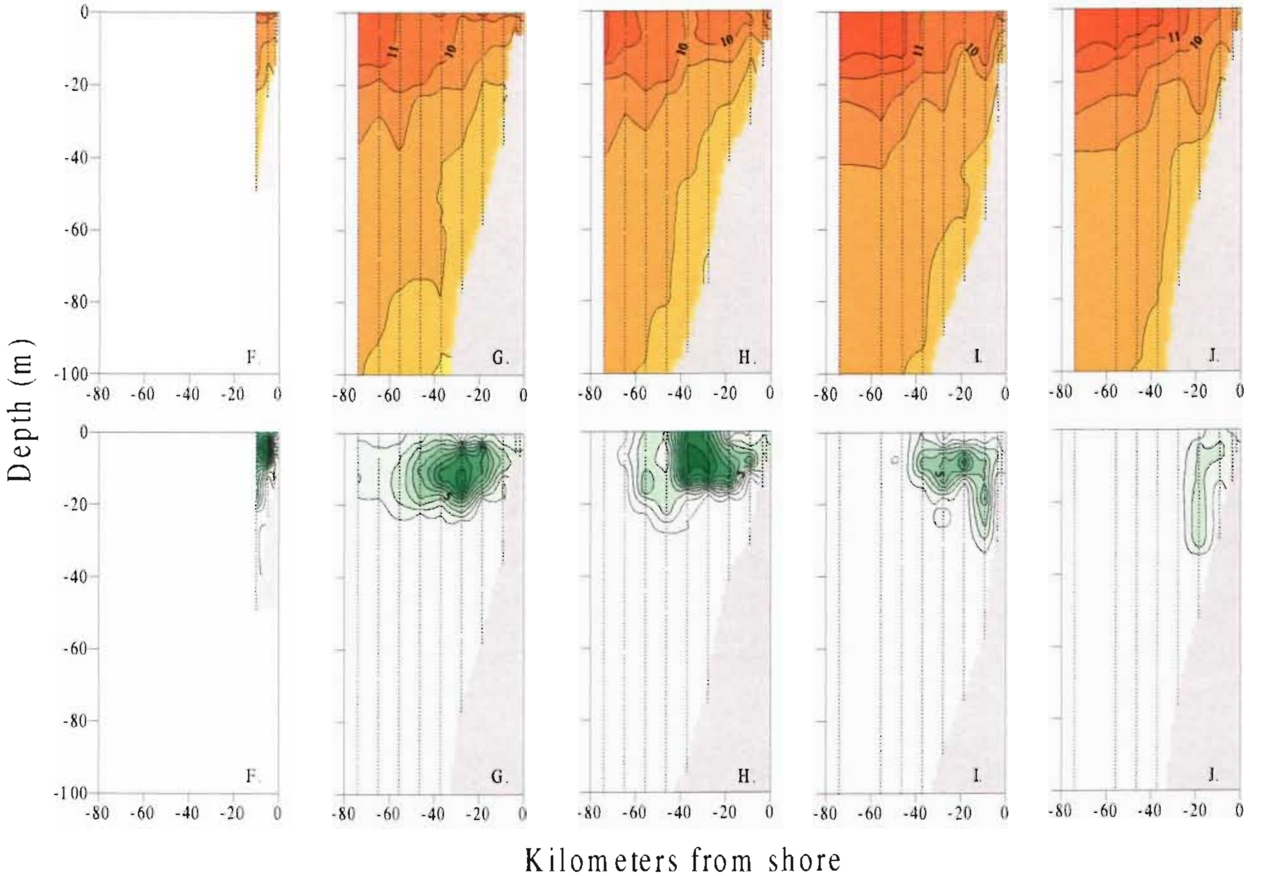


Figure 5.5. Cross-shelf transects of temperature (upper row) and chlorophyll a (lower row) during upwelling conditions. Transects were made in the order J to F (south to north). Isotherms are 1 °C intervals; chlorophyll isopleths are 1 mg/m³; gray areas indicate the bottom.

Presentations:
Curtis Roegner, "Time series of brachyuran larvae in the Coos Estuary," 1999 Pacific Estuarine Research Society, in Newport, Oregon.

Curtis Reogner, "Time series of brachyuran larvae in the Coos Estuary: Physical transport mechanisms," 1999 Estuarine Research Federation meeting, New Orleans, Louisiana.

Curtis Roegner presented "Larval crab abundance and distribution in relation to physical oceanographic signals" at the PNCERS Eat & Learn series, UW.

Workshops:
Curtis Roegner and Alan Shanks attended the PNCERS All-Hands Meeting, Jan 20-21, 2000, Seattle, Washington.

Curtis Roegner and Alan Shanks attended the WRAC annual meeting, Jan 19, 2000, Seattle, Washington.

Partnerships:
GLOBEC PI Bob Smith provided ship time aboard *R/V Wecoma*.

Personnel

Curtis Roegner, Research Associate, University of Oregon
Alan Shanks, Assistant Professor, University of Oregon
Amy Puls, Masters student, University of Oregon
Tucker Bowen, High school student
Beth Pecks, Undergraduate student, Oregon State University
David Armstrong, Professor, University of Washington

Bioindicators in Coastal Estuaries: Dungeness Crab and English Sole ...Project 6

David Armstrong, Don Gunderson, Chris Rooper, and Kris Feldman

David Armstrong and Don Gunderson

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;

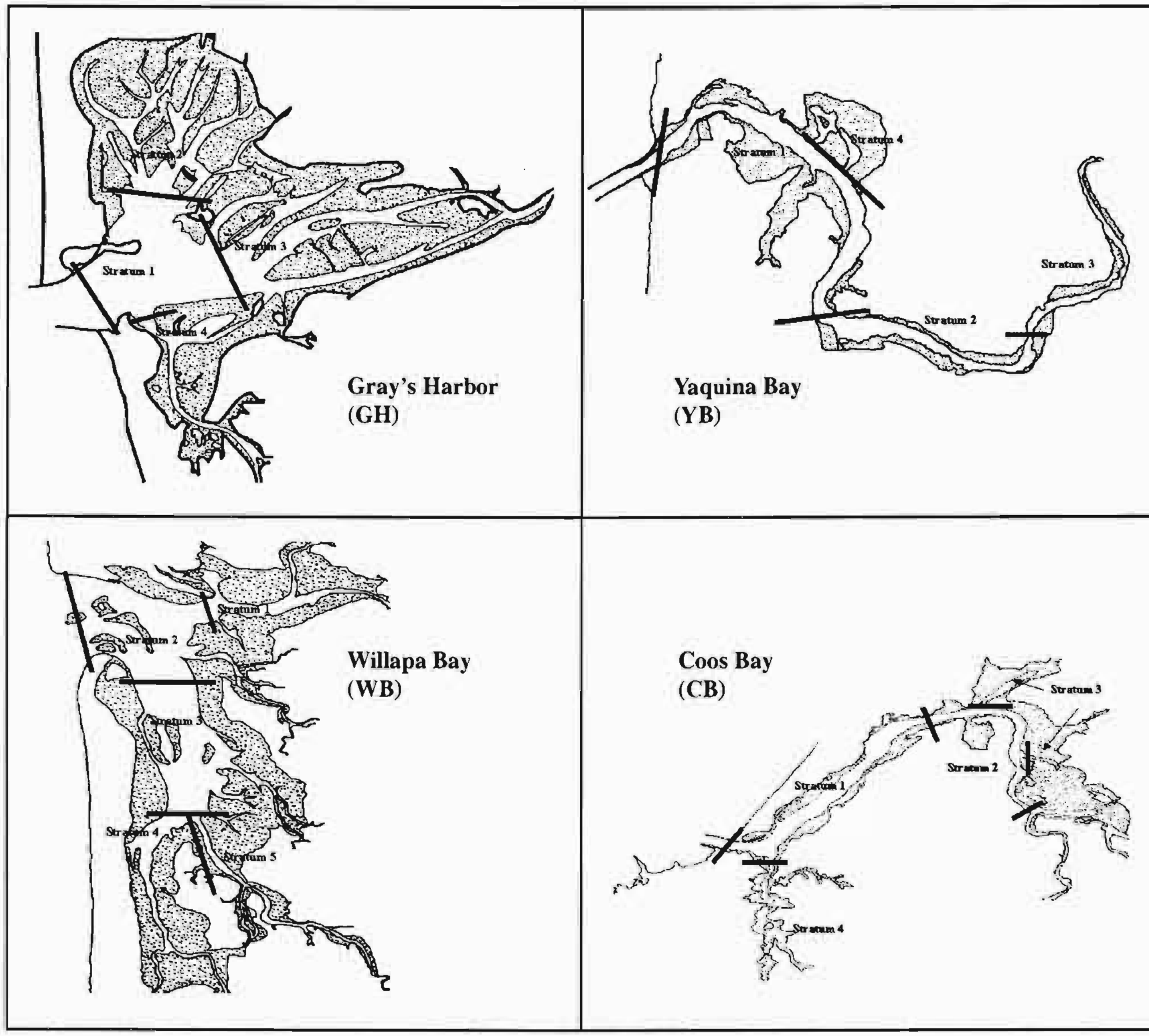


Figure 6.1. Maps of the four estuaries sampled as part of the bioindicator project. Shown are intertidal areas and boundaries of strata used to characterize spatial differences in abundance. The combined subtidal areas for GH, WB, YB, and CB are 8,545, 11,200, 487, and 1,197 ha, respectively.

3. type and quality of nursery habitat (refugia) required by small post-settlement stages of crab and sole;

4. subregions 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.

In this past year we not only continued the field surveys in four estuaries, but spent much time with collaborators working on retrospective data sets from our previous programs to especially address objectives 3 and 4. Analyses of some detailed data from 1983-1995 have proved valuable as the focus of several new proposals closely related to PNCERS. A four-year program funded by the Western Regional Aquaculture Center (WRAC) includes many of the same PNCERS scientists and is to be located in Willapa Bay (WB) and Coos Bay (CB). The principle objectives are to determine if bivalve aquaculture practices perturb intertidal juvenile salmonid habitat (primarily eelgrass), and the community ecology role of oysters as a major suspension-feeding element of the trophic web. There is great synergy between PNCERS and WRAC that expands ability to study habitat quality and system characteristics that favor certain bioindicators.

Our project is closely associated with the Mapping Estuarine Habitat project (Ron Thom and Steve Rumrill). We provide further basis on which 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 landscapes within the estuary (e.g. dredging, diking, landfill, decline in water quality) and how these actions may have curtailed estuarine production of certain fauna. The potential role of exotic bivalves in this system as habitat for small instars of Dungeness crab has focused work on the historic arrival and population expansion of *Mya arenaria* that eventually created intertidal shell habitat as "death assemblages". Introduction of the Pacific oyster, *Crassostrea gigas*, has further changed the shell-habitat landscape within NW estuaries where it is now the focus of many studies to ascertain its value as habitat and its community ecology role within the suspension-feeding guild. We are further tied to the Larval Transport and Recruitment project (Alan Shanks and Curtis Roegner) in that we study nearshore distribution of advanced larval stages, measure the timing and magnitude of entry into estuaries, and describe the physical/ behavioral means by which this occurs. Deepening knowledge of these processes has led to the idea, among collaborators and other PNCERS investigators (Hickey, Newton, Roegner, Dumbauld, DeWitt and Eldrige) that nearshore ocean processes are sources of nutrients and phytoplankton, and drive estuarine production more than previously thought.

Table 6.1. Compilation of catch for each species or group captured during PNCERS trawling in 1998 and 1999. Not included is an undetermined biomass of Crangon shrimp that was the numerically dominant catch during sampling.

Species or group	Catch
Flatfish	
English sole	12,205
Sanddab	3,237
Sand sole	347
Starry flounder	255
Cal tonguefish	7
Curlfin sole	1
Crab	
Cancer magister	24,822
Cancer productus	331
Hemigrapsis	185
Cancer oregonensis	28
Cancer gracilus	21
Other crab	18
Sculpin	
Staghorn sculpin	2,833
Buffalo sculpin	116
Other Sculpin species	31
Other species	
Gunnel	1,370
Spot shrimp	265
Prickleback	231
Lingcod	199
Starfish	144
Midshipman	143
Greenling	118
Pipefish	73
Stickleback	71
Goby/Blenny	64
Tomcod	28
Eelpout	22
Salmon	17
Tubesnout	17
Snailfish	15
Rockfish	11
Dogfish	6
Lamprey	2

Results & Discussion

Research Highlights

- Completed estuarine trawl surveys in June and August
- Developed ACCESS data base for 1983-1988 estuarine/nearshore surveys
- Entered 1998 and 1999 PNCERS data on estuarine surveys in ACCESS data base
- Acquired hydrographic data required to model nearshore oceanography.
- Monitored larval recruitment at Grays Harbor (GH) and WB in concert with the same effort at CB (Shanks and Roegner)
- Assisted coastal sampling effort for Dungeness megalopae (Roegner)

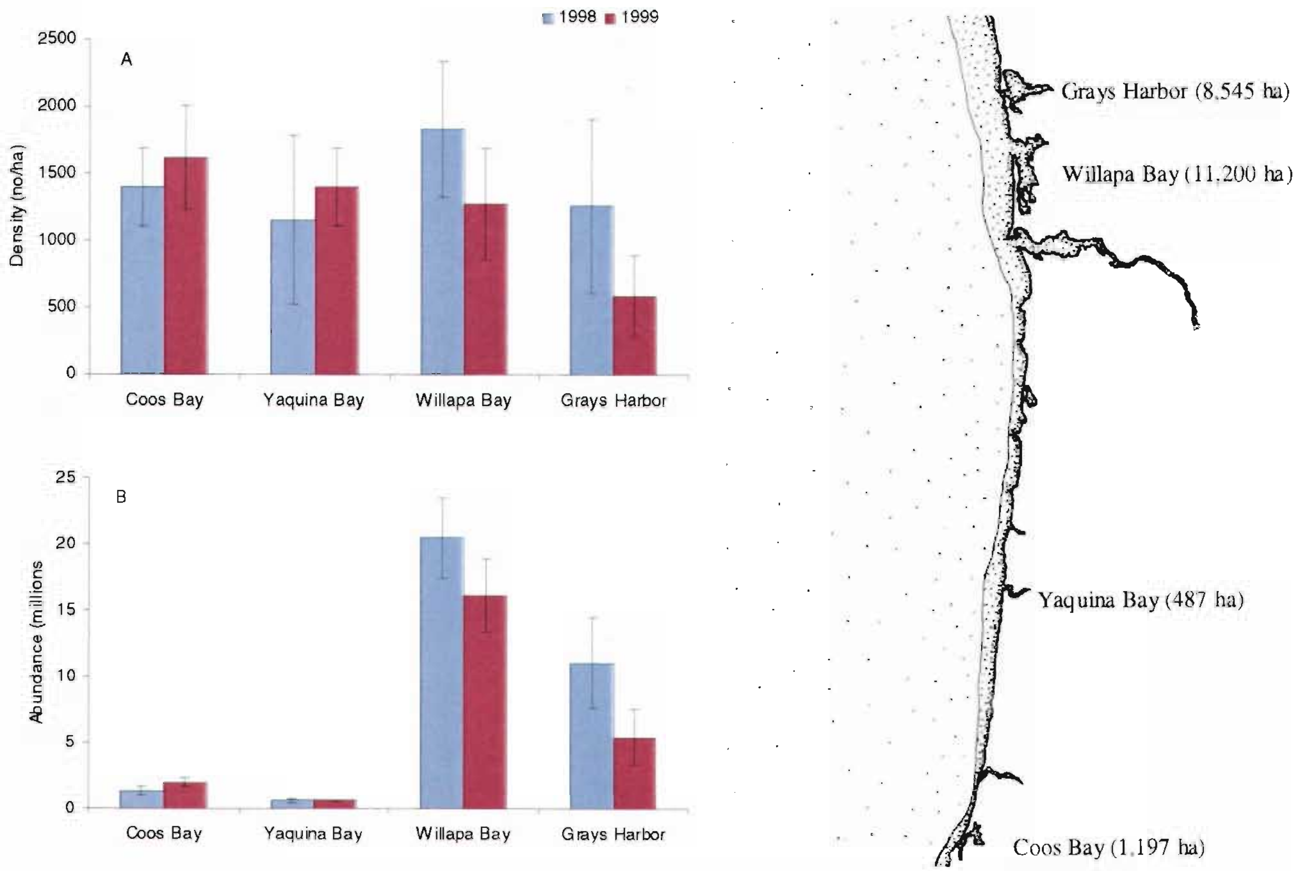


Figure 6.2. Average English sole density (A) and abundance (B) based on subtidal trawl surveys in Grays Harbor and Willapa Bay (WA) and Yaquina Bay and Coos Bay (OR), during 1998 and 1999. Data are combined over the June and August surveys of each year.

- Completed analyses of infaunal biomass as affected by predators in GH (Eggleston)

- Completed analyses of infaunal shrimp recruitment experiments for use in a major Estuaries review paper (Feldman)

Field Season Activities

Cruises: Trawl surveys were conducted during June and August in CB and Yaquina Bay (YB), Oregon, and in WB and GH, Washington. The stratified random survey design and sampling protocol followed procedures established in 1998, with catch/ha being determined for all fishes and crustaceans caught. Benthic trawl stations (18, 20, 17, and 18 in GH, WB, YB, and CB, respectively) were sampled in each estuary within 4-5 strata (Figure 6.1) selected to reflect major differences with respect to distance from the mouth (relative oceanic influence), sediment, salinity, and epibenthic cover. Size compositions were obtained for Dungeness crab (*Cancer magister*) and all species of flatfish, most notably English sole (*Parophrys vetulus*). Densities of juvenile English sole and Dungeness crab were calculated using the area swept method:

$$A=W*D$$

where W is the width of the mouth opening and D is the distance towed. Each tow was 150 to 260 m in length, and distance was calculated from differential GPS readings in 1998 and 1999. Mean density and abundance for each stratum and the entire subtidal in a given estuary were calculated according to stratified random sampling formulae. The mean lengths, densities and abundance of English sole as well as density and abundance of age 0+ crab and age 1+ crab were compared among the four estuaries over the four sampling periods using analysis of variance techniques. In 1998 and 1999 combined, a total of 286 trawls were completed in the four estuaries, where the dominant species were Crangonid shrimp, Dungeness crab (>28,000) and English sole (>12,000). The catch also included 31 other species or groups of fishes and invertebrates (Table 6.1). The amount of epibenthic debris (algae, woody debris, shells, etc.) associated with each trawl catch was also quantified in both 1998 and 1999.

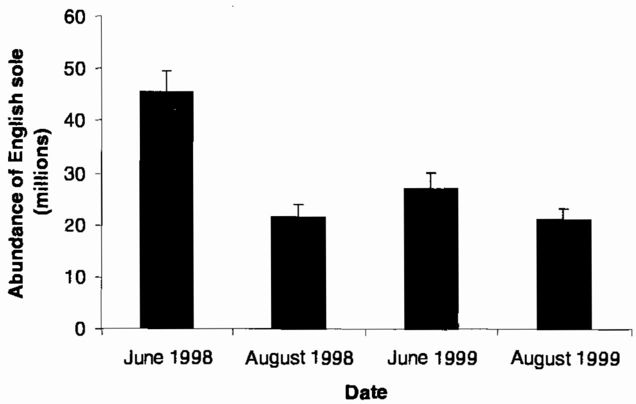


Figure 6.3. Estimated abundance of English sole combined over the four PNCERS estuaries during each of the subtidal trawl survey periods. Abundance is significantly higher in June than August.

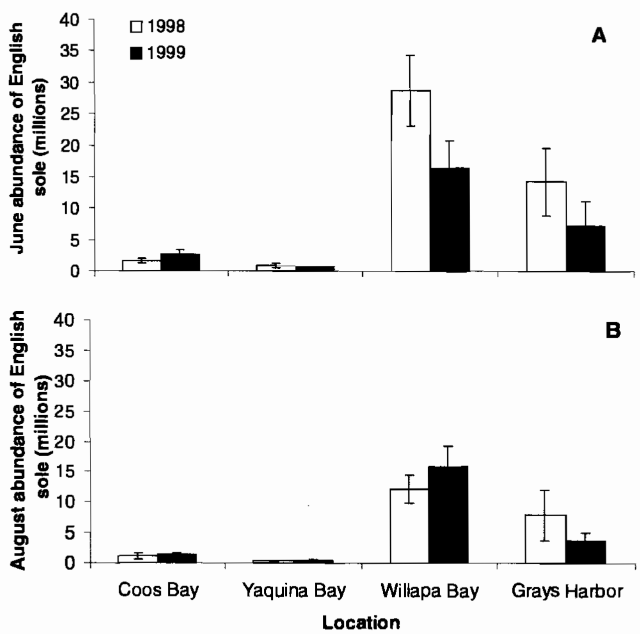


Figure 6.4. English sole abundance based on subtidal trawl surveys during 1998 and 1999. Data are shown for the June (A) and August (B) surveys in each year, and in most systems there is about a 30-50% decrease in abundance during summer.

Retrospective Analyses

Dave Eggleston continued to work on infaunal data describing predators effect on species and biomass. Experiments were done in 1992 to define the role of predation in structuring benthic communities in inter- versus sub-tidal habitats, but data only analyzed this past year. As part of his ongoing association with PNCERS, Dr. Eggleston worked with D. Armstrong this past summer and submitted a paper to Journal Experimental Marine Biology and Ecology (in review) in which they concluded that organism-habitat relationships might be more important than predation in structuring soft-bottom marine communities. Kris Feldman and Brett Dumbauld finished analyses of mud and ghost shrimp recruitment data collected across several habitats (open mudflat, oyster shell mitigation, *Mya* death assemblages) and treatments to evaluate effects of predators (cages), and used results in a publication with Armstrong and DeWitt. We worked to summarize data on weight of major epibenthic material caught during 1980s trawl surveys to portray kg/ha of shell, eelgrass and macroalgae, sticks and woody debris most common in the various strata of GH and WB. Similar data on crangonid shrimp biomass were also summarized to compute kg/ha of this common estuarine prey resource.

English Sole

Densities of English sole captured ranged from 0 to >11,200/ha over all estuaries and months. While there was no significant difference in fish density between years, there was a significant interaction between estuary and year. This result was driven primarily by the average densities in GH in 1999 which were significantly lower than most of the other year-estuary combinations (Figure 6.2A). Mean English sole density was typically between 1200-1600/ha in most estuaries both years, but was less than half this range (600/ha) in GH during summer 1999 (Figure 6.2A). The resultant estimates of abundance primarily reflect the relative size of the subtidal area in each system (Figure 6.2B). For example, since there is a 20x difference in subtidal area between WB and YB (11,200 and about 500 ha, respectively), the population estimates of about 18 million and < 1 million mirror this ratio (Figure 6.2B).

Analysis of variance showed that densities were significantly lower in August (mean = 966/ha, SE = 246) than June (mean = 1,687/ha, SE = 390), and this trend was conspicuous in June of 1998 (mean of 2000/ha) which was significantly higher than August densities in both years. Such difference in population abundance can be seen in summing mean estimates across all four estuaries, which ranged from a high of 45 million in June 1998, to 21 million in August 1999 (Figure 6.3). Notable change in abundance between June and August is most dramatic in estimates for the large systems (GH and WB) where populations decline about 50% across the 3 months (Figure 6.4).

The length of English sole caught ranged from 14 to 200 mm in the 11,720 fish measured in 1998 and 1999. Average length was significantly different among estuaries and months, as well as all combinations of estuary, month and year. The only insignificant terms in the analyses were year ($p = 0.099$) and the year*month interaction ($p = 0.147$). English sole were significantly larger in August than in June, as would be expected. But even within the same month, June, mean size of fish was about 33% greater in YB than GH (mean TL = 52 and 35 mm, respectively). Such geographic differences in mean size are better portrayed in June size-frequency plots which show more common bimodal distribution of English sole caught in CB, YB, and WB, but not GH in both years (Figures 6.5 and 6.6). Such patterns probably indicate two distinct settlement events that produce two cohorts of juve-

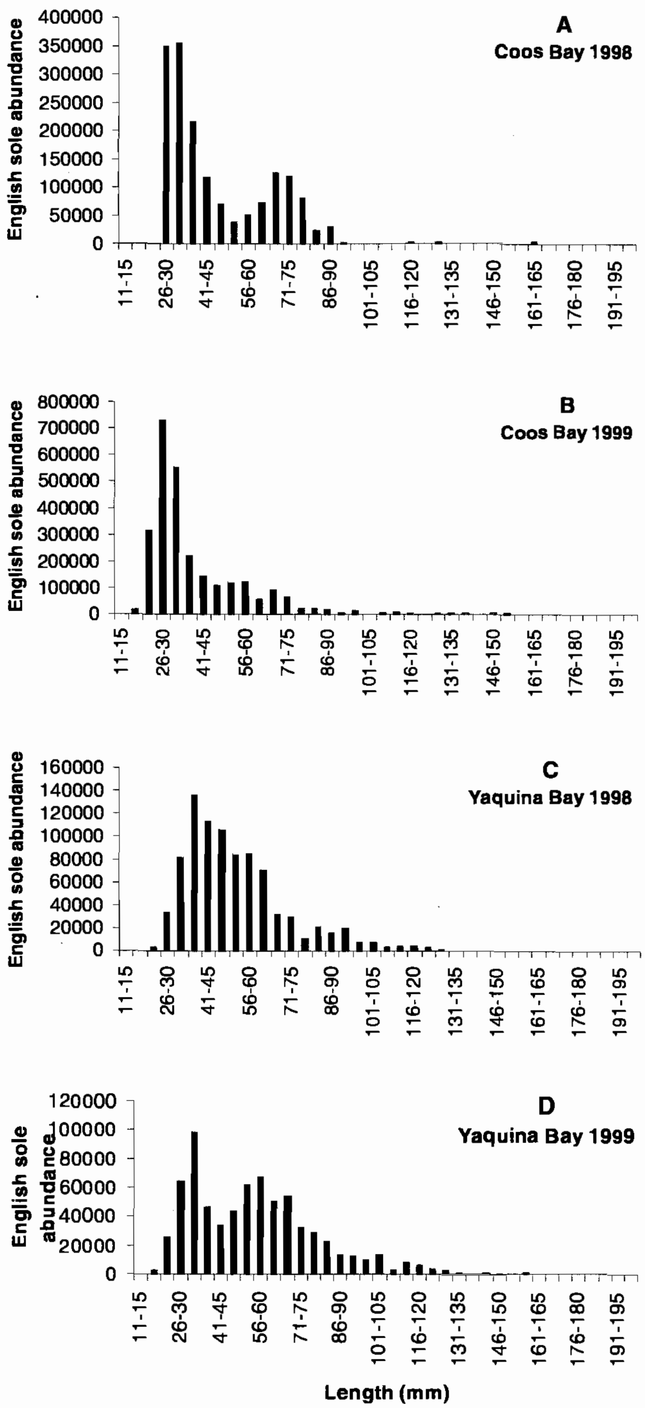


Figure 6. 5. Length frequency and estimated abundance of English sole during June sampling in Coos Bay in 1998 (A) and 1999 (B), and in Yaquina Bay in 1998 (C) and 1999 (D).

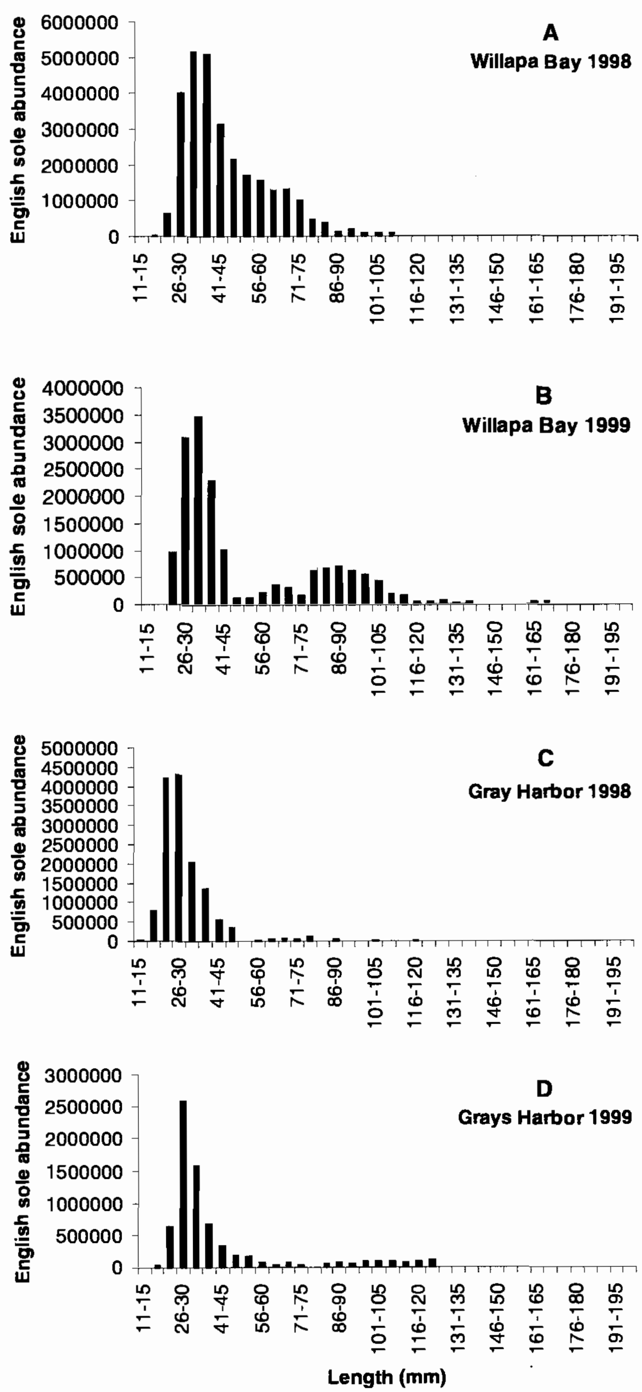


Figure 6.6. Length frequency and estimated abundance of English sole during June sampling in Willapa Bay in 1998 (A) and 1999 (B), and in Grays Harbor in 1998 (C) and 1999 (D). Note that Grays Harbor in both years did not have strong modes of larger fish as seen in the histograms for the other three estuaries (e.g., Coos Bay, June 1998).

nile English sole. In CB, for example, June '98 cohorts had size modes at about 40 and 75 mm (Figure 6.5), suggesting separate winter and spring settlement events.

Age 0+ Dungeness crab

Densities of age 0+ Dungeness crab were highly variable among estuaries, months and years of sampling, and ranged from 0 to >46,200/ha over 1998-99. Analysis of the age 0+ crab densities revealed significant effects of estuary, year, month, and a strong estuary-year interaction. Like the results for English sole, juvenile Dungeness crab are at higher densities in June than August, which reflects high mortality after settlement in May –early July. In 1998, there was a geographic cline in density from north to south where means were about 8500/ha and 1000/ha in GH and CB, respectively (Figure 6.7A). In 1999, the pattern was reversed and overall recruitment much lower than the year before with about 3700/ha and >500/ha in CB and GH, respectively (Figure 6.7A). High temporal variability in density of 0+ is common and due to time-space dynamics of the coastal larval populations, relatively long intervals between sampling trips (over a month in this case), and substantial post-settlement mortality over much of the subtidal area of estuaries. However, the geographic pattern of difference across the two years likely depicts real differences in relative entry to, and settlement in the four estuaries, which is reflected in aspects of the Larval Transport and Recruitment project (Shanks and Roegner). In general, we interpret the data of Figure 6.7 to mean that larger larval patches occurred adjacent to northern estuaries of GH and WB in 1998, but such patches and resultant estuarine advection were more common to the south off CB in 1999. An alternative hypothesis is that even though oceanic larval supply may be comparable in all four estuaries, post-settlement processes (predation, episodic physical events like reduced salinity) may result in differential survival and subsequent variable population estimates. We hope to work with Dr. Barbara Hickey to explore these hypotheses further using an oceanographic transport model.

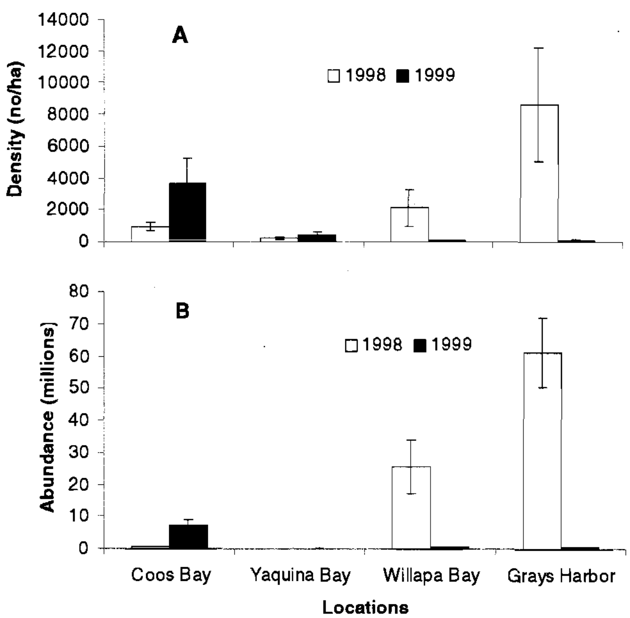


Figure 6.7. 0+ Dungeness crab density (A) and abundance (B) in the four PNCERS estuaries. Unlike the relatively comparable density for English sole, that for 0+ crab is highly variable between estuaries and years.

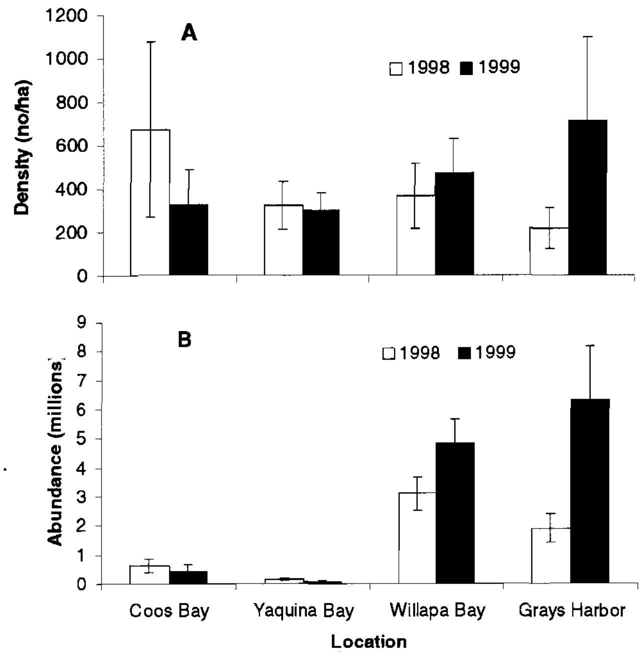


Figure 6.8. 1+ Dungeness crab density (A) and abundance (B) in the four PNCERS estuaries. Note relatively higher estimated abundance of 1+ (1998 year class = YC; strong El Niño year) during 1999 in GH and WB.

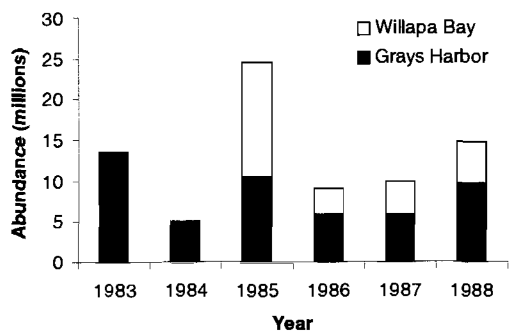


Figure 6.9. 1+ Dungeness crab abundance estimated from retrospective analyses of previous Sea Grant work from the 1980s. Shown are three month summer means for GH and WB (surveys of WB began in 1985) where abundance generally ranged between 8-12 million crab. The high estimate for the 1984 YC (1+ in 1985) is consistent with similar high abundance directly along the nearshore coast that year.

As a consequence of difference in mean density and subtidal area between estuaries, the geographic, seasonal and interannual patterns are amplified when computed as estimated population abundance (Figure 6.7B). Overall abundance of age 0+ Dungeness crab was significantly higher in June (mean = 63.7*10^6 SE = 27.6*10^6) than in August (mean = 32.2*10^6, SE = 7.5*10^6). There was also an order of magnitude difference in abundance between 1998 and 1999. Average abundance in 1998 was 87.4*10^6 (SE = 28.3*10^6), while in 1999 the abundance was 8.6*10^6 (SE = 4.0*10^6). Although estimates of over 60 million 0+ in GH were significantly higher than in the other estuaries during 1998, CB contained more 0+ crab in 1999 than the two larger Washington estuaries combined (Figure 6.7B). Unlike English sole, age 0+ crab density is not comparable across estuaries and so abundance is not a simple linear function of habitat area available.

Age 1+ Dungeness crab

Age 1+ crab density was fairly consistent in our surveys and not significantly different among the four estuaries, nor significantly different between 1998 and 1999 or between June and August. This larger size-class of crab generally occur at densities of about 300-600/ha in both months. In comparison to that of 0+, the relatively constant density of older crab may reflect both a reduced mortality rate after the highly episodic pattern of decline after settlement of megalopae, and possible carrying capacity limitations for this species at high biomass of the older age classes.

Age 1+ crab abundance reflects relative estuarine area as seen for population estimates of English sole. GH and WB account for the majority of estuarine crab production, which, together, was about 5 million, and 11 million in 1998 and 1999, respectively (Figure 6.8B). Although we lack sufficient time series to test the notion, there is a possibility that much higher abundance of 1+ in 1999 reflects strong larval settlement during the previous El Niño year. Eileen Visser has continued to monitor crab settlement in the GH Army Corps shell mitigation plots as continuation of earlier work by Armstrong that began in 1990. She found highest densities of 1st instar crab (>800/m2) in shell plots in early summer, 1998. It will be interesting to learn if larval light-trap indices (Roegner and Shanks) correspond to differences in

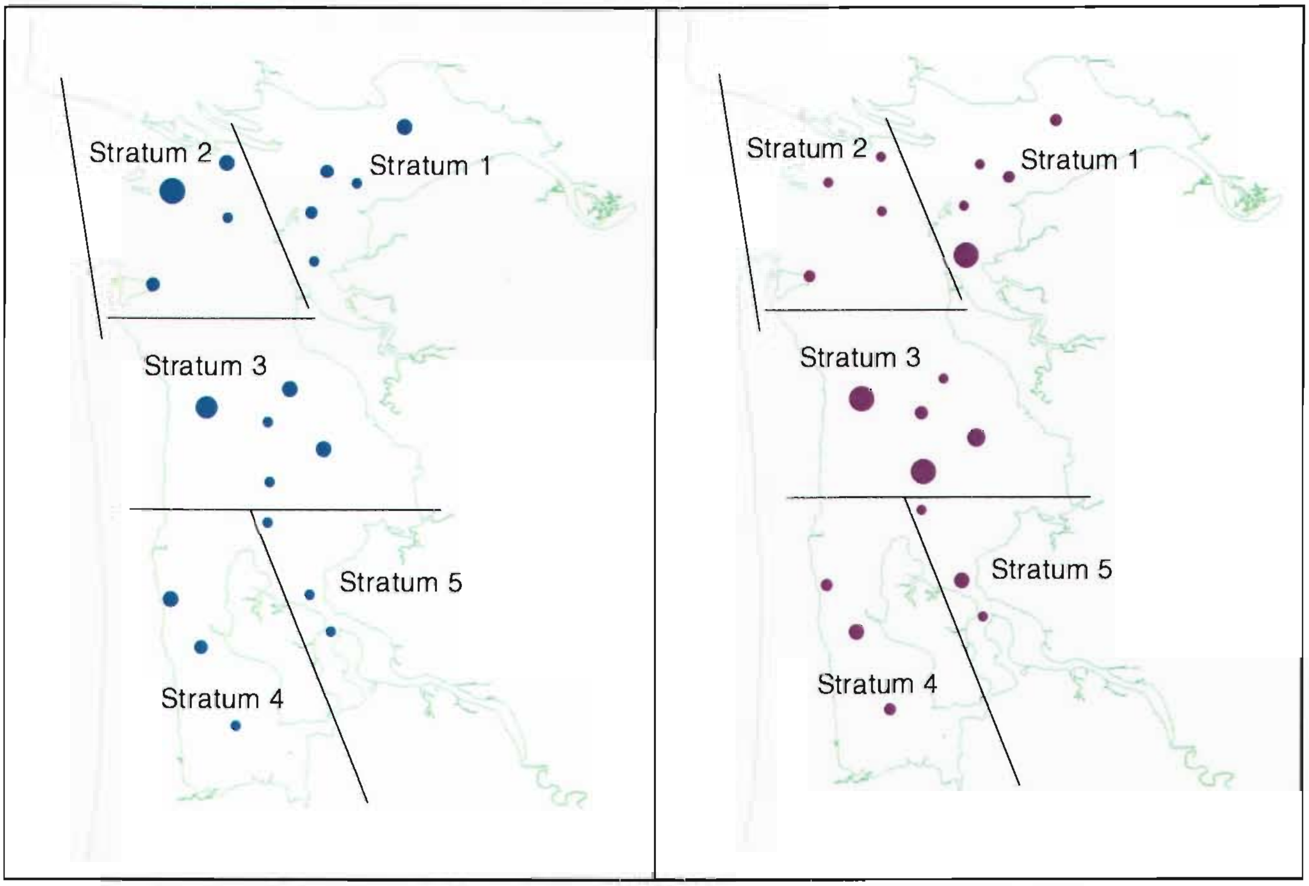


Figure 6.10. Estimated densities of English sole at trawl survey stations in Willapa Bay in June 1999 (A) and August 1999 (B). Size of the circle marking the station represents the relative density of English sole which ranged from <100 to 5300/ha.

density of early benthic instars between 1998-99. Population estimates of 1+ between 5-11 million in GH and WB in 1998-99 are somewhat lower than estimates from earlier work in the 1980s when we computed abundance of around 8-12 million, with an extraordinary value near 25 million in 1985 (the 1984 year class; Figure 6.9).

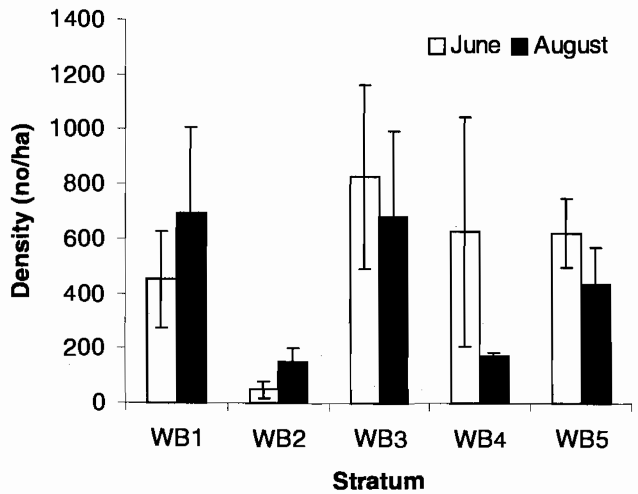


Figure 6.11. Density of 1+ Dungeness crab across the 5 sampling strata of Willapa Bay in June and August, 1999. Lower density in stratum 2 is exemplary of significant spatial difference across subregions of all estuaries studied, which implies difference in habitat quality as refuge, food, predators, and physicochemical variables.

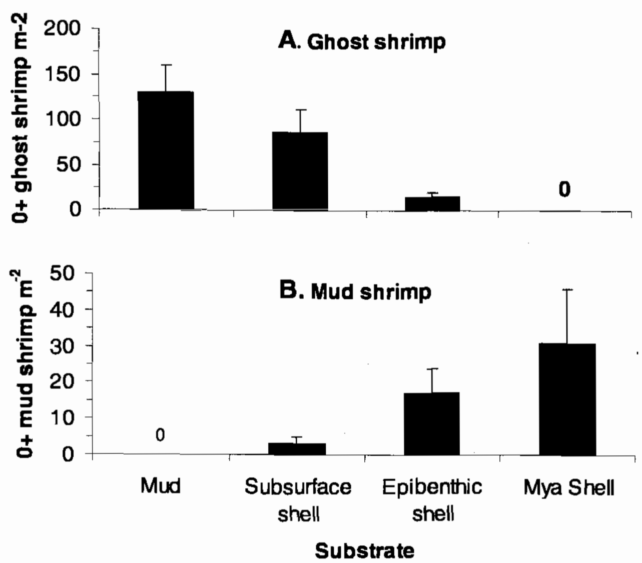


Figure 6.12. Density of juvenile ghost shrimp and mud shrimp recruiting to open mud and various configurations of shell, including shell that had sunk below the tideflats surface (subsurface shell), a thick layer of oyster shell (epibenthic shell), and deposits of Mya shell. Ghost shrimp prefer or survive better in open mud habitat, and mud shrimp are more abundant in shell.

GIS Data

Preliminary results of the analysis of surveys conducted in GH and WB during 1983-1988 indicates seasonal changes in English sole and Dungeness crab abundance within the estuary. In 1998 and 1999 differences in crab and sole distributions were also apparent between June and August surveys. In Willapa Bay, for example, these changes were most evident in English sole densities concentrated in stratum 2 during June and stratum 3 in August (Figure 6.10A and B). In the case of 1+ Dungeness crab, density commonly differed across strata (subregions) of the estuary. During both June and August 1999, crab density (and biomass) was lowest in stratum 2 adjacent to the mouth (mean about 100/ha) than in strata 1 and 3 (means ranging from 400-88/ha; Figure 6.11). Seasonal changes in distribution, as well as general distribution patterns in the four PNCERS estuaries suggest that differences in habitat within the estuaries may control abundance of our estuarine indicator species. Ongoing fieldwork and data analysis in a GIS data framework will provide an important method to answer this central question: what types of habitat delineations are important in determining how many crab or English sole are produced in estuarine subregions that can be characterized by shared abiotic and biotic attributes?

Intertidal Predator-Prey and Recruitment Dynamics

In an effort to more completely characterize the role of intertidal shell habitat in life history of key fauna, Kris Feldman and Brett Dumbauld finished analyses of settlement experiments and post-settlement monitoring of 0+ ghost shrimp (*Neotrypaea californiensis*) and mud shrimp (*Upogebia*

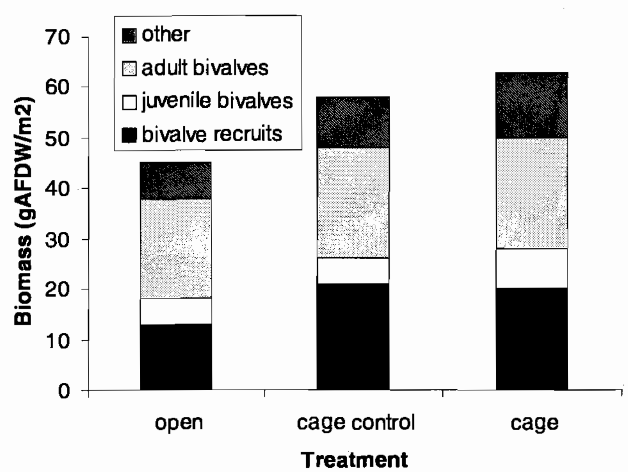


Figure 6.13. Mean total biomass and composition of soft-sediment prey as a function of predator treatment from intertidal experiments in GH. Most prey were several life history stages of bivalves, "other" prey were generally polychaete worms. The absolute quantity as g AFDW is very high and reduction in biomass during summer experiments can be seen in the "open" treatment. (Eggleston and Armstrong, in review).

pugettensis) survival in GH estuary. Density over time was compared across open mud, mud with subsurface shell about 8-10 cm deep, epibenthic oyster shell used for crab mitigation, and "natural" surface deposits of *Mya*. Data indicate that the two species behave/survive differently (Figure 6.12). Ghost shrimp settle and survive at much higher densities in open tideflats, while mud shrimp do much better in surface shell deposits. We hypothesize that ghost shrimp do poorly in shell either because it serves as a physical barrier, or supports high density of predatory 0+ Dungeness crab when this shrimp species typically settles in late summer. Mud shrimp, however, settle in early spring in advance of most 0+ Dungeness crab, and seem to have body morphology more conducive to movement through the matrices of shell hash.

Extensive work done in 1992 has been analyzed by Dave Eggleston to describe relative effects of predators (generally sculpin, crab, crangonid shrimp, and wading birds) on density and biomass of intertidal infaunal prey (mainly bivalves and polychaete worms). Results show that prey standing stock is very high (bivalves alone > 50g/m2 ash-free-dry-weight, AFDW, Figure 6.13), and that a predator guild may not deplete such resources as bivalves. This suggests very high rates of both recruitment and production of such prey as means to avoid seasonal depletion by predators. These data are also typical of a rich backdrop of such information that will be added to GIS frameworks, and used in modeling bioenergetics and trophic relationships within estuaries.

Integration & Interaction

Oceanographic Modeling

In 1999 we initiated work with Dr. Barbara Hickey to model surface transport in the California Current during the English sole pelagic egg and larval stages. Dr. Hickey has provided us with a model that calculates alongshore transport based on wind speed and direction, and has worked closely with us to apply the model. We continue to work on acquiring the data needed to run the model, and refining it to apply to time periods where English sole eggs and larvae were in the surface waters. Light trap sampling by Dr. Curtis Roegner may have captured significant numbers of larval English sole during estuarine sampling in 1998 and 1999. With his cooperation we will sort those samples to determine an index of the recruitment timing of the English sole to the PNCERS estuaries. Combining these data with the oceanographic model provided by Dr. Hickey should provide insight into the transport of English sole eggs and larvae and Dungeness crab larvae from spawning grounds to juvenile nurseries in estuaries.

Estuarine Ecology and GIS

The relative importance of intertidal and subtidal habitats in the production of juvenile crab and English sole will be evaluated in future years. We are working to compile existing information on benthic production in the intertidal zone. Using this information, we hope to apply energetics-based models to back-calculate the level of productivity required to sustain standing stocks of the dominant predators. We also plan to initiate a program of infaunal sampling in the little known subtidal area.

We remain very interactive with several scientists whose programs bear on topics of estuarine predator-prey systems, trophic web relationships and models, and key species as drivers within the systems. As noted in the introduction, collaboration with Brett Dumbauld provides an ongoing link to the oyster-eelgrass-crab-shrimp conundrum that manifests both ecological and societal issues of great importance in these estuaries. This same spectrum of themes has brought us into collaborative planning with Ted DeWitt and Pete Eldridge at EPA, Newport, to adopt their trophic models based on nutrient flow for analogous intertidal systems in WB.

Since both Curtis Roegner and Libby Logerwell are now present as post-docs within our program at UW, we have greater capability to expand both the field program to examine trophic relationships and ecosystem functions, and to begin a more concerted modeling effort tied to other elements of PNCERS. Most notable has been the recent effort to better define the ocean-estuarine coupling as a source of nutrients and phytoplankton as drivers of estuarine production, which has led to a Sea Grant pre-proposal. Jan Newton, Barbara Hickey, Curtis Roegner, Alan Shanks and Brett Dumbauld are major architects of this emerging program. We see tremendous opportunity to merge the new WRAC Essential Fish Habitat program with ongoing PNCERS logistics to broaden our research questions within WB and CB, particularly. Both programs will blend for the first time in summer, 2000. We hope that results from these studies on ecosystem processes will greatly augment modeling that may be supported in a new national Sea Grant-EFH proposal by a team of PNCERS scientists collaborating with others at NMFS, Newport (now in review).

We also plan further collaboration with colleagues working on the Institutional Mapping and Ecosystem Management project (Huppert, Bell, Leschine) to devise further means of using species-ecosystem information for economic analyses related to their program missions. In all cases, we are now moving to place our data in a GIS context, and support any collective PNCERS decision to make this a central element of the overall program. Virtually every aspect of data inventory, analyses, and future modeling will benefit from a common GIS structure that Amy Borde, Dana Woodruff, and Ron Thom have begun as part of the retrospective habitat analyses.

Applications

Publications:

Feldman, K., D. Armstrong, B. Dumbauld, and T. DeWitt. 1999. Oysters, crabs, and burrowing shrimp: An environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries. Estuaries (in press).

Dumbauld, B., E. Visser, D. Armstrong, L. Cole-Warner, K. Feldman, and B. Kauffman. 2000. Use of oyster shell to create habitat for juvenile Dungeness crab in Washington estuaries: status and prospects. J. Shellfish. Res. (in press).

Palacios, R., D. Armstrong, and J. Orensanz. Fate and legacy of an invasion: Extinct and extant populations of the soft-shell calm in Grays Harbor (Washington). Ecol. Applications (in review).

Eggleston, D. and D. Armstrong. The relative importance of predation in structuring benthic infaunal communities in inter- versus soft-bottom estuarine habitats. J. Exp. Mar. Biol. Ecol. (in review).

Presentations:

Don Gunderson. "Design criteria for a network of West Coast groundfish harvest refugia." PNCERS Eat and Learn Seminar Series. School of Fisheries

David Armstrong and Don Gunderson. "Role of Estuaries in sustaining coastal fisheries: North Pacific." AAAS special symposium, January 1999, Anaheim, California

David Armstrong. "Fisheries resources in Pacific NW Estuaries." Pacific Estuarine Research Federation, April 1999, Newport, Oregon.

David Armstrong and Don Gunderson. "Role of North Pacific Estuaries in Sustaining Coastal Fisheries." 15th Biennial International Conference Estuarine Research Federation, September 1999, New Orleans, Louisiana.

Workshops:

David Armstrong, Don Gunderson, Chris Rooper and Kris Feldman attended the PNCERS All-Hands Meeting, Jan 20-21, 2000, Seattle, Washington.

Partnerships:

Ted DeWitt and Pete Eldridge, EPA Environmental Research Laboratory. We collected specimens for EPA toxicity study during trawl surveys of Yaquina Bay. This group plans more detailed interactions and discussions on application of their models to describe trophic dynamics of intertidal systems in Willapa Bay.

David Eggleston, North Carolina State University. Worked with us on analyses of estuarine infaunal data to measure impacts of predators.

Brett Dumbauld, Washington State Department of Fish and Wildlife. Provided field logistical support for work in Willapa Bay, and collaborated on the manuscript with Feldman et al. We have formed a team (Dumbauld, Armstrong, Feldman, Roegner, Rumrill, Thom) that just won a four-year grant from the Western Regional Aquaculture Center (WRAC) to study impacts of bivalve aquaculture on intertidal juvenile salmonid habitat; focus to be in Willapa and Coos Bay to join with PNCERS programs in those systems.

Jose (Lobo) Orensanz. Analyzed data on estuarine *Mya* shell habitat as refuge for 0+ Dungeness crab, the predator-prey role, historic implications of an exotic species as affecting community ecology, and predictions about long-term prospects of populations dynamics of *Mya* in coastal systems.

Dr. Greg Jensen, Washington Sea Grant Green Crab program. Provided some field support in Willapa Bay and Grays Harbor during PNCERS trawl sampling as related to studies of green crab (*Carcinus maenas*) distribution.

Washington Sea Grant Green Crab program. Dr. Greg Jensen provided some field support in Willapa Bay and Grays Harbor during PNCERS trawl sampling as related to studies of green crab (*Carcinus maenas*) distribution.

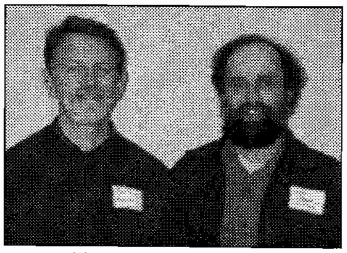
Army Corps of Engineers-Eileen Visser. The annual work in Grays Harbor has continued through summer '99 to monitor settlement of 0+ crab in the intertidal shell habitat and those data will be of great use in comparing trends at settlement to resultant distribution and abundance across the entire estuary.

Personnel

David Armstrong, Director, School of Fisheries, UW
Donald R. Gunderson, Professor, School of Fisheries, UW
Chris Rooper, graduate student, UW
Kris Feldman, graduate student, UW
Tim Loher, graduate student, UW (seasonal help)
Joe Miller, hourly employee, UW
Grace Tsai, graduate student, UW (seasonal help)
Kristen Larson, hourly employee, UW
Yunbing Shi, private consultant
Darin Waller, undergraduate student, UW
Gakushi Ishimura, non-matriculated student, UW

Habitat/Bioindicator Linkages and Retrospective Analysis ....Project 7

Ronald M. Thom and Steven Rumrill



Ronald Thom and Steven Rumrill

Introduction

The overall goal of the Habitat/Bioindicator Study is to provide resource managers and decision-makers with information about habitats that is useful for making management decisions about coastal estuaries in the Pacific Northwest. To achieve this goal, the study is addressing two broad objectives:

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

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

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, including investigations of Dungeness crab, English sole, and salmonid populations, and physical/chemical processes.

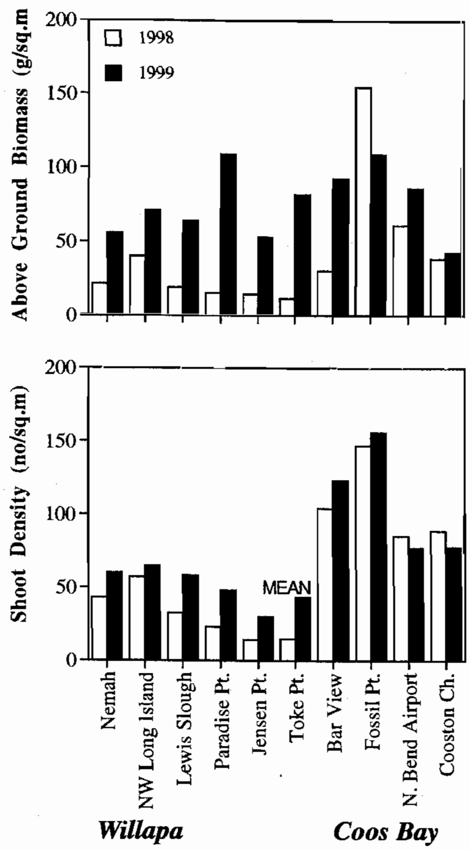


Figure 7.1. Mean eelgrass above ground biomass and shoot density at the 10 sites in 1998 and 1999.

The results of the retrospective analysis, reported in the last annual report, indicated that large-scale changes had occurred in all estuaries. These changes included loss of intertidal marshes and eelgrass through filling, diking and dredging operations conducted near developing ports in the estuaries. These data, which are in Geographic Information System (GIS) format, were provided to the Social/Economic assessment group for further analysis. They will provide data on upland development in a GIS format, which will allow direct comparison with the changes noted in the estuaries.

Eelgrass (*Zostera marina* L.) has been the primary focus of our work on spatial and temporal patterns. Eelgrass is an ideal indicator of estuarine "health" because it forms meadows throughout much of all coastal estuaries in the region, harbors large numbers of fisheries species, is a nursery and feeding area for juvenile salmon and Dungeness crab, and responds to physical and chemical forcing factors through changes in its size, morphology and distribution. To evaluate interannual variation, in 1999 we repeated sampling conducted in 1998 at all six eelgrass sites in Willapa Bay and four sites in Coos Bay. In addition, we added sampling for burrowing shrimp density. This information was gathered to try to assess the relationship between eelgrass and burrowing shrimp. We also gathered data on the range of elevations occupied by eelgrass in the systems. These data assist managers in predicting elevations that should be avoided for development and help define the limits of eelgrass to determine the best sites for eelgrass restoration projects. Finally, by sampling along a gradient between the upper and lower estuary, we are developing an understanding of the spatial patterns in eelgrass metrics. This understanding can also be used to assess anthropogenic impacts on eelgrass within the context of natural spatial variation.

Results & Discussion

Eelgrass Abundance

The same general patterns in eelgrass biomass and density seen in 1998 were documented in 1999 (Figure 7.1). In general, Willapa Bay eelgrass was less dense than in Coos Bay. However, above ground biomass was similar between the two estuaries. The reason for the difference between the two estuaries is still under investigation. We have documented cooler water temperatures in Coos Bay as compared to Willapa Bay, which may explain the greater densi-

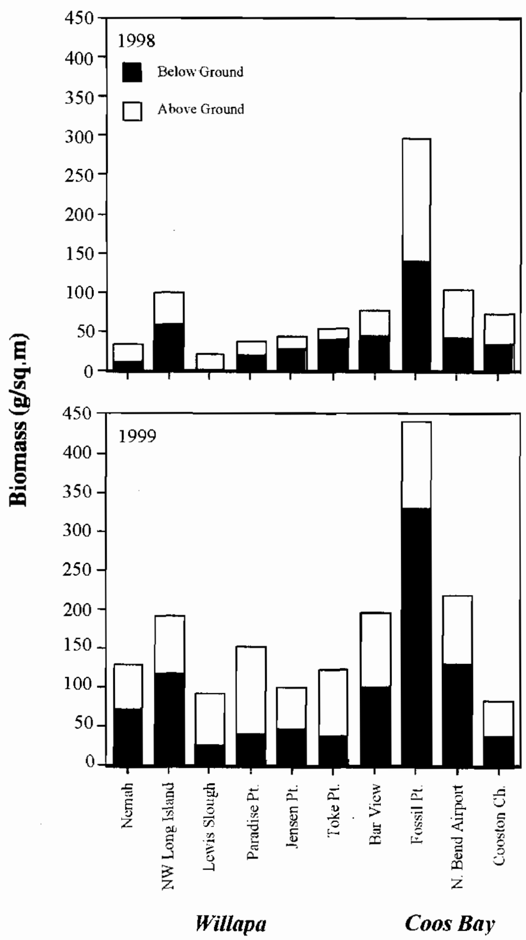


Figure 7.2. Mean eelgrass above and below ground biomass at the 10 sites in 1998 and 1999.

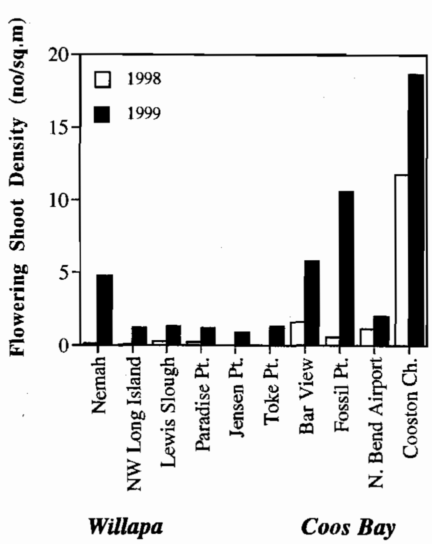


Figure 7.3. Flowering shoot density at the 10 sites in 1998 and 1999.

ties. We are also considering evaluating the effects of photoperiod. The two estuaries differ substantially in the duration of light, especially during the spring-summer growth period.

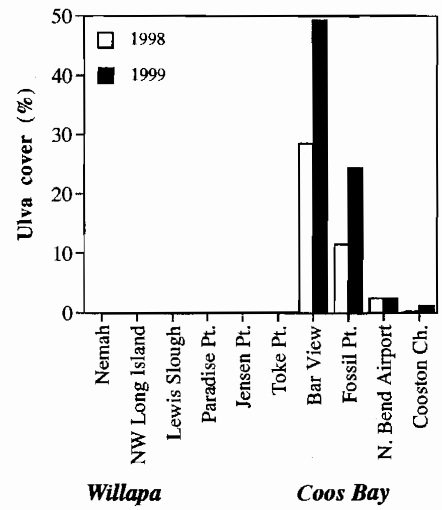


Figure 7.4. Mean percentage cover of *Ulva* spp. at the 10 sites in 1998 and 1999.

In Coos Bay, the greatest density and biomass occurred at the most marine site (Fossil Point) followed by the next most marine site (Bar View). In Willapa Bay, the densest meadows occurred at intermediate sites located at Nemah, NW Long Island and Lewis Slough. Patterns in 1998 were similar to those observed in 1999 suggesting that there is consistent spatial difference spatially throughout both estuaries that force measurable differences in the eelgrass population throughout both systems. We suspect that salinity and temperature are key factors controlling this spatial pattern.

Density, above ground biomass and below ground biomass were all greater, in general, in 1999 as compared to 1998 (Figure 7.1, 7.2). Data on temperature suggest that the pe-

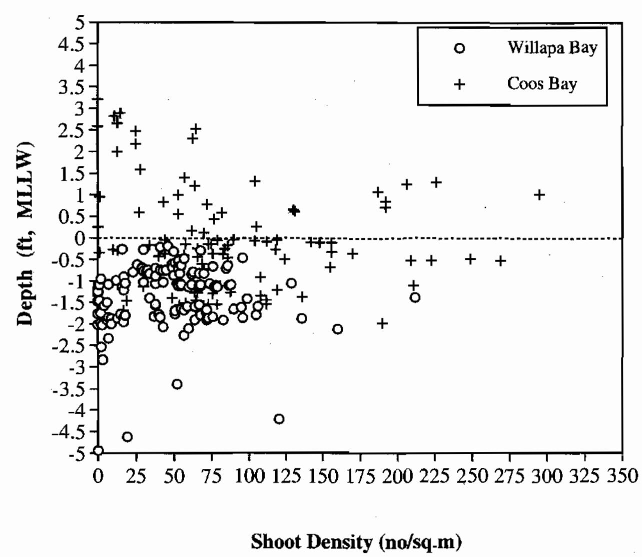


Figure 7.5. Depth versus eelgrass shoot density in Coos Bay and Willapa Bay in 1999.

riod between the summer of 1998 and the summer of 1999 were cooler than the previous 12-month period. This may indicate stronger upwelling and nutrient supply to the systems as well as less desiccation stress. This strong regional signal of increased biomass reflects an increase in productivity, which is ultimately important to and reflective of ecosystem productivity.

Flowering

Flowering was again greater in Coos Bay than in Willapa Bay (Figure 7.3). Interestingly, flowering was much greater in 1999 as compared to 1998 in both estuaries. The spatial patterns in flowering shoot density, with the most upstream site (i.e., Cooston Channel) in Coos Bay containing the greatest flowering density, indicates that this site is subject to factors consistent between years in producing more flowers than other sites. Again, salinity and temperature may be proving to be important factors driving flowering. The ultimate effect of increased flowering is seed production and seedling production. We would predict that eelgrass shoot density would be greater in 2000 owing to the fact that more seeds were introduced into the system in 1999.

Ulva *Cover*

The green seaweed *Ulva* spp. occurred in very high abundance in Coos Bay with very little noted in Willapa Bay (Figure 7.4). Ulvoids are often associated with areas of high nutrient inputs and can be indicative of eutrophication. Ulva was generally in very high abundance at the more marine sites in Coos Bay and was far more abundant at these sites in 1999 as compared to 1998. The Bar View site is located very near areas of high commercial and private shoreline development. It is also the site that suffered physical damage from oil cleanup operations following the New Carissa oil spill.

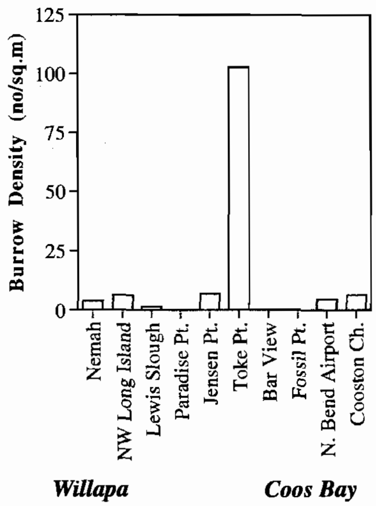


Figure 7.6. Mean shrimp burrow density at the 10 sites in 1999.

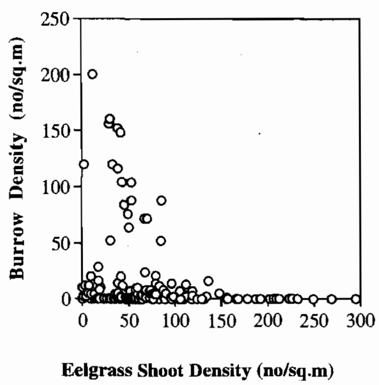


Figure 7.7. Shrimp burrow density versus eelgrass shoot density at the 10 sites in 1999.

Depth Distribution

The depth distribution of eelgrass was measured at approximately 300 points in 1999 (Figure 7.5). In general, eelgrass reaches its greatest density between +1.0 and –2.0 feet (MLLW). Our study sites are centered in the middle of the densest eelgrass in both systems. Eelgrass penetrates deeper in Willapa Bay, and appears to extend higher in the intertidal zone at Coos Bay. Potential explanations for this feature are that the flats in Coos Bay remain moister than those in Willapa Bay, thus preventing drying of the plants at low tide. There also may be a stronger freshwater signal at the surface in Willapa Bay, which could limit its extension into higher elevations. We will be exploring some of these factors in subsequent years. The data do assist in the development of a stronger biophysical understanding of the factors controlling eelgrass distribution not only horizontally along the estuarine gradient but also along the vertical gradient. These data could help managers site development in areas not likely to contain eelgrass.

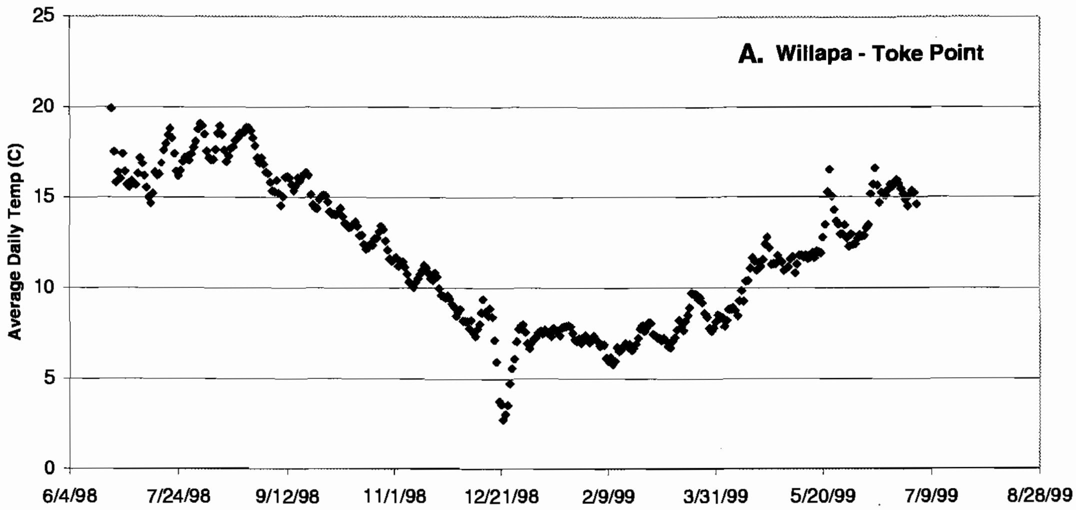
Burrowing Shrimp

Burrowing shrimp are a major component of most outer coast estuaries in the Pacific Northwest. They can be responsible for massive reworking of sediments, alterations in nutrient cycling, and elimination of some other species. Their interaction with eelgrass is still understudied. In 1999, we found burrows (an indicator of shrimp) at most sites, with the Toke Point site containing by far the greatest densities (Figure 7.6). As yet we have no definitive explanation for the high abundances at this site relative to the other sites.

The general negative correlation between burrowing shrimp burrow density and eelgrass shoot density suggests a negative interaction between these species (Figure 7.7). Our impression is that eelgrass, once established, can effectively exclude burrowing shrimp. We are evaluating these questions experimentally in a companion study in Tillamook Bay conducted for the US Environmental Protection Agency National Estuary Program. This information will improve the general knowledge about burrowing shrimp and help managers with difficult decisions regarding control.

Temperature

Temperature was measured approximately hourly between Summer 1998 and Summer 1999 site visits using Hobo temperature monitors (Figure 7.8a, 7.8b, 7.8c). We were able to recover 5 of the 10 sensors put out in 1998. Several features are evident from the recordings:



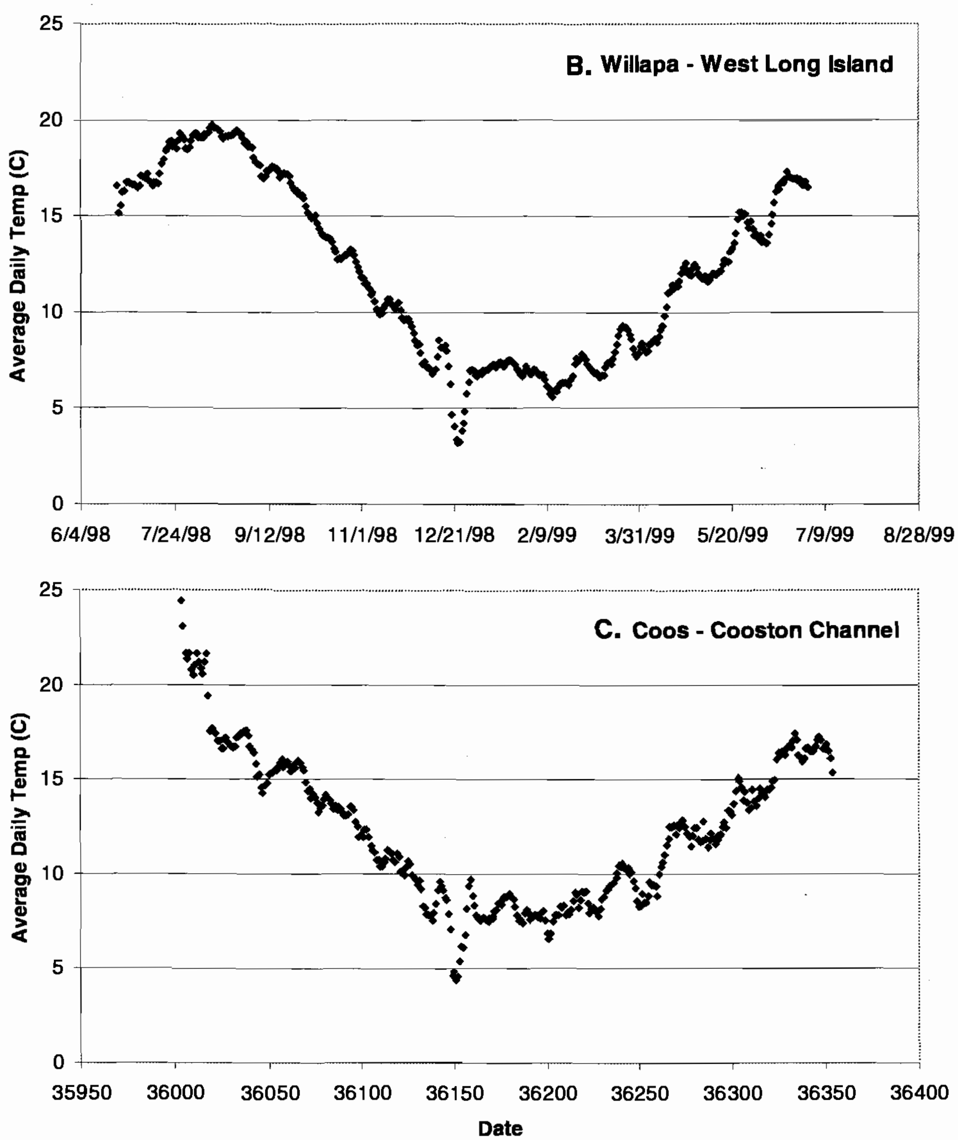


Figure 7.8. Average daily temperature as recorded by the Hobo sensors at (A) Toke Point, (B) West Long Island in Willapa Bay, and (C) Cooston Channel in Coos Bay.

- there is a repeating pattern of highs and lows on an approximate monthly cycle probably corresponding to neap and spring tides
- summer of 1998 was warmer than the summer of 1999 in both systems
- there was an extreme cold event during late December 1998 in both systems
- comparing two up-estuary sites (Cooston Channel in Coos Bay with West Long Island in Willapa Bay) it is evident that there was a warm event in Coos Bay only, autumn temperatures were cooler in Coos Bay, winter temperatures were warmer in Coos Bay, and temperatures were similar between systems in spring
- Toke Point was generally cooler than West Long Island in summer, but both sites were similar in winter and spring

Key to our work is the development of correlations between temperature and other water properties based on extensive data sets gathered in Willapa Bay by the water properties group led by Jan Newton, and from data collected by various sources in Coos Bay. Using this information we plan to characterize water property conditions at all 10 sites to better understand the factors forcing spatial and annual variations in eelgrass metrics. This information will be useful to managers to help interpret interannual and spatial differences seen in eelgrass and potentially other resources in their systems.

Conclusion

There are strong patterns that are emerging in eelgrass metrics both spatially and temporally within systems but also between systems. The patterns appear to be consistent between years within each site, and along the estuarine gradient. Increased flowering and shoot abundance in 1999 over that in 1998 points to the fact that the primary productivity of these systems varies substantially. Monitoring of temperature as well as other properties of these systems is promising in terms of interpreting the factors most responsible for the patterns. We are beginning to explore links between changes in benthic primary productivity and secondary production through discussions with other PNCERS team members. Continuing the present monitoring through one or two more years should yield even stronger and more enlightening relationships as yet undocumented in coastal estuaries of the Pacific Northwest.

Although we did not deal with these in this report, there were three distinct "disturbances" affecting our study. First, the study is spanning a period from a strong El Niño event to a strong La Niña event. This is seen in the temperature record and may explain the large interannual changes encountered. Second, the New Carissa oil spill at the mouth of Coos Bay, although not impacting our sites directly, resulted in damage at an elevation slightly below our study site at Bar View from booming activities. These impacts were caused by boats gouging the sediment when moving the booms. We will follow recovery of this site in subsequent samplings. Finally, a long line oyster culture system was established over part of our study site at Toke Point. We recorded no measurable effect of this operation so far on the eelgrass at the site. This represents a great opportunity to study the longer term effects of this type of oyster aquaculture on eelgrass.

Integration & Interaction

The Habitat/Bioindicator study is interacting with several other PNCERS team members as well as with collaborators outside of PNCERS:

1. We have provided data and are working with the social-economic group (Dan Huppert) to understand and relate land use changes to effects on habitats in the estuaries. This has involved some meetings through the year and the exchange of GIS data layers that we have produced during the retrospective analysis. We expect to work further with these individuals to try to refine the interpretations of changes.

2. We are acquiring data sets on water properties from the water column monitoring group (Jan Newton) for use in our analysis of factors affecting eelgrass metrics in Willapa Bay.

3. We have provided our Hobo temperature monitoring data to the physical oceanographic group (Barbara Hickey) for their use in interpreting the effects of the flats on water temperature.

4. We are discussing with the benthic invertebrate and fish group (Dave Armstrong) the incorporation of their data into our GIS system in order to make overlays of habitat and fish and crab abundance in the estuaries
5. We continue to collaborate with the UW-based group (Dave Armstrong) studying the effects of oyster aquaculture on eelgrass and juvenile salmon. We are providing assistance in eelgrass sampling and interpretation of results.

6. We are continuing our study in Tillamook Bay looking at interactions of oysters, eelgrass and burrowing shrimp for the National Estuary Program. This study should further refine the information on the relationship between eelgrass and burrowing shrimp as well as the effects of oyster aquaculture on eelgrass.

7. We have ongoing discussions with estuarine researchers at the US EPA Newport Laboratory (Ted DeWitt) regarding their investigation of eelgrass and burrowing shrimp ecology. We will supply them with our data which can be used to assist in their development of an eelgrass model.

Applications

Publications:

PNCERS habitat maps used in article by D.G. Gordon. 1999. Coastal Dynamics. Alaska Airline Magazine (September 1999 issue).

Presentations:

Ronald Thom, "Factors controlling the dynamics of eelgrass in the Pacific Northwest", PNCERS Eat and Learn Seminar, 19 February 1999, University of Washington, Seattle, Washington.

Ronald Thom, "Factors controlling the dynamics of eelgrass in the Pacific Northwest", Pacific Estuarine Research Meeting, April 16-18, 1999, Newport, Oregon

Amy Borde, "Factors controlling the dynamics of eelgrass in the Pacific Northwest", Society of Wetlands Scientists Meeting, May 1999, Newport, Oregon.

Ronald Thom, "Restoration of west coast ecosystems", Coastal ecosystem restoration workshop set up by the Estuarine Society of America and Restore America's Estuaries, May 6-7, 1999, NOAA, Seattle, Washington

Workshops:

Ron Thom attended the PNCERS workshop held in Vancouver, WA

Ronald Thom attended the Workshop on fish behavior near and under ferry terminals, Center for Urban Horticulture, University of Washington.

Ronald Thom attended the National Panel on C-sequestration in terrestrial ecosystems, February 3, 1999, Denver, Colorado, U.S. Department of Energy

Ronald Thom attended the workshop titled "Effects of complex stressors on aquatic ecosystems", September 11-16, 1999, Society of Ecotoxicology and Chemistry, University of Michigan Biological Station, Pellston, Michigan

Ronald Thom, Steve Rumrill, Amy Borde, and Dana Woodruff attended the PNCERS All-Hands Meeting, Jan 20-21, 2000, Seattle, Washington.

Partnerships:

Dr. Ted DeWitt, EPA Environmental Research Laboratory, Newport OR. Continued coordination of studies on eelgrass and burrowing shrimp

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. WRAC study of interaction of oyster aquaculture and effects on eelgrass in Pacific Northwest

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.

Dr. Brett Dumbauld, Washington Department of Fish and Wildlife. Provided laboratory space at the Nahcotta Laboratory for processing samples during our field trip to Willapa Bay.

The Oregon Institute of Marine Biology. Provided laboratory space for processing samples during our trip to Coos Bay.

Personnel

Ronald Thom, Staff Scientist, Battelle Marine Sciences Laboratory

Steve Rumrill, Research Coordinator, South Slough National Estuarine Research Reserve

Amy Borde, Scientist, Battelle Marine Sciences Laboratory

David Shreffler, Senior Scientist, Battelle Marine Sciences Laboratory

Dana Woodruff, Senior Scientist, Battelle Marine Sciences Laboratory

Liam Antrim, Senior Scientist, Battelle Marine Sciences Laboratory

Eve Fagergren, Student Intern, Associated Western Universities Program

Integrated Ecological-Economic Modeling: Spatial Modeling of Land Use and Management Activities ....Project 8

Kathleen Bell and Daniel Huppert

Introduction

Kathleen Bell

Since the inception of this project in May of 1999, we have explored various directions for the integrated ecological-economic modeling project, always with the primary objective of capturing feedbacks between the ecological and economic systems of PNCERS. While there are many reasons for pursuing this objective, we are studying these feedbacks to generate information for improved management decisions. We began by adopting a spatial perspective and exploring the utility of a land use change approach that had been applied elsewhere to coastal areas of the US (e.g., Bockstael and Bell, 1998). As a first step, we developed models of property (and land) values to explore the significance of certain ecological attributes in explaining price differentials and to characterize generally the preferences of residents regarding location. In collecting the data required for this modeling and other databases on regional population and land use trends, we discovered a limited amount of ongoing land use change in the PNCERS study area. Few data sources exist to even permit the tracking of changes because of the limited amount of changes. As a result, we have decided that the land use change approach is not an appropriate one to employ for this study area. Instead, we intend on continuing to use a spatial perspective in documenting human stress on and value of the coastal ecosystem but direct the research to a more conventional economic assessment of ecological-economic interactions. In the future, we hope to complement the property value (hedonic) results with other assessments of the demand for environmental quality and/or ecological service flows by studying factors such as recreation demand and habitat service flows. We also will continue to collect data related to human impacts on the coastal estuary.

There are two types of research being completed as part of the Integrated Ecological Economic Modeling Project. The first area involves valuation of ecosystem components, while the second area focuses on collecting data and information on human impacts on the ecosystem.

Using the extensive literature on applied studies of residential property values as a guide (Palmquist, 1991), a (hedonic) model of residential property values was developed for Grays Harbor County, Washington. Data were collected on a range of explanatory variables that could be used to explain residential property values. Much of the primary data on the residential property transactions (date and price of transaction, acreage, assessed land and improvement values) were acquired directly from the Grays Harbor County Department of Assessment Taxation. Additional data were collected and/or estimated using GIS data on land use, road networks, city and town locations, sewage treatment plants, pollution emission sites, and superfund sites. While the modeling results are encouraging in some ways, they are limited in other respects, and current work is addressing some of these limitations. Of particular interest is searching for a way to integrate more directly with the marine resources under study by the PNCERS natural science investigators.

The second research area of this project involves collecting spatially explicit data that are linked to potential stressors on the coastal ecosystem. These data are actively being collected for the counties falling in the PNCERS region and are being integrated with other information sources such as United States Census demographic and economic data, United States Census Tiger Line file data, USGS land cover and slope data, and various state and county GIS data resources. The data collection process largely reflects the research interests of other PNCERS PI's. In some cases (Julia Parrish and Ray Hilborn), the collaboration may be limited to the production of a basic measure of human stress such as population density or area of impervious surface. In other cases (Ron Thom and Steve Rumrill), the collaboration is more extensive with considerable tailoring of data collection to meet a specific need (e.g. determinants of habitat changes) of the natural science investigators.

Results & Discussion

Property Value Modeling

A model was estimated to examine the variation in residential property values in Grays Harbor County, Washington. One objective of this modeling effort was to explore the influence of ecological attributes on these values relative to other social and economic attributes. Many applications in the environmental economics literature (Palmquist, 1991) support the finding that housing price differentials reflect differences in environmental quality. As a result, the quantification of these relationships through modeling has served as the basis of applied welfare analyses of changes in environmental quality.

Data received from Grays Harbor County were cleaned, resulting in a sample of approximately 3,100 market transactions of residential properties from 1994 to part of 1998. The county parcel-level assessment data provide several important explanatory variables: transaction price, assessed value of the structure, assessed value of the land, date of transaction, and lot size. After creating a GIS database of these parcels, several other variables were estimated using ESRI's ARC/INFO. These include distance to the nearest major road, distance to the nearest central business district (Aberdeen or Olympia), distance to the nearest smallest town or city, distance to the nearest sewage treatment plant, distance to the

Table 8.1. Property value model: Definitions of variables and descriptive statistics. Sample includes 3,108 transactions of residential parcels in Grays Harbor County, WA, 1994-1998.

Definitions of Variables and Descriptive Statistics[1]

Variable	Description	Units	Min	Max	Mean	Std. Dev.
Market Price	Market price	Dollars	7,000.000	385,000.000	80,584.000	48,354.700
Value of structure	Assessed value of structure	Dollars	763.825	387,013.120	60,141.170	40,383.800
Lot size	Lot size	Acres	0.029	75.500	1.204	3.339
Distance to CBD	Distance to Aberdeen or Olympia	Miles	0.044	30.556	9.523	7.576
Industrial Emitter	=1 if residence is located within 0.5 miles of an NPDES or TRI site		0.000	1.000	0.079	0.269
Sewer Treatment Plant	=1 if residence is located within 0.5 miles of a Sewage Treatment Plant		0.000	1.000	0.042	0.199
Hazardous Waste Site (NPL)	=1 if residence is located within 0.5 miles of an NPL Hazardous Waste Site		0.000	1.000	0.117	0.321
Percent Developed	Percentage of land within 3/4 mile that is developed (residential, commercial etc)		0.000	1.000	0.404	0.243
Percent Agriculture	Percentage of land within 3/4 mile that is agriculture		0.000	1.000	0.078	0.144
Percent Wetland	Percentage of land within 3/4 mile that is wetland		0.000	1.000	0.111	0.153
Percent Forest	Percentage of land within 3/4 mile that is forest		0.000	1.000	0.065	0.121
Percent Water	Percentage of land within 3/4 mile that is water		0.000	1.000	0.044	0.094
Distance to Major Road	Distance to major road	Miles	0.000	15.110	0.638	1.161

Notes:

1 Data sources include Grays Harbor County Assessment and Taxation parcel datafile, US Census 1997 Tiger Line Files, USGS Land Use/Land Cover 1:250,000, US Census Place Locations, US EPA Region X BASINS GIS data.

nearest National Pollutant Discharge Elimination System (NPDES) or Toxic Release Inventory (TRI) facility, distance to the nearest National Priority List (NPL) Superfund site, distance to the coast, distance to Grays Harbor, and surrounding land uses. Surrounding land uses were measured by drawing circular land use buffers around the parcels (with a 0.75 mile radius) and identifying the different types of land surrounding the parcels. USGS land use/land cover data were used to describe these buffers. The final variables included in the model from these buffers are the percentage of area falling within established land use types. Table 8.1 presents the definition of variables used in the property value model and their descriptive statistics. Because of multi-collinearity between several of the ecological variables, only the land use variables were included in the final run.

Table 8.2 presents the results of the property value model, using three different functional forms that are commonly employed when estimating hedonic models: linear, double log or log-linear, and semi-log. The property value model is simple in design, with price regressed on numerous explanatory variables. A considerable amount of the variation in property values is explained in all 3 cases. In addition, the results are somewhat consistent across the functional forms and agree generally with other applied hedonic studies of residential values. Please note that it is incorrect to compare directly the R-squared values and that the coefficients have different interpretations in the different models. While there are some differences across the functional forms, strong relationships between certain factors and property values emerge. In short, larger lot sizes, higher valued structures or improvements, and proximity to central business districts have a significant and positive influence on residential property values. In contrast, proximity to industrial and commercial sites that are permitted emitters of pollution (TRI and NPDES) and proximity to National Priority List Superfund sites have a significant and negative influence on residential property values. Proximity to a major road appears to have a negative effect on residential property values. Overall, the suite of land use variables had mixed effects on residential property values and the significance of

Table 8.2. Property value model: Results by functional form. Sample includes 3,108 transactions of residential parcels in Grays Harbor County, WA, 1994-1998.

Dependent Variable : Market Price			
Variable	**Linear**	**Double-Log**	**Semi-log**
Intercept	6145.7671***	3.6275***	10.2456***
	(1392.1782)	(0.0584)	-0.0251
Lot size	3238.7274***	0.0872***	0.0276***
	(140.8110)	(0.0030)	-0.0025
Lot size^2	-25.7367***	-0.0078***	-0.0002***
	(3.2763)	(0.0019)	-0.0001
Value of Structure	1.0699***	0.7040***	0.000012***
	(0.0070)	(0.0050)	0.0000
Distance to CBD	1093.1679***	0.0467***	0.0173***
	(167.8169)	(0.0089)	-0.0030
Distance to CBD ^{2}	-42.3709***	-0.0129***	-0.0006***
	-7.0839	-0.0031	-0.0001
Industrial Emitter	-989.9290	-0.0295*	-0.0212
	(1379.6880)	(0.0173)	-0.0248
Hazardous Waste Site (NPL)	-3884.4718***	-0.0551***	-0.0638***
	(1071.9151)	(0.0143)	-0.0193
Sewage Treatment Plant	150.1682	0.0222	0.0088
	(3459.2757)	(0.0433)	-0.0622
Percent Developed	5042.9360***	0.0213	0.1352***
	(1549.8887)	(0.0185)	-0.0279
Percent Agriculture	873.6774	0.0228	0.0631
	(2166.2118)	(0.0274)	-0.0390
Percent Wetland	5325.2507**	0.0323	0.0585
	(2191.6313)	(0.0272)	-0.0394
Percent Forest	5654.2293**	-0.0031	0.0900**
	(2503.0822)	(0.0315)	-0.0450
Percent Water	4957.5052	0.0060*	0.2102***
	(3653.6920)	(0.0458)	-0.0657
Distance to Major Road	-898.4263***	-0.0025	-0.0187***
	(267.3225)	(0.0027)	-0.0048
R-squared	0.9027	0.8937	0.7782
F Value	2050.582	1858.884	775.434
Observations	3108	3108	3108

Notes:

*1 Parameter estimates, standard errors in parentheses below; *, **, and *** indicate significance at the 0.10, 0.05, and 0.01 levels respectively.*

these effects varied across different functional forms. Greater amounts of surrounding land in wetland, water, and developed or built up uses consistently had a positive effect on residential property values. We believe the value of living near the estuary is captured partially by the water and wetland variables and find their positive signs encouraging. While the five land use variables are jointly significant using all 3 functional forms, we are not content with the present results.

In this first county-wide model, ecological variables were represented by the percentage of land in different uses surrounding the parcel. We intend on expanding the consideration of ecological variables. In the county-wide model, we were not able to include certain variables because they were limited in spatial scale and did not apply to the whole sample. A next set of hedonic runs will focus only on the coastal portions of Grays Harbor County. These future runs on a subset of coastal properties will scrutinize the potential influence of more ecological factors on residential property values. This subset of transactions will allow for more detailed environmental variables to be included in the model, and we hope this change of scale will broaden the types of ecological variables that can be considered and, in turn, increase their prominence in the models. In doing so, future runs may involve greater levels of integration and use of data being collected by the PNCERS natural science research projects. Grays Harbor County, Washington was chosen as

Table 8.3. Summary of land use by county and county coastal areas of the PNCERS region.

Land Use By County									
Area (acres)									
	AG	BARREN	COMM	FOREST	RANGE	RES	WATER	WETLAND	OTHER
Grays Harbor County, WA	18401	5091	24702	1105534	4570	17675	11361	32827	6816
Pacific County, WA	18241	3463	2090	534801	4936	8925	15094	9756	7341
Tillamook County, OR	29309	2061	2094	657657	1892	6653	7353	1971	5228
Lincoln County, OR	9316	468	3545	601313	336	11231	6663	2176	9314
Coos County, OR	38234	10475	10260	911850	20787	20737	14671	2585	11279
Percentage of Total Area									
	AG	BARREN	COMM	FOREST	RANGE	RES	WATER	WETLAND	OTHER
Grays Harbor County, WA	0.0150	0.0042	0.0201	0.9010	0.0037	0.0144	0.0093	0.0268	0.0056
Pacific County, WA	0.0302	0.0057	0.0035	0.8845	0.0082	0.0148	0.0250	0.0161	0.0371
Tillamook County, OR	0.0410	0.0029	0.0029	0.9208	0.0027	0.0093	0.0103	0.0028	0.0176
Lincoln County, OR	0.0144	0.0007	0.0055	0.9332	0.0005	0.0174	0.0103	0.0034	0.0248
Coos County, OR	0.0367	0.0101	0.0099	0.8760	0.0200	0.0199	0.0141	0.0025	0.0108
Land Use By Coastal Sections of Counties (within 5 miles of coast)									
Area (acres)									
	AG	BARREN	COMM	FOREST	RANGE	RES	WATER	WETLAND	OTHER
Grays Harbor County, WA	2072	4566	3840	212068	2735	9896	6236	10427	4676.31
Pacific County, WA	8418	3446	1263	183101	4898	7414	14870	8515	7341.48
Tillamook County, OR	19593	2044	1339	140642	1733	5702	7325	1971	5150.53
Lincoln County, OR	2656	407	2379	140998	327	7886	5977	2174	9314.03
Coos County, OR	5469	9612	5365	94238	10159	9240	11043	1786	5925.00
Percentage of Total Area									
	AG	BARREN	COMM	FOREST	RANGE	RES	WATER	WETLAND	OTHER
Grays Harbor County, WA	0.0081	0.0178	0.0150	0.8267	0.0107	0.0386	0.0243	0.0407	0.0182
Pacific County, WA	0.0352	0.0144	0.0053	0.7653	0.0205	0.0310	0.0622	0.0356	0.0307
Tillamook County, OR	0.1056	0.0110	0.0072	0.7582	0.0093	0.0307	0.0395	0.0106	0.0278
Lincoln County, OR	0.0154	0.0024	0.0138	0.8192	0.0019	0.0458	0.0347	0.0126	0.0541
Coos County, OR	0.0358	0.0629	0.0351	0.6166	0.0665	0.0605	0.0723	0.0117	0.0388

Source: *USGS Land Use/Land Cover Data 1:250,000.*

Notes: *AG=agricultural; BARREN=barren lands; COMM=commercial lands; FOREST=forest lands; RANGE=range lands; RES=residential lands; WATER=lands covered by water; WETLANDS=wetlands; and OTHER=undefined land use types.*

the first study area because it has a parcel level GIS database system in place that documents the specific locations of parcels. In the future, we hope to contrast the results found in Grays Harbor County, Washington with a county in Oregon.

Population, Land Use, and Human Activities
In addition to the property value modeling, we also spent time developing a Geographic Information System (GIS) whose focus is human and management activities. Data on the location of human activities that are potential stressors to the coastal ecosystem and related management activities are being assembled. One early focus of this effort was the creation of a spatially explicit database of population and land use in the five PNCERS estuaries. Past research completed as part of the Socioeconomic Baseline and Institutional Mapping Project relied on county-level data. The more detailed data display some interesting traits about the different estuaries. Observing the 5 counties that are most strongly related to the 5 PNCERS estuaries (from north to south, Grays Harbor and Pacific Counties, WA; Tillamook, Lincoln, and Coos Counties, Oregon), the Oregon counties as a group are more populated and densely settled along the coast than the Washington counties. Development in coastal Washington is largely limited to the areas near Grays Harbor and Willapa Bay. In contrast, development is more persistent along the Oregon coast. This difference may be partially explained by the higher level of accessibility to the Oregon coast. The distribution of major roads and employment centers in western Oregon parallels the coast in many sections. This same distribution is not found in Washington. Within 5 miles of the coastline, the 1997 population levels were approximately 44,864 in Washington and 112,803 in Oregon. We are examining these differences in population, land use, and development patterns to characterize basic indicators of human stress (population density) and to allow for the prediction of future changes in population and human activities.

Table 8.3 displays the number of acres and percentage of area by land use type for the 5 PNCERS counties. The land use/land cover data used to generate these estimates is again the USGS 1:250,000 data for Oregon and Washington. Although these data reflect late 1970s and early 1980s conditions, we still believe the distribution of lands to be quite representative. As noted previously, the lack of land use change in this region has limited the production of data resources such as land use/land cover GIS coverages, and we were able to find no alternative data resource that was consistently produced for all 5 areas being considered here. Two different sets of land use figures are presented in Table 8.3. The first set represents county-wide estimates, whereas the second set reflects only the land area of the county that is within 5 miles of the coast. Together, these figures allow for interesting comparisons to be made across the counties and their coastal areas. From a land use perspective, the PNCERS counties are quite similar, with the majority of their land being in forest uses (greater than 80 percent in all cases), followed by small areas of agricultural, water, and developed uses. There is more variation across these areas when the coastal land uses are assessed. While forest remains a dominant land use in the coastal areas, several other uses (agriculture, residential, and commercial) account for a higher portion of the area along the coast than they do in the county-wide assessments. We are exploring these data to consider questions such as:

- Does the management of the estuarine resources in the PNCERS study area reflect and/or affect these distributions of land use? And:
- Are there correlations between land use patterns and the health or condition of select estuarine resources (e.g., habitat, seabirds, salmon, crab) being studied by PNCERS natural science investigators?

In addition to the population and land use information, other types of spatially explicit data that are linked to potential stressors on the coastal ecosystem are actively being collected for the counties falling in the PNCERS region. For example, these data include: sources of various pollution discharges, agricultural activities, oyster culture, shoreline modification/hardening, dams, and port activities. These data are being integrated with other information sources such as United States Census demographic and economic data, United States Census Tiger Line file data, USGS land cover and slope data, and various state and county GIS data resources.

Integration & Interaction

In collaboration with Ron Thom and Steve Rumrill, we intend to develop a broader understanding of the factors that have influenced historical habitat changes in the PNCERS estuaries. While the data that Thom and Rumrill have collected so far reveal an interesting story, it is somewhat incomplete, given that the human behavior and activities associated with these changes are not well documented. If future stressors are to be contained through management efforts, it will be important to understand the motivations behind the behavior causing the stressful influences. Ron Thom has shared GIS data on historical habitat changes as well as their qualitative assessments of the human stressors associated with these changes. We are now assessing human-driven changes on surrounding lands and changes in human activities at the corresponding time periods.

The GIS data collection work aims to broadly integrate with many of the other PNCERS research projects. For example, data on human activities are being collected to enable basic linking of human indicators of stress (population density, land area in developed uses) with research on the estuarine resources of PNCERS, including seabirds, salmon, and crabs (Julia K. Parrish, Ray Hilborn, and David Armstrong).

For more details on social frame integration refer to Social Frame Interactions and Integration, page 69.

References

Bockstael, N and K. Bell. 1998. Land Use Patterns and Water Quality: the Effect of Differentiated Land Management Controls. In: R. Just and S. Netanyahu (ed.), Conflict and Cooperation in Trans-Boundary Water Resources, pp. 169-192, Kluwer Academic, Boston.

Palmquist, R.B. 1991. Hedonic Methods. In J.B. Braden and C.D. Kolstad (eds.), Measuring the Demand for Environmental Quality, 77-120, Elsevier, North Holland.

Applications

Publications:
None.

Presentations:
Kathleen Bell, "Striving for Integrated Research: The Human Dimension of the Pacific Northwest Coastal Ecosystem Regional Study," Presented at the "Human Dimension of Large Marine Ecosystems Workshop", University of Rhode Island, February 14, 2000.

Kathleen Bell, "Understanding the Use of Lands in the PNCERS Region: A Foundation for Integrated Research", PNCERS Eat and Learn Seminar Series, University of Washington, February 24, 2000.

Workshops:
Kathleen Bell, Daniel Huppert, and Tom Leschine served as organizers and discussion leaders at the PNCERS "Protecting and Restoring Pacific Northwest Estuaries: Human Activities and Valued Ecosystem Components" Vancouver, Washington, December 8-9, 1999.

Kathleen Bell, Daniel Huppert, Rebecca Johnson, Tom Leschine, Michelle Pico, and Joel Kopp participated in monthly socio-economic group meetings.

Kathleen Bell, Daniel Huppert and Tom Leschine attended the PNCERS All-Hands Meeting, January 20-21, 2000, Seattle Washington.

Partnerships:
Larry Claunch and Angie Comer, Grays Harbor County, Washington. Provided access to data on the sales of properties, property characteristics, and locations and boundaries of parcels.

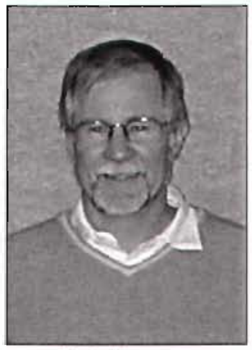
Personnel

Kathleen Bell, Research Associate, University of Washington
Daniel Huppert, Associate Professor, University of Washington

Institutional Mapping and Analysis .... Project 9

Daniel Huppert

Introduction



Daniel Huppert

As described in earlier reports, the PNCERS institutional mapping and analysis research includes three objectives:

1. to identify the underlying social units (agencies and non-governmental organizations),
2. to describe the resources and authority that support these units, and
3. to explain how the numerous agencies and groups coordinate or compete to exercise their authorities and to formulate policies.

The institutional mapping and analysis work feeds into the more in-depth explanation of policy or decision processes which are contained in other PNCERS research tasks. Drawing on the substantial data on laws, institutions, and decision processes gathered and reported in previous years, the 1999 work focused on more analytical tasks. First, we created a simple scheme for characterizing the regulatory styles (a "typology" of regulation) used for controlling use of land and water in coastal areas. The result is a logical system of nomenclature for characterizing the myriad formal and informal means of exercising individual and collective control over such resources. Second, we developed means to display the relationships between the web of institutional authorities and specific ecosystem users. To illustrate and exercise this capability, we focused on Oyster growers in Washington estuaries as a central example. These components are grouped under the heading of "institutional mapping" because they are predominantly descriptive and focused on structure and lines of authority and control.

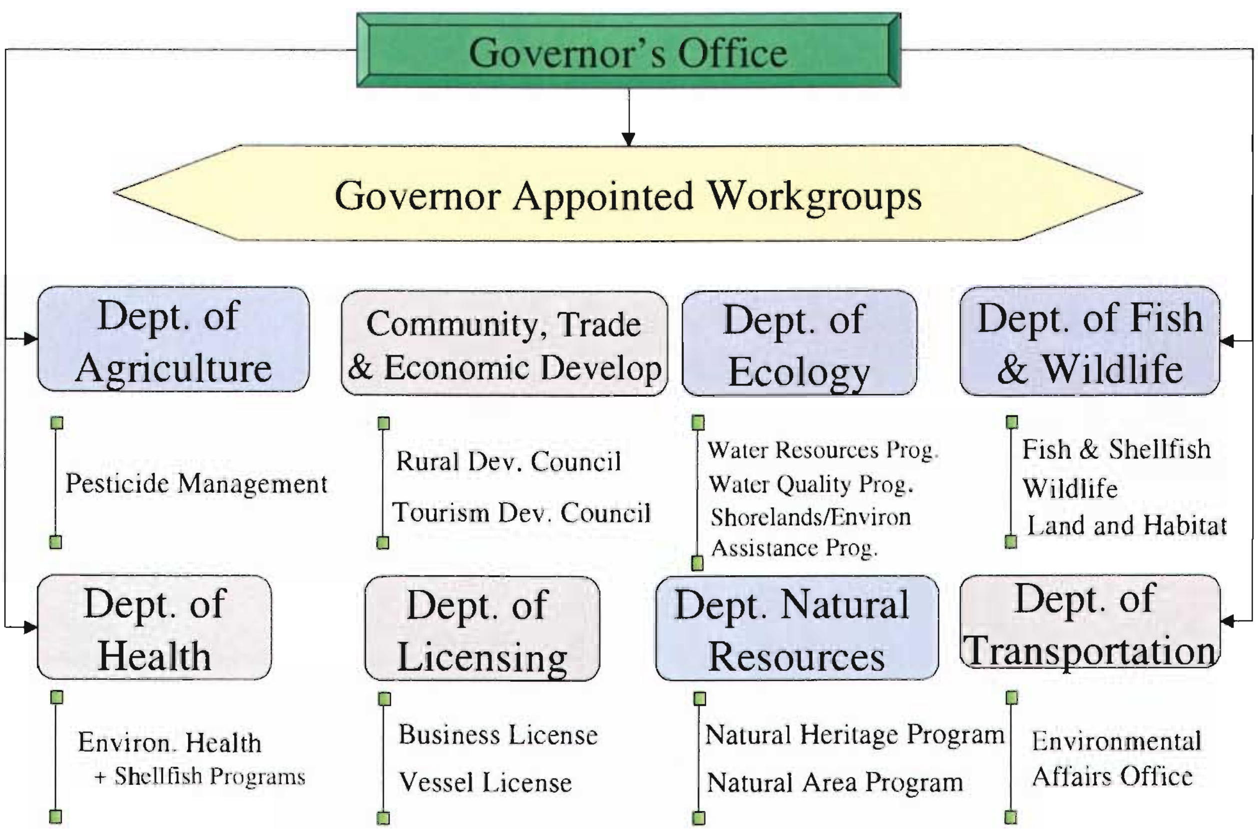


Figure 9.1. Washington State organizational chart includes eight departments directly involved in coastal resource, industry and activity management. The four departments represented in purple are directly linked to resource management. The Governor appoints all directors and most council members.

Results & Discussion

In pursuit of the PNCERS objective of understanding of how organizations and institutions influence the use and conservation of coastal ecosystems, the institutional mapping and analysis task devised information display methods that utilize our large data base of laws, institutions, and organizations. The linkages between various resource users and "external" institutional controls can be characterized as property rules, regulations, legal constraints, or contracts (i.e. voluntary, but enforceable, agreements). Property rules are the bundles of privileges and restrictions that pertain to the use of any property. In modern urban and suburban settings, for example, property rights to land are restricted in a number of ways: restrictions on construction of buildings under city or county land use zoning regulations, restrictions on uses that disturb or endanger neighbors under nuisance law, restrictions on discharge of polluted water by regulations under the Clean Water Act, and restrictions on building exterior appearance or landscaping or vehicle parking under privately agreed codes, covenants and restrictions (CCRs). Many of these property rules affect land ownership near the estuaries and coastal ocean areas in the PNCERS region. For example, owners and leaseholders of tidelands in Washington coastal estuaries frequently exercise their rights to raise oysters or to dig for clams. They, in turn, depend on the enforcement of restrictions on water pollutant discharges that reduce the wholesomeness of, or spread disease among shellfish. Zoning of land along mudflats for development of large-scale tourist facilities, for example, might pose a threat to water quality and shellfish growers. So, water quality regulations could help protect and enforce property rights of shellfish growers while weakening and restricting the rights of some shoreline land owners.

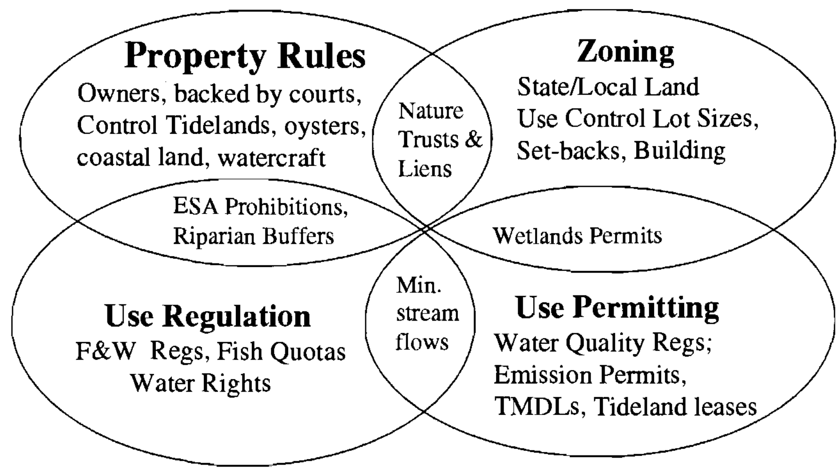


Figure 9.2. A typology of coastal ecosystem resource regulations.

Some activities are found to be directly limited through specific formal government rules. For example, channel dredging and navigation is regulated by the Army Corps of Engineers and salmon fishing is controlled by State and tribal regulations. But the bulk of human activity affecting the coastal systems occurs in a complex web of social customs, and rules promulgated by local and regional governments, special agencies and districts (Ports, water districts, watershed councils), and State and Federal governments. Water quality regulations under the Federal Clean Water Act, for example, are implemented by a State permit process that relies on self-reporting of pollution events. In Washington State the Federal Coastal Zone Management Act and the State Shorelines Management Act are developed and implemented by local governments. Both Pacific and Grays Harbor Counties have adopted Shoreline Master Plans (SMPs) under this authority,

Coastal and estuarine water use and quality are regulated by eight of Washington State's eighteen departments (Figure 9.1). Each department is responsible for specific aspects of the coastal ecosystem (water quality, State land use, navigation, human health risks, fish conservation, endangered species protection, etc.). The Department of Natural Resources, for example, leases tidelands to oyster growers, and the Department of Ecology implements water quality regulations.

The bewildering array of customary, legislative, contractual and cooperative controls on use of the bays, tidelands and nearshore lands can be understood through the use of a typology. Our typology or resource regulation (Figure 9.2) includes property rules, resource use regulations, resource use permits, and zoning rules. *Property rules* include all those customary rights and common law responsibilities and limitations pertaining to personal and business property. This includes nuisance law, liability law, and commercial or contract law. *Resource use regulations* comprise restrictions on private use of public or common resources; e.g. fishing regulations, water rights, and regulated closures of public lands and water to certain uses. *Resource use permitting* is distinguished from Use Regulation as it involves issuing a general permit to engage in a specific activity: a water pollution emissions permit, for example. *Zoning* is a restriction of private leased property that limits the location and/or size of structures. Not all regulations fall under just one category. Restriction of land for wildlife habitat under nature trusts or liens represents a hybrid of property rules and zoning. i.e. reservation of private land for a public purpose under contract. Regulation of minimum stream flows to achieve water quality (usually temperature) standards is a hybrid of water use regulation and water quality permitting. And restrictions on use of riparian or shore land to protect public wildlife or fish habitat is a hybrid of resource use regulation and property rules. This typology will facilitate further discussion and research on ecosystem management in the coastal estuaries.

To implement an ecosystem approach to managing coastal areas requires creative changes in the web of interweaving and overlapping authorities and rules. Much of the management activity is generated by government agencies. However, coordination and cooperation among government agencies, local governments and industries can be facilitated by non-governmental organizations such as the Pacific Oyster Growers Association and the Willapa Alliance. Special multiparty coordinating groups frequently form to deal with specific problems. The *Willapa Bay Water Resources Coordinating Council* is a Pacific County board appointed by the County Board of Commissioners that works to coordinate the community interests in multiple uses of Willapa Bay. The council oversees the drafting and implementation of the Willapa Bay Water Quality Plan and other similar documents. The *Pacific County Noxious Weed Control Board* oversees the noxious weed program for Pacific County interests. The Board targets weeds that are non-native, invasive and detrimental to the economy or environment. A prime example is the exotic cordgrass *Spartina alterniflora*, which has invaded mudflats and eelgrass beds used by the Oyster industry and which are potentially important to juvenile salmon.

To illustrate how the institutional environment connects to a specific coastal ecosystem use, we have developed web-like diagrams that illustrate several dimensions simultaneously. Our example (Figure 9.3) focuses on oyster growing in Willapa Bay. The Figure shows which local organizations interact with private oyster growers. Some organizations are mainly involved in regulating or protecting outside interests (e.g. public health): Washington Department of Health (closes oyster beds affected by poor water quality), US Army Corps of Engineers (permits construction & dredging in navigable waters), National Marine Fisheries Service (protects essential fish habitat for salmon), and Washington Department of Ecology (water quality monitoring and standards). Other or-

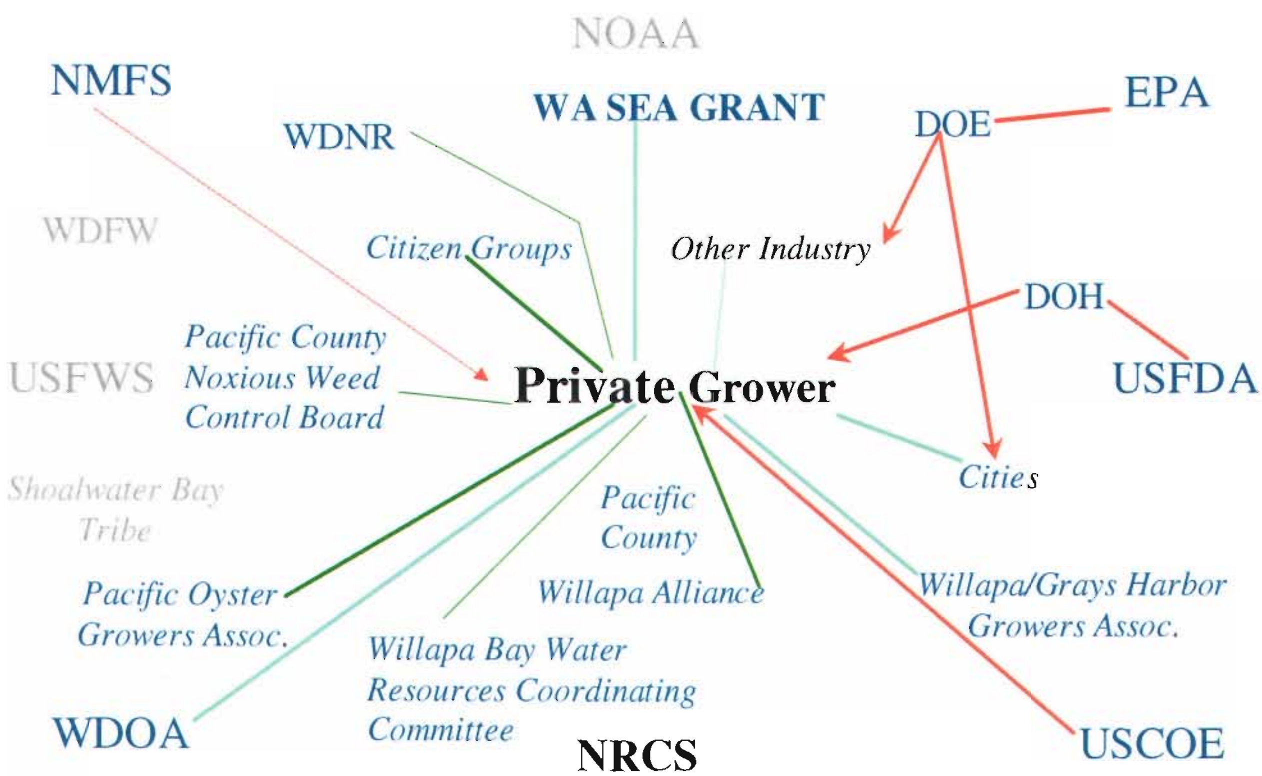


Figure 9.3. Institutional web for Willapa Bay oyster growers. Red lines indicate regulations; dark green lines indicate mutual interest; turquoise lines indicate assistance and support; and purple lines indicate possible conflicting interests. The light gray organizations (NOAA, WDFW, USFWS and Shoalwater Bay Tribe) are thought to have minimal direct interest in oyster growing practices.

ganizations have largely supportive roles: Washington Department of Agriculture (assists with pest management), Washington Sea Grant Program (research and public outreach support for marine industries). Yet others have mutual interests to promote: Pacific Coast Oyster Growers Association, Willapa Alliance, Washington Department of Natural Resources (leases state tidelands).

Institutional mapping provides a comprehensive, descriptive means of viewing and understanding the multitude of regulatory and other relationships between industries, communities, interest groups, and agencies. It also clarifies the link between legislative/judicial rules and management authorities that give these relationships staying power. Implementing management measures that protect or enhance the natural ecosystems of Pacific Northwest estuaries requires the mobilization and coordination of decision making through the webs of organizations and institutions depicted in these maps.

Integration & Interaction

By design, the Institutional Mapping and Socio-economics Baseline Project promotes integration and research interactions. Knowledge of organizations, laws, institutions, and decision processes that affect the PNCERS estuaries and regional demographic and economic trends of areas surrounding the estuaries serves as a foundation for the PNCERS social frame research. Our baseline understanding of these factors shaped the development of the coastal resident survey questionnaire (Rebecca Johnson) and the coastal practitioner survey (Tom Leschine). This knowledge will continue to be employed, especially in subsequent years when specific management questions and issues are addressed.

For more details on social frame integration refer to Social Frame Interactions and Integration, page 69.

References

Huppert, Daniel D., Michelle Pico, and Julie Nelson. 1999. Mapping of Institutions for coastal Ecosystem Management in Washington State. Draft report. School of Marine Affairs, University of Washington. 56 p.

Davis, Shannon, and Hans Radtke. 1999. Economic Description of Selected Coastal Oregon and Washington Counties. Prepared for PNCERS by The Research Group. Corvallis, OR

Washington Department of Ecology. 1995. Washington State Coastal Zone Management Program. Shorelands and Water Resources Program. Olympia. 76 p.

Applications

Publications:
The Research Group. 1999. Economic Description of Selected Coastal Oregon and Washington Counties. Part I and Part II. Corvallis, Oregon.

Presentations:
None

Workshops:
Kathleen Bell, Daniel Huppert, and Tom Leschine served as organizers and discussion leaders at the PNCERS "Protecting and Restoring Pacific Northwest Estuaries: Human Activities and Valued Ecosystem Components" Vancouver, Washington, December 8-9, 1999.

Kathleen Bell, Daniel Huppert, Rebecca Johnson, Tom Leschine, Michelle Pico, and Joel Kopp participated in monthly socio-economic group meetings.

Partnerships:
None

Personnel

Daniel Huppert, Associate Professor, University of Washington
Michelle Pico, Graduate Student, University of Washington
Courtland Smith, Professor, Department of Anthropology, Oregon State University
The Research Group, Corvallis, Oregon.

Public Perceptions, Attitudes, and Values .... Project 10

Rebecca Johnson, Kathleen Bell, and Daniel Huppert

Introduction


Rebecca Johnson

This project addresses the significance of public perceptions, attitudes, and values when considering threats to and management of the coastal ecosystem. Over the last year, we finalized the analytical framework of the coastal resident survey, incorporating different research hypotheses and interests and establishing linkages to the coastal practitioner survey research of the Environmental and Ecosystem Management Project (Tom Leschine) as well as to the ecosystem components focused on by other PNCERS projects (Julia K. Parrish, PNCERS PI Ray Hilborn, David Armstrong, Ron Thom, and Steve Rumrill).

The final questionnaire reflects a subset of the original proposed survey objectives: (1) to determine which valued ecosystem components (and their associated goods and services) are considered to be of most significance for residential choice, recreation, and quality of life in the five estuaries of the PNCERS study region; (2) to discover how changes in environmental and ecosystem conditions affect residential location choices, recreational use, and the economic values (willingness to pay) of specific ecosystem components; (3) to investigate a small number of specific social science research issues, contingent on convenience and feasibility (e.g., willingness to pay for improved coastal salmon stocks, relationship between ecosystem components and conditions and values held for residential locations); and (4) to compare attitudes and values toward coastal ecosystems across the different study sites and the two different states.

The survey questions seek the opinions of residents on characteristics of their community and residence, natural resource-based or outdoor recreation, threats to the local natural environment and natural resource management programs, threats to coastal salmon stocks, and coastal salmon preservation programs. While the majority of the questions explore the opinions of residents on community character, outdoor recreation, ecosystem components, and threats to ecosystem health, a subset of questions are aimed at gathering more practical information such as how residents gain information about the health of their local bay and what residents feel about current natural resource management and regulation efforts. In addition, the contingent valuation question that seeks respondents willingness to pay for programs that will preserve coastal coho salmon runs will allow for quantitative exploration of the basis of these willingness to pay values. Such values may prove useful to future decisions regarding coastal salmon stocks in the Pacific Northwest.

Finally, we believe there will be a large return from asking the same questions to residents over a large area along the Pacific Northwest Coast. In the past, surveys have focused on one specific area or one state. We look forward to comparing and contrasting the responses across the areas. By implementing the coastal resident survey, we have created a mechanism that will share the public perceptions, attitudes, and values of residents on a variety of important coastal issues.

Results & Discussion

Pre-test of Coastal Resident Survey Questionnaire

The coastal resident survey questionnaire was pre-tested in November of 1999 using a small sample of respondents. One hundred surveys were mailed to property owners residing within 30 miles of the respective estuaries. 20 surveys were mailed to respondents living in each of the five different areas (Grays Harbor and Willapa Bay, Washington; Yaquina Bay, Coos Bay, and Tillamook Bay, Oregon). Respondents were asked to complete the questionnaire and comment on sections or questions that were hard to understand and/or unclear. Of the 85 possible respondents (15 mailing addresses were invalid), 28 returned their questionnaires, resulting in a response rate of 33 percent. With no follow up activities and explicit recognition of the draft status of survey, this response rate is considered reasonable. The pre-test responses were closely examined to detect potential problems with the design of the survey questionnaire.

The pre-test responses were entered into a database and analyzed. In addition, written comments recorded on the surveys were also noted and entered into electronic format. The pre-test survey had five sections: (1) Characteristics of Your Community and Residence; (2) Outdoor Recreational Activities; (3) Health of the "Bay/Harbor" Environment; (4) Coastal Salmon Stocks; and (5) Demographics. Overall, we were excited by the responses and were particularly intrigued by the way these responses concurred with findings generated in the review of past surveys of coastal Oregon and Washington residents (Bell, 1999). Residents recognize the significance of ongoing economic and demographic change in their communities and have strong opinions about what they would like to see happen in the future. Second, residents acknowledge the importance of natural amenities to their communities, both socially and economically. Third, residents frequently note natural resources as the reason for locating and staying in their communities. Finally, residents have extremely strong opinions about threats to ecosystem health and the design and implementation of natural resource management strategies. It will be interesting to see whether or not the final responses will offer similar conclusions when compared and contrasted with the results of past surveys.

While the pre-test only involved a small sample, the results are useful in foreshadowing what may come out of this research effort in the future. The responses to a subset of questions are highlighted below. Prior to this discussion, some descriptive statistics of this sample are offered. The pre-test sample includes 28 individuals, 22 males and 6 females. The average age of the respondents is 58. Forty six percent of the respondents are retired and only 28 percent of the respondents have a college diploma or higher level of education. 71 percent of the respondents live in coastal communities year round, with an average length of residence of 24 years. Household incomes varies across the respondents, with 60 percent noting a household income of less than or equal to 50,000 dollars per year. Twenty one percent of the respondents indicated membership in an environmental or conservation organization and/or membership in a sporting or recreation group.

Several questions in the first section of the survey address issues related to coastal communities. These questions are included to help us better understand the role of the coastal ecosystem in these communities and attitudes about ongoing demographic and economic changes in these communities. It is interesting to compare the responses to questions where respondents were asked to rank the importance of different community attributes in affecting specific choices. Table 10.1 displays the responses to two questions on how important community attributes are in choosing to live in and move to a coastal community. Please note that the scores for these two questions are not comparable directly because of a difference in the wording of the questions. The scores for the "living" choice in Table 10.1 are the sum of 1 to 5 scale responses received for each community characteristic, with 5 being extremely important and 1 being not important. The scores for the "moving" choice are based on responses to a question that asked respondents to list the three most important community characteristics that influenced their choice to move to the coastal community. Here, scores were derived by assigning weights of 5, 4, and 3 to the top choices listed by each respondent and then summing over the sample. When asked about why they choose to live in a coastal community, high scores were given by respondents to attributes such as little traffic congestion, being near the ocean, views and scenery, clean water in the bay, recreation opportunities, and good public services. However, when asked why they moved to that community in the first place, attributes such as job opportunities, being near family and friends, having fewer people (low population density), being near the ocean, and climate/weather received the highest scores. Interestingly, many respondents noted ongoing changes in these community attributes. Over fifty percent of the sample believe that the cost of living, job opportunities, crime rate, and housing costs are getting worse in their community, while 30 percent feel health care and public services are improving in their community. Numerous respondents stated that increases in the cost of living and reductions in job opportunities are so great that they are considering moving away from their coastal community.

Table 10.1. Importance of community characteristics in choosing to live in and choosing to move to a coastal community. Scores indicate a ranking of importance of the different community attributes.

Community Characteristics	Score of Importance: Choosing to Live in a Coastal Community1	Score of Importance: Choosing to Move to a Coastal Community2
Little traffic congestion	106	12
Near ocean	105	31
Views and scenery	98	17
Clean water in the bay	98	4
Recreation opportunities	96	27
Good public services	96	4
Fewer people	95	33
Lower incidence of crime	94	3
Health care facilities	88	6
Climate/weather	85	29
Nice people	83	11
Good schools	75	15
Low cost of living	72	6
Job opportunities	69	45
Near family and friends	64	34

Notes:

1 Score is the sum of rankings of importance on a scale of 1 to 5. Each respondent was asked to rank all of the characteristics.

2 Score is the sum of rankings of the three most important characteristics. Each respondent was asked to list only three characteristics. Weights of 5, 4, and 3 were used to assign rankings.

The second section of the survey addresses recreation activities. Natural resource-based or outdoor recreation is an important factor in these communities for several reasons. First, the local economies rely on such recreation opportunities in promoting tourism. Second, recreation opportunities are an important source of value to the residents of and visitors to these areas. As a result, information on recreation behavior can be used to inform decisions regarding natural resource management. We included several questions on recreation to understand better if, how, and where residents recreate both regionally and in their communities. Overall, participation rates varied considerably by activity: fishing (64 %), beachcombing (64%), hiking/walking (57%), hunting (46%), boating (43%), clamming (39%), camping (25%), crabbing (21%), birding (14%), swimming (11%), surfing (4%), and kayaking (0%). Responses to questions on local recreation activities suggest some interesting trends in recreation near the PNCERS estuaries. In the last year, 85 percent of salmon or steelhead trips, 100 percent of clamming trips, 71 percent of crabbing trips, and 28 percent of birding trips were taken near the PNCERS estuaries. Because respondents were asked to indicate using a map where they recreated in the PNCERS estuaries, we will be able to assess which areas are more widely used for recreation and this may have implications for other PNCERS studies and resources. The small size of the pre-test sample prevents us from offering a discussion of the spatial distribution of recreation in the estuaries at this time.

Table 10.2. Importance of potential threats to the estuarine environment. Scores indicate a ranking of importance of the different potential ecological threats. Scores are calculated as the sum of responses on a 1 to 5 scale, with 5 being extremely important and 1 being not important.

Ecological Threats	Score of Importance
Oil Spills	95
Shoreline Development/Erosion	82
Decline in Fish Habitat	80
Spread of Spartina	72
Spread of Green Crabs	71
Municipal Sewage Discharge	66
Industrial Pollution	65
Logging in Upland Areas	62
Decline in Oyster Habitat	61
Water Runoff from Farms	60
Water Runoff from Urban Areas	53
Dredging of Channels	40

Notes:

1 Score is the sum of rankings of importance on a scale of 1 to 10. Each respondent was asked to rank all of the ecological threats.

The third section of the survey focuses on the health of the estuarine environment. In this section, we ask respondents for their opinion of threats to the local estuarine environment. Understanding public perceptions can help identify areas where outreach efforts may be targeted. In addition, public opinions of threats and management programs can be important because support for natural resource management policies from the community can affect the performance of those policies. Table 10.2 shows one ranking of ecological threats, where the ranking is again based on scores that reflect the sum of the (1 to 5 scale) responses indicating importance by ecological threat. Oil spills, shoreline development and erosion, and decline in fish habitat are considered the greatest threats based on this ranking. When asked who should be most influential in making natural resource management decisions, 40 percent of respondents noted existing partnerships between government and citizens. 30 percent believed county governments should be most influential. Only one respondent believed the federal government should be most influential, and only two felt that role should be assumed by the state government. These responses are consistent with other regional survey findings concerning who should be responsible for management (Bell, 1999). These pro-local sentiments were also reflected in the responses to questions about sources of information on bay environments. Widespread trust was placed in local resources (newspaper, community groups, local government) and not in the federal government and environmental groups. An open-ended question on opinions of natural resource management programs sparked much interest in the respondents. Several wrote numerous paragraphs sharing their attitudes of natural management programs.

The coastal salmon stock section of the survey discusses the decline of native salmon runs along the Pacific Northwest Coast. The section begins by asking respondents about their perceptions of the cause of salmon decline. Poor ocean conditions for salmon was cited as the greatest cause of decline, followed by degraded river habitats in forest lands, degraded marshes in the bay, and too much commercial fishing for salmon. After presenting respondents with detailed historical information on coastal chinook and coho salmon stocks, the survey then asks respondents to indicate their support or lack of support for a referendum that would establish a program that would protect coastal coho salmon runs. Respondents were asked to reveal their votes (yes or no) for two different proposed referendum programs, and the household costs (annual tax amount) of the programs were varied randomly over the surveys. 25 percent of the respondents voted yes, demonstrating support for both of the programs; while 75 percent responded no to both of the programs. This series of questions proved to be the most confusing for respondents and has been revised substantially for the final questionnaire. Because of these difficulties, we will not elaborate further on the pre-test responses.

Design of Final Coastal Resident Survey Questionnaire
During the fall of 1999, the coastal resident survey questionnaire was also circulated for further review by researchers with survey expertise. As noted previously, comments from many of the PNCERS researchers and partners were instrumental in revising early drafts. In general, we received positive feedback on the survey questionnaire from the 28 respondents who returned their questionnaires. However, the responses themselves suggested some sections of the survey were unclear. External reviewers made useful suggestions regarding the wording, design, and length of the final survey questionnaire.

Based on the pre-test responses and external reviews of the coastal resident questionnaire by individuals with survey expertise, Rebecca Johnson, Kathleen Bell, and Daniel Huppert worked as a group to finalize the coastal resident survey questionnaire. The final questionnaire attempts to meet the protocol designated by the NOAA Panel on contingent valuation in 1993 (Federal Register, 1993) and reproduced in Portney (1994) and strongly reflects the insights of Mitchell and Carson (1989) regarding the use of surveys to value public goods.

In February, 2000, 5,000 survey questionnaires were mailed to residents living within 30 miles of the different estuaries. In the final mailing, we hope to avoid a high rate of undeliverable responses. Based on discussions with the firm providing the mailing addresses, we are hopeful that the problems that arose in the pre-test will not persist. 1,000 survey questionnaires were mailed to each of the 5 different areas. The final distribution process follows generally the total design method (TDM) guidelines (D.A. Dillman (1978)) for high response rates and appropriate survey design. These guidelines are widely adopted by researchers conducting mail surveys. In cases where surveys are not returned, respondents will be mailed a post-card reminder 1 week after initial distribution and a second letter and survey 4 weeks after initial distribution.

Integration & Interaction

The coastal resident questionnaire broadly integrates with many of the other PNCERS research projects. The design of the survey reflects the research interests of both PNCERS social and natural scientists. Direct interactions are evident between the coastal resident survey and the research of Kathleen Bell and Tom Leschine. In addition, interactions with the research interests of Julia Parrish, Ray Hilborn, David Armstrong, Ron Thom, and Steve Rumrill are supported by the survey, as the survey questions focus on a range of PNCERS estuarine resources.

For more details on social frame integration refer to Social Frame Interactions and Integration, page 69.

References

Bell, K. 1999. Emerging Attitudes and Beliefs Regarding the Changing Coasts of Washington and Oregon: A Review of Coastal Resident Surveys. Draft manuscript, July 26.

Dillman, D.A. 1975. Mail and telephone surveys: the total design method. Wiley, New York.

Federal Register, 58, 4601, January 15, 1993.

Mitchell, R.C. and R.T. Carson. 1989. Using Surveys to Value Public Goods: The Contingent Valuation Method. Resources for the Future, Washington, DC.

Portney, P.R. 1994. The Contingent Valuation Debate: Why Economists Should Care. Journal of Economic Perspectives 8(4): 3-17.

Applications

Publications:
None

Presentations:
Dan Huppert, "Motivation, design, and pre-test results of the PNCERS coastal resident survey." PNCERS Eat and Learn Seminar Series, January 13, 2000.

Workshops:
Kathleen Bell, Daniel Huppert, Rebecca Johnson, Tom Leschine, Michelle Pico, and Joel Kopp participated in monthly socio-economic group meetings.

Partnerships:
Nancy Bockstael, Professor, Department of Agricultural and Resource Economics, University of Maryland. Provided review of coastal resident survey questionnaire.

Chris Carter, Oregon Department of Fish and Wildlife. Provided review of the coastal salmon section of the coastal resident survey questionnaire.

John Loomis, Professor, Colorado State University. Provided review of the coastal salmon section of the coastal resident survey questionnaire.

Ivar Strand, Professor, Department of Agricultural and Resource Economics, University of Maryland. Provided review of coastal resident survey questionnaire.

Mario Teisl, Assistant Professor, Department of Resource Economics and Policy, University of Maine. Provided review of coastal resident survey questionnaire.

Personnel

Rebecca Johnson, Associate Professor, Oregon State University
Kathleen Bell, Research Associate, University of Washington
Daniel Huppert, Associate Professor , University of Washington
Tom Leschine, Associate Professor, University of Washington
Andy Bennett, Graduate Student, University of Washington
Michelle Pico, Graduate Student, University of Washington
Laurie Houston, Faculty Research Assistant, Oregon State University, Department of Forest Resources

Environmental and Ecosystem Management .... Project 11

Tom Leschine, Andy Bennett, Michelle Pico, and Joel Kopp

Tom Leschine

Introduction

This component of the PNCERS socio-economic research agenda focuses on examining the ability and mechanisms for marine and coastal estuarine management systems to incorporate findings of PNCERS-like research efforts into decision making. It approaches this question in two ways. First, it seeks to understand the decision-making styles of the management organizations that affect the status of marine and coastal resources in the PNCERS region. Second, it seeks to understand how scientific and technical information enters this management arena and whether barriers exist that impede information being sought or utilized as fully as it might. In a sense, this work connects to all PNCERS research, as it addresses the basic working assumptions that we as PNCERS investigators hold about how PNCERS research will (or should) influence resource management in the PNCERS region.

At least three general hypotheses can be distinguished:

1. Good research with policy implication simply "finds its way" to the decision points where it can best influence the course of management and policy. (Knowledge Diffusion Model)

2. Concerted effort at "science communication" is required (or desirable) for policy-relevant scientific results to have the influence that "they should". (Orchestrated Science Communication Model)

3. Scientific information enters policy arenas in "point-counterpoint" fashion, introduced by position advocates in policy disputes. "Policy brokers" may act to filter or validate information that ultimately forms the basis for policies, or that drives policy change. ("Advocacy Coalition Framework" approach; developed by P. Sabatier and colleagues)

Specific questions being addressed by research in this area include:

- What is the capacity of the region's management institutions to incorporate PNCERS-like research results in ways that lead to more integrated management approaches and improve "sustainability" of the resource base? (Bennett and Leschine)

- How do environmental managers and scientists who work with the marine and coastal resources of the PNCERS region perceive the flow of information between science and management to operate? Do they perceive barriers that limit the ability of science to inform management decisions, and what steps would they like to see taken to improve this information flow? (Pico and Leschine)

- How effective is environmental management in the region at maintaining and improving estuarine condition, and what accounts for variations in management effectiveness? (Proposed Years 4 & 5 research)

A discussion of two research projects follows. The first, a "capacity assessment" of regional management institutions to incorporate PNCERS-like research results in ways that lead to more integrative management and a more sustainable resource base, is currently being completed by Andrew Bennett and Tom Leschine. The second examines perceptions of the flow of information between science and management. This latter research effort centers on a coastal practitioner survey and is being conducted by Michelle Pico and Tom Leschine with the assistance of Joel Kopp.

Capacity Assessment of Regional Environmental Planning and Management Institutions

A "capacity assessment" of regional management institutions to incorporate PNCERS-like research results in ways that lead to more integrative management and a more sustainable resource base is being completed by Andrew Bennett and Tom Leschine. This project has employed a case study approach, focusing on two important resource management institutions operating in Grays Harbor, Washington. A masters thesis by Andy Bennett is expected to be completed very soon. The Grays Harbor Estuary Management Task Force is the oldest estuary management organization in the region and one of the oldest such organizations in the United States, having been established in 1975. The Chehalis Basin Partnership (CBP) is much newer, now in just its third year of existence.

The Grays Harbor Estuary Management Task Force was founded originally to help implement and streamline a permit process that was becoming ever more complex and, from the standpoint of some local constituencies, burdensome. The introduction of shoreline permitting under Washington State's Shoreline Management Act in the 1970s had brought to the fore increasing conflict between the needs of environmental protection and the needs of economic development in the Grays Harbor region. One dispute, whether or not wetlands should be filled for the construction of a facility to build off-shore oil platforms, drew national attention to Grays Harbor. Out of this dispute came the creation of the Grays Harbor National Wildlife Refuge, one of the most important migratory shorebird feeding and resting areas on the West Coast.

The Task Force produced the Grays Harbor Estuary Management Plan (GHEMP), which has been adopted by the local governments into their Shoreline Master Plans and incorporated into the Washington State Coastal Zone Management Plan. Today, the agenda of the Task Force has broadened somewhat, and the plan is undergoing one of its periodic reviews. But GHEMP's primary focus remains on permitting issues.

By contrast, the CBP came into existence in 1998 as a means for local governments to exert more control over environmental management in the basin. Subsequent to its formation, it became the "Water Resource Inventory Area" (WRIA) lead entity for the Chehalis River Basin, part of a new statewide system of administrative areas established to promote integrated watershed management. As the WRIA lead entity, it is responsible for taking an inventory of scientific data on the watershed and developing a watershed management plan. It is also the lead entity for salmon recovery efforts in the watershed. In this role, the CBP's most immediate task is to evaluate proposed restoration projects in the basin for their suitability for funding under the state's Salmon Restoration Enhancement Fund. The fund was created by the state legislature in response to widespread decline in the state's salmon stocks, to the point where several were on the verge of being listed under the federal Endangered Species Act. These include the coho stocks of the outer coast, which have since been listed as 'threatened'.

We examined both organizations' current and recent past activities. For GHEMP, this meant we focused on the most recent five-year review of GHEMP (as mandated by its charter) and the process of defining adjustments to the GHEMP in light of the review. For CBP, this meant we examined the process of putting the basic CBP organization into place and defining what its mission would be. Interviews with organizational representatives, documentary review and attendance at meetings of the two entities revealed that they have or are now facing somewhat similar organizational issues.

Among questions both are facing are: how much to broaden or narrow the scope of their endeavors, how much to invest in coordination or collaboration with other local and regional entities and state and federal authorities, and how much to invest in monitoring or other efforts to understand the status of resources and resource threats in the region. Moreover, each organization's purview encompasses a geographic area in which human activity has the potential to directly affect the management efforts of the other (the Chehalis River is the dominant freshwater inflow to Grays Harbor). Thus each faces in theory at least the question of whether and how it should try to "integrate" its mission with that of the other (and, more generally, other entities with similar geographically or functionally overlapping missions).

Our research strategy was first to review relevant literatures to develop an "ideal" model of integrative resource management against which to compare each of the two entities. We examined literatures on a) estuarine, watershed and coastal management, b) "ecosystem management" (predominantly aimed at terrestrial, especially forested, ecosystems), and c) "systems" and organizational theory. As an example of the kinds of organizational characteristics that can be gleaned from such a review, the literature on "organizational learning" suggests a hierarchy of characteristics that can be applied to gauging an organization's ability to "learn." This hierarchy appears in Table 11.1.

Perceptions of the Flow of Information Between Science and Management

This research examines how environmental managers and scientists who work with the marine and coastal resources of the PNCERS region perceive the flow of information between

Table 11.1. Hierarchy of "organizational learning" characteristics applicable to examination of environmental planning management organizations affecting Grays Harbor, Washington.

Organization shows ability to recognize:
• Need for information not currently on hand (and can deploy resources to collect same)
• Management objectives not being met and approach must be modified accordingly (e.g. can design, implement and utilize monitoring to adjust operations)
• Objectives not being met and objectives must be changed (e.g., can shift to ecosystem-based, rather than single-species management)
• Need to plan for, and adapt and respond to: - uncertainty (environmental, or regarding decision consequences) - fallibility (the possibility of failing to carry out tasks as intended)
• Need for fundamentally different organizational arrangements (either to achieve different purpose or to achieve same purpose in new ways, as for example, through collaboration with other organizations)

science and management.. Specifically, we are exploring whether or not they perceive barriers that limit the ability of science to inform management decisions, and what steps they believe would improve this information flow.

This work in progress seeks generally to understand the environment in which PNCERS research might find application in improving the management of marine and estuarine resources in the PNCERS study region. This project is expected to result in a masters thesis by UW School of Marine Affairs student Michelle Pico. Our approach is to conduct a mail survey, which to date has been distributed to more than 300 environmental researchers and environmental managers in Washington (n=125) and Oregon (n=178) (refer to Table 11.2). The survey examines:

- How each of these two groups perceives its own vs. other group's "professional culture" and reward system
- Where difference is perceived, the extent to which it is seen to help or hinder the cause of science relevancy to, and use in, resource management decisions
- The effort that each group thinks is warranted to improve researcher - manager communication so that management-relevant research will be conducted and used in management

Most responses are elicited via closed-form questions. The survey also asks for the respondent's advice on how best to improve the flow of information between scientists and managers, however. Both researchers and managers are asked to identify the specific estuaries where they do their work or with which they are most familiar, and basic structural information on the "work life" of members of each group is also sought. All PNCERS investigators were targeted as part of the survey population.

Our research hypotheses, gleaned from both literature review and our own experience, are that:

- Both researchers and managers perceive differences in own vs. other group professional cultures and rewards;
- Both groups perceive these differences as affecting (+/-) the utility and actual use of research in management;
- (Null) There is no significant difference between the two groups in overall perception of the effect these differences have (+/-).

Table 11.2. Coastal practitioner survey: Preliminary assessment of the demography of respondents

A Preliminary Analysis of the Demography of Respondents to the Survey of Washington & Oregon Coastal Scientists & Managers

	Oregon	Washington	Overall
Surveys Mailed	178	125	303
Surveys Returned	54	47	101
Response Rate	30.3%	37.6%	33.3%
Percent Scientists*	21.2%	28.6%	22.8%
Percent Managers	55.8%	50.0%	49.5%
Percent Doing Both Equally	25.0%	16.7%	19.8%
Percent Whose Job is < Half Coastal Issues	37.7%	60.0%	46.5%
Percent Whose Job is > Half Coastal Issues	62.3%	40.0%	50.5%
Percent Whose Job is < Half Estuarine Issues	70.4%	74.5%	72.3%
Percent Whose Job is > Half Estuarine Issues	29.6%	25.5%	27.7%
Modal Educational Status	Master's	Master's	Master's
Affiliation			
Port Authority	0	0	0
Local Government	5	3	8
Federal Government	13	9	22
Tribal Organization	0	1	1
University/College	5	8	13
State Government	23	17	40
NGO/Non-profit	4	5	9
Business/Industry	1	3	4
Other	3	0	3

** All percentages are based on those responding. Respondents who rated themselves from 2.5 to 3.5 (on a scale from 1 to 5, with 1 being pure scientist and 5 being pure manager) were categorized as doing both equally. Those scoring below and above that range were categorized as scientists and managers, respectively.*

Results & Discussion

Capacity Assessment of Regional Environmental Planning and Management Institutions

Our use of a systems-theoretic framework, coupled with an ecosystem management perspective, enabled us to key on a few basic principles of organization and organizational conduct for our analysis. We looked for:

1. evidence of "feedback and control" (the ability to detect and correct error) as planning and management proceeds,

2. the relationship between problems of concern to the organization and its jurisdictional boundaries and management tools-in-use,

3. the extent of "integration" present, i.e., coordination or collaboration with other entities capable of affecting the same problems both at similar jurisdictional levels (local and county—'horizontal' integration) and at higher jurisdictional levels (state and federal—'vertical' integration),

4. extent of public involvement, and

5. evidence for "emergent" system properties (extent to which the system exhibits such desirable whole-system characteristics as stability, resilience, adaptability to environmental change, etc.) Evidence that biodiversity was being preserved or enhanced or that sustainable resource use was resulting from management is an example.

Several hypotheses guided our inquiry. Among them, that:

- Relatively greater incentives exist to plan than to implement (thus rendering completion of the feedback loop to assessment and adjustment relatively difficult).

  Underlying cause: Fiscal costs of (centralized) planning are much less than organizational costs of (decentralized) implementation (and in fact can be seen as an organizational "good").

- Relatively little attention beyond regulatory compliance is given to horizontal and vertical integration compared to attention to own mission;

  Underlying cause: Costs of integration are perceived to outweigh benefits, or costs of "going own way" perceived as less than costs of integration.

- Incentives for public participation in estuarine resource management are relatively low, with result that local management organizations in turn have low incentive to view problems from the "multiple perspectives" that form the foundation of ecosystem-based management.

  Underlying cause: A perceptual gulf exists between environmental managers and ordinary citizens, who interpret managers' claims that "environmental" problems exist as further evidence of continued economic and community decline.

Our assessment of the operations of the two groups largely confirms these hypotheses, particularly for the GHEMP task force. For the CBP, which is very new, our conclusions must necessarily be more tentative.

The CBP, with a specific habitat protection and restoration mandate, and state funding for at least some of the projects it recommends, appears more likely to make good use of appropriately targeted scientific information than the GHEMP task force at this point. Currently lacking buy-in from surrounding communities on several aspects of its proposed plan revision, it appears that the GHEMP task force would value new scientific information pointing to resource sensitivity to human-induced harm less than it would value information that would help facilitate and expedite permit review, and hence "buy in" from local communities. GHEMP has never conducted environmental monitoring nor has it sponsored directed study of the Grays Harbor environment. The CBP would presumably welcome information that helped it develop habitat restoration and protection spending priorities, but might find some types of information more conducive to conflict than to cooperation. The latter category potentially includes information suggesting that local habitat restoration efforts are not likely to be successful, or that habitat restoration and protection opportunities outside the Chehalis Basin are superior to those that lie within it. The CBP has a specific mandate to assemble scientific information relevant to its task, something GHEMP's overseers have never had.

The CBP appears to be open to considerable variation in how it approaches its basic mission of focusing on the Chehalis Basin. Possibilities appear even to include some that could extend the partnership to embrace economic development initiatives. As such, CBP has the character of a governmental enterprise whose way of doing business has been influenced by the "reinventing government" movement championed by Vice President Al Gore and others at the federal level. For example, some CBP representatives take an entrepreneurial stance on the organization's budget, actively seeking ways to build a bigger funding base than the organization has at present. By contrast, GHEMP task force members tend to see the budget as setting the limits on the aspirations that the organization can reasonably afford to have.

Neither organization has a strong citizen participation component to validate its endeavors at this point, and representatives of each view the lack of broader participation from the surrounding communities as a problem. Neither sees partnership with the other, even if limited to defining an agenda of problems of mutual interest, as offering very clear benefits. While CBP could be accused of exhibiting youthful enthusiasm as yet untempered by the lessons of advancing age, GHEMP has suffered its share of disappointments over its long life. Chief among these is a long-standing desire to work more closely with state and federal entities whose jurisdictions overlap with GHEMP's permit authority under the state's Shoreline Management Act. The ability to influence permit-review at all levels, so that it is more compatible with the local interest in pursuing economic development, was a primary motivation for forming GHEMP in the first place, and it has gone largely unrealized. The reason appears to be lack of interest (and perhaps authority) by higher level entities, upon whom GHEMP has been able to exert little influence.

Neither these benefits of cooperation nor other offsetting benefits have materialized, which may largely explain the modest level of its accomplishments over the past quarter century. We speculate that the CBP will similarly have realize benefits of an economic nature from its efforts at enhancing the Chehalis Basin (e.g., salmon stock recovery that stimulates segments of the local economy that derive income from recreational or commercial fishing or tourism) if it is to sustain its current levels of enthusiasm.

Perceptions of the Flow of Information Between Science and Management

Systematic analysis of survey results has not yet begun. Currently we are concentrating on efforts to maximize our response rate and the diversity of the segments of the coastal and estuarine research and management communities represented in the respondent population. The brief discussion below addresses only some of the basic demographic characteristics of those who have responded to the survey to date.

Among interesting preliminary findings are that the distinction between who is a researcher and who is a manager is not as clear as one might expect. Many, if not most, respondents feel their jobs require them to do a little of both. Only about 25% of respondents classify themselves as having purely management or purely research jobs. Another preliminary general finding concerning this group is that relatively few individuals work exclusively or even a majority of the time on estuarine or coastal problems (refer to Table 11.2). Oregon researchers and managers appear somewhat more likely to focus predominantly on estuarine or coastal issues than do their counterparts in Washington. This may reflect differences in how the two states organize their coastal and estuarine programs, a question we plan to pursue through examination of the results of the "institutional mapping" project described elsewhere in this report.

Integration & Interaction

The two projects reported on here both contribute to our understanding of how PNCERS research in the natural and social sciences can contribute to improved management of coastal and estuarine ecosystems. The proposed years 4 and 5 project to which they lead involves direct collaboration with PNCERS natural science investigators (possibly Julia Parrish, Steve Rumrill, Ron Thom, and related post-docs). The Environmental and Ecosystem Management component of the PNCERS Social Frame Studies is highly integrated with other aspects of the Social Frame work, addressing as it does the management implications of improved understanding of natural and socio-economic resource systems. The coastal practioners survey project, when completed, is expected to be highly relevant to the outreach activities of the PNCERS project management team. Active collaboration with them on how to put into practice the ideas generated by the survey on strengthening the management-research linkage is anticipated.

For more details on social frame integration refer to Social Frame Interactions and Integration, page 69.

References

A.K. Bennett. 2000. Environmental Management Systems: the Evolution of Environmental Planning in Grays Harbor. Unpublished masters thesis, School of Marine Affairs, University of Washington.

Applications

Publications:

A.K. Bennett. 2000. Environmental Management Systems: the Evolution of Environmental Planning in Grays Harbor. Unpublished masters thesis, School of Marine Affairs, University of Washington.

Presentations:

Andy Bennett, "Estuarine Ecosystem Management: Putting together all of the Pieces of the Restoration Puzzle". Society for Ecological Restoration, September 17, 1998, Tacoma, Washington.

Leschine, T. and Andy Bennett, "Estuarine Ecosystem Management: Are we ready for it?" PNCERS Eat and Learn Seminar, March, 1999, University of Washington, Seattle, Washington.

Workshops:
Tom Leschine served as an organizer and discussion leader at the PNCERS "Protecting and Restoring Pacific Northwest Estuaries: Human Activities and Valued Ecosystem Components" Vancouver, Washington, December 8-9, 1999.

Kathleen Bell, Daniel Huppert, Rebecca Johnson, Tom Leschine, Michelle Pico, and Joel Kopp participated in monthly socio-economic group meetings.

Partnerships:
Grays Harbor County Planning Department. Provided results of survey of all county landholders regarding issues of importance to landholders.

Brett Dumbauld, Washington Department of Fish and Wildlife. Provided review of the coastal practitioner survey, as did PNCERS investigators Julia Parrish, Steve Rumrill, Ron Thom, and Andrea Copping.

Personnel

Tom Leschine, Associate Professor, University of Washington
Andy Bennett, Graduate Student, University of Washington
Michelle Pico, Graduate Student, University of Washington
Joel Kopp, Research Assistant, University of Washington.

Social Frame Interactions and Integration

Kathleen Bell

Introduction

As the social research program has evolved, two types of integration have been emphasized. The first type involves the integration of the different social science research projects, while the second type reflects the integration of social and natural science research projects. Although different in some aspects, both types of integration serve the same goal: understanding how humans use, value, and impact the coastal ecosystems and marine resources of the Pacific Northwest and, in turn, how management affects the status of the Pacific Northwest coastal ecosystems and marine resources.

Much of the social research stems from the following PNCERS research objectives:

1. developing predictive models that support adaptive management of living marine resource and/or human use, and;

2. evaluating the appropriateness of management practices and programs that affect coastal ecosystems and living marine resources.

Recognizing the ultimate goals of supporting and improving management processes, the social frame has been carefully designed to inform a final set of projects tailored to meet these specific research objectives. There are currently four projects falling under the Social Frame: Institutional Mapping and Socio-economic Baseline (Daniel Huppert); Public Perceptions, Attitudes, and Values (Rebecca Johnson), Environmental and Ecosystem Management (Tom Leschine), and Integrated Ecological-Economic Modeling (Kathleen Bell). Together, these projects address the human dimension of the PNCERS project, weaving together knowledge of economic and demographic trends, public attitudes, governance, human behavior, and economic values. Proposals for future years call for narrowing the research to two projects, one on management and one on the use and value of the PNCERS coastal ecosystems and marine resources. These two projects will rely heavily on the findings of the previous social frame projects, building on the foundation established during years 1 through 3.

Integration with ongoing natural science projects is also a priority of the social frame. Several of the social science projects have been designed specifically to incorporate aspects of the marine resources and coastal ecosystems under study and have developed with considerable input from the natural science investigators. It is likely that active integration of this type will continue to gain prominence in the final years of the PNCERS research project.

Results and Discussion

The Institutional Mapping and Socio-economic Baseline Project (Daniel Huppert) established a baseline understanding of the organizations, laws, institutions, and decision processes that affect the PNCERS estuaries and the regional demographic and economic trends of counties surrounding these estuaries. When examining the latter, attention was given to the connections between estuarine natural resources and these trends. The Socio-economic Baseline information influenced the development of the coastal resident survey questionnaire (Public Perceptions, Attitudes, and Values Project; Rebecca Johnson). Several questions on the coastal resident survey seek the attitudes of respondents concerning economic and demographic trends that are noted in the socio-economic baseline research. In addition, the institutional mapping research fed directly into the development of the coastal practitioner survey (Environmental and Ecosystem Management, Tom Leschine). The sample population of the coastal practitioner survey was identified using a database of organizations constructed as part of the institutional mapping research. The institutional mapping research is also likely to further supplement both the Environmental Ecosystem Management Project and the Integrated Ecological Economic Modeling Project in the future, as these projects scrutinize specific management objectives and interactions between the ecological and economic systems.

The Public Perceptions, Attitudes, and Values Project (Rebecca Johnson) centers on the coastal resident survey that seeks the opinions of residents on characteristics of their community, outdoor or natural resource-based recreation, threats to and management of the local natural environment, and preservation of coastal salmon stocks. The design of the survey strongly reflects the goal of integration. The survey and its analytical framework were developed by the social frame researchers as a group. This joint effort ensured that numerous research interests would be met and that the design of the survey would be appropriate given our understanding of the local communities, government, and other environmental planning organizations. Two direct interactions with other social science research projects emerged as significant. First, a subset of questions on the coastal resident survey also appear on the coastal practitioner survey (Environmental and Ecosystem Management Project; Tom Leschine). This duplication will allow for comparison of the responses of coastal residents and managers. Second, one question on the coastal resident survey related to characteristics of residences and/or location is designed to parallel the property value modeling (Integrated Ecological-Economic Modeling Project; Kathleen Bell) research. Responses to these questions will act as a supplement to the findings of the empirical model. Finally, the coastal resident questionnaire broadly integrates with many of the PNCERS natural science projects. For example, the recreation activity and the threats to the natural environment questions focus on activities related to many of the PNCERS marine resources such as seabirds, salmon, crabs, and habitat. In addition to the influence on the survey design, numerous natural science PIs (Julia Parrish, Steve Rumrill, Ron Thom, and PNCERS PMT member, Andrea Copping) were asked to serve as reviewers of the survey and offered useful comments regarding the design of the survey.

The Environmental and Ecosystem Management Project (Tom Leschine) focuses on examining the ability and mechanisms for marine and coastal estuarine management systems to incorporate findings of PNCERS-like research efforts into decision making. It approaches this question in two ways. First, it seeks to understand the decision-making styles of the management organizations that affect the status of marine and coastal resources in the PNCERS region. Second, it seeks to understand how scientific and technical information enters this management arena and whether barriers exist that impede effective information flow. By design, this work connects to all PNCERS research, as it addresses the basic working assumptions that we as PNCERS investigators hold about how PNCERS research will (or should) influence resource management in the PNCERS region. By addressing the management implications of improved understanding of natural and socio-economic resource systems, this research is highly integrated with other aspects of the social frame. As noted previously, the research of this project has been shaped by the Institutional Mapping and Socio-economics Baseline (Daniel Huppert) and the Public Perceptions, Attitudes, and Values (Rebecca Johnson) research. The coastal resident practitioner survey is a particularly strong indicator of this, as it was designed in parallel with the coastal resident survey and builds on the organizational understanding gleaned by the institutional mapping project. Numerous PNCERS natural science investigators were instrumental in the review of the practitioner survey and many will serve as respondents. The proposed years 4 and 5 of the project will involve more direct collaboration with PNCERS natural science investigators (possibly Julia Parrish, Steve Rumrill, Ron Thom, Curtis Roegner, and Libby Loggerwell).

The Integrated Ecological-Economic Modeling Project (Kathleen Bell) focuses on the feedbacks between ecological and economic systems. Similar to the case of the Environmental and Ecosystem Management Project, this research broadly integrates because of its focus, the interactions of ecological and social/economic systems. Currently, research on this project is divided into two tasks. One involves property value modeling to detect whether or not price differentials in the residential property market reflect variations in the quality and type of natural environments found in the PNCERS estuaries. The second task entails the collection of data on human activities that are linked with potential stressors of the marine and coastal ecosystem. Both tasks are integrative in nature. As noted previously, in collaboration with Rebecca Johnson (Public Perceptions, Attitudes, and Values), the coastal resident survey questionnaire was designed to include a question on location preferences. This question will allow for the direct comparison of survey responses regarding the influences of different factors on location choices with those suggested by the empirical modeling of property values. This comparison will offer a unique opportunity to contrast the empirically derived and stated preferences of residents. In addition, since the survey covers residents from all five estuaries, statements about location preferences can be compared across areas. We are particularly interested in responses regarding ecological attributes such as proximity to certain types of land and water bodies. Our data collection efforts are specifically tailored to the research interests of the PNCERS natural science investigators. For example, data on human activities are being collected to enable basic linking of human indicators of stress (population density, developed land area) with research into the marine resources of the Pacific Northwest coastal ecosystem, including seabirds, salmon, and crabs (Julia K. Parrish, Ray Hilborn, and David Armstrong, respectively). In addition, more extensive collaboration continues with Ron Thom and Steve Rumrill regarding the collection of human related data. These investigators have shared GIS data documenting historical habitat changes as well as qualitative assessments of the human stressors associated with these changes. Data are now being collected to supplement their analyses and portray the social dimension of these changes.

Research Program Management

Julia K. Parrish and Sara J. Breslow

Introduction

The PNCERS Research Program is managed quarter time by Julia Parrish, with 80% time technical assistance by Sara Breslow. In addition, the PNCERS Steering Committee, composed of David Armstrong, Dan Huppert, Steve Rumrill, and Julia Parrish, is charged with directing the vision of the research program, including decisions about funding allocations. In this past year, the primary accomplishments of the management team have been to:

Parrish:

- Meet and coordinate with PNCERS Program Coordinator and Program Management Team (PMT).
- Assist Program Coordinator in the development of the annual Manager's Workshop.
- Make presentation on PNCERS research program to Coastal Ocean Programs staff.
- Make additional presentations on PNCERS research to groups and organizations collaborating with PNCERS or interested in PNCERS research results.
- Assist PMT in development of a PNCERS slide show.
- Assist PMT in development of a PNCERS brochure.
- Assist Program Coordinator in the development of a PNCERS research video.
- Assist PNCERS researchers in coordinating project and collaboration meetings.

Steering Committee:

- Issue a call for Year 4 specific proposals, based on the outcome of the All-Hands Meeting. Review proposals and associated budgets. Prepare a final Year 4 workplan and research budget.
- Hold an Annual All-Hands meeting, attended by 31 people (see Appendix A: All-Hands Meeting Report).

Breslow:

- Produce a Progress Report (November 1999).
- Produce an Annual Report (April 2000).
- Organize the Annual All-Hands meeting
- Coordinate and facilitate Eat-and-Learn seminar series.
- Develop the PNCERS metadatabase (see Metadatabase, next page).

Eat & Learn Seminar Series

This year's Eat & Learn Seminar Series, like last year, provided a lively and informal forum for PNCERS researchers, collaborators, and others to both learn about ongoing research and participate in shaping its direction. This years' series, which took place Winter Quarter, 2000 at the University of Washington, was even better attended than last year, attracting people from the nearby NMFS lab, as well as faculty and students from both the fisheries and zoology departments. Seminar speakers included those PIs who did not get a chance to present last year, PNCERS' three post-doctoral students, a graduate student and a member of the Program Management Team (Table M.1.).

One of the most important functions of the seminar series is to foster collaboration among researchers and integration of research projects. Presentations and discussions this year emphasized collaborative work that was initiated or built on during the January 20-21 All-Hands meeting.

For example, Julia Parrish presented plans to work with EPA collaborators Ted DeWitt and Pete Eldridge on including seabirds in estuarine food web models. Using stable isotope analyses, they will distinguish the percent of the diet of the Yaquina Bay common murre colony that comes from the nearshore versus the estuarine systems.

Gordon Swartzman focused his seminar on the collaborative aspects of his research on fish and plankton distribution. Most significantly, he and Curtis Roegner, with help from David Armstrong and Barbara Hickey, are working together on the question of how larvae travel from ocean feeding areas to estuarine breeding grounds without getting swept away in southwest currents. Several hypotheses have been put forward, including avoidance of currents through diurnal vertical migration.

Elizabeth Logerwell, PNCERS' most recently hired postdoctoral fellow, explained how her previous work with modeling California current sardine survival could be applied to survival analyses of Pacific Northwest salmon smolts, and how it could integrate with nearshore dynamics discussed at the all-hands meeting.

Table M.1. PNCERS Eat & Learn seminar series schedule, Winter quarter, 2000.

Jan 6	**Bob Bailey**	PNCERS: Concept and Reality
Jan 13	**Dan Huppert**	Motivation, design and pre-test results for the PNCERS Resident Survey
Feb 3	**Arni Magnusson**	Coded-wire-tag analysis of chinook and coho survival rates in the Northwest
Feb 10	**Julia Parrish**	The secret language of seabirds: seabirds as environmental indicators
Feb 17	**Curtis Roegner**	Larval crab abundance and distribution in relation to physical oceanographic signals
Feb 24	**Kathleen Bell**	Understanding the Use of Lands in the PNCERS Region: A Foundation for Integrated Research
Mar 2	**Gordon Swartzman**	Fish and plankton patches in the California Coastal Ecosystem (CCE) and their relationship to birds, salmon and ocean currents
Mar 9	**Libby Logerwell**	Spatially explicit energetics and California Current sardine: Are mesoscale oceanographic features areas of exceptional prerecruit production?

In addition to fostering integration among individual PNCERS projects, the Eat-&-Learn seminars act on a broader level to integrate disciplines. A seminar series in which presentations range in subject matter from sociological survey design to salmon smolt survival offers natural and social scientists an opportunity to learn about, and question, the methods and assumptions particular to each others' disciplines. In doing so, they bring fresh perspectives to challenges in research design and data analysis.

Metadatabase

The metadatabase currently contains information on approximately 70 different databases relating mainly to oceanography, meteorology and fisheries (Table M.2). Fifty of these records were added since last year. Plans are to provide an equal amount of information on socioeconomic and biological databases. PNCERS researchers draw on the metadatabase for a variety of purposes, from plotting sea surface temperature for a particular place and time, to assessing what kinds of GIS information is available for Willapa Bay. Like these researchers, database managers respond with great enthusiasm to the imminent on-line PNCERS metadatabase, recognizing its potential to fill urgent data dissemination and research needs. So far, about 40 database managers from agencies, research institutions and organizations around the country have confirmed the accuracy of one or more database entries. In general, responses have been positive and enthusiastic. Here are a few of the comments we have received regarding the PNCERS metadatabase:

"With the web growing every day, it becomes harder and harder to find what you're looking for, so your project sounds great .... The page looks really good and I appreciate your efforts to promote my web site." – Ray Slanina, Coast Watch West Coast Regional Node, La Jolla, California.

"Indeed, it looks like you've done a very thorough job of profiling RMIS and CWT data exchange procedures." — Jim Longwill, Regional Mark Processing Center, Pacific State Marine Fisheries Commission, Gladstone, Oregon.

"We would appreciate knowing when it is on-line ... so we can use it too!" – Julie Thomas, Coastal Data Information Program, Center for Coastal Studies, Scripps Institute for Oceanography, La Jolla, California.

In addition to this kind of encouragement, database managers have offered database and website design tips, such as ways to streamline data confirmation requests, ways to make the information more readable and intuitive, and ways to standardize a web site so it is easy to navigate. Others have made suggestions for further contacts and other sites to explore for ideas and information, such as the Bering Sea and North Pacific theme page and California's OCEAN (Ocean and Coastal Environmental Access Network). A single email sent to Scripps Institute of Oceanography was broadcast widely and resulted in 5-10 responses from researchers interested in the metadatabase, or offering information about databases they

Table M.2. Databases currently entered in the PNCERS metadatabase.

	Database Title
1	Advanced Very-High Resolution Radiometer (AVHRR) Digital Images
2	BC Lighthouse Data
3	Buoy Weather Data — Canada
4	CalCOFI Data
5	COADS on CD-ROM
6	Coast Watch — West Coast Regional Node
7	Coastal Data Information Program (CDIP) Data
8	Coastal Zone Color Scanner (CZCS) Data Access
9	Comprehensive Ocean-Atmosphere Data Set (COADS)
10	CO-OPS West Coast Station Products
11	Daily Temperature and Precipitation Data (Western U.S.)
12	Digital Orthophoto Quadrangles (DOQs)
13	Dynamic Estuary Management Information System (DEMIS)
14	El Nino Theme Page
15	EPIC: A System for Management, Display, and Analysis of Oceanographic in-situ Data
16	Essential Fish Habitat (EFH)/Pacific Coast Salmon Plan
17	Global OTIS Archive
18	Government Information Sharing Project
19	Hatfield Marine Science Center Seawater Database
20	Hydrologic Units Maps of the Conterminous United States
21	InfoRain — Bioregional Information System for the North American Rain Forest Coast
22	IRI/LDEO Climate Data Library
23	Joint Institute for the Study of the Atmosphere and Ocean (JISAO) Climate Data Archive
24	Landsat MultiSpectral Scanner Imagery
25	Landsat Thematic Mapper Imagery
26	Line-P Data
27	Live Access to Climate Data via FERRET
28	Microsoft Terraserver
29	MultiSpectral Scanner Landsat CD-ROM
30	National Atmospheric Deposition Program, National Trends Network (NADP/NTN) Data
31	National Data Buoy Center (NDBC) Data
32	National Environmental Data Index
33	National Water Information System - Web (NWISWeb)
34	NCEP/NCAR Reanalysis Other Flux Data
35	NCEP/NCAR Reanalysis Pressure Level Data
36	NCEP/NCAR Reanalysis Surface Data
37	NCEP/NCAR Reanalysis Surface Flux Data
38	NCEP/NCAR Reanalysis T62 Spectral Coefficients
39	NCEP/NCAR Reanalysis Tropopause Level Data
40	NOAA Marine Environmental Buoy Database
41	Nonindigenous Aquatic Species Database
42	North American Breeding Bird Survey (BBS)
43	Olympic Natural Resources Center Clearinghouse for the Olympic Peninsula
44	Pacific Fisheries Information Network (PacFIN)
45	Pacific Northwest Index (PNI)
46	Pacific Northwest Weather Records Search
47	Pacific Seabird Monitoring Database
48	PFEL Air/Ocean Data from NOAA Moored Buoys
49	PFEL Coastal Upwelling Indices
50	PFEL Comprehensive Air/Ocean Flow Indices
51	PFEL Live Access Server
52	PFEL Monthly Mean Pressure Maps
53	PFEL Sea Surface Temperature Maps
54	PSMFC Economics Data Program (formerly EFIN)
55	Recreational Fisheries Information Network (RecFIN)
56	Regional Mark Information System (RMIS)
57	SeaWiFS Project Image Archive
58	SIO Shore Station Information
59	Social Development Research Group Diffusion Consortium Archival Database
60	Standardized Precipitation Index (SPI)
61	StreamNet — The Northwest Aquatic Information Network
62	Surface Observed Global Land Precipitation Variations
63	The Data Zoo
64	USGS Land Use and Land Cover Data (LULC)
65	USGS National Stream Water-Quality Monitoring Networks (WQN) Data
66	USGS Real-Time Water Data
67	USGS Suspended-Sediment Database
68	Western U.S. Climate Historical Summaries
69	Willapa Watershed Information System CD-ROM and Spatial Data Catalog
70	World Ocean Atlas 1998 (WOA98)
71	World Ocean Database 1998 (WOD98)

were in charge of. A similar response rate occurred when an email was sent to British Columbia's Institute of Ocean Sciences. As these examples illustrate, database contacts have been remarkably helpful and resourceful in this effort.

We are currently working on the process of putting the metadatabase on the web, using the web-database connectivity program, Drumbeat 2000. Plans are to complete this project by the end of April 2000, with the intention of informing PNCERS researchers, collaborators, and other interested parties of the metadatabase site by the middle of May, 2000 (Table M.3).

Table M.3. Metadatabase time-line.

March 1999	• 20 databases entered
March 2000	• 75 databases entered • 40 database contact confirmations received • prototype search engine in Drumbeat established
May 2000	• build simple metadatabase search engine on web • inform database managers of web site
April 2000	• hire new metadatabase manager
Summer 2000	• work out bugs in on-line search engine • double (at least) number of databases entered
Fall 2000	• continue metadata entry • scope out options to upgrade on-line search engine

All-Hands Meeting

Sara Breslow, Julia K. Parrish, and Elizabeth A. Logerwell

Introduction

The third annual PNCERS All-Hands Meeting was held at the University of Washington's Center for Urban Horticulture on January 20 and 21, 2000. Thirty-three people attended, including all PNCERS PI's (except Ray Hilborn, in New Zealand), postdoctoral research associates, research staff, graduate students; several collaborating researchers; as well as PNCERS and Coastal Ocean Program (COP) managers (Table A.1). The meeting was structured to foster collaboration among researchers and integration of research projects, in the directions suggested by the Collaborations Diagram (Figure 1, page ix). Whereas the foundation of PNCERS has always been based on the independent research projects, two major themes have been emerging from current PNCERS research: 1) the broad scale role and consequences of physical forcing, and 2) the more local interplay between human activities and environmental change. The former defines much of the work in the nearshore environment, as physical forcing and dynamic variability in oceanographic and atmospheric forcing factors exert a large influence on trophic structure, ecosystem function, and ecosystem production of goods and services in the nearshore. The latter defines much of the work in the estuarine environment, as human activities and

Table A.1. Attendees at the PNCERS All-Hands Meeting, January 20-21, 2000.

Name	Title	Affiliation
Armstrong, Dave	PNCERS PI	School of Fisheries, UW
Bailey, Bob	PNCERS PMT	Oregon Coastal Management Program
Banahan, Sue	COP Program Officer	NOAA Coastal Office, Washington DC
Banas, Neil	PNCERS Graduate Student	School of Oceanography, UW
Bell, Kathleen	PNCERS Postdoctoral Fellow	School of Marine Affairs, UW
Borde, Amy	PNCERS Technician	Battelle Marine Sciences Lab, WA
Ric Brodeur	Collaborator	Northwest Fisheries Science Center, NMFS, OR
Breslow, Sara	PNCERS Technician	School of Fisheries, UW
Copping, Andrea	PNCERS PMT	Washington Sea Grant Program
De Witt, Ted	Collaborator	USEPA Environmental Effects Research Laboratory, OR
Dumbauld, Brett	Collaborator	Washington Department of Fish and Wildlife
Eldridge, Pete	Collaborator	USEPA Environmental Effects Research Laboratory, OR
Field, John	PNCERS Graduate Student	School of Fisheries, UW
Gunderson, Don	PNCERS PI	School of Fisheries, UW
Hamel, Nathalie	PNCERS Technician	School of Fisheries, UW
Hickey, Barbara	PNCERS PI	School of Oceanography, UW
Huppert, Dan	PNCERS PI	School of Marine Affairs, UW
Kopp, Joel	PNCERS Graduate Student	School of Marine Affairs, UW
Leschine, Tom	PNCERS PI	School of Marine Affairs, UW
Logerwell, Elizabeth	PNCERS Postdoctoral Fellow	School of Fisheries, UW
Magnusson, Arni	PNCERS Graduate Student	School of Fisheries, UW
Mantua, Nate	Collaborator	Joint Institute for the Study of Atmosphere and Ocean, UW
McMurray, Greg	PNCERS Program Coordinator	Department of Environmental Quality, OR
Moss, Jamal	Graduate Student	School of Fisheries, UW
Newton, Jan	Collaborator	Washington State Department of Ecology
Parrish, Julia	PNCERS PI	School of Fisheries/Department of Zoology, UW
Roegner, Curtis	PNCERS Postdoctoral Fellow	School of Fisheries, UW
Rumrill, Steve	PNCERS PI	South Slough National Estuarine Research Reserve, OR
Shanks, Alan	PNCERS PI	Oregon Institute of Marine Biology, UO
Stein, John	PNCERS PMT	Environmental Conservation Division, NWFSC, NMFS, WA
Swartzman, Gordon	PNCERS PI	Applied Physics Laboratory, UW
Thom, Ron	PNCERS PI	Battelle Marine Sciences Laboratory, WA
Woodruff, Dana	PNCERS Technician	Battelle Marine Sciences Laboratory, WA

the impact of them are concentrated in this arena. The all-hands meeting concentrated on defining areas of collaboration within PNCERS as well as among collaborating programs, with specific reference to nearshore and estuarine environments, focusing on physical forcing in the former and human activities in the latter.

The meeting started with 14 short presentations on the current status and most recent results from each of the 12 PNCERS research projects, as well as related and collaborative research projects (Table A.2). These summary presentations generated enthusiastic questions and discussions on potential avenues for collaboration among projects. Animated discussions continued during breaks and over lunch.

Break-out group sessions on the afternoon of the first day and all day on the second day centered on the major themes outlined above, with one group focused on physical forcing in the nearshore system and the other on human impacts and interactions in the estuarine system. Researchers were not confined to one group, so that those involved in research in both the nearshore and estuarine systems could contribute to both discussions.

The Estuarine Group

The Estuarine group's discussion centered around two main areas:

1. potential new projects that could integrate ongoing research in useful ways and

2. ideas for how to "tell a story" about Pacific Northwest estuaries based on current and projected PNCERS data.

Emphasis in both areas was on how useful these projects and/or stories would be to continued research, ecosystem management, and outreach and education.

GIS Development

There was overwhelming consensus on the need to develop a Geographic Information System that would integrate and facilitate analysis and presentation of diverse sets of estuarine-related data, such as current as well as historical information on estuarine habitat, biota, human development, and land use. This effort might include meso- to fine-scale map-

Table A.2. PNCERS All-Hands Meeting Schedule, Jan 20-21, 2000.

THURSDAY, JAN 20, 2000		
8:45 AM	**Julia Parrish**	Introduction: Integrating PNCERS research
9:00 AM	**Tom Leschine**	Ecosystem management & managers survey
9:20 AM	**Julia Parrish**	Seabirds as ecosystem indicators
9:40 AM	**Ric Brodeur**	GLOBEC and salmon
10:00 AM	**Arni Magnusson**	Coded-wire tag salmon data
10:20 AM		Morning Break
10:40 AM	**Gordie Swartzman**	Nearshore fish & plankton distribution
11:00 AM	**Barbara Hickey**	Estuarine currents and water properties
11:20 AM	**Curtis Roegner**	Larval transport
11:40 AM	**Jan Newton**	Biological oceanography
12:00 AM	**Ron Thom**	Estuarine habitat
12:20 PM		Lunch
1:45 PM	**Dave Armstrong**	Crabs in estuaries
2:00 PM	**Chris Rooper**	Fish in estuaries
2:10 PM	**Ted DeWitt/Pete Eldridge**	EPA Yaquina project
2:30 PM	**Kathleen Bell**	Integrating people and estuaries
2:45 PM	**Dan Huppert**	Socioeconomic baseline & residents survey
2:30 PM		Break out group discussions
4:00 PM		Meeting ends
FRIDAY, JAN 21, 2000		
8:45 AM - 5:00 PM		Break out groups all day

ping of the study estuaries.

Ecological-economic valuation
The group agreed to pursue "valuation" of the estuarine ecosystem, relying not only on economic data but also on biological indicators such as the Index of Biotic Integrity, and normative social values reflected in the coastal residents and managers surveys which were distributed earlier this year. It was determined that the process of valuation would work most effectively in conjunction with the development of an estuarine ecological-economic model.

Ocean Influence
The estuarine group saw the need for a more sophisticated way of understanding and visualizing the impact of ocean currents and circulation on estuarine functions. They agreed to incorporate the growing understanding of circulation and water properties in the assessment of spatial and temporal variations in habitat and biota.

In addition to these major proposed projects, several new data collection efforts were identified that are needed to fill existing data gaps: chlorophyll measurements, stable isotope (carbon and nitrogen) analysis of estuarine food webs, and nitrogen limitation for eelgrass and diatoms.

Integrating for Outreach
Discussion on integrating research for outreach purposes focused on choosing an indicator, or set of indicators that could become the focal point(s) for the Pacific Northwest estuarine "story". Ideas for potential indicators were: oyster production, salmon, marine birds, ghost shrimp, eelgrass, estuarine habitat, land use, water quality, and/or nutrient propagation and tideflat depletion. Oyster production was the most popular indicator suggestion, as it has the potential to integrate most PNCERS research, is economically relevant, links to water quality, and would be a factor involved in restoration projects, among other things. Ideas for broad thematic story "plots" were: ecosystem decline (reflected in, e.g, an oyster condition index, habitat change, and/or eelgrass change), human behavior changes due to oceanographic or climatic effects, and/or the overlay of human and biological induced variability on the "original conditions" of physical fluctuations. It was suggested that there should be two or more contrasting stories, representing estuaries that span the PNCERS region, and that these stories should highlight that complexity of human-ecosystem interactions. These were all preliminary ideas for outreach, and it was also pointed out that we don't yet know enough to tell a definitive story.

The Nearshore Group

The Nearshore group focused on defining avenues of collaboration between existing PNCERS projects (Swartzman, Parrish, Hilborn), PNCERS postdoctoral research (Logerwell, Roegner), GLOBEC-NEP research (Brodeur, Swartzman, Hickey), NMFS researchers (Brodeur, Wainwright) and JISAO and other UW research (Mantua, Francis, Fields). The possibility of collaboration between PNCERS and the various research programs being conducted by Ric Brodeur and his colleagues at NMFS was discussed extensively. Three ongoing field efforts to survey juvenile salmon, their prey, their predators and other habitat information were described by Brodeur. The projects are funded by GLOBEC, BPA (Bonneville Power Administration) and EPA. The BPA project is focussed on the Columbia River plume and the EPA project is targeting the very nearshore environment. It seemed appropriate for Libby Logerwell to participate in any of these research cruises, and discussions along that line were initiated and continued during the weeks following the meeting.

Several interesting lines of integration were discussed by the participating scientists. Regarding Hilborn and Magnusson's project on salmon survival, as assessed with coded wire tag data (CWT), integration of large scale retrospective data on upwelling and winds into his general linear model was mentioned. Collaboration with Parrish on bird predator data was also discussed. Another collaboration seriously considered was one between Parrish, Logerwell and scientists at the Newport EPA (Pete Eldridge and Ted DeWitt). The goal would be to conduct stable isotope analyses of seabird tissues to assess the relative foraging activity occurring in estuarine and nearshore habitats. This information would be required for Logerwell to construct bioenergetic models of salmon growth and survival in both habitats. Efforts on the part of NMFS, PNCERS, and other UW scientists (particularly John Field, a student of Bob Francis, and Nate Mantua, a research scientist at JISAO) to construct an ECOPATH model of the northern California Current were discussed. A follow-up meeting to cross-foster modelling efforts among the NMFS, UW, and PNCERS scientists has been set for mid-April, 2000.