Humboldt Bay and Eel River Estuary Benthic Habitat Project

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Published by California Sea Grant College Program
Scripps Institution of Oceanography
University of California San Diego
9500 Gilman Drive #0231
La Jolla CA 92093-0231
(858) 534-4446
www.csgc.ucsd.edu

Publication No. T-075

This document was supported in part by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration, and produced under NOAA grant number NA10OAR4170060, project number C/P-1 through the California Sea Grant College Program. The views expressed herein do not necessarily reflect the views of any of those organizations.

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Photographs: All photographs taken by S. Schlosser, A. Eicher or D. Marshall unless otherwise noted.

Suggested citation: Schlosser, S., and A. Eicher. 2012. The Humboldt Bay and Eel River Estuary Benthic Habitat Project. California Sea Grant Publication T-075. 246 p.

This document and individual maps can be downloaded from: http://ca-sgep.ucsd.edu/humboldthabitats

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Final Report to the
California State Coastal Conservancy
Agreement Number 06-085

August 2012

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Acknowledgements

The co-authors of the Humboldt Bay and Eel River Estuary Benthic Habitat Report have many people to thank who were involved in this project. Project funds were procured from the California Coastal Conservancy and the NOAA Coastal Services Center. This report and the associated habitat classifications were developed through a collaborative effort of the Habitat Project Advisory Committee, NOAA Coastal Service Center, Photo Science, The Nature Conservancy, the University of California Sea Grant Extension Program, and the California Coastal Conservancy. Rebecca Lunde and Christina Hoffman, NOAA Coastal Service Center, mentored and advised the project in early stages with valuable insights from their work on the San Francisco Bay Subtidal Habitat Project. Mark Finkbeiner and Nancy Cofer-Shabica, NOAA Coastal Services Center, lead the imagery collection and habitat mapping processes. Richard Eastlake and Mark Meade, Photo Science, drafted the habitat maps under the guidance of Mark Finkbeiner, Chris Robinson, and Rebecca Love, NOAA Coastal Services Center. Mark Finkbeiner also provided essential expertise on the Coastal and Marine Ecological Classification Standard. Margaret Spring, The Nature Conservancy, got us started on the Conservation Action Planning process and provided us with web resources. The Humboldt Bay Harbor, Recreation, and Conservation District provided a boat and the services of their excellent bar pilots John Powell and Tim Petrusha to accomplish groundtruthing for the habitat mapping. Bruce Slocum provided invaluable logistics in the Eel River Estuary. The imagery could not have been acquired without the assistance of the Eureka National Weather Service Office. Nancy Dean, Meteorologist-in-Charge, and her many expert colleagues provided precise weather updates when conditions were correct to ensure a successful imagery data set. Our Project Manager, Joel Gerwein, California Coastal Conservancy, contributed above and beyond his responsibilities, providing written materials and innovative approaches to addressing management considerations. The University of California Sea Grant Extension Program provided funds for the Habitat Project Advisory Committee chair and staff who wrote the report, prepared the EndNote library, verified intertidal habitats and identified algal specimens. We also thanks Joann Furse, California Sea Grant Communications, for thoroughly editing this document. We are especially thankful to Debbie Marshall, Administrative Assistant in the Eureka Sea Grant Office, for her tireless work to compile references, format, edit, and design this publication. The Habitat Project Advisory Committee contributed countless hours at meetings, reviewing draft documents, and providing their expertise and knowledge. We are thankful to have worked with a group of dedicated professional scientists and managers.

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Abbreviations	Entity
ac	acre
CAP	Conservation Action Planning
CDFG	California Department of Fish and Game
CeNCOOS	Central and Northern California Ocean Observing System
CMECS	Coastal and Marine Ecological Classification System
CSC	Coastal Service Center
DMC	Digital Mapping Camera
DO	Dissolved oxygen
EBM	Ecosystem-based management
EPA	Environmental Protection Agency
FGDC	Federal Geographic Data Committee
ft	foot
GIS	Geographic Information Service
GPS	Global Positioning System
ha	hectare
HAB	Harmful Algal Bloom
HBHRCD	Humboldt Bay Harbor, Recreation & Conservation District
HBI	Humboldt Bay Initiative
HBNWR	Humboldt Bay National Wildlife Refuge
HBWAC	Humboldt Bay Watershed Advisor Committee
HCRCD	Humboldt County Resources Conservation District
HSU	Humboldt State University
km	kilometer
LCC	Landscape Conservation Cooperative
LIDAR	Light Detection and Ranging
m	meter
MHHW	Mean Higher High Water
mi	mile
MLLW	Mean Lower Low Water
MMU	Minimum Mapping Unit
NAIP	National Agriculture Imagery Program
NGO	Non-governmental organization
NHD	National Hydrographic Database
NOAA	National Oceanographic and Atmospheric Administration
NOS	National Ocean Service
NPLCC	North Pacific Landscape Conservation Cooperative
NSSDA	National Standards for Spatial Data Accuracy
NVCS or NVS	National Vegetation Classification System
NWI	National Wetlands Inventory
NWS	National Weather Service
PSU	Practical Salinity Unit
RCAA	Redwood Community Action Agency
s	second
SGC	Surface Geology Component
SSS	Shoreline Stabilization Structure
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WAAS	Wide Area Augmentation System
Z/ISAT	Z/Image Station Automatic Aerial Triangulation

Executive Summary

The geographic scope of this project encompasses two estuarine systems on the North Coast of California: Humboldt Bay and, ten miles to the south, the Eel River Estuary. Humboldt Bay is a shallow water estuary linked to the Pacific Ocean by a narrow entrance channel. It is one of California's largest estuarine systems, second only to San Francisco Bay, though it is 1/20th the size of San Francisco Bay ; 479 mi^2 [1240 km^2] vs 25 mi^2 [64 km^2] (Nichols and Pamatmat 1988, Barnhart et al. 1992). Humboldt Bay is dominated by marine influences, with relatively little freshwater inflow. At low tide, extensive intertidal mudflats are exposed, comprising about two thirds of the bay's total area and contributing to substantial tidal exchange with the ocean. The Eel River Estuary is the fourth largest estuary in California, but is only approximately 1/7th the size of Humboldt Bay. Tidal influence extends upstream approximately 7 mi (11.3 km) inland. The Eel River estuary has a much larger freshwater influence than Humboldt Bay, a smaller tidal prism, and greater seasonal variability in water temperature and salinity. Like other estuaries on the west coast of North America, both are geologically young and small with relatively steep terrain nearby which limits their size (Hickey and Banas 2003).

Humboldt Bay and the Eel River Estuary habitats include intertidal flats, coastal marshes, eelgrass beds, complex slough and channel systems and adjacent brackish and freshwater marshes. Freshwater influence occurs during the winter rainy season when freshwater tributaries flow into the bay and estuary with their associated sediments. Incoming tides continually bring in fish, jellyfish, crabs, shrimp and many more invertebrates. Dolphins, porpoises, seals and sea lions follow the fish and invertebrates into the bay. Most are temporary visitors, though harbor seals are semi-permanent residents with established haul out areas used for resting.

Sustaining coastal ecosystems, economies and communities is a major challenge globally. Addressing these challenges requires new scientific and policy paradigms that recognize the connectivity of ocean, land and sea, and between physical, biological and human aspects of the environment. The Humboldt Bay and Eel River Estuary Benthic Habitat Project (Habitat Project) was intended to support an ecosystem-based management approach to natural resources in the Humboldt Bay ecosystem. Objectives and products completed to meet this goal include:

- Summarize existing intertidal and subtidal habitat information
  - Humboldt Bay and Eel River Estuary Benthic Habitat Project Report
  - Humboldt Bay and Eel River Estuary Benthic Habitat Project EndNote Library
- Acquire digital, aerial imagery and complete habitat mapping
  - June 2009 imagery and associated benthic habitat classifications

The Habitat Project report provides a summary of intertidal and subtidal habitat information, building on previous assessments, plans and profiles (Barnhart et al. 1992, HBHRCD 2006, HBWAC and RCAA 2006, CDFG 2010). Lack of mapped and quantified benthic habitat data is a common concern noted in these documents and others.

The EndNote library, prepared during this project, contains scanned documents from diverse sources. There are over 1,400 references for Humboldt Bay and 150 for the Eel River Estuary. The electronic library is available from the California Sea Grant Office in Eureka. Habitat information from many of these documents is reviewed in the habitat descriptions (Chapters 5 to 8).

A few habitat highlights:

- Approximately 41% of Humboldt Bay water is replaced during each tidal cycle.
- Tidal exchange in sloughs and small channels of Humboldt Bay can take 4 to 21 days.
- Eel River Estuary temperature and salinity is strongly related to changes in seasonal discharge of the river and daily high and low tides.
- Waters of Humboldt Bay and the Eel River Estuary have high water column turbidity levels due to suspended sediment from winter storms and other sources.
- Humboldt Bay supports over 100 species of marine and estuarine fish.
- Approximately 40 marine, estuarine, and freshwater fish species have been observed in the Eel River Estuary.
- Both systems are critical to adult and juvenile anadromous fishes.
- Intertidal mudflats are significant habitats representing over 66% and 46% of total area in Humboldt Bay and the Eel River Estuary, respectively.
- Intertidal flats show a trend of decreasing particle size with increasing tidal elevation and distance from the bay or estuary entrance.
- Diverse shorebird assemblages forage on intertidal flats during winter.
- The value and biological productivity of intertidal mudflats cannot be overemphasized. The bulk of the food organisms in Humboldt Bay consumed by fish and birds are produced here.
- Humboldt Bay contains over 5,000 acres of eelgrass habitat, which is critical to the survival of Brant geese and many other species.
- Intertidal mudflats dissipate energy and protect coastal marshes.
- Coastal marsh habitat has been reduced and fragmented by over 80% in both Humboldt Bay and Eel River Estuary due to highway, railroad and other levees.

Quantified benthic mapping was an identified priority for a more integrated management approach to the watershed and bay. The imagery and benthic habitat maps are a snapshot in time, consisting of independent layers of intertidal habitats and the distribution of subtidal waters in Humboldt Bay and the Eel River Estuary (Table 1). There are many opportunities for additional ecological products. For example, unconsolidated sediment could be overlaid with shorebird foraging areas to show things such as high use areas, choices or flexibility of shorebird habitat use on mudflats. Intertidal flats could be mapped in finer detail to show mud, sand and gravel areas.

Digital aerial photography and mapping benthic habitats in Humboldt Bay and the Eel River Estuary was an important part of the Habitat Project. Successful mapping of coastal benthic habitats relies on proper specifications to ensure the imagery is acquired at optimal environmental conditions (Finkbeiner et al. 2001). Optimizing environmental conditions for the imagery collection reduces errors in mapping, especially at habitat edges and gives accurate and reliable results. Benthic habitats were mapped at low tide when they were exposed. Spatial extent, distribution, and habitat fragmentation are described from this source data. Characteristics that will require more detailed information include the condition or health of the habitats and sediment texture.

Table 1. Coastal wetland habitats (acres) in Humboldt Bay and the Eel River estuary based on June 27, 2009 imagery.

Habitat	Humboldt Bay				Eel River Estuary
	North Bay	Entrance Bay	South Bay	Total	
Coastal Marsh	637	229	38	905	639
Eelgrass	3,577	123	1,948	5,646	51
Macroalgae	1,034	144	979	2,158	283
Oyster Mariculture	287	0	0	287	0
Subtidal	1,380	2,928	645	4,954	821
Intertidal mudflats	2,712	224	870	3,807	917
TOTAL	9,629	3,649	4,479	17,759	2,702

Some Humboldt Bay habitats have remained relatively stable in abundance and location between 1970 and the present: Humboldt Bay surface area (~16,000 acres), coastal marsh (~ 900 acres) and intertidal mudflats (~6,000 acres). Eelgrass distribution has been measured several times between 1953 and 2009, and has ranged from 2,000 to 5,600 acres. Factors influencing eelgrass distribution have not been studied in Humboldt Bay. It is important to note several different methods and study areas were used over the years. Eelgrass was first mapped in Humboldt Bay on the 1871 nautical chart. It appears the general area of eelgrass distribution has not changed significantly since then. Macroalgae has been mapped only twice (Gleason et al. 2007 and this study) though macroalgae has been noted by many authors in earlier studies.

Management considerations includes land use practices, especially sources of turbidity, nutrients and contaminants that may enter Humboldt Bay and the Eel River Estuary as urban and agricultural runoff. Habitat loss due to rising sea level is a major concern for coastal marshes and intertidal mudflats that are largely prevented from migrating upland by various fixed shoreline structures. Eelgrass may be affected by future aquaculture and port development and maintenance projects. Ocean acidification will place certain organisms at risk, in particulars shellfish which may not be able to maintain calcium carbonate shell structure with lower ocean pH. Rising sea level and ocean acidification could impact the distribution and productivity of benthic coastal habitats and the species they support. The distribution of eelgrass in Humboldt Bay appears to have been relatively constant since 1871. However, new information on rising sea level and local tectonic models may change eelgrass distribution significantly over the next 100 years (Shaughnessy et al. 2012)

Ecological information about Humboldt Bay and Eel River Estuary processes and functions are limited. Using existing data and models for the watershed, bay and nearshore ocean, some of these ecological questions may be answered and used for management decisions related to aquaculture expansion, sediment management and climate change adaptation. A few key studies to measure critical information for these management issues and others are:

- Sediment accretion and erosion at Humboldt Bay entrance, Hookton Slough, Eureka plain, Mad River Slough and Arcata Marsh
- Environmental effects of aquaculture practices on:
    - Humboldt Bay eelgrass populations
    - Food availability for migratory shorebirds
- Modeling efforts as tools to examine physical effects of circulation and sediment. dynamics on nutrient cycling, coastal habitat migration and whole system energy.
- The area of a habitat patch (coastal marsh, mudflat, eelgrass) required to support a given species or ecological process.

Nudibranch (*Triopha* spp.) from eelgrass

Grass rockfish (*Sebastes rastrelliger*)

Patchy eelgrass along the Eureka waterfront

Eureka waterfront

American Advocets (*Recurvirostra americana*)

Chapter 1. Introduction

The Humboldt Bay and Eel River Estuary Benthic Habitat Project (referred to hereafter as Habitat Project) began in 2007, concurrent with the Humboldt Bay Initiative, an ecosystem-based management (EBM) program. The Habitat Project was intended to support and strengthen implementation of the EBM program. The Habitat Project provides an important synthesis of existing habitat information and new habitat distribution data for the EBM information framework.

The Habitat Project deliverables are:

- The Habitat Project Report
- Multi-spectral (color and infrared) aerial imagery of Humboldt Bay and the Eel River Estuary
- Complete benthic habitat mapping of Humboldt Bay and the Eel River Estuary using the Coastal and Marine Ecological Classification Standard (CMECS)

The Habitat Project Report includes a description of subtidal and intertidal habitats within the study area, a synopsis of available scientific literature, and management recommendations garnered from the cumulative work of local scientists and community members, numerous meetings, and the work of the Habitat Project Advisory Committee.

Project Goals And Objectives

The Habitat Project has two main goals, each with specific objectives:

- **Goal 1**: Identify and describe benthic intertidal and subtidal habitats, their function, values and distribution in the study area.
  - Objective 1: Produce spatially based benthic habitat maps from new data sources
  - Objective 2: Describe habitats using existing information
- **Goal 2**: Develop recommendations for management, protection and restoration based on the best available scientific information.
  - Objective 1: Identify habitat threats
  - Objective 2: Identify management considerations for subtidal and intertidal habitats

This report compiles the project results. It is divided into 8 chapters, references and 3 appendices:

- Chapter 1: Introduction: Project Goals and Objectives; Need for the Project; Relationship to the Humboldt Bay Initiative; The Study Area; Regional Setting
- Chapter 2: Habitat Profiles: Methods for Compiling the Habitat Profiles
- Chapter 3: Benthic Habitat Imagery Acquisition and Classification
- Chapter 4: Benthic Habitat Distribution
- Chapter 5: Habitat: Subtidal —Water Column and Benthic Zone
- Chapter 6: Habitat: Intertidal Banks, Bars and Flats
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- References
- Appendix A: Species List
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- Appendix C: List of sensitive species for study area

Need for the Project

Humboldt Bay and the Eel River Estuary, a relatively remote area of California, are located in valley bottoms and include flat lowlands, which have long been sites of human settlement. Land use and management actions, past and present, have affected estuarine habitat forming processes and, as a consequence, ecosystem structure and function. Human settlement has altered natural sediment processes, and associated habitats have been eliminated or modified by activities such as channel deepening, dredging, filling and draining of tidal marshes and sloughs. Indirect effects from land-use activities in the watershed can also be significant, such as alteration of the timing and volume of water and sediment delivery. Structures such as dikes, levees, hardened shorelines, jetties, overwater structures, bridges, highways, marinas, tidegates and culverts modify natural habitat-forming riverine and tidal processes. Habitat structure, function and connectivity are altered through the disruption of tidal circulation, sediment transport processes, and light penetration (Williams and Thom 2001; Bowen et al. 2003). For example, in other estuaries, estuarine water clarity has been degraded as a result of the synergistic effect of increased sediment delivery from upstream anthropogenic activities, and increased suspension of sediments in the channel water column. Fish access to tidal marshes has been hindered or eliminated by roads, railroads, dikes and dredging, although different tidegate designs can mitigate this problem to varying degrees (Giannico and Souder 2004).

Humboldt Bay and the Eel River Estuary contain globally significant, old-growth temperate forests, rare wildlife species, unique Native American cultures, sparse human populations in small communities, and a history of fishing and forestry industries. Plant and animal species found here are subject to international treaties (International Bird Migratory Act), federal and state management and protection (Endangered Species Act, Essential Fish Habitat, the Fish and Wildlife Coordination Act, and California Coastal Act). Black brant (*Branta bernicia nigricans*), coho salmon (*Onchorhynchus kisutch*) and eelgrass (*Zostera marina*) are some of the important species regulated by these laws. Humboldt Bay hosts about 60% of the total black brant population each year, and its tributaries support viable and important coho, Chinook salmon (*O. tshawytscha*), steelhead (*O. mykiss*), and cutthroat trout (*O. clarkii*) populations that spawn and rear in its watershed. Eelgrass provides rearing and foraging habitat for juvenile marine fishes, Dungeness crab (*Cancer magister*) and numerous waterbirds. The Eel River Estuary provides diverse habitats for salmonids. High densities of juvenile Chinook use the estuary in summer where they significantly increase in size (Cannata and Hassler 1995).

Legacy impacts to the ecosystem plus environmental and societal challenges of today require current information on coastal habitats. There are few historic characterizations of the benthic habitats for Humboldt Bay or the Eel River Estuary. A quantified description of benthic habitats would provide managers, planners, the community and other interested parties a useful tool for management, research, climate change adaptation planner and restoration planning and implementation. Concentration and growth of population in coastal areas, the disproportionate economic significance of human activities, and the need for attention to the future sustainability of the coastal environments and their resources reflect national and regional needs for coastal habitat information. The last habitat inventory for Humboldt Bay was completed in the 1970s (Shapiro and Associates 1980). Few studies have been done in the Eel River Estuary The need for updated habitat information and a complete understanding of available information was apparent to scientists, managers and the community.

Three collaborative processes conducted from 1997 to 2006, addressed Humboldt Bay watershed and bay resources. These planning efforts involved large numbers of people from diverse perspectives and represented years of collaborative work, and were the first comprehensive plans of their kind for the region. The investigators conducted significant historical research and documented considerable changes to Humboldt Bay and the Eel River Estuary over the past century. Many changes have resulted from habitat loss and fragmentation due to human activity and some were effects of the area's geology, hydrology and geomorphology.

These efforts identified management issues and needs throughout the Humboldt Bay Ecosystem in their respective planning documents:

- Humboldt Bay Watershed Salmon and Steelhead Conservation Plan (HBWAC and RCAA 2005)
- Humboldt Bay Management Plan (HBHRCD 2007)
- Linking Land and Sea; Northern California Coastal Conservation Needs Assessment (RCAA and PMCC 2006)

The Humboldt Bay Watershed Salmon and Steelhead Conservation Plan provides an understanding of watershed aquatic resources and chronic salmonid habitat degradation. Historical watershed and salmon data are presented clearly by sub-basin. This watershed planning process brought together local citizens and groups, identified broad goals and objectives, described environmental problems, and outlined restoration alternatives. This plan was adopted in its entirety by the California Department of Fish and Game (CDFG) in its Coho Recovery Plan (CDFG 2004).

The Humboldt Bay Management Plan establishes clear management direction for the Humboldt Bay Harbor, Recreation and Conservation District (Harbor District) in the areas of harbor related uses, recreation, and conservation management. The plan is a foundation for an ecosystem framework. It is a valuable tool that identifies priorities, opportunities and needs. The plan states that the Harbor District shall actively focus its implementation of the management plan on protecting, maintaining and enhancing the biological, physical, hydrological and cultural characteristics of the Humboldt Bay Ecosystem. More than 100 policies and issues are identified, including application of EBM.

Linking Land and Sea assessed and documented the need for regional strategic coastal (marine and terrestrial) conservation planning and described the specific concerns of conservation organizations. The project reviewed marine and terrestrial data and emphasized taking an interdisciplinary approach to address the most pressing challenges on the North Coast.

Each of these three processes was stakeholder and community driven, and identified goals, objectives, priorities or policies for management of the local community's valued resources. Overall goals include maintaining ecological integrity, restoring damaged habitat, and promoting human wellbeing. These plans and the work of many other local groups (Science Advisory Committee for Estuarine Restoration, Science and Technology Alliance for North Coast Estuaries, Interagency Committee, Mariculture Monitoring Committee, Humboldt Bay Stewards) identified spatially based habitat information as essential and foundational for future planning and habitat restoration. An update of habitat data for Humboldt Bay and the Eel River Estuary was clearly needed.

The Habitat Project provides new spatial data and benthic habitat profiles for Humboldt Bay and the Eel River Estuary and updated information. These products are expected to have broad applications for addressing management issues such as:

- Baseline habitat information
- Comprehensive estuarine restoration planning
- Climate adaptation planning and implementation
- Habitat loss and fragmentation
- Shoreline change assessment

The accurate, high resolution, benthic habitat imagery and classification of coastal habitats provided by the Habitat Project will benefit many local projects. Aerial photography is a powerful tool for identifying benthic coastal habitats. Some types of information that can be derived are spatial extent and distribution, habitat fragmentation and qualitative measures of habitat biomass. Characteristics that are difficult to assess with aerial photography include sediment type such as sand, mud or gravel, plant density (#/m^2) and percent cover. Currently, many estuarine restoration projects are planned, designed and implemented individually and without reference to coastal habitat information. Shoreline inventories, shellfish sanitation surveys, rare plant monitoring, hazard preparation, climate adaptation planning, economic analysis of coastal habitats, and other ecosystem projects have benefited from the accurate benthic habitat information provided by this project.

Additionally, as Humboldt Bay and the Eel River Estuary are valuable commercial, recreational, and aesthetic areas that provide important habitat for fish and wildlife resources, a thorough inventory of existing data and information was essential. While much information was compiled and reported in the watershed and bay plans, it was focused on either salmonid restoration or bay management and included only historical data. A complete inventory of the existing coastal habitat information had not been prepared. As the Humboldt Bay and Eel River estuarine complex together support the greatest number of wetland-associated wildlife species between San Francisco Bay and the Columbia River (Monroe 1973; Monroe et al. 1974; Springer 1982), the Habitat Project collaborators worked to compile this information. We attempt to contribute to the understanding of these multi-faceted resources in this report.

Relationship to the Humboldt Bay Initiative

Habitat Project collaborators participated in and worked with the Humboldt Bay Initiative (HBI). The HBI works collaboratively and voluntarily to apply an EBM approach for the region. Participants are from throughout the West Coast and include, but are not limited to, those who conduct research, planning, management, live or work in, or are interested in the Humboldt Bay Ecosystem. The HBI, established in 2007, takes a leadership role in promoting and coordinating understanding of the Humboldt Bay Ecosystem. The HBI working definition of the ecosystem is its watershed, bay, adjacent river estuaries and nearshore ocean (see page 5 for detailed information). HBI works with its partners to advance scientific knowledge and to increase awareness and understanding of the ecosystems' important natural, recreational, cultural and economic resources. Addressing threats to these resources poses both challenges and opportunities and requires involvement of diverse participants including government agencies, tribes, businesses, academic institutions, nonprofit organizations and community members. HBI is committed to working together with these partners to conceptualize and build awareness for defining strengths, issues and science needs, as well as implementing ecosystem approaches to priority issues.

The HBI Project Team conducted the first scientific analysis of priorities outlined in the watershed and bay plans and the needs assessment (Schlosser et al. 2009a). The three plans assessed were prepared without the benefit of a science team. Priority issues from these plans were further assessed and integrated strategies developed during a formal strategic planning process (Schlosser et al. 2009b). The strategic planning process identified priority ecosystem threats such as habitat loss and fragmentation, sedimentation, climate change, toxic substances and human development. Except for climate change adaptation, these threats were common to the three previous plans. Many of the management issues addressed and strategies developed during the HBI process were examined in detail by the Habitat Project Advisory Committee for their impacts to coastal habitats, or to develop habitat-related management recommendations.

From its inception, the HBI identified the need for updated habitat information to effectively plan, manage and protect coastal habitats. The Habitat Project addresses the need for high quality, quantified intertidal and subtidal habitat data, a priority issue from previous plans and the HBI Strategic Plan. The Habitat Project was developed in collaboration with the NOAA Coastal Services Center within the first year of HBI activities. The overarching goal of the Habitat Project is to provide current, comprehensive habitat information for ecosystem planning and project implementation. The Habitat Project was conducted concurrent with HBI activities from February 2008 to its final product delivery in 2012.

The HBI Strategic Plan provides a blueprint of specific objectives. Each strategy relies on current habitat information. The plan includes objectives for the following strategies:

- Establish the HBI as a nonprofit organization
- Coordinated Response to Coastal and Climate Change
- Coordinated Response to Invasive Species
- Study and Control of Sediment
- Promote Sustainable Development
- Support Integrated Forest Management

Overarching HBI goals include:

- Restoration and protection activities that will result in measureable environmental improvements in the Humboldt Bay Ecosystem
- Provide accurate, useful and user friendly information to engage people in the protection and enhancement of the ecosystem
- Provide technical and scientific support to participants and partners
- Track progress of ecosystem health by developing a framework to determine the effectiveness of restoration and other management actions
- Implement an organizational strategy aimed at ensuring long-term financial stability
- Aggregate and distribute existing knowledge and resources
- Create a means for better communication and knowledge sharing

Humboldt Bay Ecosystem – Geospatial Extent

HBI defines the geographical boundary of the Humboldt Bay Ecosystem as Humboldt Bay, its watershed, the Mad River and Eel River estuaries, the Eureka Littoral Cell, and the Pacific Ocean to the edge of the continental shelf (Figure 1). The Eureka Littoral Cell is bounded by Trinidad Head to the north and False Cape to the south with Humboldt Bay approximately at the mid-point. It is approximately 40 mi (60 km) in length and varies seasonally in direction of flow (Patsch and Griggs 2007). The continental shelf between Trinidad Head and False Cape varies from 35 to 15 miles (24 to 40 km) in width, from north to south.

Ecosystem-based management (EBM) is defined as:

- Using an integrated approach to management that considers the entire ecosystem, including humans
- Emphasizes protection of ecosystem function, structure, and key processes
- Place-based and focuses on a specific ecosystem
- Acknowledges interconnectedness among systems such as land, air and sea
- Integrates ecological, social, economic and institutional perspectives
- Sustains or restores ecological systems, their functions and values
- Uses a collaborative process that integrates ecological, economic and social factors
- Applied within a geographic framework defined primarily by ecological boundaries

(From McLeod and Leslie 2009; Schlosser et al. 2009a, b)

Notable differences in implementation of EBM and traditional resource management include development of practical approaches to integrate science, management and societal values. EBM offers a way to strengthen these links. EBM also seeks to be adaptive and provide management with best information on long-term changes such as sea level rise or climate change. The information produced by the Habitat Project supports implementation of EBM in the Humboldt Bay Ecosystem. Monitoring of biophysical and social indicators and reference points is also necessary to advance EBM goals of healthy ecosystems and human wellbeing, and to determine how these indicators are linked, and how changes are characterized and monitored.

The Habitat Project includes participants in the HBI project and other interested parties. The HBI strives to support implementation of social, economic and ecological science to inform natural resource management. Overall the Habitat Project, with guidance from its advisory committee, established a baseline for the steadily improving EBM effort. The quantified benthic habitat data provides resources for adaptive management of the area’s natural resources.

The Study Area

The study area of the Habitat Project is defined as: the northern extent of the Mad River Slough (the northern arm of Humboldt Bay) to the southern extent of the Eel River Estuary (including the estuarine portion of the Salt River system) and from the coastline extending inland as far as the upper reaches of the tidal sloughs (Figure 2).

The two estuarine systems are separated by Table Bluff, less than 1 mi (1.6 km) wide. The mouth of the Eel River is approximately 9 mi (14.5 km) to the south of the mouth of Humboldt Bay. Despite their close proximity, little is known about the interrelationships between the two in terms of ecological

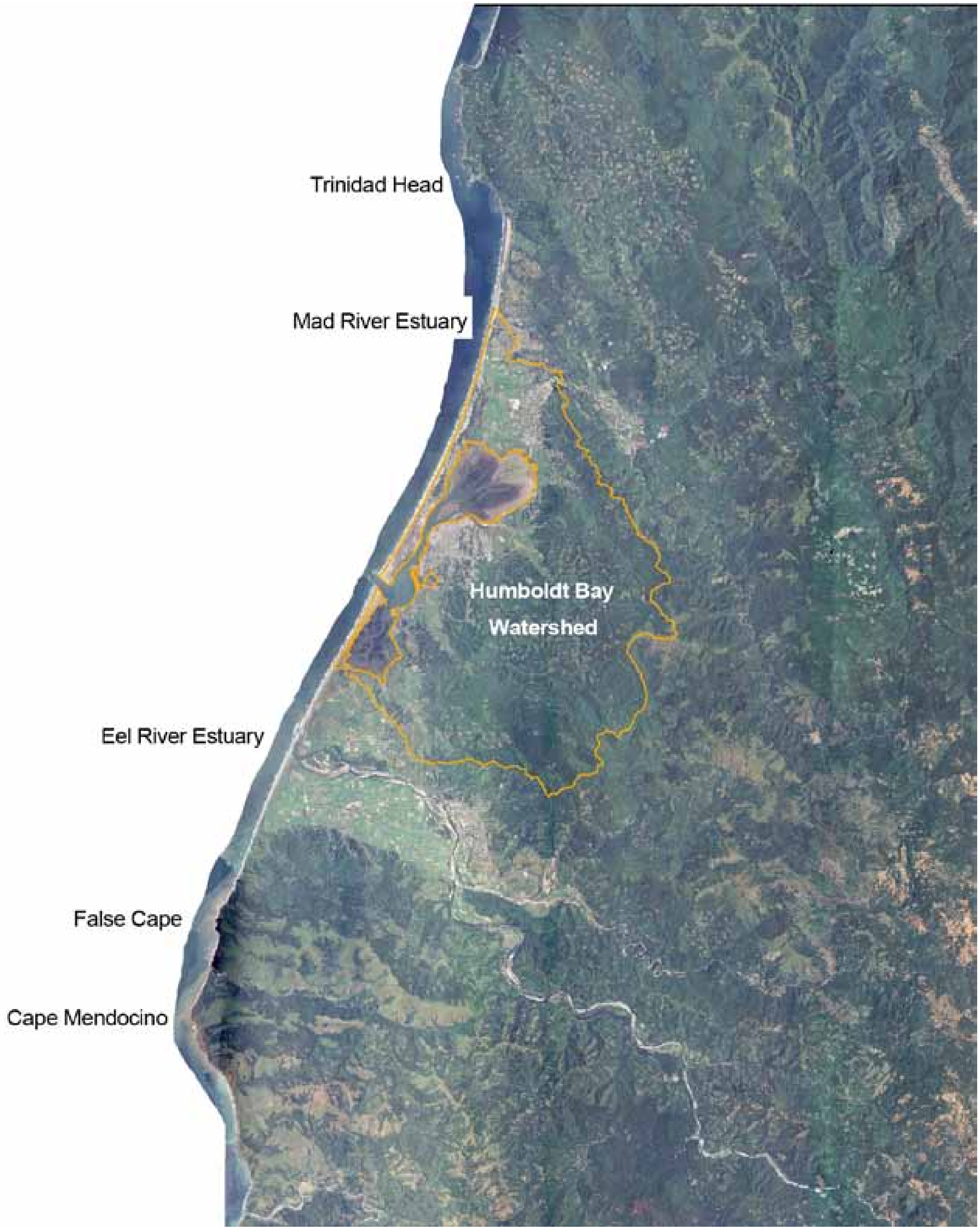


Figure 1. Humboldt Bay Ecosystem as defined by the Humboldt Bay Initiative (HBI), a community-based program on the North Coast.

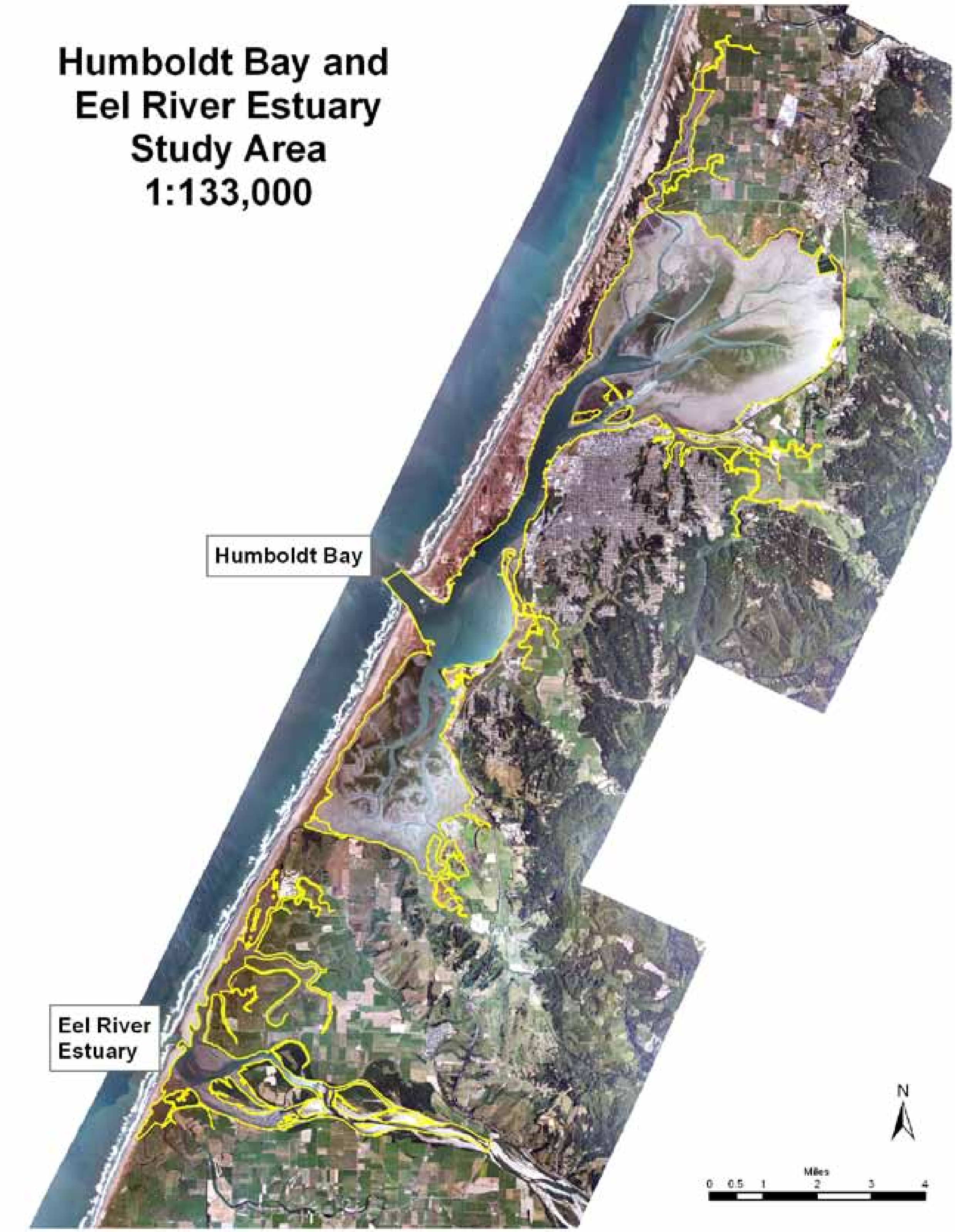


Figure 2. Habitat Project Study Area

processes, such as species dispersal. There is a need for further research on the functional connectivity between these ecosystems.

Humboldt Bay and the Eel River Estuary are about 230 mi north of San Francisco Bay. Humboldt Bay is the second largest estuary in California, but is significantly smaller than San Francisco Bay. At high tide Humboldt Bay water surface area is 24 square miles compared to approximately 479 square mi of water surface area in San Francisco Bay. The Eel River Estuary is the fourth largest in California with a high-tide water-surface area of 5 square mi that is within a 25 square mi estuarine delta. Together Humboldt Bay and the Eel River Estuary make up a complex supporting more than 100 species of fish, 500 intertidal and subtidal invertebrates, and hundreds of thousands of overwintering shorebirds and waterbirds.

The nearshore waters off the coast of Humboldt Bay and the Eel River Estuary have a notably high productivity related to seasonal upwelling. This coastline has mixed semi-diurnal tides: two high tides of unequal magnitude, and two low tides of unequal magnitude every day. The region has a temperate maritime climate with mild, wet winters and cool, foggy summers. The average annual air temperature is 52° F (11.1° C), ranging from lows in the mid-30° F (~1.7° C) to highs in the mid-70° F (~24° C), with summer days only about 10 degrees warmer than winter days. Average annual rainfall is approximately 40 in (101.6 cm), with 90% precipitation occurring between October and April. Summers are characterized by intrusions of low clouds and fog, resulting in high humidity throughout the year. Prevailing winds are from the northwest, while strong southerly winds are associated with winter storm events (Internet search; Eureka National Weather Service, accessed: September 19, 2011).

Regional Setting

Humboldt Bay

Humboldt Bay (40° 44’ 59” to 124° 12’ 34”) is situated on a low-gradient alluvial plain at the base of the Coast Ranges in Northern California (Figure 3). Humboldt Bay is the principal estuary occurring between San Francisco Bay, 231 mi (371.8 km) to the south, and Coos Bay, 185 mi (297.7 km) to the north. The bay has relatively limited freshwater input and is dominated by marine influences (Gast and Skeesick 1964; Proctor et al. 1980).

Humboldt Bay is comprised of two wide, shallow basins connected by a narrow deepwater channel that empties into the Pacific Ocean. The mouth of the bay has been stabilized by jetties since the late 1800s (Tuttle 2007). Two barrier beaches on either side of the entrance, the North and South Spits, shelter the estuary (Figure 4). The three regions of Humboldt Bay are defined as:

- North Bay: the basin north of the Highway 255 bridge that crosses the bay from downtown Eureka to Samoa via Woodley and Indian islands (Figure 5)
- Entrance Bay: the channels from the Samoa Bridge south to the South Jetty (Figure 6)
- South Bay: the basin south of the South Jetty (Figure 7)

Indian and Woodley islands, are located at the north end of Entrance Bay. North Bay includes Daby Island, adjacent to Woodley Island, and two islands exposed by low tides, Bird Island and Sand Island. Sand Island was created from dredge spoils deposited in the early part of the century. South Bay includes a large eelgrass bed, locally referred to as Clam Island, that is also exposed only at low tide. The total length of the bay is approximately 14 mi (22.5 km)

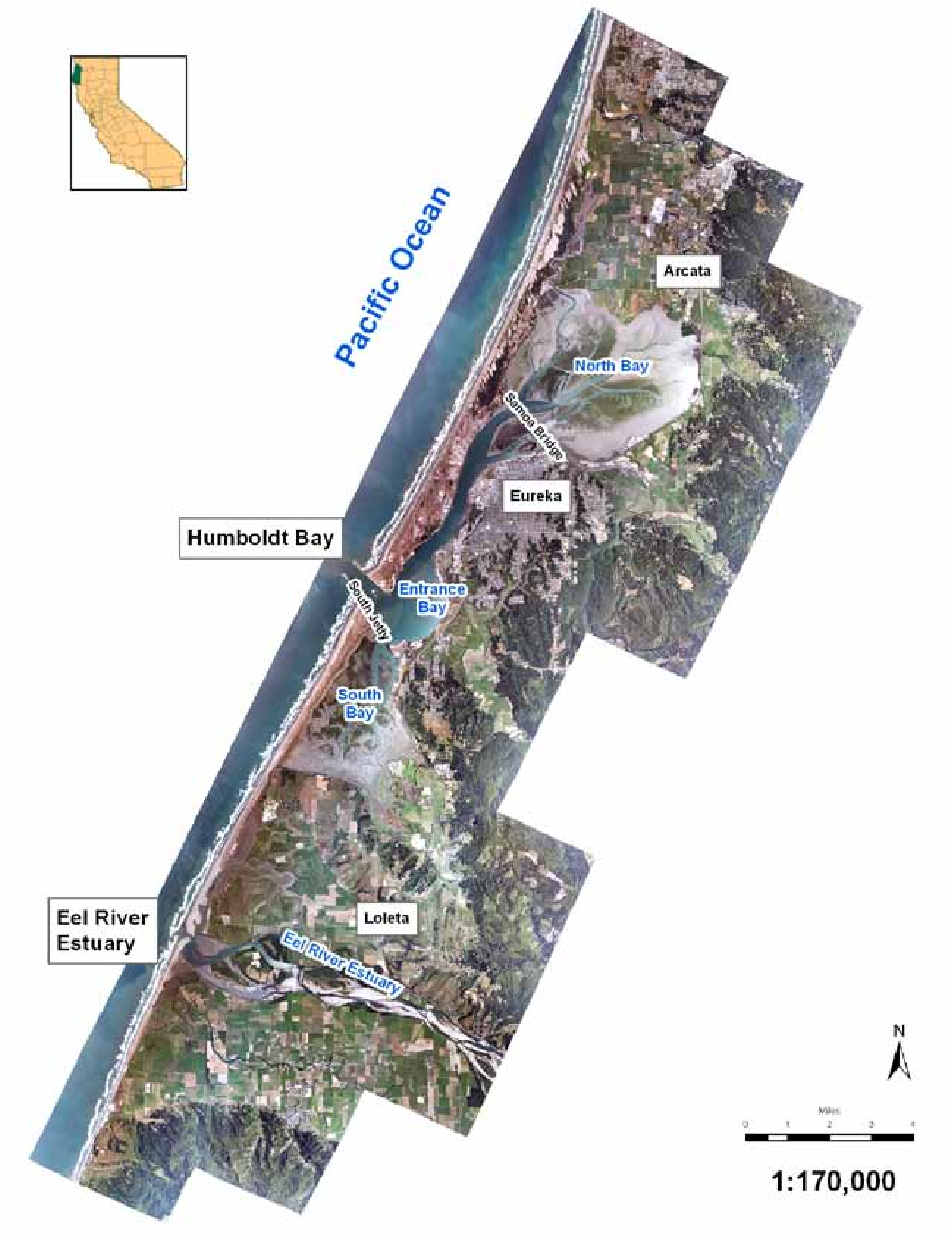


Figure 3. Full extent of the 2009 true color aerial imagery.

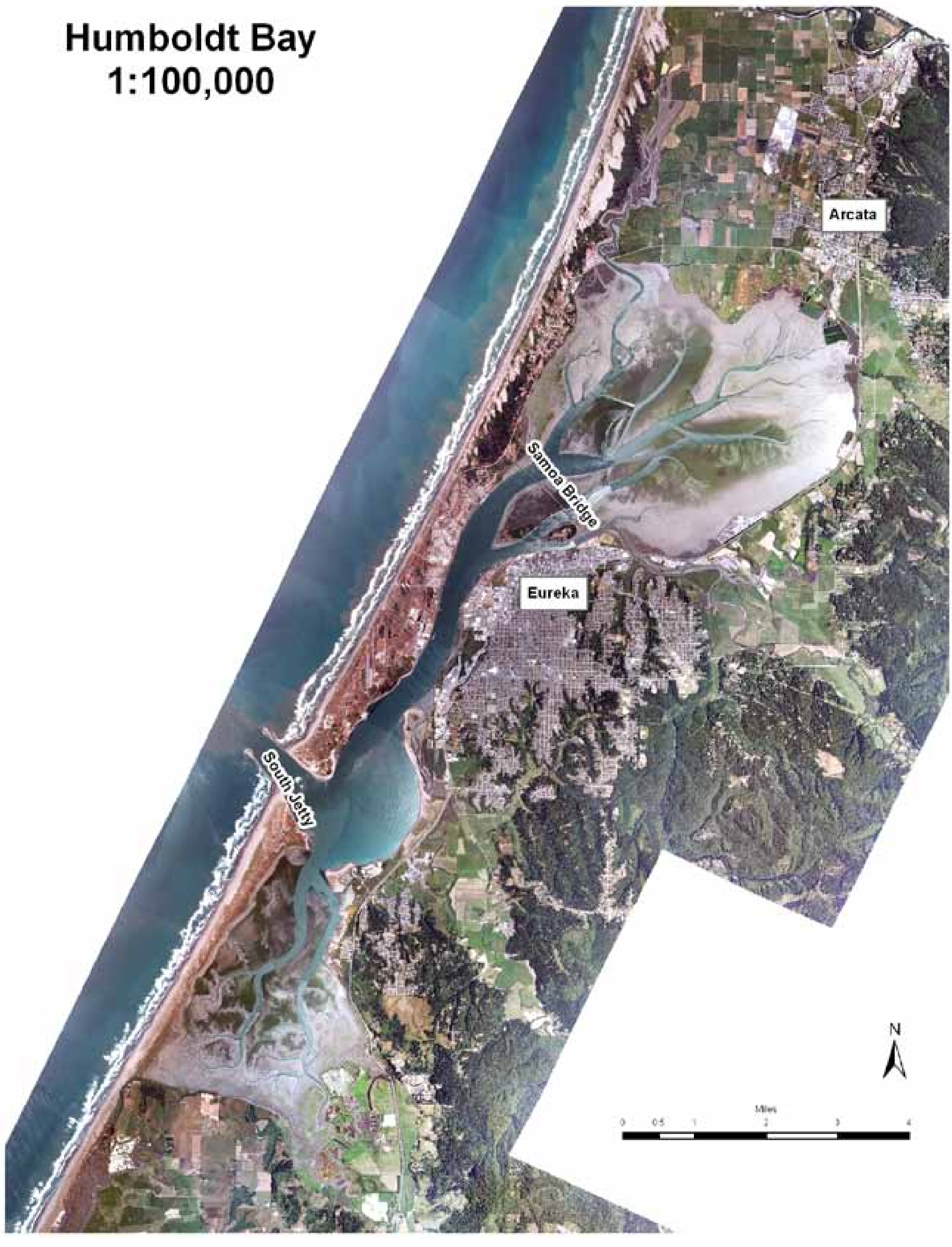


Figure 4. Humboldt Bay with landmarks used to define study regions

Figure 5. North Bay region with intertidal and subtidal islands.

Figure 6. Entrance Bay showing regional extent.

Figure 7. South Bay region

and the width varies from 0.5 mi (0.8 km) in Entrance Bay to 4.3 mi (6.9 km) across the widest part of North Bay. The bay entrance and shipping channels are maintained at a depth of 38 ft to 48 ft (11.6 m to 14.6 m) by periodic dredging (HBHRCD 2007).

The Humboldt Bay watershed is 223 mi^2 (577.6 km^2) (HBWAC and RCAA 2005), a relatively small drainage area for a bay of its size. At high tide, the bay occupies an area of 24.1 mi^2 (62.4 km^2), which is reduced to 10.8 mi^2 (27.97 km^2) at low tide (Barnhart et al. 1992).

Discharge from Elk River is Humboldt Bay's largest freshwater source. Other major tributaries include Jacoby Creek and Freshwater Creek (via Eureka Slough) that empty into North Bay. And Salmon Creek that empties into South Bay. Additional smaller tributaries are listed in Table 2. The amount of freshwater input to the bay varies with season and is largely governed by storm events. While the overall contribution is relatively small, freshwater input has important localized effects on sedimentation rates and patterns, nutrient flux and productivity.

Tidal flushing is the dominant physical process affecting the estuary. The amplitude of the tide increases with increasing distance from the mouth of the bay (Costa 1982a). Humboldt Bay has a large tidal prism, which is a measure of the volume of water exchanged during half a tidal cycle (specifically, the time between mean higher high water and mean lower low water), expressed as the percentage of the mean high tide volume. The tidal prism is 44% in North Bay and 68% in South Bay (Pequegnat and

Table 2. Area of individual Humboldt Bay sub-watersheds

Sources: (Costa and Glatzel 2002; Klein 2004a; Klein 2004b).

Tributary Streams	Approximate Drainage Area (mi^2)
Janes Creek	4
Jolly Giant Creek	1
Grotzman/Beith Creeks	2
Jacoby Creek	19
Washington Gulch	1
Rocky Gulch	2
Freshwater Creek	34
Ryan Creek	15
Elk River	53
Salmon Creek	18
Total drainage area from major tributaries	149
Drainage area from former tidelands, floodplains and small, unnamed tributary watersheds	49
Humboldt Bay surface area at high tide	24
Total Humboldt Bay watershed area	223

Butler 1982). Tidal currents are strongest in the Entrance Bay where current velocity is between 1.0.-1.7 m/sec (2.2-3.8 mph). Within North and South Bay tidal currents range from 0.5-0.75 m/sec (1.1-1.7 mph) (Barnhart et al. 1992).

The tidal influx of nutrient-rich waters associated with seasonal upwelling in nearshore coastal waters supplies nutrients to the bay. Other nutrient sources include seasonal freshwater input from several small rivers and creeks, salt marsh runoff, and regenerated nutrients from mudflats and eelgrass beds. In all regions of the bay, especially North Bay, the waters have developed chemical and biological characteristics different from nearshore ocean waters. In general, the water temperature is more affected by atmospheric conditions; nutrient levels are lower, and biological productivity is lower in the bay than in nearshore waters (Pequegnat and Butler 1982).

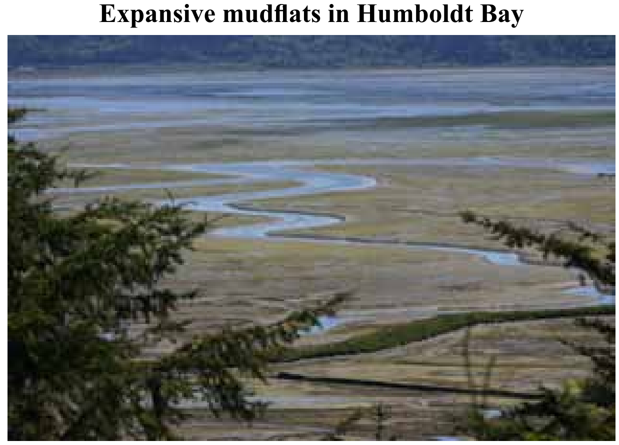
Tides propagate through Humboldt Bay jetties into the bay and sub-basins. The tidal influence is determined by sea level height and freshwater inflow.

The coastline off Humboldt Bay is subject to intense wave activity during winter storms. Sediments from both the Mad River and the Eel River enter the mouth of Humboldt Bay via littoral currents that shift seasonally. Additional, less significant sediment sources are Elk River and other tributaries entering the bay. Sediment distribution within the bay is controlled primarily by tidal currents. Generally, particle size decreases with increasing distance from the Bay entrance and increasing tidal elevation. The channels are characterized by sand, the mudflats by silt/clay mixtures, the marshes by peat, and the surrounding uplands by clay deposits (Thompson 1971). South Bay receives significant sediment from ocean currents resulting in sand and silty substrates in the western portion and soft mud substrates in the east.

Both erosion and accretion are occurring within Humboldt Bay, as evidenced by aerial photographs, sediment core samples and siltation measurements. Former marsh deposits have been found up to 100 ft (30.5 m) bayward of the marsh boundary, now overlain by more recent tidal flat sediments. Net erosion is apparent near the mouth of Eureka Slough, attributable to wave attack from prevailing north westerly winds in spring and summer. Net accretion has been noted near the mouth of Jacoby Creek, which is a source of considerable sediment, and deposition in this vicinity has allowed marsh expansion. At other areas along the bay shoreline, there appears to be seasonal cycles of erosion and accretion, in response to shifting wind and wave conditions (Thompson 1971).

Broad expanses of intertidal mud and sand flats are exposed at low tide, comprising 66%–72% of Humboldt Bay (Costa 1982b, this study). The flats have a gradual sloping topography and are dissected by numerous channels that transport incoming and outgoing tidal flows and serve as reservoirs of water at low tide. The intertidal flats support extensive perennial beds of eelgrass and seasonally dense mats of

Expansive mudflats in Humboldt Bay



Intertidal eelgrass and green algae

macroalgae. In addition, there are large areas that remain essentially unvegetated year-round. The interior of Humboldt Bay is protected from wave exposure by two narrow sand spits. This shelter allowed the historic development of expansive coastal marshes in the upper reaches of the estuary, most of which have since been diked and drained for agricultural use and urban development.

The largest urban development in the region is the City of Eureka, with a population of approximately 27,100 people (US Census Bureau 2010) located adjacent to Entrance Bay. The City of Arcata is situated adjacent to North Bay, with a population of approximately 17,100 people (US Census Bureau 2010). Research by professors and students from Humboldt State University (HSU) in Arcata has contributed greatly to the scientific information available for the region and for this report.

Butcher Slough in North Bay

Indian Island is a significant cultural site. Prior to European settlement in the mid-1800s, there were an estimated 1,000 members of the Wiyot Tribe living in the Humboldt Bay region. The Wiyot Tribe has developed plans for a portion of Indian Island to restore this cultural heritage site (e.g., Tuluwat Village and the World Renewal Ceremony) and ecological resources. Both of these restoration projects will preserve significant aspects of the bay history (Planwest Partners 2008).

Shellfish aquaculture activities are located in North Bay, but most commercial activity is found in Entrance Bay and to a lesser extent in South Bay. Entrance Bay contains a shipping channel, port facilities, commercial and recreational fishing fleets, and private and public marinas. The Harbor District maintains the largest marina, located on Woodley Island, with 237 berths serving commercial and recreational vessels. A commercial shipping dock is located in South Bay (HBHRCD 2007). Land use in the surrounding watershed includes timber harvest, agriculture, recreation and small communities.

History

The Humboldt Bay is a drowned river valley. Humboldt Bay sediments contain buried salt marsh deposits showing the rapid subsidence of low-lying areas due to large magnitude subduction zone earthquakes. Approximately 10,000 to 15,000 years ago, sea level rose rapidly, flooding stream valleys that previously extended into the current site of Humboldt Bay.

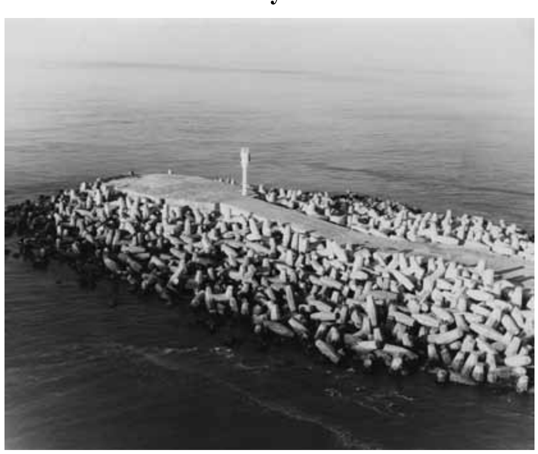
There is evidence indicating that Humboldt Bay historically represented three estuarine systems linked together by the formation of a barrier spit (Ogle 1953; Thompson 1971). During the mid-Pleistocene, the Mad, Elk, and Eel rivers all presumably drained into Humboldt Bay. Subsequently, the Mad River eroded a new channel and it now enters the ocean north of the bay. There has been speculation that the existing Mad River Slough, at the north end of Arcata Bay, represents the former channel of the Mad River. The slough does serve to transport overflow floodwaters from the Mad River to Humboldt Bay however, there is no evidence in slough sediments to indicate that the slough represents a former river channel. It is likely that the Mad River entered the ancestral bay east of what is now Mad River Slough (Vick 1988). To the south, the Eel River floodplain was separated from Humboldt Bay by the uplifting of a coastal bluff now known as Table Bluff. The third river, Elk River, still drains into Humboldt Bay.

From 1889 to 1899, the north and south jetties were constructed to stabilize the mouth of Humboldt Bay. The jetties were later reconstructed between 1911–1927 (Tuttle 1982; Tuttle 2007). Repairs and reconstruction of the jetties continued through the 1960s in response to storm damage. In 1971 and 1984 large cement doloses were installed to secure the jetties and these remain in place today (Tuttle 1982). The jetties are maintained by the US Army Corps of Engineers (Costa and Glatzel 2002).

Stabilization of the bay mouth, in combination with the deepening of navigation channels in Entrance Bay, resulted in severe erosion in the region directly east of the mouth. Approximately 188 ac of Buhne Point eroded from 1854 to 1955. Subsequent erosion control measures have protected further losses at Buhne Point however, erosion around the jetties remains a concern (Tuttle 1982, USACE 2012). Sand eroding from Buhne Point was deposited to the north, forming a spit at the mouth of Elk River (Tuttle 1982; Tuttle 2007). Pockets of intertidal coastal marsh occur along the interior of this spit. The salt marsh that historically occurred on the shoreline of Buhne Point has been lost to urban development

Dredging of channels in Humboldt Bay was initiated in 1881 for navigation and safety. In 1883 the Fields Landing Channel was first dredged, and the Entrance, Eureka, and Arcata channels, as well as the main shipping channels, were deepened and widened. Today interior navigation channels in Entrance Bay called North Bay, Samoa and Eureka channels are maintained by the US Army Corps of Engineers. Most Humboldt Bay channels were 15 to 25 ft (4.6 to 7.6 m) deep prior to dredging (U.S. Coast Survey 1871), and navigation channels are now maintained to a depth of 38 to 48 ft (11.6 to 14.6 m). The Arcata Channel in North Bay, now only 18 ft (5.5 m) in depth, was formerly maintained by dredging to provide ship access to the historic Arcata Wharf once located at the north end of North Bay (USACE 2005, HBHRCD 2007, USACE 2012).

North Jetty dolosse



Historic land-use changes have altered the way tidal slough channels function ecologically. Sloughs once functioned to provide tidal connectivity to extensive coastal marshes surrounding the bay. Today the large slough systems of Humboldt Bay have dikes on one or both sides and include the Mad River, Eureka, Elk River and Hookton sloughs. Historically, Humboldt Bay supported nearly 10,000 ac (4,047 ha) of intertidal coastal marsh, with less than 10% remaining today (Pickart 2007). Beginning in the late 19th century, European settlers diked and drained most of theses marshes for agricultural use, a practice referred to as land reclamation. The primary purpose was use for pasture and/or hay production - the same land use in effect today. Earthen levees were constructed along the margins of marsh plains to a height of approximately 3 ft - 4 ft (0.9 m - 1.2 m) above the marsh plain using locally excavated mud. The associated borrow ditches were typically located on the landward side of the dikes, creating straight, narrow channels. To alleviate long periods of saturation in reclaimed agricultural fields, underground drainage tiles were placed on several thousand acres around Humboldt Bay. These were effective for only a few years before becoming plugged. Alternatively, open ditches were excavated to facilitate drainage in some areas (Lawrence 1982) and tidegates were installed to enable the enclosed basins to drain at low tide. Construction of the Northwest Pacific Railroad was completed in 1901, further restricting tidal connectivity on the eastern rim of Humboldt Bay (Tuttle 2007).

Eel River Estuary

The Eel River Estuary (40° 38’ 29” to 124° 18’ 44”) is located just south of Humboldt Bay (Figure 2). It is a sandbar-built estuary that typically remains open to tidal exchange year round. The western edge is bordered by sandy beaches forming a spit composed of marine shoreline deposits and sand dunes. The upstream limit of estuaries can be delineated where salinity measures less than 0.5 parts per thousand (ppt) during the period of average annual low flow. By this definition, the Eel River Estuary extends inland to at least Fernbridge where salinities of 2 ppt–11 ppt. have been measured (Cannata and Hassler 1995). There is a lag time of approximately one hour for high tides to extend from the river mouth to Fernbridge (CDFG 2010). The pulse of high tides can be observed above Fernbridge and it has been noted that the effect of tides can extend to the confluence with the Van Duzen River (Van Kirk 1996). At high water, the estuarine portion of the river is estimated at 9.3 mi^2 (24.1 km^2) (CDFG 2010).

The estuary can be divided into five zones based on channel characteristics and mixing regimes of tidal marine water with freshwater river flows (Figure 8):

- North Sloughs: channels north of the river mouth
- North Bay: embayment extending from the river mouth upstream to near Cock Robin Island Bridge
- Middle Estuary: main channels from Cock Robin Island Bridge to Fulmor Road
- Upper Estuary: main channel from Fulmor Road to Fernbridge
- South Sloughs: channels south of the river mouth, including the Salt River

Eel River Estuary slough with levees and pastures

Figure 8. Eel River Estuary region

North Bay is dominated by marine influences. The Middle Estuary channel is subject to strong mixing of salt and fresh water. The Upper Estuary channel is subject to daily tidal action but dominated by riverine influences and characterized by fresh water and/or brackish water into the summer. The tributary sloughs are brackish in their lower regions and some are fresh in their upper reaches. Upper reaches are usually in pastures and protected by tidegates (Table 3) (CDFG 2010). Within these generalized zones more specific habitat types occur, including small, meandering slough channels, intertidal mudflats, intertidal sandflats, intertidal gravel/cobble, eelgrass beds and intertidal coastal marsh. These diverse habitats play important roles in reproduction, feeding, rearing, and for physiologic adaptations of organisms that use the estuary.

The estuary receives runoff from more than 800 tributary streams and 3,500 mi (5,632.7 km) of stream channels that drain 3700 mi^2 (9,582.9 km^2) of the mountainous Eel River watershed. Mean annual discharge from the Eel River Basin to the estuary is approximately 5.4 million acre-feet. The highest recorded annual discharge into the estuary was 12.6 million acre-feet in 1983 and the lowest was 410,000 acre-feet in the drought of 1977. The peak flow into the estuary was in December 1964 when 750,000 ft^3 (21,237.6 m^3) per second was recorded at the USGS gauging station at Scotia (CDFG 2010). Because the Eel River Estuary is situated on a relatively flat landscape, the river and slough channels have low stream gradients. These low gradient reaches of the river are depositional and tend to accumulate sediments delivered from higher gradient reaches upstream.

On average the Eel River discharges more suspended sediment than any river in the continental United States after the Mississippi (Meade and Parker 1984). It has the highest recorded annual average suspended sediment yield of any river its size in the United States (Brown and Ritter 1971). Where the 2.3 million cubic yards of beach sand discharged

Table 3. Eel River Estuary sloughs and tributaries
Sources: Downie and Lucey 2005; CDFG 2010

Tributary or Slough	Length of Freshwater (mi)	Length of Brackish or Salt Water (mi)	Total Length (mi)
Mosley Slough	0	1.4	1.4
Seven Mile Slough	0	3.8	3.8
McNulty Slough	4.8	3.4	8.2
Hawk Slough	2.0	3.6	5.6
Quill Slough	2.2	2.8	5.0
Hogpen Slough	1.8	1.2	3.0
Ropers Slough	1.4	1.2	2.6
Morgan Slough	0	1.3	1.3
Cutoff Slough	0	2.2	2.2
Salt River		4.8	4.8
Total length			37.9

Eel River Estuary sloughs

on average by the Eel River ends up is a debatable issue (Patsch and Griggs 2007). Some deposition is recorded on the islands, channels and sloughs of the Eel River Estuary but it appears most of the sand from the watershed ends up in the ocean (Shepard and Wanless 1971; Johnson 1972).

Like Humboldt Bay, the predominant rock formations occurring in the watershed are the highly erodible Franciscan and Wildcat formations. Logging operations in the upper watershed and the clearing of riparian vegetation have contributed to erosion and subsequent increases in sediment load to the Eel River over the last 50 to 100 years. Today, the river has one of the highest sediment loads of any river in the world (Humboldt County 1992). The sub-basin's subsurface geology consists of sedimentary formations of the Wildcat Group to a depth of more than 9,000 ft (2,743.2 m) (CDFG 2010; Brown and Ritter 1971). In general, the Eel River Estuary lacks the expansive intertidal flats found in Humboldt Bay. Eelgrass is also less extensive and it exhibits a greater seasonal fluctuation in above-ground biomass. Nonetheless, these conditions are important by providing habitat complexity and diversity for wildlife. Remnant intertidal coastal marsh borders the Eel River near its mouth, on islands in the river, and along the banks of tidal sloughs.

Located in the Eel River Delta are the City of Ferndale, with an estimated population of 1,700, (US Census Bureau 2010), and the unincorporated community of Loleta. Land use in the region includes gravel mining, dairy, timber harvest and recreational activities. In the 1850s, there were approximately 500 to 1,000 Wiyot people living around the Eel River Estuary. When Euro-Americans began to settle and develop coastal areas of Humboldt County, many Wiyot people were killed or driven off traditional lands. By 1910 only 100 Wiyot people remained within Wiyot territory (Van Kirk 1996). Today, there are approximately 150 Wiyot people residing on the Table Bluff Reservation and another 300 Wiyot tribal members who reside elsewhere.

History

The Eel River Estuary is considered a drowned river valley. There was net subsidence in the Eel River Delta during the late Holocene. Most of this subsidence occurred episodically during five or more sudden events (Li 1992). Historically, the Eel River had a narrow, deep channel with expansive intertidal coastal marshes near the mouth and a well-developed riparian corridor of willow and alder. It is thought that the Salt River occupies a former channel of the Eel River that was left behind as the dominant channel of the Eel River migrated north across the delta during centuries of change (Downie and Lucey 2005).

In the Eel River Estuary, the estuarine channels were once deep enough to allow shipping vessels access into Port Kenyon and up the Eel River past Fernbridge. A review of bathymetry maps produced in 1869 showed that depths near the river mouth were 10 ft to 16 ft (3.05 m to 4.9 m) and the North Bay and lower portions of McNulty Slough ranged between 9 ft to 13 ft (2.7 m to 3.96 m). The North Bay channel ranged from 10 ft to 14 ft (3.05 m to 4.3 m) in depth, and the river thalweg and pools around Cock Robin Island were from 25 ft to 31 ft (7.6 m to 9.4 m) in depth. Bathymetry maps produced in 1888 and 1921 showed a shallowing trend in the lower main river channel thalweg and pools, and the lower Salt River (Laird et al. 2007; CDFG 2010).

The 1906 earthquake along the San Andreas Fault caused significant morphological modifications to the Eel River Estuary including subsidence of several acres of land higher than one foot at several sites, especially on Cock Robin and Cannibal islands. It was reported that land slid into the Salt River all along its banks (CDFG 2010).

The size of the estuary, both in terms of area and volume, has decreased substantially since the mid-1800s due to the combined effects of land reclamation and sedimentation (SCS 1989). Recent flood events have deposited coarse sands in thick layers (Li 1992). Excessive sediment deposition, in combination with levees and tidegates, reduced tidal prism in the Eel River Estuary by approximately 40% since 1900 (SCS 1989). At one time, tidal influence extended upstream 10 mi (16.1 km) in the summer; now the zone affected by the tides is only about 7 mi (11.3 km). During winter periods of high runoff, the tides influence only the embayment near the mouth of the river and McNulty Slough, the northern arm of the Eel River Estuary (Roberts 1992). Sedimentation filling the estuary has reduced the capacity of the Eel River to store floodwaters. In recent years, flooding of adjacent farmland and urban areas has become a severe problem in the delta (CDFG 2010).

The channel of the Salt River, a tributary to the Eel River, has been severely reduced by sedimentation, resulting in a loss of hydraulic function, blocking fish passage, and increasing flooding of adjacent agricultural lands. Levees and tidegates have restricted the ecosystem's ability to clear sediment deposits from the channel. A watershed-scale restoration project designed to restore natural processes is in planning and design stages and will be implemented over the next few years. Project plans include controlling erosion by stabilizing streambanks and upgrading forest roads; constructing a new channel to accommodate high winter flows; and enhancing tidal action at the mouth of the Salt River (HCRCD 2007; HCRCD 2010).

Inspection of aerial photographs shows the main channel has remained in a similar

Salt River Channel

configuration since the 1964 flood event when the majority of flow was forced around the north side of Cock Robin Island. The flood delivered large volumes of sediment that accumulated in the main estuary channel, filling deep pools and raising channel bed elevations. Significant changes in channel depths occurred in the 4 mi to 5 mi (6.4 km to 8.0 km) stretch of the main stem below Fernbridge to Cock Robin Island. Singley Pool and other deep pools in that area are filled with sediments. The floods also eroded large amounts of shoreline and widened the estuary main channel (Van Kirk 1996). It has been almost 50 years since the 1964 flood and the channel still lacks the deep pools that once existed, suggesting that excessive sediments are still being transported into the estuary from upstream sources. In contrast to the main channel, depths in North Bay remain similar to what was shown in bathymetry maps produced in the 1800s. In 1994, maximum depths in the North Bay were from 10 ft to 14 ft (3.05 m to 4.3 m) during a moderate high tide (Cannata and Hassler 1995).

Commercial fishing for salmon and steelhead (*Onchorhynchus mykiss*) began in the Eel River Estuary around 1853 and continued until 1921. The early fishery was started by a few men who organized companies or teams of fishermen and claimed fishing sites in the lower Eel River Estuary. Beach seines of 360 ft to 480 ft (109.7 m to 146.3 m) in length and 20 ft to 26 ft (6.1 m to 7.9 m) in depth were used to catch salmon (Van Kirk 1996). The nets were set into the river channel, swept through the pools, and the fish were then hauled ashore by teams of men or horses. The first regulated season was from September 15 to November 25, 1859 (Wainwright 1965). However, enforcement of the regulations was difficult. In ensuing years, there were various restrictions on gear and other management actions and public interventions. Finally, the commercial fishery on the Eel River was closed by legislation in 1922, in part related to the growing presence of the ocean troll salmon fishery that harvested high quality fish. California Department of Fish and Game managers determined that the salmon populations would be at risk from the combined ocean and in-river harvests.

Like Humboldt Bay, the Eel River historically supported nearly 10,000 ac (4047 ha) of intertidal coastal marsh, with less than 10% remaining today. A system of historic tidal sloughs once functioned to provide tidal connectivity throughout these former tidelands. Most of this land has been diked and drained for agricultural use. In 1888, Westdahl described the changes in vegetation of the Eel River Delta between 1872 and 1888:

The entire delta of the river has been covered with forests of pine, spruce, and some redwood, with alder growing near the water course. These forests have nearly all been cleared away, the timber remaining only in bunches.

Today, dairy farming is the predominant land use in the Eel River Delta, followed by beef production. During the rainy season, October through April, much of the pastureland is frequently flooded, and cows are moved to higher elevation pastures, housed in barns, or corralled on mounds that have been constructed with fill material.

Harbor seal

Chapter 2. Methods for Compiling the Habitat Profiles

Introduction

The Habitat Profiles were written based on existing data and information published in or before 2012.

Habitat Profiles include:

- Identification of habitat type(s)
- Literature review of each habitat
- Themes for each habitat profile
- Criteria for habitat data selection

Identification of habitat types was closely linked with the classification system used for the new aerial imagery and benthic habitat data. The habitat classification system was under development at the time of the Habitat Project. Humboldt Bay and the Eel River Estuary intertidal and subtidal habitats considered for this report are:

- Subtidal – Water Column and Benthic Zone
- Intertidal Banks, Bars and Flats
- Eelgrass (includes oyster mariculture)
- Intertidal Coastal Marsh

Each habitat chapter includes:

- Habitat Distribution
- General Description
- Physical Characteristics
- Biotic Communities
- Ecosystem Services
- Management Considerations

Habitat data selection was based on information describing location, tidal range, salinity at specific locations, vegetation and geomorphology. Some historical data is presented for the study area, but the emphasis is on current conditions. The Habitat Profiles were prepared by California Sea Grant Extension Program staff (S. Schlosser; D. Marshall; A. Eicher). Documents, reports, theses, dissertations and other publications were gathered from the National Sea Grant Library, the Humboldt State University Library and the offices of many local planners, managers and scientists.

An EndNote library was created as part of the literature review process. Numerous references are cited to enable the reader to obtain more detailed information on specific topics. The EndNote library currently contains more than 1,400 documents on Humboldt Bay habitats and approximately 150 documents with information on the Eel River Estuary. Reviewing, selecting information, and writing the habitat profiles was challenging due to the different scale and amount of data availability for each habitat. The chapters reflect this variability and help identify missing information or key data gaps.

The EndNote library is available from the California Sea Grant Extension Program office (707-443-8369).

Habitat Profile Themes

For this project, habitat is defined as a space providing food, water and shelter suitable for the survival and reproduction of an organism or a community of organisms. Habitats are often characterized by physical features or by dominant plant associations.

Throughout this report, we use common names to refer to species except when scientific names are needed for clarity, or when the species is typically referred to by its scientific name (as for algal species and some invertebrate species). The first time a species is mentioned in the report, the common name is followed by the scientific name in parentheses. Scientific and common names presented in this report may differ from the original sources cited because of taxonomic name changes over time. All species mentioned in the text are listed in Appendix A. Following established conventions, common names are only capitalized if they contain proper names, with the exception of bird common names, which are all capitalized. In scientific nomenclature, the genus (the first part of the name) is capitalized and the specific epithet (the second part) is lowercase.

General Description

The general description of each habitat includes broad information on habitat location relative to tidal cycles, and if found, published state or federal description(s), and specific habitat descriptors.

Habitats are considered in a landscape context and descriptions of patterns and structure and function of links between habitats are provided. Landscape complexity and spatial relationships constitutes a measure of the ecosystem's diversity. Landscape connectivity refers to the degree to which movement among resource patches is facilitated. Habitat fragmentation generally refers to the loss of connectivity among resource patches caused by habitat destruction or degradation (Tischendorf and Fahrig 2000; Murphy and Lovett-Doust 2004). Landscape context is especially important for management considerations. Where available, landscape context is included in the Habitat Profiles.

Distribution and Location

If available, historic habitat distribution is presented as a map or table. Distribution based on the 2009 imagery and classification is presented in map, narrative and table format. The areal extent and location are the primary information for habitat distribution.

Physical Characteristics

This section includes consideration of the natural processes that form estuarine habitats and is integral to understanding how they relate to one another. Estuaries represent a transition zone between freshwater and marine habitats, formed primarily as the result of hydrodynamic forces and sediment supply. Estuaries are naturally dynamic because of variable physical features such as water depth, current velocity, salinity and temperature. They are ecologically rich and complex. Additionally, both longitudinal and lateral boundaries continually change with tide and river flows. The head of tide (the upstream location where water is affected by tide) is often a considerable distance upstream of the salinity limit, and varies seasonally. The lateral extent of the estuarine habitat includes all areas that interact with tidal and river flows, as well as the margins that are inundated only during extreme tides or flood events. Estuarine habitats thus exhibit a mixture of marine and riverine physical and chemical characteristics (Bottom et al. 1979; Johnson et al. 2003; Bottom et al. 2005). Climate, topography, regional geology and soils, and broad land-use patterns determine the riverine inputs to the estuarine habitat (Gibson et al. 2000).

The dominant mixing forces in an estuary are river flow, tides, waves and wind. The mixing energy influences specific physical habitat features of estuarine habitat such as channel width-to-depth ratio, salinity gradients and turbidity. In natural systems, deep channels of the estuary are connected to a dendritic pattern of smaller channels covering the mudflats and extending into intertidal marshes. The meander pattern of these channels is influenced by the energy of the flow: the lower the energy, the greater the meander. Sediment is temporarily stored in these channels and on the adjacent floodplains, but can be mobilized during high flows, often resulting in channel migration.

Habitat Profiles include physical characteristics such as geomorphology, hydrology and depth.

Biotic Communities

A wide diversity of organisms rely on estuarine habitats for survival. Planktonic organisms and fish inhabit the water column, moving with the ebb and flow of the tides. Numerous invertebrates inhabit the bottom surface that is always submerged, known as the subtidal benthic zone. Another suite of organisms have adapted to living in the harsh conditions of the intertidal zone that require tolerance both to periodic submergence in brackish to saline water and extended periods of exposure.

Wildlife use of complex estuarine ecosystems is dynamic. Many species depend on having access to a diversity of habitat types for food, water, shelter and breeding. Resident and marine fishes use the channels, eelgrass beds, and intertidal flats at high tide for foraging and as nursery grounds. Anadromous species spend much of their time in the ocean, passing through the estuary to riverine spawning grounds. Juvenile Dungeness crab use macroalgae mats and eelgrass beds as refugia from predators and the shallow subtidal benthic zone for foraging (Eggleston and Armstrong 1995). Numerous species of waterfowl and shorebirds use the open water habitats of the bay and the intertidal mudflats for foraging and intertidal coastal marshes for roosting. Brant Geese feed on eelgrass and also on the tiny invertebrates living on the eelgrass blades. Pacific herring (*Clupea harengus pallasii*) lay their eggs on eelgrass blades; the eggs in turn are an important food source for Surf Scoters (*Melanitta perspicillata*). Harbor seals (*Phoca vitulina richardsi*) are abundant in open water habitats and use intertidal flats as hauling-out grounds. Shorebirds that feed on the mudflats during low tide and loaf in the marshes at high tide also utilize dune systems for foraging and nesting. Many raptors hunt in the estuary.

Habitat Profiles include a diverse range of species information. Where possible key species identified as using the habitat are described.

Ecosystem Services

Ecosystem services are fundamental life-support processes performed by natural systems. Human civilization depends on these services. The ecosystems where humans live, whether in an urban, rural or wilderness setting, provide goods and services that are familiar to us. Ecosystem services are extensive and diverse and vary from microbes to landscapes, from seconds to millions of years. For example, a coastal marsh contributes to the ability of the Humboldt Bay and Eel River Estuary ecosystems to sequester carbon, prevent erosion, and provide habitat for wildlife as well as human recreational opportunities, all of which are ecosystem services. No literature on ecosystem services was found for Humboldt Bay or the Eel River Estuary, but the Habitat Project Advisory Committee identified many ecosystem services provided by habitats in the study area.

Each habitat chapter in this report contains a list of the ecosystem services provided by that habitat. Overall, these services include:

- Moderation of weather extremes and their impacts
- Mitigation of droughts and floods
- Protection from the sun's harmful ultraviolet rays
- Cycling and movement of nutrients
- Protection from shoreline erosion
- Detoxification and decomposition of wastes, resulting in improved water quality
- Maintenance of biodiversity
- Genetic and biochemical diversity that support agricultural and pharmaceutical industries
- Carbon storage
- Wildlife habitat
- Production of natural resources harvested for subsistence and commercial use
- Recreational, cultural and aesthetic opportunities

It is important to recognize these services, gain a better understanding of them, and take a pro-active approach towards preserving them. We know little about the impacts of human activities on ecosystem services in our region. To what extent have various ecosystem services already been impaired? How interdependent are ecosystem services? How effectively and at what scale can we repair or restore ecosystem services? These investigations require multidisciplinary teams. We are fortunate to have expertise in biology, chemistry, physics, economics, geosciences, geography and finance in our local academic, private and government institutions, as well as collaborative programs that have the capacity to examine these issues.

Framing land use and coastal resource management issues in terms of ecosystem services has helped focus some ecological research. Understanding the full consequences of policy or management decisions will lead to better environmental decision making (Sheraga et al. 1998, Ellenwood et al. 1998, Goldfinger et al. 2008).

Management Recommendations

The Habitat Project was part of an ongoing effort by scientists and resource managers in the Humboldt Bay region to explore an ecosystem-based management (EBM) approach to natural resource management. The ecosystem program emphasizes collaboration, science-based decision making, sustainability, protecting ecosystem structure, function and processes, and inclusion of humans as an integral part of the ecosystem. The last section of each chapter addresses management recommendations using an ecosystem approach.

The Habitat Project Advisory Committee members included representatives from California Coastal Conservancy, California Department of Fish and Game, California Sea Grant, Humboldt Bay Harbor, Recreation and Conservation District, the National Marine Fisheries Service, NOAA Coastal Services Center and the US Fish and Wildlife Service. Committee members had a wide range of expertise in ecological sciences. The Advisory Committee met 21 times in a 15-month period to assess habitat threats and develop management recommendations.

The Advisory Committee prepared and adopted the following mission statement:

Our mission is to integrate existing information about bay and estuarine habitats and selected species, identify research needs, and develop ecosystem-based recommendations using a collaborative process.

The Advisory Committee used a process called Conservation Action Planning (CAP), developed by The Nature Conservancy. CAP provides an adaptive management framework for planning, implementing, and measuring the success of conservation projects (The Nature Conservancy 2007) (http://conserveonline.org/workspaces/cbdgateway/cap/ , accessed June 20,2012). The Advisory Committee selected conservation targets representing the biodiversity of the study area, considered and described key ecological attributes, identified and ranked the severity of threats facing them, and developed EBM recommendations for the Humboldt Bay Ecosystem.

The CAP process distinguishes between ecological attributes and anthropogenic stressors. This enabled a systematic assessment of stressors and ecosystem impacts which were used to develop management recommendations. This process helped the Advisory Committee focus on more than the anthropogenic stressors, and to suggest comprehensive, cross-agency and integrated management recommendations for each habitat.

The CAP process was closely linked to an EBM program—the Humboldt Bay Initiative (see Chapter 1) (Schlosser et al. 2009b). Together, they provide a current state-of-the-science and knowledge view of the Humboldt Bay and Eel River estuarine ecosystems. Where possible, management recommendations evaluate habitat distribution, condition and impacts from human activities.

The recommendations presented in this report have not been reviewed in terms of compliance with the National Environmental Policy Act or the California Environmental Quality Act. Any project that proposes to implement recommendations in this report will need to complete the appropriate environmental impact analysis.

Eelgrass (*Zostera marina*) and red algae (*Graciliaria* spp.)

Humboldt Bay intertidal mudflat with a scavenging Western Gull (*Larus occindentalis*). This combination is an example of how species co-exist amidst natural and artificial habitats adjacent to a rock levee.

Chapter 3. Benthic Habitat Imagery Acquisition and Classification Methods

Introduction

Mapping habitats within the extent of tidal influence of Humboldt Bay and the Eel River Estuary was an integral part of the Habitat Project. The coastal habitat maps address the fundamental questions: How much intertidal and subtidal benthic habitat does Humboldt Bay and the Eel River Estuary have? Where are the various habitats located?

Project investigators used a new classification system to map benthic intertidal and subtidal habitats. The new system can be integrated with National Wetlands Inventory and other recent subtidal classification work (Madden et al. 2009). The Coastal and Marine Ecological Classification System (CMECS) was under development at the time of the project. Habitats were classified according to Version 3 of CMECS.

The mapping methods used for the Habitat Project include:

- Geographic Information System (GIS) Data Source Inventory and Workshop
- Aerial Imagery Acquisition
  - Definition of Imagery Criteria
  - National Hydrographic Database
  - Signature Development
- Benthic Habitat Delineation
  - Photointerpretation
    - Imagery Interpretation Guidelines
    - Classification Conventions
    - Accuracy
      - Spatial Accuracy
      - Thematic Accuracy
    - Coastal and Marine Ecological Classification System Description
    - Humboldt Bay and Eel River Estuary Benthic Habitats
    - Habitat Profile Report and Habitat Classification
- Outreach and Education
- Coastal LIDAR

Geographic Information System (GIS) Data Source Inventory

The first task in acquiring images was compiling a spatial data inventory of existing data sources. Photo Science prepared a geospatial data inventory for benthic habitats within the study area (Photo Science 2007). The Excel spread sheet and the data sets examined were presented at a workshop in 2007 (download at http://ca-sgep.ucsd.edu/humboldthabitats)

Working with regional representatives, Photo Science inventoried, cataloged and described available geospatial datasets. Their report documented 116 datasets, with coverage ranging from specific sites within the study area to the entire coast of California. Nearly three-fourths of the datasets have been generated since 2001. Metadata records compliant with the Federal Geographic Data Committee (FGDC) are available for 80% of the datasets, and 45% were assessed by Photo Science to have spatial coverage of the study area. Approximately 40% of the datasets had a habitat-related purpose. However, 75% of the habitat dataset spatial coverage assessments resulted in a poor value (Photo Science 2007).

Most existing geospatial data sets were too broad scale to be useful for this project. For example, many of the marine fish species data are coarse in scale, depicting the species distribution over a large area with no habitat information. In most cases, specific intertidal or subtidal habitats were not classified or mapped. Existing data source material included four possible data sets that could be classified by CMECS (Table 4). Collection of new benthic habitat data was determined to be necessary, especially in regard to control for the tidal elevation at the time of imagery acquisition (Table 4). Based on these findings, the decision was made to acquire new data for the purpose of mapping subtidal and intertidal habitats in Humboldt Bay and the Eel River Estuary. Other previous imagery was lower resolution, not taken at low tide and taken for other purposes (Kure oil spill 1997; CDFG 2000; Coastal Commission 2002).The spatial data base includes data description, data type and format, spatial coverage, location and accessibility of data, time period, scale, data contact information, metadata record if available, data constraints or known issues.

In late 2008, we learned of a partial data set of images taken in 2005 (Figure 9). This partial imagery dataset was georectifed by Simon Frazer University, Vancouver, Canada, in collaboration with Humboldt State University, Arcata, California. It is color infrared, 1.0 ft (0.3 m) spatial resolution, ± 9.8 ft (3.0 m)

Table 4. Data source material evaluation for Humboldt Bay and Eel River Estuary existing image sources.

Dataset	Year	Spatial Resolution	Comments	Constraints
Humboldt Coast Aerial Photography (from A. Pickart, 2007)	1999 -2000	0.17 m	Of the four sources examined, this imagery provides the best differentiation of features, although it is dated.	Imagery is from multiple dates over multiple years, is not tide controlled and does not cover the entire study area.
NAIP*	2005	1 m	This source could be used to delineate benthic features. Acquiring color and infrared band for the imagery would improve delineation.	Multiple collection dates. Price of acquiring color and infrared needs to be determined. NO tide control, tide was about 1.3 ft.
Humboldt Imagery (from J. Mello) 2000	2000	1.6 m	Southern portion of Humboldt Bay is better quality than northern portion.	Although high minimum mapping unit and resolution, this does not include the Eel River Estuary.
NAIP	2004	2 m	This source does not appear to be appropriate for benthic habitat delineation.	Imagery not taken at low tide and resolution is too low for intertidal habitat mapping

* National Agriculture Imagery Program

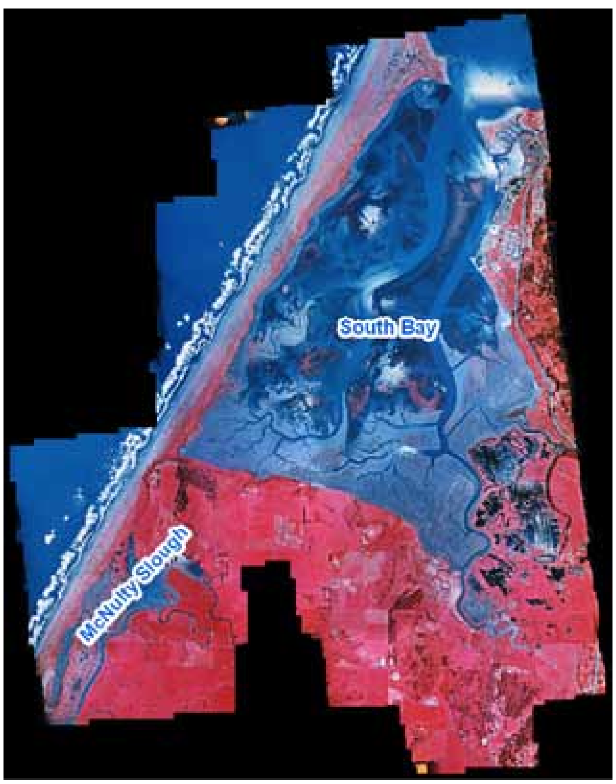


Figure 9. Extent of Humboldt Bay and Eel River Estuary imagery taken in 2005 by Humboldt State University.

horizontal spatial accuracy, covers North and South Humboldt Bay not the Entrance Bay and includes the northern tip of the Eel River Estuary. It was not considered adequate for the Habitat Project, but could significantly contribute to some trend analysis, management and research efforts. The 2005 imagery can be obtained from the California Sea Grant Extension Program office in Eureka, California.

Aerial Imagery Acquisition

Determination of Imagery Criteria

Imagery and mapping product criteria were discussed and agreed upon by project collaborators and the Humboldt Bay Initiative (HBI) project team at several meetings and workshops held in 2007.

Imagery was acquired based on a combination of tide, sun angle and weather, which build on commonly recognized best practices for mapping intertidal and shallow subtidal habitats. Numerous workshops, meetings, and conference calls among investigators and collaborators also contributed to these criteria.

Criteria for imagery acquisition was:

- Tide: 1.0 ft (-0.3 m) MLLW or lower
- Sun angle: 25^o to 50^o
- Weather: No clouds, haze, fog or wind
- Horizontal spatial accuracy: $\pm$ 3 m
- Minimum mapping unit: 10 m x 10 m (100 m^2)
- Airborne multispectral imagery: 0.5 m resolution (pixel size)
- Season: late spring or summer (June-August)
- Scale: 1:24,000
- Coordinate control points with existing network

Imagery collected at low tide and during summer was essential to expose coastal marsh and eelgrass at peak biomass for vegetation classification. Most coastal habitat studies worldwide are done during maximal biomass and distribution conditions. Collection of imagery was ideally within 2 hours of the lowest tide. In the study area, the falling tide was considered optimal to expose maximum intertidal habitat.

Aerial photography is best conducted when turbidity is low. Humboldt Bay and the Eel River Estuary are both turbid systems with a large area of soft substrate and suspended sediment. Dredging occurs annually in Humboldt Bay during March and April, therefore turbidity associated with dredging was avoided by setting seasonal criteria. Phytoplankton blooms were not a large concern for this project.

Turbidity is also influenced by wind and waves. Wind of 0 to 5 mph is not a problem but more than 5 mph is unacceptable because of areas of relatively long fetch. Breaking waves from wind fetch in areas of Humboldt Bay and the Eel River Estuary resuspend sediment, wrack lines and/or floating debris. All of these would confound habitat mapping. Because of turbidity, subtidal habitats were not classified.

Illumination of benthic habitats is affected by the sun angle. The required sun angle minimizes shadows and eliminates sun glint, which may preclude visualization of benthic habitats in the imagery. Shadows were not considered a large problem in the low gradient intertidal habitats found in Humboldt Bay and the Eel River Estuary. A high sun angle was possible due to low glint of Humboldt Bay mudflats. This was noted during pre-flight habitat observations by NOAA Coastal Services Center, Photo Science and California Sea Grant investigators.

Clouds and haze reduce the contrast in aerial imagery and may decrease the ability to distinguish benthic features or habitats and make interpretation difficult or impossible. The Humboldt Bay mission required absence of clouds, fog, or haze over the intertidal and subtidal portions of the study area.

The scale and resolution were a balance between covering the study area and detecting small features, and covering sufficient land area to include horizontal control points. Although the initial desire was to obtain 0.25m imagery, the narrow tidal window required data be acquired at 0.54m spatial resolution or half meter imagery. This permitted the aircraft to collect data over the entire study area in half the time of quarter meter imagery, allowing collection closer to optimal tide and avoiding incoming fog banks.

Flight lines were planned using U.S. Geological Survey (USGS) 7.5 minute quads with a scale of 1:24,000 that matched the scale of the images, providing good detail for a flight map. The flight lines bridged control points and included large areas of parallel lines to cover areas of open water (Figure 10).

Established ground control checkpoints used by county and state agencies were verified and used to determine the spatial accuracy of the imagery.

"Windows of opportunity" for imagery acquisition during spring and summer were identified using a Flight Planning Application developed by Photo Science (Schlosser et al. 2011). The application compared tide, sun angle and weather to calibrate local tidal elevation to barometric pressure, wind speed and wind direction. When local daily tidal regime and sun angle were considered, about 15 days per year met these criteria. The final decision to fly depended on atmospheric conditions, clouds, clarity and tidal stage.

Figure 10. Flight lines of the Humboldt Bay and Eel River Estuary imagery.

Acquiring the images was difficult. Even though the mixed diurnal tides have two high and two low tides, only one low tide per cycle was appropriate for the photography. The typical morning fog summer weather pattern in Northern California further complicated the photography acquisition. The lower tides occur in the morning resulting in few days per month that met the sun angle, tide and weather requirements. Significant time was spent from 2007 to 2009 planning for the flight the met tide, sun and weather requirements.

Digital, aerial imagery was successfully acquired on June 27, 2009 using a Z/I Imaging Digital Mapping Camera (DMC) sensor. The flight occurred between 9:48 a.m. and 10:24 a.m., with a low tide of -0.69 ft (-0.2 m) MLLW occurring at 10:11 a.m. The DMC produced spatially referenced aerial photograph collection consists of true color and color infrared imagery. The data have a horizontal spatial accuracy of ± 3 m and were captured at a spatial resolution of (pixel size) of 0.54 x 0.54 m. There were 3 flight lines and a total of 134 images. The imagery was tiled and named according to existing USGS digital ortho-quarter and boundaries. The imagery was geo-rectified using established ground control checkpoints and processed to remove atmospheric effects and to minimize exposure variations between flight lines.

A complete description of the imagery acquisition, cameras, images organization, polygon boundary accuracy, and benthic habitat classification methods are found in the metadata (Appendix B. Federal Geographic Data Committee).

National Hydrographic Database

In addition to CMECS habitat mapping, the National Hydrographic Database (NHD), (http://nhd.usgs.gov/, accessed March 21, 2011) completed in 2007, was added as a GIS layer to the imagery. The NHD contains watershed sloughs, streams, creeks, and rivers. The NHD data added to the Habitat Project study area are the sloughs, streams and rivers in the coastal plain and former tidelands. NHD includes specialized information with flow networks that can be used to trace water downstream or upstream. The NHD was created to assist scientists in modeling hydrologic features and is also useful for mapping purposes. Its geometric features combined with the flow direction, reach codes and other attributes make the NHD a powerful tool for modeling. In the Habitat Project study area, the NHD layer often shows where Humboldt Bay and Eel River Estuary tidal waters are controlled by tide gates or other water control structures (Figure 11).
It also uses an addressing system based on reach codes and linear referencing to link specific information about the water such as water discharge rates, water quality, and fish population. Using basic NHD features like flow network (that can be used to trace water downstream or upstream), linked information and other characteristics, it is possible to study cause-and-effect relationships, such as how a source of poor water quality upstream might affect a fish population downstream, or how rising sea level may effect intertidal habitats.

Signature Development

Several field visits for habitat signature development were conducted by principal investigators from Photo Science, the NOAA Coastal Services Center, and California Sea Grant Extension staff. The first visits were focused on signature development prior to any mapping activity. The principle objective of the signature development fieldwork was to collect habitat data to guide the subsequent mapping effort. In addition, a selected set of field observations were reserved for validation points and were later used to test the accuracy of the draft habitat maps. The signature development sites included habitats that were easily interpreted and others that where more difficult. The "easily" identified sites were important to ensure that initial assumptions were correct and what was considered a simple site was not a confusing site. Vehicles and boats were used to reach Humboldt Bay and the Eel River Estuary sites. Specific objectives of field visits were to capture information about ephemeral conditions, to collect representative photographs of the habitat classifications, and to establish ground control checkpoints.

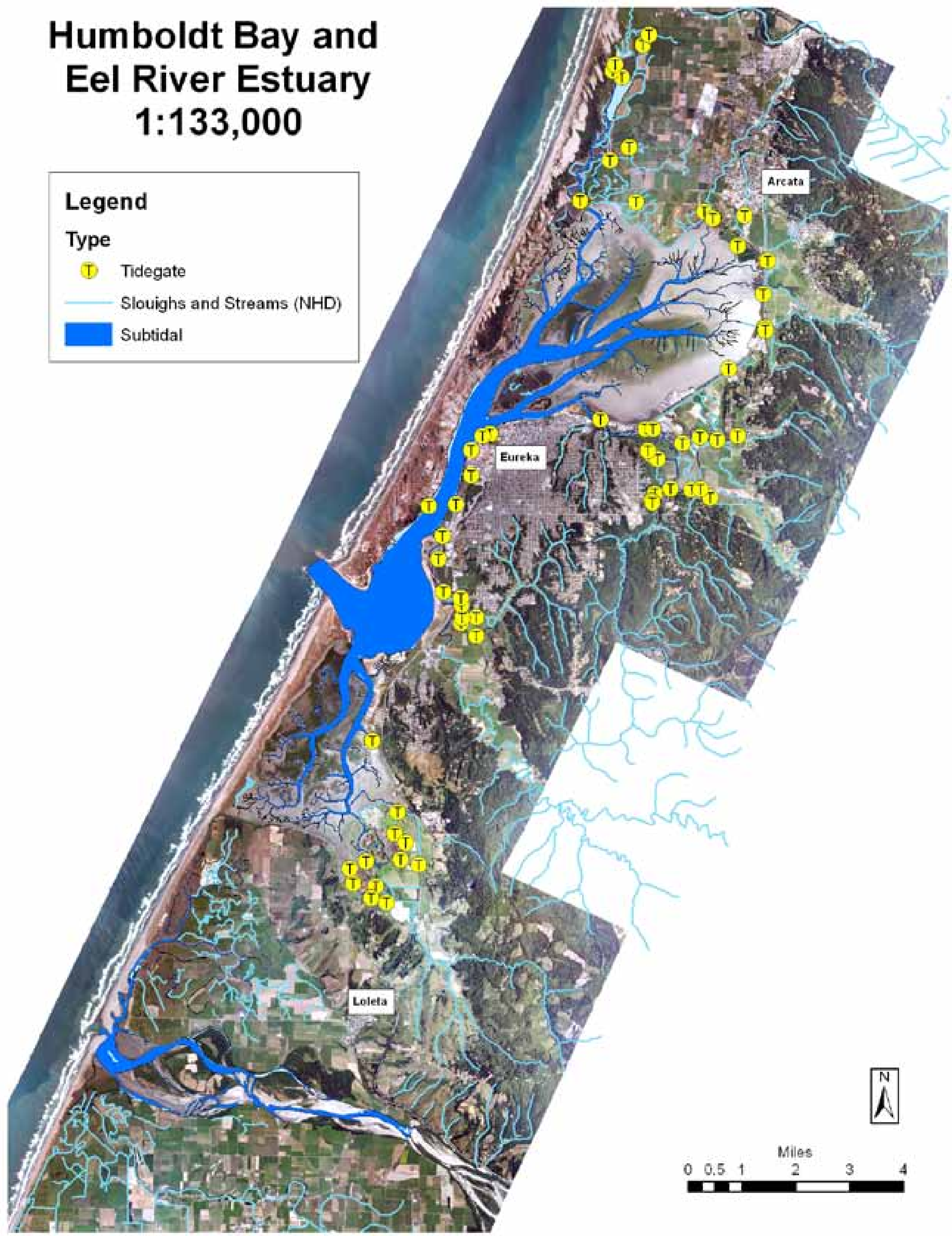


Figure 11. Study area drainage including slough and creeks from the National Hydrographic Database was added to the imagery and habitat classifications.

On the ground photographs were taken at tidal heights similar to the proposed conditions for the images. Most representative habitat images were taken as close-ups or with wide angle. Date time, viewing direction and GPS (x and y coordinates) were recorded for reach photo. These photographs served as references for spectral signatures to habitat types for the analysts as well as providing valuable field knowledge to the principal investigators. A total of 96 and 4 signatures were collected for Humboldt Bay and the Eel River Estuary, respectively (Table 5).

The field visits helped bridge the scale gap between ground observations (meters) and aerial observations (kilometers) (Figure 12). Using this information, investigators were able to better understand and analyze the images and thus produce higher quality benthic habitat maps with the field visit photographs, location information and aerial imagery.

Field sites in eelgrass habitat included sparse, dense, and submerged areas. Macroalgae includes dense and sparse areas and numerous species. Oyster mariculture includes intertidal culture areas with above ground structures and nursery areas with oyster seed or clutch. Infrastructure such as tidegates, levees and piers were included in signature development to assist analysts with photo interpretation. Some habitats visited in the

Expanses of green algae, mostly *Ulva* spp., in Humboldt Bay

Near Samoa Bridge

Entrance Bay at Del Norte Street

Indian Island, southern shore

field were not classified after the imagery was collected. For example, analysts were not able to distinguish sand, gravel, cobble, mudflat, and microbial mat from the imagery. These habitats were classified as unconsolidated sediment.

The habitat validation information was especially critical at the interface area of macroalgae and eelgrass. This ephemeral condition varies in size and location with season. They may change dramatically prior to the imagery acquisition

Table 5. Signature Development. Location, habitat, date of field visit, and number of sites per habitat that were photographed before imagery acquisition.

Location	Habitat	Date(s)	Number Sites
Humboldt Bay	Cobble	May 2008	1
	Eelgrass	Feb. 2007 & 2008, May 2007 & 2008, June 2008, July 2008, Aug. 2008	22
	Gravel	May 2008	1
	Levee	May 2008	1
	Macroalgae	Feb. May, June, July, Aug. 2008	38
	Mudflat	Feb. May, June, July 2008	17
	Microbial Mat	Feb. & May 2008	3
	Shell	Feb. 2008	1
	Pier		1
	Coastal Marsh	Feb. 2007 & 2008	4
	Wrack	Feb., May and July 2008	3
	Oyster Mariculture	Feb. and May 2008	4
		TOTAL	**96**
Eel River Estuary	Cobble	May 2008	2
	Eelgrass	May 2007	1
	Gravel	May 2007	2
	Levee	May 2008	1
	Macroalgae	May 2007 & 2008	15
	Mudflat	May 2008	1
	Sand	May 2007 & Feb. 2008	3
	Subtidal	May 2007 & 2008	5
	Coastal Marsh	May 2007 & 2008, Feb. 2008	9
	Tidegate	May 2007 & 2008	2
		TOTAL	**41**

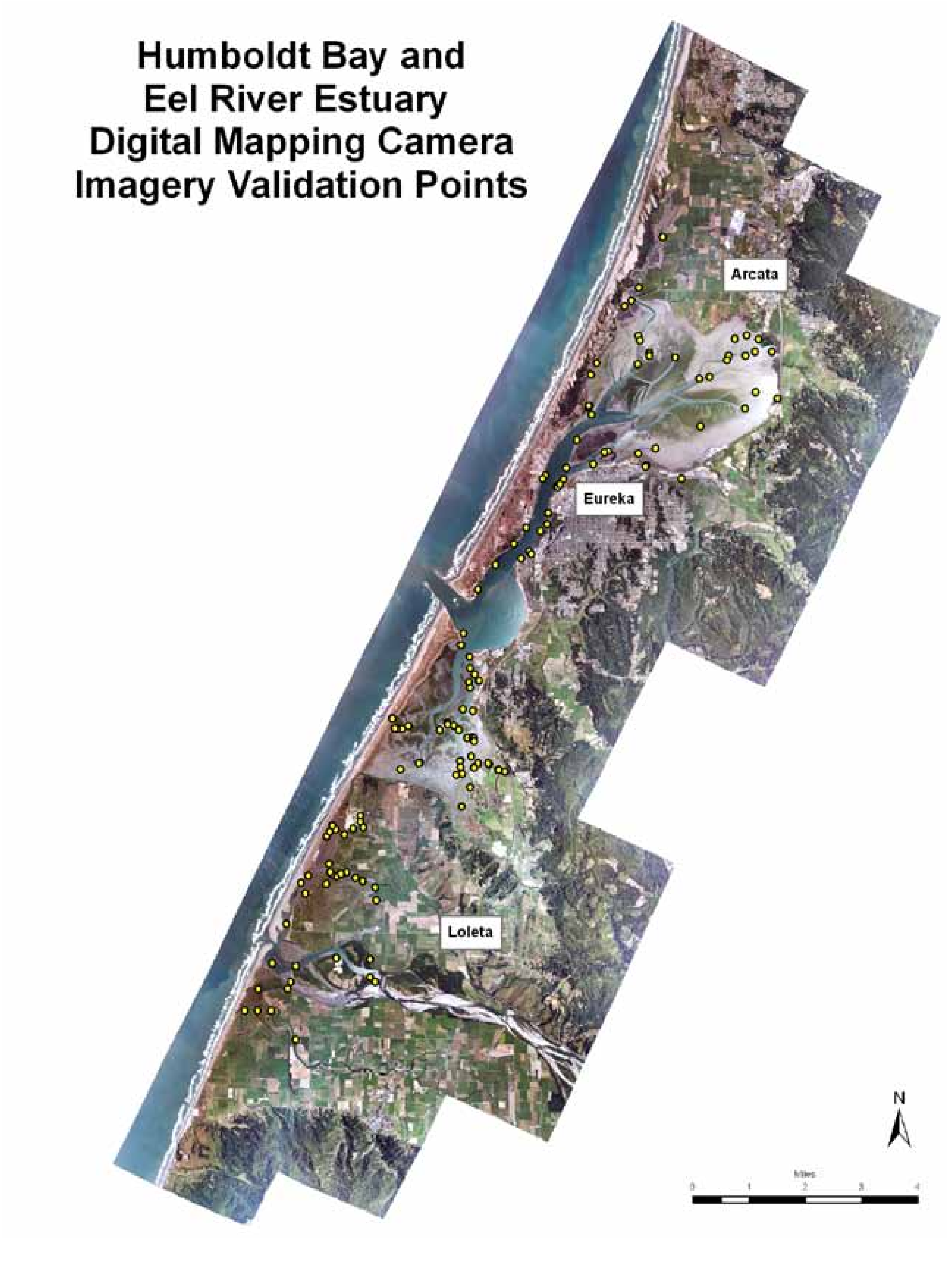


Figure 12. Validation sites for habitat signature development.

***Chaetomorphoa* sp., a macroagal species that covers large areas of mudflat in Humboldt Bay and Eel River Estuary.**

Spring (green)

Summer (brown)

Mudflat with large *Chaetomorpha* sp bed.

Macroalgae and eelgrass intermingled in mid-elevation intertidal flats

Eelgrass and *Gracilaria*, close up

Close up eelgrass and *Ulva spp.*

Green algae, lighter green lower left, and eelgrass, dark green uper right.

Patchy eelgrass in mudflat "tidepools"

(P. Davis)

Intertidal patch eelgrass

Eelgrass gradation from dense to patchy

Coastal Marsh

Small cordgrass plants, *Spartina densiflora,* surround pickleweed, *Sarcocornia pacifica*, reddish colored in the fall.

Pickleweed, *Sarcocornia pacifica,* close up

Indian Island coastal marsh interspersed with algae and intertidal mudflats

Oyster mariculture in Humboldt Bay

Oyster seed in bags.

Oyster long lines recently planted.

Oyster long lines in summer with green macroalgae.

Clam rafts in Hmboldt Bay - subtidal mariculture (not mapped)

Working at a clam raft

Floating upwelling system used to rear settled larval oysters and clams.

Levee habitats and tidal elevation zonation.

Coastal marsh in North Bay along rock levee

Gracilaria spp. and large woody debris adjacent to earthen levee

Macroalgal bed in North Bay extending to railroad levee.

or following it. Large increases or decreases in biomass, large changes in spatial extent and appearance may mask or expose other habitats. Macroalgae was the ephemeral condition of greatest interest.

Classifying and mapping additional habitats, and developing modifiers or other refinements to the habitat mapping would benefit resource managers, scientists, and recreational users. Unclassified habitats that are relatively common or easy to identify from the images offer an excellent opportunity for class projects and theses. Some unclassified habitats include rocks and algae, kelp beds, large woody debris, microbial mat, shell, and drift or floating macroalgae, and kelp (*Nereocystis luetkeana*).

Another seagrass species found in Humboldt Bay and the Eel River Estuary, *Ruppia maritima*, is widespread on some intertidal

Floating or drift kelp

Nereocystis leutkeanna, eelgrass, and macroaglae in Entrance Bay near Indian Island. This habitat is used by juvenile coho salmon during their seaward migration in Humboldt Bay (Pinnix et al. 2012)

Rock and algae: An unclassified habitat common at the base of hardened levees but often too small an area for the minimum mapping unit used in this project:

Floating eelgrass and algae is often temporarily trapped by the channel marker, docks or other structures forming a complex habitat for predators and prey.

Large woody debris in the Eel River Estuary

In the Eel River Estuary large, whole trees are periodically carried from the watershed to the estuary. In general, they are removed for firewood.

McNulty Slough

Salt River Slough

North Bay

flats. No studies have been conducted on it in the project area.

R. maritima is a perennial aquatic herb native to California and found elsewhere in North America and the world. *R. maritima*, also known as Widgeon Grass and Ditch Grass, is a low growing seagrass adapted to fine and medium textured soils. In Humboldt Bay and the Eel River Estuary, *R. maritima* grows in intertidal mudflats and forms dense patches from approximately 1-6 m^2 in size. It tolerates a wide range of environmental conditions in temperate and tropical areas. Like other seagrasses, it binds sediment and reduces erosion.

Widgeon grass *(Ruppia maritima)*

Benthic Habitat Delineation

Photointerpretation

The imagery data set was visually interpreted from 0.54 m resolution photographs. The habitats that were identifiable in the images were classified as subtidal, macroalgae, unconsolidated sediment, eelgrass, oyster mariculture, and coastal marsh.

Analysts utilized the field data collected during the signature development process as well as information provided by local partners to assist in their interpretation. Habitat boundaries were determined by the signatures apparent on the photographs. Habitat features were delineated and digitized on screen using ArcMap 9.3 resulting in accurate and efficient 3D extraction of the data. The combination of spectral and spatial characteristics allowed analysis of color, size, shape, texture, pattern, shadow, and spatial association to identify and delineate benthic habitats. In general, one habitat was digitized at a time and the resulting habitat polygons generated the benthic habitat data.

The processed imagery was combined with targeted ground control checkpoints and the collected airborne GPS data in an aerotriangulation process using Z/ImageStation Automatic Aerial Triangulation (Z/ISAT) software (Dörstel et al 2001). This provided the precise location and pointing for the exterior orientation of each captured frame of the photography. The optimized exterior orientation was used in the orthorectification phase. The digital orthophotos met the spatical accuracy requirement, $\pm$ 3 m, as defined by the National Standards for Spatial Data Accuracy (CE95, NSSDA). The Z/ISAT software contributed to data validation, but fieldwork was still required to eliminate confusion in some habitat areas.

A workstation was utilized with ESRI ArcGIS® software tools to generate a 9.3 Geodatabase containing the data. Habitat polygons were delineated with a high level of detail and the digitized vector polygon boundaries have the following specifications:

Vertex Distance $\leq$ 1.0 m
Node Snap Distance $\leq$ 4.0 m
Arc Snap Distance $\leq$ 4.0 m

Habitats were delineated with the minimum mapping unit (MMU) of 0.01 ha (10 m x 10 m). This minimum mapping unit represents the smallest feature that would be included in the final habitat map. The original DMC frames (individual tiles mosaicked together) were based on USGS 7.5-minute quad boundaries. Benthic habitats and features were classified according to CMECS (see next section for details). These mapping protocols resulted in a detailed and spatially precise baseline data set that is suitable for trend analysis and detecting changes in habitat distribution.

Imagery Interpretation Guidelines

The following interpretation guidelines were developed by the principal investigators and HBI Project team and are based on technical expertise and the project scope. The objective of the habitat delineation process is to preserve the maximum detail obtainable from the photography. This is significant, as one focus of the Habitat Project is to support habitat change detection using future aerial imagery for comparison to the 2009 images.

- Within habitats, outer boundaries are equally important as the internal structure, patchiness, shapes of sand patches, etc.
- Outer boundaries are as important as the internal density categories (for example eelgrass habitat may be patchy or in large continuous areas)
- It is more important to include small isolated habitat patches than similar sized patches that are part of a larger matrix.
- In cases where the edge of the habitat cannot be determined reliably due to depth, turbidity, glint or other limiting factor, then the boundary shall be delineated using the best possible line between points where the edge can be reliably determined. This line will be attributed as "fuzzy" in the final product.
- In cases where an area may have continuous or discontinuous eelgrass cover with macroalgae accumulations in the eelgrass canopy, then the polygon shall be assigned to the appropriate eelgrass category and a modifier used to document the presence of macroalgae.
- In other cases where an area may have many multiple small habitat components, then the polygon label shall reflect the majority habitat.
- For eelgrass, when a feature in the photograph was < 0.01 ha^2, it will be called "patchy eelgrass."
- If an area is uninterpretable, it shall be assigned to "unclassified."

Classification Conventions

The following classification conventions were used in order to ensure consistency of delineation:

- Eelgrass: The dominant feature of eelgrass beds was continuity (> 85% to 100% cover by eelgrass) and the beds may have variable density. An unvegetated area or a patch of macroalgae < 0.01 ha within an eelgrass bed is considered part of the eelgrass bed.
- Patchy eelgrass beds: Discontinuous eelgrass beds (>10% and < 85% cover by eelgrass) larger than 0.01 ha were mapped as patchy eelgrass.

- Unconsolidated Sediment: This classification consists of unvegetated substrate with < 10% eelgrass or algae.
- Macroalgae: Patchy or continuous algal beds (>10% to 100% cover) larger than 0.01 hectares were mapped as Macroalgae.
- Oyster Mariculture was delineated when active shellfish mariculture systems were present in intertidal areas, including primarily oyster culture (long line and rack and bag) and some clam culture (rack and bag). Oyster mariculture in subtidal areas was not classified.
- Coastal Marsh: Intertidal marshlands were delineated and classified as coastal marsh.
- Subtidal: The benthic environment below low tide that is always covered by water was mapped as Subtidal.
- Unclassified: Freshwater and upland areas were mapped as unclassified.

Accuracy

The final stage of accuracy assessment includes both thematic and spatial categories. Spatial accuracy is the evaluation of the positional correctness of features (roads, buildings etc.) visible in the imagery, and the position of habitat delineation lines in the derived map. Thematic accuracy measures whether the habitat is correctly labeled. This type of mapping requires expertise at the ground level in the study area. Project investigators from Photo Science, NOAA Coastal Services Center and California Sea Grant Extension conducted field visits to develop habitat signatures, habitat data validation, and accuracy. Two field visits were conducted after the imagery was collected.

Close-up of continuous eelgrass transitioning to patchy eelgrass in Humboldt Bay

Spatial Accuracy

Spatial accuracy measures the accuracy of the geographic placement of the points, lines and boundaries delineated by the analyst using ArcGIS 9.3 software.

The spatial accuracy methodology employed in Humboldt Bay and the Eel River Estuary consisted of following the process described in the NSSDA. The NSSDA requires that x and y coordinates be collected on the ground for a minimum of 20 fixed, clearly identifiable features (independent control points) for comparison to the coordinates measured for those same features on the ortho-imagery. The independent control points should be well distributed through the project area. This step was conducted by Photo Science prior to delivery of the ortho-imagery and before the mapping was initiated.

The spatial accuracy of the delineated habitat polygons can be assumed to match the accuracy of the source imagery which in this case is within 3m of position on the ground.

Thematic Accuracy

Thematic accuracy is a measure of the probability that the habitat is correctly identified in the classification scheme. In the Humboldt Bay and the Eel River Estuary Project, the habitat polygons themselves served as the sampling units. Habitat polygons were selected for field sampling according to habitat subclass. Starting with the validation points collected during the signature development trips, additional points were selected through a stratified random sampling process to generate 50 points per class. The sample points were located at the center of each of the polygons that had been targeted for inspection.

Representative sites were chosen to address:

- Macroalgae and eelgrass areas
- Eelgrass/sediment edge habitat
- Macroalgae/sediment edge habitat
- Sparse eelgrass
- Dense eelgrass
- Submerged eelgrass
- Coastal marsh

The process for conducting the field validation involved visiting sample polygons and determining the actual habitat present in the field. Priorities for these field observations were: sites with large increases or decreases in biomass; large changes in spatial extent or appearance; and areas where one feature or habitat may mask or expose something underneath it when a Garmin hand-held GPS unit with Wide Area Augmentation System (WAAS) was used for navigation. The x, y UTM coordinates and nautical chart were loaded into the unit to allow navigation to the assessment points. Habitat polygons were recorded as accurately as possible using on-board GPS, direct visual observation and an underwater camera.

The computer displayed the image of each target point as well as the real time location of the boat via the GPS unit. This system allowed precise navigation to the target point. In shallow water or when the water was clear or the bottom was exposed at low tide, direct observations were made from the boat. In deeper areas, or areas of unclear water, a towed underwater video camera with a live feed to a monitor on the boat was deployed. The camera was towed long enough (usually 2 to 4 minutes at each station) to provide complete assessment of the dominant habitat type.

From September 14 to 18, 2009 (n=39), and October 11 to 16, 2009, (n=89), a total of 128 points were visited to independently compare habitat delineations derived from the map to those in the study area. Habitats were verified on the ground and with underwater video. The sites were widely distributed throughout the study area.

All points were assembled into an error matrix where the "field" classification was compared to the "map" classification for each point by category. The resulting overall accuracy of the Humboldt Bay and Eel River Estuary benthic habitat data is 83.5 (Table 6). Navigation to each point was accomplished using source imagery, a real time WAAS enabled GPS (Garmin 76 unit) and a lap top computer (NOAA Coastal Services Center 2001).

In 2012 NOAA Coastal Services Center investigators performed the accuracy assessment on the data to compare in-field classification to photo-interpreted map classification. Random samples of coded polygons were generated, stratified by classification and located in the field with GPS. An 85%-accuracy rating for eelgrass categories based on the selected points was required. 132 stratified, random sample points were observed in the field to determine thematic accuracy. Habitat classification was recorded for statistical accuracy validation. Additionally, 24 points were manually selected to visit after the draft map was completed. As with spatial accuracy fieldwork, ground and video observations were collected and recorded.

The resulting thematic accuracy was calculated by development of an error matrix and calculation of Kappa coefficients based

On board computer for locating comparison sites and video used for thematic accuracy calculation

Analyst and computer

Lowering video camera

on comparison of field observations and ArcGIS generated benthic habitat data for predetermined polygons (Congalton 1991). Kappa coefficients, a quantitative, statistical measure of the magnitude of agreement between two observers, were calculated using the ArcGIS Kappa extension. The upper limit of Kappa is 1.0, which occurs when there is 100% agreement of the classified data with the mapped data. Kappa values below 0.5 suggest the results of the accuracy assessment may not reflect the actual validity of the data.

It is generally thought to be a more robust measure than a simple percentage agreement calculation, since Kappa takes into account the agreement occurring by chance (Landis and Koch 1977; Aspinall and Pearson 1995). The total number of observations for the Kappa calculation was 260; overall thematic accuracy 83.5%; overall Kappa values for all habitats 79.3%. The percentage of map class occurrence that is correctly identified per habitat is found in Table 6 right-hand column, "Commission."

Table 6. Thematic accuracy error matrix for Humboldt Bay and Eel River Estuary benthic habitat classifications comparing field observations and mapped classifications.

Field	Eelgrass	Macroalgae	Oyster Culture	Tidal Marsh	Unconsolidated Sediment	Subtidal	Unclassified	Total	Commission %
Eelgrass	59	4	5		7			75	79
Macroalgae	1	34		2	4			41	83
Oyster culture			44					44	100
Tidal Marsh				47				47	100
Unconsolidated	2	10	1	1	33			47	70
Subtidal		1			4			5	0
Unclassified		1						1	0
Totals	62	50	50	50	48	0	0	260	83.5

Coastal and Marine Ecological Classification System (CMECS)

Description

Obtaining habitat data that is high in quality and consistent in content is a challenge that many resource managers face. In response to this need, the NOAA Coastal Services Center and Office of Habitat Conservation, USGS, EPA, NatureServe and the MapCoast Partnership developed the Coastal and Marine Ecological Classification Standard (CMECS) (http://www.csc.noaa.gov/benthic/cmecs/). The standard's framework accommodates all information (physical, biological and chemical) that determines a marine habitat type (Madden et al. 2009, Appendix B).

CMECS's broad structure classifies the environment into aquatic settings or systems, determined by salinity, geomorphology and depth. There are five underlying components with these systems (Figure 13):

Water Column Component: describes the structure, characteristics, patterns, and processes of the water column and associated biota.

Benthic Biotic Cover Component: hierarchical classification describing the biological composition and cover of the coastal and marine seafloor benthos.

Surface Geology Component: hierarchical classification of the geological composition and environment of the upper layer of hard substrate and upper 15 cm of soft substrate as well as the structural (non-living) aspects of biogenic substrates such as coral reefs.

Sub-Benthic Component: The surface layer of the sub-benthic component is defined as the upper 15 cm of the soil/sediment beneath the water column.

Geoform Component: describes the major geomorphic or structural characteristics of the coast and seafloor at various scales.

These components provide a structured way to organize information about coastal and marine habitats and a standard terminology for describing them (Figure 14). They can be identified and mapped independently or combined as needed. The components describe different aspects of the habitat, an approach that allows information to be added incrementally as data becomes available for a specific site. Analysts have options for compiling spatial data using CMECS units, e.g. they may draw from various components to produce a single map. In the Habitat Project, the map units were selected to characterize an overhead view.

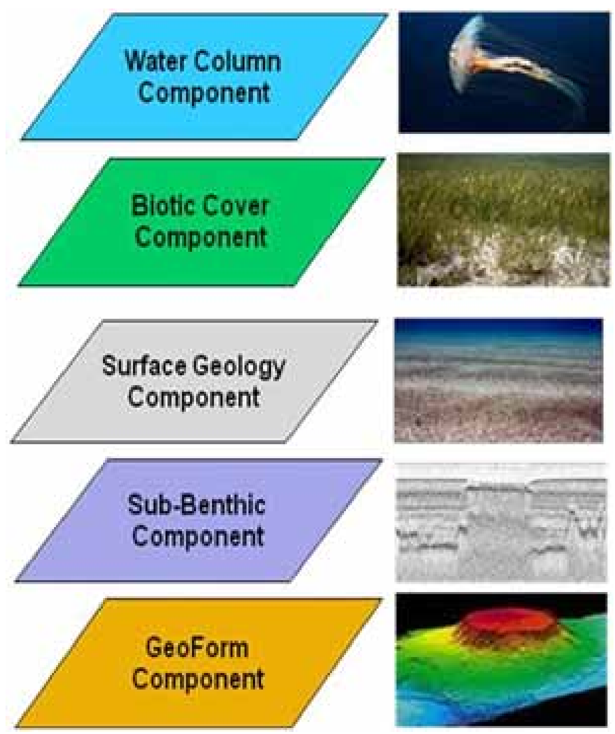


Figure 13. CMECS components

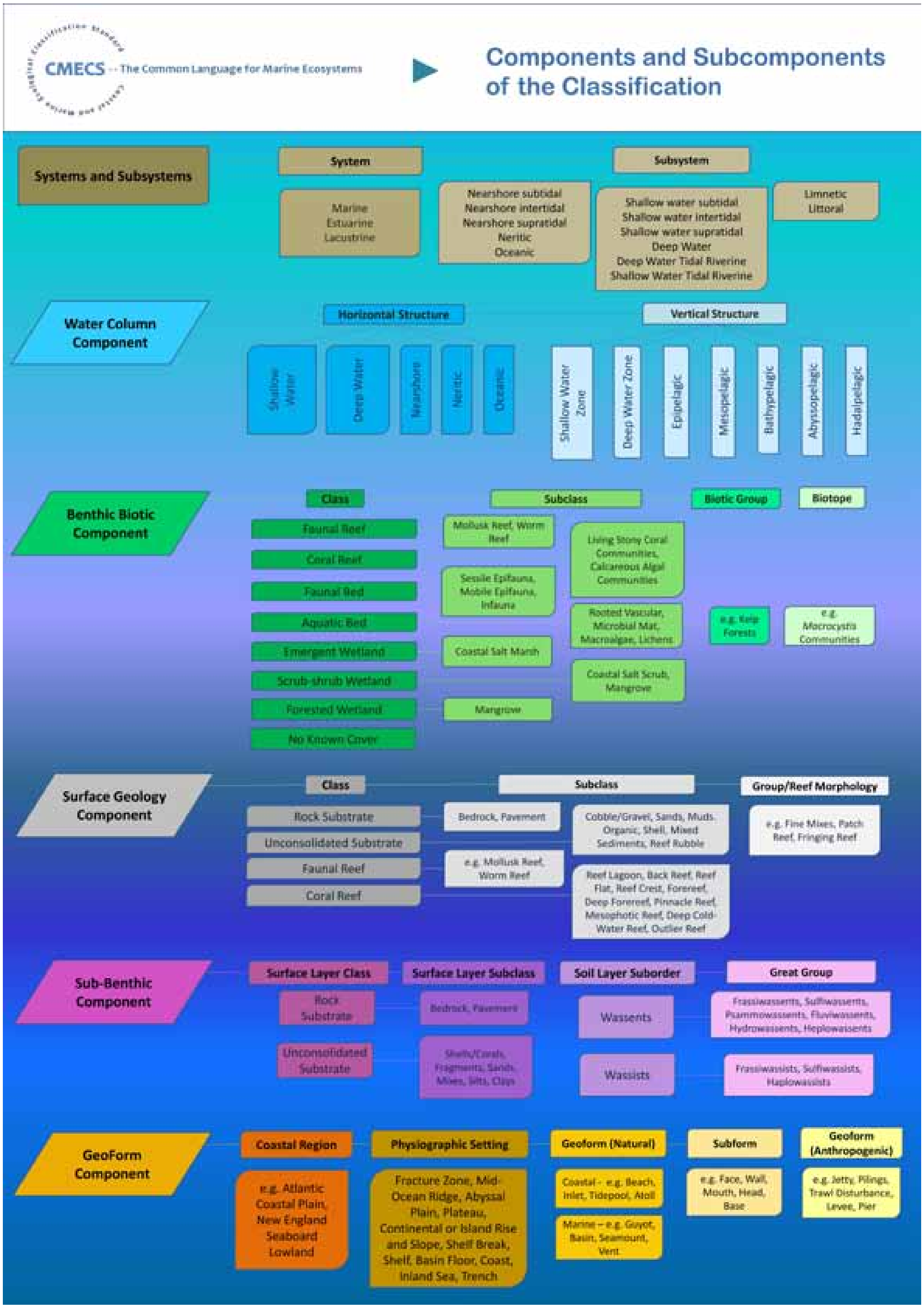


Figure 14. Components and subcomponents of CMECS
The broadest systems on the left narrow towards the right to the most detailed physical and biological elements associated with a specific habitat type.

CMECS was used for the Habitat Project because of its ability to support data at multiple scales, its consistent terminology, and ability to include all aspects of the environment relevant to biota. These characteristics support repeatable data collection for change monitoring. The habitats represented are important to management and layer components allow incremental additions as more information or field data are acquired. CMECS integrated well with conservation targets used in the Conservation Action Planning (CAP) process to develop management recommendations. CMECS is spatially based and provides a common understanding of habitats and aerial imagery. Local governments, agencies, academics, have used CMECS in many applications (see Outreach and Education section).

CMECS articulates with the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979) used for National Wetland Inventory (NWI) mapping the FGDC National Vegetation Classification Standard (NVCS) (FGDC Vegetation Subcommittee 1997; FGDC 2008; Faber-Langendoen et al. 2009; Jennings et al. 2009) the FGDC Wetlands Mapping Standard (NOS 2001; Madley et al. 2002; Greene et al. 2007; FGDC Wetlands Subcommittee 2009), as well as other coastal, estuarine, and marine habitat classification systems (Dethier 1990).

Humboldt Bay and Eel River Estuary Benthic Habitats

In the study area, Humboldt Bay and the Eel River Estuary are included in the Estuarine System. This system in CMECS, includes tidally influenced waters that have surface hydrological connection to the sea that is either partial, free, or sporadic; are partially enclosed by land; and are at least occasionally diluted by freshwater runoff from the land. .The Estuarine System extends upstream to the head of the tide and seaward to an imaginary line enclosing the mouth of the estuary at the most seaward geomorphological extent. Salinities can range from freshwater at the head of the tide to hypersaline in areas or seasons where evaporation is high. The Estuarine System covers the zone of maximum interaction between human activities and critical biological resources. It includes a shallow and deep subsystem. The intertidal and supratidal were mapped and classified. The subtidal was mapped and classified as "subtidal" with no further delineations.

Three tidal zones are included in the Estuarine System:

- Supratidal – splash zone
- Intertidal - MHHW to MLLW
- Subtidal – below MLLW

Estuarine subsystems are defined by depth relative to mean lower low water (MLLW). Estuarine subsystems include a Shallow Water Subtidal category where estuarine waters are 4 m or less depth relative to MLLW and Deep Water Subtidal below 4 m. The head of the tide and the freshwater riverine system are included be consistent with Federal Geographic Data Committee (FGDC) shoreline classification and to allow for inclusion of the entire domain of estuaries. Subtidal habitats occur below the level of MLLW, and they are exposed only at extreme low tides. Intertidal habitats are regularly and periodically exposed and flooded by tides, occupying the zone between MLLW and the extreme high tide line (Madden et al. 2009) (M. Finkbeiner (NOAA), personal communication 03/02/2010).

Within the CMECS system, the source data for Humboldt Bay and the Eel River Estuary benthic habitats focused on Benthic Biotic and Surface Geology components, a typical combination of units where physical attributes are the dominant feature characterizing a habitat and where cover by plants such as eelgrass are the dominant characteristic feature. Alternatively, mappers may work entirely within one component and develop separate maps, which can be overlain and analyzed together in a GIS environment, similar to overlaying soils and vegetation maps (Madden et al. 2009) (Figure 15).

The Benthic Biota Component includes all areas where benthic habitats were classified. The Surface Geology Component is represented by one class, unconsolidated sediments. Imagery resolution did not allow classification to subclasses such as mud, sand, gravel, etc. Individual studies of an area of shoreline or the entire study area could be conducted to add more detailed information to the surface geology component.

For Humboldt Bay and the Eel River Estuary, Photo Science generated a single map layer, with map units representing either the Benthic Biotic or Surface Geology Component of CMECS. The hierarchical level mapped varied by habitat type, depending on what could be detected through aerial photo interpretation. For example, the map unit "unconsolidated sediments" represents a class within the Surface Geology Component and it was used to map all unvegetated intertidal flats and gravel bars since the distinction between the subclasses - mud, sand, and cobble/gravel are not discernible in the imagery.

Benthic Biotic Component is the living biotic cover of the bottom. This component is hierarchical with classes and subclasses based on the National Wetlands Inventory standard. Living things on the substrate are classified in the Benthic Biotic Component. The substrate is classified in the Surface Geology Component. This allows understanding of what substrate is influencing the biota.

Benthic Biotic Component has seven classes based on dominant percent cover. In our study area, two classes were mapped: aquatic bed and emergent wetland and no known cover (unclassified).

Aquatic bed includes rooted vascular, eelgrass; attached or drift macroalgae; microbial mats, and kelp. Aquatic beds were classified as eelgrass, patchy eelgrass or macroalgae. A biogenic modifier was developed for eelgrass that allowed us to comment on the density and distribution characteristics. The modifier called "patchy eelgrass" is a quantitative determination of patchiness within eelgrass classification. It includes areas were the space between eelgrass patches is > 10 m. The distinction between continuous and patchy eelgrass beds is discernible in the imagery and it is of significance to managers, so these modifiers were applied in the mapping. Microbial mats were not discernable in the imagery and are included in "unconsolidated sediments." The kelp beds near the South Jetty were not classified.

Macroalgae includes numerous species of red and green algae that provide significant seasonal habitat on Humboldt Bay and Eel River Estuary intertidal mudflats. Several species have been identified and include *Ulva* spp., *Lola lubrigata*, *Vaucheria* spp, *Gracilaria* spp., *Gracilariopsis* spp., *Chaetomorpha* spp., *Rhizoclonium* spp. and *Fucus* sp. Many other species of algae have been identified in Humboldt Bay (Augyte 2011; Boyd et al. 2002).

Emergent wetland has only one subclass: Coastal Marsh. Humboldt Bay and Eel River Estuary salt marsh is classified and mapped as Coastal Marsh. In the Habitat Profile report, the chapter is titled Intertidal Coastal Marsh. The map unit intertidal coastal marsh represents a subclass under the emergent wetland class within the Benthic Biotic component.

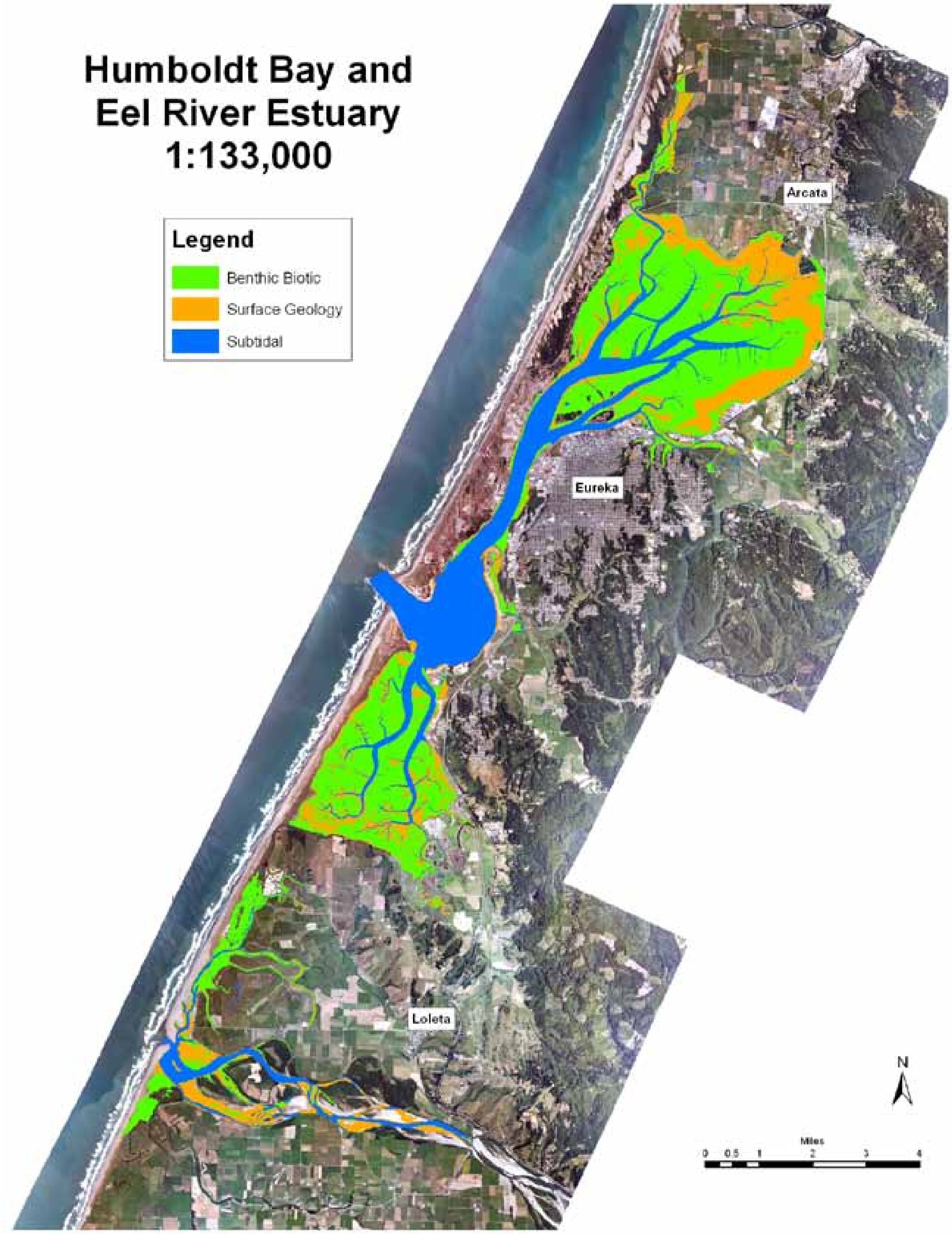


Figure 15. Study area showing benthic biotic and surface geology components.

The third classification, faunal beds, includes oyster mariculture. Intertidal oyster mariculture occurs in Humboldt Bay as long line and other above ground culture systems. Nursery areas are used for placement of newly arrived seed, or young oysters, that are produced in hatcheries outside of California.

Modifiers allow for customization of the mapping product. They can be added at any level in the CMECS hierarchy. They provide a flexible way to describe important detail in any system. For example, modifiers could be developed for aquatic bed/macroalgae based on algal species such as *Ulva* spp., *Lola lubircata*, or *Chaetomorpha/Rhizoclonium*. A physical modifier for unconsolidated sediment using detailed sediment size analysis (Thompson 1971; Borgeld 2004) could analyze Humboldt Bay bottom sediment size in dredged shipping channels. Many master thesis' could be completed to develop one or more modifiers for the Humboldt Bay and Eel River Estuary benthic habitats.

The Surface Geology Component (SGC) is the second system classified in this study. SGC provides context and setting for many aquatic processes and provides living space for benthic fauna. SGC is the first order of characterization of fine scale geology of the surface layers of the substrate. It is one of three ways to characterize the bottom. It relies on modifiers for finer classification below the group level and to deal with sediment mixes and muds.

The Surface Geology Component is determined by the percent cover or dominance of the geologic or benthic (but no longer living) upper layer of the substrate; by the composition and particle size of the substrate and on whether the reef builders are worms, mollusks, etc. Four classes can be mapped, but only one was used in this study, "unconsolidated sediment." The 0.54 m resolution of the imagery was not sufficient to identify bare sediment to subclasses.

Coastal LIDAR

The benthic habitat imagery is a rich source of information for development of these more detailed habitat analyses and classification. The California coastal LIDAR disseminated in April 2012 is expected to allow data integration of bathymetry/topography with this benthic habitat data to provide strong quantitative tools for habitat slope and rugosity analysis, use in climate and hydrologic models (Figure 16). When preparing this report, the Ocean Protection Council Coastal LIDAR for the California Coast was completed and disseminated. The Coastal LIDAR project was not part of the Habitat Project or HBI but strongly supports many of current management issues.

Figure 16. Aerial extent of Coastal LIDAR obtained in 2010 and 2011 by the State of California.
(W. Gilkerson)

This Coastal LIDAR program includes three products:

- The LIDAR point data
- A digital elevation model
- Natural color imagery of the coast from 3 miles offshore to 10 foot elevation on land

This data set is available on: http://www.csc.noaa.gov/digitalcoast/

Habitat Project Report and Habitat Classification

The relationship between the names that we selected for our habitat descriptions, the map units that represent them, and the various CMECS components are shown in Table 7. We tried to align our habitats as closely as possible to CMECS, with a few exceptions. First, we recognize water column as a habitat type in and of itself. CMECS treats water column as one of their component layers that can be described with respect to other habitat units. The layered CMECS components are a recent development that were not part of the earlier CMECS version when we started our process of habitat characterization. We decided to retain our description of water column as a habitat because it supports unique biotic communities not adequately addressed elsewhere. We did not attempt to list features of the CMECS water column component with respect to our habitat types because the water column attributes are complex and highly variable, both spatially and temporally. Finally, we selected habitat names that are widely recognized and used in scientific literature, e.g., we selected the term "intertidal flats, banks and bars", although the map unit representing this feature is "unconsolidated sediments". "Intertidal" is a CMECS subsystem and "flats" is a unit in the CMECS Geoform Component (Table 7).

CMECS includes classification units for habitats that are spatially or temporally variable, recognizing that even though they present a mapping challenge they are real ecological entities with conservation and management relevance (Madden et al. 2009). Macroalgae beds are an example in our study area of a habitat that is variable both spatially and temporally. In CMECS, macroalgae is a subclass under the aquatic bed class within the Benthic Biotic Component. Macroalgae beds are a prominent feature associated with the expansive intertidal flats of Humboldt Bay, and we have included our discussion of them in the "Intertidal Flats, Banks, and Bars", Chapter 6.

Macroalgae beds in the study area presented a mapping challenge because of their ephemeral nature. In the time that it took to geo-rectify the imagery in preparation for thematic accuracy

Table 7. Map units and CMECS classification for subtidal and intertidal habitats in the study area.

Habitat Project Report: Chapter Titles	CMECS: Mapped Habitat Names
Subtidal: water column and subtidal benthic zone	Subtidal
Intertidal banks, bars and flats	Unconsolidated sediment
	Macroalgae
Eelgrass	Eelgrass
	Patchy eelgrass
	Oyster mariculture
Intertidal Coastal Marsh	Coastal Marsh

samples, conditions on the ground appeared to have changed in a few locations. Some areas that seemed to be covered by macroalgae in June 2009 (based on aerial photo interpretation) were bare when visited in September to October that same year. In these instances, the feature was mapped as it appeared in the imagery even if it could not be later verified in the field. Overall, macroalgae was still quite abundant in the fall 2009 and provided ample opportunities for analysts to identify the signature, or unique appearance of macroalgae in the imagery.

The habitat maps will serve as a foundation for more detailed investigations, and new data may be added as layers, or used to further refine the maps.

The project's benthic data can be found at http://www.csc.noaa.gov/digitalcoast/data/benthiccover/download.html

The imagery is at http://www.csc.noaa.gov/digitalcoast/data/highresortho/download.html

Sub-Benthic Component – Preliminary Information

Humboldt Bay has been included as a site in a water quality project by Dr. E. Fong at University of California Los Angeles. Dr. Fong's research evaluates benthic habitat condition. She measures sub-surface nutrient dynamics, depth of anaerobic layer and other water quality parameters in and out of macroalgal beds throughout California. The size of each sample is approximately 10x10x2in (25.4x25.4x5.08cm). The benthic sampler is pushed down into the mud or sand to remove a slab of intact habitat. In Humboldt Bay, a mudflat site near Manila in North Bay and a sandflat site on the South Spit were sampled in Fall 2010 and 2011. The benthic imager gathers a sample of substrate that is frozen for later analysis of nitrate content and sediment size. The overlaying algal mat and core samples of sediment for particle size are also collected for analysis.

Outreach and Education

Project investigators conducted extensive outreach to ensure broad dissemination of the imagery and benthic habitat data. The data are available from the NOAA Coastal Services Center website or by borrowing an external hard drive from the California Sea Grant Extension office in Eureka.

Between August and December 2011, the benthic habitat data and imagery was obtained from California Sea Grant Extension by local governments, tribes, several divisions of five federal and four state agencies, numerous non-profits and businesses, teachers and students (Table 8). Outreach efforts are on-going. We have made every attempt possible to ensure all GIS analysts in the region were aware of the new imagery and benthic habitat data by giving presentations at user group meetings. We also gave presentations about the project at local city and county boards and commissions so that decision makers, managers, and planners would know about the images and habitat maps.

Sub-benthic sampling

Sub-benthic samples taken from Humboldt Bay

South Bay sub-benthic sample with macroaglal cover.

South Bay sub-benthic sample with no aglal cover.

North Bay sub-benthic sample with eelgrass cover

Table 8. Selected examples of Habitat Project imagery and benthic data applications.

Entity	Project and/or Use
NOAA – Marine Protected Area Center	Habitat mapping
USGS - National Geospatial Intelligence Agency	Port security, preparation for special events requiring federal security
USFWS – Humboldt Bay National Wildlife Refuge	▪ Invasive cord grass monitoring and control ▪ Day to day management ▪ Mapping unit acreages and boundaries ▪ Updating National Wetland Inventory maps ▪ Rare plant monitoring
North Coast Water Quality Control Board	Imagery added to their database
California Coastal Commission	Management and regulatory activities
California Dept. of Fish and Game	▪ Invasive crab monitoring ▪ California Environmental Quality Act project review ▪ Oyster mariculture lease mapping ▪ Restoration project mapping, design & planning ▪ Mapping locations of endangered species
California Dept. of Public Health	Shellfish sanitation surveys and harvest management
Humboldt County	Hazard planning
City of Arcata	Restoration project mapping
Humboldt State University	Projects and theses: invasive eelgrass environmental factors; native oyster restoration; native eelgrass distribution

Outreach materials were widely disseminated by NOAA Coastal Services Center and California Sea Grant Extension. We have used email list serves, websites, rack cards and press releases. We encourage recipients of our outreach materials to freely share the information. The imagery and derived data are available to the public at no cost.

We have also given several conference presentations on the Habitat Project. These include:

- Coastal Zone 2007 Portland, Oregon
- Coastal Zone 2009 Boston, Massechusetts
- Coastal GeoTools 2009 Charleston, South Caroloine
- EBM Network Annual meeting
- 2008, 2009, 2010, 2011
- California and the World Oceans 2010 San Francisco, California
- Ocean Protection Council Workshop 2011 Oakland, California

Websites

- Digital Coast In-Action [http://www.csc.noaa.gov/digitalcoast/action/humboldtbay.html]
- Habitat and image data available on Digital Coast [http://www.csc.noaa.gov/digitalcoast/data/benthiccover/download.html]

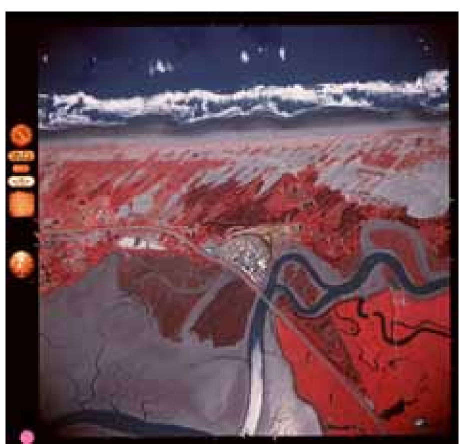
Feature Articles

- Schlosser, S., M. Finkbeiner, and M. Meade. 2011. Out of the fog. Point of Beginning. January 2011: 20-25. [http://www.pobonline.com]
- NOAA Coastal Services Center. 2011. Updating aerial imagery and benthic data for a California bayland estuary. Coastal Services Center, Charleston, SC. 14(6): 1

Awards

- Management Association of Private Photogrammetric Surveyors (MAPPS) project award 2010

Infared image of the Mad River Slough and the Highway 255 Bridge



Chapter 4. Benthic Habitat Distribution

In this chapter we give an overview of the data available from the habitat classifications for the entire study area. In each habitat chapter, a description of location and distribution is given by region. The regions used in this report are North Bay, Entrance Bay, and South Bay in Humboldt Bay, and the fourth region is the Eel River Estuary (Figure 17). Many other subsets are possible to obtain from the habitat polygons. For example primary, secondary and tertiary channels in Humboldt Bay mudflats could be quantified from the habitat classifications, or a detailed study of the distribution of small eelgrass patches could be made in Humboldt Bay or Eel River sloughs. Smaller scale descriptions of each habitat are given in the appropriate chapter. The quantified habitat information is shown in Table 9 and the distribution of the classified Coastal and Marine Ecological Classification Standard (CMECS) habitats in the study area is shown in Figure 18.

The CMECS classifications for the Habitat Project study area resulted in the following five habitats:

- Coastal Marsh
- Eelgrass
- Patchy Eelgrass
- Macroalgae
- Oyster Mariculture

Other, more general, CMECS classifications identified and mapped were:

- Subtidal - open water at the time images acquired
- Unconsolidated Sediment – unvegetated, intertidal areas could not be classified to mud, gravel, etc., with imagery taken at 0.5-m resolution.

Table 9. Coastal wetland habitats (ac) in Humboldt Bay and the Eel River Estuary based on June 27, 2009 imagery and CMECS V. 3.0 classification.

Habitat	Humboldt Bay				Eel River Estuary
	North Bay	Entrance Bay	South Bay	Total	
Coastal Marsh	637	229	38	905	639
Eelgrass	1,880	96	1,638	3,614	28
Patchy Eelgrass	1,697	26	307	2,031	11
Macroalgae	1,034	144	979	2,158	283
Oyster Mariculture	287	0	0	287	0
Subtidal	1,380	2,928	645	4,954	821
Unconsolidated Sediment	2,712	224	870	3,807	917
Total	9,629	3,649	4,479	17,759	2,702

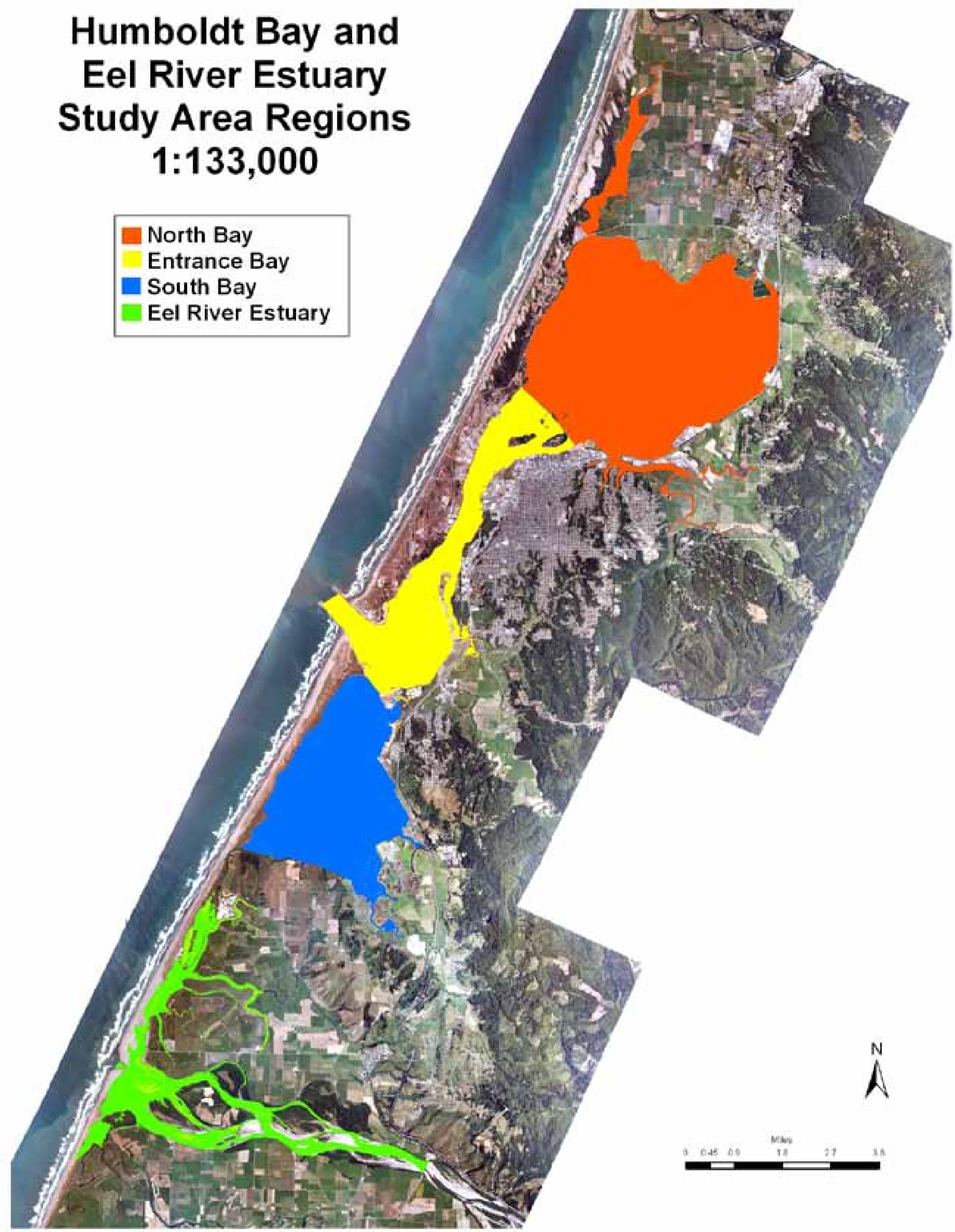


Figure 17. Habitat Project study area regions.

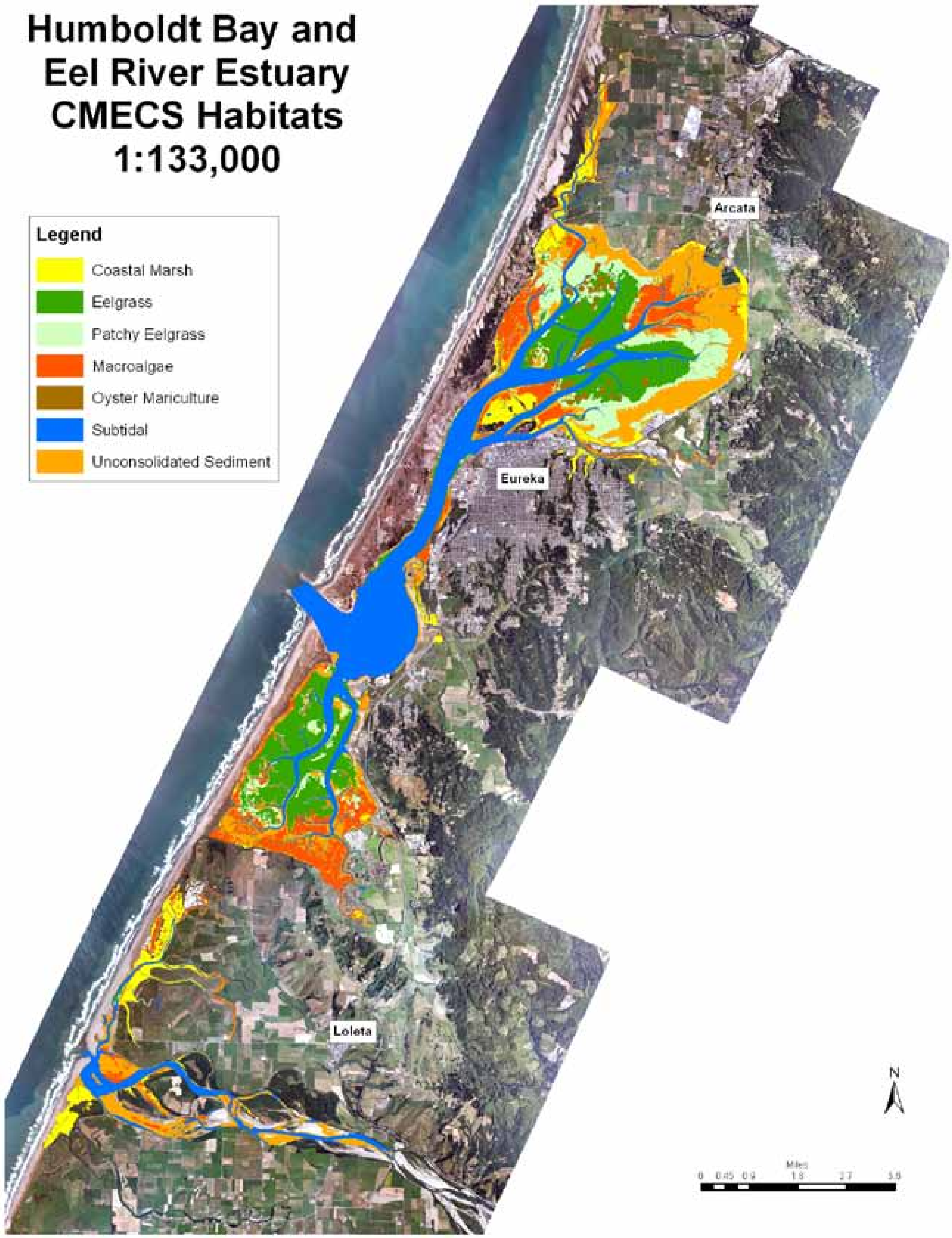


Figure 18. Classified benthic habitats in the study area.

Humboldt Bay

Intertidal and subtidal habitats have been previously described for Humboldt Bay from 1871 to 1978 (Shapiro and Associates 1980; Monroe et al. 1973; Thompson 1971; Gleason et al. 2007). Each study gives information on the water surface area of Humboldt Bay at high tide. Monroe et al. (1973), Thompson (1971), and Shapiro and Associates (1980) interpreted aerial photography (Table 10). Shapiro and Associates (1980) used color infrared and aerial photos of 1 in = 500 ft for photointerpretation. Open water and intertidal areas were verified by field visits. Planimetry was used to determine habitat area with the verified data. The scale of the photography was 1:24,000. Gleason et al. (2007) used digitized National Wetland Inventory (NWI) maps. Humboldt Bay habitats from this study are shown in Figures 19-22.

The earlier studies used slightly different study areas than the 2009 imagery and did not always sample the same habitats, which is reflected in the habitat distributions. Variations in surface and subtidal area are probably a result of different study areas, different methods, and the expertise of the photointerpreters. For instance, Thompson (1971) excluded sloughs from his study. However, Humboldt Bay has major sloughs including Mad River, Eureka, Martin and Hookton, all of which have considerable acreage.

Coastal marsh was relatively stable in distribution and location from 1971 to 2009. Monroe et al. (1973) and Shapiro and Associates (1980) noted approximately 200 ac of coastal marsh on Indian Island and 100 ac scattered throughout Mad River Slough. Shapiro and Associates (1980) gave an excellent review of the changes in coastal marsh distribution since 1871 (Table 11). Decreases in salt marsh from 1903 to 1926 were caused by construction of dikes (Barnhart et al. 1992). In this study, we found 133.25 ac of coastal marsh in Mad River Slough.

Eelgrass distribution varied in previous Humboldt Bay eelgrass studies (Keller 1963; Keller and Harris 1966; Waddell 1964; Harding and Butler 1979). In these studies variability was thought to be related to oyster mariculture operations and oceanographic conditions.

Since 2006, Humboldt Bay oyster mariculture firms converted many acres of ground culture to long-line systems. From the 1950s to 1996, the primary culture method in Humboldt Bay was ground culture, with about 500 to 600 ac of North Bay intertidal area used for production. In some years prior to 1980, as many as 1000 ac of oysters were cultured on Humboldt Bay intertidal areas. Additionally, the nursery areas where seed or young oysters are hardened is currently used for approximately 17,000 to 20,000 bags of seed annually, compared to 60,000 to 70,000 bags when ground cultures were the dominant growing method. Since converting to long-line systems, about 300 ac of intertidal habitat are used for oyster mariculture (Czeisla 2006). Other shellfish culture operations employ in-water systems in deeper channels, and rack-and-bag culture in the intertidal.

In-water oyster culture system located in North Bay subtidal channels

Table 10. Total habitat area (ac) for Humboldt Bay in previous studies.

Habitat	Acres	Reference	Comments
Surface area at high tide	16,000	Monroe et al. 1973	
	14,092	Thompson 1971	Excludes sloughs
	14,853	Shapiro and Associates 1980	Humboldt Bay study area included entire bay and surrounding lands to 10 ft (3 m) elevation. In Humboldt Bay, the subset of data that included intertidal lands from MLLW (−3.0 ft) to extreme high water (10 ft above MLLW) were used for comparison.
	17,639	Gleason et al. 2007	National Wetland Inventory digital map of Humboldt Bay used for this GIS study, four estuarine habitat types in Humboldt Bay not sampled
	17,759	This study	Photointerpretation of color and infrared digital aerial photos taken at 1:24000
Coastal Marsh	900	Monroe et al. 1973	Indian and Daby Islands, Eureka Slough, Jacoby Creek, South Bay, Mad River Slough
	970	Thompson 1971	
	973	Shapiro and Associates 1980	Extensive, detailed mapping of marshes around the bay
	970	Gleason et al. 2007	Used National Wetland Inventory
	905	This study	
Eelgrass	6,000	Monroe et al. 1973	It is not entirely clear how Monroe et al. delineated eelgrass and unconsolidated sediment.
	3,800	Thompson 1971	
	2,935	Shapiro and Associates 1980	
	2,967	Gleason et al. 2007	
	5,645	This study	
Unconsolidated Sediment (may or may not include eelgrass)	6,100	Monroe et al. 1973	It is not entirely clear how Monroe et al. delineated eelgrass and unconsolidated sediment.
	5,900	Thompson 1971	
	7,050	Shapiro and Associates 1980	
	5,873	Gleason et al. 2007	
	3,807	This study	
Macroalgae	1,655	Gleason et al. 2007	
	2,158	This study	
Subtidal	3,000	Monroe et al. 1973	Dredged shipping channel and tidal channels
	3,422	Thompson 1971	Total channel area
	4,138	Shapiro and Associates 1980	Tidal sloughs, tidal channels, deep channels
	6,164	Gleason et al. 2007	
	4,954	This study	

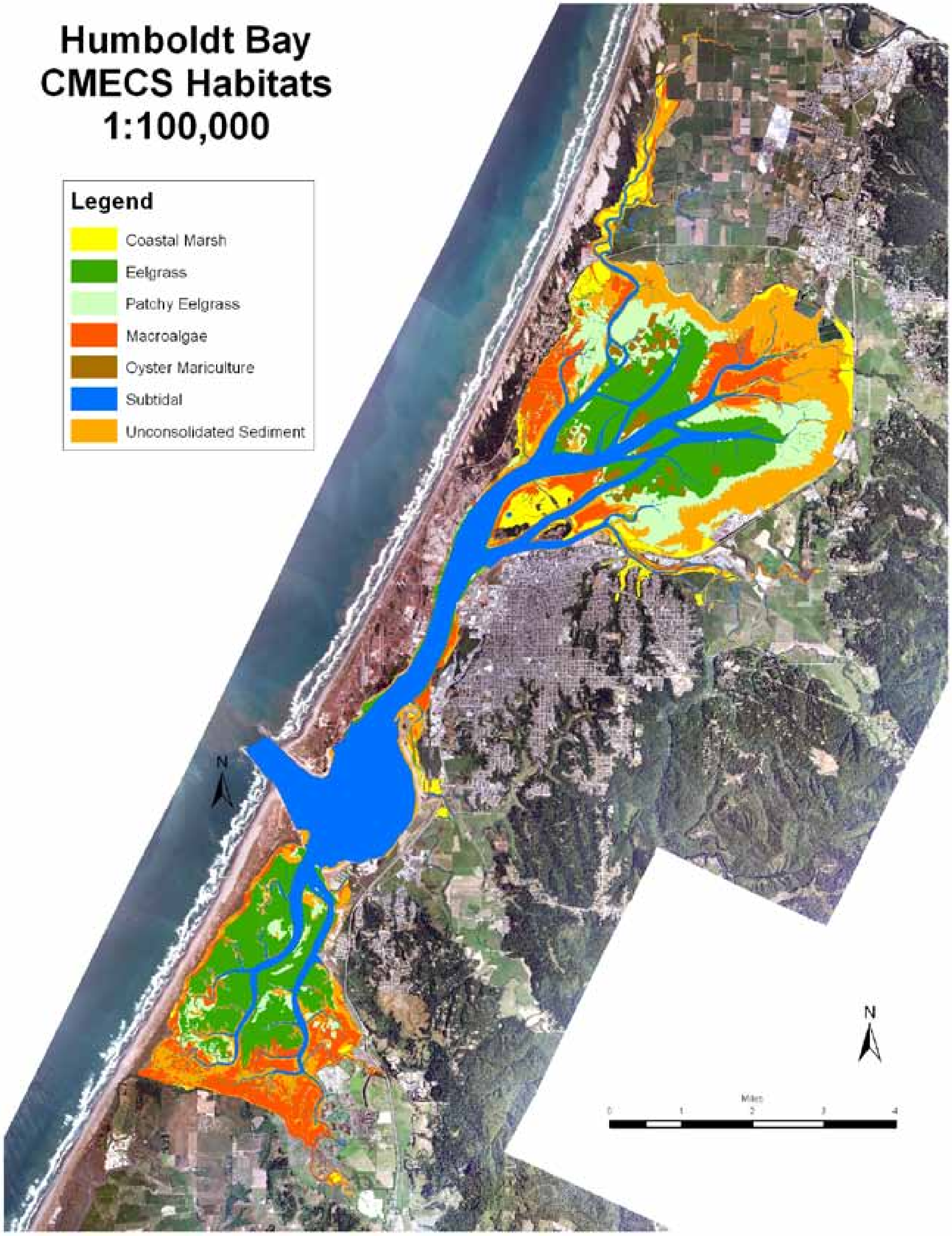


Figure 19. Map of Humboldt Bay habitats.

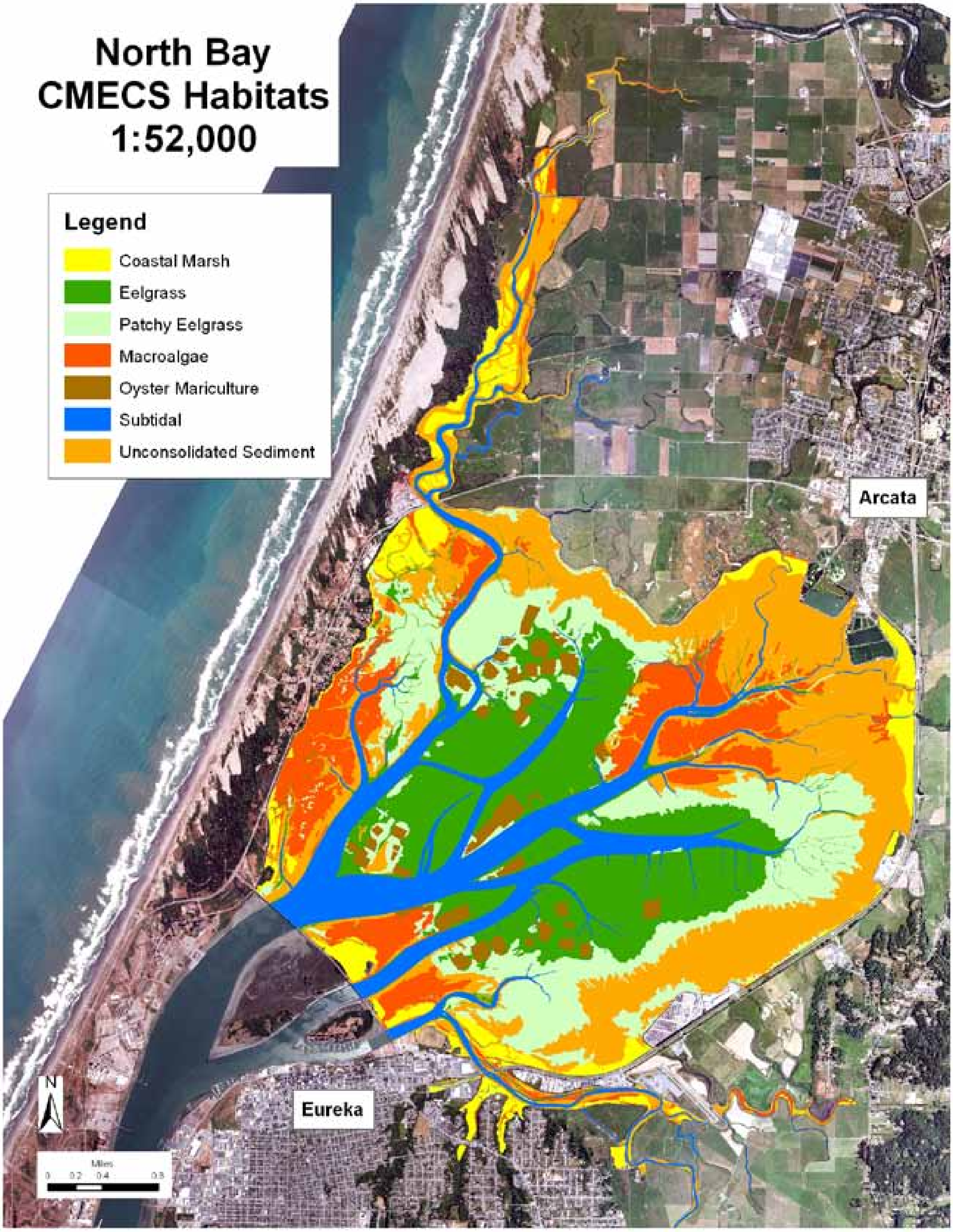


Figure 20. Map of North Bay habitats

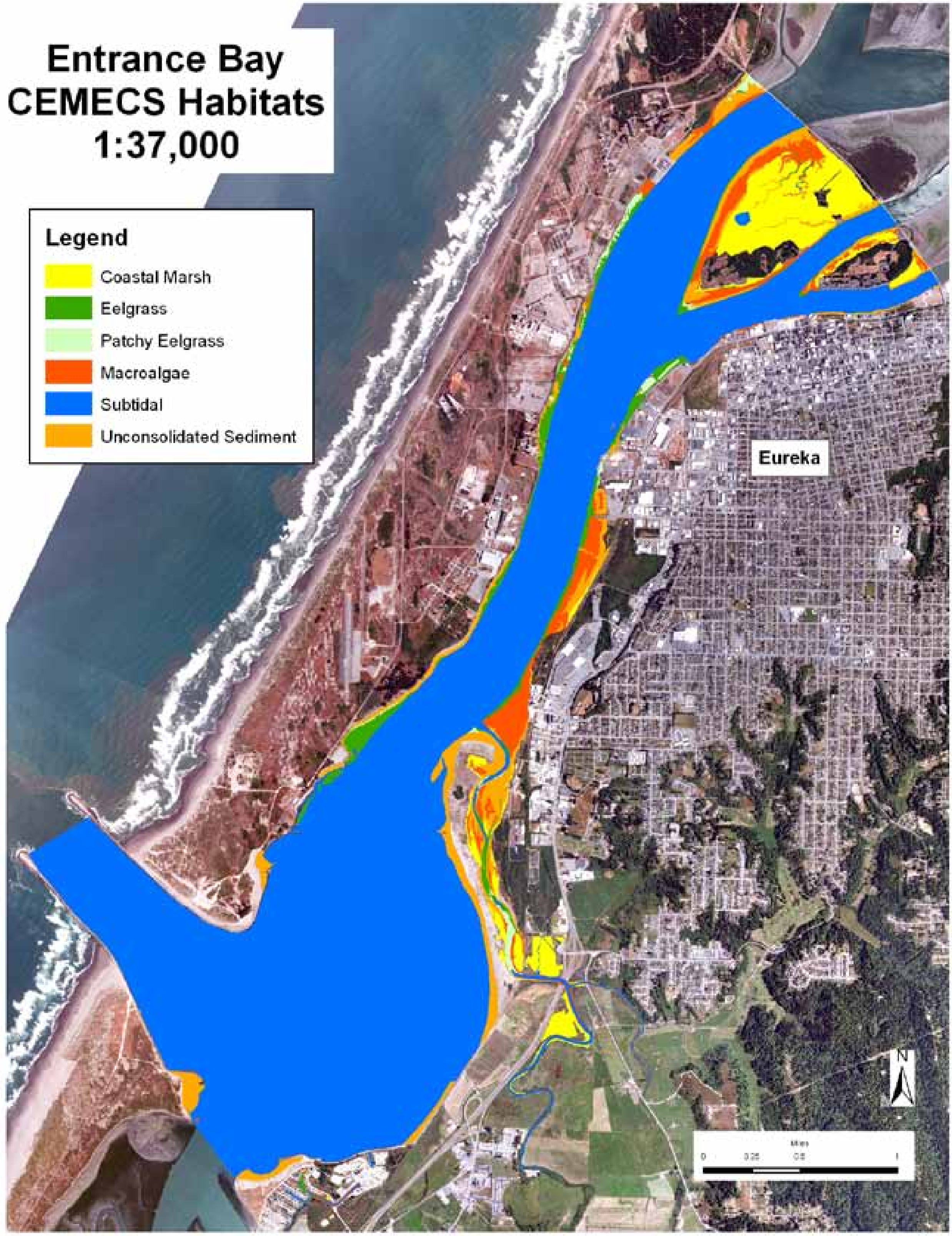


Figure 21. Map of Entrance Bay habitats

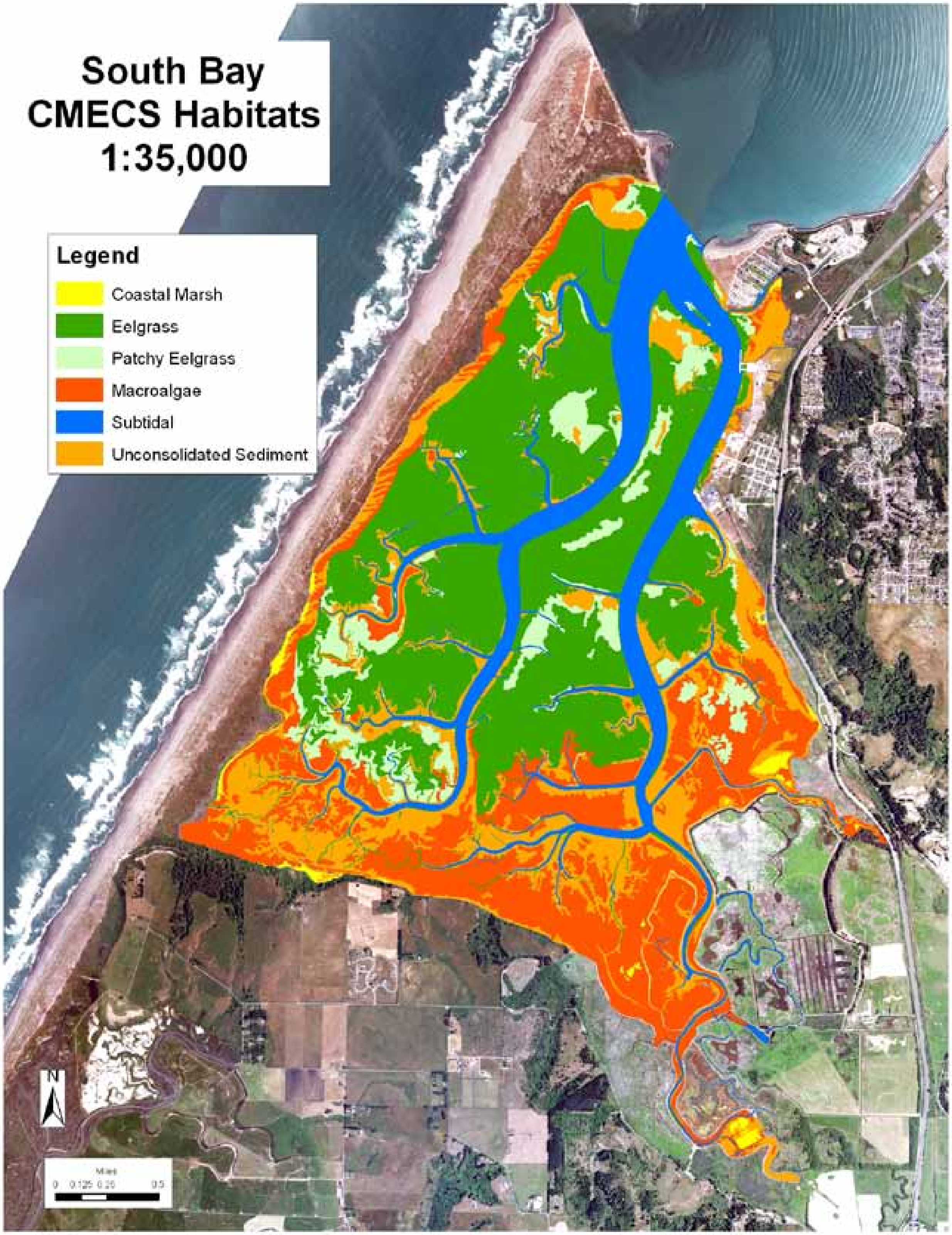


Figure 22. Map of South Bay habitats

Table 11. Changes in salt, brackish and freshwater coastal marsh distribution around Humboldt Bay (Shapiro and Associates 1980).

Date	Number of Acres
1871	8738
1903	8354
1926	2382
1948	1337
1958	1136
1969	1128
1978	1108

Macroalgae cover on Humboldt Bay mudflats was described by Gleason et al. (2007) using the NWI. The acreage covered was similar to our study: 1655 ac of macroalgae reported in Gleason et al. (2007) compared to 2158 ac in this study (Table 10). The difference may result from sampling at different seasons, inter-annual variability, different study areas or different methods. Gleason et al. (2007) noted they did not sample four NWI habitat types in their study.

Unconsolidated sediments or intertidal mudflats distribution varies between the studies. The higher values, 6000 ac to 7000 ac, are generally in the earlier studies and may reflect different groupings of habitats. For example, Monroe et al. 1974, group lower intertidal, eelgrass area and tidal channels in some places and describe them individually in others. The intertidal habitat itself can be confusing. Higher intertidal mudflat can be smooth and gently contoured or hummocky with mounds separated by shallow depressions (see photos in Chapter 6, page 122). Plant life such as algae, diatoms, microbial mats and eelgrass may have confounded habitat delineation in intertidal areas. Lower mudflats are usually smooth, gently contoured, low gradient or covered with dense beds of eelgrass.

Patchy eelgrass is generally found at a higher tidal elevation as a zone surrounding dense eelgrass beds, primarily in North Bay and in small patches in South Bay.

Mad River Slough

The benthic habitat maps can be used to examine specific areas in detail. For example, in North Bay, the Mad River Slough extends from the northwest corner, northward onto the coastal plain and meanders through former tidelands. The Mad River Slough is approximately 4.9 mi (7.9 km) in length from the Highway 255 Bridge to its undiked terminus in the Arcata Bottoms. It has a total area of 497.2 ac (201.2 ha). The habitats within Mad River Slough can be quantified and show that unconsolidated sediment (intertidal flats), coastal marsh, subtidal channels, macroalgal beds and eelgrass made up 47.4%, 26.7%, 16.5%, 7.8% and 1.5 % of the benthic habitat, respectively, (Table 12).

It is also important to note the level of detail shown in the benthic habitat maps (Figure 23). Using the zoom capacity in ArcGIS, the benthic habitat classifications may be used to determine habitat distribution in subsets of the study area.

Table 12. Mad River Slough intertidal habitats (ac) from 2009 classifications.

Habitat	Area	% of total habitat
Coastal Marsh	133.25	26.8%
Eelgrass	7.46	1.5%
Subtidal	82.04	16.5%
Macroalgal bed	38.78	7.8%
Unconsolidated Sediment (intertidal flats)	235.67	47.4%
Total	**497.2**	**100%**

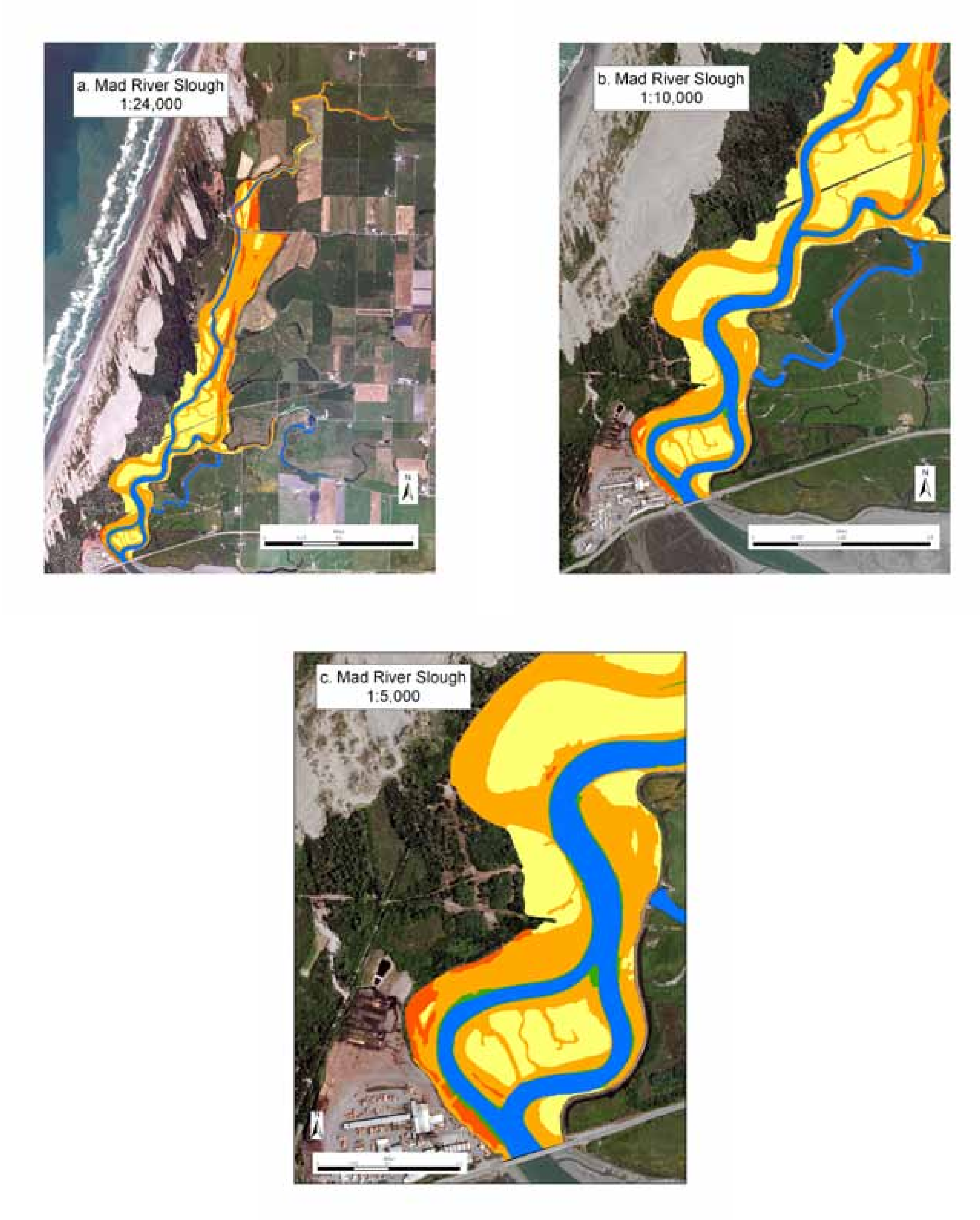


Figure 23. Mad River Slough habitats shown zoomed in at a. 1:24,000, b. 1:10,000 and c. 1:5,000.

Note the increasing level of detail as the scale is reduced. It is possible to study and identify small habitat areas with the classified benthic imagery.

Eel River Estuary

Eel River Estuary habitats were described by Monroe et al. (1974). That project documented the estuary's natural resources (Table 13), and included the Eel River floodplain to its confluence with the Van Duzen River. This is an area of approximately 33000 ac (13,355 ha) and includes 136 mi^2 (352.2 km^2) of waterways and adjacent terrestrial environments. The Habitat Project extended to Fernbridge and includes only intertidal and subtidal habitats of the Eel River Estuary, an area of 2,702 ac (1,093.5 ha) (Figure 24).

Table 13. Habitat comparison in the Eel River Estuary from 1974 to 2009.

Habitat	Acres/ Hectares	Reference	Comment
Estuary Surface Area	3,500 (1,416.4)	Monroe et al. 1974	Includes shallow water bays and sloughs, deepwater channels, coastal marsh, tidal mudflats to the confluence of the Van Duzen River
	2,702 (1,093.5)	This study	Includes coastal marsh, unconsolidated sediment, macroaglae, eelgrass, subtidal to Fernbridge.
Coastal Marsh	700 (283,3)	Monroe et al. 1974	
	639 (258.6)	This study	
Unconsolidated Sediments	500 (202.3)	Monroe et al. 1974	
	917 (371.1)	This study	

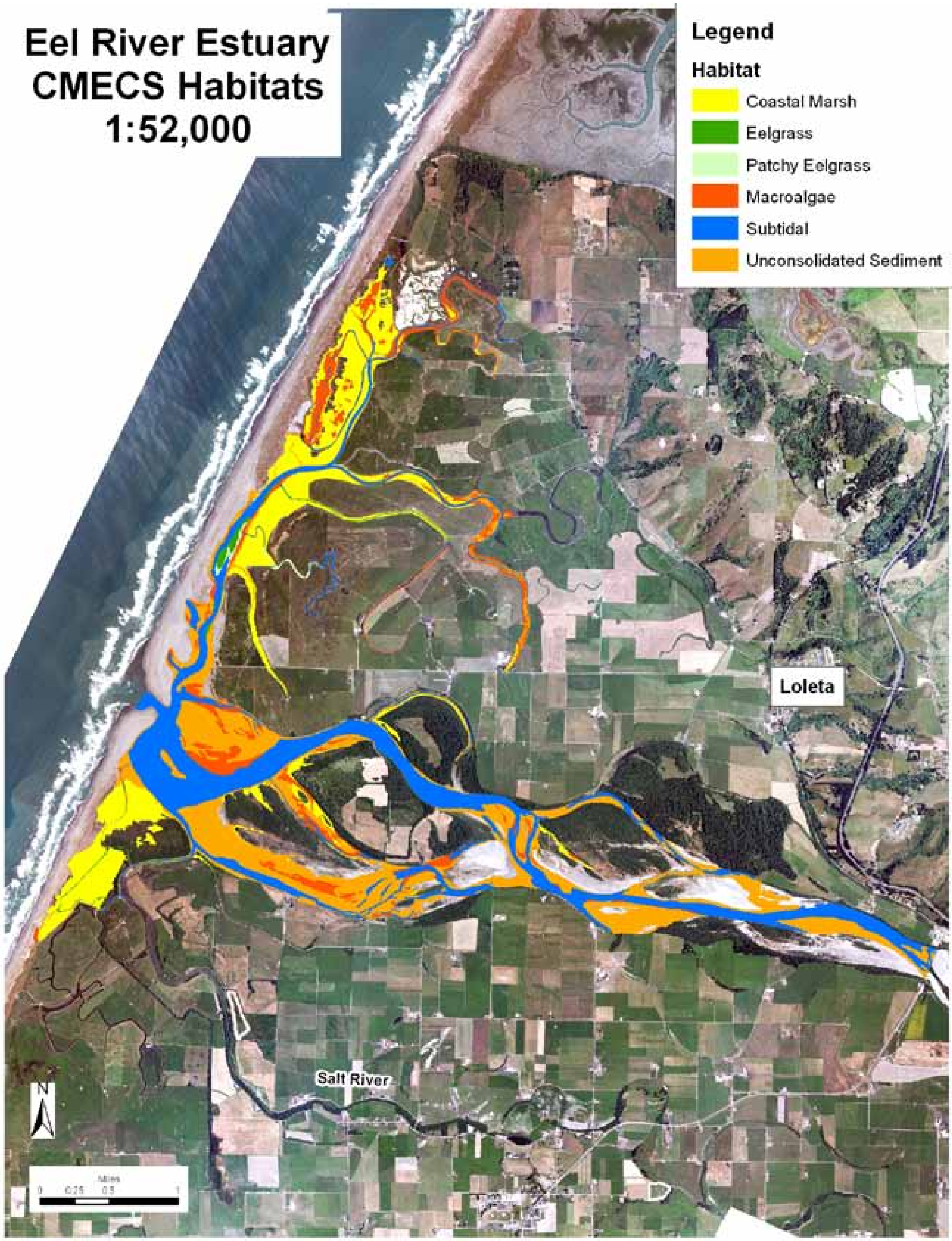


Figure 24. Eel River Estuary habitats.

Chapter 5. Habitat: Subtidal - Water Column and Benthic Zone

CMECS
Mapping Unit:
Subtidal
System
Water Column Component/estuarine
Subsystem
Subtidal
Class
Not Classified
Subclass
Not Classified

Aerial image (above) of North Spit (left) and Eureka industrial area (right). Same area (below) viewed from mid-channel

Subtidal

Habitat Distribution

In this section we describe the area and distribution of the subtidal habitat of Humboldt Bay and the Eel River Estuary. The subtidal habitat includes the water column and subtidal benthic zone.

In Humboldt Bay, subtidal habitat encompasses 7.8 ac (3.2 ha), 16.5 ac (6.7 ha), and 3.65 ac (1.48 ha) of the total bay surface area in North, Entrance and South bays, respectively.

Within each region of Humboldt Bay, the percentage of area comprised of subtidal habitat is 14.3%, 80.2%, and 14.4% for North, Entrance and South bays, respectively (Figures 25-28).

In the Eel River Estuary, subtidal habitat includes 30.4% of the total area, the majority of which is in the entrance area. Significant northern and southern slough systems extend into agricultural lands (Figure 29).

Subtidal - Water Column

General Description

The liquid realm between the bottom substrate and the water surface is called the water column. It is a dynamic feature, with high spatial and temporal variability associated with the daily ebb and flow of tides, and the annual change of seasons.

The mixing of freshwater and seawater characterizes an estuary and makes it unique. Water circulation is driven by both tidal action and river flows, and the relative importance of these two forces determines salinity characteristics in the water column. A salt wedge is a layer of saltwater that resides on the bottom overlain by freshwater above. Salt wedges develop in river-dominated estuaries such as the Eel River Estuary. In marine-dominated estuaries such as Humboldt Bay, strong tidal influences result in a high degree of mixing and less stratification. In addition to tidal mixing, estuarine channels are scoured by the surge of winter storm flows and during outgoing tides. The combination of outgoing tides and large river flows is a major force in estuarine channel morphology, depth and sediment dynamics.

Organisms living in the water column move in accordance with river and tidal flows. They may also migrate vertically within the water column in response to changes in salinity, temperature, dissolved oxygen, or the availability of light or nutrients. Topographic variations and distance from the shore affect the nature of physical characteristics in the water column and hence the types of organisms that are found there. CMECS recognizes five types of water column habitats: 1) Open water; 2) Deep channels (> 17 ft [5.2 m] deep at low tide); 3) Shallow channels (3 ft–17 ft [0.9 m–5.2 m] deep at low tide); 4) Tidal sloughs; and 5) Tidal creeks.

Distribution

Humboldt Bay

Open water covers the entire bay at high tide and subtidal areas at low tide. Channels are the deepest and widest in Entrance Bay and near the entrance to North and South bays. Deep channels taper off into shallow channels at the furthest reaches of intertidal flats. The Bar Channel and Entrance Channel are located in Entrance Bay along with a turning basin for ships. The North Bay Channel extends into North Bay, branching into the Samoa Channel and the Eureka Channel. The Arcata Channel

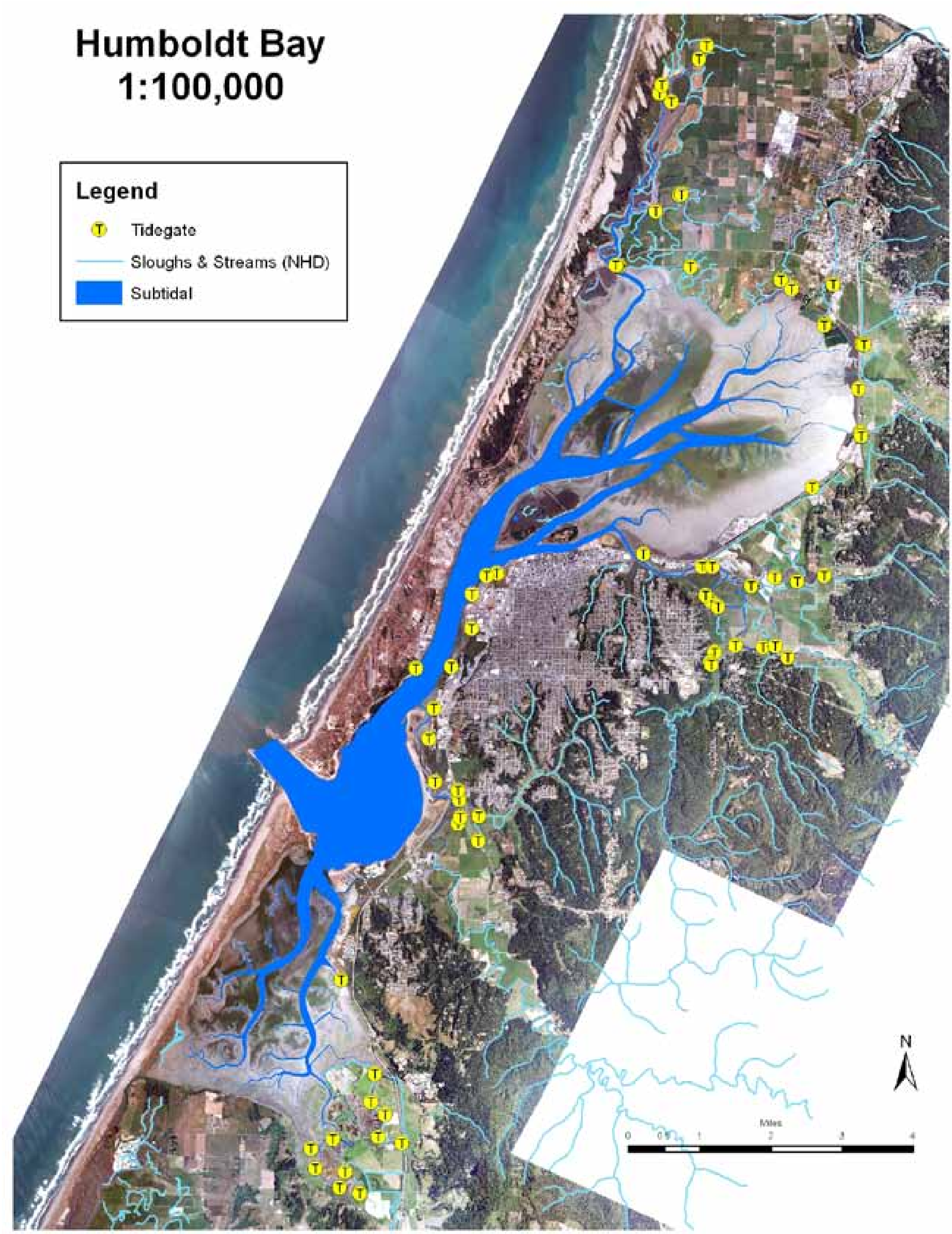


Figure 25. Humboldt Bay subtidal habitat distribution and location of tidegates.

Figure 26. North Bay subtidal habitat distribution.

Three major subtidal channels with numerous crossover channels are found in North Bay. These are important habitat for many fishes, invertebrates, water birds, and support in-water aquaculture facilities and recreational boating.

Figure 27. Entrance Bay subtidal habitat distribution.

The deepest portion of the subtidal is located in Entrance Bay, where the federal navigation channels are maintained by annual dredging (USACE 2012). Commercial shipping and fishing, barge traffic, recreational vessels, and in-water oyster facilities are the main uses of the subtidal in Entrance Bay.

Figure 28. South Bay subtidal habitat distribution.

The South Bay has two main subtidal channels with numerous secondary and tertiary branches nearly reaching the shore in many places. South Bay subtidal channels are used primarily by recreational boaters, clammers and hunters, with some commercial shipping and fishing activity at Fields Landing.

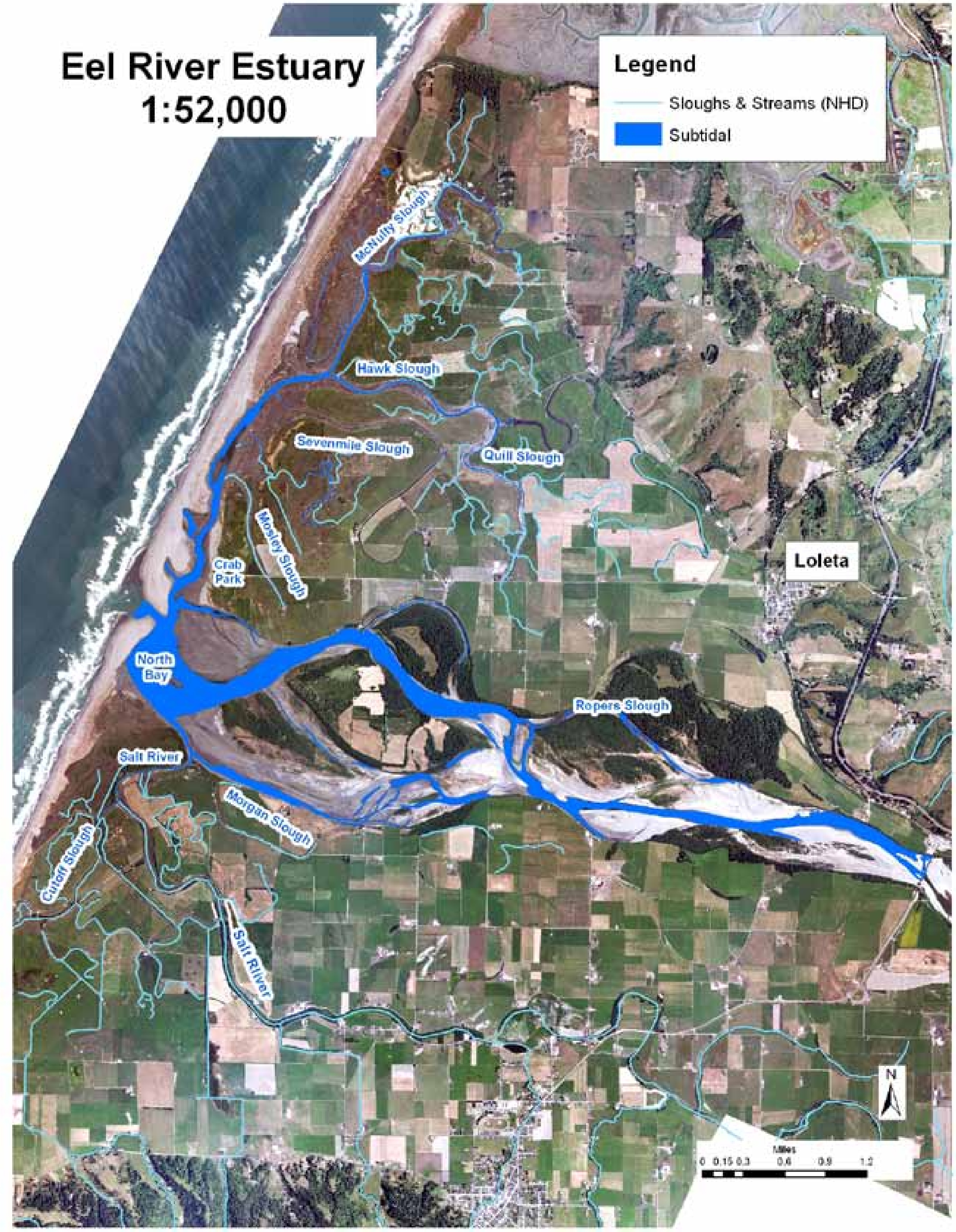


Figure 29. Subtidal habitat of the Eel River Estuary.
The total area is 821.8 ac (332.6 ha).

extends into North Bay towards the City of Arcata. The Fields Landing Channel extends from Entrance Bay into South Bay where it joins Hookton Channel to the east. Southport Channel drains the western half of South Bay.

Deep channels in Entrance Bay are maintained by annual dredging for commerce and recreation safety. The depth of the main shipping channel varies from 12 to 47 ft (3.7 to 14.3 m) below MLLW, maintained by the US Army Corps of Engineers. Humboldt Bay's shallow tidal channels do not undergo dredging; these natural meandering channels act to drain mudflats when the tide ebbs. The relative lack of disturbance of shallow channels allows eelgrass to grow along channel banks, and on the bottom of channels shallow enough to receive light penetration. North and South jetties protect the Humboldt Bay harbor entrance.

Tidal sloughs are secondary channels that transport tidal waters. They extend to the furthest reaches of tidal influence and function to drain receding tidewaters from intertidal coastal marshes. Sometimes small streams or creeks empty into tidal sloughs. Major sloughs associated with North Bay include Mad River, McDaniel, Gannon, Freshwater and Eureka sloughs. White and Hookton sloughs occur in South Bay. The network of tidal sloughs in the Humboldt Bay system was once much more extensive before land reclamation of intertidal coastal marshes surrounding the bay. Tidal creeks are tributaries that are influenced by tidal action in their lower reaches. Jacoby Creek and the Freshwater Creek system flow into North Bay, Elk River into Entrance Bay, and Salmon Creek into South Bay. Many small urban creeks in Eureka and Arcata also flow into North and Entrance bays.

Eel River Estuary

The area covered by open water habitat in the Eel River Estuary does not exhibit the extreme fluctuation with every tidal cycle that is evident in Humboldt Bay because the channel morphology is different and the tidal prism is much smaller. There is, however, a greater degree of seasonal variability. The area covered by open water is considerably higher during large storm events when the river level is elevated. Eel River's North Bay represents open water habitat year round and at all stages of the tidal cycle. The Middle Estuary and Upper Estuary zones of the main river channel are shallow-to-deep channels.

Sloughs north of the river mouth include McNulty, Hawk, Quill, Hogpen, Seven Mile, Mosley and Ropers sloughs. Sloughs south of the river mouth include Morgan and Cutoff sloughs and the Salt River. Tidal flows are generally contained on major sloughs by levees and tidegates that have altered natural tidal connectivity as well as drainage patterns between slough channels, streams and their adjacent wetlands.

Humboldt Bay jetties

(P. Davis)

Subtidal habitats of Humboldt Bay

Deep channel

Open water along the North Spit

Shallow channel between eelgrass beds in South Bay

Tidal slough on Woodley Island

Open water near the Samoa Bridge

Butcher Slough at mid-tide

Subtidal habitats of the Eel River Estuary

Open water in the Eel River estuary near the river mouth.

Open water at Cock Robin Island bridge

Shallow channel in the Eel River Estuary

Tidal slough at high tide.

Roper Slough

Many tidal sloughs are controlled by tidegates

Physical Characteristics

The estuarine water column exhibits high heterogeneity, both horizontally and vertically. Factors affecting the physical characteristics of the estuarine water column include seasonal upwelling in nearshore ocean waters, evaporation of bay waters, episodic freshwater input from the watershed, winds, circulation patterns, and tidal mixing, salinity, temperature, water quality, and vorticity (a measure of the rate of rotational spin occurring in the water column). The upwelling season is generally between May and August. However, nearshore waters may change from conditions associated with upwelling to periods of nonupwelling within days or weeks. In winter there are often calm periods in between strong storms. The amount of freshwater input also fluctuates seasonally. In response to these factors, turbidity, water temperature, salinity, dissolved oxygen, and nutrient levels in the water column may vary daily and seasonally.

In Humboldt Bay, many characteristics of the water column are monitored as part of the Central and Northern California Ocean Observing System (CeNCOOS), a federal program that utilizes the academic resources of coastal universities to implement long-term monitoring. To date, eight state universities are involved in water quality, benthic and biological monitoring, including (since 2003) Humboldt State University (HSU). In Humboldt Bay, CeNCOOS uses devices called sondes to collect data on temperature, salinity, dissolved oxygen and turbidity. Data and data products are available on the HSU CeNCOOS website for Humboldt State University: http://cencoos.humboldt.edu/ (accessed June 6, 2012).

In October 2002, the Wiyot Tribe established a water quality monitoring program that includes three sites in Humboldt Bay (Entrance Bay, Indian Island, and Mad River Slough) and two sites in the Eel River Estuary (McNulty Slough and Table Bluff Reservation Wetland), with plans for a third Eel River site on Cock Robin Island. Data is available at the Wiyot Tribe website: http://www.wiyot.com/water-quality-monitoring-program (accessed June 6, 2012) and also at the CeNCOOS website: http://www.cencoos.org/ (accessed June 6, 2012).

Great Blue Heron (*Ardea herodias*) and northern anchovy (*Engraulis mordax*) in Clark Slough, a tidal channel

Circulation

Water movement influences the dispersion of nutrients, effluent and pollutants. Tidal fronts occur at the junction of different water masses, and in shear zones separating water flows that have different velocities. Tidal convergence zones, a type of front, may occur at the junction of two tidally driven channel flows. Strong horizontal shears can develop in such environments, resulting in intense mixing of the two converging water masses. Sites of intense mixing play a key role in determining water properties as well as contributing to biological productivity (Farmer et al. 1995). These fronts/shear zones provide unique habitats, albeit ephemeral. Concentrations of planktonic organisms can "stack up" at these transition points. This creates efficient feeding opportunities for a multitude of organisms.

Circulation patterns in Humboldt Bay are dominated by the large changes in water volume that occur during each tidal cycle. Approximately 41% of the entire bay's volume is replaced each day, with total replacement occurring in about one week, depending somewhat on the amount of freshwater input, but mostly depending on distance from the bay entrance (Costa 1982; Anderson 2008a). Overall, freshwater input has relatively little influence on circulation because of its seasonal and episodic nature. The entire annual freshwater input to Humboldt Bay is approximately equal to two days of tidal mixing. The amount of freshwater entering the bay from rainfall fluctuates. Significant discharges are associated with five to seven large storms each season.

The water column in Humboldt Bay is affected by large winter waves due to the shape of the offshore bar, the incident wave direction, and the alignment of the jetties, which tends to focus wave energy into Entrance Bay. Waves near the mouth of Humboldt Bay are consistently large year round, ranging from 5.6 ft to 10.2 ft (1.7 m to 3.1 m). Waves from the northwest are most common but waves from the southwest that occur during winter storms are the largest and have the greatest energy. Tidal currents in the inlet reflect these large waves, with peak velocity at 6.9 ft/sec (2.1 m/sec) at ebb tide, and average velocities of 3.3 ft/sec (1.0 m/sec) and 2.7 ft/sec (0.8 m/sec) at ebb and flood tides, respectively. Tidal current velocity is strongest in the channels, especially the deep channels of Entrance Bay, decreasing with increased distance from the mouth (Costa 1982b; Largier 2005). The strong and sometimes dangerous tidal currents near the bay's entrance and their interactions with oceanic waves were studied and formulated into an interactive model that is available at the National Weather Service's Eureka Office website: http://www.wrh.noaa.gov/eka/ (accessed June 6, 2012).

The mouth of the Eel River migrates both north and south. The location of the mouth directs ocean waves that enter and strike the shoreline. Wave energy can cause significant erosion of loosely consolidated or sandy shorelines that do not have protection provided by woody debris or vegetation. The location of the mouth also affects how the lower delta drains during winter floods and where wave action will strike the shore. Floodwaters drain slower in the southern end of the estuary when the mouth is located in its northern extent, compared to when the river flows straight to sea (Bruce Slocum, personnel communication 2009). This is likely because the main river channel flows into the southern estuary area, and flood flows must circulate around Crab Park to reach the mouth located to the north.

The migration of the mouth north and south along the sand spit over recent years has affected sediment deposition. Movement of the mouth is likely related to variations of longshore transport of sands from ocean currents, but also related to debris accumulations, tides and flood flows. During the 1990s, the river mouth migrated along the sand spit approximately 1.5 mi (2.4 km) to the north (across from Seven Mile Slough) and 0.3 mi (0.5 km) to the south where Cannibal Island

North Jetty inundated by storm waves

Road ends at Crab Park. After the flood of 1996 and during the summer of 1997, McNulty and Hawk slough channels were isolated from the North Bay by a dry sand bar that formed between the two water bodies. At that time the Eel River channel flowed slightly to the north of Crab Park, and the sloughs formed a separate channel to the sea nearly 2 mi (3.2 km) to the north. The formation of the sand bar was associated with large amounts of wood debris that accumulated during winter storms (CDFG 2010).

Salinity

Salinities in the Humboldt Bay water column are similar to nearshore oceanic conditions, reflecting the predominant marine influence in the estuary, ranging from 25–34 parts per thousand (ppt). Lower values are associated with periods of runoff during the rainy season. Higher values are associated with periods of offshore upwelling and with high evaporation rates, both of which occur during clear, calm weather, typically during summer months (Barnhart et al. 1992, Humboldt State University 2008). Salinity in Humboldt Bay can become hypersaline (higher than seawater) in late summer, most pronounced in the eastern part of North Bay (Tennant 2006). The average monthly salinity, as reported by CeNCOOS for three sites in Humboldt Bay from 2003 to 2008, is shown in Figure 30.

In the Eel River Estuary, salinity is strongly related to changes in the seasonal discharge of river flows and daily high and low tides. Salinity ranges from fresh (< 0.5 ppt) to hypersaline (>35 ppt) (Cannata 1995). Flood flows due to large winter rainstorms can temporally inundate the estuary with freshwater. After peak flows subside, high tides move a mass or wedge of seawater back into the lower estuary. Mixing occurs both vertically in the water column and horizontally along the channel. In general, salinity decreases in the main channel along a longitudinal gradient

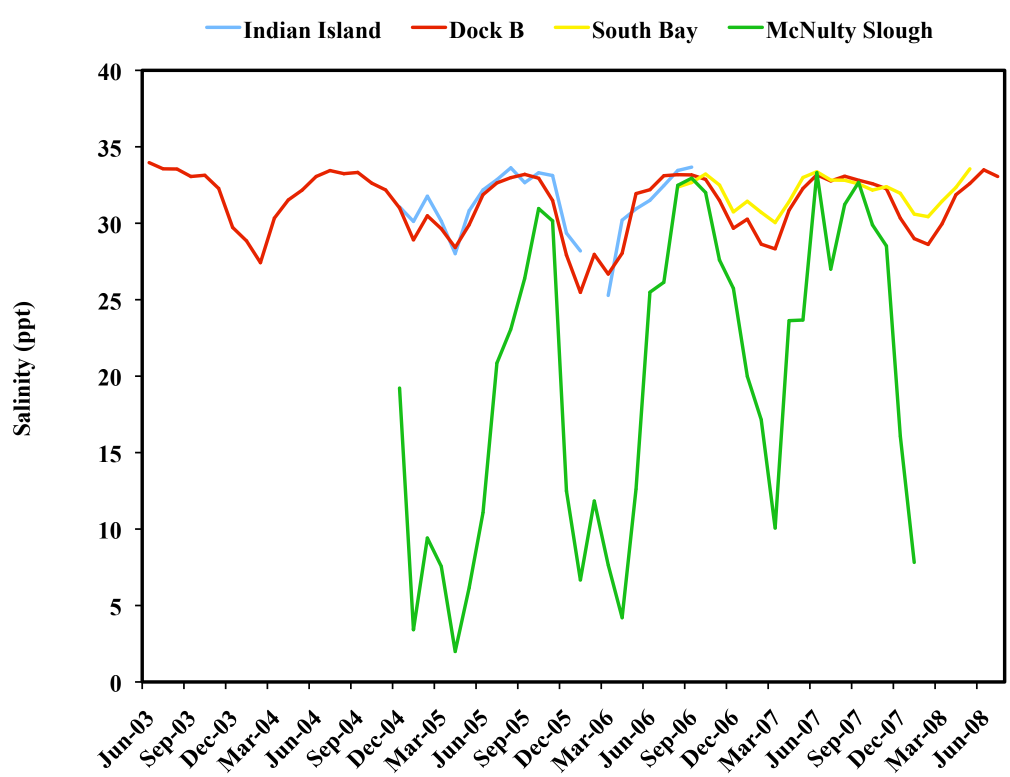


Figure 30. Mean monthly salinity in Humboldt Bay (Indian Island, Dock B and South Bay) and the Eel River Estuary (McNulty Slough).

from the mouth extending up to Fernbridge, but during summer/fall, brackish conditions can extend further upstream (CDFG 2010). In the 1800s, tidewater was noted to extend to the confluence with the Van Duzen River (Van Kirk 1996).

The decrease in river flow during the summer/fall season allows greater influence by marine tides which shifts the conditions in the upper estuary channel from predominantly fresh to include tidally driven brackish water (1–15 ppt.) (Cannata and Hassler 1995). During the warm summer season, when evaporation rates are high, the water can become hypersaline in slough channels where reduced exchange of water occurs between tides (CDFG 2010). The average monthly water salinity for McNulty Slough in the Eel River Estuary, as reported by CeNCOOS from 2004 to 2008, is shown in Figure 30.

Temperature

Water temperatures vary with time of day, season, stage of the tide, depth, distance from the bay mouth, wind, and nearshore water conditions. Humboldt Bay water temperatures range from 48° to 68° F (8.9° to 20° C) (Barnhart et al. 1992; Humboldt State University 2008). Nearshore waters have a narrower range and do not get as warm, ranging from 48° F to 57° F (8.9° C to 13.9° C) (Barnhart et al. 1992).

In a one-year study, Humboldt Bay temperatures decreased with distance from the entrance in winter, presumably due to the influx of cold freshwater. In summer this trend was reversed and water temperatures were higher at greater distances from the entrance (Tennant 2006). A similar pattern has been noted in other Pacific Northwest estuaries, such as Yaquina Bay, Oregon (Kentula and Dewitt 2003).

The average monthly water temperature, as reported by CeNCOOS for three sites in Humboldt Bay from 2003 to 2008, is shown in Figure 31. Indian Island temperatures are taken twice a month over a five-minute period using a Yellow Springs Instrument (YSI) sonde. Dock B and South Bay have YSI instrumentation measuring seawater temperatures every 15 minutes. This data is available on line at:
http://cencoos.humboldt.edu/
(accessed June 6, 2012).

In the Eel River Estuary, water temperatures vary depending on the season, location, channel depth, heights of tides and river discharge. Seasonal water temperature can range from ambient seawater (~ 50° F to 55° F; 10° C to 12.8° C) to ambient river water (~ 38° F to 75° F; 3.3° C to 23.9° C) (Puckett 1977) and Cannata (1994–1995 field notes). During winter the coldest water is usually found on the surface, when river flows exposed to cold air flow into the estuary. In summer, as river flows decline, the coldest water is delivered by ocean tides. Tides push a wedge of cold seawater up the main estuarine channel that mixes with the warmer fresh or brackish water of the middle and upper estuary zones. Vertical salinity profiles collected in the estuary from 1994 to 1995 show that large differences in salinity can occur between the surface and bottom waters (CDFG 2010). The average monthly water temperature for McNulty Slough in the Eel River estuary, as reported by CeNCOOS during the period 2004 to 2008, is shown in Figure 31. McNulty Slough temperatures were taken twice a month over a five-minute period using a YSI sonde.

Dissolved Oxygen

Oxygen saturation or dissolved oxygen (DO) is a relative measure of the amount of oxygen that is dissolved or carried in the water column (much of the DO in water comes from the atmosphere). After dissolving at

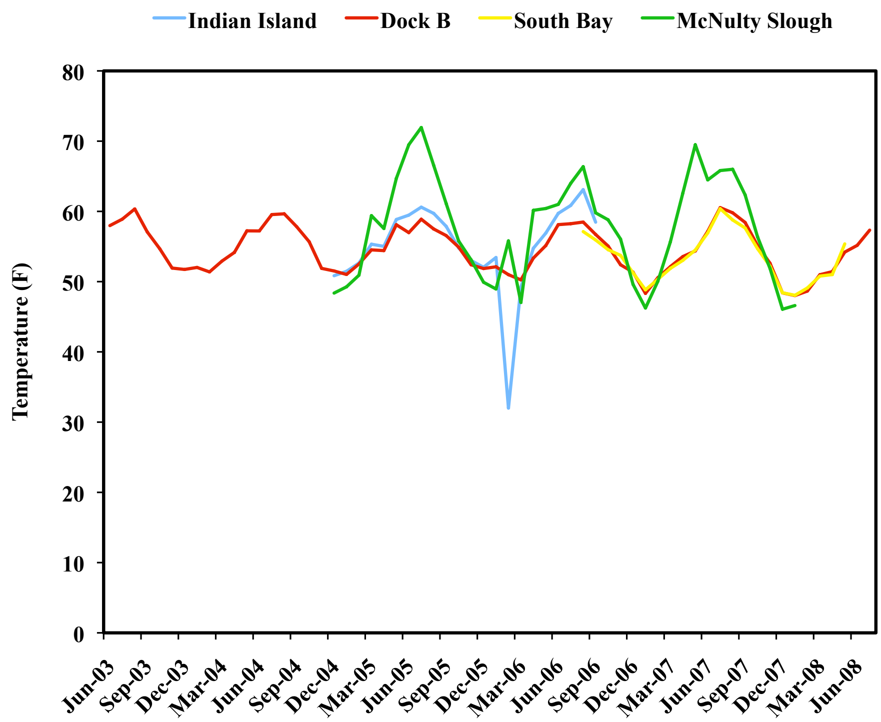


Figure 31. Mean monthly water temperature in Humboldt Bay (Indian Island, Dock B and South Bay) and the Eel River Estuary (McNulty Slough).

the surface, oxygen is distributed by currents and turbulence. Algae and rooted vascular plants also deliver oxygen to water through photosynthesis. DO can be measured with a probe or sensor and it is typically expressed in parts per million (ppm). The ratio of DO content to the potential capacity of water to hold oxygen is expressed as percent saturation (% sat), which is an indicator of water quality. Oxygen saturation varies with temperature, pressure, salinity and water depth.

Aquatic organisms including microorganisms, submerged plants, invertebrates and fish all require DO for respiration. DO is also needed for the biochemical breakdown of organic matter by microorganisms. The breakdown of pollutants can place a heavy demand on available DO, resulting in oxygen depletion in estuaries overloaded with pollutants.

In Humboldt Bay, DO is relatively low in the deep channels, but it is typically near saturation in the shallow waters that spread out over the mudflats (Barnhart et al. 1992). The average monthly DO, in terms of percentage of saturation, is shown in Figure 32, as reported by CeNCOOS for two sites (Dock B and South Bay) in Humboldt Bay from 2003 to 2008. In the Eel River Estuary, DO levels can drop below 5 ppm in McNulty and other slough channels. This may be a signal of nutrient loading and/or poor circulation (CDFG 2010).

Nutrients

Nutrients are often a limiting factor in the biological capacity of a freshwater stream. However, estuaries are naturally high in

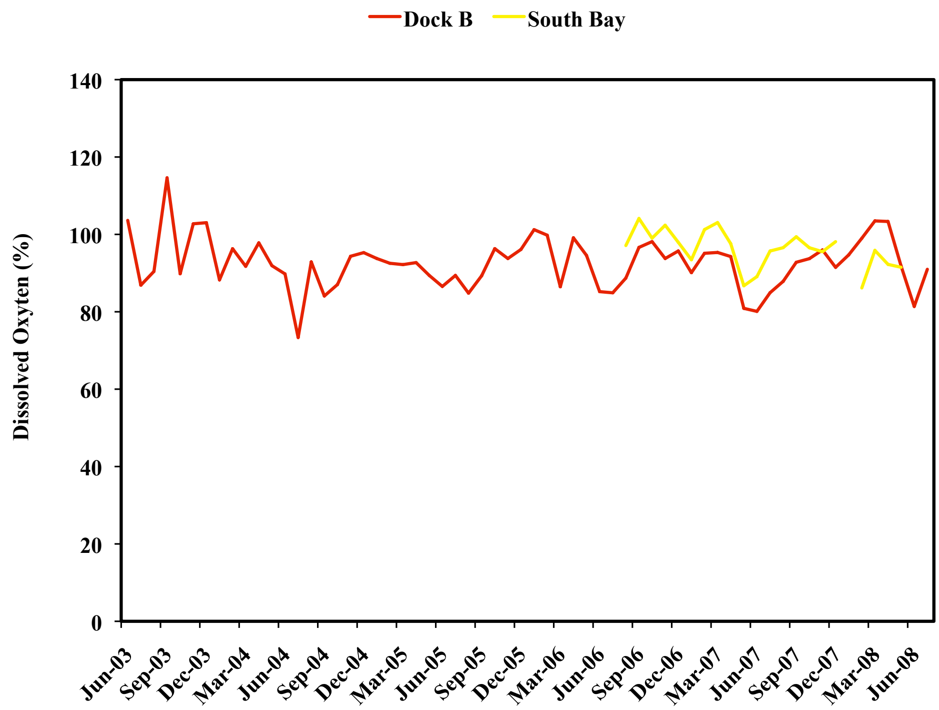


Figure 32. Mean monthly dissolved oxygen (DO) as percentage of saturation at two sites in Humboldt Bay (Dock B and South Bay).

nutrients as they receive sources of carbon, nitrogen and phosphates from both freshwater and seawater. The mixing of freshwater and seawater helps to precipitate nutrients and keeps them within the estuary. Decaying algae and wood in the estuary add to the nutrient supply; an excess of nutrients can degrade water quality by fueling harmful algal blooms (HABs) that increase biological demand either through respiration or decomposition. Typically, tidal exchange prevents high concentrations of nutrients from causing HABs.

Nutrients are cycled in the estuarine ecosystem through complex detrital pathways. Detritus (dead plant material) is initially broken down to small particles by wave action. Particulate organic matter settles out in bottom sediments and is further broken down by benthic microorganisms. These microbes provide a food base for small invertebrates, which in turn are eaten by larger animals such as fish. As a result of detrital decomposition, primary nutrients are released back into the water column to be used by primary producers in the production of new biomass.

In Humboldt Bay, data on nutrient levels in the water column are available for nitrate and ammonium (Pequegnat and Butler 1981; Barnhart et al. 1992; Althaus et al. 1997; Tennant 2006) and for phosphate (Tennant 2006). Nitrate enters Humboldt Bay from freshwater sources during times of precipitation (Tennant 2006) and from the ocean during times of upwelling (Althaus et al. 1997; Tennant 2006). Ammonium enters the bay in large pulses from freshwater sources during times of precipitation, and in small pulses of scattered origin during the dry season. Phosphate concentrations in the bay are similar to phosphate concentrations in the ocean with the greatest loading occurring during the rainy season (Tennant 2006).

In the Eel River Estuary, Boles (1977) found nitrate levels to be high near the mouth and much lower upstream in the main channel, where freshwater influences prevail. Phosphate levels were highly variable at all locations sampled, but generally were higher in the slough channels than in the main channel (Boles 1977).

Turbidity

Turbidity is a measure of fine sediments suspended in the water column. Turbidity magnitude and duration vary temporally and spatially with rainfall depth and intensity. Turbidity affects the depth that light can penetrate in the water column, called the photic zone. Submerged aquatic plants require sunlight to grow, hence plant growth in the lower depths can be limited by high levels of turbidity in the water column.

Turbidity in the Humboldt Bay water column is high, mainly due to suspended sediments. A number of scientists have noted the need for research on the sediment dynamics of Humboldt Bay, including development of a sediment budget (Klein 2004a; Schlosser et al. 2009a). A sediment budget, as defined by Reid and Dunne (1996), provides an accounting of sediment from its point of origin to eventual export from a drainage basin.

Sand, silts and clay from offshore areas enter the bay with tidal inflow and are deposited in intertidal areas and tidal channels. Sources of sediment to the inlet of Humboldt Bay include the Eel River, 9 mi (14.5 km) to the south, and the Mad River, 15 mi (24.1 km) to the north. The processes that transport and deposit sediment from the Eel River mouth to the continental margin and Humboldt Bay were the subject of recent research by a large collaborative team (Wheatcroft et al. 2007).

Sediments also enter Humboldt Bay from the watershed through runoff. Humboldt Bay is differentiated from other estuaries on the West Coast by having a low ratio of land area in the watershed compared to the surface area of the bay, resulting in a relatively small source area for sediment delivery—a factor that is partially offset by the highly erosive Franciscan and Wildcat soils found in the surrounding uplands (Klein 2004a; Barrett 2007). Sediments from the watershed include poorly consolidated, unstable mudstones and siltstones with high surface erosion rates, delivered primarily as silts and clays to the streams and into the bay. Approximately 75% of this material consists of silts, which are likely transported by tidewaters through the bay and into the ocean. Barrett (2007) noted that the total sediment yield delivered to the bay from the watershed appears to be a relatively small contribution to the total sediment budget. Further investigation is needed to better understand the sediment dynamics and sedimentation rates of Humboldt Bay (Schlosser et al. 2009a).

The water column of the Eel River has one of the highest sediment loads of any river in the world (Humboldt County 1992). The Eel River delivers an average sediment yield to the oceanic continental shelf of 2×10^7 ton/year (Wheatcroft et al. 1997; Sommerfield and Nittrouer 1999). Most (90%) of this sediment deposition occurs during the winter (Brown and Ritter 1971). Approximately 15%–30% of the sediment load is discharged via gravity flows to an elliptical deposit on the continental shelf, 6 mi to 19 mi (9.7 km to 30.6 km) north of the Eel River mouth in water 165 ft to 230 ft (50.3 m to 70.1 m) deep, an area known as the Eel River margin (Ogston et al. 2000; Wheatcroft and Borgeld 2000;Wright et al. 2001; Nittrouer et al. 2007). The remainder flows into the chasm of the Eel Canyon or travels southerly along the continental shelf (Alexander and Simoneau 1999; Mullenbach and Nittrouer 2000; Nittrouer et al. 2007).

On the continental shelf, floods create thick layers of sediment, which are mixed and redistributed by energetic ocean storms and abundant benthic organisms in the Eel River margin. Sediment deposition is closely related to the intensity of winter storms (Wheatcroft and Borgeld 2000). The Eel River margin has the greatest wave energy along the California coast north of San Francisco, with waves reaching heights greater than 33 ft (10.1 m) (Wiberg 2000). The Davidson and California Currents move surface sediment beyond the Eel River margin, and Humboldt Bay receives some sediment from these deposits (Mertes and Warrick 2001).

Biotic Communities

Plant Communities

The flow of energy through any ecosystem starts with primary producers. Through the process of photosynthesis, plants and some species of bacteria convert energy from sunlight into chemical energy that serves as the base of the food web. The total energy generated is gross primary production. However, since primary producers use some of this energy themselves during the process of respiration, it is not all available for the food web; the difference between what is generated and what is available for the food web is called net primary production. The rate at which the energy is produced is called primary productivity, and it is expressed in units of mass/area/time. Accurate quantitative assessments of net primary productivity are elusive because of the complex factors involved and the difficulty of measuring them (Shaughnessy 2008).

Diverse populations of photosynthetic organisms called phytoplankton float freely in the water column. Phytoplankton are primary producers that generate large quantities of organic matter, providing food for filter feeders such as worms, molluscs and crustaceans living on the bottom and in the water column. These creatures in turn provide food for fish and waterfowl, hence many organisms are either directly or indirectly dependent on phytoplankton. Phytoplankton productivity is governed by the availability of light and nutrients in the water column.

In winter months, phytoplankton productivity is low in both Humboldt Bay and nearshore oceanic waters. As days grow longer in the spring, the higher intensity of solar insolation combined with periods of offshore upwelling result in phytoplankton blooms. In summer months, phytoplankton productivity levels remain steady in the bay but continue to increase in nearshore waters. Lower nutrient concentrations (especially nitrogen) and competition for nutrients with microalgae and macroalgae may limit phytoplankton productivity in the bay (Pequegnat and Butler 1981; Barnhart et al. 1992).

A computer model was constructed to examine the relationship between the tidal cycle and phytoplankton productivity in North Humboldt Bay. Based on the model, the timing of the tidal cycle relative to solar noon can affect gross productivity by as much as 30%, highest when clear days coincide with mid-day high tides (Headstrom 1994). The highest production was found to occur on clear days when high tide occurs in the middle of the day, while the sun is at its peak. Research on phytoplankton species abundance and distribution in Humboldt Bay is the subject of a current M.A. thesis research project at Humboldt State University (G. O’Connell, Humboldt State University, personal

communication January 25, 2010).
In the Eel River Estuary, phytoplankton abundance is influenced by the stratification apparent in the water column, as measured by the levels of chlorophyll *a* concentrations. A study conducted in the Eel River Estuary from 1982 to 1983 found the concentration of chlorophyll *a* was higher in the bottom layers of the water column than at the surface during both high- and low-water sampling periods. The dominant phytoplankton species detected were *Chaetoceros* spp. and *Skeletonema costatum.* These species also occur in nearshore waters (Matos 1983).

Animal Communities

Invertebrates

Zooplankton are tiny animals that float freely or swim weakly in the water column. This group includes crab larvae, fish larvae and small crustaceans. Diverse communities of zooplankton occur in Humboldt Bay. Zooplankton communities studied in North Bay, South Bay and offshore were found to be distinctly different from one another in terms of species composition (Pequegnat and Haubenstock 1982). The seasonal and spatial distribution of copepods have been studied in North Humboldt Bay (Gore 1971) and in the Mad River Estuary to the north (Buttolph 1987). Gore (1971) also measured total zooplankton biomass, and found that the highest seasonal production occurred in the spring. Overall, total population numbers of zooplankton in Humboldt Bay appear to be relatively low compared to other estuaries on the US Pacific Coast. Possibly the high flushing action in the bay does not allow the development of large numbers of zooplankton (Pequegnat and Butler 1982).

Macroinvertebrates are larger than 0.5 mm, and visible without magnification. In the Eel River Estuary water column, macroinvertebrates that have been noted include gregarious jellyfish (*Phialidum gregarium*) and sea walnut comb jelly (*Mnemiopsis leidyi)* (Boles 1977).

Fish in Humboldt Bay

Humboldt Bay supports a diverse fish fauna of resident and immigrant species. The various types of water column habitat (i.e., open water, deep channels, shallow channels, sloughs and tidal creeks) each support different species and life stages of fish. One hundred thirteen species from 43 families have been recorded, using the area for feeding, breeding, and/or as a nursery ground (Gotshall et al. 1980; Fritzsche and Cavanagh 1995; Pinnix et al. 2005).

Pinnix et al. (2005) documented seasonal patterns in dominant fish species and analyzed their association with mudflat, eelgrass and oyster culture "habitats." The dominant species in trawl catches were English sole (*Parophrys vetulus*) and shiner surfperch (*Cymatogaster aggregata*), which together represented 73% of the individual fish captured in shrimp trawls. Other species captured included speckled sanddab (*Citharichthys stigmaeus*: 9% of the total shrimp trawl catch), bay pipefish (*Syngnathus leptorhynchus*: 4% total catch), bay goby (*Lepidogobius lepidus*: 3% total catch), walleye surfperch (*Hyperprosopon argenteum*: 3% total catch), Northern anchovy (*Engraulis mordax*: 2% total catch), staghorn sculpin (*Leptocottus armatus*: 1% total catch), juvenile black rockfish (*Sebastes melanops*: 1% total catch), and saddleback gunnel (*Pholis ornate*: 1% total catch).

Some dominant species (English sole, shiner surfperch, bay goby, walleye surfperch and black rockfish) that use Humboldt Bay as nursery grounds have peaks in abundance during late spring and summer (Pinnix et al. 2005). These species are thought to be obligatory estuarine residents during their juvenile life stage.

During summer months, Northern anchovy, an important baitfish species, may occur in large schools that seemingly fill Humboldt Bay, at times appearing to drive the upper trophic levels of the Humboldt Bay ecosystem. During the summer of 2007, a US Fish and Wildlife Service crew witnessed a large school of anchovy migrating out of Humboldt Bay with the ebbing tide. The school appeared to extend from the mouth of the Elk River to the Humboldt Bay jetties, a distance of approximately 1.3 mi (2.1 km), and occupied most of Entrance Bay. The crew was tracking an acoustically tagged juvenile coho salmon that was either feeding on the anchovy or utilizing the large school as cover from predators. There were thousands of birds including gulls, Caspian Terns (*Hydroprogne caspia*), Brown Pelicans (*Pelecanus occidentalis*), Cormorants (*Phalacrocorax* spp.), Surf Scoters (*Melanitta perspicillata*), Common Murres (*Uria aalge*), and many other avian species; hundreds of marine mammals including harbor porpoises (*Phocoena phocoena*), harbor seals, California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and a pair of gray whales (*Eschrichtius robustus*). The water seemed to be boiling with activity indicating that larger predatory fish were driving the anchovy to the surface. This whole mass of life moved with the tide out of the bay over the course of approximately 30 minutes (W.D. Pinnix, 2007).

Northern anchovy enter Humboldt Bay in April and depart in October or November. They enter the bay to feed before and after spawning. Sexually mature anchovy leave the bay around June and July to spawn offshore and return in September. They tend to school by size and move into upper reaches of North and South bays at high tide (Waldvogel 1977). Anchovy in Humboldt Bay feed on detrial material, phytoplankton and zooplankton (Peters, 1971).

Variations in abundance of Northern anchovy can be quite large between years, and were extremely abundant in the summers of 2003 and 2005, but nearly absent from catches during the summer of 2004 (Pinnix et al. 2005). This illustrates the ephemeral nature of the fish community composition in Humboldt Bay, and the ability of the bay to support a rich and diverse community of organisms.

Many of the fish species inhabiting Humboldt Bay waters are commercially and/or recreationally important. Nine fish species are commercially fished and 45 species are caught by sport fishermen. Juveniles of some species found in Humboldt Bay include green sturgeon (*Acipenser medirostris*), Chinook salmon, coho salmon, coastal cutthroat trout, steelhead, Pacific herring, black rockfish (*Sebastes melanops*), kelp greenling (*Hexagrammos decagrammus*), lingcod (*Ophiodon elongates*), English sole, and Northern anchovy.

Adult and sub-adult green sturgeon enter Humboldt Bay in the spring and leave in the fall (W.D. Pinnix, personal observation, 2007). It is assumed this summer residency in the estuary is primarily for feeding, as green sturgeon spawn in large freshwater pools. Acoustic telemetry studies (Pinnix et al 2012) have shown that most of the individual green sturgeon that reside in Humboldt Bay originate from San Francisco Bay and belong to the Southern Distinct Population Segment of green sturgeon listed as threatened by the federal Endangered Species Act. All of Humboldt Bay has been designated as Critical Habitat for green sturgeon (Federal Register 2009). Research on diet habits and habitat use and availability for green sturgeon would provide valuable information on those habitats within Humboldt Bay needed for this endangered species. This information would be helpful in recovery of this threatened population.

Humboldt Bay tributaries support some of the last significant populations of wild coho salmon in California as well as Chinook salmon, steelhead, and cutthroat trout (Brown et al. 1994). For juvenile salmon, estuaries provide a food rich environment that promotes rapid growth and increased chances for survival, refuge from predators in winding channels with overhanging vegetation, and brackish salinities allowing salmon to make the physiological transition between fresh and marine environments. Estuarine residence times have been documented for Humboldt Bay tributaries (Wallace 2005, 2006a, 2006b, 2008; Wallace et al. 2005; Wallace and Allen 2007). Juvenile salmonids, especially young-of-the-year (YOY are fish less than one-year old), rear in the tidal freshwater portions of tributaries and tidal sloughs throughout the summer. Some coho continue to rear in the estuarine/freshwater habitats over winter, bringing their total time rearing in the estuary to eight months. In winter, the coho move from the main stream channel to low velocity habitats such as Martin Slough or Wood Creek. Tidal meanders, dead-end sloughs, salt marshes, non-natal streams and golf course ponds are used by coho during winter months in the Humboldt Bay ecosystem. YOY coho reared in estuarine habitats grow larger than cohorts reared in streams, resulting in increased ocean survival rates (Solazzi et al. 1991). Estuaries are also important for adult salmon, providing a necessary transition zone before they begin their upstream migration to reproduce.

Cormorants, sea gulls, terns, pelicans, egrets foraging in South Bay.

Coho salmon smolts leaving the Freshwater Creek watershed for Humboldt Bay were observed during a two-year telemetry study (Pinnix et al. 2012). Young coho migrated through the Freshwater Creek Estuary in 10 to 12 days and remained in the deeper channels of Humboldt Bay for an average of 22 days. While coho smolts did not use eelgrass beds, they were frequently detected in association with floating eelgrass mats (Pinnix et al 2012).

Wallace (2005) studied juvenile salmonid use of the tidal portions of Freshwater Creek, Elk River, and Salmon Creek in Humboldt Bay. The study documented that YOY coho salmon rear in the tidal freshwater portion of Humboldt Bay tributaries for at least three months, and that they will use appropriate habitat adjacent to mainstem channels. The coho that reared in the estuary grew larger than their cohorts rearing in stream habitat farther upstream in the basin. Based on other studies, larger size at the time of ocean entry by salmonids usually results in higher ocean survival. Wallace (2005) also found that YOY Chinook salmon reared in the estuary for an average of three weeks and as long as eight weeks, strongly suggesting that these habitats are important to their survival. Individual juvenile steelhead and cutthroat trout were found to rear in the estuary for a month or more.

Four salmonid species (coho salmon, Chinook salmon, steelhead trout and cutthroat trout) may use slough channels in intertidal coastal marsh as rearing habitat. The federally listed endangered tidewater goby was collected in August 2004 in an unnamed tidal slough near Cannibal Island.

Toole (1980) expanded on earlier English sole studies by describing the relationship between life stage and feeding behavior as it pertained to specific locations within Humboldt Bay. Bloeser's (2000) research on the biology of adult California halibut (*Paralichthys californicus*) was the first study to research this species' use of Humboldt Bay and the effect of an El Niño event on the population's presence in the bay.

The presence of leopard sharks (*Triakis semifasciata*) in Humboldt Bay has been noted by several researchers, especially their

Brown rockfish

Grass rockfish

Fish of Humboldt Bay

Cabezon

Copper rockfish

Stried surfperch

Black rockfish: young-of-the-year and 1 year old

Kelp greenling

Starry flounder

Midshipman

Staghorn sculpin

Redtail surfperch

Buffalo sculpin

Juvenile lingcod

Pile surfperch

pupping in far reaches of North and South bays (Samuelson 1973; Sopher 1974;Gotshall et al. 1980; Shapiro and Associates Inc. 1980; Fritzsche and Cavanagh 1995). Gray (1994) suggested that Humboldt Bay is an important nursery area for young bat rays (*Myliobatis californica*), noting that juvenile and subadult bat rays outnumber adults. More bat rays are present in the bay in spring through fall, with few occurring in the winter. Food items include clams, polychaetes, crabs, crangon shrimp, burrowing shrimp, echiuran worm, sea cucumber, brittle stars, gastropods, hooded shrimp, hermit crabs and isopods (Gray 1994).

Fish abundance and diversity in Humboldt Bay were examined from 2000 to 2001 by Gleason et al. (2007). Fish distribution was assessed with respect to habitat type and water quality parameters using GIS. Spatial analyses showed that fish utilize many habitats in the bay, and that juvenile fish are abundant in shallow areas. Sixty-seven fish species from 25 families were documented. Threespine stickleback (*Gasterostues aculeatus*) was the most abundant species and shiner surfperch the second most abundant, while staghorn sculpin was the species most commonly captured. Twenty-six tidewater gobies (*Eucyclogobius newberryi*), a federally listed endangered species, were collected in six habitat types (Gleason et al. 2007). These results are consistent with those from other published studies of Humboldt Bay (Samuelson 1973; Misitano 1970; Sopher 1974; Misitano 1976; Shapiro and Associates 1980; Chamberlain and Barnhart 1993).

Fish in the Eel River Estuary

The diversity of water column habitats in the estuary support marine fish, resident estuarine fish, freshwater fish, and anadromous fish species (Murphy and Dewitt 1951; Puckett 1977; Cannata and Hassler 1995). These fish rely on the productive estuarine waters for spawning, feeding, and/or rearing. Juvenile nursery habitat is one of the Eel River Estuary's most important attributes. The estuary is utilized for juvenile nursery areas by several important fishery resources including threatened anadromous salmonids, English sole, flounder (*Platichthys stellatus*), surfperch species, sturgeon and Pacific herring. Marine species that can tolerate estuarine conditions find fewer competitors and predators in the estuary, making it a favorable place for spawning and rearing.

Main factors affecting fish distribution within the estuary are salinity and water temperature. These water quality parameters are influenced by complex relationships between seasonal changes in freshwater flows, ocean tides, channel morphology, land use, and coastal fog climate. Physical conditions are constantly changing due to the dynamic nature of the estuary. Due to salinity gradients, it is possible to catch a freshwater fish and a marine fish at the same site where freshwater flows on the surface and seawater flows along the bottom. Many fish show preferences for specific areas while others are spread widely across the estuary, are only occasional visitors, or are drawn in by tidal currents.

Some are present year round, such as

Leopard shark in intertidal South Bay channel.

salmonids, starry flounder, staghorn sculpin and stickleback. Other species are represented by a relatively few individuals that occasionally find their way in the estuary, such as jack mackerel (*Trachurus symmetricus*); most of these occasional visitors are marine species. Some species' populations are far below historic numbers, such as green sturgeon, white sturgeon (*Acipenser transmontanus*), and longfin smelt (*Spirinchus thaleichthys*). A few species are abundant for a period of time, such as surf smelt, topsmelt (*Atherinops affinis*), anchovies, English sole, sardines and herring.

The Eel River Estuary is part of a critical spawning migration route for coho salmon, Chinook salmon, steelhead trout, and cutthroat trout. They use the estuary as transitional habitat as they move between seawater and freshwater. Deeper pools in the estuary are especially important as holding areas until sufficient rains allow the fish to pass upstream. Spawning runs of adult Chinook salmon begin to enter the estuary in August and continue through January. Adult coho salmon generally enter the estuary from November to February. Adult steelhead can be found in the Eel River Estuary year round, with peaks entering the estuary in winter and spring. These peaks represent the onset of winter- and summer-run fish, respectively. Winter steelhead runs typically range from November to April and summer runs generally range from March to June. The winter-run stock has the largest population in the basin and, based on sportfishing records, the summer-run fish have shown a decline from historic numbers and are now rarely caught in the estuary. In general, all salmonids were once much more plentiful in the estuary than they are today (CDFG 2010).

The Eel River Estuary has been shown to be a critical juvenile salmonid nursery area. Studies conducted in 1951, 1977 and 1995 indicate the presence in the estuary of juvenile Chinook from spring to fall, coho from spring through summer, and steelhead year round (Murphy and Dewitt 1951; Puckett 1968, 1976, 1977; Cannata and Hassler 1995; CDFG 2010). Juveniles acclimate to seawater during seaward migrations and also find nursery areas where they feed and grow in the relative safety of the estuary before entering the ocean. Water temperature is generally suitable for anadromous salmonids year round, although the upper channel waters near Fernbridge can warm above 70°F (21.2° C) during summer months (CDFG 2010).

There has been a significant decline in the Eel River coho salmon population size over the last several decades. Considering the habitat alterations of the estuary, it is difficult to determine how the estuary historically functioned as coho habitat by studies of present conditions. Presence of juvenile coho in December and February suggests that the estuary provides an important refuge area for coho that may be flushed from tributaries during high winter-storm runoff. Alternatively, Eel River coho may naturally move to the estuary during winter months. Coho presence and wide distribution across estuarine habitats also suggests the estuary is a rearing area and an important transition area between freshwater and the marine environment. Studies of other estuaries have shown coho rearing in estuarine habitats for a range of days to months before migrating to sea, or moving back into freshwater habitat to overwinter (Miller and Sadro 2003, Wallace and Allen 2007).

Juvenile steelhead are mostly found in the upper estuary zone during the summer and fall seasons, and seem to prefer these fresh and slightly brackish waters. However, juvenile steelhead were found by Puckett (1977) and Cannata and Hassler (1995) in all areas of the estuary over their study periods. The importance of estuarine rearing for steelhead is less studied than for the Chinook and coho. Studies of the Garcia and Noyo river estuaries and estuarine channels of Humboldt Bay tributaries show that, like the Eel River Estuary, steelhead use these habitats year round (Wallace and Allen 2007). Adult and subadult green and white sturgeon have been documented in the Eel River Estuary, but there is no evidence of recent spawning activity in the river.

Less conspicuous species such as federally endangered tidewater goby rely on unique protected areas for year-round habitat. Chamberlain (2006) suggests that preferred tidewater goby habitats may be areas with low velocity tidal currents or stable areas with infrequent tidal exchange. Such habitats can be found in upper and lateral extents of tidal sloughs and marshes.

In May 2010, tidewater gobies were observed by USFWS at four of six sites surveyed in Riverside Ranch; gobies were found in small, quiet pools (i.e., 4–5 m diameter) downstream from tidegates adjacent to the Salt River channel (Grassetti Environmental Consulting 2011)

A non-native nuisance fish species called the Sacramento pikeminnow (*Ptychocheilus grandis*) is present in the Eel River Estuary, and this predatory species is a threat to juvenile salmonids. In August 2008, the first Sacramento pikeminnow was detected in Humboldt Bay, within the Martin Slough tributary. The California Department of Fish and Game rapidly responded with control measures. Surveys of other tributaries did not reveal any additional occurrences of pikeminnow (Gilroy and Wallace 2008).

Birds

About 49 bird species utilize tidal creeks and sloughs at some stage in their life history. The major bird groups are waterfowl, shorebirds and wading birds. Herons and egrets hunt for fish in shallow water. Swifts, osprey and raptors forage over open water.

The Eel River Estuary provides important habitat for many species of water-dependent birds. Waterfowl use the estuary for feeding and refuge from predators. Shorebirds feed on mudflat invertebrates during low tide. Herons and egrets hunt in intertidal and shallow subtidal areas. A more extensive discussion of shorebirds and waterfowl in the study area is found in Chapter 6, “Intertidal Flats, Banks, and Bars”.

Caspian Terns are summer visitors to Humboldt Bay

Mammals

The most common mammal using open water is the harbor seal. The seals feed on the abundant fish available year-round. Rosentha (1968) conducted a census of harbor seals, noting that Humboldt Bay is one of the major pupping grounds in California. Knudtson (1977) made observations of harbor seal mating, birth, and the behavior of mothers with pups in Humboldt Bay. There is an open herd structure with the absence of territorial or harem-maintaining activities. Courtship and mating take place in the water. Pups are born in the spring, usually on land, and often at low tide, although the newborn pups are able to swim immediately after birth. The mother/pup nursing bond occurs on land and is continuous until weaning. The mother seals exhibit aggressiveness towards other adults. Harbor seals also use intertidal mud and sand flats as

Waterbirds in Humboldt Bay and Eel River Estuary subtidal habitats

Sanderlings in drift algae

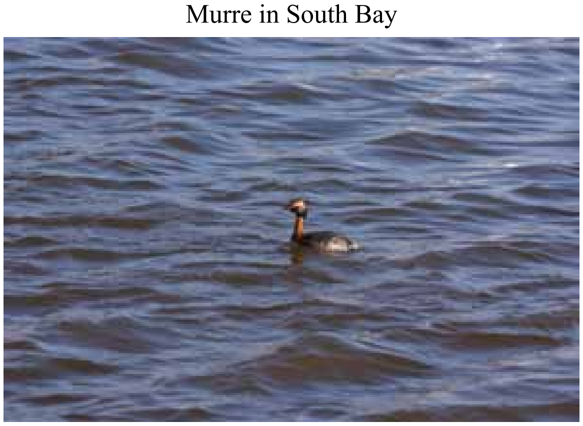
Western Grebe

Cormorants feed in Entrance Bay

Common Egret

Murre in South Bay

Brown Pelican



Horned Grebe in breeding plumage

Great Blue Heron

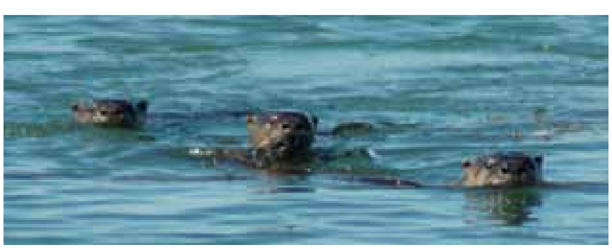
Harbor seals at the Eel River Mouth

loafing grounds, and more information on this behavior can be found in Chapter 6, "Intertidal Flats, Banks, and Bars".

Others mammals that use Humboldt Bay and the Eel River Estuary are the river otter (*Lontra canadensis*), harbor porpoise and sea lion (Barnhart et al. 1992; Roberts 1992). River otters are a top predator and make use of a variety of prey—fish, crustaceans, birds and aquatic insects— in a range of habitats from the watershed to estuaries and the bay (Penland and Black 2009). In Humboldt Bay and throughout the North Coast, river otter groups ranged in size from one to nine individuals, with an average group size of 2.3. Litter size ranged from one to four with an average of 2.2, and pups were usually seen between March and May (Black 2009). The peak feeding on

River otters foraging around old pilings in Entrance Bay near the Elk River mouth

(photos thanks to Holly and Ron Vetter, October 7, 2007)



shorebirds in Humboldt Bay corresponds to the peak influx of migratory shorebirds in winter and early spring (Colwell 1994). Similarly, more crustaceans were consumed between May and July. The general patterns support the concept that river otters are opportunistic and consume prey in relation to their availability, or ease of capture (Melquist et al. 2003).

California sea lions (*Zalophus californianus*) are seen in Humboldt Bay throughout the year. Non-breeding sea lions gather around docks and marinas. Between May and August, they gather at coastal beaches and rocks to breed.

Ecosystem Services

The water column is the fundamental habitat linking intertidal and subtidal habitats in Humboldt Bay and the Eel River Estuary. It provides ecosystem services including:

- Primary production by phytoplankton, algae, and other aquatic vegetation
- Foraging habitat for fish, crabs, birds and mammals
- Nutrient regeneration and recycling by microbial plankton decomposers
- Seed dispersal for marsh plants and eelgrass
- Carbon storage
- Climate moderation on a local level
- Aesthetic beauty, intellectual and spiritual stimulation, and recreational activities
- Support of fisheries

Management Considerations

Critical threats to the water column habitat identified by the Habitat Project Advisory Committee include:

- Anthropogenic greenhouse gas (GHG)
- Urban runoff
- Hydrologic barriers
- Dredging

- Timber harvest

Ocean acidification is a process resulting from increased atmospheric CO_2 concentrations that is degrading habitat in the water column. At a global scale, with atmospheric CO_2 expected to increase, further degradation of the water column from this process can be expected (Tans 2009; Hauri et al. 2009). The California Current already shows pH values that are as low as expected for most open-ocean waters in following decades. Widespread and persistent impacts are predicted in the California Current System, with high variability largely driven by seasonal upwelling. A range of species from microbes to large predatory fish and mammals may be sensitive to these changes in ocean chemistry (some benthic organisms appear likely to be most affected). Acidification is of particular concern to management if it reaches the point where ocean water becomes undersaturated with calcium carbonate causing minerals to dissolve. Shellfish, including molluscs, crustacenas and echinoderms, could be threatened by the loss of calcium carbonate because of low pH seawater. Given the economic and ecological importance of the California Current System, it will be valuable to assess which organisms and ecosystems are vulnerable to such change (Hauri et al. 2009). Local participation in the North Pacific Landscape Conservation Cooperative (NPLCC) is contributing to development of a regional approach to meet the challenge of climate change. The NPLCC represents a partnership of agencies, tribes, NGOs, and other organizations that, together with LCC partners across the country, is working on new technologies to reduce and sequester carbon, adapt to climate change, and raise public awareness about these issues. In addition, collection of consistent data is needed to develop predictive models regarding the rate of sealevel rise.

Other local management issues for the water column originate in land-use practices.

Environmental remediation of a former chrome plating facility on the Eureka waterfront.

The work is removing contaminants such as heavy metals from the soil groundwater, sediment and surface water. Generally, environmetal remediation is conducted to protect human health and the environment for a site intended for redevelopment.

Turbidity, pollution and nutrients from urban and agricultural runoff impact the water column. A better understanding is needed for watershed, bay, and oceanic sediment sources and sediment transport and distribution. When fine sediments are suspended in the water column, the turbidity increases, water clarity decreases, and the contrast between objects and the background is reduced,. limiting the growth of aquatic plants and successful capture of prey by visual predators. Management issues related to high concentrations of suspended sediment include the clogging of salmonid gills in fresh, estuarine and marine habitats, and the collapse of essential fish habitats such as eelgrass beds.

The development of a sediment dynamics and circulation model for Humboldt Bay and the watershed and bay would provide predicative capacity for planning and management to:

- Forecast the effects of rising sea level on habitats and infrastructure
- Facilitate long-term planning by local

agencies

- Explore quantitative projections of anticipated patterns of temperature, salinity and sea level

Education is needed to increase public awareness on the effect of commercial, residential and recreational activities on subtidal habitats. Effective outreach could result in reduced levels of contaminants that enter the water column through urban runoff.

Subtidal – Benthic Zone

General Description

The benthic zone refers to the seafloor underlying a body of water, and the term benthos refers to the organisms that live there. The habitats described in this report, with the exception of the water column, are benthic habitats. In this section reference is specifically made to subtidal benthic regions that are always submerged, even at the lowest tides of Humboldt Bay and the Eel River Estuary. The focus is largely on unvegetated areas. Eelgrass growth extends into the shallow subtidal benthic zone, but is addressed in Chapter 7, “Eelgrass”.

The subtidal benthic zone habitat type described here includes the sediment surface and sub-surface layers, which support distinct types of biotic communities. In the accompanying habitat maps, these habitats were generally mapped as “subtidal” because the analysts could not determine the nature of the submerged floor when using aerial photo interpretation.

Distribution

Following CMECS, the delineation between the subtidal and intertidal zones is the elevation of MLLW (Madden et al. 2009). For Humboldt Bay and the Eel River Estuary, the elevation of extreme low tides is −2.9 ft (− 0.9 m) MLLW (National Ocean Service 2005). The types of subtidal benthic habitat occurring in the study area are closely aligned with the categories described for the water column. Distinctly different biotic communities are found in the subtidal benthic zone associated with channels (> 17 ft [5.2 m] deep at low tide), shallow channels (3–17 ft [0.9–5.2 m] deep at low tide), tidal sloughs and tidal creeks.

Physical Characteristics

Sediments in the estuarine system have three main sources: watershed runoff; oceanic input; and biological activity. Tidal circulation and wind both play roles in the transport, redistribution, and deposition of sediments. The term “fetch” refers to the length of water over which a given wind has blown. Fetch, together with wind speed, determines the power and energy of waves produced. The longer the fetch and the faster the wind speed, the larger and stronger the resulting wave . Fine sediments are resuspended and transported away from areas with strong wind waves, leaving coarser sediments behind. Sediment particles are classified according to grain size (Table 14).

Humboldt Bay

Much of the silt and clay deposited in Humboldt Bay enters the mouth of the bay

Table 14. Sediment classes and corresponding grain size

Sediment Class	Grain Size (mm)
Gravel	2.00–16.0
Sand	0.0625–2.00
Silt	0.0039–0.0625
Clay	< 0.0039
Mud or Fines	Silt and clay combined

during flood tides and storm events. Thompson (1971) estimated the annual oceanic sediment input at 1.9–2.3 × 10^8 cubic ft. Most of the oceanic input probably originates from river sources such as the Eel River to the south and Mad River to the north. A majority of the navigation channel shoaling is materials carried into the bay by longshore drift along the Pacific Coast (USACE 2006). Watershed (fluvial) inputs have a smaller sediment contribution than oceanic inputs, but localized effects are evident at the mouth of tributaries.

Thompson (1971) and Borgeld and Stevens (2007) produced the most complete descriptions of Humboldt Bay sediments. Both studies noted that the coarsest sediments are found in the channels near the mouth of the bay, where tidal currents scour the bottom and leave only coarse sand, gravel and shell fragments. The sediments decrease in size farther from the bay entrance and on the mudflats where reduced current activity results in fine sediments. Overall, sediments in South Bay tend to be coarser than in North Bay, possibly because South Bay is closer to the bay entrance and experiences higher flushing rates and tidal mixing.

The sand and silty sand characteristics of North and South bay channels are found along the channel axis. Channel walls are often clayey or sandy/silts, but the origin of these finer sediments and their age is unknown. The most important factor in decreasing sediment size in North and South bay channels is probably tidal current velocities. In the deeper channels, conditions are turbulent and fast moving, whereas in the upper reaches tidal currents become sluggish and the sediments finer.

Regions of the bay that are protected from wind waves tend to have fine-grained sediments. An example is the area around McDaniel's Slough at the north end of North Bay. The south and southeast areas of North Bay have coarse sediments. These areas experience a long fetch, especially during spring and summer when northwesterly winds prevail. Sediment runoff from the watershed influences grain size in some areas, most notably at the mouth of Jacoby Creek Delta on the northeast side of North Bay, where sediments are a mixture of sand, silt and clay. In the lower reaches of Arcata Channel near Indian Island and in Hookton Channel, abundant large shell fragments occur on surface sediments (Thompson 1971). These are apparently deposits reworked from the channel banks and are concentrated in the channel floor by tidal currents.

Sediment size in Humboldt Bay navigation channels are sampled periodically by the US Army Corps of Engineers in conjunction with maintenance dredging. Most of the channels are comprised predominantly of sand and gravel (> 75%), with the exception of the Fields Landing Channel, which is mostly silt (USACE 2006).

Eel River Estuary

In the Eel River, the grain size of the combined bedload and suspended load is relatively coarse (25% sand; Brown and Ritter 1971). During winter storm events, large amounts of sediment are transported out of the estuary and deposited on the seafloor. Near the mouth of the estuary, the bottom material is primarily sand, becoming a mixture of silty fine sands with fine gravels upstream near the Cock Robin Island Bridge. Further upstream, in the Middle Estuary, the substrate is composed of silty-to-medium sands mixed with fine-to-coarse gravel. In the Upper Estuary, east of Fulmor Road, the channel bottom is sandy coarse gravel with small cobble. The slough channels exhibit a similar pattern as the main channel, with clean sands near the slough mouths, progressing to sand/silt/clay mixtures further upstream. The bottoms of the slough channels contain relatively more sand, while the banks contain greater amounts of clay and decomposing organic matter (Boles 1977).

Biotic Communities

Plant Communities

Primary production in the subtidal benthic zone is primarily from microalgae and blue-green algae. The sediments typically have a high level of bacteria, which can include sulfur-fixing species. Species of macroalgae found in the subtidal benthic zone include *Ulva* spp. and *Gracilaria* spp. (CDFG 2010).

Boles (1977) sampled periphyton assemblages from 1975 to 1976 in the Eel River Estuary using artificial substrates placed at the mouth of McNulty, Cutoff and Hawk sloughs, and the Salt River. Green macroalgae (Phylum *Chlorophyta*) was represented by *Cladophora* sp. Blue-green algae (Phylum *Cyanophyta*) was represented by *Stigonema* sp. and *Oscillatoria* sp. Diatoms of the Phylum *Chrysophyta* were the most diverse group of organisms sampled. The diatom community was dominated by *Synedra* sp., which made up 75%–80% of the population, with *Navicula* sp. also common, making up 10%–15% of the population.

Animal Communities

Most animals that inhabit the subtidal benthic zone are scavengers eating carrion or detritivores that feed on decomposing organic matter. Organic matter from higher up in the water column drifts down to the bottom. This dead and decaying matter sustains the benthic food chain.

In CMECS, faunal organisms are classified as follows: 1) Sessile epifauna live attached to the substrate with the majority of their body lying above the substrate surface; 2) Mobile epifauna move on top of the substrate surface; and 3) Infauna live with the majority of their body below the sediment surface, although feeding or respiratory appendages may extend into the water column (Madden et al. 2009). Benthic fauna can also be classified by their size. Microfauna are microscopic organisms not visible with the naked eye. Macrofauna are larger than approximately 1/16 inch, and organisms in between these two sizes are called meiofauna. Studies worldwide on these small organisms show that while larger forms may be dominant in biomass, smaller ciliates may be dominant in terms of total metabolism (Fenchel 1978).

Benthic Invertebrates in Humboldt Bay

In the soft mud sediments that characterize the Humboldt Bay subtidal benthic zone, sessile epifauna include sedentary molluscs, tube-dwelling amphipods and worms. Mobile epifauna include snails, crustaceans such as crabs (e.g., Dungeness crab), and echinoderms such as starfish. Infauna include burrowing polychaetes, tunneling crustaceans and clams. The above examples are primarily macrofauna. Examples of meiofauna include nematodes, ostracods, kinorhynchs, harpacticoid copepods, formamiferans, and many others in this classification. Microfauna include unicellular organisms such as flagellates and ciliates.

The most extensive studies of Humboldt Bay subtidal benthic invertebrate communities were conducted in 1974 (Boyd et al. 1975) and in 1980 (Bott and Diebel 1982). The first study served to provide baseline data prior to extensive dredging activities conducted from 1977 to 1978 that increased the depth of the lower North Bay and Samoa channels and the turning basin to 35 ft (10.7 m). The 1980 post-dredging study was conducted to assess recovery and long-term changes in the benthic community. Statistical analysis of invertebrate abundance, percentage of composition, and percentage of occurrence were conducted. Sediment core samples were analyzed for particle size distribution.

In both pre- and post-dredging results, polychaetes were the dominant taxon collected, followed by crustaceans and molluscs (Table 15). A total of 133 or 71% of species were common to both studies. Sixty-eight percent of polychaetes, 77% of crustaceans, and 72% of molluscs present in 1980 had been collected in 1974. Species unique to either study were rare and often found in fewer than five stations. At many stations there was a dramatic increase in the total number of individuals collected in 1980 compared to 1974, attributable primarily to high numbers of a single polychaete species: *Owenia collaris* (Table 16).

Cluster analysis of the 1974 survey (Boyd et al. 1975) identified two distinct assemblages: a species-rich assemblage and a species-poor assemblage. Mean species density was eight to nine times greater at the species-rich sites. In the post-dredging study, five unique clusters or species assemblages were distinguished using sediment and biological characteristics. The clusters were grouped into species-rich

Table 15. Species composition by major taxa for the 1974 pre-dredging and 1980 post-dredging studies on benthic invertebrate communities in Humboldt Bay.
(Source: Bott and Diebel 1982).

	Number of species		
Taxon	**1974**	**1980**	Species in Common
Polychaetes	83	102	69
Crustaceans	37	31	24
Pycnogonida	3	2	2
Molluscs	32	39	28
Nemerteans	5	6	5
Phoronids	1	1	1
Sipunculids	1	1	1
Turbellarians	0	1	0
Echinoderms	4	5	3

Table 16. Mean species density and total number of individuals for the 1974 pre-dredging and 1980 post-dredging studies on benthic invertebrate communities in Humboldt Bay.
(Source: Bott and Diebel 1982).

Location	Mean Density (# species/0.1m^2)		Number of Individuals	
	1974	**1980**	**1974**	**1980**
Entire Study Area	26.66	34.19	21,008	70,166
Eureka Channel	32.08	35.25	7,682	1,5931
Samoa Channel	23.56	35.78	5,312	3,4754
North Bay Channel	25.38	32.96	7,714	19,481

and species-poor assemblages. The clustering was attributed primarily to individual species being distributed along gradients of physical sediment characteristics, although biological interactions cannot be discounted as a contributing factor. The species-poor assemblages were found in areas comprised of at least 90% sand. These sediments were well sorted. In contrast, the species-rich assemblages were found in areas with well-mixed particles comprised of less than 80% sand (Bott and Diebel 1982).

One of the most pronounced changes found was an increase in the areas dominated by sand between 1974 and 1980. Sand replaced gravel in southern and central parts of the North Bay and Samoa channels. There was a strong decrease in silt and clay in the Eureka and Samoa channels. Overall the trend was towards coarser sediment in the channel beds and flanks, except in the southernmost part, where sand dominated in both years. A corresponding shift was seen in the distribution of species assemblages, with an overall increase in the area covered by species-poor assemblages, especially at the lower Eureka, the mid-Samoa and the upper North Bay channel sites.

The correlation between sediment and species assemblage type may have some predictive value in Humboldt Bay. Channel alterations that prevent deposition of silts and clays and result in a permanent shift to sediments composed almost entirely of sand-sized particles will likely increase the extent of the area covered by the species-poor invertebrate assemblages. Replication of the 1974 and 1980 transects in the subtidal benthic zone of dredged channels in Humboldt Bay would should how the species-rich and species-poor assemblages have changed in distribution and composition. The results would help determine whether essential habitat is increasing or decreasing in Humboldt Bay and would indicate the current availability of food resources for fish, birds and mammals. This information is needed to give a better understanding of benthic habitats and as a basis for making management decisions. The results may also have applications for fisheries management.

Benthic Invertebrates in the Eel River Estuary

The bottom sediments of the Eel River Estuary are inhabited by clams and other bivalves, along with a multitude of worms, amphipods, isopods and crustaceans (Monroe et al. 1974). Among the most commercially valuable of these is Dungeness crabs, which use the subtidal benthic zone for juvenile nursery and adult rearing (Cannata and Hassler 1995).

Aquatic invertebrates were sampled in the Eel River Estuary from 1975 to 1976 (Boles 1977). Sampling was conducted at 16 sites in the estuary, including Crab Park, North Bay, the North Sand Spit, and McNulty and Cutoff sloughs, and as far upstream as Fernbridge. Sampling was conducted by hand and using dip nets, bottom trawls, and hoop nets baited with dead fish. Boles (1977) was not able to demonstrate which physical factors controlled invertebrate species distribution in the Eel River Estuary, but his results suggested the importance of the degree of tidal influence, which affects substrate composition, salinity, dissolved oxygen, electrical conductivity and pH.

Boles (1977) found that the most common amphipod in the bottom muds of the lower Eel River Estuary was *Corophium stimpsoni*, which builds a tube that attaches to the bottom substrate; this amphipod was also found as far upstream as Fern Pool. Bay shrimp (*Crangon franciscorum*) were abundant in all sampled areas of the estuary. Dungeness crab was found to be common in the Eel River Estuary as far upstream as Dungan Pool, and large numbers of small Dungeness crab exuvia found in the early summer months indicate the estuary's importance as a nursery area. Boles (1977) reported that Dungeness crab and bay shrimp are preferentially associated with sandy substrates. Stout coastal shrimp (*Heptacarpus brevirostris*) were also present in subtidal sandy areas in the Eel River Estuary, although Oligochaete annelids were common in benthic mud near Crab Park, as were polychaete annelids, including *Glycinde polygnatha*, *Nereis procera*, *N.zonata* and *Polydora brachycephala*.

Ecosystem Services

The subtidal benthic zone is not encountered by many people, so it is not surprising that the vital role played by this habitat receives little attention. Many species important to the local community are found in this habitat, such as Dungeness crab and rockfish.

Ecosystem services provided by the subtidal benthic zone include:

- Foraging habitat for fish, crabs, birds and mammals
- Nutrient regeneration and recycling
- Detoxification and decomposition of wastes
- Sediment filtration and trapping
- Water purification
- Water storage in bottom sediments
- Support of fisheries

Management Considerations

Critical threats to the subtidal benthic zone identified by the Habitat Project Advisory Committee include:

- Urban runoff
- Dredging

The subtidal benthic habitat receives watershed runoff from urban, agricultural and wildland areas. Urban runoff is a component of nonpoint source pollution. The local Northcoast Stormwater Coalition is using an innovative approach to stormwater runoff management and community education. Support of this work is essential to protect the subtidal benthic

Erosion of sand bank near county road, Entrance Bay at low tide.

Same location at high tide after rock added.

zone and other habitats in Humboldt Bay and the Eel River Estuary.

Dredging impacts the subtidal benthic habitat by direct removal of sediments, and by changes in the sediment composition of the benthos resulting from changes in circulation and sediment transport. Dredging is necessary for vessel safety and access to the port of Humboldt Bay. The impacts of dredging on subtidal benthic communities were studied in great detail from 1970 to 1984. The US Army Corps of Engineers has conducted many studies of sediment size and distribution in federal navigation channels. Sediment management is a significant issue in Humboldt Bay and the Eel River Estuary. Both systems are impacted by significant sediment deposition and erosion. A complete sediment budget accounting for sources and sinks of sediment would benefit management in many areas, such as shipping, erosion and shellfish culture. More information is also needed on the presence and distribution of contaminants in benthic sediments and related effects on the associated biotic communities.

A large management question remains concerning the input of sediment, nutrient and contaminants (if any) from the watershed and ocean-to-bay water and benthos. As sea level rises, a hydrodynamic model with projection of hourly water levels would assists managers to:

- Assess potential inundation scenarios
- Identify vulnerable areas and allow adaptive planning for climate change impacts
- Help understand where and how coastal environments could change
- Provide quantitative projections of altered patterns of sea level, temperature and salinity

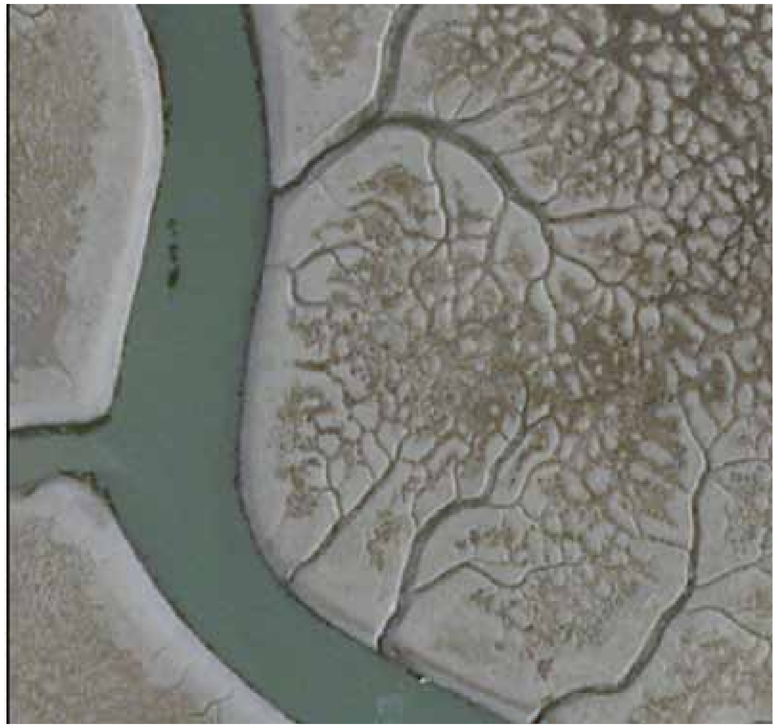
Many excellent and appropriate hydrodynamic models have been developed by state and federal agencies. The work to build a Humboldt Bay and watershed hydrodynamic model would require populating one of these models with data and information. The California Sea Grant Extension Program recently completed a data characterization project that identified over 200 datasets for such a model. This database can be downloaded from http://ca-sgep.ucsd.edu/humboldthabitats. Some management questions that could be answered by using a Humboldt Bay and watershed hydrodynamic model include:

- What percent of mudflat, salt marsh, eelgrass or other coastal habitat or infrastructure will be lost with a 1 ft, 2 ft or 3 ft rise in sea level?
- How often will levees be overtopped?
- Some estuarine species may be unable to migrate because of habitat loss due to sealevel rise. Which species or habitats should we work hardest to protect or conserve?
- What will be the impact of proposed projects on circulation, erosion, sediment deposition, and contaminant transport?
- Which species and natural communities will be most impacted by climate change?
- Will sediment supply allow shoreline areas to keep up with rising sea level?

Intertidal flats with incoming tide

Chapter 6. Habitat: Intertidal Banks, Bars and Flats

CMECS
Mapping Unit:
Macroalgae
System
Biotic Cover Component
Subsystem
Intertidal
Class
Aquatic Bed
Subclass
Macroalgae
Mapping Unit:
Unconsolidated Sediment
System
Surface Geology Component
Subsystem
Intertidal
Class
Unconsolidated Sediment
Subclass
Not classified



Aerial image (above) of bare mud (unconsolidated sediment) with macroalgae. Same area (below) viewed from a secondary channel

General Description

The intertidal zone is periodically submerged and exposed with the ebb and flow of the tides. The zone extends from 0 ft (0 m) MLLW up to the level of extreme high water (EHW). In the study area, EHW is 9.7 ft (3.0 m) above MLLW. This chapter describes intertidal flats, banks, and bars that are either bare or covered by microbial mats or macroalgae. Habitats in the intertidal zone that are vegetated by eelgrass are addressed as a separate habitat type in Chapter 7, "Eelgrass".

Small-scale heterogeneity apparent in intertidal flats is important for providing a diversity of microhabitats. Habitat variables include the density and dimensions of channels, sediment size, slope and pools of standing water.

Intertidal mudflats in Humboldt Bay and the Eel River Estuary are most commonly gently sloping seabeds that are exposed by medium-to-large tides. They occur in the sheltered parts of Humboldt Bay and the Eel River Estuary. They are amongst the most widespread marine and estuarine habitats and cover areas from a few hectares to several square kilometers within the study area.

Habitat Distribution

In Humboldt Bay, unvegetated intertidal flats and areas covered with macroalgae, occupied approximately 21.1% of the bay's area below the average high tide line (5.7 ft [1.7 m] MLLW) in North Bay, and about 10.4% of the area of South Bay In Entrance Bay, intertidal flats are restricted to the margins of the deepwater channels, comprising an estimated 2.07% of the total bay's surface area (Table 17). Within North Bay, 38.9% of the bay's total area is intertidal flat and macroaglae, and the percentage is 10.1% and 41.3%, respectively for Entrance Bay and South Bay (Figures 33-36). In the Eel River Estuary unvegetated flats and macroalgal beds make up 44.4% of the total estuarine area (Figure 37). Overall, of the total 17759.5 ac (7187.8 ha) of intertidal and subtidal habitats in Humboldt Bay, 33.6% is bare intertidal flats and macroalgae (Table 18).

Table 17. Combined intertidal flats and macroalgae in Humboldt Bay and the Eel River Estuary as percentage of total area.

	Humboldt Bay	North Bay	Entrance Bay	South Bay	Eel River Estuary
Total Area (ac)	17,759.5				2,702.1
% of Total	33.6	21.1	2.07	10.4	44.4

Table 18. Intertidal flats and macroalgae cover as percentage of the total area of each region of Humboldt Bay.

	North Bay	Entrance Bay	South Bay
Regional Area (ac)	9,629.7	3,649.7	4,479.9
% of Total	38.9	10.1	41.3

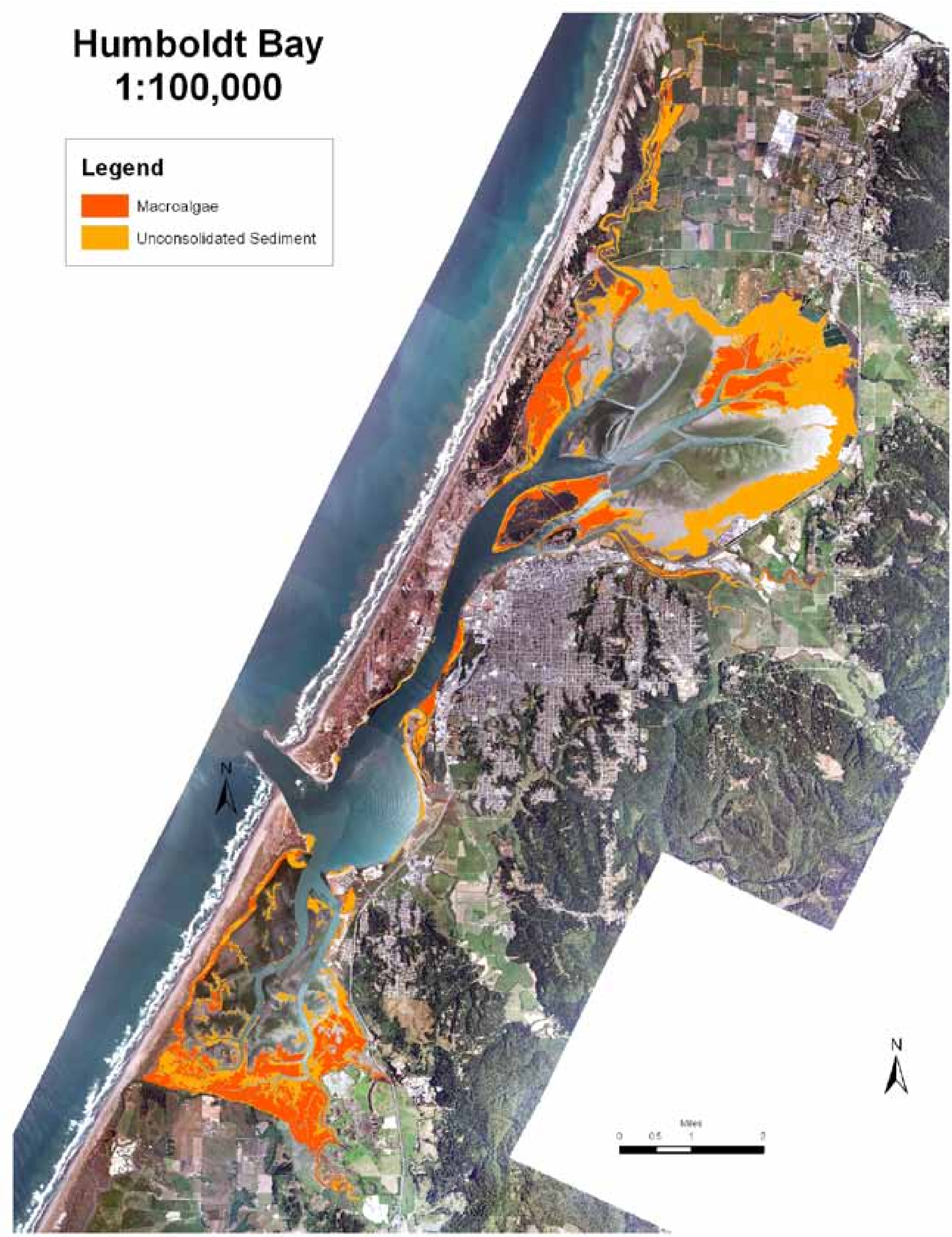


Figure 33. Humboldt Bay unconsolidtated sediments (intertidal flats) and macroalgae

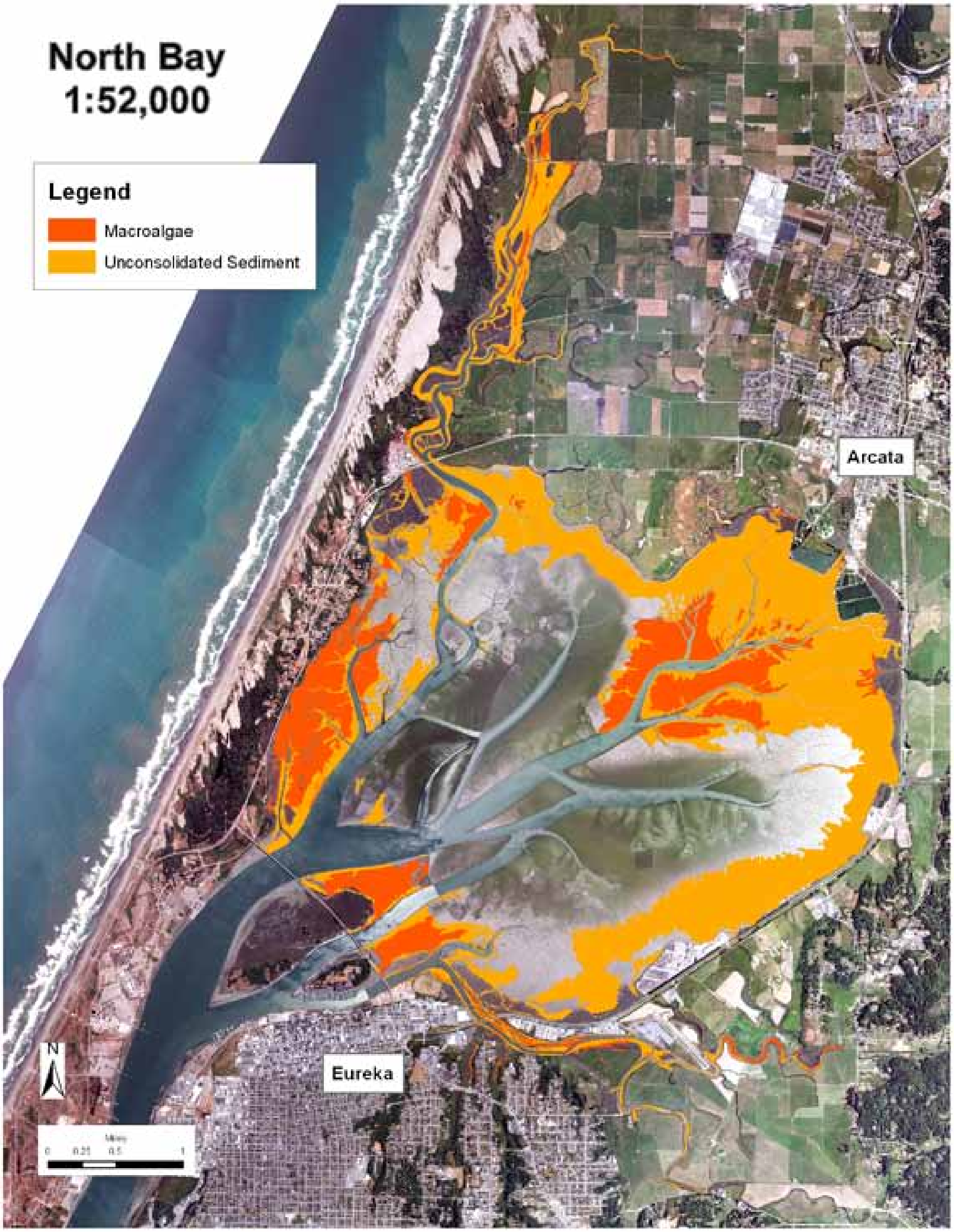


Figure 34. North Bay unconsolidated sediment (intertidal flats) and macroalgae.

Intertidal flats are found along the outer reaches of North Bay and along some subtidal channels. Large patches of macroalgae are found adjacent to the North Spit, along the northern shore of Indian Island, near the mouth of Eureka Slough, and in the northwestern portion of North Bay. Small patches of macroalgae are scattered throughout the sloughs. It is unknown whether tidal currents, nutrients, tidal elevations or other factors are the most significant to macroalgal distribution.

Figure 35. Entrance Bay unconsolidated sediment (intertidal flats) and macroalgae.

Narrow bands of intertidal flats are found in Entrance Bay. One large macroalgal patch extends from the mouth of the Elk River north to the Del Norte Street pier. Many smaller patches are found along the shore, in the Elk River Slough, and along the northern shore and tip of Indian Island.

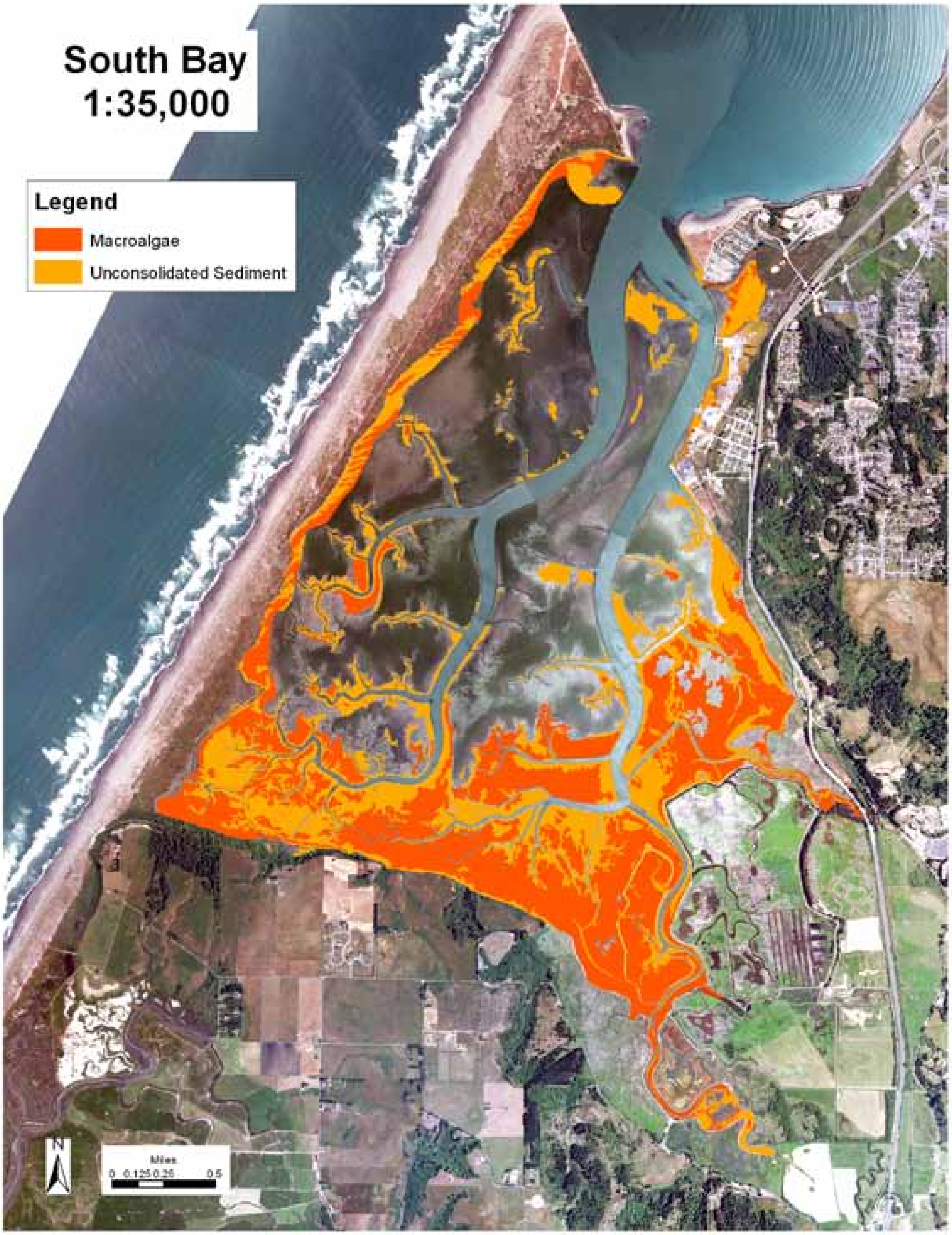


Figure 36. South Bay unconsolidated sediment (intertidal flats) and macroalgae.

In South Bay, the intertidal flats were split about equally between areas of bare mud (19.4%) and macroalgal (21.9%). Macroalgal beds and unconsolidated sediment are generally found around the periphery of South Bay and along the edges of some channels. Many South Bay channels have a berm of mud or sand that is a higher elevation than the interior, eelgrass beds.

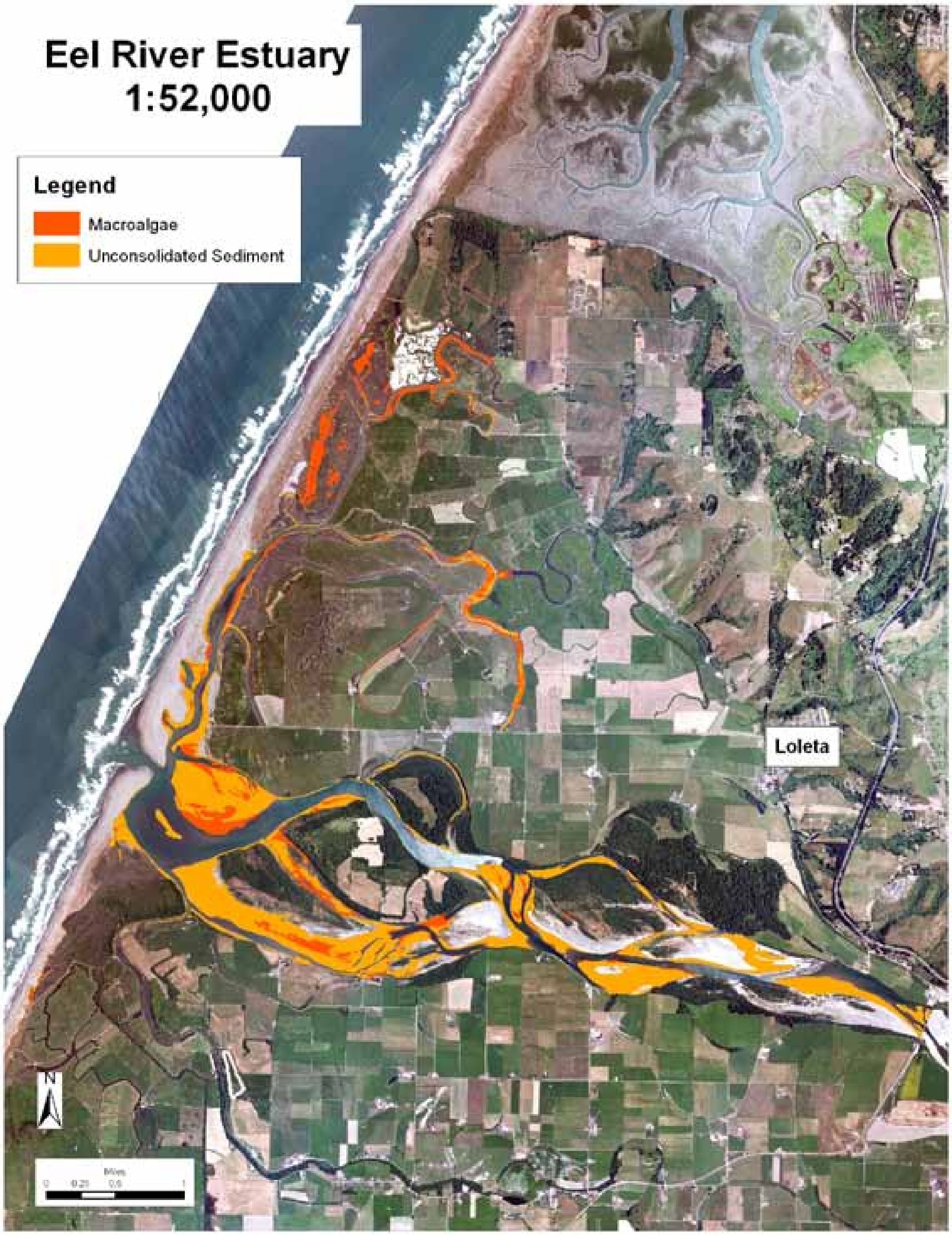


Figure 37. Eel River Estuary unconsolidated sediment (intertidal flats) and macroalgae.

In the Eel River Estuary, unvegetated flats extend upstream to Fernbridge where much of the unconsolidated sediment habitat is gravel bars, as well and sand and mudflats nearer the entrance.

Humboldt Bay

North and South bays are relatively shallow basins characterized by expansive intertidal flats exposed at low tide. The substrate is predominantly mud, and the habitats are commonly referred to as mudflats. In some locations the substrate is sand or sandy mud, especially near the bay mouth. In a few locations, dense accumulations of shell characterize the substrate. Extensive networks of channels and gullies carry tidewaters across the flats. Eelgrass grows in the channels and in pools, or in small depressions that retain water at low tide.

At their upper margin, intertidal flats are bordered either by intertidal coastal marsh, or by man-made structures such as dikes and hardened shoreline, that were constructed to block the flow of tidal waters. The dikes range in width from 50 ft to 500 ft (15 m to 152 m) and are elevated 3 ft to 6 ft (1 m to 2 m) above the intertidal flats. Dikes are sometimes hardened with rock or rip rap, but many are earthen.

A complete inventory of the location and condition of the Humboldt Bay shoreline was recently completed (A. Laird 2012 in prep). The project report will highlight shoreline areas of concern as well as areas that are functioning well.

Eel River Estuary

In the Eel River Estuary, intertidal flats are found in relatively narrow bands along the shores of sloughs, in the former main channel near Camp Weott, and adjacent to the sand spits located north and south of the mouth. Mudflats are found in the slough channels, including the Salt River, and often occur between vegetated, emergent marsh habitats and subtidal channels. Mudflat shores can be steep in areas where slough channels are confined by levees. Sandflats and sandy shores are found in the North Bay in the vicinity of Crab Park, and sandflats also occur where McNulty Slough joins North Bay and muddy sands border the northern edges of Cock Robin Island. Gravel and cobble bottoms are found in the more riverine portions of the upper and middle zones of the Eel River Estuary, including just above the Cock Robin Island Bridge to Fernbridge. Gravel and cobble often provides substrate for growth of macroalgae. Gravel and cobble form large bars in the more riverine areas of the upper estuary zone (CDFG 2010).

Physical Characteristics

Humboldt Bay

The mean grain size of intertidal flats throughout Humboldt Bay is 0.016 mm– 0.032 mm. Thompson (1971) divided Humboldt Bay flats into three categories: Group 1 (silty clay and very clayey silt) found in the high flats of North and South Bay; Group 2 (moderately clayey silts and silty sand) covering extensive areas of the low flats; Group 3 (slightly clayey silt) with more sand and occuring at the lowest elevations. Overall, the intertidal flats show the trend of decreasing particle size with increasing tidal elevation and distance from the bay mouth.

In 2000, Borgeld and Stevens (2007) repeated the sampling design and analysis of Thompson (1971) for Humboldt Bay sediments. The sediment size in the intertidal flats did not change significantly between 1971 and 2000, and the locations of the highest current velocity match the largest sediment diameter in both studies. Apparently, sediment distribution continues to be controlled primarily by tidally driven circulation (Borgeld and Stevens 2007). The fine-grained high intertidal flats are typically soft because of high water content. Sediment cores do not reveal vertical stratification in the upper layers. The burrowing activities of benthic infauna mix

Humboldt Bay mudflats

Large, low gradient mudflat with a steep drop off to a shallow channel

High intertidal mudflat with numerous small channels

Narrow, low gradient mudflat with drainage to a shallow channel

Eel River Estuary intertidal flats

Gravel bars of the Eel River estuary.

Sandflats near the river moith

Mudflats along a slough

sediments. This process is called bioturbation. Sediments from the watershed that accumulate and/or are redistributed there may also contribute to the soft substrate and fine grain size.

There are some areas in Humboldt Bay that show exceptions to the general trend of decreasing particle size with distance from the mouth. One area is Jacoby Creek Delta. The near surface sediments consist of silty sand with gravel extending about 500 ft (152 m) from the salt marsh. The deposition of these materials are associated with winter runoff. This area is accreting sediment, and sediment cores show stratification.

Sand Island, in North Bay, contains patches of gravel, sand and shell about 7 ft (2 m) thick, overlaying the silty clay and clayey silt typical of the intertidal flats. Sand Island was created by the US Army Corps of Engineers around 1920 from dredge spoils associated with the deepening of the Arcata Channel (USACE 2005).

Eel River Estuary

In the Eel River Estuary, the pattern is generally an increase in particle size with distance from the mouth in the main channel, progressing from sandflats, banks, and bars near the river mouth to sandy, coarse gravel with small cobbles upstream. The soft clay muds so prevalent in Humboldt Bay are much more limited in the Eel River Estuary, occurring primarily on the banks of the upper reaches of tidal sloughs (Boles 1977).

Biotic Communities

Though they are generally considered unvegetated, intertidal flats contain a living system of diatoms: green, red, and brown algae; protozoa,; and invertebrates. In general, intertidal flats exhibit variable primary productivity and high secondary productivity from detritus consumption. Detritus sources include salt marshes, diatoms, blue-green algae eelgrass and macroalgae. This microscopic and macroscopic plant material is consumed by zooplankton, which are then consumed by numerous sediment-dwelling invertebrates.

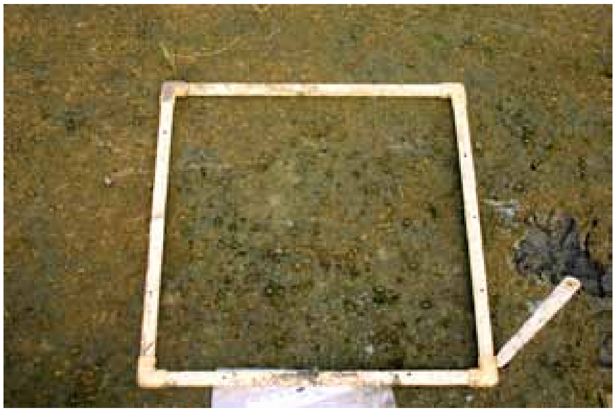
Mudflats are highly productive areas that support large numbers of birds and fish. They provide feeding and resting areas for internationally important populations of migrant and wintering waterfowl, and during neap low tides provide the only readily available food source. At high tide they are important nursery areas for flatfish. The most important marine predators on intertidal sand and mudflats are particularly the flatfish—English sole, sandabs and starry flounder—that feed on polychaetes, bivalves and tidally active crustaceans. In summer, large numbers of flatfish, rockfish, sculpins and other juvenile fishes move over flats at high tide to feed on mobile epifauna, sedentary infauna and protruding siphons and tentacles. These demersal fish are opportunistic predators and their prey choice will reflect the infaunal species distribution of the area.

Plant Communities

Microbial Mats

Microalgae, cyanobacteria and diatoms form dense patches on intertidal flats. They create a brown, blackish, purplish, olive green or dark green hue to the substrate. Microalgae and settled phytoplankton represent a readily available food source for creatures such as worms and clams within the mudflats. Little is known about microscopic organisms that live on Humboldt Bay or the Eel River Estuary intertidal flats. Microbial mats were not classified as the image resolution did not provide a sufficient signature for the photointerpreters .

Dense, complex, multi-taxa mats form at the surface of intertidal mud and sandflats.



Close up of a microbial mat with a 0.1 m^2 quadrant

Large woody debris common in Eel River Estuary mudflats

Extensive microbial mats are characteristics of Humboldt Bay shorelines near salt marsh. Because of the scarcity of information, they offer an area of fruitful research for scientists.

Macroalgae

Some mid- to high-intertidal flats of Humboldt Bay, which are not permanently vegetated, are characterized by large mats of green algae, especially abundant in the late summer and fall (Thompson 1971; Bixler 1982; Tennant 2006). The most abundant green algae are the filamentous forms (e.g., *Chaetomorpha aerea*) and tubular forms (e.g., *Ulva intestinalis*), with sheet forms (e.g., *Ulva* spp.) locally abundant. In some locations, the red alga (*Gracilariopsis andersonii*) is abundant on mud and sandflats, and sheet forms of red algae (*Porphyra* spp.) are occasional. On high intertidal flats and in sloughs that dissect intertidal coastal marshes dark spongy mats of *Vaucheria longicaulis*, which is a member of a group known as yellow-green algae, are found (Table 19). Brown algae, mostly *Fucus* spp., are found attached to rocks in at the upper margin of intertidal flats.

Macroalgae undergo seasonal cycles of abundance, becoming common in warmer months and in some locations disappearing in colder months. The largest expanses of macroalgae are observed in summer and fall. These algal forms are weakly attached to

Table 19. Macroalgae species collected on Humboldt Bay intertidal flats during summer 2007 and 2008. (Source: Schlosser and Eicher, unpublished data).

Green Algae, Sheet	Green Algae, Filamentous	Green Algae, Tubular	Red Algae	Yellow-green Algae
Ulva lactuca	*Chaetomorpha* spp.	*U. intestinalis*	*Gracilariopsis andersonii*	*Vaucheria longicaulis*
U. linza	*Rhizoclonium riparium*	*U. clathrata*	*Gracilaria* sp.	
	Lola lubrica		*Ceramium* sp.	
			Polysiphonia sp.	

***Fucus* attached to intertidal rocks in Entrance Bay**

sediment grains or not attached at all. Early winter storms and strong northwesterly winds dislodge masses of algae that float in the bay or are transported offshore. Eventually, macroalgae become part of the detrital food web.

Recently, observations of persistent macroalgal mats have been noticeable, especially on North Bay intertidal flats. At a permanent eelgrass monitoring site in Entrance Bay, near the Eureka Wharfinger Building, the percent cover of *Ulva lactuca*, a sheet form of green algae, was included in data collected from January 2002 to December 2008 (Figure 38). This data represents only one site, but shows two important trends: 1) an overall increase in *Ulva* cover in this time period; and 2) an increasing tendency for *Ulva* to persist for longer periods and into late fall.

In the Eel River Estuary, *Ulva* spp. covers much of the gravel bars and banks of the main channel from Cock Robin Island and Fernbridge. The mud banks of tributary sloughs such as the Salt River, and McNulty and Hawk sloughs support dense growth of *Gracilariopsis andersonii.*

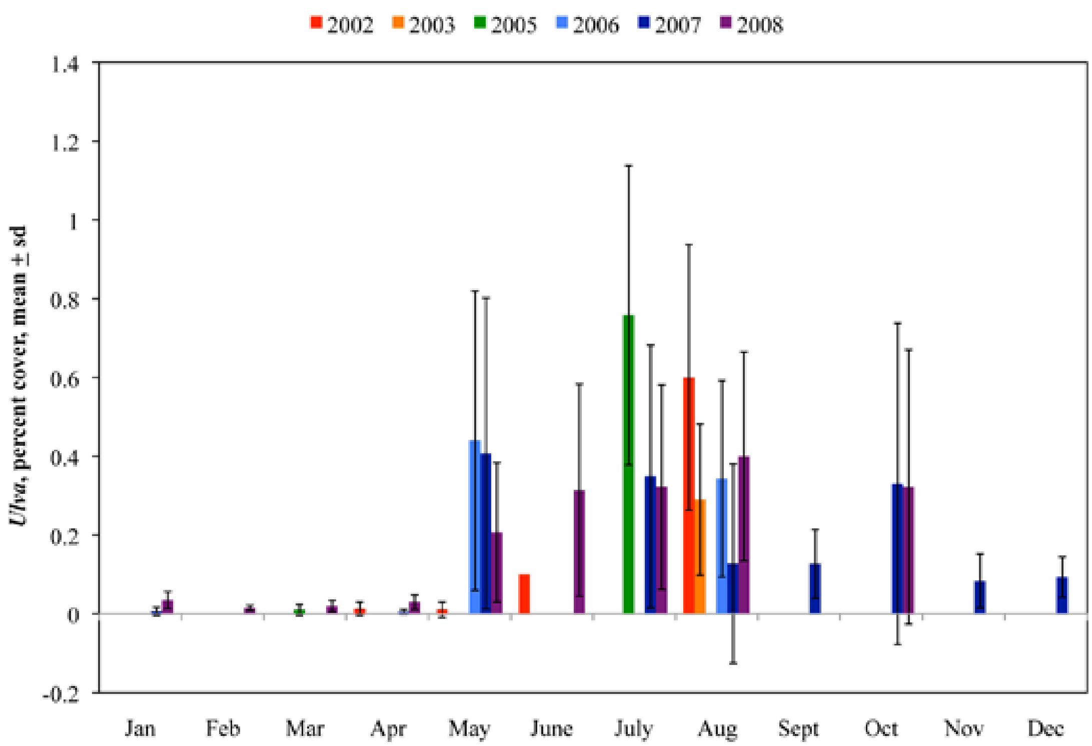


Figure 38. Percentage of cover of the macroalga, *Ulva lactuca*, **at permanent study plots in Entrance Bay from January 2002 to December 2008. No** *U. lactuca* **was present in 2004. (n=8)**
(Source: Schlosser, unpublished data).

Macroalgae species in Humboldt Bay and the Eel River Estuary found in large expanses on interitidal mudflats.

Gracilaria sp. beds, McNulty Slough

Lola lubricata, South Bay

Chaetomorpha sp., Rhizoclonium sp. and Ulva spp.

Animal Communities

Invertebrates

Benthic invertebrates provide food for larger consumers such as shrimp, fish, crabs and birds. Invertebrates support tens of thousands of migrating shorebirds that stop to feed, and they sustain local populations of egrets and herons. Many fish, including leopard sharks, English sole, young rockfish and staghorn sculpins, prey on invertebrates, as do river otters and raccoons (*Procyon lotor*).

Distinctly different benthic invertebrate communities occur in the high-versus-low intertidal flats of Humboldt Bay. The high intertidal flats are dominated by polychaetes, crustaceans and molluscs. The change in species composition occurs around 2 ft to 3 ft (0.6 m to 0.9 m) MLLW. There is less exposure during low tides below this elevation, and the abundance of infaunal organisms is considerably higher. Sandy substrates at low elevations are dominated by polychaetes and molluscs, including clams (clamming at low tide has been a popular activity in the bay for many years). Both sandy and muddy substrates contain large nereid worms that are commonly used for bait (Barnhart et al 1992).

Descriptions of some of the larger, more common intertidal invertebrate species occurring in Humboldt Bay follow. The fat innkeeper worm (*Urechis caupo*) digs a semi-permanent U-shaped burrow in sandy areas, and several other animal species coinhabit the burrow. Horseshoe worms (*Phoronopsis harmeri*) are embedded in sand or muddy sand with a feeding structure, crowned by a ring of ciliated tentacles, which extend above the substrate surface. Ghost shrimp (*Neotrypaea californiensis*) are active burrowers found mostly in high intertidal flats. They constantly excavate tunnels and loosen sediments, allowing oxygenated water to percolate deeper than would otherwise be the case. Ghost shrimp have been credited with exerting more influence on mudflat associations through bioturbation than any other animal. They are also a favored prey item for many shorebirds. The bent-nosed clam (*Macoma nasuta*), the most common clam in Humboldt Bay, is more abundant on low flats than high flats. It is an active burrower that produces volcano-like surface mounds. The gaper clam *(Tresus capax*), with a shell that may measure 10 in (254 mm) in length, can burrow to a depth exceeding 3 ft (0.9 m), squirting a forceful jet of water through its long siphons when disturbed. The gaper feeds on suspended planktonic particles, and in turn serves as prey for Lewis' moon snail (*Polinices lewisii*), bat ray and leopard shark. The gaper, along with the Washington clam (*Saxidomus giganteus*), constitutes the bulk of the Humboldt Bay clam sportfishery (Dinnel 1971). The Lewis' moon snail is a large predatory gastropod, preying mostly on clams. It produces egg cases resembling thin, rubbery "collars", which are frequently seen on eelgrass beds or low intertidal flats.

Common shore crabs include the striped shore crab (*Pachygrapsus crassipes*), the yellow shore crab (*Hemigrapsus oregonensis*), and

Rock crab (*Cancer productus*) among red algae (*Gracilariopsis* sp.) on a North Bay intertidal flat

the purple shore crab (*H. nudus*). These crabs spend a considerable time out of water, and are found along slough banks where they fall prey to shorebirds.

Carrin (1973) examined invertebrates in North Humboldt Bay mudflats, assessing their distribution according to habitat characteristics, vertical stratification, biomass, and fluctations in daily and seasonal abundance. Sixty percent of the total infaunal biomass occurred in the top stratum at 0 in–2 in (0 cm–5 cm) depth, 33% occurred at 2 in–4 in (5 cn10 cm) depth, and 7% at 4 in–6 in (10 cm15 cm) depth. The cheliferan *(Leptochelia dubia)* was the dominant species, followed by *Transenella tantilla, Notomastus tenuis* and gammarid amphipods. Epifauna identified in the study included both yellow and purple shore crabs, mask limpets (*Acmaea persona*), isopods (*Neosphaeroma oregonensis*), amphipods (*Allorchestes angusta* and *Corophium ascherusicum*), checkered periwinkles (*Littorina scutulata*), barnacles (*Balanus glandula*), native oysters (*Ostrea lurida*), and small bay mussels (*Mytilus edulis*). All of these species are important shorebird food sources. Seasonal abundance varied, with peak populations occurring in the summer and lows in the winter (Carrin 1973).

In the Eel River Estuary, Boles (1977) found that common invertebrates on pilings and driftwood in the intertidal zone included periwinkle, the barnacle (*Balanus cariosus)*, edible mussel, Atlantic soft shelled clam (*Mya arenaria*), ribbon worms (*Emplectonema gracile*), and isopods, including aquatic pillbug (*Dynamella dilatata*), olive-green (*Idotea wosnesenskii*), sea slater (*Ligia pallasii*), and Fewkes' (*Idotea fewkesi*).

Fish

The intertidal flats in Humboldt Bay and the Eel River Estuary provide foraging habitat

Saddleback gunnel

for many species of fish including longfin smelt, staghorn sculpin, anchovies and starry flounder. Juvenile fish of all types feed on amphipods, worms, and other soft-bodied benthic invertebrates. Larger species such as California halibut, leopard sharks, bat rays and green sturgeon feed on the rich invertebrate communities of the intertidal flats.

Birds

The intertidal flats in Humboldt Bay and the Eel River Estuary provide foraging habitat for a large numbers of shorebirds. The extensive intertidal flats of Humboldt Bay are considered a key migratory staging, roosting, and refueling area for overwintering shorebirds using the Pacific Flyway; more than 100,000 shorebirds (approximately 30 species) use Humboldt Bay as an overwintering migration stopover site (Gerstenberg 1972). Willets (*Catoptrophorus semipalmatus*), Marbled Godwits (*Limosa fedoa*), Curlews, American Avocet, Dunlin (*Calidris alpina*), and Western Sandpiper (*C. mauri*) feed on intertidal flats.

Humboldt Bay has been identified as one of 58 important North American sites for shorebirds, and it was designated as an International Site in the Western Hemisphere Shorebird Reserve Network. The bay is included in two North American monitoring projects, the International Shorebird Survey and the Pacific

Flyway Project, that assess trends in shorebird populations and gauge the relative importance of wetland complexes to nonbreeding shorebird populations (Howe et al. 1989). Humboldt Bay lies at the northern limit of the wintering ranges of several species: American Avocets (*Recurvirostra americana*); Marbled Godwits; Red Knots (*Calidris canutus*); Long-billed Curlews (*Numenius americanus*); and Short-billed Dowitchers (*Limnodromus griseus*) (Boland 1988).

Humboldt Bay's rich shorebird species assemblage results from the close juxtaposition of diverse foraging habitats including sandy beaches, rocky intertidal zones, intertidal flats, and seasonal freshwater wetlands and pastures, offering a variety of foraging (feeding) and roosting (resting) sites. Shorebirds generally depart roosts to feed on intertidal flats after high tide and return to the roosts when high tides inundate the mudflats (Colwell and Dodd 1995; Colwell et al. 2003a; Danufsky and Colwell 2003). In estuarine habitats, tidal variation and day length are considered the most important environmental factors influencing abundance, distribution and behavior of nonbreeding shorebirds. The mudflats are exposed for a longer duration during spring tides than neap tides. While some shorebirds feed at night, most foraging occurs during daylight hours. In winter months, because of the shorter day length, the amount of time available for foraging on exposed mudflats is less than in the summer. Physical features of tidal flats also influence the distribution patterns of wintering shorebirds in Humboldt Bay. American Avocets favor habitats with fine sediments, while Sanderlings (*Calidris alba*) prefer coarse, sandy sediments. In areas with standing water, Whimbrels (*Numenius phaeopus*) are more abundant, and Short-billed Dowitchers and Long-billed Dowitchers (*Limnodromus scolopaceus*) are less abundant. Sites with the earliest ebb tides tend to have more Whimbrels, Sanderlings, and Long-billed Curlews, but less Greater Yellowlegs (*Tringa melanoleuca)* and Lesser Yellowlegs (*T. flavipes*). The width of the tidal flat and the degree of channelization also affect shorebird use patterns. Both Greater and Lesser Yellowlegs typically take prey from the water column while standing in water (Evans and Harris 1994; Elphick and Tibbits 1998;Tibbits and Moskoff 1999; Colwell et al. 2001; Danufsky and Colwell 2003).

Marbled godwits on a Humboldt Bay mudflat

In a study in Mad River Slough, shorebird use of salt marsh islands, mudflats, channels, and adjacent pastureland was assessed. Most species used pastureland for both foraging and roosting, including some species previously considered to be mudflat specialists. After seasonal rains began in late fall, Dunlins, Least Sandpipers (*Calidris minutilla*), Long-billed Curlews, and Marbled Godwits became opportunists, and used pastures at intermediate and high tides when mudflats were inundated. Black-bellied Plovers (*Pluvialis squatarola*) and Greater Yellowlegs were seasonal generalists during the two wettest seasons, using pastures at all tides and mudflats at low and intermediate tides. Western Sandpipers were mudflat specialists, and Willets were salt marsh opportunists that mainly used mudflats, but shifted to salt marsh at high tide. Killdeers

(*Charadrius vociferus*) and Common Snipes (*Gallinago gallinago*) were pasture specialists and did not use the other two habitats in significant densities during any season. The presence of short vegetation and the presence or absence of standing water were the two most important characteristics influencing increased use of pastures by all avian species (Long and Ralph 2001).

Shorebirds are generally opportunistic feeders, consuming a wide variety of invertebrate and plant foods. In Humboldt Bay, seven species of shorebirds were examined for their digestive tract content. Least Sandpipers consumed molluscs, crustaceans and plants. Western Sandpipers and Dunlins fed on polychaetes, arthropods, molluscs and plants. Dowitchers and Marbled Godwits consumed polychaetes and pelecypods. Willets were the greatest generalists, consuming surface-dwelling invertebrates such as arthropods, pelecypods, polychaetes and fish. Black-bellied Plovers, with relatively short bills, feed at the surface on polychaetes insects, and molluscs. Curlews forage on bivalves (*Macoma* sp., *Clinocardium* sp.), shrimp (*Callianassa* sp.), and marine worms (*Nereis* sp.) (Holmberg 1975).

Dunlins

Dunlins are the most abundant overwintering shorebirds in Humboldt Bay, with annual populations from 10,000 to 20,000 individuals (Conklin and Colwell 2007). Dunlins use more than 120 roosting sites, including mudflats, salt marsh, islands, beaches, jetties, rip rap, wharves and pilings and pastures. They use many roosts and frequently switch roosts during successive high tides during the day, in part relating to the presence of predators such as Peregrine Falcons (*Falco peregrinus*) and Northern Harriers (*Circus cyaneus*). Nocturnal roost sites are farther from the intertidal flats than daytime roosts (Fox-Fernandez 2006; Conklin and Colwell 2008).

Long-billed Curlews

Approximately 200 to 300 Long-billed Curlews overwinter at Humboldt Bay. Patchy distributions of these birds indicate that areas of the bay vary in quality of foraging habitat, probably correlated with habitat features that influence prey abundance. With the onset of winter rains, Curlews shift from feeding on intertidal mudflats to adjacent pastures, which provide important foraging habitat throughout the winter. Curlews appear to use pastures only during the daytime, and they spend almost all daylight feeding hours foraging to meet energetic requirements. Long-billed Curlews exhibit territorial behavior for foraging grounds. Prime prey items are yellow shore crabs, bivalves, polychaetes, ghost shrimp, and a burrow-dwelling fish—arrow goby (*Clevelandia ios*) (Bryant 1979;Hoff 1979; Mathis 2000; Colwell and Mathis 2001; Leeman et al. 2001; Mathis et al. 2006).

Long-billed Crulew in Humboldt Bay

Caspian Terns

These birds historically bred on Sand Island, Arcata Bay, but they abandoned the site in the late 1960s for unknown reasons. However, in 2002, adults and fledglings were found on Sand Island, suggesting re-establishment

Caspian Tern in Humboldt Bay

of an historical breeding site. Adults were observed carrying fish to the site to feed chicks (chicks were observed in May). While nesting habitat is limited by competition with the large population of Cormorants on Sand Island. the benefits are the proximity to food, lack of human/predator disturbance, and minimal vegetation (Shuford and Craig 2002; Colwell et al. 2003b).

Western Snowy Plovers

The Pacific Coast population of Western Snowy Plovers (*Charadrius alexandrinus nivosus*) is a federally listed, threatened species under the Endangered Species Act and by the state of California as a "species of special concern." One goal of federal and state programs is to provide sufficient habitat for a viable population. The population located in Humboldt County was studied for five breeding seasons (April 15 to June 15 of years 2001 to 2005) on sandy beaches on Humboldt Bay and Eel River Estuary spits, and gravel bars in the Eel River. On sandy beaches, such as Clam Beach, movement of adults and fledglings was unrestricted and frequent. However, Western Snowy Plovers on gravel bars were nearly always separated by river channel, which restricted chick movements (Nelson 2007). Snowy Plovers have a low reproductive rate of three eggs per clutch, one to three broods per year, and high nest mortality (Colwell et al. 2005). Adults often return to the same nest site during the same or subsequent years.

Male Western Snowy Plovers in Humboldt County have higher survival rates than females (there may be more predation on females during the breeding season). Males provide parental care while females go in search of a new mate. Males tend to be more secretive while brooding the chicks, and females more visible while seeking a new breeding site or mate. (Mullin 2006).

Mammals

The harbor seal (*Phocina vitulina*) is the most common mammal frequenting intertidal flats, hauling out for pupping, molting and resting. Hundreds of harbor seals use Humboldt Bay's intertidal flats (RCAA 2008). Small "nursery" groups of females and pups often are formed at a distance away from other seals (Knudtson 1974; Loughlin 1978). Loafing grounds used by harbor seals are typically mudflats with a gradual slope that are relatively undisturbed, and near areas of deep water, where they forage.

During a statewide survey of harbor seals conducted in 2002, 1,465 individuals were

Harbor seals on a mudflat in North Bay

counted at 13 haul-out sites in Humboldt Bay, with an additional 17 harbor seals hauled out at a site in the Eel River Delta. The average number of seals at each site was 113 (Lowry and Carretta 2003). More recently harbor seals have been observed hauling out at 16 locations in Humboldt Bay. Two haul-out sites are located along the southern reaches of Arcata Bay, four are in mid-Arcata Bay, and one is within the Mad River Slough. Nine haul-out sites are located in the area northwest of the Humboldt Bay National Wildlife Refuge in South Bay. California sea lions also haul out on mudflats and sandflats in Humboldt Bay and near the mouth of the Eel River.

Coastal marsh and intertidal flats with macroalgae

Ecosystem Services

Intertidal mudflats are important in the functioning of estuarine systems and may have a disproportionately high productivity compared to subtidal areas (Elliott 1998). Intertidal mudflats have a low species diversity but huge overall invertebrate productivity, resulting in an important and perpetually exploited food source for waders, waterfowl and fish. At low tide they provide feeding and resting areas for internationally important populations of migrant and wintering waterfowl, whereas at high tide they are also important nursery areas for flatfish, and feeding grounds for numerous fish species.
Intertidal areas dissipate wave energy, thus reducing the risk of eroding saltmarsh habitat, damaging coastal defenses, and flooding low-lying land. The mud surface also plays an important role in nutrient chemistry. In polluted areas , organic sediments sequester contaminants that may contain high concentrations of heavy metals.

Ecosystem services provided by intertidal flats, banks, and bars include:

- Primary productivity by microscopic and macroscopic algae
- Foraging habitat for fish, crabs and birds
- Nutrient regeneration and recycling
- Sediment trapping and filtration
- Export of nutrients to subtidal habitats
- Wave and current energy dampening
- Countering sea level rise
- Support of fisheries
- Open, aesthetic landscape for viewing shorebird foraging

Management Considerations

Extensive intertidal mudflats are especially characteristic of Humboldt Bay, but are also an important habitat in the Eel River Estuary. The upper limit of intertidal mudflats is often marked by saltmarsh, and the lower limit by channels and sloughs. Sediments consist mainly of fine particles, mostly in the silt and clay fraction (particle size less than 0.063 mm in diameter), though sandy mud may contain up to 80% sand (mostly very fine and fine sand), often with a high organic content. Little oxygen penetrates these cohesive sediments, and an anoxic layer is often present within inches of the sediment surface. Intertidal mudflats support communities characterized by polychaetes, bivalves and oligochaetes.

High tide around Humboldt Bay (taken Jan. 9, 2005, at approximately 11 am)

Mad River Slough flooding the road and adjacent pastures.

Highway 255 bridge at Mad River Slough

Drift eelgrass on South Spit Road from previous high tide.

Critical threats to intertidal flats, banks and bars identified by the Habitat Project Advisory Committee include:

- Anthropogenic greenhouse gas emissions (GHG) influence of air and seawater temperatures
- Nonpoint and point source pollution
- Hydrologic barriers, habitat fragmentation and degradation
- Sediment erosion and accretion
- Shoreline development
- Invasive species

The long-term impacts of sea level rise associated with GHG are significant management considerations for intertidal flats that require adaptive management policies. Loss of this habitat could lead to extensive changes in circulation patterns, erosion and deposition of sediment, and displacement of species and habitats. Shoreline development restricts the ability of the intertidal flats habitat to shift landwards as the sea level rises. A collaborative development of shoreline protection strategies is needed to help agencies deal with sea level rise and manage coastal wetland habitats. Rising sea level may potentially cause losses of important intertidal habitat for migrating shorebirds (Galbraith et al 2002).

Sea level rise reduces the intertidal zone when sufficient sediment import is lacking and/or shoreline barriers prevent inland habitat migration. Higher sea level and increased storm frequency, resulting from climate change, may further affect the sedimentation patterns of mudflats in the study area.

Another cause for management concern is the phenomenon called "coastal squeeze". In an entirely natural situation when sea levels rise, coastal habitats such as saltmarsh and intertidal mudflats would respond by moving landward to adjust their positions. Fixed man-made structures such as seawalls prevent or

Mudflats and levees

Levee with rip rap at Cock Robin Island

Levee without hardening

Weakened levee

severely limit this landward movement. The coastal habitats are therefore "squeezed out" between rising sea levels and fixed defense lines. Hydrologic barriers such as levees and tidegates restrict, and in some places, impair natural tidal inundation and habitat migration.

Many Humboldt Bay and Eel River Estuary intertidal flats are adjacent to levees. The effects of levees include exacerbating sediment accumulations, contributing to losses of estuarine habitat area and tidal connectivity to slough channels, and a reduction of the tidal prism. Management considerations of levee systems and their physical and ecological impacts, as well as benefits to agriculture operations, residential areas and public lands would be useful for climate change adaptation planning. Questions raised include: Would increasing the tidal prism by reconnecting tidal sloughs reduce rising sea level impacts? Would levee setbacks be more effective and efficient for agriculture operations?

Mudflats are naturally resilient and can recuperate well from isolated physical and chemical disturbances. However, intertidal flats are sensitive to oil pollution; the oil enters lower layers of the mudflats where lack of oxygen prevents decomposition of the oil. Industrialized areas are often subject to a variety of pressures, such as degradation through high levels of pollution and waste discharge. Oil covering intertidal mud prevents oxygen transport to the substratum and produces anoxia that results in the death of infauna. In sheltered, low-energy areas, pollutant dispersion will be affected and the finer substrata in these areas will act as a sink. The pollutants will then enter the food chain.

Dredging and propeller wash may resuspend pollutants in the water column. In addition, diffuse and point-source discharges from agriculture, industry and urban areas (including polluted stormwater run-off) may create abiotic areas or produce algal mats affecting invertebrate communities. Discharges may also remove embedded fauna and destabilize sediments thus making them liable to erode. The increased coverage of macroalgal mats of opportunistic green algae such as *Ulva* spp. result in anoxic conditions below the mats. Intertidal flats receive watershed runoff that includes nutrients, pollutants and sediments that should be monitored and assessed.

Macroalgal blooms appear to be increasing in area and duration and pose questions. Will algal species continue to increase coverage of mudflats? How will Humboldt Bay and the Eel River Estuary respond to increasing abundance of drifting macroalgae that inundate eelgrass beds, and cover benthic fauna living in the sediment?

As increasing invasive species infestations are likely with climate change, it is important to bolster the capacity of agencies and the private sector to assess and respond to threats posed by invasive species. Enhanced and expanded educational outreach on the value of mudflat habitat, threats from human activities, effects of invasive species, and the reasons for management measures are essential topics for educational programs.

The prolific spread of the cordgrass, *Spartina densiflora,* is one of many factors impacting intertidal mudflat habitat in Humboldt Bay and the Eel River Estuary by colonizing its upper limits. A saltmarsh by definition is an intertidal mudflat or sandflat that has been colonized by salt tolerant (halophytic) vegetation. Thus, saltmarshes and mudflats are linked in a continuum of intertidal habitats. Estuarine mudflats naturally progress towards marsh areas over time. A reduction in the area and biological integrity of intertidal mudflats will reduce their ability to support bird and fish

Invasive *Spartina densiflora* adjacent to a mudflat.

predator populations. Due to the accessibility and wide distribution of this habitat within the California Department of Fish and Game Oil Spill Prevention and Response (OSPR) region a great deal of information is available on many aspects of intertidal mudflat cleanup.

Dwarf eelgrass (*Zostera japonica*) is a non-native seagrass that has invaded intertidal flats in Humboldt Bay and the Eel River Estuary. A monitoring and eradication program has been underway since the species was first detected in 2002. More information on this species can be found in Chapter 7, "Eelgrass".

S. densiflora is a major pest in the region's intertidal coastal marshes and in some places is spreading onto adjacent intertidal flats. Recently, innovative control methods for *S. densiflora* have been developed for Humboldt Bay. Further details on *S. densiflora* can be found in Chapter 8, "Intertidal Coastal Marsh".

Management actions to minimize future invasions by non-native species using regular monitoring programs for potential invaders would allow early detection and limit impacts of future invasions.

Large numbers of nonbreeding shorebirds forage on intertidal flats, and are vulnerable to stressors such as habitat degradation, pollutants and invasive species. There is little knowledge about the effects of many pollutants on shorebirds so some management concerns might include: How have these stressors affected shorebirds? Is one habitat more beneficial than another? Is it possible or necessary to manage or restore declining habitats? Natural resource managers might consider an environmental risk assessment to identify toxins, and help pinpoint sources and transport routes of pollutants. A consistent monitoring program would characterize sediment contamination problems.

Disturbances to waterfowl in estuaries and nearshore areas include people, dogs and horses, helicopters and light aircraft, and watersports such as windsurfing, yachting and boating. The impact is subjective and depends on the species of birds involved, and the speed, duration and direction of the stressor in relation to bird flocks.

Harbor seal populations in California are thought to be stable or increasing slightly. They are protected by the Marine Mammal Protection Act of 1972. Harbor seals pup between March and June in California so consideration of the species

***Sparina densiflora* coastal marsh at the mouth of the Elk River.**

Eel River Estuary slough with pastures, earthen levee, invasive eelgrass, red algae and shorebirds

in future management practices for the Humboldt Bay Ecosystem will likely be strongly supported by the protection act. The primary threats to harbor seals in Humboldt Bay and the Eel River Estuary are human harassments and disturbance to hauled-out seals while the animals are resting. Seals typically scan the surrounding area and will leave the mudflat, rock or beach when disturbed (Terhune 1985). In Alaska, disturbance during the pupping season has been known to cause the death of some pups due to separation from their mothers (Hoover-Miller1994). The effects of environmental contaminants such as oil and hydrocarbons may be locally significant. For example, the1998 *Exxon Valdex* oil spill in Prince William Sound, Alaska affected harbor seals hauled out on contaminated sites. Like other seal species, harbor seals are threatened by organochlorine pesticides that harm their immune systems and decrease reproductive capacity.

Management of both terrestrial and marine activities will be important to control factors leading to the decline and threats to intertidal flats. Mudflats deposited in the past may erode because of changed estuarine dynamics, and remobilized sediment may be redeposited elsewhere in the same littoral sediment cell. Therefore it is essential to consider a holistic view of this habitat's high variability. Much of this responsibility is likely to fall to local governments who are trustees of intertidal and subtidal lands.

Management considerations to address:

- Halting the erosion and pollution of intertidal mudflats by decreasing mechanical disturbances
- Keeping sediment input "flowing" and improving estuarine and coastal water quality
- Giving special protection to highly impacted areas that are important for the persistence of the habitat and the populations it supports

There is a need to understand the distribution, extent and condition of intertidal flats, including how they have changed over time, and relate this back to the range of pressures they have been subjected to. Essential information includes:

- Overall surface area
- Carrying capacity
- Economic value of intertidal flats and the invertebrate communities of the habitat
- Regular surface area assessment of the habitat to evaluate its destruction, erosion or accretion
- Assessment of the status of the benthic macrofaunal communities
- A survey of the fish and bird populations linked to the habitat could also be used to evaluate its functional value

Chapter 7. Habitat: Eelgrass

CMECS
Mapping Unit:
Eelgrass and Patchy Eelgrass
System
Biotic Cover Component
Subsystem
Intertidal and Subtidal
Class
Aquatic Bed
Subclass
Rooted Vascular

Aerial image (above) of Humboldt Bay eelgrass bed and small channels. The same area from the ground (below)

General Description

The species of eelgrass native to Humboldt Bay and the Eel River Estuary is *Zostera marina*, hereafter referred to as eelgrass. Eelgrass is not actually a grass but a flowering plant that has adapted to living submerged in the shallow subtidal and lower intertidal zones of protected bays and estuaries in temperate regions of the world. Eelgrass is found from Alaska to Baja California, from Quebec to North Carolina, in Hudson Bay, Newfoundland and Nova Scotia, and from the Baltic Sea to Spain. The leaves are ribbon-like, typically measuring less than 0.5 in (13 mm) in width and may be as much as 7 ft (2 m) in length. Eelgrass reproduces both sexually by seed and asexually by vegetative growth.

Eelgrass provides important structure, habitat and food for a broad range of birds, fish and invertebrates (Phillips 1984). Eelgrass habitat is protected by federal and state law: Clean Water Act of 1977; California Coastal Act of 1976. Humboldt Bay eelgrass populations represent approximately 45% of California's eelgrass (Gilkerson 2008).

Distribution

In the study area, most eelgrass occurs in Humboldt Bay (Figures 39-42). In the Eel River estuary, eelgrass is found in small patches in the northern arm and in the Salt River and Centerville Channels (Figure 43).

Oyster mariculture occurs at tidal elevations from −1.0 ft to 1.0 ft (−0.3 m and 0.3 m). Eelgrass is found at tidal elevations ranging from −6.9 ft to 2.5 ft (−2.1 m to 0.8 m).

Eelgrass in Humboldt Bay

Dense, continuous eelgrass

Patchy eelgrass

Eelgrass growing near a channel.

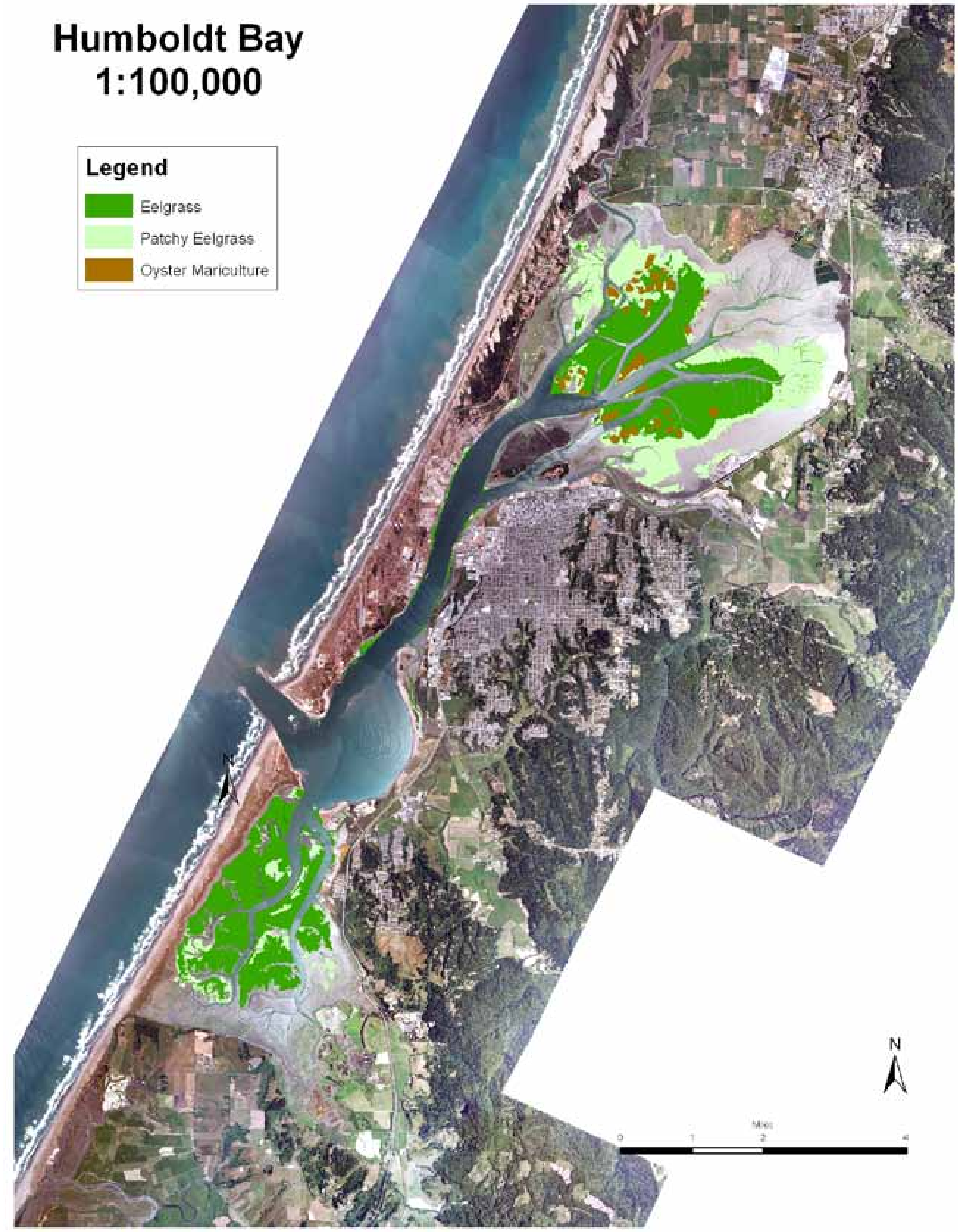


Figure 39. Eelgrass distribution in Humboldt Bay.

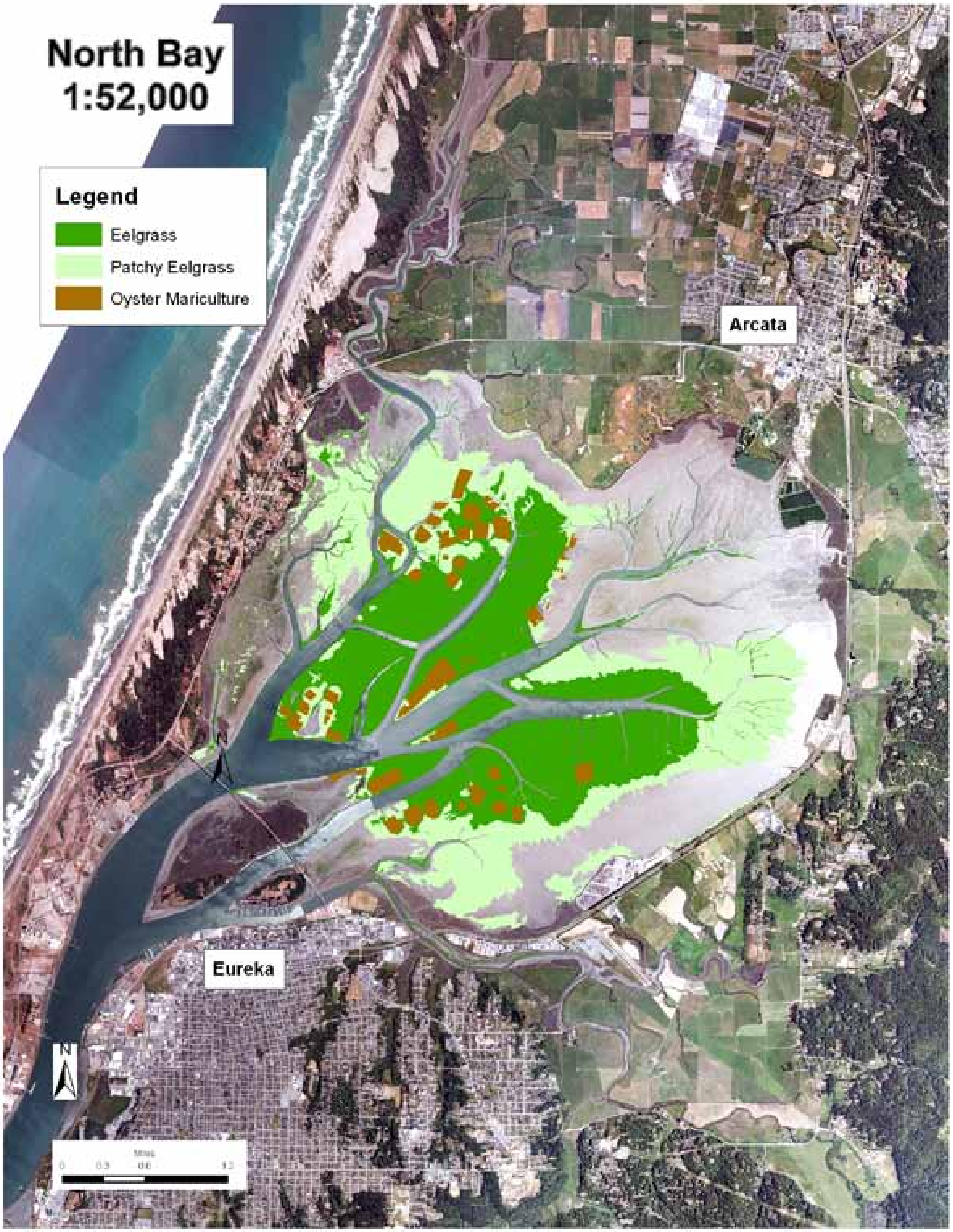


Figure 40. Dense and patchy eelgrass in North Bay, shown with oyster mariculture locations.

Dense, continuous eelgrass beds in North Bay form a heart-shaped area adjacent to the interior channels. Patchy eelgrass surrounds the dense beds and extends into intertidal mudflats. In North Bay, eelgrass and oyster mariculture overlap in their distribution. Some dense and patchy eelgrass areas are found along the North Bay perimeter and in Mad River and Eureka sloughs.

Figure 41. Eelgrass beds in Entrance Bay along the federally managed navigation channel and in the Elk River estuary.

In Entrance Bay, dense eelgrass beds form a fringe along the deep, shipping channels. These eelgrass beds are often intermingled with historic, unused pilings and other shoreline structures.

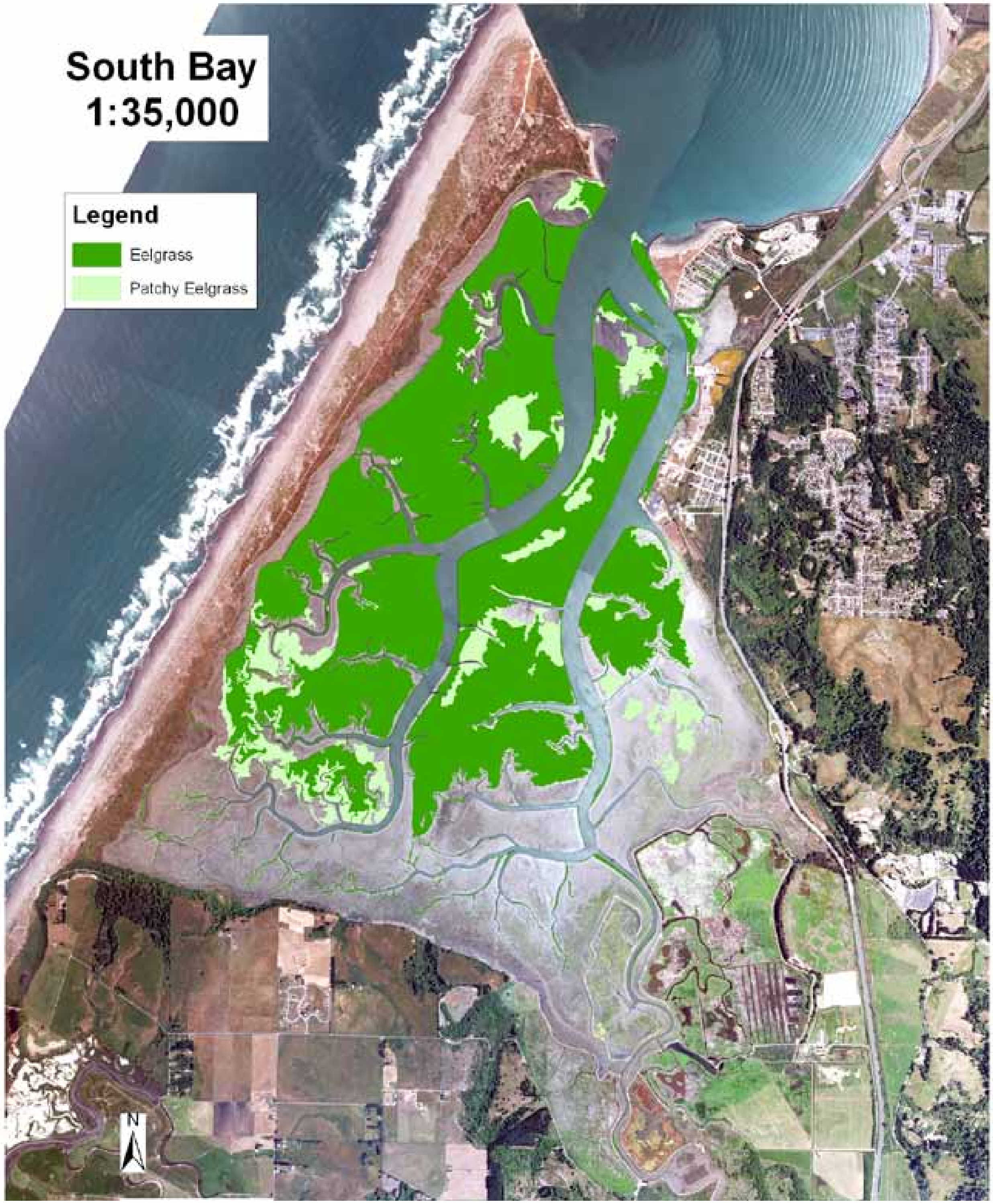


Figure 42. Eelgrass distribution in South Bay

In South Bay, eelgrass grows in large, dense beds adjacent to the interior channels. It extends shoreward in the western portion as this part of South Bay has lower tidal elevations closer to shore than North Bay.

Figure 43. Eelgrass distribution in the Eel River Estuary.

An eastern area in North Bay showing dense eelgrass, and rectangular footprint of longline culture systems. Long lines are spaced approximately 2.5 feet apart (Figure 44).

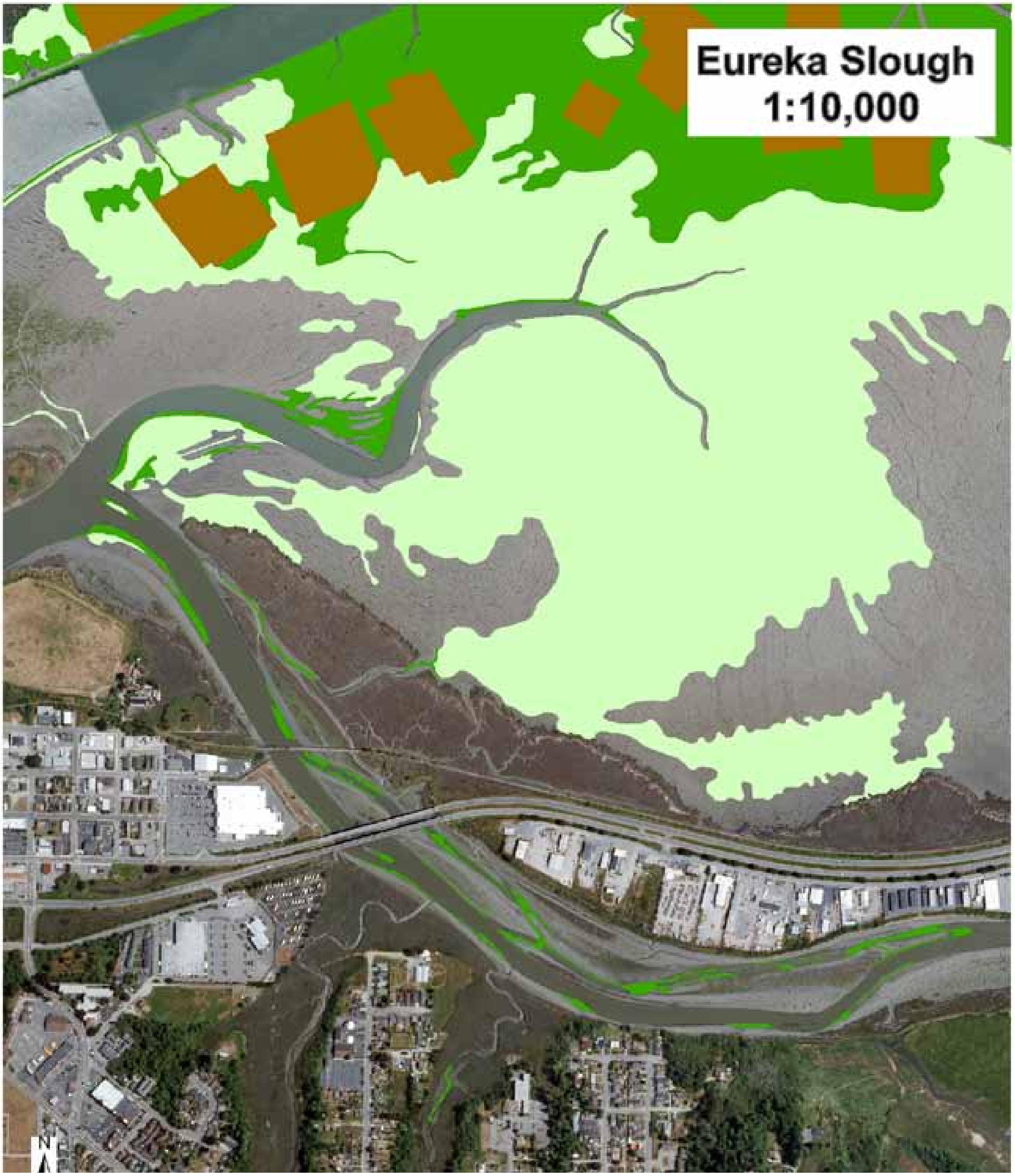


Figure 44. A portion of the eastern area of North Bay (top of image) and the classified area of the Eureka Slough system (lower right).

This includes some secondary creeks, showing an enlarged view of eelgrass habitat in sloughs and secondary channels.

Photo-interpretation of the aerial images in North Bay, showed remnants of previous shellfish culture practices. Prior to 2005, most Humboldt Bay shellfish culture occurred directly on the mudflats. This type of shellfish culture is called ground culture. Shellfish were harvested with a suction dredge. Adult oysters were harvested leaving circular patterns in the eelgrass beds.

The acreage of eelgrass in Humboldt Bay and the Eel River estuary is shown in Tables 20 and 21.

Continuous and patchy eelgrass in North Bay.

Historic circular suction dredge marks and rectangular areas of current shellfish culture are visible along the East Bay Channel

Table 20. a. Dense eelgrass, patchy eelgrass and oyster mariculture area (ac) in Humboldt Bay and the Eel River Estuary; b. As percentage of total eelgrass habitat.

a. Habitat	North Bay	Entrance Bay	South Bay	Humboldt Bay	Eel River Estuary
Eelgrass	1,880.01	96.27	1,638.44	3,614.72	28.98
Patchy Eelgrass	1,697.10	26.56	307.64	2,031.30	11.93
All Eelgrass	3,577.11	1,22.83	1,946.08	5,646.02	40.91
Mariculture	287.32	0	0	0	0
Eelgrass and Mariculture	3864.43	122.83	1946.08	5933.34	
b. Percentage of total eelgrass area in each region. (%)					
Eelgrass	52.55	78.37	84.19	64.04	70.84
Patchy Eelgrass	47.44	21.62	15.81	35.97	29.16
Mariculture	8.03	0	0	8.03	0

Table 21. Dense eelgrass, patchy eelgrass and oyster mariculture as a percentage (%) of the total area of Humboldt Bay and the Eel River Estuary.

Habitat	North Bay	Entrance Bay	South Bay	Humboldt Bay	Eel River Estuary
Eelgrass	10.58	0.54	9.22	20.35	1.07
Patchy Eelgrass	9.55	0.15	1.73	11.44	0.44
All Eelgrass	20.14	0.70	10.96	31.79	1.51
Mariculture	1.62	0	0	1.62	0

Humboldt Bay

In Humboldt Bay, eelgrass forms extensive, dense meadows in the basins of North and South bays. Narrow eelgrass beds fringe both sides of the main channel in Entrance Bay. Tidal channels and sloughs often support lush eelgrass growth, while on high intertidal mudflats, eelgrass occurs in depressions that retain water during low tide. This patchy distribution, sometimes referred to as "leopard-skin," is prominent in the eastern section of North Bay. Previous estimates of eelgrass acreage range from 840 to 3,104 ac (339.9 to 1,256.1 ha) in North Bay, and 1,378 to 2,338 ac (557.7 to 946.2 ha) in South Bay (Table 22).

Eelgrass growing in a high intertidal tide pool with green algae on adjacent mudflat.

Inter-annual variability exhibited in eelgrass coverage in Humboldt Bay is quite high. Eelgrass distribution ranged from 840 to 3,577 acres in North Bay. There were 10 samples between 1959 and 2009 with a mean distribution of 1,875 ac and a standard deviation of 998 ac . In South Bay there were 9 studies between 1959 and 2009. Mean eelgrass distribution was 2,001 ac with a standard deviation of 328 ac. The large changes in eelgrass coverage, which naturally occur from year to year, are important when considering the thresholds for ecological relevance to listed and managed species. It is also important to consider this natural variability when determining the amount of change above the threshold of "insignificant and discountable."

Another important note when considering variability in eelgrass distribution is the differing methods used by the authors. The range of methods is quite diverse. Authors varied in stating whether continuous eelgrass was only measured or if their methods included patchy and continuous eelgrass areas. Observing the generally higher eelgrass distribution after 2000, it appears use of aerial imagery and computer based distribution mapping is more comprehensive than earlier methods. A notable exception in North Bay is Weddell (1964) eelgrass distribution in 1962 which is similar to values for eelgrass distribution after 2000. Only one study (Judd 2006) was conducted at high tide.

Past records suggest that eelgrass distribution in Humboldt Bay has retained the same general footprint over the last 150 years, with some year-to-year fluctuations. The earliest information on the distribution of eelgrass in Humboldt Bay was found as notations on the 1871 US Coast Survey Map of Humboldt Bay. George Farquhar, a member of the Coast Survey, states *"The bay south of the entrance is nearly all mudflats at low water except two channels and is covered for the most part with grass in patches. The channels are generally well marked by grass on either side"* (Pierce 1871). This historical notation and associated map are consistent with current eelgrass distribution in Humboldt Bay.

Fluctuations are more evident in North Bay than in South Bay, and may be related to seasonal rainfall pattern, stronger currents, more turbidity events, lower salinity, and different nutrient levels. In a few locations, such as near the mouth of the Elk River and near the Samoa boat ramp on the North Spit,

Table 22. Estimates of eelgrass acreage in Humboldt Bay from previous studies (ac).

Location	Acres	Year	Survey Method	Source
North Bay	840	1959	Aerial photography (1958), walking and boat field surveys, planimetry to outline eelgrass beds, noted algal beds not distinguishable from eelgrass in photos	(Keller 1963)
	1,670	1961	Aerial photography AT 4800 feet (April 1, 1961), no field surveys	(Waddell 1964)
	2,600	1962	US Coast and Geodetic Survey Chart 5832 used to map by boat and on foot with landmarks and channels as reference points. Mapped continuous eelgrass areas, not patches or discontinuous eelgrass beds	(Waddell 1964)
	1,275	1963	Same as 1962	(Waddell 1964)
	1,075	1972	US Coast and Geodetic Survey Chart 5832 used to map by boat, on foot and with light aircraft. Eelgrass beds were outlined with a plane planimeter.	(Harding and Butler 1979)
	1,035	1979	Aerial photography (Nov. and Dec. 1978, March 1979) utilizing color infrared to map eelgrass distribuiton at 1:24000. Ground verification conducted but no details stated. Compensating polar planimeter used to outline eelgrass distribution.	(Shapiro and Associates 1980)
	1,011	1992	Aerial photography, ground verification, and planimetry.	(Ecoscan Resource Data 1992)
	2,562	2000	Aerial photography (Dec,1997) , ARC GIS 3.0, photointerpretation of continuous eelgrass beds.	(Mello 2000)
	3,104	2004	High resolution bathymetric data (LIDAR), multibeam sonar and single beam sonar imagery (2002-2005) used to model eelgrass habitat. Intertidal (low tide) and subtidal (diving) field surveys used for round verification.	(Gilkerson 2008)
	3,577.11	2009	Aerial imagery (June 2009, low tide) See Ch. 3 for methods	(this study)

Table 22. Continued

Location	Acres	Year	Survey Method	Source
Entrance Bay	128	2000	See North Bay above	(Mello 2000)
	122.83	2009	See North Bay above	(this study)
South Bay	1,999	1959	See North Bay above	(Keller 1963)
	1,378	1966	Same as Keller 1963	(Keller and Harris 1966)
	1,942	1972	See North Bay above	(Harding and Butler 1979)
	1,900	1979	See North Bay above	(Shapiro and Associates 1980)
	1,979	2000	See North Bay above	(Mello 2000)
	2,582	2002	Kriging to interpolate eelgrass distribution from samples collected in 1999 and 2000 using a 1 ha grid.	(Moore et al. 2004)
	2,338	2004	See North Bay above	(Gilkerson 2008)
	1,947	2005	Hyperspectral, aerial imagery (Oct. 2004,high tide) , bathymetric LIDAR (2002) and tide gauge data used to classify submerged eelgrass distribution with ARC GIS 9.1.	(Judd 2006)
	1,948.08	2009	See North Bay above	(this study)
Entire Humboldt Bay Area	2,839	1959	See North Bay above	(Keller 1963)
	2,017	1972	See North Bay above	(Harding and Butler 1979)
	2,935	1979	See North Bay above	(Shapiro and Associates 1980)
	4,670	2000	See North Bay above	(Mello 2000)
	5,441	2004	See North Bay above	(Gilkerson 2008)
	5,642.02	2009	See North Bay above	(this study)

the beds are dynamic, with notable changes in distribution and density between summer and winter (Schlosser, personal observation). Shellfish culture in North Bay affects eelgrass density locally but not the overall distribution (Rumrill and Poulton 2004). Humboldt Bay eelgrass beds are persistent all year, however they exhibit seasonal fluctuations in density and biomass.

Mapping the distribution of eelgrass using aerial photography was challenging. Clouds and fog often prevented flights at desirable low tides. Macroalgae, which is abundant in mid- to high- intertidal elevations, can be difficult to differentiate from eelgrass through aerial photo interpretation of true color and infrared imagery. A plane equipped with hyperspectral sensors, using the absorption properties of specific plant pigments, was flown over Humboldt Bay at high tide in 2004. The imagery obtained was used in conjunction with LIDAR data to create a digital map of submerged eelgrass in South Humboldt Bay (Judd 2006). The analysts were able to distinguish between macroalgae and eelgrass, and to detect eelgrass growing along channel edges. This "fusion" map product is available at the CeNCOOS website for Humboldt State University: http://cencoos.humboldt.edu/ (accessed June 6, 2012).

Eel River Estuary

Eelgrass occurs in the saline to brackish portions of the estuary, being most prominent in tributaries near the mouth, including McNulty Slough to the north and Salt River to the south (CDFG 2010, this study). Eel River Estuary populations of eelgrass generally die back during winter, presumably due to freshwater influences. New growth appears in April and forms locally dense stands during summer (Bruce Slocum, personal communication 2009). To our knowledge, there are no studies of eelgrass in the Eel River estuary.

Eelgrass growing in the Eel River Estuary

Small amount of *Gracilaria* sp at the base of eelgrass plant

Physical Characteristics

Physical habitat features include substrate, depth, temperature, location, light and nutrient availability. Tidal and wave regimes also contribute to variability in plant morphology. The upper and lower limits of eelgrass distribution vary from site to site, but the maximum depth to which eelgrass has been recorded for Humboldt Bay is −6.9 ft (−2.1 m) MLLW and the upper limit for continuous eelgrass beds is 2.5 ft (0.8 m) MLLW, with patchy eelgrass occurring as high as 4.7 ft (1.4 m) MLLW (Gilkerson 2008). The primary limiting factor at the lower elevation range of distribution is light availability in the water column, which is a function of water clarity. The degree to which water column turbidity affects the depth distribution of eelgrass in Humboldt Bay is not known. At the upper range, eelgrass distribution is limited by desiccation, and possibly by higher air temperatures, that occur in the upper intertidal zone during periods of exposure. Ambient nitrate, ammonium, and phosphate concentrations in the water column do not appear to limit eelgrass growth (Tennant 2006).

Eelgrass typically grows on substrates comprised of sand, silt and clay. Where abundant, eelgrass forms dense matted roots and rhizome structures that stabilize soft bottoms such as the small grained, rich, organic mudflats around Humboldt Bay. Its buoyant, flexible leaves slow currents and dampen wave action, causing sediment and organic material to accumulate.

Eelgrass survives in water temperatures ranging from 21.2° F to 93.2° F (−6° C to 34° C). In Humboldt Bay, the temperature ranges from 42.8° F to 75.7° F (6.0° C to 24.3° C), though monthly averages are generally 50° F to 59° F (10° C to 15° C) (Humboldt State University 2008). The salinity range for eelgrass is 9 ppt to 42 ppt (Phillips 1984). Minimum light requirements for eelgrass are 10% to 22% of surface light (Zimmerman et al. 1991).

Dry eelgrass leaves at high tide with a small patch of red algae (*Polysiphania* spp.)

Biotic Communities

Plant Communities

Three seagrasses are found in Humboldt Bay and the Eel River Estuary. In addition to the native eelgrass, an invasive species called dwarf eelgrass (*Z. japonica* Aschers and Graebn) was detected in Humboldt Bay in 2002. *Z. japonica* occurs in isolated locations and is the subject of an ongoing eradication program (Ramey et al. 2011; Manning and Schlosser 2011). Widgeon grass (*Rupia maritima*) is a native seagrass that grows in brackish water and in scattered patches on high intertidal mudflats throughout the study area, in sufficient abundance or density to be mapped as a habitat type.

From 1963 to 2008, several studies directly addressed eelgrass plant characteristics in Humboldt Bay. Data from the following studies taken in July and August are used for comparison: Waddell (1964); Keller and Harris (1966); Harding and Butler (1979); Bixler (1982); Moore (2002); Rumrill (2004); Tennant (2006); and the Humboldt Bay Cooperative Eelgrass Project 2001–2008 (Schlosser et al. unpublished data). Plant growth characteristics measured included shoot density (number of shoots per m^2), above ground biomass (g dry weight/m^2), shoot length (mm), and reproductive output (# reproductive shoots/m^2).

Shoot Density and Above-Ground Biomass

In general eelgrass shoots have higher density in South Bay than North Bay (Figure 45). This difference in eelgrass bed structure between North and South bays has been noted since the 1960's (Waddell 1964). Eelgrass shoot density in Entrance Bay has been observed to vary widely (12 shoots/m^2 to 208 shoots/m^2), reflecting the strong influences of wind, currents and waves on eelgrass beds along the main shipping channel (Tennant 2006; Gilkerson 2008). Above-ground biomass follows the same general trends as shoot density: higher in South Bay than North Bay, (Figure 46).

Shoot Length

The length of eelgrass shoots, or turions, is typically assessed by measuring the longest leaf in the shoot. In most years sampled, eelgrass shoots were longer in North Bay (750 mm to 948 mm) than in South Bay (453 mm to 691 mm), with a wide range of shoot lengths occurring in Entrance Bay (447 to 896 mm) (Figure 47).

Eelgrass grows and produces leaves throughout the year, with peak growth occurring in the summer. In South Bay, Bixler (1982) measured a mean daily summer growth rate of 4.1 cm^2/shoot, with a peak growth rate of 7.3 cm^2/shoot in June. Growth rates in winter averaged 0.74 cm^2/shoot (Bixler 1982).

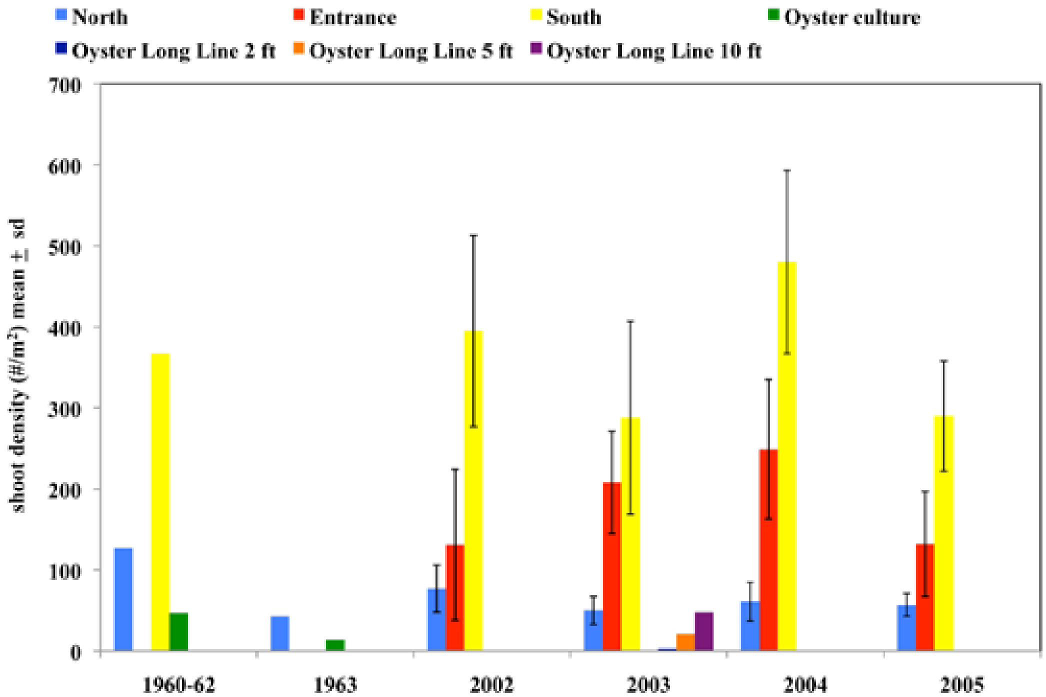


Figure 45. Eelgrass mean vegetative shoot density, shoots/m², in undisturbed eelgrass, in oyster ground culture and oyster long-line culture, and at a permanent site in Entrance Bay
(Sources: Waddell 1964; Keller and Harris 1966; Rumrill 2004; Humboldt Bay Cooperative Eelgrass Project)

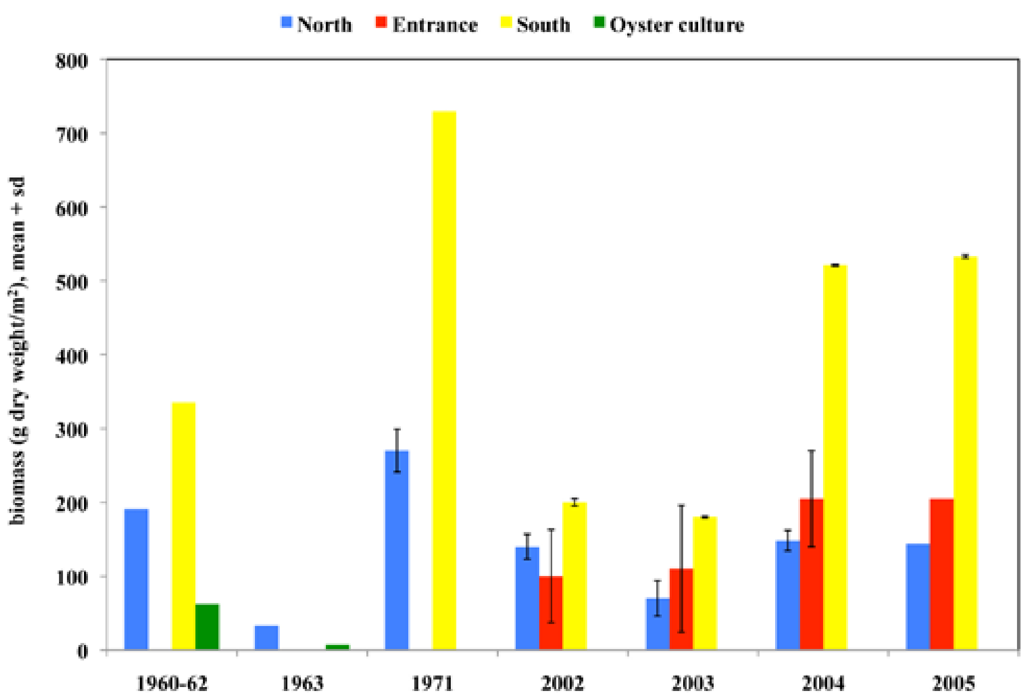


Figure 46. Eelgrass above-ground biomass in Humboldt Bay from undisturbed eelgrass and in oyster ground culture (dry weight kg/m²).
(Sources: Waddell 1964; Keller and Harris 1966; Harding and Butler 1979; Humboldt Bay Cooperative Eelgrass Project, unpublished data)

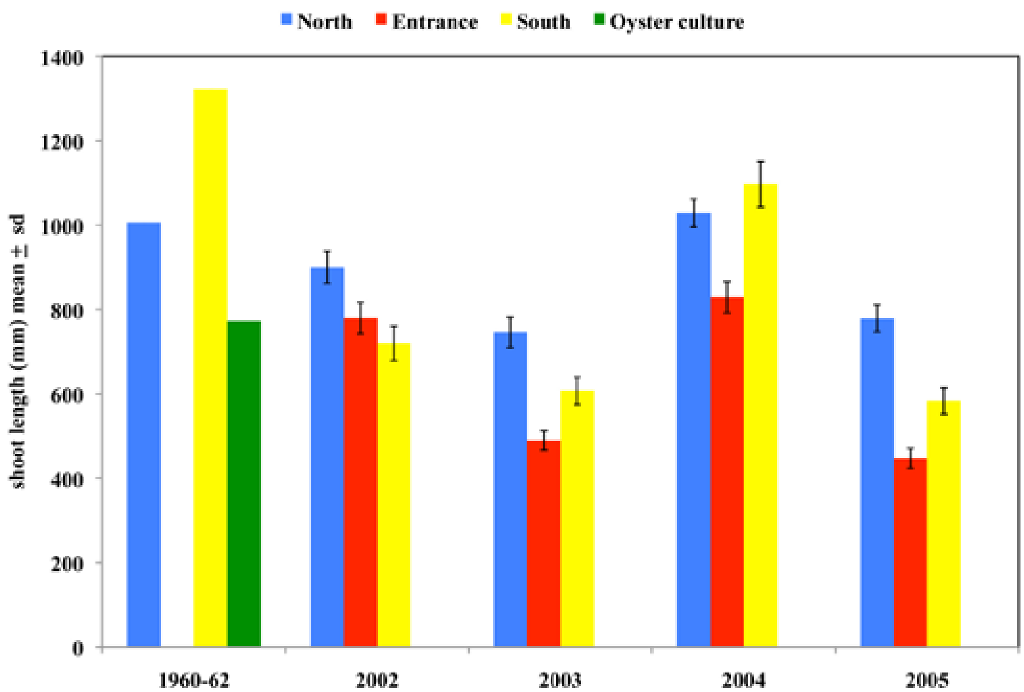


Figure 47. Eelgrass shoot length (mean length of the longest leaf per shoot), June–August . (Sources: Waddell 1964; Keller and Harris 1966; Humboldt Bay Cooperative Eelgrass Project 2001–2006, unpublished data).

Vegetative growth occurs mostly in the summer. In Entrance Bay permanent study plots that have been monitored regularly since 2001, shoot length increased from June through September in all years sampled, and continued to increase though December in some years (2003, 2005 and 2008). This is possibly attributable to the late onset of winter storms in those years (Figure 48).

Reproductive Shoots

Large differences were observed in the number of reproductive shoots between years and between regions of Humboldt Bay. South Bay had consistently lower reproductive shoot densities than North and Entrance bays, and was never greater than 10%, suggesting growth

Dense eelgrass vegetative shoots and light green/yellow stems indicating reproductive shoots

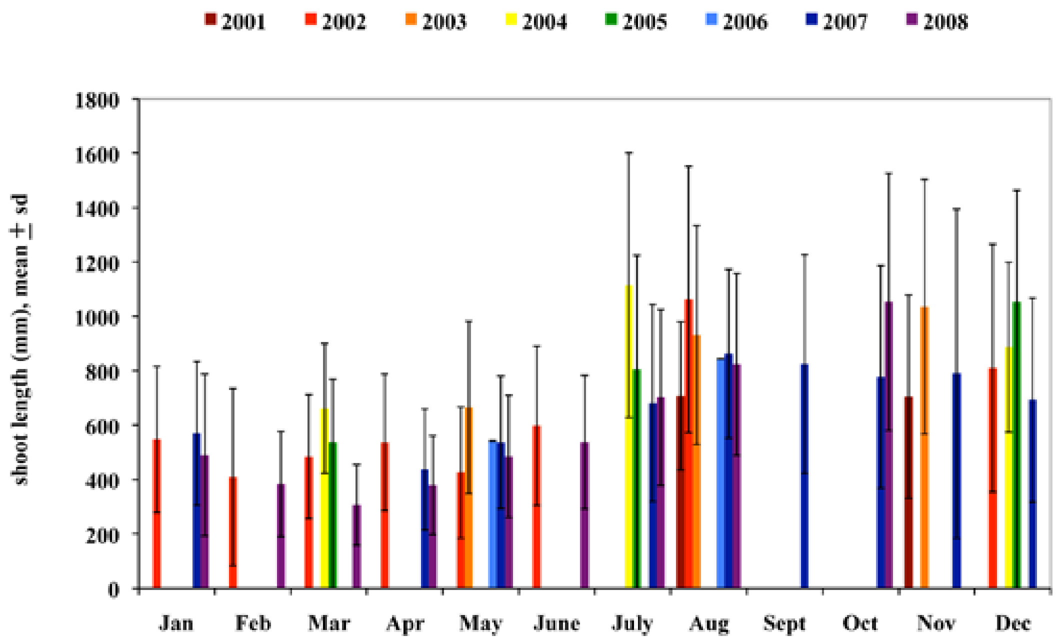


Figure 48. Eelgrass shoot length at a permanent study site in Humboldt Bay (n=8) (Source: Humboldt Bay Cooperative Eelgrass Project 2001–2008, unpublished data).

is primarily vegetative. Some years (2003 and 2005) had low reproductive shoot density throughout Humboldt Bay. Reproductive shoots are found year round in Humboldt Bay, with the highest densities occurring from spring to late summer (Figure 49).

Seedlings

At a permanent study plot in Entrance Bay monitored from 2001 to 2008, eelgrass seedlings were observed in late winter and early spring. Seedlings were defined as shoots

Extended anthers, male flower parts

Immature male and female flowers held in a protective sheath, the spadix

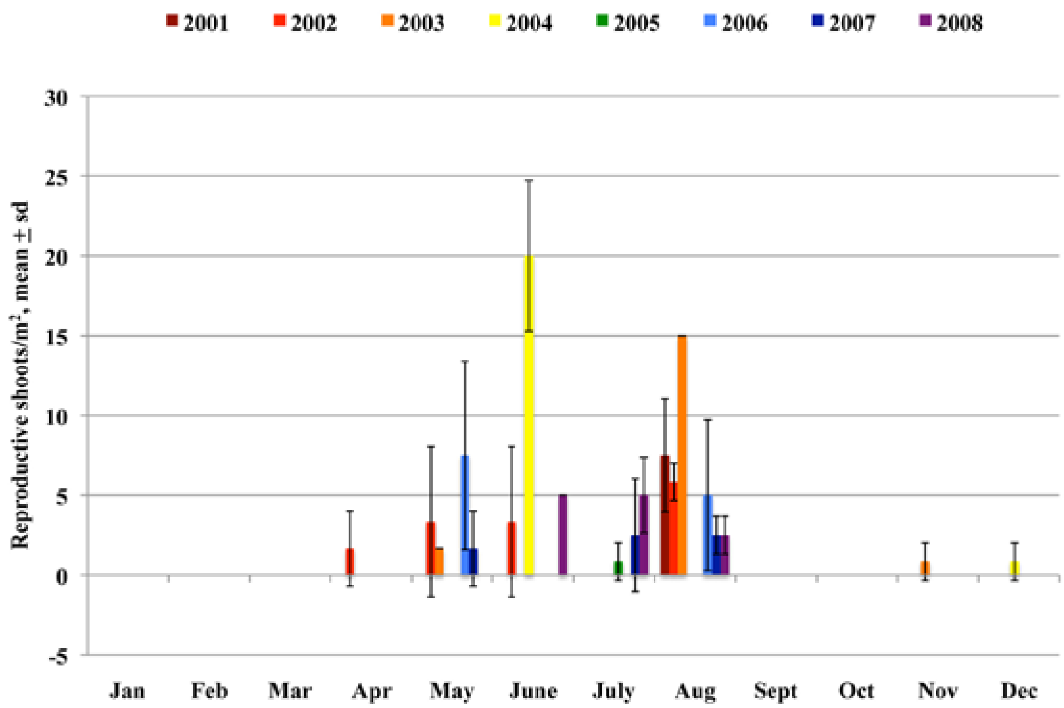


Figure 49. Density of eelgrass reproductive shoots from annual summer sampling in Humboldt Bay, 2001–2008. South Bay was not sampled in 2001. No sampling was conducted in summer 2006
(Source: Humboldt Bay Cooperative Eelgrass Project 2001–2008, unpublished data).

< 15 cm in length and with blades ≤ 2 mm, based on observations of the phenological development of plants in Humboldt Bay. In 2004 and 2006 there were no seedlings present in study plots, although low numbers were observed outside of study plots (Figure 50). No studies of eelgrass seedling survival have been conducted in the study area.

Eelgrass Wasting Disease

Eelgrass wasting disease is visible on Humboldt Bay eelgrass as brown or black spots and streaks on the leaves, which expand to form patches. The disease is caused by the marine slime mold-like protist, *Labyrinthula zosterae*. *Labyrinthula* invades healthy green plant tissue, penetrates cell walls, initiates enzymatic degradation, and destroys cells. Wasting disease spreads by leaf-to-leaf contact or by contact with infected drifting leaves. Overall, wasting disease impairs photosynthesis, results in the loss of leaves, and can cause eventual death of the plant (Short et al. 1987; Muehlstein 1992). Wasting disease is capable of killing vast expanses of eelgrass, as it did in the North Atlantic during the 1930s (Rasmussen 1977). No studies of *Labyrinthula* on Humboldt Bay eelgrass have been conducted.

Animal Communities

Biotic assemblages associated with eelgrass are diverse. Plants that attach to eelgrass leaves are called epiphytes and attached animals are epizoites. Some of these organisms graze on the eelgrass leaves and some feed on each other. Epibenthic (epifloral or epifaunal) organisms live on top of the sediment surface associated with eelgrass beds, and infauna live within the sediments. Some animals, such as fish and invertebrates, live in the water column among eelgrass shoots. Other animals, such as birds, forage in eelgrass beds at low- or mid-tide.

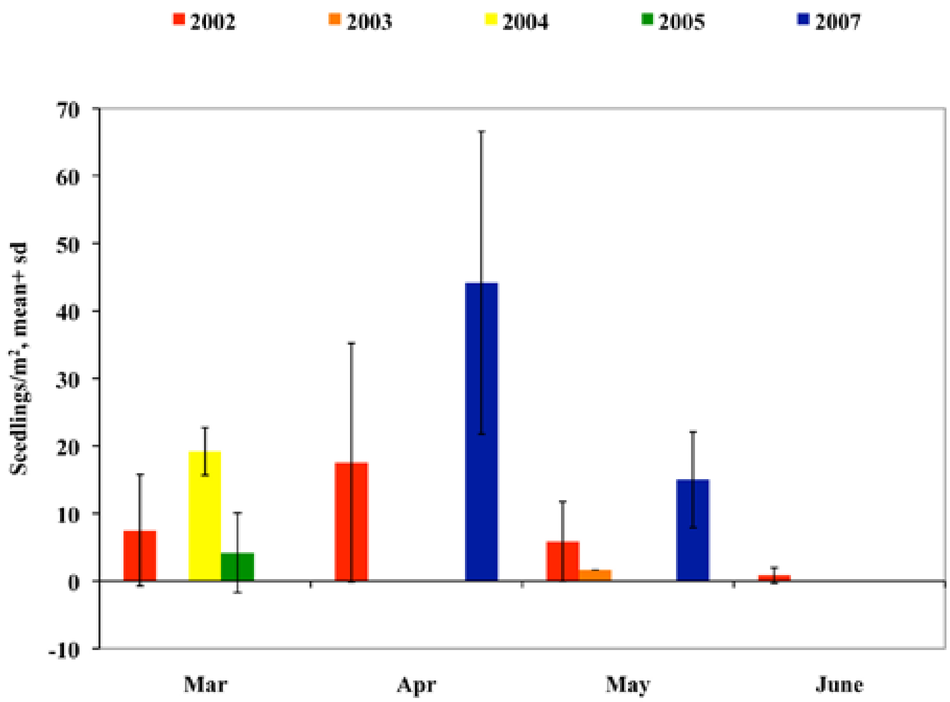


Figure 50. Eelgrass seedling density (#/m^2) at a permanent study site in Humboldt Bay (n=8). (Source: Schlosser, unpublished data).

Epiphytes and Epizoites

Diatoms, epiphytic algae, and bacteria grow on eelgrass blades, forming a brownish layer resembling felt. A red algae, *Smithora naiadum*, also grows as an epiphye on eelgrass leaves. These epiphytes provide a food source for a range of grazers and their predators. Normally, epiphytes do not have a detrimental effect on eelgrass; however, under certain conditions they may become overabundant and lead to eelgrass decline. In Humboldt Bay, Tennant (2006) found that eelgrass in North Bay had significantly higher epiphyte biomass than in South Bay.

Epizoites are abundant on Humboldt Bay eelgrass. Some of the more common sessile (attached) invertebrates include bryozoans (e.g., *Hippothoa hyalina*), ascidians (e.g.,

An eelgrass leaf with wasting disease in situ and compared to an uninfested leaf.

Epizooites of Humboldt Bay eelgrass beds.

Idothea, a common isopod in eelgrass

Colonial tunicates, *Aplidium californicum*

Eelgrass, oyster shell, boring sponge, *Clionia celata* (yellow), colonial tunicate, *Aplidium californicum* (orange) and red alga, *Chondrancanthus tepidus*

Eelgrass leaves with dense epiphytes including red algae, *Smithora naiadum*.

Botrylloides spp, and *Diplosoma macdonaldi*), and hydroids (e.g., *Obelia longissima* and *Tubularia marina*). Colonies typically develop on new growth of eelgrass blades in spring and summer, and gradually decrease through fall and winter, although many of the same species can be found on docks and pilings during winter months (Dykhouse 1976).

Motile epizoites crawl on eelgrass blades, grazing on the blades or epiphytes or preying on other epizoites. Frimodig (2007) found an abundance of caprillid and gammarid amphipods, heptacarpid shrimp, and the isopod *Idotea resecata.* The isopods *Synidotea* spp. are periodically found in high numbers in Humboldt Bay (Schlosser, unpublished data). The diminutive nudibranch *Hermaeina smithi* can also be found on eelgrass blades in Humboldt Bay (Carrin 1973).

Taylor's sea hare (*Phyllaplysia taylori*) is a sea slug that lives exclusively on eelgrass blades, grazing both on the blades themselves and on epiphytes. It is present year round in Humboldt Bay, with maximum abundance in spring and summer, especially in dense eelgrass beds with long blades (Keiser 2004; Frimodig 2007). Tennant (2006) found Taylor's sea hare to be more abundant in South Bay than North Bay.

Epibenthos

Once eelgrass leaves are shed from the plant, they decompose. This detritus provides abundant organic matter that serves as the foundation for detrital food chains and nutrient cycling. Many epibenthic fauna feed on fine detrital particles.

The Dungeness crab uses eelgrass beds as nursery grounds (Eggleston and Armstrong 1995). In one Humboldt Bay study, young Dungeness crabs (0.5 in to 2.0 in [12.7 mm to 50.8 mm] wide) were found to be significantly more abundant in dense eelgrass beds (1016 shoots/m^2); however, the abundance of larger Dungeness crab was not correlated with eelgrass density (Williamson 2006).

Lewis' moon snail is a conspicuous epibenthic predator in Humboldt Bay eelgrass beds, especially abundant in Entrance Bay and South Bay. These snails feed mostly on clams. Other

Drift eelgrass in the South Bay intertidal

Drift eelgrass and green algae alongside a North Bay dock.

Fauna of Humboldt Bay eelgrass beds.

Dungeness crab juveniles about 1 inch in carapace width

Coonstripe shrimp juvenile

Moonsnail

Invasive invertebrates and algae found in Humboldt Bay eelgrass beds

Washington clam, *Saxidomus giganteus*

Green heptacarpid shrimp and bay shrimp

Yellow crab, *Cancer anthoni*

Epifaunal colonial turnicate

Brown algae, *Sargarum muticum,* and eelgrass

Sargasum close-up

Red bryzoan, *Watersipora subtorquata*, first found in Southern California in the 1960's, its native range is unknown.

epibenthic animals found in association with Humboldt Bay eelgrass beds include filter-feeding molluscs, polychaetes, rock crabs, mussels, starfish, nudibranchs, carid and hippolytid shrimp, brittle stars, amphipods and cnidarians. Williamson (2006) found the common bay shrimp (*Crangon* spp.) in moderately dense eelgrass beds (154 to 160 shoots/ m^2) near channels where staghorn sculpins were not present.

Infauna

Many invertebrates that inhabit the surrounding intertidal flats also live in the soft muds underlying eelgrass beds. Williamson (2006) found the bent-nosed clam to be present in 95% of sites sampled in South Humboldt Bay, with densities significantly higher in dense eelgrass beds than sparse beds. Carrin (1973) found the bent-nosed clam, and other clams (*Transennella tantilla*; *Mya arenaria*) in an eelgrass bed on the east shore of Mad River Slough, along with a cheliferan, a polychaete (*Notomastus tenius*), shrimp (*Spirontocaris paludicola*; *S. picta*; *Crago nigromaculata*; and *Hippolyte* spp.); caprellid amphipods (*Caprella californica);* and a fish species, the threespine stickleback.

Infauna of Humboldt Bay eelgrass beds

Polychaete, *Spiochaettopterus costarum*, a cosmopolitan species

Tube dwelling Bristle Worm, *Pista pacifica*

Fish

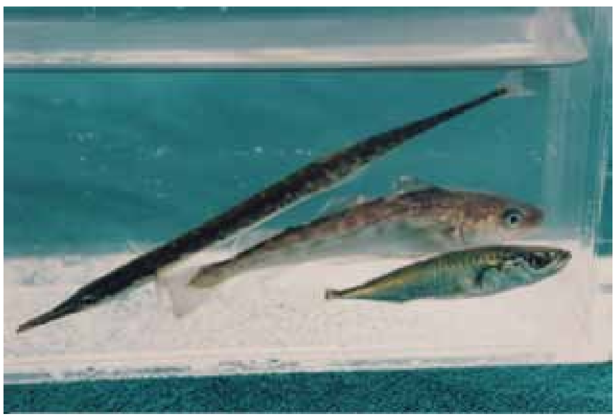
A high diversity and abundance of fish use eelgrass beds for refuge and for foraging. These include threespine sticklebacks, smelts, Pacific herring, sole, flounder, saddleback gunnels, shiners and other surf perches, surf smelts, tubesnouts (*Aulorhynchus flavidus*), bay pipefish, about 10 species of sculpins, and early life history stages of rockfish, cabezon (*Scorpaenichthys marmoratus*), greenlings, lingcod, gunnels and other species (Gleason et al. 2007).

Young-of-the-year (YOY) rockfish use Humboldt Bay eelgrass beds during their early benthic settlement. Between April and October, YOY black, brown, grass, and copper rockfish (*Sebastes melanops; auriculatus*; *rastrelliger*; *caurinus,* respectively) grow from approximately 2 in to 6 in (50.8 mm to 152.4 mm) in length. The young rockfish then move to other habitats, either deeper in the bay or offshore (Schlosser, unpublished data).

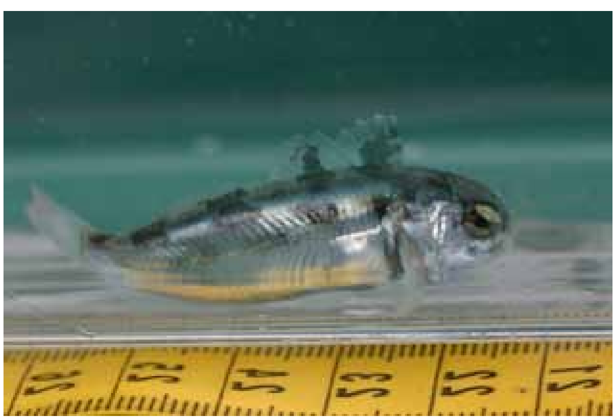
Pacific herring are unique in their dependence on eelgrass for spawning. Females deposit up to 20,000 adhesive eggs onto eelgrass blades or associated benthic algae. The density of eggs ranges from 6,796 to 7,512 eggs/m^2 of leaf surface area (Rabin 1976; Rabin and Barnhart 1977). Two- and three-year-old herring account for more than 50% of the spawning herring. Gulls and Surf Scoters prey on herring eggs

A few species of Humboldt Bay eelgrass beds

Copper and black rockfish



Tubesnout (left), tomcod, and stickleback (right)



Youg-of-the-year cabezon

Bay goby

Surf perch

Sanddab

Octopus refescens

deposited on eelgrass. In Humboldt Bay, between 1974 and 2005, an average of 34 tons of herring were harvested each year, while the annual catch varied widely: from 0.1 tons to 60 tons (Mello 2007). This extreme inter-annual variability in herring numbers in Humboldt Bay, and elsewhere, is not well understood. There has been no fishing effort for herring in Humboldt Bay since 2006 (J. Mello, personal communication 2008).

Birds

Brant Geese

Small black geese called Brant feed heavily on eelgrass blades. Brant are one of the few birds that can digest eelgrass, which has a high carbon-to- nitrogen ratio and contains sulfated phenolic compounds (McMillan et al. 1980). Some other birds, including Canada Geese (*Branta canadensis*), Widgeon (*Anas americana*), and Gadwall (*A. strepera*) eat eelgrass, but only as a minor portion of their diet.

Brant Geese are found in Humboldt Bay between October and April with the largest number of birds occurring in March. The geese stop to feed during both their southerly and northerly migrations. Humboldt Bay is believed to be the most important spring staging area for Brant in California, and one of the most important in the entire Pacific Flyway. An estimated 80,000 birds use the bay each year, representing more than 60% of the total Brant population (Lee et al. 2007; USFWS 2009). Historically, the geese were found year round in Humboldt Bay (Moore and Black 2006a).

Humboldt Bay's eelgrass beds provide over-wintering Brant with the bulk of their diet. Both the quantity and quality of Humboldt Bay's eelgrass are important for Brant breeding success; the geese forage 8 to 12 hours per day while floating, with each bird consuming approximately 300 g dry weight of eelgrass leaves per day. Brant prefer young eelgrass leaves, which contain relatively more nitrogen (Moore 2002; Moore and Black 2006b).

In addition to feeding on eelgrass, Brant ingest grit, which is utilized in the birds' gizzards to aid in grinding food, and is also thought to be an important source of calcium for eggshell formation (Lee et al 2007). Large numbers of Brant Geese congregate at grit sites at their earliest opportunity, and then depart to feed on eelgrass beds. Sandy grit sites, submerged most of the day in the interidal zone, are the first resources to become available as tides retreat (Lee et al. 2007).

Brant Geese densities have been positively correlated with eelgrass protein, calcium and biomass. Brant usually feed in the deepest possible areas permitted by tides, and closest to tidal channels, where biomass and nutrient content of eelgrass are greater. Tide cycles change over the course of the Brant's staging period on the bay, enabling longer and more frequent access to deeper eelgrass meadows as spring progresses. These seasonal changes in tidal pattern coincide with seasonal changes in Brant's foraging activities (Moore and Black 2006a). Brant induce changes to eelgrass structure and

Brant Geese

affect animal species abundance and size. In a manipulative field experiment, Brant grazing was simulated by clipping eelgrass leaves and fertilizing the leaves with geese feces. Taller leaf growth and shoot densities were found in the moderately clipped eelgrass treatment (Ferson 2007).

Other Bird Species

Many bird species prey on fauna associated with eelgrass beds. Shorebirds snatch epifauna on the mud surface, or use their bills to probe into the mud and extract infauna. Shorebird species that forage in Humboldt Bay eelgrass beds include Black-bellied Plovers; Great Blue Herons (*Ardea herodius*); Marbled Godwits; Black Turnstones (*Arenaria melanocephala*); Long-billed Curlews; Dunlins; Whimbrels; Willets; Dowitchers, Great Egrets (*Ardea alba*); Black-crowned Night Herons (*Nycticorax nyticoras*); Semipalmated

Shorebirds foraging in eelgrass.

Marbled Godwit

Marbled godwits and sea gulls foraging on an Entrance Bay eelgrass bed.

Great Blue Heron

Great Egret

Mallards

Plovers (*Charadrius semipalmatus*); Snowy Egrets (*Egretta thula*); Sanderlings, and Lesser and Greater Yellowlegs. Waterfowl, including Pintails (*Anas acuta*); Mallards (*A. platyrhynchos*); and teals feed on eelgrass seeds and infaunal bivalves (Yocum and Keller 1961; Holmberg 1975).

Invasive Species

Dwarf Eelgrass

Dwarf eelgrass, *Z. japonica*, is a non-native seagrass that invades intertidal mudflats, threatening vital feeding grounds for migratory shorebirds using the Pacific Flyway. Native to Asia, this eelgrass variety has become established from British Columbia to Oregon. The only known incidences of the species in California are in Humboldt Bay (first detected in 2002) and the Eel River Estuary (2008). Both estuaries are part of the Pacific Flyway and are major foraging and resting grounds for migratory shorebirds. Dwarf eelgrass was included in a list of non-native species that have invaded California, where it was characterized as a species with high potential for being an invasive pest (Dean et al. 2008).

Dwarf eelgrass is capable of rapid expansion over nonvegetated mudflats (Baldwin and Lovvorn 1994; Dudoit 2006). It invades the high intertidal zone (above 2 ft [0.6 m] MLLW), is generally smaller than the native eelgrass. There is overlap in ranges of the two species, which can be found growing together in some locations. This is true of the Humboldt Bay and Eel River Estuary populations, as well as the infestations further north (Harrison and Bigley 1982; Posey 1988; Thom 1990a and b; Baldwin and Lovvorn 1994; Bulthuis 1995; Larned 2003; Schlosser and Eicher 2007). Bando (2006) reported that in Washington, dwarf eelgrass is also invading flats historically dominated by the native eelgrass. This invasive eelgrass forms a dense, sod-like root matrix that may completely cover the substrate surface, altering the physical structure of the sediments (Posey 1988). Alterations to intertidal substrates, including small-scale heterogeneity such as changes in particle size, affects which invertebrates inhabit the sediment, and this change in invertebrate community structure can impact shorebird populations that feed on invertebrates (Baldwin and Lovvorn 1994; Danufsky and Colwell 2003). Most notable is a decline in the burrowing ghost shrimp and other large epifauna (Posey 1988; Harrison 1987). Burrowing ghost shrimp are a favored prey for Long-billed Curlews and are found in the diets of the Marbled Godwits and Willets

Zostera japonica

Eel River Estuary

Zostera japonica and *Zostera marina*, size comparison

(Dr. Nils Wornock, PRBO Conservation Science, personal communication).

In Yaquina Bay, Oregon, Larned (2003) demonstrated that dwarf eelgrass altered the balance of nutrient flux between the sediment and the water column, and suggested that this could negatively impact pelagic productivity. Dwarf eelgrass is a net sink for NH_4^+ and PO_4^- during the summer and for NO_3^- during the spring, while nearby unvegetated mudflat act as an NH_4^+ source in both seasons. By removing nutrients from the system, dwarf eelgrass may be reducing the abundance of phytoplankton that in turn reduces the productivity of the estuary. Dwarf eelgrass also decomposes faster than the native eelgrass, thereby changing the microbial community and further altering the sediment chemistry (Hahn 2003).

Since its initial discovery in 2002, monitoring and eradication efforts have been underway in Humboldt Bay, using an adaptive management approach. The work represents collaboration between California Sea Grant Extension and the California Department of Fish and Game, with support from the Wiyot Tribe, the Humboldt Bay Harbor District and other local agencies, and community members. On-the-ground eradication measures included a combination of excavation, thermal treatments, and experimental methods. Manual excavation using hand shovels has been effective for relatively small infestations that have good access, either from the shore or by boat. At the initial detection site, on the shoreline of Indian Island in Humboldt Bay, dwarf eelgrass was successfully reduced from 188 m^2 of plant cover in 2004, less than 2 m^2 in 2008, to zero plant cover in 2010 and 2011. For larger infestations and those sites with restricted access, researchers are working to develop alternative treatments. It is imperative to control the species at these locations, and to prevent potential dispersal further south to other bays and estuaries on the Northern and Central California coast.

Ecosystem Services

Eelgrass provides three-dimensional structure important to biodiversity and productivity. Eelgrass creates habitat that is used preferentially by other species.

It provides multiple ecosystem services, including:

- Food for waterfowl
- A substrate for epiphytes and grazers
- Cover from predators for fish and invertebrates
- Rearing habitat for juvenile fish and invertebrates
- Reduction of local current turbidity
- Stabilization of bottom sediments with a matrix of roots and rhizomes
- Decrease in anoxia by contributing oxygen to the sediment from roots and rhizomes
- Linkage between nutrients in the water column and sediment
- Sediment filtration/water clarity — diminishes wave action so sediments settle, which increases water clarity
- Adding to local habitat complexity and surface area by increasing secondary productivity
    - Physically supports other biota
    - Provides either settlement substrate or protection for the associated community

Management Considerations

Many activities and environmental conditions can threaten or stress the health and extent of native eelgrass beds. Critical threats to eelgrass identified by the Advisory Committee include:

- Anthropogenic greenhouse gas (GHG)
- Urban runoff
- Dredging
- Artificial structures
- Shoreline development
- Invasive species

Management recommendation include:

- Protect current and future eelgrass populations
- Prevent current and future loss or degradation of eelgrass to the maximum extent practical
- Ensure existence of suitable habitat conditions for future natural eelgrass re-establishment and future restoration and enhancement initiatives
- Advance understanding of eelgrass dynamics
- Build an established, consistent and comprehensive eelgrass inventory program and sentinel monitoring program (e.g., SeagrassNet http://www.seagrassnet.org/, accessed June 7, 2012.

Higher seawater temperatures are expected to lead to changes in eelgrass distribution and possibly extensive, slow die-off events. Sea level rise will likely require eelgrass to retreat landward toward shallower waters, but where shoreline structures exist, they may prevent and restrict eelgrass retreat and migration.

Understanding and reducing impacts on eelgrass habitat is essential; e.g., managers need to ensure that light requirements for eelgrass are met. Activities that increase turbidity and reduce light penetration in the water column may be detrimental on existing eelgrass populations and associated food webs.

Dredging may be detrimental to water quality and result in reduced distribution and connectivity of eelgrass beds in Humboldt Bay. Changes in flow dynamics in and out of the Entrance Channel may affect the flow dynamics inside the Bay. For example, normal wind and wave conditions in South Bay may be altered by continued dredging in the Entrance Channel as erosion of eelgrass beds in South Bay has been observed in the area between the Fields Landing Boat Ramp and the Southport Channel (F. Shaughnessey pers. comm.). Dredged channels can result in fragmented eelgrass beds and become a barrier for growth and migration. The sides or edges of dredged channels may also subside back into the excavated areas, and slowly cause disruptions in suitable habitable areas for eelgrass and sediment processes. Releasing or disposing of dredged materials may increase the amount of total suspended solids in the water column, hampering light penetration. However, while uninformed and misguided dredging can be particularly harmful to eelgrass, not all dredging is bad. Some eelgrass beds can benefit from channel maintenance dredging and projects that increase tidal flushing. Such dredging projects can improve water quality parameters necessary to support eelgrass.

An eelgrass management plan could identify areas where maintenance dredging for navigation purposes or excavation activities are needed, and implement a dredging strategy that maximizes eelgrass protection.

Shoreline stabilization structures (SSS), including docks, piers, bulkheads, seawalls, groins, jetties, etc. may directly and indirectly impact eelgrass beds. During construction and placement of SSS, eelgrass beds may be removed or damaged by altering sediment characteristics. Construction activity within the water column suspends bottom sediments, increasing turbidity and decreasing light penetration (this shading effect is most pronounced with east/west-oriented structures), and also has the ability to change current and wave energy patterns. In addition, materials used to construct SSS—sometimes wood treated with toxic chemicals—can leach into the water surrounding eelgrass beds.

A long-term eelgrass bed monitoring program that includes an established, consistent and comprehensive inventory and sentinel monitoring program would also be useful to protect and understand the species. A monitoring partnership between Humboldt State University, California Department of Fish and Game, the US Army Corps of Engineers and other interested parties could be established and include a research program to formulate and test hypotheses by identifying threats and factors affecting eelgrass existence and health.

The Humboldt Bay Cooperative Eelgrass Project (Eelgrass Project) began in 2001 to meet information and data needs identified during the Humboldt Bay Management Plan process (HBHRCD 2007). This collaborative project included participants from the California Department of Fish and Game, Humboldt State University, the Humboldt Bay Harbor, Recreation and Conservation District (Harbor District) and California Sea Grant Extension Program. Over the seven years of sampling (2001–2008), many volunteers assisted with field and laboratory work. Data entry and proofing, and preparation of graphs was completed by California Sea Grant staff and reviewed by project collaborators before presentations were made to various local committees and interested groups. Humboldt Bay eelgrass monitoring ended when the Harbor District began a SeaGrassNet (http://www.seagrassnet.org/, accessed June 7, 2012)) program in the bay. Currently the Harbor District maintains two SeaGrassNet sites in Humboldt Bay that are sampled quarterly or biannually, depending on available staff and volunteers.

Humboldt Bay Cooperative Eelgrass Project collaborators

Laboratory work

Ready to go!

The key ecological indicators and habitat criteria for eelgrass are:

- Presence of sunlight
    - Light extinction <0.46 Kd or = 0.46 Kd
- Saline waters
    - Water temperature < 28° C
- Balanced nutrient regime
- Sediment size and characteristics

- Inorganic-to-organic ratio
- Presence of macroalgae

- Adequate size, acreage and density of eelgrass beds

Eelgrass Habitat Status: Selective Monitoring Program

- Measure every 2-5 years:
  - Eelgrass light availability
  - Plant size, density and biomass
  - Algal species cover in eelgrass beds
- Assess effects of land use and human activities every five years
- Coordinate monitoring, inventory and mapping efforts biennially.
  - Ensure results are reported and easily accessible to local governments and the community

An educational outreach program to increase stakeholder, user group and public awareness of eelgrass, and its importance would be valuable. Such an educational program should emphasize:

- Value of eelgrass as fish, bird and invertebrate habitat
- Threats from human activities
- Creating a sense of stewardship
- Fostering responsible resource enjoyment.
- Establishing a website and annual eelgrass newsletter

The negative effects of invasive species can be severe and irreversible, and are only now beginning to receive attention in Humboldt Bay and the Eel River Estuary. Continued monitoring and eradication of the invasive dwarf eelgrass is necessary for preserving native eelgrass.

Many eelgrass beds along deep channels in Humboldt Bay have derelict pilings treated by creosote

***Ulva* spp.on oyster mariculture long line culture systems on an eelgrass bed**

Chapter 8. Habitat: Intertidal Coastal Marsh

CMECS
Mapping Unit:
Coastal Salt Marsh
System
Biotic Cover Component
Subsystem
Intertidal
Class
Emergent Wetland
Subclass
Coastal Salt Marsh

Aerial image (above) of high salt marsh in North Bay.
Same area from the ground (below)

General Description

Intertidal coastal marshes are dynamic habitats that occupy a relatively narrow band of elevation in the upper intertidal zone of sheltered bays and estuaries within temperate latitudes worldwide. Other coastal marshes that occur within the coastal zone but do not receive tidal inundation are primarily freshwater or brackish, but also include saline marshes that are naturally cut off from the tide (e.g., due to barrier bars) or that have been diked to prevent tidal immersion. In intertidal coastal marshes, the tidal marsh plain is periodically inundated at high tide and drained at low tide by a system of meandering slough channels. Tidal influence may extend further inland than saltwater intrusion. As a result, while intertidal coastal marshes are typically saline to brackish, they may also support freshwater species. Patterns of plant distribution within intertidal coastal marshes vary in response to the frequency and duration of tidal inundation and biological interactions.

The type of plant species found in a marsh provides a good indicator of marsh salinity. Intertidal coastal marshes dominated by halophytic (salt-loving) plant species are called salt marshes, and they occur in areas with a strong marine influence such as Humboldt Bay. Brackish marshes occur near river mouths or seeps where seawater is diluted by freshwater. Intertidal coastal freshwater marshes occur at the head, or furthest reaches, of the tide, and they are more common in estuaries with a strong freshwater influence, such as the Eel River Estuary. Ecosystems with a complex of salt, brackish, and freshwater marshes have high biodiversity, which means that they support an abundance and variety of plant and animal species.

In this chapter, we focus on intertidal coastal marshes dominated by herbaceous vegetation, which in CMECS are within the emergent wetland class. Emergent wetland is defined as being "characterized by erect, rooted, herbaceous hydrophytes. The vegetation is present for most of the growing season in most years, and is typically dominated by perennial plant species" (Madden et al. 2009).

Distribution

Humboldt Bay and the Eel River Estuary together contain the largest area of intertidal coastal marsh between San Francisco, California and Coos Bay, Oregon. There are currently about 905 ac (366 ha) of intertidal coastal marsh in Humboldt Bay and 639 ac (259 ha) in the Eel River estuary, less than 10% of the estimated historic extent (10,250 ac [4,148 ha]) in Humboldt Bay and 9,665 ac (3,911 ha) in the Eel River Estuary (Figures 51-56). The current acreages reported here are from this study and the historical acreages are from maps presented in "An Historical Atlas of Humboldt Bay and the Eel River Delta" (Laird et al. 2007). Other investigators have reported similar acreages for Humboldt Bay (Shapiro and Associates 1980, Pickart 2005c), and the Eel River Estuary (Roberts 1992, CDFG 2010).

Green-winged teal in a coastal marsh channel on a frosty winter morning

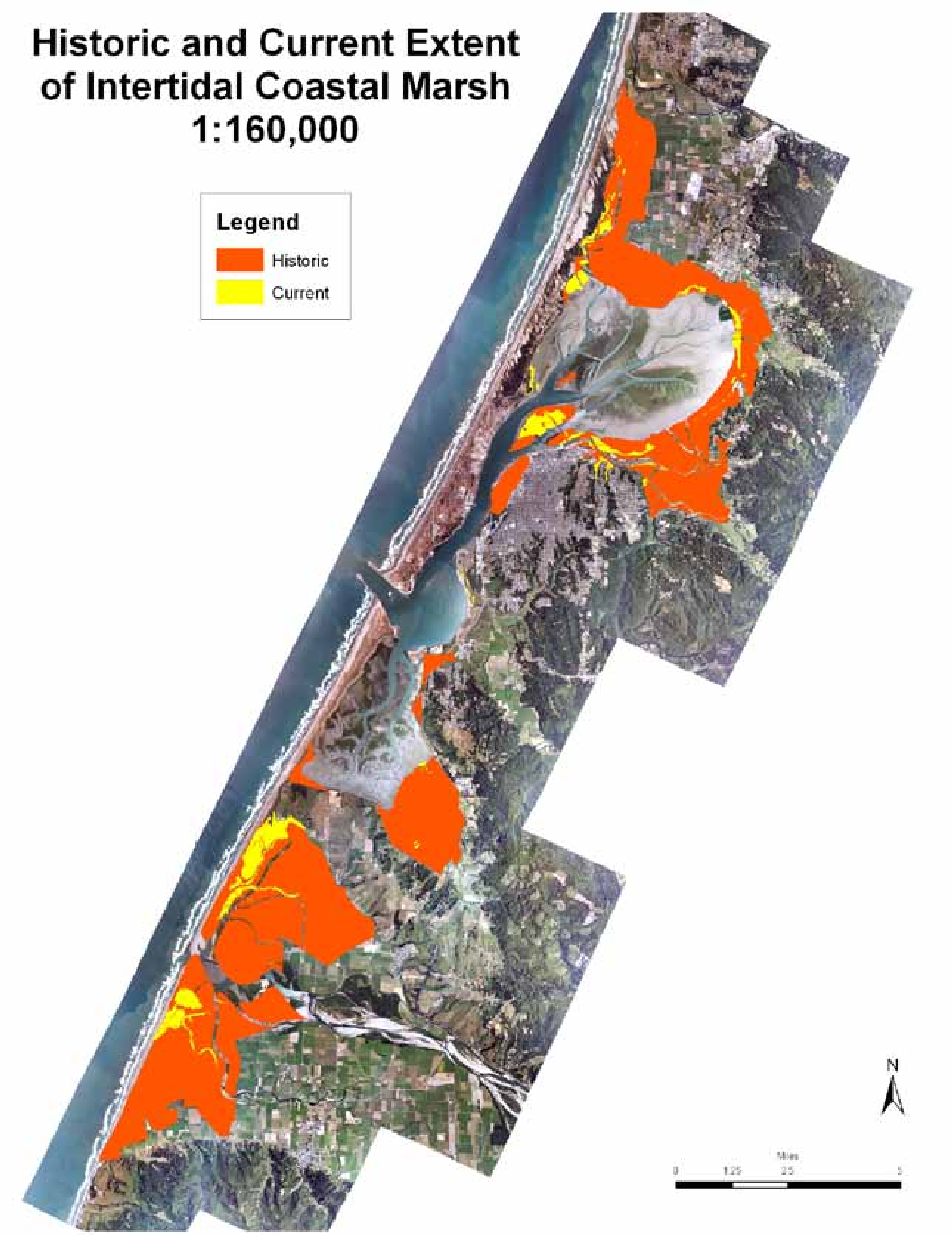


Figure 51. Map showing the historic and current extent of intertidal coastal marsh.
(Source: adapted from Laird et al. 2007).

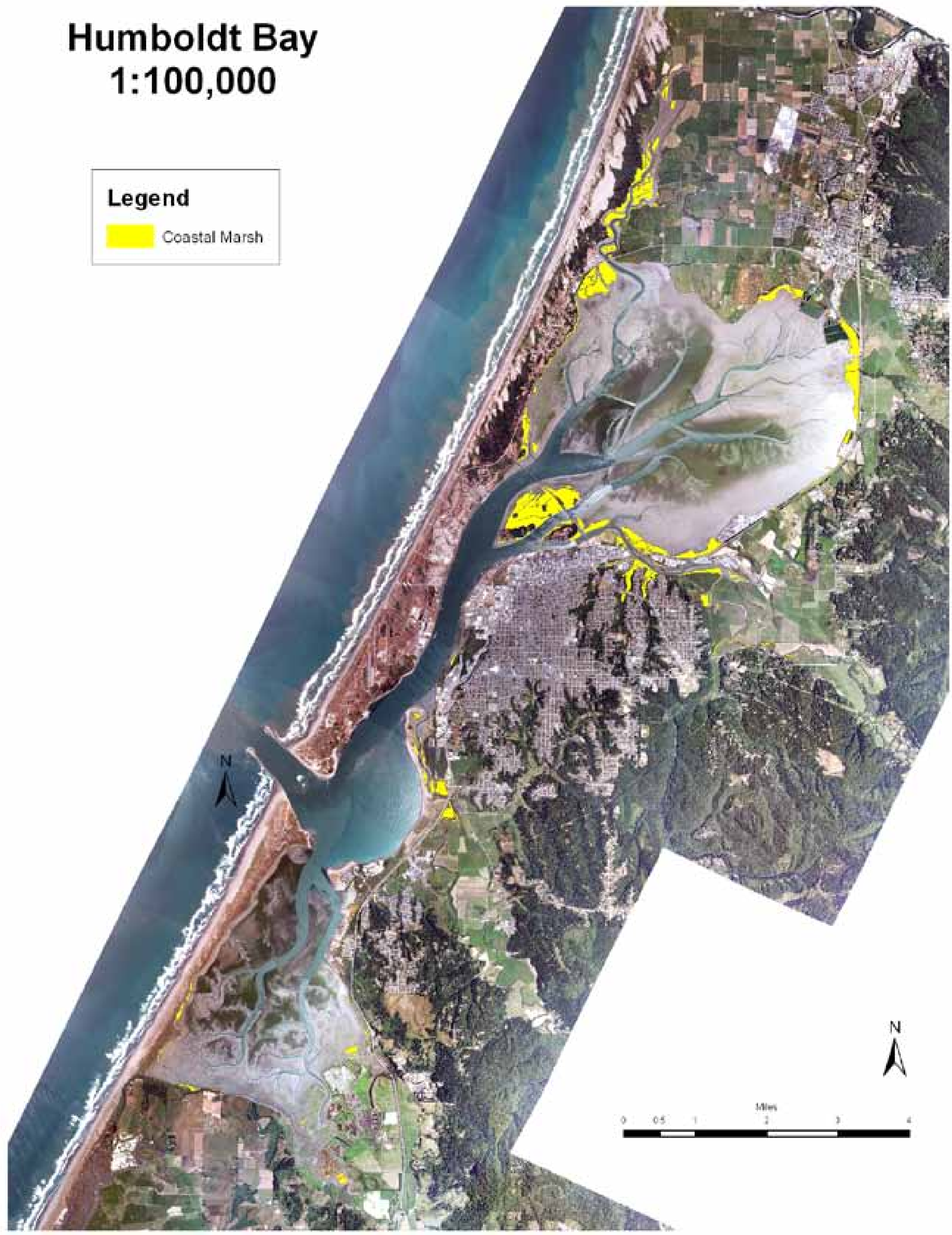


Figure 52. Intertidal coastal marsh in Humboldt Bay.

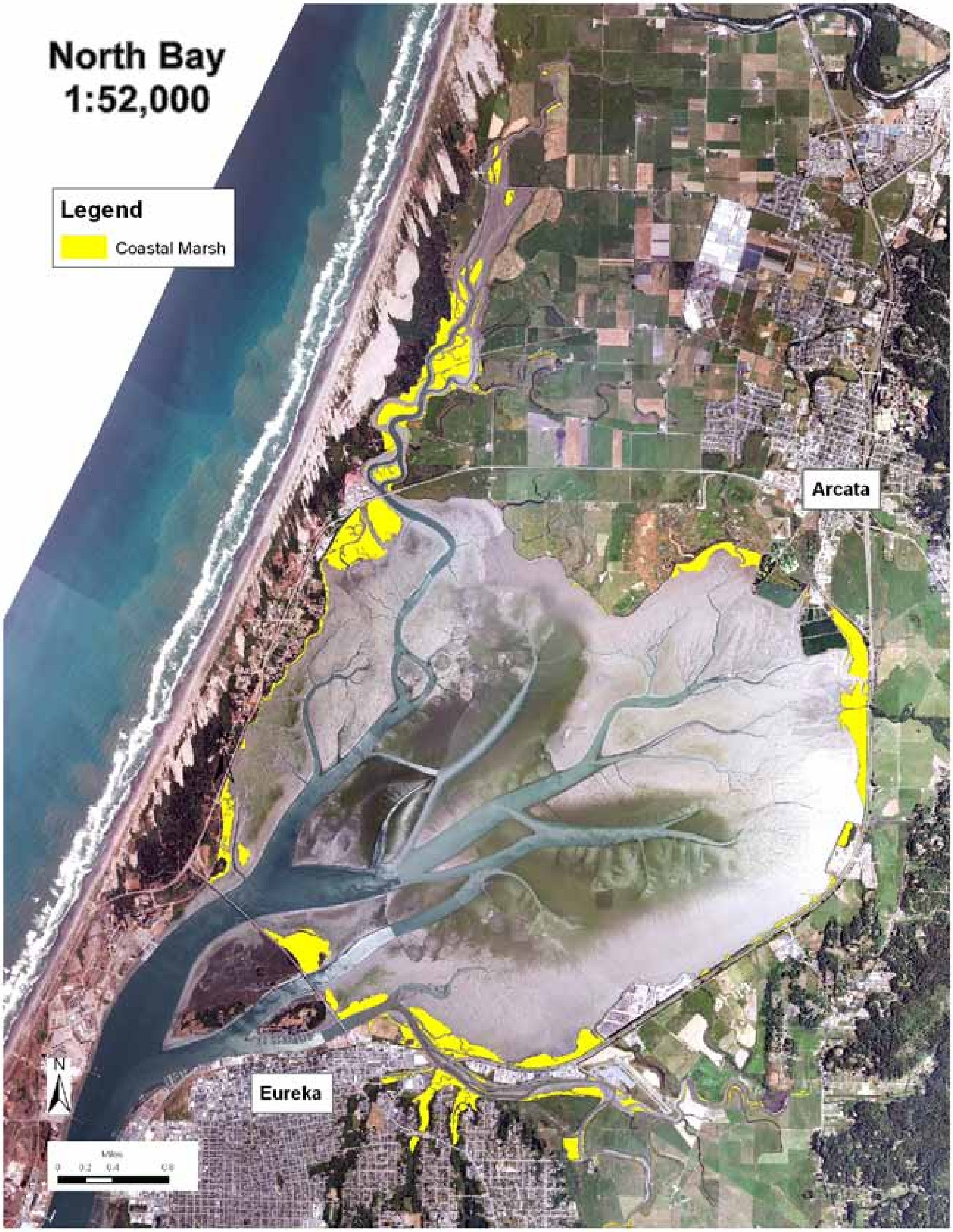


Figure 53. Intertidal coastal marsh in North Bay.

Figure 54. Intertidal coastal marsh in Entrance Bay.

Figure 55. Intertidal coastal march in South Bay.

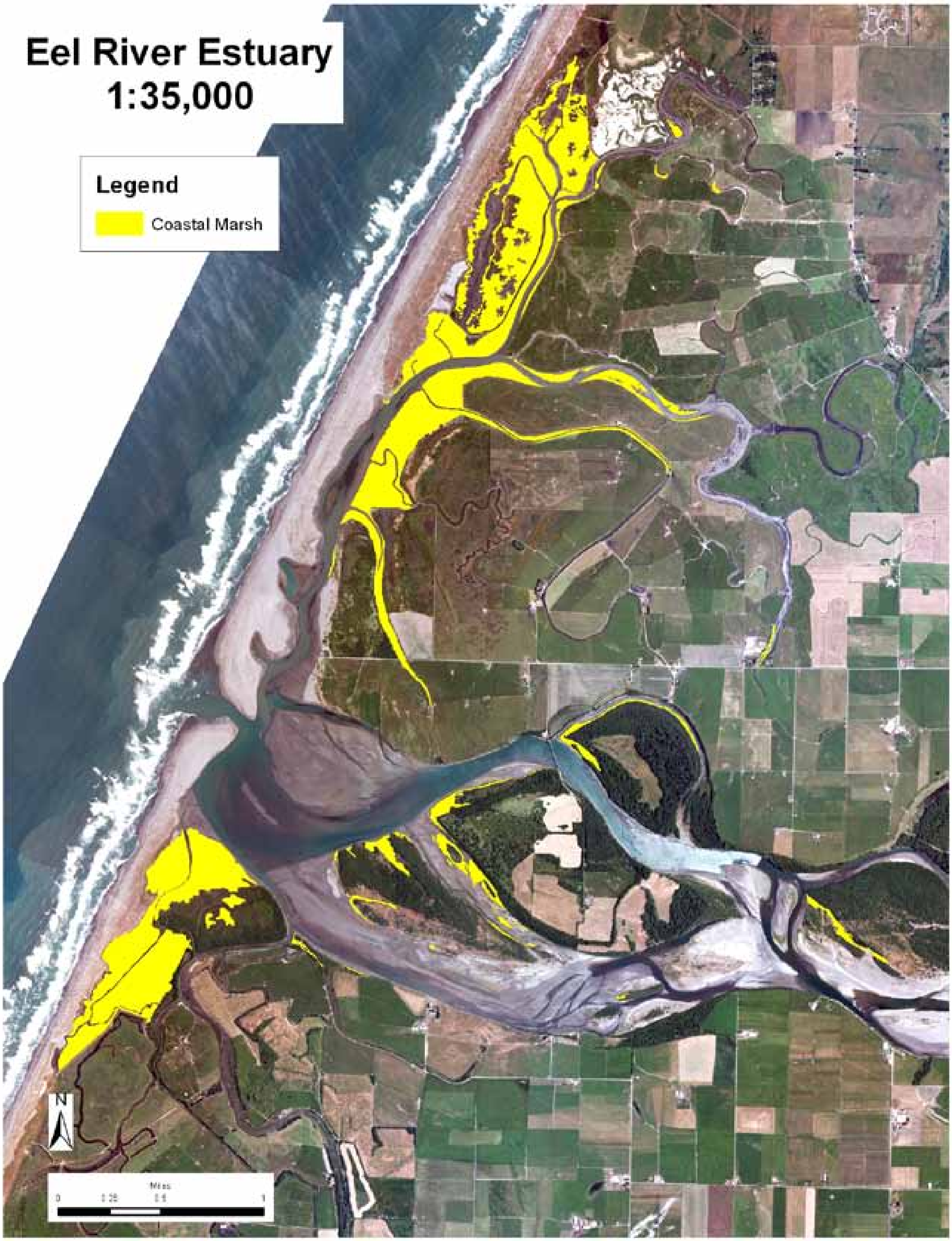


Figure 56. Intertidal coastal marsh in the Eel River Estuary.

Humboldt Bay

In North Humboldt Bay, intertidal coastal marsh occurs on interior islands; on the islands and banks of Mad River Slough; bordering the channels of McDaniel, Butcher, Gannon, Eureka, Freshwater and Fay sloughs as well as smaller secondary sloughs; near the mouth of Jacoby Creek and Rocky Gulch; and as an interrupted fringe around the basin perimeter.

Salt marsh in Entrance Bay adjacent to upland riparian habitat

The shoreline of Entrance Bay has extensive urban development and only a narrow and intermittent remnant fringe of intertidal coastal marsh. Additionally, some areas of restored tidal marsh occur near the mouth of Elk River.

In South Humboldt Bay, small amounts of intertidal coastal marsh occur in association with White and Hookton sloughs and the South Spit. Tidal connectivity has recently been restored to lower portions of Salmon Creek with restoration of salt marsh habitat in progress (USFWS 2009) (Figure 55),

Restored salt marsh at Salmon Creek in the Humboldt Bay National Wildlife Refuge

Eel River Estuary

In the Eel River Estuary, north of the river mouth, intertidal coastal marsh occurs bordering McNulty, Hawk, Quill, and Seven Mile sloughs and North Bay. South of the river mouth, intertidal coastal marsh occurs bordering Morgan and Cutoff sloughs and in the Centerville Slough area of the Salt River drainage. Marshes are also found sporadically on the banks of the main channel, Cock Robin Island, and Roper Slough. Freshwater input has a much stronger influence in the Eel River Estuary than in Humboldt Bay, as evidenced by a more extensive occurrence of brackish and freshwater intertidal coastal marsh.

Salt and brackish coastal marsh in the Eel River Estuary

Physical Characteristics

The pattern of tidal currents in Humboldt Bay results in smaller grain size with higher tidal elevation and farther distance from the bay mouth, with intertidal coastal marshes having the most consistently fine-grained sediments of any bay environment (Thompson 1971; Borgeld and Stevens 2007). Thompson (1971) characterized the substrate of Humboldt Bay's intertidal coastal marshes as highly organic silty clay or clayey peat, olive-gray to black streaked with yellow-brown iron concretions that form around plant remains.

There is evidence of both erosion and accretion occurring at different locations in Humboldt Bay. Thompson (1971) monitored seven sites in North Bay over a nearly three-year period. Net erosion was observed at Eureka Slough and Indian Island, while net deposition occurred near the mouths of Jacoby Creek and Mad River Slough. At the other three sites, two near McDaniel Slough and the third at Manila, seasonal fluctuations occurred with no notable net change. Thompson (1971) noted that the bayward margin of many intertidal coastal marshes in Humboldt Bay are cliffs several feet high, undercut and with slump blocks, indicating active erosion by wave action. Thompson found former marsh deposits as far as 100 ft (30.5 m) seaward of the marsh edge, buried beneath layers of tidal flat sediments—evidence that at one time, the marshes extended further bayward, at least in some locations.

The Jacoby Creek Marsh is an example of a location where accretion is evident. Thompson (1971) measured a deposition rate of 0.71 in (18.0 mm) per year. Based on comparison of a 1911 US Corps of Engineers map and 1966 aerial photos, Thompson described marsh progradation of 125 ft to 300 ft (38 m to 91 m) within a 600-ft (183-m) wide section centered on the mouth of Jacoby Creek. The bayward edge of the Jacoby Creek Marsh is a gradual slope, in contrast to the undercut banks found at other locations.

Klein (2005) examined aerial photographs between 1941 and 2000 as a case study of three remnant intertidal coastal marshes in North Bay. Like Thompson (1971), he found an increase in the area of intertidal coastal marsh near the mouth of Jacoby Creek, estimating a growth rate of 10 ac (4 ha) between 1941 and 2000. Klein (2005) found that intertidal coastal marsh bordering McDaniel Slough, which drains Janes Creek, remained about the same acreage between 1941 and 2000, while the marsh plain near the mouth of Mad River Slough had diminished substantially due to erosion.

Anderson (2008) examined hydraulic geometric characteristics of G Street Marsh, a remnant salt marsh in North Humboldt Bay, and compared the results to salt marshes in San Francisco Bay. Mature marsh plains typically have elevations close to mean higher high water (MHHW), with tidal flows contained primarily within the channel. The marsh plain of G Street Marsh was found to be approximately 0.3 ft (0.1 m) lower than MHHW within the marsh, and 0.6 ft (0.2 m) lower than MHHW for North Humboldt Bay. While this difference is relatively small, it may mean that accretion rates are insufficient to keep pace with sealevel rise. The constricted channel inlet to the G Street Marsh appears to be a source of chronic disturbance that has resulted in muted tides. The disparity between marsh plain elevation and MHHW may result in an undesirable loss of tidal marsh. Removing the constricted inlet and levee to allow for higher sediment delivery to the marsh plain could alleviate the problem. Similar actions may be warranted throughout the region, as human disturbances to marsh hydrology and sediment delivery are common. These include truncation at the upper margin by levees, remnant drainage ditches, constricted inlets, and soil subsidence or compaction (Anderson 2008a). While removing constrictions and obstructions to tidal flow may enhance sediment delivery, the increased tidal inundation that could accompany these actions may be incompatible with existing land uses. The relationship of marsh plain elevation to MHHW is an important factor to consider when designing intertidal coastal marsh restoration projects (Anderson 2008b).

Biotic Communities

Plant Communities

Though intertidal coastal marshes are relatively flat, slight variations in elevation within the marsh influence the types of plants that grow there; lower areas are subject to longer and more frequent periods of tidal inundation. Low tidal elevations also tend to have higher soil and water salinity, higher soil organic matter, but lower soil aeration (Clarke and Hannon 1969; Zedler 1977). Patterns of plant distribution along an elevation gradient are referred to as zonation. The gradual transition from salt-to-brackish-to-freshwater intertidal coastal marshes correspond to decreasing saltwater influence at the furthest reaches of the tide and wherever diluted by freshwater inflow (Barnhart et al. 1992; Pickart 2005c).

A list of species found in Humboldt Bay wetlands, including salt, brackish and freshwater marshes has been compiled (Leppig and Pickart 2009). Intertidal coastal marshes in Humboldt Bay and the Eel River Estuary share a number of floristic features with other West Coast intertidal coastal marshes. Salt marsh plant species that range from British Columbia, Canada to Baja California, Mexico include common pickleweed (*Sarcocornia pacifica* [Standl.] A. J. Scott—formerly known as *Salicornia virginica* L.), saltgrass (*Distichlis spicata* [L.] E. Greene), marsh jaumea (*Jaumea carnosa* [Less.] A. Gray), arrowgrass (*Triglochin maritima* L., now includes the former *T. concinna*), and saltmarsh dodder (*Cuscuta salina Engelm*. var. major Yuncker).

Undercut and eroding saltmarsh in Humboldt Bay

Intertidal coastal marshes in the study area are also unique in several respects. Primary species that are absent from Eel River or Humboldt Bay salt marshes but occur from Bodega Bay south include California cordgrass (*Spartina foliosa* Trin.) and alkali heath (*Frankenia salina* [Molina] I.M. Johnston). Intertidal coastal marshes to the north of Humboldt Bay generally occur in association with larger rivers and therefore have a greater freshwater influence. Lyngbye's sedge (*Carex lyngbyei* Hornem), a species typically associated with brackish conditions, is locally abundant in the region, but it is a dominant species in intertidal coastal marshes further north.

A non-native species of *Spartina* (*S. densiflora* Brongn.) was likely introduced to Humboldt Bay in the late 19th century (Spicher and Josselyn 1985) and today it is a dominant species in intertidal coastal marshes throughout the region (Eicher 1987; Eicher and Bivin

1991; Kittelson and Boyd 1997; Pickart 2001; Pickart 2008b). While non-native populations of *S. densiflora* have invaded marshes both to the north and south, nowhere do they dominate the marshes as in this region (Eilers 1975; Macdonald 1977; Grewell et al. 2007; Flora of North America Editorial Committee 2008; Sutula et al. 2008b).

Dwarf saltwort (*Salicornia bigelovii* Torrey) is an annual species of pickleweed newly established in Humboldt Bay salt marshes. The species was first detected there in fall 2004 (personal communicaiton M.Wallace, A. Pickart, Nov. 3, 2004). This species detection was reported to the Global Invasive Species Initiative website. *S. bigelovii* has since become widespread throughout the area's salt marshes. Unlike common pickleweed, which turns red in the fall, dwarf saltwort turns yellow and is readily visible. The species is native to Southern California salt marshes so its appearance in Humboldt Bay could represent a range extension, possibly in association with climate change, or it may have been inadvertently introduced. Leppig and Pickart (2009) list the species as native to Humboldt Bay salt marsh.

***Spartina densiflora* in a North Bay salt marsh with adjacent macroaglal beds on intertidal mudflats.**

Saltmarsh plain in Humboldt Bay

Dwarf salwort in the fall (A. Pickart)

Following the CMECS hierarchy, within the emergent wetland class, the subclass coastal salt marsh is divided into three biotic groups: emergent low salt marsh; emergent high salt marsh; and emergent brackish marsh. The characterization of intertidal coastal marsh vegetation according to elevation and/or salinity is common, and this classification is consistent with FGDC Wetlands Subcommittee (1997) Wetlands Mapping Standard. Salt marshes have salinities of 30 PSU (Practical Salinity Unit—roughly equivalent to ppt) or greater, and brackish marshes 0.5–30 PSU. Marshes with 0–0.5 PSU salinity are considered freshwater, and they are not included in CMECS, although freshwater

Table 23. Salinity categories corresponding to marsh type.

PSU=Practical Salinity Unit			
	Marsh Type	Salinity Category	PSU
	Freshwater Marsh	Fresh	0–0.5
CMECS	Brackish Marsh	Oligohaline	0.5–5
		Mesohaline	5–18
		Polyhaline	18–30
	Salt Marsh	Euhaline	30–40
		Hyperhaline	>40

marshes can be influenced by tidal flows (Madden et al. 2009) (Table 23).

CMECS biotic groups are further divided into biotopes following the National Vegetation Classification Standard (NVCS or NVC) (FGDC Vegetation Subcommittee 1997; Faber-Langendoen et al. 2009; Jennings et al. 2009). The US NVC is based on a partnership between nongovernmental organizations, the Ecological Society of America's Vegetation Panel and NatureServe, and federal partners, through the auspices of the FGDC Vegetation Subcommittee. NVC classifies vegetation to the association/alliance level. The association level is the most basic classification unit of vegetation defined, "on the basis of a characteristic range of species composition, diagnostic species occurrence, habitat conditions and physiognomy." The alliance is the next level up in the hierarchy, "containing one or more associations, and defined by a characteristic range of species composition, habitat conditions, physiognomy and diagnostic species, typically at least one of which is found in the uppermost or dominant stratum of the vegetation." Physiognomy is defined as, "the structure and life form of a plant community." A stratum is "a layer of vegetation defined by the height of the plants." Each stratum is named for the typical growth form that occupies that layer of vegetation, e.g., the tree stratum, shrub stratum, or herbaceous stratum (Jennings et al. 2009).

In Humboldt Bay, intertidal coastal marsh vegetation has been described by a number of investigators, and characterized in terms of dominant plant species, elevation, and/or salinity (although typically without empirical data for the latter two). One recent investigation (Pickart 2006) used NVC methodology to classify marsh vegetation to the association/alliance level, and this study also included direct measurements of elevation and salinity. Previous investigations, while using different methodologies, can be grouped using CMECS/NVC terminology for intertidal coastal marshes in the study area (Table 24).

In North Humboldt Bay, salt marsh occurs from approximately 5.4 ft (1.7 m) MLLW (slightly below the level of MLHW) to approximately 8.8 ft (2.7 m) MLLW, or potentially higher where not truncated at its upper limit by levees. The transition from low- (including mid-) elevation salt marshes to high salt marshes occurs at approximately 7.3 ft (2.2 m) MLLW (Claycomb 1983; Eicher 1987; Falenski 2007). The distribution of major plant species in relation to the tidal elevation gradient is shown in Figure 57.

Emergent Low Salt Marsh

Emergent low salt marshes in the study area are dominated either by common pickleweed or *S. densiflora*. In a 1985 investigation, dense mats of common pickleweed, with few other species present, was the most common vegetation type occurring at the lowest marsh elevations (Eicher 1987); however, there is evidence that continuing *S.*

Table 24. Intertidal coastal marsh vegetation types in the study area.

CMECS Biotic Group	(Sawyer et al. 2009) Name of Alliance or Semi-Natural Stand	Bay: North Bay	Bay: Entrance Bay	Bay: South Bay	Eel R Estuar	Descriptions Within the Study Area: Name of Marsh Type Described	Descriptions Within the Study Area: Citation
Emergent Low Salt Marsh	*Sarcocornia pacifica* Herbaceous Alliance *S. pacifica--Cuscuta salina--Spartina densiflora* Association			X		*Salicornia virginica* Alliance	Pickart 2006
		X				Pickleweed/Cordgrass Vegetation Type	MRB & PWA 2004
		X	X	X		*Salicornia* Marsh	Eicher 1987
		X				Low Marsh	Claycomb 1983
		X				*Salicornia* Marsh	Rogers 1981
			X			*Salicornia* Marsh	Newby 1980
	Spartina densiflora Semi-Natural Herbaceous Stand				X	Tidal Marsh	H.T.Harvey & Associates 2008
				X		*Spartina densiflora* Alliance	Pickart 2006
				X		Cordgrass Vegetation Type	Pickart 2005 c
		X				Cordgrass Vegetation Type	MRB & PWA 2004
		X				Cordgrass Cover Type	McBain and Trush 2004
					X	Salt Marsh	Eicher and Bivin 1991
			X			*Spartina* Marsh	Newton 1989
		X	X	X		*Spartina* Marsh	Eicher 1987
		X				*Spartina* Marsh	Rogers 1981
		X	X	X		Cordgrass Community	Shapiro & Assoc 1980
			X			*Spartina* Marsh	Newby 1980

Table 24. Continued

CMECS Biotic Group	California NVC Classification (Sawyer et al. 2009): Name of Alliance (A) or Semi-Natural Stand (SNS)	Humboldt Bay: North Bay	Humboldt Bay: Entrance Bay	Humboldt Bay: South Bay	Eel R Estuary	Descriptions Within the Study Area: Name of Marsh Type Described	Descriptions Within the Study Area: Citation
Emergent High Salt Marsh	*Sarcocornia pacifica* Herbaceous Alliance *S. pacifica--Distichlis spicata* Association & *S. pacifica--Jaumea carnosa--Distichlis spicata* Association	X				Pickleweed-Saltgrass Cover Type	McBain and Trush Inc. 2004
			X			*Salicornia/Distichlis* Marsh	Newton 1989
			X			*Salicornia/Jaumea* Marsh	Newton 1989
		X	X	X		Mixed Marsh	Eicher 1987
		X				High Marsh	Claycomb 1983
		X				*Salicornia/Distichlis/Jaumea* Marsh	Rogers 1981
		X	X	X		Pickleweed-Saltgrass Community	Shapiro & Assoc 1980
Emergent Brackish Marsh	*Distichlis spicata* Herbaceous Alliance					*Distichlis spicata* Alliance	Pickart 2006
				X		Salt Marsh Vegetation Type	Pickart 2005 c
		X				Saltgrass Cover Type	McBain and Trush Inc. 2004
			X			*Distichlis* Marsh	Newby 1980
	Atriplex prostrata--Cotula coronopifolia Semi-Natural Herbaceous Stand			X		*Atriplex triangularis* Alliance & *Cotula coronopifolia* Alliance	Pickart 2006
	Bolboschoenus maritimus Herbaceous Alliance			X		*Scirpus maritimus* Alliance	Pickart 2006
			X			*Scirpus/Scirpus* Marsh	Newton 1989

Table 24. Continued

CMECS Biotic Group	California NVC Classification (Sawyer et al. 2009): Name of Alliance (A) or Semi-Natural Stand (SNS)	Humboldt Bay: North Bay	Humboldt Bay: Entrance Bay	Humboldt Bay: South Bay	Eel R. Estuary	Descriptions Within the Study Area: Name of Marsh Type Described	Descriptions Within the Study Area: Citation
Emergent Brackish Marsh	*Carex lyngbyei* Herbaceous Alliance (not in Sawyer et al. 2009, but recognized locally)	X				Lyngbye's Sedge Cover Type	McBain and Trush Inc 2004
		X	X	X		Sedge Community	Shapiro & Associates 1980
	Deschampsia cespitosa Herbaceous Alliance			X		*Deschampsia cespitosa* var. *holciformis* Alliance	Pickart 2006
		X				Hairgrass Cover Type	McBain and Trush 2004
		X				Tufted Hairgrass Vegetation Type	MRB & PWA 2004
		X	X	X		Hairgrass Community	Shapiro & Associates 1980
	Typha latifolia Herbaceous Alliance			X		*Typha latifolia* Alliance	Pickart 2006
		X				Cattail Cover Type	McBain and Trush Inc 2004
	Juncus lescurii Herbaceous Alliance			X		*Juncus lesueurii* Alliance	Pickart 2006
				X		Brackish Marsh (Salt Rush)	Pickart 2005 c
			X			Brackish Marsh	Eicher et al. 1992, 1995

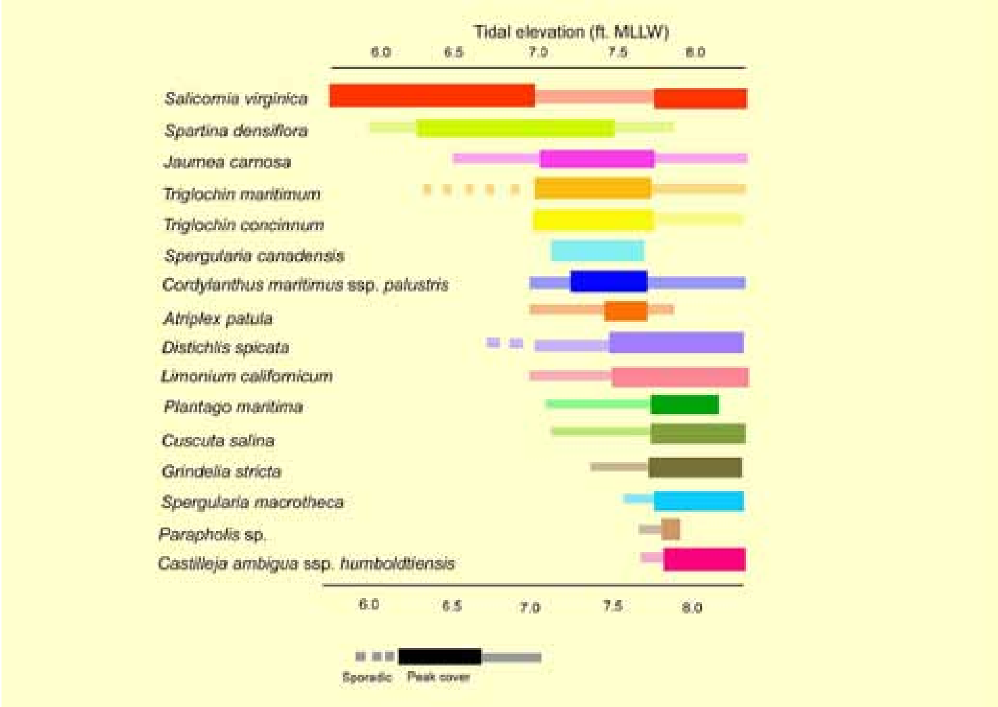


Figure 57. Distribution of major saltmarsh plant species across the tidal elevation gradient in North Humboldt Bay, 1985
Source: adapted from Eicher 1987

densiflora invasion over the last 25 years has displaced much of this vegetation type. Dense monocultures of *S. densiflora* are common in low- to mid-elevation salt marshes throughout Humboldt Bay (Eicher 1987; Pickart 2001; Pickart 2008b), as well as the Eel River Estuary (Eicher and Bivin 1991; H.T. Harvey & Associates 2008) (Table 24).

Emergent High Salt Marsh

Emergent high salt marshes in the study area are generally dominated by common pickleweed, with saltgrass or marsh jaumea as co-dominants; however *S. densiflora* is also continuing to invade these vegetation types (Eicher 1987; Pickart 2001, 2008). The pickleweed- dominated marsh meadows

Pickleweed turning fall color

Emergent high salt marsh in South Bay with adjacent macroalgal mats on intertidal sand flats

found at high elevations differ from low-elevation pickleweed mats by having higher species diversity. In addition to saltgrass and marsh jaumea, other commonly occurring plant species are arrowgrass, western marsh rosemary, coastal gumplant (*Grindelia stricta* DC. var *stricta*), and maritime plantain (*Plantago maritima* L.). This vegetation type supports three rare plant species: Humboldt Bay owl's clover, Point Reyes bird's beak, and Western sand spurrey (Eicher 1987) (Table 24, Figure 57). High diversity marshes in the study area typically have unrestricted tidal inundation, with regular tidal flushing (Sutula et al. 2008a, 2008b).

Emergent Brackish Marsh

Following CMECS, within the estuarine system/intertidal subsystem, emergent brackish marshes occur where freshwater influences are sufficient to dilute salinity levels to 0.5PSU–30 PSU. Freshwater sources include runoff, impoundment, and occasional freshwater seeps or springs. Freshwater runoff is delivered by the main channel of the Eel River, by tributary channels throughout the study area, and through culverts. Impoundment occurs in marshes contained within levees, where impeded drainage results in the ponding of rainwater. Under natural hydrological conditions, brackish marshes tend to occur at the upper margins of salt marshes. In the case of diked former tidelands that now receive muted tidal action, these brackish marshes may actually be at a lower elevation than salt marshes because of subsidence. Muted tidal inundation ranges from unintentional seepage through leaky tidegates to tidal exchange that is funneled through levee breaches, or managed via functional tidegates.

Common three square bulrush, Eel River Estuary, brackish marsh

Bordering tributary channels, and at the upper margins of salt marshes, common dominants of brackish marshes in the study area are: seacoast bulrush (*Bolboschoenus maritimus* L., synonym: *Scirpus m*.); coastal tufted hairgrass (*Deschampsia cespitosa* ssp. *holciformis* J. Presl.); Lyngbye's sedge, broad-leaved cattail (*Typha latifolia* L.); and salt rush (*Juncus lesueurii* Bolander. synonym: *J. lescurii*). In brackish marshes with muted tidal influence, saltgrass dominated communities are common. Common pickleweed is sometimes a co-dominant species, and overall species diversity is typically low. Disturbed marshes with brackish conditions are often invaded by the non-native species orache (*Atriplex prostrata* Boucher) and/or brass buttons (*Cotula coronopifolia* L.)

Agricultural Wetlands

The diked former tidelands in the bottomlands of Humboldt Bay and the Eel River Delta that are managed agriculturally are commonly referred to as agricultural wetlands. The scope of this study is defined as areas under tidal influence, therefore agricultural wetlands are not included. Some mention is warranted, however, because of the past, present, and future significance of these lands to Humboldt Bay and Eel River estuarine habitats. To a large extent, diked former tidelands represent the historical footprint of estuarine influence and provide insight into how these systems functioned under natural conditions.

Agricultural wetlands in the bottomlands of Humboldt Bay and the Eel River Delta have poorly drained soils that pond water during the rainy season. Marsh soils typically have high organic matter content because the anaerobic conditions associated with frequent flooding are not conducive to decomposition. When tidal inundation is restricted or eliminated, the organic matter in the soil breaks down and the soil subsides, often resulting in lower elevations in diked former tidelands than in adjacent intertidal coastal marshes.

The agricultural wetlands associated with Humboldt Bay and the Eel River Delta are mostly brackish as a result of residual salinity in the soils, and they are sometimes saline in areas with leaking tidegates. Agricultural wetlands are dominated by common velvetgrass (*Holcus lanatus* L.), perennial ryegrass (*Lolium perenne* L.), or creeping bentgrass (*Agrostis stolonifera* L.) (Eicher and Bivin 1991; McBain and Trush Inc 2004; Pickart 2005a, 2006; H.T. Harvey & Associates 2008). Although managed for agricultural production, agricultural wetlands are recognized as important habitat for a variety of birds and other wildlife species (Springer 1982; Colwell and Dodd 1995, 1997; Colwell et al. 2001; Colwell and Mathis 2001; Bachman et al. 2003; Leeman and Colwell 2005; Pickart 2006; Conklin and Colwell 2007; Bachman 2008).

Goldsmith and Golightly (2007) conducted a comprehensive survey and mapping of water control structures in Humboldt Bay and the surrounding wetlands. Information on the location and function of tidegates, culverts, and other water control structures was considered important for the development of a strategic approach to estuarine restoration, and for the development of improved management strategies for operation, replacement, or modification of the structures where needed. The resulting database includes a total of 371 water control structures, of which 158 structures were determined to be fully functional; 22 features were either broken, leaking, crushed or impeded; and the remaining 191 structures were classified as unknown in terms of functional capacity (see Water Control Structure map, Figure 25, page 78). A shoreline inventory completed in 2011 found additional water control structures (Laird 2012 in prep.). Water control structures and associated dikes and levees are a barrier to upland coastal marsh migration when sea level rises.

Animal Communities

Invertebrates

In Humboldt Bay intertidal coastal marshes, the dominant benthic invertebrates are gastropods, crustaceans, and polychaetes, which graze on microalgae growing on the soil surface. They also feed on algal mats that are deposited in the marsh at high tide. Common gastropods include the native species *Assiminea californica* and the non-native *Ovatella myosotis*. On the fringes of the salt marsh, the non-native gastropod *Alderia modesta* feeds on mats of the macroalgae *Vaucheria longicaulis*. Polychaete species include the native species *Eteone californica* and *Capitella capitata*, and the non-natives *Polydora cornuta* and *Streblospio benedicti*. The most common crustacean is the native amphipod *Orchestia traskiana*, typically found in low-elevation marshes, under driftwood and at the base of *S. densiflora* stems. The yellow shore crab, a native species, often burrows in saltmarsh banks and feeds in tidal sloughs that dissect the marsh. In high-elevation salt marshes the native isopods: *Armadilloniscus coronocapitalis*; *Littorophiloscia richardsonae*; and *Porcellio* spp. are common (Boyd 1982; Barnhart et al. 1992; Boyd et al. 2002; Read 2003). Thompson (1971) noted that activity by benthic infauna in Humboldt Bay intertidal coastal marshes results in thorough mixing or turning of sediments, a process known as bioturbation.

Little is known about the taxonomy or ecology of insects or arachnids (spiders) that inhabit salt marshes, even though they are more abundant than all other macroinvertebrates and are clearly important components of saltmarsh food webs. Boyd (1982) collected insects and arachnids at the Park Street intertidal coastal marsh restoration site in North Humboldt Bay, but the species were not identified. Spider webs are common amidst the vegetation of Humboldt Bay and Eel River Estuary salt marshes.

Mitchell (2011) collected data on terrestrial invertebrates, including insects and arachnids, at coastal saltmarsh sites in the Mad River Slough. He found an abundance of orb weaving spiders from the Tetragnathid family in marshes dominated by *S. densiflora*, and many soil mites and hemipteran insects in marshes dominated by pickleweed and saltgrass. Common soil mites identified in his study included predatory mites from the Trombiculid family, and fungivores and detritovores from the Oribatid family. Phloem feeding plant hoppers from the Delphacid family were among the most common hemipterans identified, particularly in sites dominated by saltgrass.

Fish

Gleason (2007) examined fish abundance and diversity in a variety of subtidal and intertidal habitats in Humboldt Bay. In the channels associated with regularly flooded intertidal coastal marsh, she found 15 fish species. The most abundant was shiner surfperch. Topsmelt and surf smelt were also common. Two Coho salmon were collected in small channels in North Bay. In irregularly flooded marsh channels, Gleason found 17 fish species, mostly staghorn sculpin and speckled sanddab. Boyd (1982) noted that salt marshes are used by larval stages of fish species such as Pacific herring, Northern anchovy, and various goby species. Zedler (1982) recognized the importance of salt marshes as refuge from predation by larger fish.

Birds

Numerous species of birds use intertidal coastal marshes in Humboldt Bay and the Eel River Estuary as a place to roost at high tide and/or as a place to forage. Bird species include herons and egrets, ducks, hawks, Virginia Rails (*Rallus limicola*), American Coots (*Fulica Americana*), gulls, swallows, Marsh Wrens (*Cistothorus palustris*), Savannah Sparrows (*Passerculus sandwichensis*) and Song Sparrows (*Melospiza melodia*), and shorebirds such as Black-bellied Plovers, Willets, Least Sandpipers, Dunlins, Short-billed and Long-billed Dowitchers, Western Sandpipers, and Marbled Godwits (Monroe 1973; Springer 1982). Raptors such as Red-tailed Hawks (*Buteo jamaicensis*), Red-shouldered Hawks (*B. lineatus*) and Northern Harriers are commonly observed foraging in local salt marshes.

Humboldt Bay and the Eel River Estuary are located on the Pacific Flyway, a major north-south travel route for migratory birds extending from Alaska to Patagonia. Any given species of bird travels approximately the same route at the same time each year, stopping at

Virginia Rail in Arcata Marsh

Song Sparrow, *Melospiza melodia*

key locations to rest and feed. Humboldt Bay and the Eel River Estuary are major foraging and resting grounds for numerous species of migratory birds (Monroe 1973; Monroe et al. 1974; Springer 1982).

Gerstenberg (1972, 1979) studied habitat utilization by wintering shorebirds at Humboldt Bay in 1968 and 1969. He found that at high tide, most birds move from the mudflats to roost on the salt marsh, and at extremely high tides, they moved to the surrounding bottomlands. Long (1993) studied habitat use by ten shorebird species in Humboldt Bay in 1988 and 1989, comparing use of mudflat, saltmarsh and field habitats.

There were variations among species, but in general few species forage in salt marsh, preferring either mudflats or pastureland. Long and Ralph (2001) found that Willets use salt marshes in the Mad River Slough for foraging when mudflats are flooded, particularly during higher tides in the spring. Yull (1972) studied habitat use by Common Egrets in Humboldt Bay. Mudflats were the preferred feeding grounds for these birds when accessible during daylight hours. Salt marshes were used as loafing grounds during high tides, especially from mid-summer through early fall, and channels within the salt marsh were occasionally used for feeding. The importance of intertidal coastal pastures for winter foraging by Curlews at Humboldt Bay has been noted by Leeman (2000); Mathis (2000); Colwell and Mathis (2001).

Tens of thousands of Aleutian Cackling Geese (*Branta hutchinsii leucopareia*) from California's Central Valley fly northward and stopover in Humboldt Bay and the Eel River Estuary where they forage on pastureland, preferring areas with short grass (2 in to 3 in [51 mm to 152 mm]). In mid-April the geese begin their annual migration to the Aleutian Islands for breeding (U.S. Fish and Wildlife Service 2009). Their presence is a welcome sight as they were once nearly extinct.

Indian Island heron and egret rookery in Entrance Bay is surrounded by coastal marsh.

Geese on agriculture land.

As the numbers of these geese have risen in recent years, so has the concern of local ranchers about the impacts of their pasture grazing. The Aleutian Goose Working Group was formed to address this issue. Their proposed long-term solution includes goose management zones, consisting of strategic parcels purposely managed to attract and hold the majority of geese throughout the spring season. These areas include both public lands designated for this purpose and portions of private holdings contributed by landowners.The Pacific Flyway Management Plan (Pacific Flyway Council 2006) calls for a target population of 60,000, and limited hunting of Aleutian Cackling Geese is now allowed.

Humboldt Bay salt marsh on a frosty winter morning.

Mammals

Small rodents such as the California vole (*Microtus californicus*), vagrant shrew (*Sorex vagrans*), and house mouse (*Mus musculus*) feed and nest in high-elevation intertidal coastal marshes. Other mammals that use intertidal coastal marsh habitats in Humboldt Bay and the Eel River Estuary include raccoons, mule deer (*Odocoileus hemionus*), river otters, striped skunks (*Mephitis mephitis*), and mink (*Neovison vison*). Bats forage over the marsh for insects. Mammals that use agricultural wetlands include shrews, moles, Botta's pocket gophers (*Thomomys bottae*), long-tailed weasels (*Mustela frenata*) and gray foxes (*Urocyon cinereoargenteus*) (Springer 1982).

Sensitive Species

Sensitive plant species that occur in intertidal coastal marshes in the Humboldt Bay/Eel River region include: Humboldt Bay owl's clover (*Castilleja ambigua* Hook & Arn. ssp. *humboldtiensis* [Keck] Chuang & Heckard); Point Reyes bird's beak (*Cordylanthus maritimus* Benth. ssp. *palustris* [Behr] Chuang & Heckard); Western sand spurrey (*Spergularia canadensis* [Pers.] G. Don var. *occidentalis* R. Rossbach); Lyngbye's sedge, seacoast angelica (*Angelica lucida* L.); and dwarf alkali grass (*Puccinellia pumila* [Vasey] A. Hitch.) (Grewell et al. 2007; CNPS 2008; Leppig and Pickart 2009).

Humboldt Bay Owl's Clover and Point Reyes Bird's Beak

Humboldt Bay owl's clover and Point Reyes bird's beak are discussed together here because they are related taxa that co-occur in similar habitat (high-elevation salt marshes) and have similar growth characteristics (Eicher 1987). Both are ranked as rare, threatened, or endangered by the California Native Plant Society (CNPS 2008). Humboldt Bay owl's clover has a limited distribution, occurring

Humboldt Bay Owl's Clover at Arcata Marsh

only from Humboldt Bay south to Tomales Bay, California (Grewell et al. 2007). Point Reyes bird's beak is endangered in Oregon, but in California the subspecies has been reported as far south as San Luis Obispo County (CNPS 2008; Calflora 2009). These taxa are small annuals and are facultative hemi-parasites—they parasitize other plant species by root connections called haustoria, but also derive some of their energy through photosyntesis. They both occur in high-elevation salt marshes The life histories of these two rare annuals were studied in intertidal coastal marsh at Mad River Slough (in high-elevation salt marsh on islands) and on the mainland of Mad River Slough in north Humboldt Bay (Bivin et al. 1991).

Pickart (2001) mapped Humboldt Bay owl's clover from May to June 1998 and Point Reyes bird's beak in June 1999 in salt marshes throughout Humboldt Bay. The US Fish and Wildlife Service maintains an ongoing monitoring program for these species on Humboldt Bay National Wildlife Refuge (HBNWR) lands. Both species have exhibited high annual fluctuations in population numbers during more than a decade of monitoring in Mad River Slough (Pickart and Miller 1988; Pickart 2001).

Western Sand Spurrey

Western sand spurrey is listed by the California Native Plant Society (2008) as seriously endangered in California, but is more common elsewhere. The plant grows in Oregon and Washington intertidal coastal marshes, but in California it is known only in the marshes of Humboldt Bay and the Eel River Estuary. This tiny annual occurs in high-elevation salt marshes. Eicher (1987) found the plant ranging from 7.1 ft to 7.7 ft (2.2 m to 2.3 m) MLLW in North Humboldt Bay, typically associated with arrowgrass, common pickleweed and marsh jaumea, whereas the more stout perennial sticky sand spurrey (*Spergularia macrotheca* [Hornem.] Heynh. var. *macrotheca*) tended to grow at higher elevations (7.6 ft to 8.4 ft (2.3 m to 2.6 m) MLLW), often in association with saltgrass.

Lyngbye's Sedge

Lyngbye's sedge is listed by the California Native Plant Society (2008) as fairly endangered in California, but more common elsewhere. Lyngbye's sedge is locally abundant in intertidal coastal marshes along the coasts of Alaska, Washington and Oregon. In California, the species extends as far south as Bolinas Lagoon, just north of San Francisco Bay (California Native Plant Society 2008). In Humboldt Bay and Eel River Estuary intertidal coastal marshes, Lyngbye's sedge is typically found bordering sloughs near river mouths and where there are other freshwater inputs. Locally, the species has become more abundant in recent years (G. Leppig, personal communication 2008).

Seacoast Angelica

Seacoast angelica is on the "Watch List" of the California Native Plant Society (2008) as a species with limited distribution and fairly endangered in California. Seacoast angelica occurs in Oregon and Washington, while in California the species extends as far south as Mendocino County. In Humboldt Bay and the Eel River Estuary, seacoast angelica occurs in brackish marshes, usually at the upper margin of the marsh, or growing on adjacent levees.

Invasive Species

Spartina densiflora

In intertidal coastal marshes of Humboldt Bay and the Eel River Estuary, the main invasive species of concern is *S. densiflora* now believed to be native to the east coast of South

America, where it ranges from São Paulo in Brazil to Rio Gallegos in Argentina. From there, it spread by various means to Chile, the United States, Spain and Morocco (Bortolus 2006). In the 1850s and 1860s, Chile imported lumber from Humboldt Bay, and presumably *S. densiflora* seeds were transported inadvertently on lumber ships returning to the bay that were weighted with ballast obtained from Chilean shorelines (Spicher and Josselyn 1985).

Until the mid-1980s, *S. densiflora* in Humboldt Bay and the Eel River Estuary was believed to be a northern ecotype of *S. foliosa*, a species that is native to intertidal coastal marshes from Bodega Bay, California, south to Baja California, Mexico. Under that erroneous assumption, plant material from Humboldt Bay was transplanted to a marsh restoration site in San Francisco Bay in 1976, where it has since naturalized (Josselyn 1982; Faber 2001; Olofson 2008). The differences between the two plants were noted when they were growing side-by-side; *S. densiflora* grows in clumps and is higher in the intertidal zone than *S. foliosa*. Spicher (1984) conducted a taxonomic investigation and determined the Humboldt Bay cordgrass to be *S. densiflora*.

S. foliosa is the only species of *Spartina* native to the Pacific Coast of North America (Daehler and Strong 1996). Four invasive species of *Spartina* have been documented: dense-flowered cordgrass (*Spartina densiflora*); smooth cordgrass (*S. alterniflora* Loisel.); saltmeadow cordgrass (*S. patens* [Aiton] Muhl.); and English cordgrass (*S. anglica* C.E. Hubb.).

Spartina densiflora **with macroalgae bed in the Eel River Estuary**

Besides *S. densiflora*, the only other *Spartina* species that has been documented in Humboldt Bay or the Eel River Estuary is *S. alterniflora*. Native to the East and Gulf Coasts of North America, *S. alterniflora* was first detected in Humboldt Bay in 1985 at an intertidal coastal marsh in Samoa, North Bay, where it was growing lower in the intertidal zone than *S. densiflora* (Eicher and Sawyer 1989). After observing the stand to increase from 10 ft^2 to 5,000 ft^2 (3 m^2 to 1524 m^2) over a three-year period, the California Department of Fish and Game effectively eradicated the species by diking the area, cutting the grass, applying salt, and covering it with black plastic and sand bags. Around the same time, an occurrence of *S. alterniflora* was detected in the Eel River Estuary, but this population was washed away by winter floods and did not re-establish (Kovacs, personal communication 2008).

Like most invasives, *S. densiflora* species are recognized to have positive ecological functions within their native ranges, but deleterious impacts to the communities where they have been introduced, including displacement of native plant species. *S. densiflora* exhibits growth year-round, giving it a competitive advantage over native saltmarsh plant species that undergo winter dormancy (Kittelson 1993). Additionally, invasive *Spartina* species are considered to be ecosystem engineers, able to reshape the physical structure of invaded communities through sediment retention/accretion, increased stem and root density, and by shading that reduces algal growth on the soil surface

***Spartina densiflora* in the Eel River Estuary**

(Daehler and Strong 1996; Bortolus 2006; O'Connell 2006). Of special concern in San Francisco Bay is *S. alterniflora* because it is hybridizing with the native *S. foliosa* (Olofson 2005, 2008). In response, land managers in Washington, Oregon and California initiated large scale control and/or eradication programs for invasive *Spartina* species, including chemical, mechanical and biological control methods (O'Brien 2000; O'Connell 2006; Olofson 2008; Patten 2008).

Clifford (2002) prepared a literature review of *S. densiflora* in Humboldt Bay. Eicher (1987) recorded *S. densiflora* as occurring at tidal elevations between 5.9 ft (1.8 m) and 7.9 ft (2.4 m) MLLW—almost the full range of saltmarsh occurrence—with peak abundance at elevations between 6.9 ft and 7.3 ft (2.1 m and 2.2 m) MLLW. Newby (1980) found a correlation between high *S. densiflora* abundance and high levels of phosphorous in plant tissue, suggesting that low phosphorus levels may be limiting to *S. densiflora* at higher elevations. Falenski (2007) found that *S. densiflora* is most abundant where the available phosphorus concentration in the soil is greater than 5 ppm. Phosphorus is deposited on the marsh with the clay particles found in tidal waters, and is most abundant at low elevations in the marsh. Other environmental factors correlated with *S. densiflora* abundance by Falenski (2007) were negative redox values (associated with high soil saturation), low elevation, and a low elevation gradient.

Pickart (2001) mapped *S. densiflora* throughout Humboldt Bay in June 1999, documenting that it was present in 94% of the area's salt marshes, and that it was dense (≥70% cover) in 62% of the marshes. Most alarming was the rate of invasion for some locations in recent years, showing a 50-fold increase between 1989 and 1997 in high-elevation marshes in Mad River Slough. An additional *S. densiflora* mapping effort was completed for Humboldt Bay, the Mad River Estuary, and the Eel River Estuary in 2011 (Grazul and Rowland 2011). Results are summarized in Table 25.

Table 25. Total acres infested by *Spartina densiflora* mapped as linear and polygon features distributed by cover class within the Humboldt Bay Region 2010-2011.

Project Area	61%–100% Cover	26%–60% Cover	1%–25% Cover	Linear Features	Total Infested Acres
Mad River	7.36	1.88	0	0.16	7.36
North Bay	314.94	243.37	308.18	14.43	867.5
South Bay	26.71	45.17	68.31	8.57	140.21
Eel River	278.96	171.78	205.66	2.61	656.42
Total	622.49	460.32	587.62	25.77	1,671.49

A successful manual/mechanical method of control for *S. densiflora* in Humboldt Bay has been developed by HBNWR staff (Pickart 2005b, 2008a). In a pilot study at HBNWR, established *S. densiflora* has been eradicated over a 25-acre region (10-ha) using metal-bladed brush cutters applied in a specialized manner (Pickart 2008b). Methods were refined in a later experiment that showed a summer-vs.-winter start date resulted in faster plant mortality. However, a summer start date also resulted in greater seedling establishment. *S. densiflora* has been shown to have a persistent seed bank in Humboldt Bay (unpublished data HBNWR), although longevity has yet to be determined. Preliminary indications are that seed-bank density is low, relative to the density of seedlings that become established on mowed areas. For this reason, a regional approach to eradication is needed. Experiments at HBNWR show that a single top mow is effective at preventing seed set, and can be used as a cost-effective method to defer more expensive eradication (Pickart and Goodman in press).

Managers at HBNWR have used flaming as well as brush cutters to control seedlings. Flaming is only useful when applied while seedlings are young, or in the first year after mowing. Seedling density is correlated with algal cover, suggesting that algae create more hospitable conditions for seedling emergence or survival (Pickart 2008a). The effectiveness of the winter start date in preventing seedlings may be because algal succession hasn't advanced sufficiently after a summer mow (vs. a winter mow) by the following spring to facilitate seedling survival.

Research is in progress on algal succession in restored areas; plugs of native marsh species were planted in treated sites. However, preliminary results indicate that natural recolonization may be sufficient to achieve restoration goals, especially if controling the seed source could be achieved through large-scale regional eradication efforts (Pickart 2008a). *S. densiflora* can produce as many as 2,000 viable seeds per plant—higher than other *Spartina* species (Kittelson and Boyd 1997).

Large-scale eradication is supported by other West Coast estuary land managers who are currently struggling to control *S. densiflora* invasions and who view Humboldt Bay as a continual seed source for *S. densiflora*. A driftcard study carried out by Portland State University in 2004 and 2005 demonstrated rapid long-distance transport, with the range of dispersal from Humboldt Bay exceeding that of the other two bays included in the study: San Francisco Bay, California, and Willapa Bay, Washington. Drift cards from Humboldt Bay dispersed to numerous locations on the coast—as far as 1,740 mi (2,800 km) north to Alaska, and 330 mi (531 km) south beyond San Francisco Bay, at a maximum velocity rate of 15 mi (24 km) per day (Sytsma and Howard 2008). *S. densiflora* seeds float and can be dispersed by currents in a manner similar to the drift cards, with the seeds remaining viable for four to seven months (Callaway and Josselyn 1992; Kittelson and Boyd 1997; Sytsma and Howard 2008), while mats of wrack are capable of floating for more than two months (Sayce et al. 1997).

Common Reed

Common reed (*Phragmites australis* [Cav.] Steudel) occurs at several locations in Humboldt Bay. The species is widespread throughout the United States, with both native and non-native genotypes recognized. Material from Humboldt Bay was sent to Cornell University, and all of it was determined to be non-native. Humboldt Bay habitats occupied by common reed include: intertidal; regularly flooded intertidal coastal marsh; marsh with muted tidal influences; former intertidal coastal marsh with relict saline soils; and freshwater drainage ditches. Efforts are underway to eradicate all known populations in the bay. Each site poses unique considerations for methods of treatment (Gedik 2005).

European Green Crab

The European green crab (*Carcinus maenas*) is native to Europe's North Atlantic Coast. The species was introduced to the East Coast of North America some time in the 1800s (Scattergood 1952), where it has caused dramatic declines in the native Atlantic soft-shelled clam through predation (Glude 1955). The European green crab was first detected on the West Coast of North America in 1989 near San Francisco Bay, where its transoceanic introduction was likely related to shipping (Cohen and Carlton 1995). From Central California, the species spread rapidly both south to Morro Bay, California and north to British Columbia, Canada (Kuris 2002). In Humboldt Bay, the first detection was in 1995, probably introduced through ballast water (Miller 1996; Boyd et al. 2002; McBride 2002). The advance further north may be attributable to the transport of planktonic larvae via unusually strong northward-moving coastal currents off the Northern California and Oregon coasts in 1997 and 1998 (Yamada et al. 1999).

European green crab

The European green crab inhabits protected areas on mud, sand or rocks, and burrows in the banks of *S. densiflora* marshes (Cohen and Carlton 1995). Since its arrival on the West Coast, there has been considerable concern about potential impacts to native species and to fisheries (Grosholz et al. 2000; Kuris et al. 2005). A recent investigation in Central California suggests that native species may offer biotic resistance, i.e., larger native crab species may be able to out-compete the European green crab for food and shelter where they co-occur (Jensen et al. 2007). Nonetheless, the European green crab's broad environmental tolerances allow it to inhabit areas that native crabs cannot tolerate, such as shallow, warm sloughs, where the species may have intense, localized effects on the benthic invertebrate community (Jensen et al. 2007).

Since its discovery in Humboldt Bay, the European green crab has been monitored by California Sea Grant Extension (Schlosser, unpublished data). The species has been found at several sites in the bay, but in low numbers. European green crab establishment in Humboldt Bay appears to favor areas with restricted water flow (Meyer 2001; McBride 2002).

Other Non-Native Invertebrate Species

Boyd (2002) conducted a survey of Humboldt Bay for nonindigenous species in 2000 and 2001, with a focus on invertebrate species, also considering fish and macroalgal plant species and with a cursory treatment of vascular plant species. One challenge of determining the native origins of marine and estuarine species is that global marine trade has occurred for hundreds of years, prior to the identification and listing of species at specific locations. Consequently, species with broad worldwide distributions cannot always be determined as native to any particular region, and these species are called cryptogenic, which translates as "hidden origin" (Cohen and Carlton 1995).

In this section, we include invertebrate species that Boyd et al. (2002) found in or on the edges of intertidal coastal marshes in Humboldt Bay that are considered either non-native or cryptogenic. In most cases, there is little information on the invasiveness of these species or what impacts they have had and, or are having on native species.

The starlet sea anemone (*Nematostella vectensis*) is a small anemone that is abundant in shallow pools in Humboldt Bay salt marshes and is considered to be cryptogenic here (Barnhart et al. 1992; Hand and Uhlinger 1994; Boyd et al. 2002). It is unknown what effect the starlet sea anemone has on native species.

Mouse-ear marshsnail (*Ovatella myositis/ Myosotella myosotis*) is common and abundant in salt marshes around Humboldt Bay, living under debris near the high tide line (Boyd et al. 2002). The species is believed to be native to Europe—from Great Britain and the western Baltic Sea to the Mediterranean and Black Seas. The first record of the mouse-ear marshsnail, (as *M. myositis)*, on the Pacific Coast is from San Francisco Bay in 1871, followed by Humboldt Bay in 1876. It probably arrived on the Pacific Coast in transcontinental shipments of Atlantic oysters (*Crassostrea virginica*), which started in 1869 (Cohen 2005). Mouse-ear marshsnail is now found on the Pacific Coast from Boundary Bay, British Columbia, to Scammons Lagoon in Baja California, Mexico (Carlton 1979; Cohen and Carlton 1995). In Coos Bay, Oregon, Berman and Carlton (1991) found dietary overlap with the native saltmarsh snails, *Assiminea californica* and *Littorina subrotundata*, but there was no evidence of the introduced *O. myosotis* having a competitive advantage over native snail species.

The introduced sea slug, *Alderia modesta*, was first reported in Humboldt Bay by Boyd et al. (2002). The species feeds on the macroalga *Vaucheria longicaulis*, native to Humboldt Bay and which grows in spongy mats on mudflats at the lower edge of salt marsh, and in slough channels within salt marsh.

Sphaeroma quoyanum is an isopod introduced from Australia on ship hulls during the California gold rush, and it now occurs from Coos Bay, Oregon, to San Diego, California (Ray 2005). The species was first reported in Humboldt Bay in the 1920s (Boyd et al. 2002). The small isopod bores into the mud banks of salt marshes, and some investigators believe that excessive burrowing by this species can weaken the banks and contribute to erosion (Ray 2005). *Iais californica* is a small commensal isopod that lives on *Sphaeroma quoyanum*, and it was first reported in Humboldt Bay by Boyd et al. (2002). *I. californica* is occasionally found on the native isopod *Gnorimosphaeroma oregonensis*, but this isopod actively removes it, unlike *S. quoyanum* (Boyd et al. 2002).

Chaetocorophium lucasi is a small amphipod native to New Zealand, first reported in Humboldt Bay in 1992 (Boyd et al. 2002). In the 1970s, logs were imported from New Zealand to Humboldt Bay and this is the most likely mode of introduction. In their 2000 to 2001survey, Boyd et al. (2002) found hundreds of individuals at numerous sample sites in Humboldt Bay. The species was most abundant at sites in North Bay with freshwater input, often in shallow channels or pools in salt marsh.

Hyale plumulosa is an amphipod with possibly cryptogenic origin, now with a circumboreal distribution. In Humboldt Bay, this species was found on protected shores in salt marsh at the base of *S. densiflora* roots, under rocks, and occasionally in upper tidepools (Boyd et al. 2002).

Ecosystem Services

Intertidal coastal marshes provide high-value ecosystem services such as water filtration, flood abatement, protection for infrastructure, and carbon sequestration (Crooks et al. 2011; Zedler and Kercher 2005; Costanza et al. 1997; Greenberg et al. 2006) They also have high ecological value, supporting a large number of specialized species. Intertidal marshes have experienced dramatic historical declines in area (Costanza et al. 1997; Barnhart et al. 1992).

Intertidal coastal marsh habitats provide many ecosystem services such as:

- Primary production/base of food webs
- Wildlife habitat
- Organic matter reservoir
- Nutrient and contaminant filtration/water quality
- Absorption of wave and current energy
- Nutrient regeneration, recycling and export
- Support of fisheries
- Counter sealevel rise
- Recreational, aesthetic open space

Management Considerations

Critical threats to intertidal coastal marsh habitat identified by the Habitat Project Advisory Committee include:

Indian Island coastal marshes inundated by high tide in Decemeber 2010.

Humboldt Bay salt marsh is frequently bounded by the railroad which prevents an upland migration in response to rising sea level.

- Anthropogenic greenhouse gas (GHG)
- Coastal intertidal marsh drowning
- Urban runoff
- Hydrologic barriers
- Shoreline development
- Invasive species

Invasive *S. densiflora* is established in more than 90% of Humboldt Bay and Eel River Estuary intertidal coastal marshes. Current efforts to eradicate *S. densiflora* could have a major beneficial impact for native intertidal coastal marsh species.

Community adaptation strategies to rising sea level are needed for long-term conservation of Humboldt Bay and Eel River Estuary salt marshes. It is unknown precisely how projected sealevel rise will affect rates of erosion and accretion in intertidal coastal marshes within the study area. It is important to gather data and develop models that will help in predicting shoreline changes. One reason for this concern is the restricted ability of intertidal coastal marshes to expand their range landwards. Most intertidal coastal marshes in the region are truncated at their upper margin by levees. A large proportion of diked former tidelands remain as open land used for agriculture, and this land has

Experimental mowing of *S. densiflora* as eradication method

potential for restoration to intertidal coastal marsh if that were to emerge as a restoration goal. There is pressure to keep these lands in agricultural production, as they provide wildlife habitat in their current state. Additionally, it remains uncertain what measures would need to be taken to achieve restoration, especially considering subsidence of these lands, and unknown variables associated with sealevel rise. Nonetheless, the potential for tidal restoration that exists at Humboldt Bay and in the Eel River Estuary is a significant feature to note because in many other parts of the state that potential has been lost to urban and commercial development.

The sensitivity of Humboldt Bay and Eel River Estuary tidal marshes to rising sea level will vary depending on factors such as sediment supply, vegetation productivity, rates of subsidence and uplift, changes in storm frequency, and the intensity and availability of upland habitat suitable for marsh migration.

Management recommendations to analyze coastal intertidal marsh sustainability and restoration potential are as follows:

- Select climate, hydrologic and habitat indicators to develop an integrated view of climate change manifestation across the landscape to understand bay-wide habitat change
- Use future climate projections for restoration planning
- Clearly identify sensitivity and thresholds of climate, hydrologic and habitat indicators to sediment supply, organic accumulation rates, and starting elevation for marsh sustainability
- Identify barriers to marsh upland migrations to prioritize restoration strategies
- Identify suitable upland adjacent sites for lateral marsh migration or expansion
- Use spatially based models such as SLAMM (Sea Level Affecting Marshes Model) in combination with process-based models (such as hydrologic models) to incorporate spatial variability with geomorphology, channel dynamics and erosion
- Reinstate natural processes (i.e., tidal action) to aquatic and terrestrial communities in ways that favor native species, with a particular interest in waterfowl and sensitive species
- Protect and restore habitat for ecological and public values such as supporting sensitive species, ecological processes, recreation, scientific research, and aesthetic appeal
- Provide long-term protection for valuable resources by improving the integrity of the levee system
- Prevent the establishment of non-native species and reduce the negative ecological and economic impacts of established invasive species.
- Improve water quality and reduce toxin inputs:
    - Urban development and transportation corridors are sources of runoff during the winter that are presumed to contain

various contaminants. The amount and impact of these contaminants is not known and will need research

- Maintain waterfowl hunting; increase the awareness of surrounding communities of the ecological values of Humboldt Bay and Eel River Estuary coastal marshes
- Develop a general model of water, nutrients and aquatic organisms in Humboldt Bay, reflecting coastal connections with the surrounding region
- Maintain water quality within the marsh, in particular dissolved oxygen sags in some channels.

Butcher's Slough

Brackish marsh, Eel River Esutary

There are considerable data gaps concerning water movement into and within Humboldt Bay and Eel River Estuary channels, and how water movement varies with flows, tides and structures. These data, including calibration and verification of mathematical models. are needed for many purposes:

- There is little knowledge about the effects of contaminants on coastal marshes
- There are considerable data gaps concerning the potential effects of restoring habitat to tidal marsh on breeding and production of waterfowl, and on the effects of changes in salinity on waterfowl habitat use and survival
- There are several data gaps concerning coastal marsh food webs, specifically on the productivity in marsh channels.

Woodley Island saltmarsh at sunrise

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Appendix A: Species List

ALGAE	
Common	**Scientific**
Diatom	
	Chaetoceros
	Navicula sp
	Skeletonema costatum
	Synedra sp
Blue-green algae	
	Oscillatoria sp
	Stigonema sp
Green algae	
	Chaetomorpha spp.
	Lola lubrica
	Rhizoclonium riparium
	Ulva clathrata
	Ulva intestinalis
	Ulva lactuca
	Ulva linza
Brown algae	
	Fucus spp.
Red Algae	
	Ceramium sp
	Gracilaria sp
	Gracilariopsis andersonii
	Polysiphonia sp
	Porphyra spp
Yellow-green algae	
	Vaucheria longicaulis

VASCULAR PLANTS	
Common	**Scientific**
alder, red	*Alnus rubra*
alkali grass, dwarf	*Puccinellia pumila* (Vasey) A. Hitch.)
alkali heath	*Frankenia salina* (Molina) I.M. Johnston
angelica, seacoast	*Angelica lucida* L.
arrowgrass	*Triglochin maritima* L (includes *T. concinna*)
bentgrass, creeping	*Agrostis stolonifera* L.
bird's beak, Point Reyes	*Cordylanthus maritimus* Benth. ssp. *palustris* (Behr) Chuang & Heckard
brass buttons	*Cotula coronopifolia* L.
bulrush, common three square	*Schoenoplectus pungens* (Vahl) *Palla var. longispicatus* (Britton)
bulrush, seacoast	*Bolboschoenus maritimus* L.
cattail, broad-leaved	*Typha latifolia* L.
cordgrass, California	*Spartina foliosa* Trin.
cordgrass, dense-flowered	*Spartina densiflora*
cordgrass, English	*Spartina anglica* C.E. Hubb.
cordgrass, saltmeadow	*Spartina patens* (Aiton) Muhl.
cordgrass, smooth	*Spartina alterniflora* Loisel.
cottonwood, black	*Populus balsamifera* L. ssp *trichocarpa* (Torry & A. Gray) Brayshaw
dodder, saltmarsh	*Cuscuta salina Engelm.* var. major Yuncker
eelgrass	*Zostera marina*
eelgrass, dwarf	*Zostera japonica* Aschers and Graebn
gumplant, coastal	*Grindelia stricta* DC. var *stricta*
hairgrass, coastal tufted	*Deschampsia cespitosa* ssp. *hociformis* J. Presl.
jaumea, marsh	*Jaumea carnosa* (Less.) A. Gray
orache	*Atriplex prostrata* Boucher
owl's clover, Humboldt Bay	*Castilleja ambigua* Hook & Arn. ssp. *humboldtiensis* (Keck) Chuang & Heckard
pickleweed	*Sarcocornia pacifica* (Standl.) former *Salicornia virginica* L.
plantain, maritime	*Plantago maritima* L.
reed, common	*Phragmites australis* (Cav.) Steudel
rosemary, western marsh	*Limonium californicum*
rush, salt	*Juncus lesueurii* Bolander
ryegrass, perennial	*Lolium perenne* L.
saltgrass	*Distichlis spicata* (L.) E. Greene
saltwort, dwarf	*Salicornia bigelovii* Torrey
sedge, Lyngbye's	*Carex lyngbyei* Hornem
sicklegrass	*Parapholis* spp
Spartina	see lisiting for cordgrass

VASCULAR PLANTS	
Common	**Scientific**
spurrey, sticky sand	*Spergularia macrotheca* (Hornem.) Heynh. var. *macrotheca*
spurrey, western sand	*Spergularia canadensis (*Pers.) G. Don var. *occidentalis* R. Rossbach
velvetgrass	*Holcus lanatus* L.
widgeon grass	*Ruppia maritima*
willow, arroyo	*Salix lasiolepsis*
willow, coastal	*Salix hookeriana*
willow, narrow-leaved	*Salix exigua*
willow, Sitka	*Salix sitchensis*

INVERTEBRATES	
Common	**Scientific**
amphipod	*Allorchestes angustu*
amphipod	*Caprella californica*
amphipod	*Chaetocorophium lucasi*
amphipod	*Corophium ascheruaicum*
amphipod	*Corophium stimpsoni*
amphipod	*Hyale plumulosa*
amphipod	*Orchestia traskiana*
aquatic pillbug	*Dynamella dilatata*
ascidian	*Botrylloides* spp
ascidian	*Diplosoma macdonaldi*
barnacle	*Balanus glandula*
barnacle	*Balanus cariosus*
bivalve	*Clinocardium* sp
bivalve	*Macoma* sp
bryzoan	*Hippothoa hyalina*
cheliferan	*Leptochelia dubia*
clam	*Transennella tantilla*
clam, Atlantic soft shelled	*Mya arenaria*
clam, bent-nosed	*Macoma nasuta*
clam, gaper	*Tresus capax*
clam, Washington	*Saxidomus giganteus*
crab, Dungeness	*Cancer magister*
crab, European green	*Carcinus maenas*

INVERTEBRATES	
Common	**Scientific**
crab, purple shore	*Hemigrapsus nudus*
crab, striped shore	*Pachygrapsus crassipes*
crab, yellow shore	*Hemigrapsus oregonensis*
gastropod	*Alderia modesta*
gastropod	*Ovatella myosotis*
gastropod, common	*Assiminea californica*
hydroid	*Obelia longissima*
hydroid	*Tubularia marina*
isopod	*Armadilloniscus coronocapitalis*
isopod	*Gnorimosphaeroma oregonensis*
isopod	*Idotea resecata*
isopod	*Littorophiloscia richardsonae*
isopod	*Neosphaeroma oregonensis*
isopod	*Porcellio* spp
isopod	*Sphaeroma quoyanum*
isopod	*Synidotea* spp
isopod, commensal	*Iais californica*
isopod, Fewkes'	*Idotea fewkesi*
isopod, olive-green	*Idotea wosnesenskii*
jelly, sea walnut comb	*Pleurobrachia bachei*
jellyfish, gregarious	*Phialidum gregarium*
limpets, mask	*Acmaea persona*
marshsnail, mouse-ear	*Ovatella myosotis*
moon snail	*Polinices lewisii*
mussel, bay	*Mytilus edulis*
nudibranch	*Hermaeina smithi*
oyster, Atlantic	*Crassostrea virginica*
oyster, native	*Ostrea lurida*
periwinkle, checkered	*Littorina scutulata*
polychaete	*Capitella capitata*
polychaete	*Eteone califonica*
polychaete	*Owenia collaris*
polychaete	*Polydora cornuta*
polychaete	*Streblospio benedicti*
polychaete	*Glycinde polygnatha*
polychaete	*Nereis procera*

INVERTEBRATES	
Common	**Scientific**
polychaete	*Nereis zonata*
polychaete	*Notomastus tenuis*
polychaete	*Polydora brachycephala*
sea anemone, starlet	*Nematostella vectensis*
sea cucumber	*Leptosynapta albicans*
sea slater	*Ligia pallasii*
sea slug	*Alderia modesta*
shrimp	*Crago nigromaculata*
shrimp	*Hippolyte* spp
shrimp	*Spirontocaris picta*
shrimp	*Spirontocaris paludicola*
shrimp, bay	*Crangon franciscorum*
shrimp, ghost	*Neotrypaea californiensis*
shrimp, stout coastal	*Heptacarpus brevirostris*
snail, mouse-ear	*Myosotella myosotis*
snail, salt marsh	*Assiminea californica*
snail, salt marsh	*Littorina subrotundata*
worm, fat innkeeper	*Urechis caupo*
worm, horseshoe	*Phoronopsis harmeri*
worm, ribbon	*Emplectonema gracile*
worms, marine	*Nereis* sp

FISH	
Common	**Scientific**
anchovy, northern	*Engraulis mordax*
bat ray	*Myliobatis californica*
burrow-dwelling fish	*Clevelandia ios*
cabezon	*Scorpaenichthys marmoratus*
flounder, starry	*Platichthys stellatus*
goby, arrow	*Clevelandia ios*
goby, bay	*Lepidogobius lepidus*
goby, tidewater	*Eucyclogobius newberryi*
greenling, kelp	*Hexagrammos decagrammus*
gunnel, saddleback	*Pholis ornate*

FISH	
Common	**Scientific**
halibut, California	*Paralichthys californicus*
herring, Pacific	*Clupea harengus pallasii*
lingcod	*Ophiodon elongatus*
mackerel, jack	*Trachurus symmetricus*
midshipman	*Porichthys notatus*
pikeminnow, Sacramento	*Ptychocheilus grandis*
pipefish, bay	*Syngnathus leptorhynchus*
rockfish, black	*Sebastes melanops*
rockfish, brown	*Sebastes auriculatus*
rockfish, copper	*Sebastes caurinus*
rockfish, grass	*Sebastes rastelliger*
salmon, Chinook	*Onchorhynchus tshawytscha*
salmon, coho	*Onchorhynchus kisutch*
sanddab	*Citharichthys stigmaeus*
sardine, Pacific	*Sardinops sagax*
sculpin, Pacific staghorn	*Leptocottus armatus*
shark, leopard	*Triakis semifasciata*
smelt, longfin	*Spirinchus thaleichthys*
smelt, surf	*Hypomesus pretiosus*
topsmelt	*Atherinops affinis*
shark, leopard	*Triakis semifasciata*
sole, English	*Parophrys vetulus*
steelhead	*Onchorhynchus mykiss*
stickleback, threespine	*Gasterostues aculeatus*
sturgeon, green	*Acipenser medirostris*
sturgeon, white	*Acipenser transmontanus*
surfperch, redtail	*Amphistichus rhodoterus*
surfperch, shiner	*Cymatogaster aggregata*
surfperch, striped	*Embiotoca lateralis*
surfperch, walleye	*Hyperprosopon argenteum*
tomcod, Pacific	*Microgadus proximus*
trout, coastal cutthroat	*Onchorhychus clarkii*
tubesnout	*Aulorhynchus flavidus*

BIRDS	
Common	**Scientific**
Avocet, American	*Recurvirostra americana*
Brant	*Branta bernicla nigricans*
Coot, American	*Fulica americana*
Cormorant	*Phalacrocorax spp*
Curlew, Long-Billed	*Numenius americanus*
Dowitcher, Long-billed	*Limnodromus scolopaceus*
Dowitcher, Short-billed	*Limnodromus griseus*
Dunlin	*Calidris alpina*
Egret, Great	*Ardea alba*
Egret, Snowy	*Egretta thula*
Falcon, Peregrine	*Falco peregrinus*
Gadwall	*Anas strepera*
Godwit, Marbled	*Limosa fedoa*
Goose, Aleutian Cackling	*Branta canadiensis leucopareia*
Goose, Canada	*Branta canadiensis*
Hawk, Red-shouldered	*Buteo lineatus*
Red-tailed Hawk	*Buteo jamaicensis*
Heron, Great Blue	*Ardea herodius*
Killdeer	*Charadrius vociferus*
Mallard	*Anas platyrhynchos*
Murre, Common	*Uria aalge*
Murrelet, Marbled	*Brachyramphus marmoratus*
Night Heron, Black-Crowned	*Nycticorax nyticoras*
Northern Harrier	*Circus cyaneus*
Pelican, Brown	*Pelecanus occidentalis*
Pintail	*Anas acuta*
Plover, Black-Bellied	*Pluvialis squatarola*
Plover, Semipalmated	*Charadrius semipalmatus*
Plover, Western Snowy	*Charadrius alexandrinus nivosus*
Red Knot	*Calidris canutus*
Sanderling	*Calidris alba*
Sandpiper, Least	*Calidris minutilla*
Sandpiper, Western	*Calidris mauri*
Scoter, Surf	*Melanitta perspicillata*
Snipe, Common	*Gallinago gallinago*
Sparrow, Savannah	*Passerculus sandwichensis*

BIRDS	
Common	**Scientific**
Sparrow, Song	*Melospiza melodia*
Teal, Cinnamon	*Anas cyanoptera*
Teal, Green-winged	*Anas carolinensis*
Tern, Caspian	*Hydroprogne caspia*
Turnstone, Black	*Arenaria melanocephala*
Virginia Rail	*Rallus limicola*
Whimbrel	*Numenius phaeopus*
Widgeon	*Anas americana*
Willet	*Catoptrophorus semipalmatus*
Wren, Marsh	*Cistothorus palustris*
Yellowlegs, Greater	*Tringa melanoleuca*
Yellowlegs, Lesser	*Tringa flavipes*

MAMMALS	
Common	**Scientific**
deer, mule	*Odocoileus hemionus*
fox, gray	*Urocyon cinereoargenteus*
gopher, Botta's pocket	*Thomomys bottae*
mink	*Neovison vison*
mouse, house	*Mus musculus*
otter, river	*Lontra canadensis*
porpoise, harbor	*Phocoena phocoena*
raccoon	*Procyon lotor*
sea lion, California	*Zalophus californianus*
sea lion, Steller	*Eumetopias jubatus*
seal, harbor	*Phoca vitulina richardi*
shrew, vagrant	*Sorex vagrans*
skunk, striped	*Mephitis mephitis*
vole, California	*Microtus californicus*
weasel, long-tailed	*Mustela frenata*
whale, gray	*Eschrichtius robustus*

Appendix B: Aerial Imagery Metadata – Federal Geographic Data Committee

http://csc-s-maps-q.csc.noaa.gov/DAV_metadata/ca_hb09.html - 7

Identification_Information:

Citation:

Citation_Information:

Originator:

Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Coastal Services Center (CSC)

Publication_Date: 201006

Title: Humboldt Bay, California Benthic Habitats 2009

Geospatial_Data_Presentation_Form: vector digital data

Publication_Information:

Publication_Place: Charleston, SC

Publisher: NOAA's Ocean Service, Coastal Services Center (CSC)

Online_Linkage: <ftp://ftp.csc.noaa.gov/pub/benthic/ca_hb09.zip>

Online_Linkage:

<http://www.csc.noaa.gov/digitalcoast/data/benthiccover/download.html>

Online_Linkage: <http://www.csc.noaa.gov/>

Description:

Abstract:

Humboldt Bay is the largest estuary in California north of San Francisco Bay and represents a significant resource for the north coast region. Beginning in 2007 the Coastal Services Center began collaborating with the California SeaGrant program and other local partners to support an ecosystem-based management (EBM) project for Humboldt Bay. One element of this project was to develop subtidal habitat goals for the long-term management of the bay and provide a framework for conservation and management across the land-sea interface. The imagery collection and benthic habitat delineation for Humboldt Bay were essential to the development of subtidal goals and implementation of EBM for the region. Together, these efforts will provide important and replicable data and an information framework for ecosystem-based coastal and marine conservation planning and implementation. 12 Bit 4 Band imagery was collected in June,2009 within 1 hour of either side of a minus one (-1) foot tide with low turbidty,low wind,low sun angle and no cloud cover. The horizontal spatial accuracy of the imagery is within +/- 3 meters CE95 of position on the ground and was captured at a spatial resolution (pixel size) of 0.54m x 0.54m. The imagery was tiled and named according to the existing USGS digital ortho quarter quad boundaries (ex. Arcata_South_NE.tif). A small buffer (~100 m) was produced with each tile to prevent gaps in coverage. Habitat features were interpreted and digitized on screen in an ARCGIS Geodatabase 9.3 resulting in accurate and efficient 3D extraction of the data. Habitats were delineated with a high level of detail with the minimum mapping unit (MMU) being 0.01 hectares(approx.10m x 10m).

Purpose:

The data was developed to support ecosystem based management in the Humboldt Bay region. The focus of the mapping was on shallow water benthic habitats with particular concern for eelgrass meadows.

Supplemental_Information:

The study area covers Arcata (North) Bay, Entrance Bay, South Bay and the Eel River Delta, Humboldt County, California.

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 20090627

Currentness_Reference: ground condition

Status:

Progress: Complete
Maintenance_and_Update_Frequency: None planned
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -124.391793
East_Bounding_Coordinate: -124.003949
North_Bounding_Coordinate: 40.964791
South_Bounding_Coordinate: 40.539057
Keywords:
Theme:
Theme_Keyword_Thesaurus: ISO 19115 Topic Category
Theme_Keyword: environment
Theme_Keyword: imageryBaseMapsEarthCover
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: Environmental Monitoring
Theme_Keyword: NOAA
Theme_Keyword: Benthic
Theme_Keyword: Habitat
Theme_Keyword: UC Sea Grant
Place:
Place_Keyword_Thesaurus: none
Place_Keyword: U.S.
Place_Keyword: California
Place_Keyword: Humboldt Bay
Place_Keyword: Eel River Delta
Place_Keyword: Arcata Bay
Place_Keyword: Entrance Bay
Place_Keyword: South Bay
Access_Constraints: Data is available upon request
Use_Constraints:
Data should not be changed or modified by anyone other than NOAA
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: CRS Program Manager
Contact_Address:
Address_Type: mailing and physical
Address: 2234 South Hobson Avenue
City: Charleston
State_or_Province: SC
Postal_Code: 29405-2413
Country: USA
Contact_Voice_Telephone: 843-740-1200
Contact_Electronic_Mail_Address: clearinghouse@noaa.gov
Security_Information:
Security_Classification_System: None
Security_Classification: Unclassified
Security_Handling_Description: None
Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 3; ESRI ArcCatalog 9.3.1.3000

Data_Quality_Information:

Attribute_Accuracy:

Attribute_Accuracy_Report:

Polygon labels and boundaries were visually inspected for delineation precision and attribute accuracy. Thematic accuracy assessment methods: The thematic accuracy of the benthic habitat data set was assessed in two phases. The first phase took place in between September 14 and 18 2009, in the same season as image acquisition but prior to any mapping having been completed. A total of 128 points were visited on this trip. The points were selected manually to ensure that both representative habitats visible in the imagery as well as areas of potential confusion. The second phase also involved field visits which took place in May 10 through 13 2010. A total of 24 points were manually selected and visited after reviewing the draft habitat map. Navigation to each field point is accomplished using the source imagery as a backdrop, a real time Wide Area Augmentation System (WAAS) enabled GPS (Garmin 76 unit), and a ruggedized field lap top PC . The PC displays the image of the area with each "target" point as well as a real time symbol display of the boat location via the GPS. This system allows navigation precisely to the "target" point. In shallow or extremely clear water or during low tides when the bottom was exposed direct observations were made from the boat. In deeper areas or areas of unclear water a towed underwater video camera with live feed to a monitor on the boat was deployed. The camera was towed long enough (~2-4 minutes) at each station to provide a complete assessment of the dominate habitat type. The "field" classes were recorded to at least the two digit SCHEME classification level and where possible to the three digit level. The field points were sorted by habitat subclass and additional points were selected through a stratified random sampling process to generate a total of 50 points per class which would support a statistically valid accuracy assessment. These points were visually interpreted by viewing the source imagery. A total of 132 points were analyzed in this way. All the points were assembled into an error matrix where the "field" classification is compared to the "map" classification of each point by category. The resulting accuracy for the Humboldt Bay benthic habitat data at the 2 digit SCHEME classification code level is 84% with a kappa coefficient of 0.793.

Logical_Consistency_Report:

Polygon topology present. All polygons were tested for slivers. Every polygon has a label, there are no multiple labels within polygons, there are no contiguous polygons.

Completeness_Report:

Minimum mapping unit for habitat polygons was 10 square meters. The study area boundaries for the project were defined by NOAA. Benthic habitat features were captured and classified according to the rules, conventions, and descriptions in the Statement of Work.

Positional_Accuracy:

Horizontal_Positional_Accuracy:

Horizontal_Positional_Accuracy_Report:

The positional accuracy of this data meets USGS NMAS for 1:12000 scale maps. Horizontal accuracy of the data corresponds to the positional accuracy of the aerotriangulated photography that was controlled by GPS survey control points.

Lineage:

Source_Information:

Source_Citation:

Citation_Information:

Originator: Photo Science, Inc

Publication_Date: 2009

Title: 2009 Benthic Habitat DMC Imagery

Source_Scale_Denominator: 12000

Type_of_Source_Media: Digital orthophotos

Source_Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 20090627

Source_Currentness_Reference: ground condition

Source_Citation_Abbreviation: none

Source_Contribution:

photographic signature for interpretation of benthic habitat data.
Process_Step:
Process_Description:
The imagery was flown on 6/27/2010 between 9:35 and 10:24 A.M. by HJW geospatial Pacific Aerial Surveys The horizontal spatial accuracy of the imagery is within +/- 3 meters CE95 of position on the ground. The radiometric resolution of the 4 band image composites is 12-bit. The imagery was processed to remove atmospheric effects such as haze and to highlight the spectral response of submerged areas. The imagery has a minimal exposure variation between adjacent flight lines. The 4 band imagery is tiled and named according to the existing USGS digital ortho quarter quad boundaries (ex. Arcata_South_NE.tif). A small buffer (~100 m) was produced with each tile to prevent gaps in coverage. The tiles are in GeoTIFF format. An index shape file indicating the image file name, location in the final file structure and the USGS tile name is included to enable users to easily identify the location of an individual tile. The 4 band image sets was delivered within a "Unmanaged Raster Catalog" created within the ESRI GeoDatabase structure to serve as an easy method for users to access the images The imagery was captured at a spatial resolution (pixel size) of 0.54m x 0.54m and was delivered in a Universal Transverse Mercator - Zone 10 projection using the NAD1983 datum.
Process_Date: 20100609
Cloud_Cover: 0

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 2165

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: Universal Transverse Mercator
Universal_Transverse_Mercator:
UTM_Zone_Number: 10
Transverse_Mercator:
Scale_Factor_at_Central_Meridian: 0.999600
Longitude_of_Central_Meridian: -123.000000
Latitude_of_Projection_Origin: 0.000000
False_Easting: 500000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 1.0
Ordinate_Resolution: 1.0
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: ca_hb09
Entity_Type_Definition: SCHEME class
Entity_Type_Definition_Source: NOAA
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: CLASS
Attribute_Definition:
Classes describe the general dominant life forms or the physiography and composition of the substrate.
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: SUBCLASS1
Attribute_Definition:
Subclasses define habitats with finer resolution descriptions or with geographic extents that require field measurements for verification.
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: SUBCLASS2
Attribute_Definition:
Subclasses define habitats with finer resolution descriptions or with geographic extents that require field measurements for verification.
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: SUBCLASS3
Attribute_Definition:
Subclasses define habitats with finer resolution descriptions or with geographic extents that require field measurements for verification.
Attribute_Definition_Source: SCHEME

Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: SUBCLASS4
Attribute_Definition:
Subclasses define habitats with finer resolution descriptions or with geographic extents that require field measurements for verification.
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: Modifier
Attribute_Definition:
The modifiers allow detailed information to be included at all levels of the structure.
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: TAXONOMIC
Attribute_Definition:
Taxonomic modifiers classify complex habitats with mixed geological and biological components.
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission
Attribute:
Attribute_Label: SCHEME_COD
Attribute_Definition: Numeric value for SCHEME class and subclass units
Attribute_Definition_Source: SCHEME
Attribute_Domain_Values:
Codeset_Domain:
Codeset_Name: SCHEME System
Codeset_Source: Florida Fish and Wildlife Conservation Commission

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: NOAA Coastal Services Center
Contact_Position: Clearinghouse Manager
Contact_Address:
Address_Type: mailing and physical
Address: 2234 South Hobson Avenue
City: Charleston
State_or_Province: SC
Postal_Code: 29405-2413
Country: USA

Contact_Voice_Telephone: 843 740 1210
Contact_Facsimile_Telephone: 843 740 1224
Contact_Electronic_Mail_Address: clearinghouse@noaa.gov
Resource_Description: Downloadable Data
Distribution_Liability:
NOAA manages much of the data to users of digital geographic data.NOAA is in no way condoning or endorsing the application of this data for any given purpose.It is the sole responsibility of the user to determine whether or not the data is suitable for the intended purpose.It is also the obligation of the user to apply the data in an appropriate and conscientious manner.NOAA provides no warranty,nor accepts any liability occurring from any incomplete,incorrect, or misleading data, or from any incorrect,incomplete, or misleading use of the data.Much of the data is based on and maintained with ARC/GIS software developed by the Environmental Systems Research Institute (ESRI).In addition, much of the information presented uses conventions and terms popularized by ARC/GISand its user community.NOAA in no way represents the interests of ESRI,nor acts as agents for them.

Metadata_Reference_Information:
Metadata_Date: 20100625
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: NOAA Coastal Services Center
Contact_Position: Clearinghouse Manager
Contact_Address:
Address_Type: mailing and physical
Address: 2234 South Hobson Avenue
City: Charleston
State_or_Province: SC
Postal_Code: 29405-2413
Country: USA
Contact_Voice_Telephone: 843-740-1210
Contact_Electronic_Mail_Address: clearinghouse@noaa.gov
Metadata_Standard_Name: FGDC Content Standard for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Extensions:
Online_Linkage: <http://www.esri.com/metadata/esriprof80.html>
Profile_Name: ESRI Metadata Profile

Appendix C. Special status species occurring in the study area (FWS 2009).

Taxon	Scientific Name	Common Name	Status	Habitat Type
Amphibians	*Rana aurora aurora*	Northern Red-Legged Frog	CA: SSC	freshwater emergent wetland, riverine, wet meadow
Birds	*Agelaius tricolor*	Tricolored BlackBirds	FED: BCC CA: SSC	freshwater emergent wetland, pasture
Birds	*Ammodramus savannarum*	Grasshopper sparrow	CA: SSC	grasslands
Birds	*Asio flammeus*	Short-Eared Owl	CA: SSC	wide variety of habitats
Birds	*Asio otus*	Long-Eared Owl	CA: SSC	wide variety of habitats
Birds	*Aquila chrysaetos*	Golden Eagle	FED: BBC CA: Fully protected	wide variety of habitats
Birds	*Athene cunicularia*	Burrowing Owl	CA: SSC FED: BCC	annual, perennial grassland
Birds	*Brachyramphus marmoratus*	Marbeled Murrelet	FED: Threatened CA: Endangered; Critical Habitat	old growth forest, ocean
Birds	*Branta bernicla*	Brant	CA: SSC	shallow bays and estuaries
Birds	*Buteo swainsoni*	Swainson's Hawk	CA: Threatened	annual, perennial grassland
Birds	*Chaetura vauxi*	Vaux's Swift	CA: SSC	riparian, also upland forest nesting, foraging in wide variety of habitats
Birds	*Charadrius alexandrinus nivosus*	Western Snowy Plover (Coastal Population)	FED: Threatened, FED: BCC (full species) CA: SSC	shoreline, dunes
Birds	*Chlidonias niger*	Black Tern	CA: SSC	marine, estuarine, wet meadow
Birds	*Circus cyaneus*	Northern Harrier	CA: SSC	wide variety of habitats

Taxon	Scientific Name	Common Name	Status	Habitat Type
Birds	*Coccyzus americanus*	Western Yellow-billed Cuckoo	FED: Candidate CA: Endangered	open woodlands, dense shrub layers
Birds	*Contopus cooperi*	Olive-Sided Flycatcher	FED: BCC CA: SSC	Douglas-fir forest, also found in other habitats
Birds	*Cypseloides niger*	Black Swift	FED: BCC CA: SSC	grasslands
Birds	*Dendroica petechia brewsteri*	Yellow Warbler	CA: SSC	montane riparian, valley foothill riparian woodland
Birds	*Elanus leucurus*	White-Tailed Kite	CA: Fully Protected	freshwater, saline emergent wetland, annual grassland
Birds	*Empidonax traillii*	Willow Flycatcher	CA: Endangered	montane riparian, valley foothill riparian woodland
Birds	*Falco peregrinus anatum*	American Peregrine Falcon	FED: BBC CA: Delisted, Fully Protected	variety of habitats
Birds	*Fratercula cirrhata*	Tufted Puffin	CA: SSC	marine, offshore rocks
Birds	*Haliaeetus leucocephalus*	Bald Eagle	FED: Threatened FED: DelistedCA: Delisted, Fully protected	wide variety of habitats
Birds	*Icteria virens*	Yellow-Breasted Chat	CA: SSC	valley-foothill riparian
Birds	*Lanius ludovicianus*	Loggerhead Shrike	FED: BCC CA: SSC	wide variety of habitats
Birds	*Melanerpes lewis*	Lewis' Woodpecker	FED: BCC	wide variety of habitats
Birds	*Oceanodroma furcata*	Fork-Tailed Storm-Petrel	CA: SSC	marine, offshore rocks
Birds	*Pelecanus erythrorhynchos*	American White Pelican	CA: SSC	estuarine

Taxon	Scientific Name	Common Name	Status	Habitat Type
Birds	*Pelecanus occidentalis*	Brown Pelican	FED: Threatened CA: Fully Protected	marine
Birds	*Phoebastris albatrus*	Short-tailed Albatross	FED: Endangered	open ocean
Birds	*Progne subis*	Purple Martin	CA: SSC	wide variety of habitats
Birds	*Ptychoramphus aleuticus*	Cassin's Auklet	FED: BCC CA: SSC	marine, offshore rocks
Birds	*Riparia riparia*	Bank Swallow	CA: Threatened	valley-foothill riparian
Birds	*Sterna caspia*	Caspian Tern	FED: BCC	freshwater emergent wetland, marine, riverine, estuarine
Birds	*Strix occendentalis caurina*	Northern Spotted Owl	FED: Threatened; Critical Habitat CA: SSC	forest, multi-canopied
Birds	*Synthliboramphus hypoleucus*	Xantus's Murrelet	FED: Candidate CA: Threatened	ocean, offshore islands
Fish	*Acipenser medirostris*	North American Green Sturgeon	CA: SSC FED: Threatened Southern DPS; Proposed Critical Habitat for Southern DPS	riverine, marine, estuarine
Fish	*Eucyclogobius newberryi*	Tidewater Goby	FED: Endangered CA: SSC	riverine, estuarine
Fish	*Lampetra tridentata*	Pacific lamprey	CA: SSC	estuarine
Fish	*Oncorhynchus clarki clarki*	Coast Cutthroat Trout	CA: SSC	marine, estuarine, riverine
Fish	*Oncorhynchus kisutch*	Coho Salmon - Southern Oregon / Northern California ESU	CA, FED: Threatened	marine, estuarine, riverine

Taxon	Scientific Name	Common Name	Status	Habitat Type
Fish	*Oncorhynchus mykiss*	Steelhead- Northern California ESU	FED: Threatened CA: SSC	marine, riverine, estuarine
Fish	*Oncorhynchus tshawytscha*	Chinook Salmon - California Coastal ESU	FED: Threatened	marine, riverine, estuarine
Fish	*Spirinchus thaleichthys*	Longfin Smelt	CA: Threatened	estuarine, riverine
Fish	*Thaleichthys pacificus*	Eulachon, Southern DPS	FED:PT CA: SSC	marine, riverine, estuarine
Mammals	*Arborimus albipes*	White-Footed Vole	CA: SSC	redwood, Douglas fir, riparian forest
Mammals	*Eumetopias jubatus*	Steller (northern) Sea-Lion	FED: Threatened	marine, offshore rocks
Plants	*Abronia umbellata ssp. brevifolia*	Pink Sand Verbena	CA: Special Plant	dune mat
Plants	*Castilleja ambigua ssp. humboldtiensis*	Humboldt Bay Owl's Clover	CA: Special Plant	saline estuarine marsh
Plants	*Cordylanthus maritimus Benth. ssp. palustris*	Point Reyes Bird's-beak	CA: Special Plant	saline estuarine marsh
Plants	*Erysimum menziesii ssp. eurekense*	Humboldt Bay Wallflower	FED: Endangered CA: Endangered	dune mat
Plants	*Layia carnosa*	Beach Layia	FED: Endangered CA: Endangered	dune mat
Reptiles	*Emys (Clemmys) marmorata marmorata*	Northwestern Pond Turtle	CA: SSC	wide variety of habitats

FED=listed under the Federal Endangered Species Act
CA=listed under the California Endangered Species Act
SSC=Species of Special Concern
BCC=Birds of Conservation Concern
DPS=Distinct Population Segment.

Listing Categories

California Endangered Species Act (CESA) Listing Codes:
• CA: E State-listed as Endangered
• CA: T State-listed as Threatened
• CA: CE State candidate for listing as Endangered
• CA: CT State candidate for listing as Threatened
• CA: CD State candidate for delisting

Endangered Species Act (ESA) Listing Codes:
• FED: E Federally listed as Endangered
• FED: T Federally listed as Threatened
• FED: PE Federally proposed for listing as Endangered
• FED: PT Federally proposed for listing as Threatened
• FED: PD Federally proposed for delisting
• FED: C Federal candidate species (former Category 1 candidates)
• FED: SC Species of Concern – list established by National Marine Fisheries Service (NMFS) *effective 15 April 2004*

Other Codes:
SSC: California Species of Special Concern. It is the goal and responsibility of the Department of Fish and Game to maintain viable populations of all native species. To this end, the Department has designated certain vertebrate species as “Species of Special Concern” because declining population levels, limited ranges, and/or continuing threats have made them vulnerable to extinction. More information is available on the Department’s web site at: http://www.dfg.ca.gov/hcpb/species/ssc/ssc.shtml. All of the Species of Special Concern reports are now available on-line:
Birds: http://www.dfg.ca.gov/hcpb/info/bird_ssc.shtml.
Mammals: http://www.dfg.ca.gov/hcpb/info/mammal_ssc.shtml.
Fish: http://www.dfg.ca.gov/hcpb/info/fish_ssc.pdf.
Amphibians & Reptiles: http://www.dfg.ca.gov/hcpb/info/herp_ssc.pdf.

Fully Protected: The classification of Fully Protected was the State’s initial effort to identify and provide additional protection to those animals that were rare or faced possible extinction. More information on Fully Protected species and the take provisions can be found in the Fish and Game Code, (birds at ¤3511, mammals at ¤4700, reptiles and amphibians at ¤5050, and fish at ¤5515). Additional information on Fully Protected fish can be found in the California Code of Regulations, Title 14, Division 1, Subdivision 1, Chapter 2, Article 4, ¤5.93. The category of Protected Amphibians and Reptiles in Title 14 has been repealed. The Fish and Game Code is available online at: http://www.leginfo.ca.gov/cgibin/calawquery?codesection=fgc. Title 14 of the California Code of Regulations is available at: http://ccr.oal.ca.gov.

BCC: US Fish and Wildlife Service has designated Birds of Conservation Concern: The goal of the Birds of Conservation Concern 2002 report is to accurately identify the migratory and nonmigratory bird species (beyond those already designated as Federally threatened or endangered) that represent our highest conservation priorities and draw attention to species in need of conservation action.
Vagrant: Visitor or vagrant. Those with very few records, and not expected but once in every 5 to 10+ years.

This report is available at: http://library.fws.gov/Bird_Publications/BCC2002.pdf