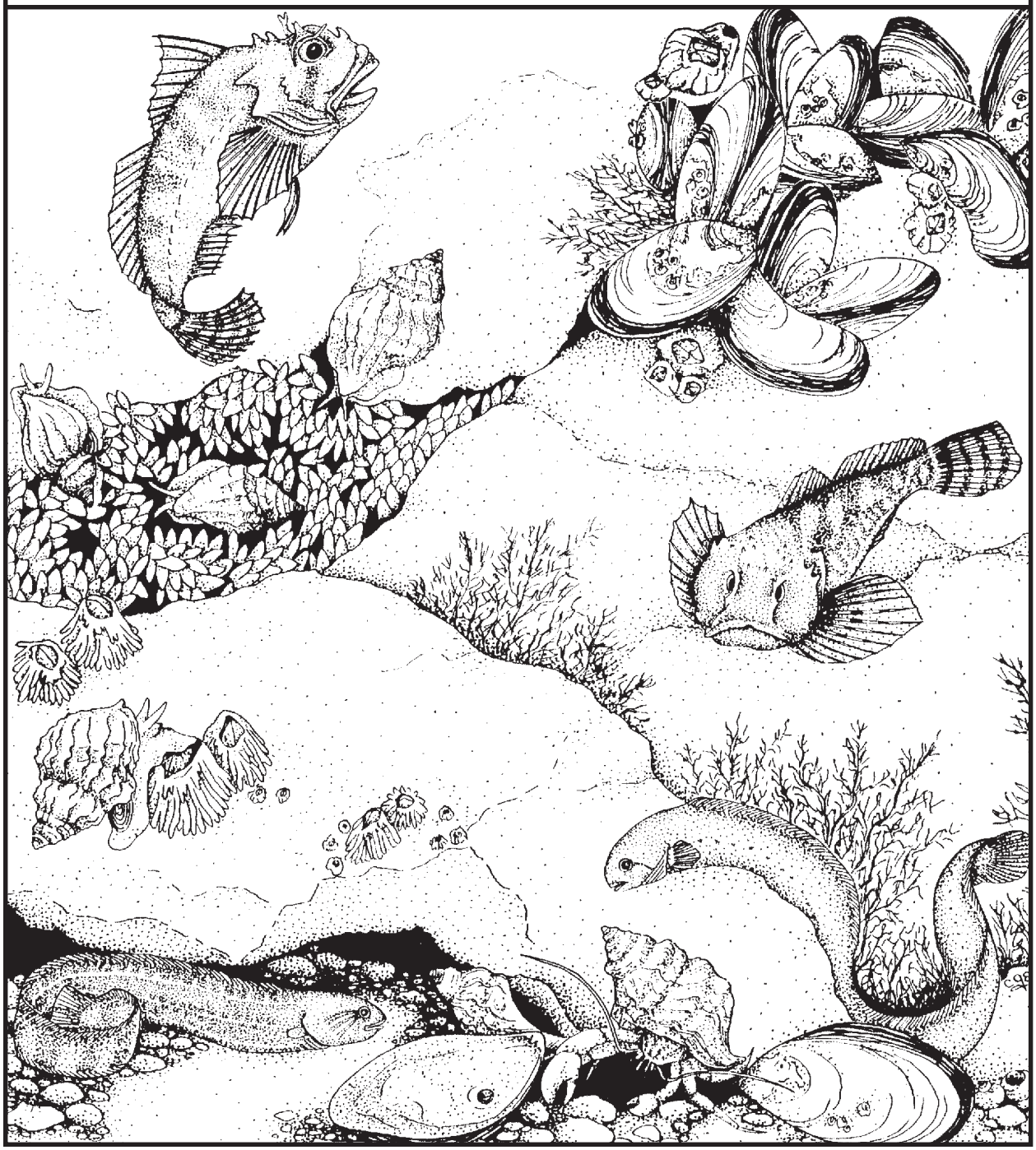
A Marine and Estuarine Habitat Classification System for Washington State



WASHINGTON STATE DEPARTMENT OF
Natural Resources

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Table of Contents

Acknowledgements	inside front cover
Abstract	5
Preface	6
Introduction	7
Outline of the System	8
Definitions	10
Description of Habitats	15
Marine Systems	15
Estuarine Systems	29
Bibliography	47
Appendix A - Translation Table	A-1

Abstract

A classification system for marine and estuarine habitat types in Washington State is described. It builds on the National Wetland Inventory scheme of Cowardin, but (1) adds an "Energy" level in the hierarchy to incorporate the critical importance of waves and currents in structuring marine communities; and (2) removes the "Aquatic Bed" categories from all levels, making substratum type (by itself) one of the highest levels in the hierarchy. Definitions generally concur with those of Cowardin, although a geographic (not salinity-based) line for the marine-estuarine boundary had to be drawn for the northern Puget Trough.

Marine and estuarine habitats are thus defined by their depth, substratum type, energy level and a few modifiers. For each combination of these physical variables, species (plants and animals) that are diagnostic of the habitat are described based on surveys from around the state. Other species commonly found in each community (including fishes and birds) are listed also, as are locations where such habitats have been surveyed. Approximately 60 intertidal and subtidal habitats are described in this fashion. An extensive bibliography is appended.

Preface

This document presents a classification system designed to identify and describe marine and estuarine natural communities in Washington State, covering the full array of nearshore habitat types. Its primary purposes are to:

- Serve as a framework for existing data and future inventory work on the status and distribution of exemplary marine and estuarine communities in the state. Eventually it will allow selection and ranking of sites for marine preserves.

- Aid in the statewide effort to map intertidal and shallow subtidal lands by providing mapping units, thus creating maps with uniform terminology useful to resource managers and planners. The mapping units (nearshore habitat types, each with a distinct physical regime) have an ecological basis, and eventually may allow mapping overlays of functions of different community types. To make effective decisions, land use planners, regulators and agency personnel need information not found in the National Wetland Inventory maps. This classification system should provide that detail by facilitating collection, organization and presentation of information describing the characteristics of nearshore marine and estuarine environments that make them important to humans (e.g., fish and wildlife habitat).

Introduction

An effective classification system must weigh ecological reality (and complexity) against the need to remain tractable. The system described here builds upon the wetland classification scheme of Cowardin et al. (1979), using its definitions wherever possible but making additions that increase its ecological reality for the marine realm. Appendix A illustrates how categories in the Cowardin scheme correspond to categories in the system described below.

Departure from the Cowardin/National Wetland Inventory System

The Cowardin et al. (1979) system has several limitations with regard to adopting it for marine and estuarine classification in this state.

First, it does not explicitly include exposure to waves and currents as a part of the hierarchy, yet Cowardin et al. (and most workers in marine systems) acknowledge this as one of the most important factors controlling the distribution of marine organisms. The system described here adds an "Energy" level in the hierarchy, just below substratum type (see below).

Second, there is high redundancy between the "Class" (Rock / Unconsolidated / Aquatic Bed) and "Subclass" (Bedrock, etc.) levels (see Appendix A), and sometimes also with the "Dominance" level. While practical from the limitations of aerial photography, this mixed hierarchy confounds the classification process as well as "wasting" a hierarchical level. The system suggested below eliminates this redundancy by making the "Class" level as Substratum (only).

A related problem with Cowardin's "Class" category of "Aquatic Bed" is that any vegetation-dominated unit falls out here, rapidly defining dominance types but bypassing the definition of substratum type. In marine communities, areas of different substrata may have the same dominant species (e.g., kelp on bedrock or cobbles, eelgrass in sand or mud), but these different substrata will be occupied by very different co-dominants. Stopping community definition at the dominant overstory species ignores important differences in understory layers or less common species. Thus communities that differ in composition and diversity (and probably function) are not always separated under the Cowardin system.

In addition, marine and estuarine "aquatic beds" are more variable and transient than terrestrial vegetation types; defining and mapping a community solely on the basis of current vegetation dominance will often be misleading. Vegetation types become key at the "Dominance Type" or "Diagnostic Species" level in the system described here, and higher levels are all descriptors of the physical environment.

In marine and estuarine ecosystems, a limited set of physical parameters — substratum types, wave or current energy, salinity, and depth or elevation — strongly constrain the distributions and interactions of marine plants and animals. The more physical constraints considered, the greater the predictive power we gain about the organisms present. The hierarchy of physical factors used in this classification should provide reasonable predictability of "Dominance types." The end product or lowest level of this classification scheme can be described either as "Dominance Types," as determined above and in agreement with Cowardin, or as "Natural Community Types," in keeping with other Heritage Program classifications. Thus we can refer to either a "Marine intertidal exposed bedrock community" or a "*Mytilus* / kelp dominated" habitat.

A natural community can be defined as a distinct and recurring assemblage of plants and animals naturally associated with each other and with a particular physical environment. The habitats listed below are distinguished by their physical constraints and by their biotic communities: the composition of resident organisms. Habitats and their communities are seldom as distinct as we would like them to be, but this classification attempts to establish a set of discrete categories into which they can be sorted.

Marine landscapes, perhaps even more than terrestrial ones, are characterized by a high degree of patchiness. Organisms often form mosaics even when the physical environment seems uniform. In other cases there is a clear change in dominance types over a gradient (e.g., from high to low zone on a rocky shore). In many communities, temporal changes are common, either with season or with successional state.

Incorporating these dynamic attributes as well as spatial variation into a classification scheme is very difficult. Ideally, a classification should seek uniformity of organisms within a stand, but this would not be possible in the marine realm unless a "stand" was extremely small — making a small patch of organisms into the unit of classification. Rather than multiplying the numbers of habitats described to encompass all variations, habitats that contain either mosaics or gradients (spatial or temporal) are described by listing several dominance types for each.

OUTLINE OF THE SYSTEM (OMITTING MODIFIERS)

The following includes only habitat types that exist (and have been surveyed) in Washington. It is subject to modification.

"Nothing living can escape the influence of the environment which furnishes its means of existence." (Molinier, 1959)

MARINE

Intertidal

- Rock (Solid bedrock)
  - Exposed (wave action)
  - Partially exposed
  - Semi-protected and Protected
- Boulders
  - Exposed
  - Partially exposed
  - Semi-protected
- Hardpan
- Cobble
  - Partially exposed
- Mixed-Coarse
  - Semi-protected to Protected
- Gravel
  - Partially exposed
  - Semi-Protected
- Sand
  - Exposed and Partially exposed
  - Semi-protected
- Mixed-Fine
  - Semi-protected and Protected
- Mud
  - Protected
- Organic (e.g., wood chips, marine detritus)
- Artificial (e.g., pilings, tires, concrete)
- Reef (e.g., oyster, worm) (not important in Washington)

Subtidal

- Bedrock and boulders
  - Moderate to high energy
  - Low energy
- Cobble
  - High energy
- Mixed-Coarse
  - Moderate to high energy
  - Low energy
- Gravel
  - High energy
- Mixed-Fine
  - High energy
  - Moderate energy
  - Low energy
- Mud and Mixed-Fine
  - Low energy
- Organic
- Artificial
- Reef

ESTUARINE

Intertidal

- Bedrock: Open
- Hardpan
- Mixed-Coarse: Open
- Gravel
  - Open
  - Partly enclosed, Eulittoral
- Sand
  - Open
  - Partly enclosed, Eulittoral
  - Lagoon
- Mixed-Fine
  - Partly enclosed
  - Lagoon
- Mixed-Fine and Mud
  - Partly enclosed, Eulittoral
  - Lagoon
  - Channel-Slough
- Mud: Partly enclosed and enclosed
- Organic: Partly enclosed, Backshore
- Artificial
- Reef

Subtidal

- Bedrock-Boulder: Open
- Cobble: Open
- Mixed-Coarse: Open
- Sand
  - Open
  - Partly enclosed
- Mixed-Fines: Open
- Mud
  - Open
  - Partly enclosed
- Sand and Mud: Channel
- Organic
- Artificial
- Reef

DEFINITIONS

Wherever possible, definitions follow those of Cowardin et al. (1979). These are refined or clarified below.

Systems

Marine System

The Marine System encompasses all coastal areas not appreciably diluted by freshwater (surface salinities seldom falling below 30 ppt), including open coastal areas, straits, and euhaline inland waters. It can extend from the outer edge of the continental shelf to (1) the landward limit of tidal inundation or wave splash or (2) the seaward limit of the Estuarine System. This classification does not deal extensively with deep waters (e.g., those below the photic zone) where benthic plant growth is impossible. We primarily are classifying nearshore habitats.

Estuarine System

The Estuarine System generally consists of waters that are semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, and in which seawater is at least occasionally diluted by freshwater runoff from land. It extends upstream and landward to where ocean-derived salts near the water surface measure <0.5 ppt during the period of average annual low flow, and downstream or out to sea to where freshwater dilution is minimal (salinities seldom falling below 30 ppt). The Estuarine System thus includes classic river-mouth estuaries, lagoons, and large bodies of water such as Puget Sound and the Strait of Georgia which are signficantly diluted by freshwater input from numerous sources.

Many areas in the Puget Trough are difficult to categorize as either Estuarine or Marine. In these transition areas, salinities are generally high (>25 ppt) and the assemblages resemble those in truly marine waters, but surface salinities occasionally drop lower than this, and circulation and nutrient levels are influenced by estuarine processes. The San Juan Islands fall into this category. Extensive turbulent mixing, combined with strong tidal flow from Juan de Fuca Strait into deep, narrow channels (Thompson and Robinson, 1934; Thomson, 1981) generally keep salinities and nutrient levels high. Most regional scientists consider the flora and fauna to be marine. However, the strong influence of the Fraser River from the north occasionally causes large drops in surface salinities, and areas to the east are influenced by freshwater runoff into Bellingham, Padilla, and Skagit Bays.

Rather than rely on a purely salinity-based Marine/Estuarine cutoff for this area (which would require arbitrary definition not only of a salinity level but also a frequency for this level of intrusion), we have drawn a geographic boundary for this transition through Rosario Strait. Areas to the east of a line from Green Point (Fidalgo Island) to Lawrence Point (Orcas Island) are considered Estuarine, as are all of the Strait of Georgia and the San Juans north of Orcas. Areas to the west are Marine (including islands on both sides of Haro Strait), as is the west side of Whidbey Island down to Admiralty Head. To the east of Deception Pass, and to the south and east of Admiralty Head (and south of Point Wilson on the Quimper Peninsula) is Puget Sound proper, which is considered to be entirely estuarine. Deeper waters (> approx. 50 m) in all these areas are quite "marine" in terms of both salinities and assemblages, but are defined as Estuarine along with their accompanying shallower zones.

In the "Marine" areas outside this invisible line there clearly exist some estuarine pockets: Dungeness Bay (Dungeness River), Sequim Bay (enclosed, with stream input), the outer coast estuaries of Grays Harbor and Willapa Bay, and perhaps others. Discovery Bay, which is relatively open and has little freshwater input, is considered marine.

Subsystems

The INTERTIDAL subsystems (both Marine and Estuarine) include the substratum from extreme low water of spring tides (ELWS=ELLW) to the upper limit of spray or influence of ocean-derived salts. It includes all land that is sometimes submerged but sometimes exposed to the air: mud and sand flats, rocky shores, salt marshes, and even terrestrial areas where salt influence is still seen. ELWS is used rather than the 0 datum (MLLW), because the desiccation experienced during the frequent tides falling below MLLW appears to limit the distribution of many species. This very low zone is more "intertidal" than "subtidal," although it clearly is transitional.

The SUBTIDAL subsystems include any benthic habitat below ELWS (i.e., any substratum that is constantly submerged). The habitats described in this document are mostly within the photic zone (i.e., shallower than about 40 meters in the waters of Washington).

Classes: Substrata

- Consolidated

Bedrock
Boulders: Rocks >256 mm (=10") diam. — those large enough not to be rolled by moderate wave action.
Hardpan: Consolidated clays forming a substratum firm enough to support an epibenthos and too firm to support a normal infauna (clams, worms, etc.), but with an unstable surface which sloughs frequently.

- Unconsolidated

Cobble: rocks <256 mm but >64 mm (2.5") diameter — unstable
Mixed-coarse: substrata consisting of cobbles, gravel, shell, and sand (no one substratum type exceeding 70 percent surface cover)
Gravel: small rocks or pebbles, 4-64 mm diam.
Sand: .06-4 mm
Mixed-Fine: mixture of sand and mud, with little gravel, likely to change seasonally
Mud: fine substrata <.06 mm, usually mixed with organics
Organic: substrata composed primarily of organic matter such as wood chips, leaf litter, other detritus.

- Artificial

Concrete blocks
Tires
Bulkheads
Riprap
Log booms
Pilings (concrete or wood)
Oyster culture
Junk/Other

- Reefs — oyster, coral, polychaete worm (not important in Washington).

Energy

While energy levels are critical to marine organisms, a rigorous categorization of degree of wave exposure is almost impossible. Subjective decisions will probably have to be made. For MARINE INTERTIDAL systems, we define the following four categories:

- Exposed: Highly exposed to oceanic swell and wind waves. Wind fetch virtually unlimited.

- Partially exposed: Oceanic swell attenuated by offshore reefs, islands, or headlands, but shoreline substantially exposed to wind waves.

- Semi-Protected: Shorelines protected from sea swell, but may receive waves generated by moderate wind fetch.

- Protected: No sea swell, little or no currents, and restricted wind fetch.

For MARINE SUBTIDAL areas, we recognize three categories based largely on current regime, although in areas exposed to oceanic swell this will affect subtidal environments as well:

- High energy: Exposed to oceanic swell or very strong currents.

- Moderate energy: Exposed to only wind waves, but moderate tidal currents.

- Low energy: Exposed to only very weak or no currents, and little wave action.

For ESTUARINE systems (Intertidal and Subtidal), we recognize four energy / enclosure categories:

- Open: Shorelines exposed to moderate to long fetch and receiving some wind waves and / or currents, but still diluted by freshwater as defined under Estuarine. Headlands and many beaches within Puget Sound fall within this category.

- Partly Enclosed: Bays or river mouths partially enclosed by headlands, bars, spits, or artificial obstructions reducing circulation. Minimal wave action or currents. Drift algae and seagrass often concentrate here.

- Lagoon: Protected, largely-enclosed pond or embayment, flushed regularly or irregularly because tidal influence is partially blocked by a spit.

- Channel / Slough: Open or blind narrow inlets, (e.g., abandoned stream channels) constantly submerged and with tidal backup water at high tide. Subtidal channels are deeper areas carrying much of the water mass discharged from a river.

Modifiers

MARINE systems will have one additional modifier, depth. For Intertidal subsystems, the categories are:

- Backshore: Areas above mean high water line of spring tides (MHWS) but still receiving marine influence, through spray or irregular flooding. High salt marshes and transition-zone wetlands fall into this category.

- Eulittoral: Areas between MHWS and ELWS, regularly inundated and uncovered by the tides.

For Subtidal subsystems, the categories are:

- Shallow: 15 m or less below MLLW

- Deep: deeper than 15 m below MLLW.

Deeper categories are occasionally noted where information on these habitats was available. There are few distinct transitions with depth among subtidal assemblages, so any cutoff is somewhat arbitrary. The shallow / deep transition was chosen to be 15 m because most of the large brown seaweeds (kelps) drop out below this depth, and primary production generally is reduced. Precise lower limits vary with site, water clarity, and season.

ESTUARINE systems will use the above modifiers for intertidal and subtidal depths, and in addition will have one other modifier for salinity. This modifier will likely only be used in distinguishing marsh and other backshore communities (lagoons, etc.). Definitions are according to Cowardin:

Hyperhaline:	>40 ppt
Euhaline:	30-40 ppt
Mixohaline (brackish):	0.5-30 ppt
Polyhaline:	18-30 ppt
Mesohaline:	5-18 ppt
Oligohaline:	0.5-5 ppt

For Heritage purposes, another modifier or qualifier will be used in the description of sites, although not in mapping: quality, or degree of disturbance or alteration. This would include comments or codes for structural alteration of the beach, degree of disturbance by clam digging or other harvesting activity, degree of invasion by exotics, etc.

Dominance types/diagnostic species

Cowardin et al. (1979) are vague on the subject of defining dominance. In this classification, "Diagnostic Species" are listed for each habitat type (where known). The term diagnostic is used because it both describes what is known — the species *characteristic* of a given habitat type — and because many communities cannot readily be said to have a "dominant" species. Often the two terms converge: for instance, in

habitats with eelgrass, or kelp, or sea pens. Usually no one species by itself is diagnostic of a habitat type, but the correlated occurrence of several species can be characteristic. The seagrass *Zostera* is listed as diagnostic in four different habitat types, each time with different co-dominants. Diagnostic / dominant species for each habitat type are chosen based on some or all of the following:

- The species (plant or animal) most abundant at the end of the growing season.

- A combination of numerical and biomass measures, since either alone can be skewed by small- abundant or large-rare individuals.

- The most "obvious" species in a habitat, but not if these are widely distributed among different habitats.

- The functionally-important species, either habitat-forming (eelgrass, mussel beds), or strongly-interacting (urchins, key predators). Diagnostic species are ones which are predictably present through time, whenever possible.

- The species with high "fidelity" to one habitat type — preferably restricted to one habitat type, even if not necessarily abundant.

Common species

Common plant and animal species are listed for each habitat type in addition to diagnostic species. Organisms smaller than 2-3 mm length are generally not listed, except where a smaller species is strikingly abundant. Common names are given for birds and fish, but invertebrates and plants are referred to by their Latin binomials due to lack (or ambiguity) of common names for them.

Habitats

The following habitat descriptions list plants and animals characteristic of the marine and estuarine habitats classified in the Washington Natural Heritage Program system. Habitat types are lumped where ecological differences among them are unclear (e.g., between some mud and mixed-fine habitats). Artificial habitats are not described at this time. They contain few unique organisms, since most hard artificial substrata will be occupied by rock-dwelling species. However, pilings and other wooden artificial structures contain unique wood-boring organisms, and subtidal structures often attract fish.

Marine systems

Intertidal habitats

Marine intertidal rock: exposed (eulittoral)

Bedrock habitats exposed to the full range of wave energies are found on the outer coast and in the western Strait of Juan de Fuca. Rock types range from soft sandstones to conglomerates to hard metamorphic and igneous types. Little is known of how community type varies with rock type. Communities of exposed rocky coasts are dominated by toughly constructed sessile plants and animals, and are usually distinctly zoned from the upper rocks reached by spray to the lowest levels. Low zones are usually algal-dominated and thus portions of this habitat could be mapped as "Aquatic Bed" under the NWI system. Productivity and biomass are high in these habitats. The three-dimensional aspect provided by the large algae and invertebrates contribute to the great spatial complexity and species diversity.

Diagnostic species

The California mussel *Mytilus californianus*, the sea palm *Postelsia palmaeformis* (most exposed areas only, and with patchy distribution), the gooseneck barnacle *Pollicipes polymerus* (= *Mitella polymerus*), and (in low zones) kelps in the genera *Laminaria* and *Lessoniopsis*.

Common associates

Several hundred species of macroscopic plants and animals may inhabit this diverse and productive community. Common plants seen most often on exposed coasts include (from high to low zones): the brown rockweed *Pelvetiopsis limitata,* diverse red algae including *Iridaea cornucopiae* (very high), *Iridaea splendens*, *Dilsea californica*, *Ptilota* and *Neoptilota* spp., encrusting and articulated coralline algae; the kelps *Hedophyllum sessile* and *Egregia menziesii*, and the surfgrass *Phyllospadix scouleri*. Common animals include the urchin *Strongylocentrotus purpuratus* (low), the limpets *Lottia pelta*, *L. strigatella*, *Acmaea mitra* and *Tectura scutum*, the chitons *Katharina tunicata* and *Mopalia* spp., four species of barnacles including the very large *Balanus nubilus* (very low), the ochre star *Pisaster ochraceus* and the six-rayed star *Leptasterias hexactis*, the nestling crab *Oedignathus inermis*, various compound ascidians and hydroids, the violet sponge *Haliclona permollis* and the crumb-of-bread sponge *Halichondria panicea*. Characteristic tidepool species include the green anemone *Anthopleura xanthogrammica*, and many fish.

Sites undisturbed by humans are used as feeding territories by black oystercatchers, and haulout and pupping sites by harbor seals and northern sea lions. Sea otters, mink, weasels, raccoon, and deer all forage occasionally in the rocky intertidal zone, as do gulls, crows, bald eagles, surfbirds, ruddy and black turnstones, rock sandpipers, and other shorebirds. At high tide, various subtidal fishes may forage in these habitats, including sea perch, sculpins, various rockfish, and cod, although there has been little investigation of this topic. Pools are occupied by various small fish: high cockscomb, sculpins (tidepool, calico, mosshead), northern clingfish, and black prickleback. Areas offshore of rocky sites are used by cormorants, scoters, harlequin ducks, and buffleheads.

Surveyed sites

Pillar Point, Waadah Island, Tatoosh Island, Portage Head, five sites in Olympic National Park.

Sources

Dethier, 1984, 1988; Paine, 1980; Dayton, 1971 and 1975; Cross et al., 1978; Nyblade, 1979b; Rigg and Miller, 1949.

Marine intertidal rock: exposed and partially exposed: sand-scoured

Rocky areas impacted by sand scour have a unique complement of species adapted to this disturbance. Such assemblages are seen especially clearly on outer coast rocky headlands adjacent to sand beaches.

Diagnostic species

The kelp *Laminaria sinclairii*, the red algae *Ahnfeltia fastigiata*, *A. gigartinoides*, *Gymnogongrus linearis*; the brown alga *Phaeostrophion irregulare*, the gregarious tube worm *Eudistylia vancouveri*, and the surfgrass *Phyllospadix torreyi* (all low intertidal zone). Mid zones are characterized by the cloning anemone *Anthopleura elegantissima* and the small barnacle (*Chthamalus dalli*).

Surveyed Sites

Variety on the outer coasts of Washington and Vancouver Island.

Sources

Dethier; 1988; unpubl. data from Gabrielson, Mumford.

Marine intertidal rock: backshore (all exposures)

Splash zones in rocky intertidal areas have characteristic types of organisms, although the width of this zone and the precise species found vary with wave exposure and sunlight.

Diagnostic species

The lichens *Verrucaria* spp. (black), *Caloplaca* (orange), and others; films of cyanobacteria (blue-green algae), the green alga *Prasiola meridionalis*, the snails *Littorina* spp., the isopod *Ligia pallasii*, and in pools the red copepod *Tigriopus californicus*.

Sources

Kozloff, 1983; Dethier unpubl. data.

Marine intertidal rock: partially exposed

Sites not directly exposed to oceanic swell but with substantial wave action are found throughout the Strait of Juan de Fuca, and on the west and south sides of the San Juan Islands and Whidbey Island. Outer coast areas with long intertidal benches or adjacent offshore islands that break the swell also fall in this category. Wave energies are less but there is a consequent increase in desiccation stress (and perhaps other stresses) leading to somewhat lower diversities than at the most exposed sites. In Washington, low tides on the more inland waters also fall at highly stressful hours (nearer midday in the summer and midnight in the winter), contributing to lower diversities. Seals use these protected habitats as well as the exposed ones. Similar complements of birds roost and forage here.

Diagnostic species

The kelp *Hedophyllum sessile*, the surfgrass *Phyllospadix scouleri*, and the chiton *Katharina tunicata* (all low zones), and the cloning anemone *Anthopleura elegantissima* (mid zone).

Common associates

The kelp *Alaria marginata* (low), the mid zone red algae *Iridaea splendens*, *Endocladia muricata*, *Mastocarpus papillatus*, and *Halosaccion glandiforme*; the erect coralline reds *Corallina vancouveriensis* and *Bossiella plumosa* (low). Invertebrates include *Semibalanus cariosus*, *Balanus glandula*, limpets, the "shell-less limpet" *Onchidella borealis*, the seastars *Pisaster ochraceus* and *Leptasterias hexactis*, and the predatory snails *Nucella* spp. Fish are similar to those in more exposed habitats.

Surveyed sites

Tongue Point (Straits), numerous sites on San Juan Island including Pile and Cattle Points, Edwards Reef.

Sources

Nyblade, 1979b; Muenscher, 1915; Dayton, 1971, 1975; Dethier pers. obs.

Marine intertidal rock: semi-protected and protected

Many areas in the northern Puget Trough receive neither oceanic swell nor extensive wind fetch, but retain their rocky character due to steepness of the shore or currents that sweep away most sediment. Examples are the inside waters of the San Juan Islands. Siltation, desiccation, and temperature stresses all take their toll on rocky-shore organisms in these areas, and diversity is correspondingly relatively low.

Diagnostic Species

The brown rockweed *Fucus gardneri* (=*distichus*), the red algae *Porphyra* spp. and *Mastocarpus papillatus*, the snails *Littorina* spp. (all high zones), and the whelk *Nucella lamellosa*.

Common associates

The brown algae *Fucus spiralis* and *Leathesia difformis*, the reds *Endocladia muricata*, *Iridaea splendens*, the barnacles *Semibalanus cariosus*, *Balanus glandula*, and *Chthamalus dalli*, limpets, *Katharina tunicata*, the mussel *Mytilus edulis*, the periwinkle *Lacuna* spp., the seastar *Leptasterias hexactis*. Coralline algae are absent except in pools. Fish resemble those in more exposed areas.

Surveyed sites

Variety of sites in the San Juan Islands.

Sources

Smith and Webber, 1978; Mauzey, 1965 and 1967; Nyblade, 1979a; Houghton, 1973; Muenscher, 1916; Dethier pers. obs.

Marine intertidal boulders

No specific surveys have been done in these habitats, which generally resemble bedrock shores of similar wave exposures. A few species are more common in boulder fields than on bedrock shores, probably because the bases of boulders provide protection from sun and from predators: these include the red algae *Plocamium cartilagineum* and *Prionitis* spp., the limpet *Tectura persona*, the turban snail *Tegula funebralis* (outer coast only), the shore crab *Hemigrapsus nudus* and the red rock crab *Cancer productus*, the anemones *Metridium senile*, *Urticina crassicornis*, and *Anthopleura xanthogrammica* (outer coast); and several tunicates (especially *Pyura haustor*) and intertidal sponges (*Halichondria panicea*, *Haliclona permollis*, and *Ophlitaspongia pennata*). Characteristic species in the gravel commonly found at the base of boulders include the northern clingfish, porcelain crabs *Petrolisthes* spp., sipunculid worms, and the polychaete *Thelepus* spp.

Marine intertidal hardpan

No complete surveys have been done in these habitats. Species found in particular abundance in hardpan include boring clam *Adula californiensis*, the urchin *Strongylocentrotus purpuratus*, and red alga *Halosaccion glandiforme* (Sekiu Point: R. Anderson pers. comm.).

Marine intertidal cobble: partially exposed

Cobble habitats are relatively unstable environments, suffering frequent overturning by waves, and also are hybrid environments because cobbles are virtually always mixed with, or overlie, other substrata. Beaches visually dominated by cobbles, rather than being a clear mix of substrate types, are put into this category. However, all the cobble beaches censused had underlying sand. The organisms characteristic of this habitat include two types: epibiota — the plants and animals living on or hiding just under the cobbles, and infauna — the animals living in the sand or other substrata under the cobbles. Only areas exposed to moderate wave action are placed in the "cobble" category, since more exposed areas tend toward pure sand, and more protected areas tend toward "mixed-coarse" substrates where the cobbles are not the dominant feature. Defining diagnostic species for this habitat type is difficult because species composition varies dramatically with degree of exposure, amount of silt in the sand, slope of the beach, etc.

Diagnostic Species

Littorina spp., *Hemigrapsus nudus*, *Macoma inquinata*, *Mysella tumida*.

Common associates

The alga *Mastocarpus papillatus*, barnacles (especially *Balanus glandula* and *Chthamalus dalli*), the isopods *Exosphaeroma* spp., the mussel *Mytilus edulis*, the clams *Protothaca staminea*, *Macoma balthica*, and *Transennella tantilla*; cirratulid polychaetes, *Cancer productus* and porcelain crabs (*Petrolisthes* spp.), the seastar *Leptasterias hexactis*, and the brittle star *Amphipholis squamata*. Beach seines at one site produced quantities of *Pandalus danae*, *Crangon* spp., and *Cancer magister*. Low zones often have finer substrata and may contain ghost shrimp or mud shrimp. Herring spawn on seaweeds on some cobble beaches. Tidepool, calico, and mosshead sculpins, northern clingfish, and penpoint and high cockscomb gunnels use these habitats.

Sites surveyed

Partridge Point (Whidbey Island), North Beach (Quimper Peninsula), Morse Creek and Slip Point (Strait of Juan de Fuca).

Sources

Long, 1983; Webber, 1980; Nyblade, 1979a,b; Smith and Webber, 1978; Webber, 1989.

Marine intertidal mixed-coarse sediments: semi-protected to protected

Mixed-coarse sediments are those where no one grain size occupies more than 70 percent of a stretch of beach. Instead, the beach is a mix (in variable quantities) of a few boulders, with cobble, gravel, and sand. Few marine sites (but many estuarine) qualifying as mixed-coarse have been surveyed. Data on dominant species are limited. Drift algae may accumulate in these habitats seasonally, creating anaerobic sediments beneath them but providing food and habitat for a variety of small organisms.

Diagnostic Species

Fucus gardneri, *Mytilus edulis*, *Protothaca staminea*.

Common associates

Ulvoid algae (*Ulva*, *Enteromorpha*, *Monostroma*), *Balanus glandula*, the clams *Tapes philippinarum*, *Saxidomus giganteus*, *Macoma* spp. especially *M. inquinata*, *Mya arenaria*, and *Tresus capax*, the burrowing shrimp *Upogebia pugettensis* and *Callianassa* spp.; the anemones *Anthopleura artemisia* and *Urticina coriacea*, and the polychaetes *Naineris dendritica*, *Neoamphitrite robusta*, *Eunice kobiensis*, *Saccocirrus eroticus*, and nereids.

Sites surveyed

Turn Island, Partridge Point (Whidbey Island), and parts of False Bay (San Juan Island).

Sources

Smith and Webber, 1978; Pamatmat, 1966; H. Wilson, R. Shimek, and R. Anderson unpubl. data.

Marine intertidal gravel: partially exposed

Gravel beaches, like cobble beaches, are seldom one uniform grain size; most surveys report some sand mixed in with gravel. Some partially exposed habitats in the Strait of Juan de Fuca have nearly uniform gravel, and have very low biological diversities. Due to the instability of the substratum, the exposed habitats are relatively unproductive with virtually no plant life, and are occupied solely by mobile burrowing animals or epibenthic forms such as shrimp. Protected habitats with gravel intermixed with sand fall under "mixed-coarse." Gulls sometimes forage in these habitats, and oystercatchers may nest in high intertidal gravel areas.

Diagnostic species

Gammarid amphipods: *Paramoera mohri*, and *P. serrata* n.sp., *Traskorchestia traskiana*.

Common associates

Oligochaete and nemertean worms, and the crustaceans *Allorchestes angusta* and *Exosphaeroma* spp. are the only other infauna. Beach seines contain *Crangon* spp, *Cancer magister* and *C. productus*, *Archaeomysis* spp. A variety of fish use these beaches and the areas just offshore: shiner perch, juvenile tomcod and English sole, starry flounder, crescent gunnels, and sculpins (great, tidepool, padded, staghorn, and buffalo). Surf smelt spawn here, and larvae of sand lance use these habitats.

Sites surveyed

Outer Dungeness Spit, Twin Rivers (Straits), West Beach and Ebey's Landing on Whidbey Island, Deadman Bay on San Juan Island.

Sources

Nyblade, 1979a,b; Cross et al., 1978; Webber, 1980; Long, 1983; C. Simenstad and C. Staude, unpubl. data.

Marine intertidal gravel: semi-protected

More protected gravel beaches contain more sand, are more stable and consequently have higher biological diversity.

Diagnostic species

The isopod *Exosphaeroma inornata* (=*media*), and the polychaete *Hemipodus borealis*.

Common associates

The amphipod *Paramoera mohri*, the isopod *Excirolana kincaidi*, and the polychaete *Owenia fusiformis*. Areas with higher proportions of sand will contain various clam species such as *Transennella* and *Protothaca staminea*. Seines contain three species of *Cancer* crabs, *Crangon alaskensis*, and *Pandalus* spp. Fishes include shiner perch, juvenile English sole, starry flounder, and padded, buffalo, and staghorn sculpins.

Sites surveyed

Beckett Point in Discovery Bay.

Sources

Nyblade, 1979a,b; Cross et al., 1978.

Marine intertidal sand: exposed and partially exposed

Pure marine sands without significant silt or organic content are found only in high and moderately-high energy areas such as on the outer coast and in the Straits of Juan de Fuca. They tend to be erosional beaches, are well-drained, and moderately sloped. Due to their unstable nature, they have no permanent vegetation and are low-diversity habitats, although a few species may be abundant. These areas are used extensively by loons, scoters, and grebes at high tide, and by gulls, sanderling and other sandpipers, and herons at low tide.

Diagnostic species

Phoxocephalid amphipods and *Eohaustorius* spp., the polychaete *Paraonella platybranchia*, the mysid *Archaeomysis grebnitzkii*, and the olive shell *Olivella biplicata* and the razor clam *Siliqua patula* (patchy but locally abundant on the outer coast). Diagnostic fish species are juvenile Pacific tomcod and English sole, Pacific staghorn sculpin, sand sole, and redtail surfperch.

Common associates

The isopod *Excirolana vancouverensis*, the amphipods *Proboscinotus loquax* and *Megalorchestia californiana*, the polychaetes *Euzonus mucronatus*, *Streptosyllis latipalpa*, *Abarenicola pacifica*, *Axiothella rubrocincta*, *Magelona* sp, and *Nephtys* spp.; and nemertean worms. Seines reveal shrimp (*Crangon* spp.), soles, starry flounder, Pacific sand lance, Pacific tomcod, pile, surf, and shiner perch, various sculpins, crescent gunnels, sturgeon and tubenose poachers, and sometimes schools of Pacific herring and surf smelt.

Sites surveyed

West Beach on Whidbey Island, North Beach (Quimper Peninsula), Kydaka Beach, Eagle Cove on San Juan Island, outer coast beaches.

Sources

Webber, 1980; Nyblade, 1979a,b; Cross et al., 1978; Dethier, 1988; Albright et al., 1980; Long, 1983; H. Wilson unpubl. data.

Marine intertidal sand: semi-protected

These sands begin to have some silt mixed in with them and are more stable, making them a more favorable environment for burrowing and for deposit-feeding organisms. These habitats are found in bays and inlets with some wave action, and often are bordered at their upper edges by salt marshes. The shallow water fish fauna in these habitats provides food for seals and for a variety of local and migratory birds, including mew gulls, grebes, and great blue herons.

Diagnostic species

The clams *Macoma secta*, *Tellina bodegensis* and *Transennella tantilla*; the burrowing sea cucumber *Leptosynapta clarki*, the lugworm *Abarenicola claparedi*, the tanaid crustacean *Leptochelia savignyi*, and sand sole.

Common associates

Zostera marina may occur in low zones, as may the sand dollar *Dendraster excentricus* and the moon snail *Polinices lewisii*. Other species in these sometimes rich assemblages include the ghost shrimp *Callianassa californiensis*, the clams *Tellina modesta*, *Macoma balthica* and others; the polychaetes *Malacoceros glutaeus* (= *Rhynchospio arenincola*), *Axiothella rubrocincta*, *Owenia fusiformis*, and many others. Seines tend to catch *Cancer magister* and *gracilis*, and diverse shrimp, including *Crangon alaskensis*, *Pandalus* spp., and *Heptacarpus brevirostris*. Sole, salmonids and sculpin (especially Pacific staghorn) feed extensively in these habitats. This is a spawning habitat for surf smelt, and is used by larvae of sand lance and candlefish.

Sites surveyed

Alexander's Beach (Fidalgo Island), False Bay (low zones), Jamestown.

Sources

Pamatmat, 1966; Shelford et al., 1935; Cross et al., 1978; Nyblade, 1979b; H. Wilson and C. Staude unpubl. data.

Marine intertidal mixed-fines: semi-protected and protected

This habitat type (or its estuarine equivalent) occurs in most bays and harbors in the Pacific Northwest. Protection from waves allows finer sediments to accumulate, and the substratum is relatively stable. The beaches tend to be accretional. The mixed-fine sediments include sand and mud with patches of gravel (especially in the higher intertidal). Few marine (but many estuarine) sites in this category have been surveyed. Species are generally a mix of those found in sand and in mud habitats. Birds and fish using these areas are described under the counterpart Estuarine habitat. Drift algae and seagrass may be abundant.

Common species

Zostera marina (low zones) and *Z. japonica* (higher), with the red alga *Gracilaria pacifica*, and green ulvoids on the beach surface in spring and summer. Commonly found are the clams *Macoma nasuta* and *balthica*, *Tresus capax*, *Clinocardium nuttallii*, and *Cryptomya californica*. In areas with some gravel, hard shell clams (*Protothaca staminea*, *Saxidomus giganteus*) are characteristic. The phoronid worm *Phoronopsis harmeri* is very patchy in distribution. Other organisms include the crabs *Hemigrapsus oregonensis*, *Cancer magister*, and *C. productus*, ghost shrimp, and the polychaetes *Lumbrineris* sp., *Axiothella rubrocincta*, and *Owenia fusiformis*. Representative fishes include juvenile Pacific tomcod and lingcod, tube-snout, bay pipefish, shiner perch, snake prickleback, saddleback gunnel, silverspotted sculpin, sharpnose sculpin, Pacific staghorn sculpin, tidepool sculpin, sturgeon poacher, Pacific sanddab, surf smelt, juvenile English sole, and starry flounder.

Sites surveyed

False Bay, other sites in the San Juans.

Sources

Pamatmat, 1966; Kozloff, 1983; Webber, 1989; Long, 1983; H. Wilson unpubl. data.

Marine intertidal mud: protected

In calm bays and inlets where there is little to no wave or current energy, fine sediments settle and form mudflats. Often such areas have seasonal freshwater inflow from streams, but salinities are not regularly below 30 ppt. Such habitats support a rich infauna and are used extensively by birds as foraging areas; these habitats and their estuarine counterparts support the highest densities (seasonally) of marine birds in the region. These include great blue herons, gulls, terns, turnstones, dunlin, sandpipers, grebes, and ducks. Areas with eelgrass are used by black brant and wigeon, and to a lesser extent by Canada geese, pintails, and greater scaup. Seals sometimes haul out on undisturbed mudflats. Drift algae and seagrass may accumulate.

Diagnostic species

Zostera marina, the clam *Macoma nasuta* (especially in areas with freshwater inflow), the polychaete *Polydora* (*Pseudopolydora*) *kempi japonica*, the mud shrimp *Upogebia pugettensis*.

Common associates

The clams *Mya arenaria*, *Transennella tantilla*, *Macoma inquinata*, *M. balthica*, and *Clinocardium*; the polychaetes *Abarenicola pacifica*, *Thelepus crispus*, *Lumbrineris zonata*, *Pygospio elegans*, *Notomastus tenuis*, *Capitella capitata*, *Chaetozone* sp., *Streblospio benedicti*, *Eteone longa*, and *Glycinde picta*; the crabs *Cancer magister*, *C. gracilis*, and *C. oregonensis*; and the opisthobranchs *Melanochlamys diomedea* and *Haminoea* spp. Starry flounder, juvenile English sole, tube-snout, shiner perch, bay pipefish, saddleback gunnel, bay goby, and sculpins (Pacific staghorn, silverspotted, sharpnose, tidepool, padded) are characteristic species that use mud flats for feeding and as nursery areas. Herring often spawn on *Zostera*.

Sites surveyed

Westcott Bay, Garrison Bay, and other sites in the San Juan Islands, and Jamestown / Port Williams.

Sources

Shelford et al., 1935; Thorson, 1957; Nyblade, 1979a; Long, 1983.

MARINE SYSTEMS

SUBTIDAL HABITATS

MARINE SUBTIDAL ROCK AND BOULDERS: MODERATE TO HIGH ENERGY, SHALLOW (<15 M)

Subtidal bedrock and boulders have very similar assemblages, except on boulders small enough to roll in high currents. These habitats, like the rocky intertidal, are productive and diverse. Communities are often patchy, containing areas with herbivorous urchins and few kelps, or no urchins and many kelps. Kelp beds create a semi-protected habitat used as resting areas by gulls, heron, waterfowl, and cormorants, and as feeding sites by surf scoters and white-winged scoters, loons, grebes, goldeneyes, buffleheads, and harbor seals. In their currently limited range along the outer coast, sea otters feed primarily in this habitat.

DIAGNOSTIC SPECIES

The kelps *Macrocystis integrifolia* (outer coast), *Nereocystis luetkeana*, and *Agarum* spp.; the urchin *Strongylocentrotus franciscanus*, the anemones *Metridium* sp. and *Epiactis lizbethi*, encrusting corallines and fleshy red crusts, and rock greenling.

COMMON ASSOCIATES

The brown algae *Pterygophora californica*, *Pleurophycus gardneri*, *Desmarestia* spp., and *Laminaria* spp., a wide variety of red algae, especially *Gigartina corymbifera*, *Laurencia spectabilis*, *Iridaea splendens*, *Constantinea simplex*, *Plocamium cartilagineum*, and *Opuntiella californica*. Invertebrates include the urchins *S. droebachiensis* and *S. purpuratus*, the sea cucumbers *Parastichopus californicus* and *Cucumaria* spp.; the abalone *Haliotis kamtschatkana*, the snails *Fusitriton oregonensis*, *Ceratostoma foliatum*, *Acmaea mitra*, *Lacuna* spp., *Margarites* spp., *Lirularia* spp., and *Calliostoma* spp., *Octopus dofleini*, the chitons *Tonicella* spp. and *Cryptochiton stelleri*, the rock scallop *Hinnites giganteus*, kelp crabs (*Pugettia* spp.) and red rock crabs (*Cancer productus*), the seastars *Pycnopodia helianthoides*, *Orthasterias koehleri*, *Henricia leviuscula*, and *Leptasterias hexactis*, the anemone *Urticina piscivora*, the tunicate *Styela montereyensis*, and the orange finger sponge *Neoesperiopsis digitata*.

Fish found predominantly in these habitats include red Irish lord, longfin and scalyhead sculpins, and black, copper, Puget Sound, yellowtail, and quillback rockfish, kelp and painted greenling, lingcod, blackeye goby, cabezon, gunnels, and striped sea perch. The rockfish, hexagrammids, and seaperches are particularly associated with macrophytes. Herring spawn on *Nereocystis* and *Laminaria*.

SITES SURVEYED

Barnes and Allan Island, Tongue Point (Juan de Fuca), Neah Bay, and various sites in the San Juan Islands, including Point George, Edward's Reef and Turn Island.

SOURCES

Shelford et al., 1935; Neushul, 1965 and 1967; Vadas, 1968; G.F. Smith, 1979; Irvine, 1973; Nyblade, 1979b; Moulton, 1977; Simenstad et al., 1988; Long, 1983; R. Kvitek, R. Shimek, R. Anderson, P. Gabrielson, and D. Duggins unpubl. data.

MARINE SUBTIDAL ROCK AND BOULDERS: LOW ENERGY, SHALLOW

These rocky areas are out of the main currents or in bays protected from wave action, and thus suffer some siltation. Diversity is lower than in high-current areas, although the same general types of organisms are found.

COMMON SPECIES

The brown algae *Laminaria* spp., *Agarum fimbriatum* and *A. cribrosum, Desmarestia* spp., and *Sargassum muticum*, green ulvoids, diatoms, red *Neodilsea borealis* and *Odonthalia floccosa*, the sea cucumbers *Parastichopus* and *Cucumaria* spp. Fish are similar to those in higher energy areas.

SITES SURVEYED

Brown Island (San Juans), Rosario Point, Neah Bay.

SOURCES

Neushul, 1967; G.F. Smith, 1979; Simenstad et al., 1988; Duggins unpubl. data.

MARINE SUBTIDAL ROCK AND BOULDERS: MODERATE TO HIGH ENERGY, DEEP

Rocky areas deeper than 15 meters with fairly high currents are common in the San Juan Islands and probably in the Strait of Juan de Fuca. These have few kelps relative to shallower areas. Encrusting invertebrates dominate the space.

DIAGNOSTIC SPECIES

The giant white anemone *Metridium* sp.

COMMON ASSOCIATES

Encrusting and erect coralline algae, foliose red algae such as *Callophyllis* spp., red and green urchins, brachiopods (several species), the polychaetes *Sabellaria cementarium* and *Dodecaceria* sp., the cucumbers *Eupentacta quinquesemita* and *Psolus chitonoides*, the cup coral *Balanophyllia elegans* and the soft coral *Gersemia* sp., the anemones *Urticina* spp. and *Cribrinopsis fernaldi*, the scallops *Chlamys* spp. and *Hinnites giganteus*, the large barnacle *Balanus nubilus*, and the seastar *Orthasterias koehleri*. Even deeper areas (below 25 m) have no erect algae and are dominated by brachiopods (*Terebratalia transversa* and *Terebratulina unguicula*), the large anemone *Metridium senile*, bryozoans and hydroids, encrusting cnidarians such as *Epizoanthus scotinus* and *Allopora* spp., and the "white" urchin *Strongylocentrotus pallidus*. The basket star *Gorgonocephalus eucnemis* is common in patches. Fishes include rockfish, lingcod, gobies, and sculpins in the genus *Artedius*.

SITES SURVEYED

Numerous sites in the San Juan Islands (few complete surveys).

SOURCES

Vadas, 1968; Shelford, 1935; Neushul, 1965 and 1967; Moulton, 1977; R. Shimek, R. Anderson, and C. Staude unpubl. data.

Marine subtidal rock and boulders: low energy, deep

Diagnostic species

The glass sponges *Aphrocallistes vastus* and *Rhabdocalyptus dawsoni*, the serpulid polychaete *Protula pacifica*, the galatheid crab *Munida quadrispina*, the sponge *Geodia* sp.

Common associates

The anemone *Urticina piscivora*, the cup coral *Balanophyllia elegans*, the zoanthid *Epizoanthus scotinus*, the sea cucumbers *Parastichopus* spp. and *Eupentacta* spp., the ascidians *Halocynthia* spp, the seastar *Mediaster aequalis*, and longfin sculpin, gobies, and widow, quillback, and copper rockfish.

Sites surveyed

Barkley Sound, British Columbia.

Source

R. Shimek unpubl. data.

Marine subtidal cobble: high energy, deep

Several sites, surveyed by dredging, consist of a "scoured" substratum consisting largely of cobbles. All these sites were in channels or passes with high currents that affect the substratum well below 15 m.

Diagnostic species

The horse mussel *Modiolus modiolus*, the giant barnacle *Balanus nubilus*, the serpulid worm *Serpula vermicularis*.

Common associates

The urchins *Strongylocentrotus pallidus* and *S. droebachiensis*, the rock scallop *Hinnites giganteus*, the fan worms *Sabellaria cementarium* and *Schizobranchus insignis*, hydroids, ophiuroids, occasionally the basket star *Gorgonocephalus eucnemis*, anemones, and clam *Humilaria kennerlyi*.

Sites surveyed

Haro Strait, Deception Pass, sites in the San Juan Islands.

Sources

Wennekens, 1959; R. Shimek, R. Anderson unpubl. data.

Marine subtidal: mixed-coarse: moderate to low energy, shallow

Substrata in these areas consist of cobbles of varying stability lying over a matrix of sand and gravel. Few complete surveys have been done in this habitat type, but areas examined are quite rich due to the mix of infauna and epibiota.

Common species

On cobbles, the surfgrass *Phyllospadix scouleri* (higher energy areas) or *Zostera marina* (lower energy), along with the brown algae *Laminaria* spp., *Desmarestia* spp., *Pterygophora californica* and others, and foliose reds including *Odonthalia* spp., plus ulvoids. Invertebrates in these habitats include the snails *Lacuna* spp., the bivalves *Modiolus rectus, Astarte* spp., and *Saxidomus giganteus*, the crabs *Cancer productus* and *C. oregonensis*, the polychaetes *Glycymeris subobsoleta, Thelepus* sp., *Platynereis bicanaliculata*, the sea cucumbers *Cucumaria* spp., the tanaid crustacean *Leptochelia savignyi*, and the amphipods *Pontogeneia* sp. and others. These habitats are probably used by similar fish and diving birds as are intertidal mixed-coarse areas.

Sites surveyed

Partridge Point and Ebey's Landing (Whidbey Island), Buck Bay (Orcas Island), Lonesome Cove (San Juan Island).

Sources

Webber, 1980 and unpubl. data; G.F. Smith, 1979; Irvine, 1973.

Marine subtidal mixed-coarse: moderate to high energy, deep

Common species

Assemblages in these habitats resemble those in the deep "cobble" habitat, with a mixture of epifauna: the mussel *Modiolus modiolus*, the jingle shell *Pododesmus cepio*, the barnacle *Balanus rostratus*; and infauna: *Humilaria kennerlyi*, *Glycymeris subobsoleta*, *Protothaca staminea*. Sites surveyed were in the San Juan archipelago and the eastern Strait of Juan de Fuca (Wennekens, 1959; G.F. Smith, 1979; Shimek unpubl. data). Surveys in gravel-sand habitats on the outer coast (Lie and Kelley, 1970) revealed different assemblages, dominated by bivalves *Nemocardium centifilosum* and *Nuculana minuta*, the ophiuroids *Ophiura lutkeni* and *Amphipholis squamata*, and the amphipods *Byblis veleronis* and *Melita desdichada*.

Marine subtidal gravel: high energy, shallow

Few sites of this habitat type have been surveyed for benthic organisms, although the fish fauna has been more thoroughly sampled (reviewed in Long 1983). Two sites in the Strait of Juan de Fuca exposed to strong wave action and swells were classified by the investigators as gravel.

Common species

Mysella tumida, *Leptochelia savignyi*, the polychaetes *Tharyx multifilis* and *Mediomastus* sp., ophiuroids, the isopod *Gnorimosphaeroma oregonense*, and the snail *Amphissa columbiana*. A wide variety of sculpins, perch, flatfish, and others use these and more mixed-substratum habitat types.

Sites surveyed

Morse Creek (near Port Angeles), Twin Rivers.

Sources

Nyblade, 1979b.

Marine subtidal mixed-fines: moderate to high energy, shallow

These habitats consist of mixed sand and shell substrata, sometimes with some gravel or mud. They may be very rich, with algae on pebbles as well as having a diverse infauna. Glaucous-winged and other gulls, and surf scoters feed extensively in shallow areas.

Diagnostic species

The bivalves *Psephidia lordi* and *Mysella tumida*, polychaetes *Mediomastus* sp. and *Prionospio steenstrupi*.

Common Associates

Moderate-energy sites have pebbles with small laminarians, the red algae *Gracilaria lemaneiformis*, *Sarcodiotheca gaudichaudii*, and other foliose reds. Invertebrates include phoxocephalid amphipods and *Isochyroceros* spp., the bivalves *Crenella decussata*, *Tellina* sp., *Astarte* spp., *Saxidomus giganteus*, *Clinocardium nuttallii*; and scallops (*Chlamys* spp.), the polychaetes *Scoloplos* spp., *Glycymeris subobsoleta*, *Exogone* spp., chaetopterids, *Platynereis bicanaliculata*, and *Micropodarke dubia*, the crabs *Cancer* spp. and *Pugettia gracilis*, the snails *Alia tuberosa* and *Lacuna* spp., the tanaid *Leptochelia savignyi*, the seastar *Pisaster brevispinus*, and ophiuroids. Slightly calmer areas have more *Macoma* spp. and may contain geoducks, although the latter

were not recorded in any of the surveys. Exposed sandy areas may contain razor clams (*Siliqua patula*) or sand dollars (*Dendraster excentricus*). Epibenthic crustaceans are likely to be abundant, and these as well as the infauna provide food for sculpins, pile and shiner perch, juvenile English sole, sand sole, starry flounder, juvenile Pacific tomcod, and sturgeon poacher.

Sites surveyed

West Beach and Partridge Point (Whidbey Island), Pillar Point, Dungeness Spit, Jamestown, North Beach, and Kydaka Beach (all in Strait of Juan de Fuca), Beckett Point (Discovery Bay) (extremely rich site).

Sources

Nyblade, 1979b; Webber, 1980 and unpubl. data; R. Shimek unpubl. data.

Marine subtidal mixed-fines: high energy, deep

Several sites deeper than 15 m in the Strait of Juan de Fuca and on the outer coast have been surveyed via grabs. These deep habitats are more stable than their shallow counterparts and have fairly diverse infauna.

-15 to at least 100 m: Sand

Common species

The bivalves *Tellina modesta* and *Macoma expansa*, the amphipods *Rhepoxynius abronius*, *Foxiphalus obtusidens*, *Eohaustorius washingtonianus*, and *Monoculodes spinipes*; the snails *Buccinum plectrum*, *Neptunea lyrata*, and *Antiplanes thalea*; the ophiuroids *Ophiura* spp., the polychaetes *Chaetozone setosa* and *Maldane glebifex*.

Sites surveyed

Strait of Juan de Fuca.

Sources

Lie and Kelley, 1970; Lie and Kisker, 1970; R. Shimek unpubl. data.

Marine subtidal mixed-fines: moderate to low energy, deep

-15 to 50 m: Sand, shell, pebbles

Diagnostic species

The burrowing anemone *Pachycerianthus fimbriatus*.

Common associates

Areas with finer substrata have beds of the sea pens *Ptilosarcus gurneyi* and *Virgularia* sp. and accompanying nudibranchs and asteroids. Other species include chaetopterid polychaetes, hydroids, the bivalves *Saxidomus giganteus*, *Mya truncata*, *Protothaca staminea*, *Humilaria kennerlyi*, *Solen sicarius*, *Pododesmus cepio* (on pebbles and shells); the scaphopod *Dentalium rectius*, the sea cucumbers *Parastichopus californicus* and *Pentamera populifera*, the crabs *Cancer magister* and *Pugettia* spp., the seastars *Luidia foliolata*, *Pisaster brevispinus* and *Pycnopodia helianthoides*, the cephalopods *Octopus rubescens* and *Rossia pacifica*. Geoducks may occur in patches. Pebbles at the shallower limit may have the red algae *Stenogramme interrupta*, *Polyneura latissima*, *Nienburgia andersoniana* and others. Fish include rocksole, ratfish, dogfish, and tomcod.

Site surveyed

San Juan Islands.

Sources

R. Shimek, C. Simenstad unpubl. data.

-50 to 180 m: Sand and silt

Common species

The bivalves *Yoldia scissurata*, *Tellina carpenteri*, *Acila castrensis*, *Nucula tenuis*, *Macoma carlottensis*, and *Axinopsida serricata*; the amphipod *Rhepoxynius variatus*, the polychaetes *Magelona* sp. and *Sternaspis scutata*.

Sites surveyed

Strait of Juan de Fuca and outer coast.

Sources

Lie and Kelley, 1970; Lie and Kisker, 1970; R. Shimek unpubl. data.

Marine subtidal mud and mixed-fines: low energy, shallow

Surprisingly few complete surveys have been done in these habitats, which should be commonly found in bays and inlets. In general, they appear to have similar flora and fauna to their estuarine counterparts. Fish and bird faunas are diverse, especially when eelgrass is present. (See "Estuarine Intertidal Mixed-Fines.")

Diagnostic species

Zostera marina, the red alga *Gracilaria pacifica*, the small snails *Lacuna* spp., the anemone *Epiactis prolifera*.

Common associates

Pebbles often have *Laminaria saccharina*, ulvoids, and a variety of red algae such as *Sarcodiotheca gaudichaudii* and *Nitophyllum* spp. attached to them. Also seen are the bivalves *Clinocardium nuttalli*, *Mysella tumida*, *Psephidia lordi*, *Axinopsida serricata*, *Transennella tantilla*, *Tellina* sp., and *Modiolus rectus*, polychaetes *Owenia fusiformis*, *Armandia brevis*, *Ampharete* spp., and sabellid tubeworms (in thick patches), *Cancer magister*, *C. gracilis*, and the pea crab *Pinnixa occidentalis*, the moon snail *Polinices lewisii*, nudibranchs *Melibe leonina*, *Melanochlamys diomedea*, and *Aeolidia papillosa*, and the amphipod *Allorchestes angusta*. Herring spawn on the algae and eelgrass. Other common fish include tube-snout, bay pipefish, kelp greenling, buffalo and Pacific staghorn sculpins, Pacific sand lance, starry flounder, juvenile English sole, C-O sole, shiner and striped seaperch, penpoint gunnel, juvenile lingcod, and speckled sanddab.

Sites surveyed

Indian Cove (Shaw Island), Brown Island and Beaverton Cove (near San Juan Island), Shoal Bay (Lopez Island), sites in Barkley Sound and Neah Bay.

Sources

Neushul, 1967; Shimek, 1977 and unpubl. data; Muenscher, 1916; Simenstad et al., 1988; R. Anderson, C. Staude, P. Gabrielson unpubl. data .

MARINE SUBTIDAL MUD: LOW ENERGY, DEEP

-15 to 30 m

DIAGNOSTIC SPECIES

The cephalopod *Rossia pacifica*, the sea cucumber *Pentamera populifera*, and the small snail *Alia gausapata*.

COMMON ASSOCIATES

The clam *Saxidomus giganteus*, the scallop *Pecten caurinus*, the small bivalves *Yoldia scissurata* and *Compsomyax subdiaphana*, *Octopus rubescens*; the sea whips *Virgularia* spp., the anemone *Pachycerianthus fimbriatus*, the nudibranchs *Dendronotus* spp., the polychaetes *Tharyx* spp., *Sternaspis scutata*; chaetopterids, *Axiothella rubrocincta*, *Paraprionospio pinnata*, *Lumbrineris* spp., *Nephtys cornuta* and others; the starfish *Luidia foliolata* and *Pycnopodia helianthoides*. Fish include spotted ratfish, Pacific tomcod, curlfin sole, and speckled sanddab.

SITES SURVEYED

Near the Friday Harbor Labs and elsewhere on San Juan Island.

SOURCES

Shimek, 1977 and unpubl. data; Neushul, 1967; R. Anderson and C. Simenstad unpubl. data.

> 30 m

DIAGNOSTIC SPECIES

The scaphapod *Dentalium rectius*, the heart urchin *Brisaster latifrons*, and the ophiuroid *Amphiodia urtica*.

COMMON ASSOCIATES

The sea cucumber *Molpadia intermedia*, the ophiuroids *Amphipholis* sp. and *Ophiura lutkeni*, the bivalves *Macoma carlottensis*, *Axinopsida serricata*, *Pandora* sp., and *Yoldia* sp.; the polychaetes *Sternaspis scutata* and *Prionospio* sp., and the sea whip *Virgularia* sp. Fish include hagfish (outer coast), ratfish, and blackbelly eelpout.

SITES SURVEYED

Outer coast, Barkley Sound, San Juan Islands.

SOURCES

Lie and Kelley, 1970; Shelford et al., 1935; R. Shimek unpubl. data.

ESTUARINE SYSTEMS
INTERTIDAL HABITATS

ESTUARINE INTERTIDAL BEDROCK: OPEN

Rocky intertidal areas in estuarine waters occur occasionally in the Puget Sound. Many of these could be classified as artificial substrata (riprap), while some are classified below as hardpan. All tend to be in areas exposed to moderate waves or currents which keep silt from settling on the substratum and allow an epifauna to develop. The plants and animals seen on these rocky substrata are largely a freshwater-tolerant subset of those seen on marine shores. These habitats are used at high tide by sculpins and probably other fishes. Few complete surveys have been done on such sites.

COMMON SPECIES

From high to low zones: *Littorina* spp., *Fucus gardneri*, *Balanus glandula, Mytilus edulis*, ulvoids, *Mopalia* spp., *Onchidella borealis, Iridaea splendens, Sargassum muticum, Leptasterias hexactis.*

SITES SURVEYED

Riprap at five sites in central Puget Sound, Kiket Island, Fidalgo Head.

SOURCES

Thom, 1978; Smith and Webber, 1978; Houghton, 1973; C. Staude unpubl. data.

HARDPAN

Areas of hardpan are common in Puget Sound, yet few surveys have been done. Hardpan is resistant basal till, composed of poorly sorted but well compacted glacial deposits often including clays.

COMMON SPECIES

Balanus glandula, the boring polychaete *Polydora* (*Boccardia*) *proboscidea*, and the boring clams *Petricola pholadiformis* (introduced), *Zirfaea pilsbryi*, and *Platyodon cancellatus* (an uncommon, native species). Pockets of gravel over hardpan (often wetted by runoff) are characterized by the amphipod *Paramoera bousfieldi* n.sp. Many of the species found on bedrock and riprap nearby may also occur here.

SITES SURVEYED

Goose Point (Willapa Bay), Alki Point, north of Shilshole Bay, Lincoln Park, Richmond Beach.

SOURCES

Kozloff, 1983; Hedgpeth and Obrebski, 1981; R. Anderson, C. Staude unpubl. data.

ESTUARINE INTERTIDAL MIXED-COARSE: OPEN

Most open estuarine intertidal sites in the Puget Trough have a poorly sorted substratum of mixed cobble, gravel, and sand, often distributed in patches along the beach. Some small boulders, which are relatively stable, often overlie other substrata. Organisms in these habitats are diverse, with both epifauna and infauna. Eelgrass beds often lie just subtidally of these beaches where the substratum becomes less coarse. These beaches are used as feeding areas by cutthroat trout, juvenile salmon (chum and pink), fish-eating birds such as cormorants, grebes, loons, mergansers, and great blue herons, and bivalve-eating birds such as scoters and goldeneyes.

Diagnostic species

Green ulvoid algae, the clams *Macoma inquinata* (especially on more exposed beaches) and *Protothaca staminea* (less exposed), the phoronid worm *Phoronopsis harmeri*, the polychaetes *Owenia fusiformis, Mediomastus capensis* and *Notomastus tenuis.*

Common associates

The clams *Saxidomus giganteus*, *Tresus capax*, *Transennella tantilla*, *Mysella tumida*, and *Tapes philippinarum*; the polychaetes *Hemipodus borealis, Protodorvillea gracilis, Nereis* spp. and *Malacoceros glutaeus*; the amphipod *Corophium brevis*, the crabs *Hemigrapsus nudus, Cancer productus*, *Petrolisthes eriomerus* and *Pagurus* spp.; the algae *Fucus gardneri, Mastocarpus papillatus, Iridaea splendens*, *Pterosiphonia bipinnata, Odonthalia floccosa, Alaria marginata,* and *Porphyra* spp.; the epifauna *Mytilus edulis*, oysters, limpets, *Littorina* spp., *Anthopleura elegantissima, A. artemisia, Urticina coriacea*, and *Balanus glandula*, and the predators *Leptasterias hexactis, Evasterias troschellii*, and *Nucella lamellosa.* Fish include the blennies *Anoplarchus purpurescens* and *Xiphister mucosus*, penpoint gunnels, northern clingfish, shiner perch, surf smelt, C-O sole, and three-spined stickleback. Herring spawn on vegetation in cobbly areas.

Sites surveyed

In central Puget Sound—Richmond Beach, Carkeek Park, West Point, West Beach, Alki Point, Lincoln Park Beach, Salt Water State Park, Covenant Beach, Redondo Beach, Seahurst, Seola, Normandy Cove. On Vashon Island—Point Robinson, Tramp Harbor, Aquarium, and Fern Cove. In Hood Canal— Anderson Cove. In northern waters—Port Gardner, Kiket Island, Skiff Point, Cherry Point / Birch Bay, Migley Point (Lummi Isl.), Shannon Point, and Point Washington Narrows.

Sources

Houghton, 1973; Shimek, 1977; Armstrong et al., 1976; Thom et al., 1976; Thom et al., 1979; Staude, 1979; Nyblade, 1979a,b; Webber, 1980; Smith and Webber, 1978; Thom et al., 1984; Chew, 1970; Sylvester and Clogston, 1961; Roetcisoender and English, 1976.

Estuarine intertidal gravel: open

These habitats tend to have gravel or pebbles overlying or mixed in with sand.

Diagnostic species

The isopod *Exosphaeroma inornata*, the polychaetes *Hemipodus borealis* and *Armandia brevis.*

Common associates

The crustaceans *Anisogammarus pugettensis*, *Paramoera mohri*, and *Excirolana kincaidi*; the polychaetes *Glycinde picta*, *Capitella capitata*, and *Notomastus tenuis.* Fish characteristically include shiner seaperch, juvenile English sole and cabezon, starry flounder, sculpins (padded, buffalo, staghorn, silverspotted, sharpnose, great, and tidepool), whitespotted greenling, penpoint gunnel, sturgeon poacher and tubenose poacher.

Sites surveyed

Guemes Island, Fidalgo Bay, Legoe Bay (Lummi Island).

Sources

Nyblade, 1979a; Smith and Webber, 1978; C. Simenstad unpubl. data.

Estuarine intertidal gravel: partly enclosed, eullitoral (marsh)

This habitat occurs on gravelly deltas and along relatively steep shores in inlets. The substratum is a mix of gravel, sand, mud and in some areas, cobbles. The energy level is high enough to prevent siltation, but low enough not to scour the rooted salt marsh vegetation that occurs in upper littoral zones. Interstitial soil salinities range from meso- to polyhaline. These areas are sparsely vegetated. Gravelling deltas to improve oyster culture has been a practice in the Puget Trough for a long time, so many of these habitats are enhanced or artificial.

Diagnostic species

The vascular plant *Glaux maritima* (saltwort) is the primary salt marsh species in this habitat. The pickleweed *Salicornia virginica* is the co-diagnostic species in polyhaline environments. Pockets of two other dominant species occur in microhabitats of different salinities: the sedge *Carex lyngbyei* has a broad range, but tends to be the co-diagnostic species for mesohaline environments. Those habitats where freshwater seeps over the surface are oligohaline. The sole diagnostic plant species is the umbel *Lilaeopsis occidentalis*.

Common associates

The brown rockweed *Fucus* sp. and the vascular plant *Plantago maritima.*

Sites surveyed

Quilcene Bay, Dosewallips River Delta, Duckabush River Delta, Hamma Hamma River Delta, Skokomish River Delta, Stavis Bay, Priest Point Park.

Sources

Kunze, 1984.

Estuarine intertidal sand: open

These habitats are common, consisting of gently to moderately sloping beaches, often bordered on their uppermost portions by a gravelly or rocky zone. Portions of the large coastal estuaries of Grays Harbor and Willapa Bay have sandy substrata. Drift algae and seagrass may accumulate in high zones.

Diagnostic species

Zostera marina, Gracilaria pacifica, Macoma secta, Malacoceros glutaeus.

Common associates

The clams *Macoma inquinata, Clinocardium nuttallii, Tresus nuttallii,* and *Tellina modesta*; the cumacean *Cumella vulgaris*, the isopod *Gnorimosphaeroma luteum*, the polychaetes *Mediomastus, Notomastus, Heteromastus filiformis, Streblospio benedicti, Magelona pitelkai, Scoloplos armiger*; and the "burrowing" anemone *Anthopleura artemisia*. Coastal estuaries also have the amphipod *Eohaustorius* spp., the tanaid *Leptochelia savignyi*, the polychaetes *Pygospio elegans* and *Nephtys* spp., and the ghost shrimp *Callianassa californica.* Intertidal sandflats are heavily used as a nursery area by young English sole, Pacific staghorn sculpin, bay goby, and starry flounder, and juvenile chum and chinook salmon feed there.

Sites surveyed

Dash Point, Seahurst, Seola Beach, Fern Cove, Point Robinson, Dumas Bay, Skiff Point, Cherry Point / Birch Bay, Grays Harbor, Willapa Bay.

Sources

Houghton, 1973; Thom et al, 1979; Thom et al., 1984; Schneider and Dube, 1969; Smith and Webber, 1978; Nyblade, 1979a; Thom, 1981.

Estuarine intertidal sand: partly enclosed eulittoral, euhaline (marsh)

This is a common habitat often associated with spits, berms or deltas where sand collects, where either there is little freshwater influence or marine derived salts are concentrated through evaporation. Substrata are sand, silty sand, or gravelly sand. Salt pannes are common.

Diagnostic species

The pickleweed *Salicornia virginica* dominates in upper zones, where it forms dense mats.

Common associates

Jaumea carnosa, Distichlis spicata, Puccinellia spp., *Glaux maritima, Plantago maritima, Atriplex patula, Stellaria humifusa, Spergularia* spp.

Sites Surveyed

Dungeness Spit, The Lagoon, Travis Spit, Oak Bay, Scow Bay, Shoal Bight, Fisherman Bay, Henry Island, Westcott Bay, Tarboo Bay, Quilcene Bay, The Sink, Leadbetter Point.

Sources

Mumford and Shaffer pers. com.; Kunze, 1984; Kunze and Cornelius, 1982; Frenkel, Boss and Schuller, 1978; Jefferson, 1975.

Estuarine intertidal sand: partly enclosed, eulittoral, polyhaline (marsh)

This is a common habitat often associated with deltas and along shorelines having some freshwater influence. Waves, currents, tides or freshwater flows are sufficient to prevent siltation. Substrata often have some peat or silt.

Diagnostic species

There are three marsh communities dominant in this habitat: (1) *Distichlis spicata* community; (2) *Distichlis spicata-Salicornia virginica* community; and (3) *Salicornia virginica* community. They generally occur in order from higher to lower on the shore.

Common associates

Each of the three communities can occur as pure stands of the diagnostic species, but typically the following vascular plant species are also found: *Jaumea carnosa, Puccinellia* spp., *Triglochin maritimum, Glaux maritima, Spergularia* spp. *Plantago maritima, Stellaria humifusa.*

Sites surveyed

Thorndyke Bay, Gibson Spit, Duckabush River Delta, Hamma Hamma River Delta, Dosewallips River Delta, Skokomish River Delta, Lynch Cover, Skookum Inlet, Kennedy Creek, Nisqually River Delta, The Sink, Markham Island, Elk River Estuary, Westport, Leadbetter Point, Long Island, Niawiakum River.

Sources

Kunze, 1984; Kunze and Cornelius, 1982; Burg, 1980; Jefferson, 1975.

Estuarine intertidal sand: partly enclosed eulittoral, mesohaline (marsh)

This habitat occurs in bays and deltas with significant freshwater influence and high enough energy to prevent siltation. Salinities range from oligohaline to polyhaline. On low terraces along stream and river channels, the sand may contain pockets of clay or peat (organic).

These and other marsh types provide great amounts of food and habitat for terrestrial and marine organisms as well as exporting large quantities of detritus to estuarine ecosystems. Animals using salt marshes range from deer and elk to voles, owls, insects, and snow geese and a tremendous variety of other birds. Insects are consumed by fish at high tide, and detritus is eaten by amphipods, clams, and worms, which in turn are eaten by larger invertebrates, shorebirds, mammals, and fish. See Albright et al. (1980) for discussion about Washington salt marsh food webs.

Diagnostic species

The bulrush *Scirpus americanus* is the diagnostic plant species in bays and on deltas. It often forms monospecific stands. Along freshwater streams and river channels the habitat is dominated by the sedge *Carex lyngbyei* which often forms dense monospecific swards.

Common associates

Triglochin maritimum, *Carex lyngbyei*, *Zannichellia palustris*

Sites surveyed

Skagit Bay, Snohomish / Port Susan Bay, Quilcene Bay, Nooksack River Delta, Quilceda Creek, Stavis Bay, Duckabush River Delta, Hamma Hamma River Delta, Skokomish River Delta, Lynch Cove, Minter Creek, Skookum Inlet, Kennedy Creek, Nisqually River Delta, Humptulips River Delta, Chenois Creek, Johns River, Elk River, Andrews Creek, Bone River, Niawiakum River, Palix River, Nemah River, Naselle River, Bear River, Baker Bay.

Sources

Mumford and Shaffer pers. com.; Kunze, 1984; Ewing, 1982 and 1983; Kunze and Cornelius, 1982; Disraeli, 1977; Jefferson, 1975.

Estuarine intertidal sand or mixed-fine: lagoon, hyperhaline and euhaline

Lagoons are formed when longshore water-borne sediments are deposited to form a spit closing off (partially or totally) an embayment. Open lagoons are regularly flushed by freshwater and tidal action through a channel, while enclosed ones have no permanent channel and rarely flush. The latter are usually filled gradually by salt marsh vegetation. Some lagoons drain completely at low tide, while others retain water because of a sill in the channel. Water in the lagoon evaporates, concentrating salts. Interstitial salinities can reach as much as 80 ppt, but are more commonly in the euhaline range. Toward the landward end of these lagoons, the salinity can grade to <0.5 ppt if there is freshwater influence. Productivity is high because of marsh vegetation, eelgrass, microalgae, and terrestrial input. Shorebirds, waterfowl, river otters, and hawks all use these habitats. Tidal creeks draining lagoons tend to contain mixed-coarse substrata and are occupied by a unique set of plants and animals using this high-flow, variable-salinity habitat. Probably the inhabitants of each lagoon creek are different, although all will contain filter feeders, epifaunal and infaunal. Few surveys of benthic organisms in lagoons were found.

Diagnostic species (marsh)

The same vascular plant communities which occur in the Estuarine Intertidal Sand: Partly Enclosed, Eulittoral, Euhaline habitat occur in this habitat. This habitat is dominated by *Salicornia virginica*, but a *Jaumea carnosa-Salicornia virginica* community also occurs.

Common associates (marsh)

Puccinellia spp., *Distichlis spicata*, *Spergularia* spp.

Common benthic species

Zostera marina, benthic diatoms, ulvoids, mats of *Ceramium pacificum* and *Polysiphonia paniculata*; dominant animals are the polychaete *Axiothella rubrocincta* and the clams *Macoma nasuta* and *Transennella tantilla*. Other bivalves include *Protothaca staminea, Psephidia lordi, Tapes philippinarum*, and *Mya arenaria*. Other worms include *Ophiodromus pugettensis, Armandia brevis, Polydora ligni*. The brittle star *Amphipholis squamata* is also abundant.

Sites surveyed

Foulweather Salt Marsh, American Camp Lagoons, Argyle Lagoon, Spencer Spit, White Point, Mud Bay, Westcott Bay, Jefferson Point Marsh, Perego's Lagoon, Lake Hancock, Elger Bay, Thorndyke Bay.

Sources

Kunze, 1984; Albright et al., 1980; Friday Harbor Labs unpublished reports.

Estuarine intertidal mixed-fines: partly enclosed

These habitats occur in backwaters or on deltas away from large distributary channels. They consist of mixed sand and mud with small amounts of gravel or with some clay and peat. The substratum is generally stable, firm, and organic-rich. Productivity is high due to eelgrass, micro- and macro-algae, and salt marsh vegetation. Drift algae and seagrass may be abundant seasonally. Areas with gravel are characterized by an abundance of hard-shelled clams. Detritivores in the sediment are very dense, and are preyed upon by other invertebrates as well as by numerous birds and fishes. The amphipod *Corophium* provides a major food resource for numerous fish and shorebirds. Because of the presence of eelgrass (which reaches its highest densities in muddy sand) and marsh grasses, these habitats are used by a variety of birds: great blue herons, mergansers, western grebes, and brant. Areas without eelgrass are much less diverse, although crows, gulls, killdeer, great blue herons, mallards, and pintails forage in muddy sand. Raccoons, deer, skunks, and weasels forage on these shores.

Diagnostic species

There are four marsh communities which occur in the habitat: (1) *Carex lyngbyei-Distichlis spicata* co-dominated community; (2) *Distichlis spicata-Salicornia virginica-Triglochin maritimum* co-dominated community; (3) *Jaumea carnosa-Salicornia virginica-Triglochin maritimum* co-dominated community; and (4) *Salicornia virginica-Triglochin maritimum* co-dominated community. In order these four communities occur from higher to lower in the low marsh zone with the fourth colonizing tide flats.

Diagnostic benthic species in lower zones are *Zostera marina, Protothaca staminea, Saxidomus giganteus*, and *Callianassa californica*.

Common associates: marsh

These communities tend to be species rich for being low marsh. *Glaux maritima, Stellaria humifusa, Puccinellia* spp., *Spergularia* spp. *Carex lyngbyei, Triglochin concinnum, Plantago maritima*, and *Atriplex patula* are common vascular plant associates.

Common associates: benthos

Leafy green ulvoid algae are characteristic on the surface in spring and summer, and a variety of small algae (*Smithora, Ceramium, Chondria*) are epiphytic on *Zostera*. The introduced species *Zostera japonica* is found in some high intertidal areas. Infauna include the clams *Mya arenaria, Macoma secta, Clinocardium nuttallii, Protothaca tenerrima, Tresus* spp., and *Cryptomya californica*; the introduced oyster *Crassostrea gigas*; the crabs *Cancer magister, Hemigrapsus oregonensis*, and *Pugettia producta*; the moon snail *Polinices lewisii* and the sea slug *Haminoea virescens*; the polychaetes *Abarenicola pacifica, Manayunkia aestuarina, Pygospio elegans, Polydora kempi japonica, Hobsonia florida, Euzonus williamsi, Nereis limnicola, Nephtys* spp., *Eteone longa*; the crustaceans *Corophium salmonis, Eogammarus confervicolus, Leptochelia savignyi*, and *Upogebia pugettensis*; and ophiuroids. Coastal estuaries also have high densities of *Streblospio benedicti* and may have mats of the algae *Vaucheria longicaulis, Rhizoclonium riparium*, and *Polysiphonia hendryi*. Some areas of the uncommon enteropneust *Saccoglossus* sp. are found in Willapa Bay. Numerous, diverse fish are found in these habitats, especially at high tide: Pacific herring, Pacific sand lance, tubesnout, juvenile English sole, starry flounder, sculpins (tidepool, rosylip, sharpnose, Pacific staghorn, great), three-spined stickleback, bay pipefish, snake prickleback, saddleback gunnel, crescent gunnel,

surf smelt, shiner perch, and juvenile chum and chinook salmon. It has been said that the eelgrass fish fauna is the "richest, most abundant pelagic fish fauna of any habitat sampled" in the Puget Sound region. In addition, coonstripe and broken-back shrimp can be found in channels and pools.

Sites surveyed

- MARSHES — Dosewallips River Delta, Skokomish River Delta, North Bay, Oakland Bay, Chapman Cover, Nisqually River Delta, Kennedy Creek, Skookum Inlet, Tokeland marsh, Long Island, Seal Slough, Niawiakum River, Bone River, Elk River Estuary, Westport marsh, Markham Island, North Bay.

- BENTHOS — Kiket Island, Skagit Flats, Ellisport (Vashon), Anderson Cove and other sites in Hood Canal, Bellingham Bay, Drayton Harbor, Padilla Bay, inner Dungeness Spit, Grays Harbor and Willapa Bay.

Sources

- MARSHES — Kunze, 1984; Kunze and Cornelius, 1982; Frenkel, Boss and Schuller, 1978; Jefferson, 1975.

- BENTHOS — Houghton, 1973; Thom et al., 1984; Eckman, 1979; Gallagher et al., 1983; Chew, 1970; Webber, 1978; Schneider and Dube, 1969; J.E. Smith, 1980; Thom, 1981; Albright, 1982; Hedgpeth and Obrebski, 1981; Albright and Borithilette, 1982; Thom et al., 1988; Thom, 1988; Harman and Serwold, 1978; Mumford and Shaffer unpubl. data; C. Simenstad unpubl. data.

Estuarine intertidal mixed-fine and mud: partly enclosed, eulittoral, mesohaline (marsh)

This habitat occurs in quiet areas back from stream channels, currents and wave action where silt or a mixture of silt and sand settles and where there is freshwater influence. The substratum is often very soft and typically anoxic.

Diagnostic species

The bulrush *Scirpus maritimus*, *Triglochin maritimum* and the sedge *Carex lyngbyei* are the most commonly occurring marsh species in this habitat.

Common associates

The bulrush *Scirpus americanus* occurs where there is a relatively high sand content.

Sites surveyed

Nooksack River Delta, Skagit Bay, Port Susan Bay, Oakland Bay, Quilcene Bay, Nemah River, Bear River.

Sources

Kunze, 1984; Ewing, 1983 and 1982; Kunze and Cornelius, 1982; Disraeli, 1977; Jefferson, 1975.

Estuarine intertidal mixed-fine: lagoon, mesohaline and oligohaline

This habitat occurs in lagoons which are nearly completely separated from tidal influence by a berm. Salt water enters the lagoon by occasionally over-topping or breaching the berm, or seeping in subsurface. There is always a source of freshwater and usually horizontal salinity gradients. Substrata are silt and muck.

Diagnostic species

Three marsh communities occur in this habitat: (1) *Scirpus maritimus*; (2) *Scirpus acutus*; and (3) *Typha latifolia*. *Scirpus maritimus* usually occurs in higher salinity (mesohaline) areas, while the other two communities are found in more oligohaline conditions. However, salinity gradients occuring in this habitat sometimes permit all three communities to be located in a single lagoon. The latter two communities can also occupy the oligohaline portions of a euhaline lagoon.

Common associates

Eleocharis palustris.

Sites surveyed

Foulweather Bluff Preserve, Watmough Bay, Alec Bay.

Sources

Kunze, 1984; Cornelius, 1983.

Estuarine intertidal mud: partly enclosed and enclosed

This substratum type differs from the mixed-fines in lacking gravel or a significant amount of sand and consequently is softer and oozier. It is found in the heads of bays and inlets. Eelgrass and its associated invertebrate, fish, and bird fauna are less common in these habitats, as are hard shelled clams.

Diagnostic species

Macoma nasuta, Macoma balthica.

Common associates

The clams *Mya arenaria* and *Cryptomya californica*; the crustaceans *Upogebia* and *Callianassa*, the amphipod *Corophium salmonis*, the polychaetes *Polydora kempi japonica, Pygospio elegans, Capitella capitata* (especially in polluted areas), *Hobsonia florida, Manayunkia aestuarina*, and *Glycinde picta*; the sea slug *Melanochlamys diomedea*. *Zostera marina* and *Z. japonica* occur in some areas.

Sites surveyed

Dockton (Vashon Island), Fidalgo Bay, Fraser River Estuary, Anderson Cove (Hood Canal), portions of Grays Harbor.

Sources

Thom et al., 1984; Nyblade, 1979a; Smith and Webber, 1978; Levings et al., 1983; Chew, 1970; Thom, 1981; Albright and Borithilette, 1982.

Estuarine intertidal organic: partly enclosed, backshore, polyhaline (marsh)

This habitat is intermediate between true low and high marsh. Salinities as high as 28 ppt have been measured. It can occur as a band between high and low marsh, along the edges of tidal sloughs, or in slight depressions in the high marsh.

Diagnostic species

Two commonly occurring marsh communities in this habitat are: (1) *Deschampsia caespitosa-Distichlis spicata*, and (2) *Deschampsia caespitosa-Distichlis spicata-Salicornia virginica*. The first community appears to occur at slightly lower salinities and higher elevations than does the second. Some infrequently occurring assemblages also fall into this intermediate habitat: (3) *Potentilla pacifica*, (4) *Grindelia integrifolia*, and (5) *Juncus gerardii* dominated areas.

Common associates

Deschampsia caespitosa-Distichlis spicata community can have no associates or any of the following: *Atriplex patula, Triglochin maritimum, Juncus balticus, Hordeum* spp.

Deschampsia caespitosa-Distichlis spicata-Salicornia virginica has several associates: *Carex lyngbyei, Glaux maritima, Grindelia integrifolia, Jaumea carnosa, Triglochin maritimum, Juncus balticus, Juncus gerardii, Atriplex patula* and *Potentilla pacifica.*

Sites surveyed

Pysht River, Salt Creek, Lynch Cove, Nisqually River Delta, Skookum Inlet.

Sources

Kunze, 1984; Kunze and Cornelius, 1982; Burg, 1980; Frenkel, Boss and Schuller, 1978; Jefferson, 1975.

Estuarine intertidal organic: partly enclosed, backshore, mesohaline (marsh)

This habitat includes the high marsh and occurs on peat soils. Interstitial soil salinities can drop below 5 ppt.

Diagnostic species

Four native plant communities can occur in this habitat: (1) *Deschampsia caespitosa-Juncus balticus-Potentilla pacifica*, (2) *Juncus balticus-Potentilla pacifica*, (3) *Carex lyngbyei-Potentilla pacifica*, and (4) *Festuca rubra.* The fourth community is seldom found any more. A fifth community is found in this habitat, but it is dominated by an exotic (non-native) plant species, *Agrostis alba.*

Common associates

Aster subspicatus, Triglochin maritimum, Hordeum spp. are frequent vascular plant components of these communities.

Sites surveyed

Nisqually River Delta, Tarboo Bay, Lynch Cove, Quilceda Creek, Salt Creek, Skookum Inlet, Kennedy Creek, Henry Island North Bay, Elk River estuary, Cedar Creek, Bone River, Niawiakum River, Palix River, Nemah River, Bear River, Leadbetter Point, Baker Bay.

Sources

Kunze, 1984; Kunze and Cornelius, 1982; Burg, 1980; Frenkel, Boss and Schuller, 1978; Jefferson, 1975.

Estuarine intertidal organic, sand, mixed-fine or mud: partly enclosed, backshore, oligohaline (marsh)

This habitat is transitional between wetland and upland and between freshwater and estuarine environments. Occasionally it is inundated with water of salinity greater than 0.5 ppt. Substrata are usually organic, either peat for areas transitional between wetland and upland, or muck for areas transitional between freshwater and estuarine. Other substrata in these areas are sand (along stream channels) and clay.

Diagnostic species

Five communities can occur in this habitat: (1) *Juncus balticus-Potentilla pacifica*-forb, (2) *Calamagrostis nutkaensis*, (3) *Picea sitchensis*, (4) *Scirpus acutus* and (5) *Typha latifolia*. The first three communities are generally transitional between wetland and upland and are species rich. The last two communities are transitional between freshwater and estuarine, substrata are usually anoxic muck and stands are often monospecific.

Common associates

The first community is similar to the high marsh communities but adds several forb species typically found in uplands, notably *Achillea millefolium, Angelica lucida* and *Heracleum lanatum*. The second community contains some of the high marsh species, but is dominated by a whole new set of species, most notably *Calamagrostis nutkaensis, Pyrus fusca* and *Sidalcea hendersonii*. The third community is very similar in species composition to the second, except *Picea sitchensis* is a dominant species.

Other common vascular plant associates in the first three communities are: *Carex lyngbyei*, *Oenanthe sarmentosa*, *Trifolium wormskjoldii*, *Vicia gigantea* and *Festuca rubra*. The fourth and fifth communities usually occur as monospecific stands.

Sites surveyed

Hamma Hamma River Delta, Skagit River Delta, Port Susan Bay, Quilceda Creek, Kennedy Creek, Johns River, Elk River, Andrews Creek, North Bay, North River, Bone River, Niawiakum River, Palix River, Bear River, Naselle River, Baker Bay.

Sources

Kunze, 1984; Ewing, 1983 and 1982; Kunze and Cornelius, 1982; Frenkel, Boss and Schuller 1978.

Estuarine intertidal mixed-fines and mud: channel/slough

Undisturbed channels and sloughs are troughs within a tidal flat that drain slowly throughout the tidal cycle. They are usually lined with marsh plants, contain numerous invertebrates and fishes, and are used by shorebirds, herons, raccoons, otter, mink, and other organisms as important foraging areas. Dunlin, sanderling, and western sandpipers are especially abundant. Most resident and migratory birds, especially waterfowl, that use estuaries for feeding or roosting occupy channels at various times. Precise invertebrate and plant assemblages probably vary with salinity, flow rate, and substratum type, but common species of blind and subsidiary (shallow, intertidal) channels can be enumerated. The drift line commonly is covered with organic debris.

Common species

Zostera marina is found in some channels. Common animals include chironomid (insect) larvae, the amphipods *Corophium salmonis*, *Paramoera columbiana*, and *Eogammarus* spp.; the polychaetes *Hobsonia florida* and *Manayunkia aestuarina*, the clam *Macoma balthica*, the shore crab *Hemigrapsus oregonensis*, tanaids, and mysids. Fishes found in channels include fry of chum, coho, and pink salmon, three-spined stickleback, starry flounder, and staghorn sculpin.

Sites surveyed

Skagit flats, coastal estuaries.

Sources

Congleton, 1978; Smith, 1980; Simenstad, 1983; C. Staude unpubl. data.

ESTUARINE SYSTEMS
SUBTIDAL HABITATS

ESTUARINE SUBTIDAL ROCK: OPEN, SHALLOW

Few complete surveys have been done in these habitats, even though they are common offshore from rocky points in Puget Sound and Hood Canal. Algae often dominate these habitats.

DIAGNOSTIC SPECIES

Nereocystis luetkeana, *Agarum* spp., *Metridium* spp.

COMMON ASSOCIATES

The large brown algae *Pterygophora californica* (high currents), *Laminaria saccharina* and *L. groenlandica*, *Desmarestia ligulata*, and *Sargassum muticum* (low currents); the red algae *Iridaea splendens*, *Rhodymenia pertusa*, *Callophyllis flabellulata*, *Polyneura latissima*, *Gigartina exasperata*, and others, the tube-building polychaete *Serpula vermicularis*, the chitons *Tonicella lineata* and *Mopalia* spp., the small snails *Margarites* spp., the jingle shell *Pododesmus cepio*, the slipper limpet *Crepidula adunca*, the crabs *Cancer productus* and *Pugettia* spp., the tunicate *Pyura haustor*, and the seastars *Pycnopodia helianthoides*, *Henricia leviuscula*, *Mediaster aequalis*, *Dermasterias imbricata*, and *Pisaster brevispinus*.

SITES SURVEYED

Restoration Point (Bainbridge), Lincoln Park, West Point, Blakely Rock, Hoodsport, Howe Sound (British Columbia), Fox Island, Steamboat Island, Fidalgo Head, Saltspring Island and elsewhere in the Strait of Georgia.

SOURCES

Neushul, 1965; Thom et al., 1976; Thom, 1978; McDaniel, 1973; Hodgson and Waaland, 1979; Harlin, 1969; Lindstrom and Foreman, 1978; Lim, 1980; H. Webber, R. Shimek unpubl. data.

ESTUARINE SUBTIDAL ROCK AND BOULDERS: OPEN, DEEP

These habitats are found in narrow channels or headlands where currents are rapid and remove sediment. Because freshwater flowing in can remain layered in shallower water, conditions in these habitats are essentially marine.

COMMON SPECIES

Ascidians, especially *Ascidia paratropa*, *Chelyosoma productum*, *Corella willmeriana*, *Boltenia villosa*; the large barnacle *Balanus nubilus*, the hydrocoral *Allopora* sp., the anemone *Metridium* sp. and the colonial zoanthid *Epizoanthus scotinus*, the white urchin *Strongylocentrotus pallidus*, the brachiopods *Terebratalia* and *Terebratulina*, the sea cucumbers *Eupentacta* spp., and the tubiculous polychaete *Serpula vermicularis*.

Below 20 m, especially in the Strait of Georgia, other species appear: glass sponges (*Rhabdocalyptus dawsoni*, *Aphrocallistes vastus*), brachiopods such as *Terebratulina unguicula*, the cup coral *Balanophyllia elegans*, the sessile sea cucumber *Psolus chitonoides*.

SITES SURVEYED

Lower Puget Sound, Boundary Pass, Howe Sound, British Columbia.

SOURCE

McDaniel, 1973; Wennekens, 1959; R. Anderson unpubl. data.

Estuarine subtidal cobble: open, shallow

As in parallel marine systems, subtidal cobble systems have mixed substratum types, as the cobbles generally overlie sand. Few surveys have been done in these habitats.

Common species

Laminaria saccharina, Agarum fimbriatum, numerous red algae especially *Gigartina exasperata*, the clams *Saxidomus giganteus* and *Tresus capax*, the polychaetes *Platynereis bicanaliculata* and *Scoloplos armiger*, the crab *Cancer gracilis*, the sunstar *Pycnopodia helianthoides.*

Sites surveyed

Hood Canal (variety of sites), Fox Island.

Sources

Shimek, 1977; Phillips and Fleenor, 1970; Hodgson and Waaland, 1979; R. Anderson unpubl. data.

Estuarine subtidal cobble: open, deep

Only one survey examined habitats that might qualify as cobble with rocks of various sizes overlying coarse shell-sand in 15-35 m of water.

Common species

The crab *Lophopanopeus bellus*, the clams *Semele rubropicta* and *Humilaria kennerlyi*, the sipunculid *Golfingia pugettensis*, the sea cucumbers *Leptosynapta clarki* and *Pentamera* spp., the slipper shell *Crepidula* spp., the barnacles *Balanus nubilus* and *B. rostratus*, *Octopus rubescens*, and the amphipod *Byblis veleronis.*

Sites surveyed

Johnson Point (Case Inlet), Admiralty Inlet, numerous other Puget Sound sites.

Sources

Lie, 1968; Wennekens, 1959; R. Harman unpubl. data.

Estuarine subtidal mixed-coarse: open, deep

Several deep to very deep sites (15-100 m) in Puget Sound have been surveyed. These are scoured by tidal currents running through deep channels of the Sound. They have mixed substrata of gravel, shell, and sand.

15-30 m:

Common species

The gastropods *Crepidula adunca*, *Ceratostoma foliatum*, *Calliostoma* spp., and *Trichotropis cancellata*; the bivalves *Glycymeris* sp., *Pododesmus cepio*, *Humilaria kennerlyi*, *Macoma brota*, and *Hiatella arctica*; a variety of polychaetes including serpulids, sabellids, terebellids, and ampharetids; the sea stars *Pisaster brevispinus* and *Solaster stimpsoni*; and *Octopus rubescens.* Various shrimp are usually abundant.

Sites surveyed

Variety in Puget Sound and Hood Canal.

Sources

R. Harman, J. Serwold, and R. Anderson unpubl. data.

30-100 m:

Common species

The clams *Mysella tumida* and *Panope abrupta*, the ophiuroid *Ophiura lutkeni*, the sea cucumber *Parastichopus californicus*, and *Pyncopodia helianthoides*. Sites with organic debris are dominated by the clam *Mya arenaria* and the polychaetes *Lumbrineris* spp. and *Chaetozone setosa*.

Sites surveyed

Johnson Point, other sites at narrow passages and entrances to inlets in Puget Sound and Hood Canal.

Sources

Lie, 1968, 1974; R. Harman unpubl. data.

Estuarine subtidal sand: open, shallow

Shallow subtidal sandy habitats usually have similar flora and fauna as low intertidal communities, and grade gradually into different assemblages in deeper water. These are high-current areas with little debris and some gravel. A variety of different dominant species can be seen.

Common species

Abundant organisms may include sand dollars (*Dendraster excentricus*), *Zostera marina*, sea pens, or phoronids (*Phoronopsis harmeri*). Other common species include the bivalves *Psephidia lordi*, *Protothaca staminea*, *Mysella tumida*, and *Macoma secta*; the gastropod *Nassarius mendicus*, the polychaetes *Platynereis bicanaliculata* and *Owenia fusiformis*, the seastar *Evasterias troschelii*, and *Cancer magister* and *C. gracilis*.

Sites surveyed

Windy Point (Kitsap Peninsula), Hood Canal, Shilshole Bay.

Sources

Shimek, 1977 and unpubl. data; Phillips and Fleenor, 1970; Harman et al., 1977.

Estuarine subtidal sand: open, deep

Assemblages in these habitats vary with depth. The shallower areas are current-swept where little organic debris can accumulate, while debris does accumulate in deeper zones. Some gravel may be present, especially deeper.

-15-30 m:

Diagnostic species

Beds of the sea pen *Ptilosarcus guerneyi* or of the tube-building polychaete *Phyllochaetopterus prolifica*, and their associates (below).

Common associates

Tunicates such as *Chelyosoma*, many starfish including *Mediaster aequalis*, *Hippasteria* spp., *Luidia foliolata*, *Pisaster brevispinus*, and *Evasterias troschelii*, many nudibranchs, especially *Armina californica*, *Dendronotus* spp., and *Tritonia festiva*. Some areas have beds of geoducks (*Panope abrupta*), with other bivalves such as *Psephidia lordi*, *Tellina carpenteri*, *Saxidomus giganteus*, and *Tresus* spp., the burrowing anemone *Pachycerianthus fimbriatus*, the gastropods *Nassarius mendicus* and *Polinices lewisii*, and *Octopus rubescens*. Fish include sanddabs, C-O sole, snake prickleback, tomcod, and dogfish.

Sites surveyed

Golden Gardens, Alki Point, Brace Point, Windy Point (Kitsap Peninsula), West Point, Howe Sound (British Columbia).

Sources

Birkeland, 1968; Shimek, 1977 and unpubl. data; Wennekens, 1959; Harman et al., 1977; McDaniel, 1973; Goodwin, 1973; R. Anderson unpubl. data.

>30 m:

Diagnostic species

The bivalves *Astarte* sp., *Nuculana minuta*, *Nemocardium centifilosum*, and *Megacrenella columbiana*, the snail *Bittium attenuatum*, and the polychaete *Chaetozone setosa*.

Common associates

The bivalves *Mysella tumida* and *Chlamys* spp., the pea crabs *Pinnixa* spp., the amphipod *Byblis veleronis*, and chaetopterid polychaetes.

Sites surveyed

Central Puget Sound, West Point.

Sources

Lie, 1968; Harman et al., 1977.

Estuarine subtidal sand: partly enclosed, deep

Common species

The ostracodes *Euphilomedes* spp., the polychaetes *Travisia brevis*, *Laonice cirrata*, *Axiothella rubrocincta*, and pectinariids, the clam *Axinopsida serricata*, and the ophiuroid *Amphiodia urtica*.

Sites surveyed

Port Madison, Heron Island (Case Inlet), Dabob Bay.

Sources

Lie, 1968; Battelle, 1986; C. Staude unpubl. data.

Estuarine subtidal mixed-fines: open, shallow

Sites in this category have substrata of sand, shells, pebbles, and woody debris. There was high variation in the species composition of these sites, so no diagnostic species have yet been described.

Common species

Zostera marina (shallow), the red algae *Sarcodiotheca gaudichaudii*, *Gracilaria* spp., *Gigartina* spp., and *Iridaea* spp., the green ulvoids, and the brown kelp *Laminaria saccharina*. Bivalves include *Psephidia lordi* and *Clinocardium* spp. Some areas have sea pens or phoronids. Crustaceans include the tanaid *Leptochelia savignyi*, *Pinnixa schmitti*, *Cancer productus*, and *Euphilomedes carcharodonta*; ophiuroids include *Amphiodia urtica*, and polychaetes include *Scoloplos* spp., *Platynereis bicanaliculata*, *Lumbrineris* spp., *Owenia fusiformis*, and *Axiothella rubrocincta*.

Sites surveyed

Strait of Georgia, Saltspring Island, Clark Island, Lummi Island, Port Madison, Similk Bay, Cherry Point, Guemes Island, Polnell Point, Bush Point, Pratt's Bluff, and Padilla Bay.

Sources

Lindstrom and Foreman, 1978; Lim, 1980; G.F. Smith, 1979; Lie, 1968; H. Webber unpubl. data.

Estuarine subtidal mixed-fines: open, deep

-15 to 50 m: sand, shell, pebbles

Common species

Areas with finer substrata have beds of the sea pens *Ptilosarcus gurneyi* and *Virgularia* spp. and accompanying nudibranchs. Other species include the burrowing anemone *Pachycerianthus fimbriatus*, chaetopterid polychaetes, hydroids, the bivalves *Saxidomus giganteus*, *Mya truncata*, *Protothaca staminea*, *Humilaria kennerlyi*, *Solen sicarius*, and *Pododesmus cepio* (on pebbles and shells); the sea cucumber *Parastichopus californicus*, the crabs *Cancer magister* and *Pugettia* spp., the starfish *Luidia foliolata* and *Pycnopodia helianthoides*, and the red algae *Stenogramme interrupta*, *Polyneura latissima*, *Nienburgia andersoniana* and others.

Sites surveyed

Jack Island, Saltspring Island (British Columbia).

Sources

Lim, 1980; D. Duggins unpubl. data.

Estuarine subtidal mud: open, shallow

Common species

Zostera marina (mostly <4 m depth), ulvoids, and the herbivorous snail *Lacuna* sp. Bivalves include *Psephidia lordi*, *Macoma nasuta*, *Acila castrensis*, *Axinopsida serricata*, and *Mysella tumida*; polychaetes include *Owenia fusiformis*, *Sternaspis scutata*, and *Scalibregma inflatum*. Ophiuroids and the gastropod *Melanochlamys diomedea* are also present. Fishes may include lemon sole, sculpins, and others common to eelgrass.

Sites surveyed

Echo Bay (Sucia Island), Samish Bay, Birch Bay, Fidalgo Bay, Cama Beach.

Sources

G.F. Smith, 1979; H. Webber unpubl. data.

Estuarine subtidal mud: partly enclosed, shallow

These habitats, which are common in partly enclosed bays in Puget Sound, show little consistency in organisms. This variability may be due to the range of physical parameters seen in these environments, especially in the degree of organic enrichment, pollution, and freshwater input.

Diagnostic species

The bivalves *Macoma nasuta* and *Mysella tumida*, the polychaetes *Armandia brevis, Glycinde picta, Terebellides stroemi,* and *Lumbrineris luti*.

Common associates

The bivalves *Macoma inquinata, Protothaca tenerrima*, and sometimes geoducks (*Panope abrupta*). Polychaetes are abundant but variable, and include glycerids, cirratulids (especially *Tharyx* spp.), *Nepthys* spp., *Eteone pacifica*, *Podarkeopsis brevipalpa, Schistomeringos moniloceras*, and *Capitella capitata.* Gastropods include the predatory *Polinices lewisii*. The sea cucumber *Parastichopus californicus* is seen in some bays. Amphipods include *Aorides columbiae* and *Corophium salmonis.* Many estuarine bays are used by river otters. Fishes found here include Pacific tomcod, flounder, C-O sole, Pacific staghorn sculpin, and smelts.

Sites surveyed

Commencement Bay, Shilshole Marina, Eld Inlet, Lynch Cove and Anderson Cove (Hood Canal), and Bellingham Bay.

Sources

Blaylock and Houghton, 1981; Wennekens, 1959; Milne, 1976; Harman et al., 1977 and unpubl. data; Chew, 1970; Webber, 1978; G.F. Smith, 1979; C. Staude unpubl. data.

Estuarine subtidal mud: partly enclosed, deep

These habitats are found in the heads and centers of inlets in Puget Sound where there is little water motion and the bottom is soft. They tend to retain fine sediments, wood, and other organic debris, and support large populations of deposit feeding clams and tube-dwelling polychaetes. Salinities are relatively constant, varying seasonally less than do shallower waters.

-15-30 m:

Diagnostic species

Acila castrensis, *Alia* (=*Mitrella*) *gausapata*.

Common species

The bivalves *Axinopsida serricata* and sometimes *Panope abrupta*, the brittle star *Amphiodia urtica*, the crab *Cancer gracilis*, the small snails *Alvania* sp. and *Barleeia* sp., the sea whip *Virgularia* spp., the cephalopod *Rossia pacifica*, and the polychaetes *Tharyx* spp., *Nephtys cornuta*, *Sternaspis scutata*, *Spio cirrifera*, and other lumbrinerids and pectinariids. Polluted bays tend to be dominated by capitellids, cirratulids, and nematodes.

Sites surveyed

Similk Bay, Samish Bay, Sequim Bay, Bellingham Bay, Port Gardner, Sinclair Inlet, numerous sites in Puget Sound proper.

Sources

Mayer, 1973; Lie, 1974; Battelle, 1986; R. Harman, R. Shimek, R. Anderson unpubl. data.

> 20 m (Deep Basins):

Diagnostic species

The heart urchin *Brisaster latifrons*, the sea cucumber *Molpadia intermedia*, the bivalves *Macoma carlottensis* and *Axinopsida serricata*, and the sea whip *Stylatula elongata*.

Common species

The bivalves *Nucula* spp., *Yoldia scissurata*, and *Acila castrensis*, the polychaetes *Pectinaria californiensis*, *Ampharete acutifrons*, *Glycera capitata*, *Travisia pupa*; dorvilleids (especially *Schistomeringos* spp.), *Glycinde picta*, *Tharyx multifilis*, *Nephtys cornuta*, and *Laonice serrata*; the cephalopod *Rossia pacifica*, the crustacean *Euphilomedes producta*; fish: English, rock, and Dover sole, shiner sea perch, Pacific tomcod, ratfish.

Sites surveyed

Deep basins of Puget Sound, Hood Canal, Port Gardner, Strait of Georgia, and Bellingham Bay.

Sources

Lie, 1968, 1974; Wennekens, 1959; Harman et al., 1977; Webber, 1978; Battelle, 1986; Nichols, 1987; Kisker, 1976; R. Anderson, C. Staude, R. Shimek unpubl. data.

Estuarine subtidal sand and mud: channels

Estuarine "intertidal" channels (described above) combine into larger and deeper channels and eventually into the mainstem channels of river mouths. These rich habitats are extremely important as feeding and nursery areas for diverse bird and fish assemblages. Wading and surface-foraging birds use the edges of channels, while surface and diving birds such as grebes, cormorants, mergansers, scoters, waterfowl, and even auklets and murrelets feed and roost in open channels. Kingfishers, osprey, eagles, terns, and others dive for fish from the air. Raccoon, beaver, nutria, river otter, and marine mammals (sea lions and seals) feed in channels. Substratum composition (relative abundances of sand and mud) and salinities vary with flow rate and distance from the estuary mouth.

Common species

A wide variety of polychaetes, including *Magelona* spp, *Capitella capitata*, *Paraonella platybranchia*, *Eteone* spp., *Hobsonia florida*, and numerous spionids. Amphipods include phoxocephalids (river mouths), *Corophium salmonis, Paramoera columbiana*, and *Eogammarus* spp. Other common species are *Macoma balthica*, *Cancer magister*, and the shrimp *Crangon* spp. Fishes include shiner perch, peamouth, Pacific tomcod, snake prickleback, sculpins, speckled sanddab, English sole, starry flounder, and juvenile salmon.

Sites

Coastal estuarine channels.

Sources

Simenstad, 1983; Albright and Borithilette, 1982; C. Staude unpubl. data.

Bibliography

Albright, R.C. 1982. Population dynamics and production of the amphipod *Corophium salmonis* in Grays Harbor, Washington. MS thesis. Univ. of Wash. Seattle, Wash.

Albright, R.C. and P.K. Borithilette. 1982. Benthic invertebrate studies in Grays Harbor, Washington. Grays Harbor and Chehalis River Improvements to Navigation Environmental Studies. U.S. Army Corps of Engineers. Seattle Dist.

Albright, R., R. Hirschi, R. Vanbianchi, and C. Vita. 1980. Coastal Zone Atlas of Washington. Land Cover/Land Use Narratives. Vol. II. Wash. Dept. of Ecology. Olympia, Wash.

Armstrong, J.W., C.P. Staude, R.M. Thom and K.K. Chew. 1976. Habitats and relative abundances of the intertidal macrofauna at five Puget Sound beaches in the Seattle area. Syesis 9:277-290.

Battelle. 1986. Reconnaissance survey of eight bays in Puget Sound. Vol I and II. U.S. EPA, Region X.

Birkeland, C.E. 1968. Reciprocal interactions between a single prey species, *Ptilosarcus gurneyi*, and its complex of predators. MS thesis. 68 pp. Univ. of Wash. Seattle, Wash.

Blaylock, W.M. and J.P. Houghton. 1981. Commencement Bay studies technical report. Vol. IV. Invertebrates. U.S. Army Corps of Engineers.

Burg, M.E., D.R. Tripp and E.S. Rosenberg. 1980. Plant associations and primary productivity of the Nisqually saltmarsh on southern Puget Sound. Northwest Sci. 54:222-235.

Burrell, G. 1979. Snohomish Estuary Wetlands Study, Vol. III. Classification and Mapping. Prepared for U.S. Army Corps of Engineers.

Chew, K.K. 1970. Preliminary survey of macrofauna in Anderson Cove. Prepared for Boise Cascade Properties, Inc. 43 pp.

Congleton, J.L. 1978. Feeding patterns of juvenile chum in the Skagit River salt marsh. pp. 141-150 In: Lipovsky, S.J. and C.A. Simenstad, eds. Fish Food Habits Studies: Proc. of the 2nd PNW Technical Workshop. Wash. Sea Grant Program. Seattle, Wash.

Cornelius, L.C. 1983. Baseline inventory of a brackish wetland and berm at Foulweather Bluff Preserve, Kitsap County, Washington, March to October 1983. The Nature Conservancy. 82 pp. Seattle, Wash.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Cross, J.N., K.L. Fresh, B.S. Miller, C.A. Simenstad, S.N. Steinfort, and J.C. Fegley. 1978. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca, including food habits of the common nearshore fish. NOAA Tech. Memo. 188 pp. ERL MESA-32. MESA Program. Environ. Res. Lab. Boulder, Colo.

Dayton, P.K. 1971. Competition, disturbance, and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol. Monogr. 41:351-388.

Dayton, P.K. 1975. Experimental evaluation of ecological dominance in a rocky intertidal algal community. Ecol. Monogr. 45:137-159.

Dethier, M.N. 1984. Disturbance and recovery in intertidal pools: maintenance of mosaic patterns. Ecol. Monogr. 54:99-118.

Dethier, M.N. 1988. A survey of intertidal communities of the Pacific Coastal Area of Olympic National Park, Washington. Report to the National Park Serv. 60 pp.

Disraeli, D.J. 1977. Gradient analysis of the vegetation in a brackish marsh in Bellingham Bay, Washington. MS thesis. 54 pp. Western Wash. Univ. Bellingham, Wash.

Disraeli, D.J. and R.W. Fonda. 1979. Gradient analysis of the vegetation in a brackish marsh in Bellingham Bay, Washington. Can. J. Bot. 57:465-475.

Driscoll, A.L. / Shapiro & Assoc. 1978. Snohomish Estuary Wetlands Study, Vol. I: Summary Report. 162 pp. U.S. Army Corps of Engineers.

Driscoll, A.L. / Shapiro & Assoc. 1979. Snohomish Estuary Wetlands Study, Vol. II: Base Information. 323 pp. U.S. Army Corps of Engineers.

Duxbury, A.C., ed. 1977. The Use, Study, and Management of Puget Sound: A Symposium. Wash. Sea Grant Program: WSG-WO 77-1. 272 pp. Seattle, Wash.

Eckman, J.E. 1979. Small-scale patterns and processes in a soft-substratum, intertidal community. J. Mar. Res. 37:437-457.

Evergreen State College. 1972. Hood Canal Project Report; Political Ecology Coordinated Study Program.

Ewing, K. 1982. Plant responses to environmental variation in the Skagit marsh. Ph.D dis. 203 pp. Univ. of Wash. Seattle, Wash.

Ewing, K. 1983. Environmental controls in Pacific Northwest intertidal marsh plant communities. Can. J. Bot. 61:1105-1116.

Frenkel, R.E., T. Boss, and W.R. Schuller. 1978. Transition zone vegetation between intertidal marsh and upland in Oregon and Washington. EPA grant No. R804963. 320 pp.

Gabrielson, P.W., R.F. Scagel and T.B. Widdowson. 1987. Keys to the benthic marine algae of British Columbia, northern Washington and southeast Alaska. Dept. of Botany, Univ. of British Columbia. 197 pp. Vancouver, British Columbia.

Gallagher, E.D., P.A. Jumars and D.W. Trueblood. 1983. Facilitation of soft-bottom benthic succession by tube builders. Ecology 64:1200-1216.

Gardner, F. 1978. North Puget Sound baseline program, 1974-1978. Baseline Studies Program. 82 pp. Wash. Dept. of Ecology.

Goodwin, C.L. 1973. Subtidal geoducks of Puget Sound, Washington. Wash. Dept. of Fisheries Tech. Rep. #13. Olympia, Wash.

Harlin, M.M. 1969. A phycological survey of Steamboat Island, Thurston County, Washington state. Syesis 2:257-261.

Harman, R.A. and J.C. Serwold. 1978. Recolonization of benthic macrofauna over a deep-water disposal site. Appendix F, Dredged Material Research Program. Tech. Report. U.S. Army Engineer Waterways Exper. Stat. D-77-24. Springfield, Vir.

Harman, R.A., J.C. Serwold, R.E. Sylvester, Q.J. Stober, L. Mobrand, and R.E. Nakatani. 1977. Puget Sound Interim Studies: Distribution and partial analysis of data of subtidal habitats near West Point. 150 pp. METRO report. Seattle, Wash.

Hedgpeth, J.W. and S. Obrebski. 1981. Willapa Bay: a historical perspective and a rationale for research. Coastal Ecosystems Project. U.S. Fish and Wildlife Service. FWS / OBS-81 / 03.

Hodgson, L.M. and J.R. Waaland. 1979. Seasonal variation in the subtidal macroalgae of Fox Island, Washington. Syesis 12:107-112.

Houghton, J.P. 1973. The intertidal ecology of Kiket Island, Washington, with emphasis on age and growth of *Protothaca staminea* and *Saxidomus giganteus* (Lamellibranchia: Veneridae). Ph.D dis. 179 pp. Univ. of Wash., Seattle, Wash. 179 pp.

Hutchinson, I. 1987. The influence of deltaic environment on marsh community structure in the coastal wetlands of the Puget Trough. Proc. Symp. '87 on Wetlands / Peatlands:517-525. Edmonton, Alberta.

Irvine, G.V. 1973. The effect of selective feeding by two species of sea urchins on the structuring of algal communities. MS thesis. 95 pp. Univ. of Wash. Seattle, Wash.

Jefferson, C.A. 1975. Plant communities and succession in Oregon coastal salt marshes. Ph.D dis. 192 pp. Ore. State Univ. Corvallis, Ore.

Kisker, D.S. 1976. Distribution and abundance of benthic macrofauna adjacent to a sulfite pulp mill discharge pipeline in Port Gardner, Washington. In: Ecological baseline and monitoring study for Port Gardner and adjacent waters. Dept. of Ecology, DOE 76-20. Olympia, Wash.

Kozloff, E.N. 1983. Seashore Life of the Northern Pacific Coast. Univ. of Wash. Press. 282 pp. Seattle, Wash.

Kozloff, E.N. 1987. Marine Invertebrates of the Pacific Northwest. Univ. of Wash. Press. 511 pp. Seattle, Wash.

Kunze, L.M. 1984. Puget Trough coastal wetlands: a summary report of biologically significant sites. Report by the Wash. Dept. of Nat. Res. Nat. Heritage Prog. to the Wash. Dept. of Ecology. 154 pp. Olympia, Wash.

Kunze, L.M. and L.C. Cornelius. 1982. Baseline inventory of rare, threatened and endangered plant species / communities along Washington's Pacific Coast. Report by the Wash. Dept. of Nat. Res. Nat. Heritage Prog. to Wash. Dept. of Ecology. 164 pp. Olympia, Wash.

Levings, C.D., R.E. Foreman and V.J. Tunnicliffe. 1983. Review of the benthos of the Strait of Georgia and contiguous fjords. Can. J. Fish. Aquatic Sci. 40:1120-1141.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, USA, in 1963-1964. FiskDir. Skr. Ser. HavUnders. 14(5):229-556.

Lie, U. 1974. Distribution and structure of benthic assemblages in Puget Sound, Washington, USA. Mar. Biol. 26:203-223.

Lie, U. and R.A. Evans. 1973. Long-term variability in the structure of subtidal benthic communities in Puget Sound, Washington, USA. Marine Biology 21:122-126.

Lie, U. and J.C. Kelley. 1970. Benthic infauna communities off the coast of Washington and in Puget Sound: identification and distribution of the communities. J. Fish. Res. Bd. Canada 27:621-651.

Lie, U. and D.S. Kisker. 1970. Species composition and structure of benthic infauna communities off the coast of Washington. J. Fish. Res. Bd. Canada 27:2273-2285.

Lim, P.G. 1980. Saltspring Island subtidal ecological survey: a guide for planners. 48 pp. Min. Environ. Wat. Investigations Branch, Victoria, British Columbia. (In Williams 1988).

Lindstrom, S.C. and R.E. Foreman. 1978. Seaweed associations of the Flat Top Islands, British Columbia: a comparison of community methods. Syesis 11:171-185.

Long, E.R., ed. 1983. A synthesis of biological data from the Strait of Juan de Fuca and northern Puget Sound. MESA Puget Sound Proj. EPA-600 / 7-82-004.

Mauzey, K.P. 1965. Feeding behavior and reproductive cycles in *Pisaster ochraceus*. MS thesis. 54 pp. Univ. of Wash., Seattle, Wash.

Mauzey, K.P. 1967. The interrelationship of feeding, reproduction and habitat variability in *Pisaster ochraceus*. Ph.D dis. 125 pp. Univ. of Wash. Seattle, Wash.

Mayer, D.L. 1973. The ecology and thermal sensitivity of the Dungeness crab, *Cancer magister* and related species of its benthic community in Similk Bay, Washington. Ph.D dis. 188 pp. Univ. of Wash. Seattle, Wash.

McDaniel, N.G. 1973. A survey of the benthic macroinvertebrate fauna and solid pollutants in Howe Sound. Fish. Res. Bd. Canada Tech. Rep. no. 385. 64 pp.

Milne, D.H., ed. 1976. Studies of the marine ecology of Eld Inlet, Puget Sound, Washington. Vol. II. 173 pp. The Evergreen State College. Olympia, Wash.

Molinier, R. 1959. Étude des biocenoses marines du Cap Corse. Vegetatio 121-192.

Moulton, L.L. 1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Ph.D dis. 181 pp. Univ. of Wash. Seattle, Wash.

Muenscher, W.L.C. 1915. A study of the algal associations of San Juan Island. Puget Sound Mar. Stat. Publ. 1:59-84.

Muenscher, W.L.C. 1916. Distribution of shore algae on Shaw Island. Puget Sound Mar. Stat. Publ. 1:199-210.

Neushul, M. 1965. SCUBA diving studies of the vertical distribution of benthic marine plants. Proc. 5th Mar. Biol. Assoc.:161-176.

Neushul, M. 1967. Studies of subtidal marine vegetation in western Washington. Ecology 48:83-93.

Nichols, F.H. 1987. Long-term changes in a deep Puget Sound benthic community: local or basin-wide? Proc. 1st Annual Meeting on Puget Sound Research: 65-71. Seattle, Wash.

Nichols, F.H. and M.M. Pamatmat. 1988. The ecology of the soft-bottom benthos of San Francisco Bay: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.19). 73 pp.

Nyblade, C.F. 1979a. Five year intertidal community change, San Juan Islands, 1974-1978. Wash. Dept. of Ecology Baseline Study Prog. North Puget Sound. 134 pp. Appendix F (update).

Nyblade, C.F. 1979b. The Strait of Juan de Fuca intertidal and subtidal benthos. Second Annual Report. 129 pp. EPA-600/7-79-213.

Paine, R.T. 1980. Food webs: linkage, interaction strength and community infrastructure. J. Anim. Ecol. 49:667-685.

Pamatmat, M.M. 1966. The ecology and metabolism of a benthic community on an intertidal sandflat (False Bay, San Juan Island, Washington). Ph.D dis. 243 pp. Univ. of Wash. Seattle, Wash.

Phillips, R.C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/24. 85 pp.

Phillips, R.C. and B. Fleenor. 1970. Investigation of the benthic marine flora of Hood Canal, Washington. Pac. Sci. 24:275-281.

Ricketts, E.F. and J. Calvin. 1968. Between Pacific Tides. 4th Edition, revised by Joel Hedgpeth. Stanford Univ. Press. Stanford, Calif.

Rigg, G.B. and R.C. Miller 1949. Intertidal plant and animal zonation in the vicinity of Neah Bay, Washington. Proc. Cal. Acad. Sci. 26:323-351.

Roetcisoender, D.R. and T.S. English. 1976. Beach observations in Port Gardner, Washington, 1973, 1974, and 1975. In: Ecological baseline and monitoring study for Port Gardner and adjacent waters. Wash. Dept. of Ecology, DOE 76-20. Olympia, Wash.

Schneider, D.E. and M.A. Dube 1969. Survey of the intertidal zone from Sandy Point to Birch Park Marina, Whatcom County, Washington. Prepared for Mobil Oil Co. and Atlantic Richfield Oil Co. 53 pp.

Shelford, V.E., A.O. Weese, L.A. Rice, D.I. Rasmussen, A. MacLean, N.M. Wismer and J.H. Swanson. 1935. Some marine biotic communities of the Pacific coast of North America. Ecol. Monogr. 5:251-354.

Shimek, R.L. 1977. Resource utilization and natural history of some northeastern Pacific Turridae. Ph.D dis. 216 pp. Univ. of Wash. Seattle, Wash.

Shoreline Community College and Fisheries Research Inst., Univ. of Wash.. 1977. Distribution and partial analysis of data of subtidal habitats near West Point. Puget Sound Interim Studies, METRO. 150 pp. Seattle, Wash.

Simenstad, C.A. 1981. Juvenile salmonid and baitfish distribution, abundance, and prey resources in selected areas of Grays Harbor, Washington — Appendices. FRI-UW-8117. Final Report to U.S. Army Corps of Engineers, Seattle Dist. Fish. Res. Inst. 162 pp. Univ. Wash. Seattle, Wash.

Simenstad, C.A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-83/05. 181 pp.

Simenstad, C.A., R.M. Thom, K.A. Kuzis, J.R. Cordell and D.K. Shreffler. 1988. Nearshore community studies of Neah Bay, Washington. FRI-UW-8811, Final Rept. to U.S. Army Corps of Engineers, Seattle Dist. Fish. Res. Inst. 200 pp. Univ. of Wash., Seattle, Wash.

Smith, G.F. 1979. A quantitative sampling program of benthic communities in nearshore subtidal areas within the Rosario Strait region of northern Puget Sound, Washington State (1976). (WWU Subtidal Study, Huxley College). Wash. Dept. of Ecology. Oil Baseline Program. Appendix L. 105 pp. Olympia, Wash.

Smith, G.F. and H.H. Webber. 1978. A biological sampling program of intertidal habitats of northern Puget Sound. (WWU Intertidal Study). Wash. St. Dept. of Ecology. Oil Baseline Program. Appendix D. 330 pp.

Smith, J.E. 1980. Seasonality, spatial dispersion patterns and migration of benthic invertebrates in an intertidal marsh-sandflat system of Puget Sound, Washington, and their relation to waterfowl foraging and the feeding ecology of staghorn sculpin, *Leptocottus armatus*. Ph.D dis. 177 pp. Univ. of Wash. Seattle, Wash.

Smith, J.L., ed. 1976. The effect of intertidal dredged material disposal on benthic invertebrates in Grays Harbor, Washington. Appendix E: Invertebrates, and Appendix F: Vegetation. U.S. Army Corps of Engineers. Seattle, Wash.

Staude, C.P. 1979. Changes in the intertidal macrofauna and macroflora near Seattle's West Point Sewage Treatment Plant from 1971 to 1975. MS thesis. 161 pp. Univ. of Wash. Seattle, Wash.

Stober, Q.J. and E.O. Salo. 1970. Biological studies of the Kiket Island nuclear power site. Annual Report. Fisheries Res. Inst. 114 pp. Univ. of Wash. Seattle, Wash.

Stober, Q.J. and E.O. Salo. 1971. Biological Studies of the Kiket Island nuclear power site. Second Annual Report. Fisheries Res. Inst. 197 pp. Univ. of Wash.

Swinbanks, D.D. and J.W. Murray. 1981. Biosedimentological zonation of Boundary Bay tidal flats, Fraser River Delta, British Columbia. Sedimentology 28:201-237.

Sylvester, R.O. and F.L. Clogston 1961. A report on the 1961 reinspection of the intertidal zone in the vicinity of the Ferndale, Washington refinery. Prepared for the Mobil Oil Co. 50 pp.

Thom, R.M. 1978. The composition, growth, seasonal periodicity and habitats of benthic algae on the eastern shore of central Puget Sound, with special reference to sewage pollution. Ph.D dis. 237 pp. Univ. of Wash. Seattle, Wash.

Thom, R.M. 1981. Primary productivity and organic carbon input to Grays Harbor Estuary, Washington. Grays Harbor and Chehalis River Improvements to Navigation Environmental Studies. U.S. Army Corps of Engineers. 71 pp. Seattle, Wash.

Thom, R.M. 1988. Benthic primary production in the eelgrass meadow at the Padilla Bay National Estuarine Research Reserve, Washington. NOAA Tech. Rept. Series OCRM / MEMD. Fisheries Res. Inst. 33 pp. Univ. of Wash. FRI-UW-8808. Seattle, Wash.

Thom, R.M., R. Albright, C. Simenstad, J. Hampel, J. Cordell and K. Chew. 1984. Renton Sewage Treatment Plant Project: Seahurst Baseline Study. IV. Intertidal and shallow subtidal benthic ecology. Rept. to METRO. 177 pp. Seattle, Wash.

Thom, R.M., J.W. Armstrong, C.P. Staude and K.K. Chew. 1976. A survey of the attached marine flora at five beaches in the Seattle, Washington area. Syesis 9:267-275.

Thom, R.M., K. Chew, D. Crisostomo, B. Dumbauld, A. Escofet, C. Falmange, J. Hampel, C. Lau, J. Orensanz, and D. Waumann de Pinet. 1979. Habitats, abundance, and diversity of the intertidal benthic biota of Skiff Point, Bainbridge Island, Washington. Rept. to METRO. 61 pp. Seattle, Wash.

Thom, R.M., C.A. Simenstad, J.R. Cordell and E.O. Salo. 1988. Fisheries mitigation plan for expansion of moorage at Blaine Marina, Blaine, Washington. Rept. to Port of Bellingham. 24 pp. Univ. of Wash. Fisheries Res. Inst. Rept. (FRI-UW-8817). Seattle, Wash.

Thompson, T.G. and R.J. Robinson. 1934. The sea water of the Puget Sound region. Wash. State Univ. Publ. in Oceanogr. Suppl. Ser. 27:2101-2107 / 2.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Can. Spec. Publ. Fish. Aquatic Sci. 56:291 pp.

Thorson, G. 1957. Bottom communities (sublittoral or shallow shelf). Geol. Soc. Am. Mem. 67:461-534.

Vadas, R.L. 1968. The ecology of *Agarum* and the kelp bed community. Ph.D dis. 280 pp. Univ. of Wash. Seattle, Wash. Seattle, Wash.

Webber, H.H. 1980. Whidbey Island intertidal and shallow subtidal benthos. EPA Report #EPA-600 / 7-80-167. 91 pp.

Webber, H.H. 1989. The ecology of intertidal hardshell bivalves of Puget Sound and adjacent waters: a community profile. U.S. Fish and Wildl. Ser. Portland, Ore. (in press).

Wennekens, M.P. 1959. Marine environment and macro-benthos of the waters of Puget Sound, San Juan Archipelago, southern Georgia Strait, and Strait of Juan de Fuca. Ph.D dis. 298 pp. Univ. of Wash. Seattle, Wash.

Williams, G.L. 1988. Coastal / estuarine habitat description and assessment manual. Part II. Pacific coastal classification. [Draft]

Yoshinaka, M.S. and N.J. Ellifrit. 1974. Hood Canal — priorities for tomorrow. U.S. Fish Wild. Ser. 97 pp. Portland, Ore.

Zeh, J.E., J.P. Houghton and D.C. Lees. 1981. Evaluation of existing marine intertidal and shallow subtidal biologic data. 262 pp. Prepared for Off. of Environmental Engineering and Tech., Off. of Res. and Devel., U.S. E.P.A. Washington D.C. EPA-6001 7-81-036.

Appendix A

TRANSLATION TABLE

Correspondences between the marine and estuarine habitat classification systems of Cowardin et al. (1979) and the Washington Natural Heritage Program. Correspondences between modifiers are given at the end of the table.

COWARDIN ET AL.	NATURAL HERITAGE
System	**System**
Subsystem	**Subsystem**
CLASS	CLASS
Subclass	**Subclass**
(Modifiers)	Energy / Enclosure
	(Modifiers)
Marine	**Marine**
Intertidal	**Intertidal**
ROCKY SHORE	CONSOLIDATED
Bedrock	**Bedrock**
	ENERGY: Incl. Exposed, Partially Exposed, Semi-Protected, Protected
Rubble	**Hardpan**
	Boulders
UNCONSOLIDATED SHORE	UNCONSOLIDATED
Cobble-Gravel	**Cobble**
	Mixed-Coarse
	Gravel
Sand	**Sand**
	Mixed-Fine
Mud	**Mud**
Organic	**Organic**
AQUATIC BED	*Falls under the appropriate **Substratum** type above (e.g., rockweed dom. = **Consol.**/Bedrock)
REEF	REEF
	ARTIFICIAL
Subtidal	**Subtidal**
ROCK BOTTOM	CONSOLIDATED
Bedrock	**Bedrock**
	ENERGY = High, Moderate, Low
Rubble	**Hardpan**
	Boulders

COWARDIN ET AL.

UNCONSOLIDATED BOTTOM
- **Cobble-Gravel**
- **Sand**
- **Mud**
- **Organic**

AQUATIC BED

REEF

NATURAL HERITAGE

UNCONSOLIDATED
- **Cobble**
- **Mixed-Coarse**
- **Gravel**
- **Sand**
- **Mixed-Fine**
- **Mud**
- **Organic**

*Falls under the appropriate **Substratum** type above (e.g., Eelgrass=**Unconsol.**/ Mixed-Fine)

REEF
ARTIFICIAL

ESTUARINE

Intermittent
ROCKY SHORE
- **Bedrock**
- **Rubble**

UNCONSOLIDATED SHORE
- **Cobble-Gravel**
- **Sand**
- **Mud**
- **Organic**

AQUATIC BED

REEF

STREAMBED

EMERGENT WETLAND
- **Persistent**
- **Nonpersistent**

SCRUB-SHRUB WETLAND
- **Needle-leaved Evergreen**
- **Broad-leaved Evergreen**
- **Needle-leaved Deciduous**
- **Broad-leaved Deciduous**
- **Dead**

ESTUARINE

Intertidal
CONSOLIDATED
- **Bedrock**
  - ENCLOSURE = Open, Partly Enclosed, Enclosed
- **Hardpan**
- **Boulders**

UNCONSOLIDATED
- **Mixed-Coarse**
- **Gravel**
- **Sand**
- **Mixed-Fine**
  - ENCLOSURE may also include Lagoon, Channel-Slough
- **Mud**
- **Organic**

*Falls under the appropriate **Substratum** category above

REEF
ARTIFICIAL

*Falls under **Unconsolidated**/appropriate **Substratum** (e.g., mud) /Channel-Slough (Enclosure category)

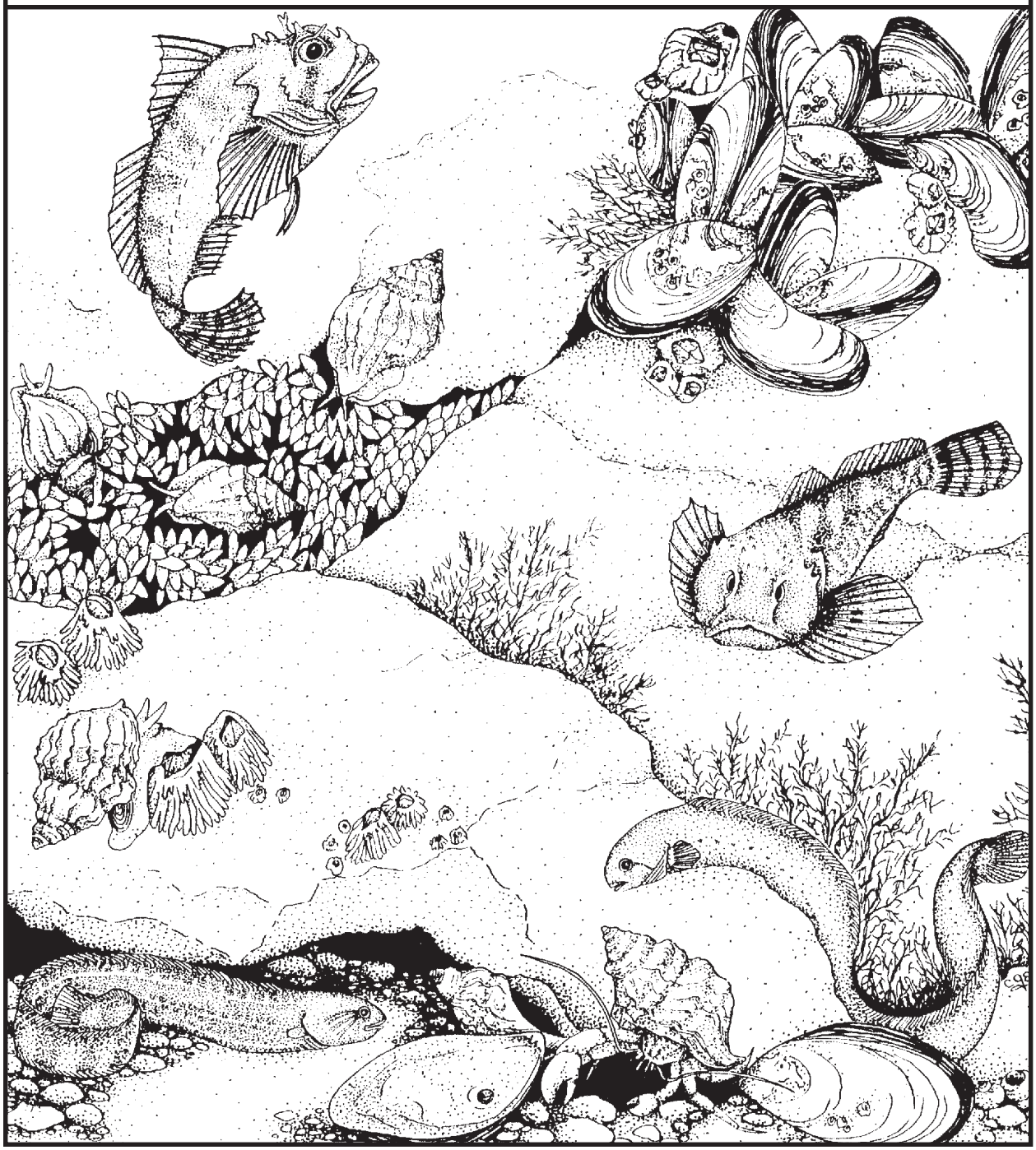
*All “Wetlands” fall under the appropriate **Substratum** category (sand, mud, organic), then under the appropriate ENCLOSURE category (Open, Partly Enclosed, Lagoon, Channel -Slough), then under the appropriate tidal height and salinity regime (see MODIFERS)

COWARDIN ET AL.	NATURAL HERITAGE
FORESTED WETLAND	
Needle-leaved Evergreen	
Broad-leaved Evergreen	
Needle-leaved Deciduous	
Broad-leaved Deciduous	
Dead	
Subtidal	**Subtidal**
ROCK BOTTOM	**CONSOLIDATED**
Bedrock	**Bedrock**
	ENCLOSURE = Open, Partly Encl.
	Hardpan
Rubble	**Boulders**
UNCONSOLIDATED BOTTOM	**UNCONSOLIDATED**
Cobble-Gravel	**Cobble**
	Mixed-Coarse
	Gravel
Sand	**Sand**
	Mixed-Fine
Mud	**Mud**
Organic	**Organic**
AQUATIC BED	*Falls under the appropriate **Substratum** category above
Algal	(Mostly Consolidated)
Rooted Vascular	(Unconsolidated)
Floating	(Unconsolidated)
REEF	**REEF**
	ARTIFICIAL

Modifiers

Subtidal	**= Subtidal**
Irregularly Exposed + Regularly Flooded	**= Intertidal, Eulittoral**
Irregularly Flooded	**= Backshore**
Salinities	**= same definitions, used only for ESTUARINE, Intertidal and Backshore (marshes)**

A Marine and Estuarine Habitat Classification System for Washington State



WASHINGTON STATE DEPARTMENT OF
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