Final Report on Intertidal Invertebrates in Tillamook Bay

A Report to the Tillamook Bay National Estuary Project

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Introduction

This report incorporates information about a series of related activities intended to survey some of the intertidal invertebrates of Tillamook Bay, to provide teaching tools about these invertebrates to the local school system in the forms of labelled specimens, a photo CD, and a set of slides, and to document quantitatively some aspects of the ecological diversity of Tillamook Bay's intertidal invertebrates in the period immediately following the great inrush of sediment and low salinity water that accompanied the flood of 1996. It is the authors' intention to help provide local educators with some tools and information to help them develop among the youth of the area an appreciation for the wonderful natural resources that are part of their daily existence, and also to produce a data set that might in future be a baseline for an understanding of how Tillamook Bay's invertebrate community changed in time after a flood event of rare proportions.

Survey of Organisms found in two Habitats

Tillamook Bay contains a number of different habitats for marine organisms. The organism survey undertaken by our group from the University of Portland concentrated mainly on a sheltered area of rocky intertidal, found North of Garibaldi, called the Three Graces Rocks. It is so named for the three haystack rock formations there. The rocky shore is typically home to a great diversity and number of marine organisms (Snively 1978). The other habitat that organisms were surveyed in was a sandy/gravel shore. Organisms found at the surface of both habitats were photographed, as well as some found when sampling to a depth of 25 cm, at low tide in the sand.

In the material that follows, we begin with a list of organism names that corresponds to the organisms in the images on the Photo CD produced as part of this porject. Then, general characteristics of the organisms photographed as well as a number of other common organisms that a student would be likley to encounter in Tillamook Bay will be discussed by phylum. Some groups are found in a variety of habitats. The organisms discussed are by no means a comprehensive list of all those that can be found in Tillamook Bay, but it is representative of those that those that could be most commonly found by an interested observer at a low tide. Much of the information about the organisms has been extracted from Kozloff (1993) although a number of other sources are cited as appropriate.

Organisms Pictured on the Photo CD of Invertebrates:

Scientific Names	Common Names	Number of images
Cancer magister	Dungeness Crab	2
Hemigrapsus nudus	Purple Shore Crab	2
Hemigrapsus oregonensis	Hairy Shore Crab	2
Idodea sp	Isopod	2
Ligia pallasii	Rock Louse	1

Crangon franciscorum	Sand Shrimp	1
Pagurus hirsutiusculus	Little Hairy Hermit Crab	1
Upogebia pugettensis	Mud Shrimp (includes images of Mud Shrimp burrow)	4
Balanus glandula	Common Acorn Barnacle	1
Balanus nubilus	Giant Acorn Barnacle	2
Semibalanus cariosus	Thatched Acorn Barnacle	1
Pollicipes polymerus	Goose Barnacle	2
Mytilus edulis	Edible Bay or Blue Mussel	1
Clinocardium nuttallii	Heart Cockle	7
Macoma balthica	Baltic Macoma	1
Modiolus modiolus	Horse Mussel	3
Mya arenaria	Soft Shelled or Mud Clam	2
Saxidomus giganteus	Butter Clam	1
Tresus capax	Gaper Clam	3
Venerupis staminea	Littleneck Clam	2
Collisella digitalis	Fingered Limpet	2
Littorina scutulata	Checkered Periwinkle	1

Nucella (Thais) emarginata	Rock Whelk or Dogwinkle	2
Nucella (Thais) lamellosa	Wrinkled Whelk or Wrinkled Dogwinkle	7
Tegula funebralis	Black Turban Snail	1
Lepidochitona dentiens	Chiton	1
Mopalia hindsii	Chiton	1
Pisaster ochraceus	Purple Sea Star	1
Bugula spp.	Bryozoan	3
Membranipora spp.	Bryozoan	2
Anthopleura elegantissima	Aggregate Anemone	4
Anthopleura xanthogrammica	Giant Green Anemone	4

Common Invertebrates of Tillamook Bay:

There are over one million described species of animals (Ruppert and Barnes, 1994). Less than 5% of those have a backbone and are known as vertebrates; more than 95% of all animals are invertebrates that are grouped in 29 phyla. The marine world is particularly rich in invertebrate species. Some phyla are exclusively marine, like the phylum Ctenophora which includes the sea walnuts and comb jellies. Others, like the phylum Cnidaria that includes sea anemones and jellyfish, are primarily marine but have a few representatives in fresh water. Some of the largest phyla, including the phylum Arthropoda and the phylum Mollusca, include both marine species and other species that are found in fresh water or terrestrial habitats.

It would be impossible to provide a full description of all the marine invertebrate species in a report of this size. However, we would like to provide some background on some of the major phyla with representatives in Tillamook Bay, including those included in the photo CD accompanying this report.

Phylum Arthropoda

The phylum Arthropoda is the largest phylum of invertebrates. Arthropods are organisms characterized by an external skeleton (an exoskeleton) and jointed legs. Representatives of this group include such familiar organisms as insects, crabs, lobsters and barnacles. Bound by their external skeleton, these creatures shed their old skeleton and form a new one when they need to grow. They are an extremely diverse group and occupy many different niches. Phylum Arthropoda is divided unto several subphyla, one of which is an important marine group. This is subphylum Crustacea, which contains the copepods, barnacles, shrimps, lobsters, isopods, and crabs. Another subphylum that has a few species that occur at the shore is subphylum Uniramia, which contains the insects, centipedes, and millipedes.

Crustaceans are typical arthropods, and are almost all marine (Ruppert and Barnes, 1994). Special terminology must be used in order to help identify of the species of this subphylum. The carapace is a continuous covering over the head and thorax. Crustaceans may have a rostrum, an anteriorly projected prolongation of the head or carapace. Often supraorbital (above the eye socket), median (in the middle), or submedian (below the middle) spines are present on the carapace (especially in shrimp). Most have pleopods used for swimming. The abdomen, if visible, is divided into numbered segments, and there is a telson, or terminal flap, attached to the sixth segment of an arthropod's body. Uropods are flaps coming off of the pleon (abdomen). Two sets of antennae are present and are also numbered for identification purposes. Shrimps, crabs, and lobsters have chelipeds, which are legs with a chela (pincer). Pleopods are paired appendages arising from the underside of the abdomen. The pleopods are used for swimming,walking, copulation and other functions. Uropods, one or more pairs of appendages coming off of the posterior part of the abdomen, are also present (Kozloff, 1987).

Crabs are common crustaceans found on beaches throughout the world. They belong to the class Malacostraca, along with shrimps and lobsters. We noticed an abundance of several species of crabs present in Tillamook Bay. A feature that distinguishes crabs from shrimps, lobsters, and isopods, is that their abdomens are curved forwards underneath their bodies. Therefore, many people think that they don't have a "tail".

Cancer magister, the Dungeness Crab, is one of the most important commercial species along the Pacific Coast (Kozloff, 1993). This crab (family Cancridae) ranges from Alaska to southern California (Meinkoth, 1981). It is seen at low tide in sandy or muddy bays, in eelgrass, or on sandy bottoms in deep water (Kozloff, 1993). The crab depends on shallow water to molt (Meinkoth, 1981). This crustacean has a fan-shaped carapace that can be up to 20 cm across the widest part (Kozloff, 1993). The top of the crab is grayish-brown and sometimes bears a purple tinge. The bottom side of the Dungeness crab is cream-colored. The surface of the carapace is granular, with five unequal teeth (spines) between the eye sockets. The margin of the carapace has ten teeth from the eye socket to the side of the carapace, with the last tooth being the largest (Meinkoth, 1981). The eyes of this species are significantly closer together when compared with *Hemigrapsus spp.* crabs. The dactyl and propodus of the chelipeds on Dungeness have characteristic spiny ridges (Kozloff, 1987). The tip of the dactyl and fixed claw of the cheliped are light in color. The walking legs of the Dungeness are short (Meinkoth, 1981).

The Dungeness crab eats fish, crustaceans, and small clams, which it opens by chipping away at the shell with its heavy pincers (Wild and Tasto, 1983). One of the crab's main predators is humans. It is frequently taken commercially with traps set on sandy bottoms in deep water. The minimum size allowed to be taken for food is 16 cm across (Kozloff, 1993).

Cancer productus, the Red Rock Crab, is another common crab all along the Pacific Coast. It is found intertidally in sandy, muddy, or gravelly bays, and also in eelgrass beds and on rocky shore (Kozloff, 1993). This crab is characteristically brick red in color, and has a fan-shaped, smooth carapace that resembles that of the Dungeness. Unlike the Dungeness, the Red Rock Crab has black-tipped claws, and equal sized, less pointed, evenly spaced teeth between its eyes and the widest part of the carapace (Kozloff, 1993). It is smaller than Dungeness, rarely reaching a maximum of 15 cm (Kozloff, 1993). The pincers are short and stout, and the walking legs are short. Juveniles vary greatly in color. They can be white, brown, blue, red, or orange, in a solid color or a pattern (Meinkoth, 1981).

Red Rock Crabs are edible but not exploited commercially, because their shell is heavier and smaller than Dungeness (Kozloff, 1993). Its preferred food seems to be snails and barnacles (Yates, 1988).

Turn over many of the rocks at Three Graces Rocks, and you will find *Hemigrapsus oregonensis*, the Hairy Shore Crab, also known as the Green Shore Crab. It is quite common in rocky intertidal areas and is typical of quiet water and rocky, gravelly habitats within estuaries (Kozloff, 1993). It can also be found in saltmarshes, mudflats, and eelgrass beds (Meinkoth, 1981). The range of the Hairy Shore Crab of family *Grapsidae,* is from Alaska to Baja California (Meinkoth, 1981). This crustacean has a smooth, rectangular carapace, with wide-set eyes. It is grayish-green, usually mottled with brownish-purple or black. There are three teeth on the front edge of the carapace (Kozloff, 1987). This crab is characterized by having fringes of hair on its legs and no purple spots on its chelipeds (Kozloff, 1987). The pincer tips are yellow to white. The walking legs are sturdy and flattened.

The Hairy Shore Crab mostly feeds on sea lettuce, a seaweed that is a member of the genus *Ulva* (Kozloff, 1993). Sea lettuce is used as a condiment in salads, soups, and other dishes (Waaland, 1977). An increase in collection of *Ulva* from Tillamook Bay may impact available food sources for crabs like *Hemigrapsus oregonensis* and *H. nudus*. However, *H. oregonensis* scavenges for other food if sea lettuce is not available. During the day, *H. oregonensis* hides under debris, or in special burrows it makes in the sand. It may also burrow in tidal ditches of saltmarshes (Kozloff, 1993).

Another shore crab that is often found in the same habitat as the Hairy Shore Crab is *Hemigrapsus nudus*, the Purple Shore Crab or Beach Crab. It is found in rocky intertidal areas at Tillamook Bay. The two *Hemigrapsus* species look similar, except that the Purple Shore Crab (family *Grapsidae*) lacks the fringes of hair on its legs, is reddish or purple in color, and has distinctive purple spots on its white-tipped chelipeds (Kozloff, 1993). This crab is also found from Alaska to Baja California, in bays, estuaries and gravelly situations (Meinkoth, 1981). It is not as common in saltmarshes as the Hairy Shore Crab (Kozloff, 1993). The Purple Shore Crab is primarily a vegetarian, also feeding on Sea Lettuce. Like *H. oregonensis, H. nudus* will occasionally scavenge on dead plant and animal matter (Kozloff, 1993).

A common hermit crab species on the Oregon coast is *Pagurus hirsutiusculus*, the Little Hairy Hermit Crab. This small crustacean (family *Paguridae*) ranges from Alaska to Baja California (Meinkoth, 1981). In rocky intertidal areas, this crab is abundant in tidepools, between and under rocks, within coarse gravel, under seaweed, and is the only hermit crab likely to be found quite high in the intertidal (Kozloff, 1993). This species is characterized by white spots on its antennae, and a white or blue band around the base of the next to the last segment of its second and third legs (Kozloff, 1993). It is slightly hairy, and has white pincer tips.

Pagurus species of hermit crabs live in empty gastropod shells. The larger individuals of *P. hirsutiusculus* (3 cm long) prefer the shells of the Rock Whelk, *Nucella emarginata* (Kozloff, 1993). The smaller ones will most likely reside in the shells of the Checkered Periwinkle, *Littorina scutulata*, or the Eroded Periwinkle, *L. planaxis* (Kozloff, 1993). These crustaceans mostly eat detritus, such as dead animal or plant material.

Scleroplax granulata is a small pea crab commonly associated with the burrows of *Upogebia pugettensis*, the Mud Shrimp, and *Callianassa californiensis*, the Ghost Shrimp, in muddy sand (Kozloff, 1993). This tiny crab of family *Pinnotheridae* has a calcified, firm carapace, with a width that is less than 1.5 times the length (Kozloff, 1987). The dactyls of the walking legs are only slightly curved (Kozloff, 1987).

More pea crabs of *Pinnotheridae* belong to the genus *Pinnixa*. These crustaceans have a firm carapace, with the width at least 1.5 times the length (Kozloff, 1987). The dactyls noticably curve to meet. *Pinnixa faba,* and *Pinnixa littoralis*, live in the mantle of the Gaper Clam, *Tresus capax* as (Kozloff, 1993). A female *Pinnixa* crab is bigger than the male and usually stays in one place in the mantle, causing a blistering or irritation of the clam's flesh. She eats diatoms brought in by the clam's current. It is not known what the male eats. These crabs are found in almost every gaper (Kozloff, 1993). Younger stages of *Pinnixa* are known to be found in various other species of clams such as *Mya arenaria*, the Soft-Shelled Clam, *Clinocardium nuttallii,* the Heart Cockle, and *Saxidomus giganteus*, the Butter Clam, all of which are common along the Oregon coast. These small commensal crabs also like the tubes of parchment worms, the "throats" of tunicates (sea squirts), or the surface of sea stars (Meinkoth, 1981). They feed by eating the organic particles that their host captures in filter feeding.

Shrimps are another large group of crustaceans found around the world. Three of the most commonly found shrimp in muddy or sandy bays are *Callianassa californiensis,* the Ghost Shrimp, *Upogebia pugettensis*, the Mud Shrimp or Blue Mud Shrimp, and *Crangon franciscorum*, the Sand Shrimp (Kozloff, 1993). These organisms often occur in the same habitats, and they are common in Tillamook Bay. The Ghost Shrimp (family *Callianassidae)* ranges from southern Alaska to Baja, California (Meinkoth, 1981). It is a long, slender, delicate shrimp with yellow swimmerets and yellow bristles on its legs. The carapace is 1/3 the length of the abdomen, and it is transparent on both sides. The rostrum is a small non-hairy tooth. The first pair of walking legs are unequal and have pincers. The male has one particularly large pincer. When the cheliped is closed, an obvious gap is formed between the dactyl and the propodus. These beautiful organisms are waxy pale pink and orange in color, and indeed ghostly looking. The largest Ghost Shrimps can be up to 10 cm in length, and at least 10 years old (Kozloff, 1993).

The Ghost Shrimp burrows in the same area as the Mud Shrimps. You might have seen the opening to a Ghost Shrimp burrow, which looks like a dime sized hole surrounded by a heap of sand. The Ghost Shrimp must make its burrow in muddy sand where there is enough clay or silt to make the substrate cohesive for lining the tunnels. Kozloff (1993) gives an excellent description of how this shrimp makes its distinctive burrow: "*Callianassa* burrows by means of the chelate first and second legs, which loosen the substratum and pull it backward. A pushing movement of the third legs, aided by a raking activity of the mouthparts, causes accumulation of the material in a sort of receptacle formed by the last pair of mouth parts (third maxillipeds). The animal then crawls backward, reverses itself in a special turnaround chamber, and moves to the mouth of the burrow to dump its load. Eventually the burrow will have a number of branches and turnaround chambers, with at least two openings to the surface, which provide for some circulation of sea water though the system of tunnels" (p. 300).

The Ghost Shrimp feeds on detritus in the mud. It does this by collecting fine particles on the hairs on its legs. The hairs on the third maxillipeds scrape the food off and move it toward the mouthparts which then moves the food to the mouth opening. Its burrows are inhabited by many commensals. Several species of pea crabs, a particular scale worm, and one goby fish have been found sharing living arrangements. Some species of copepods have also been found to live under the carapace of the *C. californiensis* (Kozloff, 1993).

The Mud Shrimp (family *Upogebiidae)* is found from Alaska to Baja California (Meinkoth, 1981). It prefers muddier substratum than most other shrimps. This shrimp is easy to identify due to the extensive bristles of hairs on its legs and claws. The color of this shrimp is a mixture of gray, brown, and bluish tones. It has a large tail fan, and a broad, flattened rostrum divided into three teeth. It also has hair on its back. The Mud Shrimp burrows in the mud, much like the Ghost Shrimp. However, the Mud Shrimp does not heap sand around the opening of the burrow (Kozloff, 1993). It uses its pleopods to fan water through the tunnels of the burrow, and feeds on the detritus it stirs up during the process. Interestingly, this shrimp is frequently parasitized by the isopod, *Phyllodurus abdominalis* (Kozloff, 1993). The 1 cm long female likes to attach to the pleopods, accompanied by the smaller male. Another commensal organism that attaches to the anterior part of the underside of *Upogebia's* abdomen is *Orobitella rugifera*, a tiny clam. This clam seems to secrete a byssus (strong thread of protein) to hold onto the shrimp. It gains the protection of a burrow while having access to the microscopic food the Mud Shrimp stirs up in the water current.

Crangon franciscorum, the Sand Shrimp occurs in Tillamook Bay. This shrimp and *Crangon spp.* (family *Crangonidae*) in general, are abundant in shallow water, especially at lower tide levels. They have been found deeper, on sandy or muddy bottoms, on open shore, and in bays and estuaries (Kozloff, 1993). *Crangon franciscorum* is a buff color, with numerous, tiny, black, star-shaped, spots on its body. This, along with its slight transparency, makes it very difficult to see in similarly colored sand. It has a great tolerance for variation in salinity. The range of this shrimp is from Alaska to southern California, and it has been heavily trawled for commercial purposes (Meinkoth, 1981).

Amphipods are small crustaceans, in class Malacostraca. They are related to crabs, shrimp, and lobsters, and are mostly marine. There are burrowing and tube dwelling species of amphipods (Ruppert and Barnes, 1994). Some are carnivorous, and some eat algae or detritus. Some build small nests from pieces of seaweed that they stick together (Kozloff, 1993). Generally, most amphipods are found in sandy beaches or tidepool situations. Most of the shore amphipods have flattened sides and long first and second antennae. They have seven pairs of legs. Usually, amphipods associate with seaweed the same color as they, in order to hide from predators (Kozloff, 1993).

The *Corophium spp.* is one of the most obvious amphipods found in sandy areas. It is extremely abundant in estuaries where the salinity is low and silting is heavy (Kozloff, 1993). Most will be found in areas were both silt and detritus accumulate (Kozloff, 1993). This debris is needed for *Corophium* to build masses of soft, muddy tubes that constitute its home (Kozloff, 1993). *Corophium* is slightly flattened top-to-bottom, rather than side-to-side. It has characteristically stout, thick, long, second antennae. The organism rarely exceeds 1 cm. This amphipod feeds by filtering out detritus. It does this by creating a current with its abdominal appendages, while the fringes of fine hair present on its legs strain out food (Kozloff, 1993). The food is then scraped off by the mouth parts and eaten (Kozloff, 1993). Another amphipod that occurs on the Pacific Coast intertidally is *Pontogeneia* (Kozloff, 1987).

Isopods are also crustaceans, mostly living in the sea. They are benthic animals that are adapted for crawling and/or swimming (Ruppert and Barnes, 1994). Most are scavengers, but some have herbivorous diets as well. Some isopods are even parasitic on other crustaceans (Ruppert and Barnes, 1994). *Idotea spp.* of isopods are very common along coasts. One in particular, *Idotea wosnesenskii*, (family *Idoteidae*), the Rockweed Isopod, is often found in the Tillamook Bay area. This animal is also referred to as the Green Isopod, and is the most common of all isopods (Kozloff, 1993). It ranges from Alaska to Southern California, in mussel beds, eel grass, open coasts, bays, and among algal holdfasts (Meinkoth, 1981).

Idotea wosnesenskii can be bright green, olive green, brown, reddish-brown, or black. The color of the organism depends on its diet and surrounding environment. For example, a Rockweek Isopod that is on coralline algae can be pink (Kozloff, 1993). The isopod is flattened top-to-bottom, and is obviously segmented except for the abdominal region. The terminal portion of the body is rounded except for a tiny blunt tooth at the tip. It has seven pairs of claw-tipped legs important for clinging to plants. The body is elongate, straight, and it has kidney-shaped eyes on the sides of its head. It is actually a graceful swimmer and uses paddle-like appendages on its abdomen to do so. A common predator of this isopod is shallow water fish. Another isopod, *Idotea stenops* is also found in the same area, but can be distinguished from *I. wosnesenskii* by having a broader body and angular corners on the terminal portion of its abdomen.

Ligia pallasii Brandt *(*family *Ligiidae*), the Rock Louse, is another isopod found intertidally in rocky shores along with *Idotea*. It ranges from Alaska to San Francisco Bay (Kozloff, 1993). This animal forages on decayed algal material at night and squeezes itself into crevices during the day or low tide. The females of this species are larger and wider, with a maximum length of 3 cm. The overlapping plates on the bottom of the thoracic region forms a brood pouch for young (Kozloff, 1993). The Rock Louse is a mottled brown and black color, often with a diamond shaped pattern on the dorsal surface. There are obvious eyes on the lateral sides of the head, along with fairly large antennae. The flagella on antennae 2 have at least ten segments. The uropods on the abdominal region are short, with square basal pieces that are barely longer than wide. You can distinguish *L. pallasii* from its relative *L. occidentalis*, the Western Sea Roach, by looking at their uropods. The uropods of the Western Sea Roach are very long and narrow. It is also smaller than the Rock Louse (Kozloff, 1993).

Another common marine isopod encountered in similar habitats, is *Gnorimosphaeroma oregonense*, the Oregon Pill Bug. This tiny 1 cm long isopod of the family *Sphaeromatidae*, is a drab, mottled gray or brown color. The basal segments of the first antennae are distinctly separated from one another by a short rostrum (prolongation of head or carapace). The pleotelson is slightly triangular and broad. It is similar to its relative, the terrestrial pill bug, in that it can roll itself into a ball when threatened (Kozloff, 1993). It is most likely living under mussels, among barnacles, or in cavities of wood mined by shipworms. If the substratum is loose rocks, the Oregon Pill Bug is abundant, along with other organisms such as the Hairy Shore Crab and the Green Isopod. The Oregon Pill Bug could be confused with another marine isopod, *Cirolana harfordi*, Harford's Greedy Isopod, which has a more acute, narrow, triangular pleotelson, and lacks the ability to roll into a ball (Meinkoth, 1981). Large populations of the Oregon Pill Bug indicate lower salinity than sea water, probably due to fresh water seepage off shore. This isopod is found from Puget Sound to San Francisco Bay (Kozloff, 1993).

Barnacles are common marine crustaceans that are closely related to shrimp, lobsters, and crabs. The life cycle of a barnacle begins when the adults release planktonic larvae into the ocean. These larvae have eyes and the ability to swim. Once a larva lands on a rock, shell, piece of wood or other surface, it wanders around until it finds a suitable open space to make its permanent home (Yates, 1988). It then cements itself to the substrate, by its antennules. Essentially, the larva is "standing on its head," on some sort of surface. It then slowly metamorphosizes into an adult form, and forms six outer calcified plates and four calcified inner plates for protection (Yates, 1988). The barnacle's legs are modified into feeding appendages that collect drifting detritus and plankton (Yates, 1988). The extended plume that one sees while a barnacle is feeding, is really six segmented legs, or "cirri." Barnacles must regularly molt or shed their inner covering in order to make room for their bodies to grow (Snively, 1978). One can sometimes see these cast off skins from barnacles, floating in bays.

Several species of barnacles are commonly found on the Oregon Coast. These are *Chthamalus dalli, Balanus glandula,* and *Semibalanus cariosis. Chthamalus dalli* , commonly known as the Small Acorn Barnacle, is found at the highest intertidal zone height, from Alaska to San Diego and in Northern Japan (Meinkoth, 1981). This barnacle of family *Chthamalidae*, is also the smallest barnacle, averaging a diameter of 5-6 mm. It can be larger if it is an adult with eggs. It is not usually present with *Balanus glandula*, the Common Acorn Barnacle, with which it competes for space.

The Small Acorn Barnacle has a conical but flat shape, and can become elongate when crowded by others of its own species (Meinkoth, 1981). The opercular opening is oval in shape. This barnacle is a pale gray or brownish color, and has a white interior. The outer surface is smooth, with no major cracks running down the sides. The most commonly used characteristic that distinguishes this species from other acorn barnacles, is the cross shape formed by the junction of *C. dalli*'s four cover plates (Kozloff, 1993). There is also a characteristic arrangement of the six external plates (Cornwall, 1955). The two "rostrolateral" plates and one "rostrum" plate are next to each other and separate in the Small Acorn Barnacle, whereas in the Common Acorn Barnacle, these three plates are fused into one plate (Cornwall, 1955). Examination of mouth parts and legs is necessary for identification. By doing this the feathery projections of the second cirri of the Small Acorn Barnacle occur on both sides of the cirri axis can be seen (Morris et al., 1980).

Balanus glandula, (family *Balanidae*), the Common Acorn Barnacle, is the most common barnacle found along the Oregon Coast (Kozloff, 1993). It is usually found at or above the water line though not as high as the Small Acorn. However, it can be quite high in the intertidal zone if the Small Acorn is not present. The Common Acorn Barnacle's most voracious predator, is the *Nucella* species of whelks (Kozloff, 1993). It is also a favorite food of the Purple Sea Star, *Pisaster ochraceus* (Yates, 1988).

The Common Acorn Barnacle's external surface is grayish white and usually has ridges or longitudinal cracks. It has been described as resembling an acorn, when looking at the top of the barnacle (Snively, 1978). The diameter is usually 10-18 mm if it is not crowded. It will grow elongate if it is among a dense area of other Common Acorn Barnacles. The Common Acorn can grow to a height of around 1.5 cm. The shell is cone shaped, and there is a characteristic black lining of the cover plates. This latter attribute is not often noticed in older specimens where the plates grow too thick for the underlaying lining to show. This barnacle can be distinguished from *C. dalli* by looking at the external plates. *B. glandula* usually has cracks and ridges in its shell, whereas *C. dalli* does not. Also, the line at the junction of the cover plates of *B. glandula* is sinuous, rather than a neat cross.

Semibalanus cariosis, the Thatched Acorn Barnacle, is not too difficult to distinguish from the above mentioned barnacles. This animal (family *Archaeobalanidae*) ranges from the Bering Sea to Morro Bay (Meinkoth, 1981). It may reach 5 cm in diameter, which is larger than the Common and Small Acorn Barnacles. Also, it can sometimes be 3-6 cm in height (Snively, 1978). The Thatched Acorn Barnacle is usually found lower in the intertidal than the Common Acorn Barnacle, but can be found with that species.

The outer surface of the Thatched Acorn Barnacle is a steep-walled white or gray cone, with numerous downward pointing spines (that somewhat resembles a volcano). The furrows present in the shell may also have spiny outgrowths. Sometimes this barnacle can also grow elongate in crowded areas where their characteristic ridges may not be evident. In this case, the animal resembles *B. glandula*. Fortunately for the identifier, *S. cariosis* is almost always larger, darker, and lower in the intertidal than *B. glandula* (Yates, 1988). How low the Thatched Acorn can be depends on whether or not there is heavy predation by the Purple Sea Star (Yates, 1988). Thatched Acorn Barnacles, unlike any other barnacles, leave a membranous base on the surface if ripped off a rock. All other barnacles leave a calcareous scar instead (Kozloff, 1993).

Pollicipes polymerus, the Goose Barnacle is an easily identifiable barnacle found from British Columbia to Baja California (Meinkoth, 1981). It can be located between high and low tide lines in rocky intertidal areas, and was seen in crevices between large boulders at Three Graces Rocks. These crustaceans are not seen in Puget Sound proper, or on most islands of

San Juan Archipelago (Kozloff, 1993). The Goose Barnacle has a grayish or brownish stalk that is usually 2 cm long. The stalk is thick, tough, and covered with fine spines (Meinkoth, 1981). The gonads and adhesive glands are housed in the barnacle's stalk. The upper portion of the body holds the viscera and cirri, and is protected by six major smooth, calcareous, white plates surrounded by many smaller overlapping plates (Meinkoth, 1981).

Goose Barnacles feed differently than other barnacles. Instead of rhythmically extending their cirri, they spread them out so that water can rush through the appendages. They eat small crustaceans and other planktonic organisms that are larger than those collected by the other acorn barnacles. When sufficient food has accumulated, the cirri are withdrawn and the particles are fed into the mouth (Kozloff, 1993). These barnacles have the ability to take advantage of water flowing off a rock. The Goose Barnacles in one colony on one part of a rock mass may all be oriented in one direction to face down-rushing water for feeding (Brusca and Brusca, 1978; Kozloff, 1993). The highest colonies are usually found in gulleys or crevices where the waves crash over the substratum.

A very large barnacle is *Balanus nubilus* , the Giant Acorn Barnacle. Several of these were found at Tillamook Bay. These animals belong to the family *Balanidae* and are the only really large barnacles found north of San Francisco (Kozloff, 1993). The Giant Acorn Barnacle ranges from Alaska to Southern California. It is mostly subtidal in the Puget Sound area, but can be common intertidally in certain places along the Pacific Coast (Kozloff, 1993).

The Giant Acorn Barnacle can grow to 10 cm in diameter, and 10-12 cm in height. The younger specimens have well-developed thatched ribs, and the older barnacles are smoother, and eroded (Snively, 1978). The external shells are a dirty gray color, and are usually covered with encrusting organisms or other Giant Acorn Barnacles. The boring sponge *Cliona* has been known to slowly "attack" the shells (Kozloff, 1993). Two of the four inner cover plates are very sharp, curved, and resemble a bird's beak (Kozloff, 1987). Orange or yellow colors can sometimes be seen around the opercular opening when the barnacle extends its cirri (Kozloff, 1993).

Most of the insects observed at Three Graces Rocks were Rove Beetles, all belonging to the family *Staphylinidae* (Kozloff, 1993). These beetles are small insects that bury in sand or hide under debris on the ground or on rock slopes. We have seen staphylinids near the ground in the low intertidal, or as high as 300cm up a rock face. These insects have small wing covers but substantial wings (Kozloff, 1993). They also have powerful jaws which pierce the shell or protective covering of their prey, and then suck out the juices (Kozloff, 1993). Some examples of prey are other small insects and amphipods. Three commonly found Rove Beetles on our coastline is *Emplenota arenaria, Diaulota densissima,* and *Thinopinus pictus* (Kozloff, 1993).

Phylum Mollusca

Bivalves are soft-bodied marine organisms, covered by two hinged, calcified shells (valves) (Yates, 1988). When exposed to air at low tide, bivalves use one or two adductor muscles to tightly close the valves. Bivalves are the second largest molluscan class, next to gastropods (e.g. snails) (Yates, 1988).

Tillamook Bay is well known for its consistent supply of clams (Griffin, 1995). Clam harvesting is commercially important here, and is done for profit or for recreation. The four most sought after commercial species in this area includes, *Clinocardium nuttallii*, the Heart Cockle or Basket Cockle, *Tresus capax*, the Gaper Clam or Horse Clam, *Saxidomus giganteus*, the Butter Clam, Washington, or Quahog, and *Venerupis staminea*, the Steamer or Littleneck Clam (Griffin, 1995). All of these species occupy the same basic habitat of sandy substrate mixed with small rocks or gravel along Oregon's coastline (Griffin, 1995). Around Tillamook Bay, the greatest densities of The Heart Cockle and Gaper Clam are in sand/silt substrate, whereas large numbers of Littlenecks, and Butter Clams are more commonly found in rock/sand/silt substrate (Griffin, 1995).

A few important terms are used in identification of bivalve species. The shell of a bivalve has two halves called valves. The oldest portion of a valve, near the hinge, (usually beaklike or elevated) is the umbo. The hinge ligament holds the valves together. The teeth that radiate from the part of the hinge immediately adjacent to the umbo, are called the cardinal teeth, and are usually present in clams. All bivalves have a siphon, which is a tube through which water pumps in and out during feeding and excretion. Some species have a chondrophore, which is a plate or shelf to which an internal hinge ligament is attached (Kozloff, 1987).

Clinocardium nuttallii, the Heart Cockle, is commonly found in Tillamook, Netarts, Yaquina, and Coos Bays (Jacobson et al., 1993). This bivalve ranges from Alaska to Southern California, in quiet bays in sand or sand-mud habitats, or in beds of eelgrass that are growing on mud (Meinkoth, 1981). It is versatile, and may be found in clean sand. The Heart Cockle *(*family *Cardiidae)* may be found just under the surface in the intertidal, or down to 8 or 10 cm below the surface. This bivalve has approximately 38 prominent, evenly spaced ridges on the outside of its shell (Kozloff, 1993). These ridges fan from the hinge to the edge, creating a scalloped appearance. There are also very weak concentric growth lines. The siphon is extremely short and fringed, and the valves are equal. The coloration of this species is characteristically warm brown, with some mottling. Older specimens are usually a uniform dark brown color. The average size of this clam is 6-9 cm. It has a very powerful foot, that can be extended in order to escape from predators such as the Sunflower Star, *Pycnopodia helianthoides* (Kozloff, 1993). If threatened by sea stars, or even humans, it will retract its body and tightly close its shells. Usually, people fry or mince the cockle meat (Jacobson et al., 1993). If left undisturbed, this cockle can live up to 15 years (Griffin, 1995).

The Soft-Shelled Clam or Mud Clam, *Mya arenaria* , of the family *Myidae*, is also quite common in this same habitat along the Pacific Coast, as well as in Europe. The range is Labrador to North Carolina, and Vancouver Island to San Diego (Meinkoth, 1981). It is found in almost every Oregon bay. It's typical habitat is a mixture of mud and sand, or mud and gravel, around 20 cm below the surface (Kozloff, 1993). It prefers fresh water seepage from offshore. This clam has a thin, fragile shell that is often cracked when dug. It has an elongate, oval shape, being rounded anteriorly and truncated posteriorly. The left valve is characterized by a large internal flap called a chondrophore. One cannot see this hinge ligament from the outside of the shell. The valves are equal, but with a slight gape at both ends. The Soft-Shelled Clam has a whitish, chalky gray, or brown periostracum that is restricted to the edges of its shell. One can also see slight, wrinkled, rough concentric growth lines. The clam's siphons are fused into a neck with tough, gray skin. The entire length of the clam may exceed 10 cm, but usually the size is 5-10 cm (Jacobson et al., 1993). The Soft-Shelled Clam is preyed upon by birds and humans. It is not very commercially or recreationally important (Griffin, 1995).

Tresus capax, the Gaper Clam, is frequently encountered in Oregon's bays. It is also found in British Columbia, and in Washington (Kozloff, 1993). Another species, *Tresus nuttallii*, the Gaper Nut Clam, co-exists with the Gaper Clam in Humboldt Bay, and in some places in Oregon and Washington (Kozloff, 1993). The shell of the Gaper is one and a half times as long as high. There is usually an eroded dark covering (periostracum) on the shell. The siphon of the Gaper is extremely long when extended, and there are two leathery plates on the tip of it which are not easily seen. There is a large gape where the neck protrudes, and often the shells of the Gaper cannot fully close. Due to this gape, three species of crabs enjoy safety within the mantle of the clam. The Pea Crabs *Pinnixa faba, P. littoralis,* and *Fabia subquadrata* are often found when cleaning a gaper (Kozloff, 1993). The Gaper has a maximum length of 17 cm. Since Gapers have very tough meat, humans take them primarily for frying and mincing (Jacobson et al., 1993). Other predators include birds, sea stars, and drilling gastropods (Griffin, 1995).

The tiny clam *Macoma balthica* L., the Baltic Macoma *(*family *Tellinidae),* is found in muddy sand in quiet bays, or in brackish estuaries (Meinkoth, 1981). It lives close to the surface. It ranges from the Arctic to Georgia, and from the Bering Sea to Central California (Meinkoth, 1981). The Baltic Macoma is not as abundant in Puget Sound or San Juan Archipelago, as it is in San Francisco Bay and bays that front the open coast of the Northwest (Kozloff, 1993). The oval shell rarely exceeds 1.5 cm in length. It is pink, white, yellow, or bluish-white. The valves are equal. One can see very fine concentric lines on the valves as well. An interesting characteristic of this species is the separate, narrow, white, tubular siphons that can extend to more than ten times the length of the valves (Meinkoth, 1981). Predators include mudflat feeding birds and fish (Griffin, 1995). This species is not commercially or recreationally important to humans (Griffin, 1995).

Saxidomus giganteus, the Butter Clam, is a thick-shelled bivalve common in sandy and gravelly muds in British Columbia, Washington, and Oregon (Kozloff, 1993). The range is from Alaska to San Francisco Bay, however, it is rarely seen south of Humboldt Bay (Kozloff, 1993). This clam may be as deep as 30 cm, but it is usually found closer to the surface. This is probably because its black-tipped siphon is relatively short. The oval shell of the Butter Clam (family *Veneridae*) is basically white, but may have blackish discoloration due to the presence of iron sulfide (Kozloff, 1993). On the surface one can see raised concentric growth lines as well as weak grooves. The grooves between the growth lines represent the slow rate of the clam's growth in winter (Kozloff, 1993). The shell is commonly 5-8 cm long. The hinge of the shell is thick, and there is practically no gape at the siphonal end when both valves close. Birds, humans, fish, and drilling gastropods eat this clam (Griffin, 1995). The Butter Clam is an important commercial species because its rubbery flesh is good for chowder, frying, or steaming. There is moderate to heavy digging for this species in Coos, Netarts, and Tillamook Bays (Jacobson et al., 1993).

One of the most popularly dug clams is *Venerupis staminea*, the Littleneck Clam. It is definitely one of the most abundant West Coast clams (Morris et al., 1980). It is present in the low intertidal, in protected situations where there is gravel mixed with sand or mud. The range is from the Aleutian Islands to Baja, California (Meinkoth, 1981). The shell of the Littleneck Clam is moderately heavy, and is sculptured with radiating and concentric ridges that give it a crosshatched appearance. The ribs, which are heaviest toward the rear of the clam, are much less prominent than those of the Heart Cockle. Younger individuals have brown markings, but the older specimens tend to be uniformly pale brown or gray. The interior of the valves is white. The distinguishing feature of the Littleneck (family *Veneridae*) is the file-like sculpturing of the valves just inside the bottom margins (Kozloff, 1993). This bivalve has short, fused siphons, meaning that the posterior end of the clam cannot be found far beneath the surface. In fact, it is usually 25-76 mm below (Meinkoth, 1981). The average size of this clam is 2.5-5 cm, with the maximum length being 6 cm (Jacobson et al., 1993). Bird, humans, and drilling gastropods eat this species of clam.

Mytilus edulis, the Edible Bay Mussel or Blue Mussel, is the most common mussel of Tillamook Bay. It is quite characteristic of quiet waters and estuaries (Kozloff, 1993). It is also the most common bivalve on floats and pilings. It is not only found along the Pacific Coast, but also from the Arctic to South Carolina as well (Meinkoth, 1981). This mussel, found in dense masses, is blue-black, or brown-black, with a shiny periostracum. The Bay Mussel grows to a maximum of 6 cm. There are numerous growth lines on the shell, though these lines are not raised. These mussels are important substratum for other animals, such as barnacles. They filter feed microscopic organisms from the water. The Bay Mussel is not often found on exposed open coasts where *Mytilus californianus* (the Sea Mussel, or California Mussel) is prevalent. The Sea Mussel competes successfully for space due to their larger size (Kozloff, 1993). The Sea Mussel is easily distinguished from other mussels because of its larger size, and its obvious, radiating, raised ribs. There has recently been some debate about the taxonomy of *Mytilus edulis*, the bay mussel. Some researchers suggest that the bay mussel in the Pacific Northwest should be labelled *Mytilus trossulus* rather than *Mytilus edulis;* we are retaining the former species designation until the debate is resolved.

Modiolus modiolus, the Horse Mussel, is also occasionally found intertidally in bays (Kozloff, 1993). They tend to aggregate and attach to one another or empty shells. They are usually partly buried in mud. In younger specimens, the periostracum is brown and shiny, and there are soft yellow hairs on the broader end of the shell. Older organisms are more black-brown and sometimes lack the hairs. The maximum length of this species is 15 cm (Kozloff, 1993).

Snails and whelks all belong to class Gastropoda, in phylum Mollusca. Gastropods have invaded so many habitats that they are considered to be the most successful of all molluscan classes (Ruppert and Barnes, 1994). All gastropods have a rasping tongue called a radula, which is used to scrape algae and microscopic animals off of rocks (Ruppert and Barnes, 1994). Their heads bear two tentacles with an eye at the base of each one. Gastropods are also known for their muscular foots used to move in migration with the tides or cling tenaciously to rocks (Ruppert and Barnes, 1994). They have an external shell.

The shells of gastropods are unique for each species. For someone identifying a gastropod, certain terms for each part of a shell must be known. The shell is cone-shaped and is composed of whorls (a 360 degree turn) that contain the body of the animal. The apex is the very top point of the shell, and contains the smallest, oldest whorls. The larger whorls are coiled about the central axis of the shell, called the columella. The last largest whorl is the body whorl and ends at the aperture (opening) of the shell. The head and foot of the gastropod protrude through the aperture. The edge of the aperture on the body whorl is called the inner lip, and the opposite edge is called the outer lip of the aperture. Many gastropods have a hard oval plate on their posterior surface. This is called the operculum, and when necessary, the animal will fold its body so that only the operculum is exposed at the aperture. The whorls above the body whorl make up the spire of the shell. A gastropod that has a siphon to direct water flow, will have a siphonal canal in its shell to house this siphon. The canal is a notch or a drawn out tube in the anterior portion of the aperture. The shell may have spiral ribs, which are raised folds that encircle the whorls. There may also be longitudinal folds on the whorls, called sculpture (Ruppert and Barnes, 1994).

The two *Littorina* species found off the coast of Oregon are *Littorina scutulata,* and *Littorina planaxis*. Both periwinkles (family *Littorinidae*) are grazers, using their radula to scrape off algae, films of diatoms, and lichens. They have the ability to strongly cling to substrate. These mollusks move via muscular contractions in the foot. This is needed for their migration up and down rocks in response to high and low tides (Morris et al., 1980). These periwinkles are intermediate hosts for many parasites. In Oregon, over 10% of the *L. scutulata* population is infected with a fluke larvae (Morris et al., 1980). The periwinkles are heavily preyed upon by the Angular Unicorn, *Acanthina spirata* (which prefers *L. planaxis*), the Spotted Unicorn, *Acanthina punctulata*, and the Six-Rayed Star, *Leptasterias hexactis* (Morris et al., 1980).

Littorina scutulata, also known as the Checkered Periwinkle, is the most common periwinkle. It ranges from Alaska to Baja California (Morris et al., 1980). It is found at vertical heights of 50-200 cm (lower than *L. planaxis*), and is usually present with the Common Acorn Barnacle, *Balanus glandula*, and/or the Small Acorn Barnacle, *Chthamalus dalli* (Kozloff, 1993). This is because the Checkered Periwinkle likes to hide in crevices in between barnacles and among algal holdfasts at low tide. The juveniles are extremely small, and the adults can reach a maxmium of 1 cm in length. They are brown to bluish-black in color, and often have some type of checkered or spotted pattern. The interior of the aperture is whitish-brown or purple, with no white spiral band at the base, and the columella is usually white. The shell of the

Checkered Periwinkle is slender, with a sharp, pointy spire. There is no significant spiral sculpturing (Kozloff, 1993).

Littorina planaxis, the Eroded Periwinkle, ranges from Oregon to Baja California (Morris et al., 1980). This gastropod prefers high intertidal areas and therefore lives out of water most of the time. As the common name suggests, this periwinkle usually has a badly eroded shell. It can be 1-2 cm in length (Abbott, 1954). The shell has three or four whorls, a blunt apex, and a gray-brown color often with blue-white spots. There is an eroded, flattened area on the body whorl beside the wide columella. The interior of the aperture is big, and is a chocolate color with a white spiral band curving inward at the base. There is scientific interest in this periwinkle, because it occupies a higher vertical position on the shore than any other marine molluscan species in California (Morris et al., 1980). It therefore lives out of water for most of its time. The Eroded Periwinkle can secrete a mucus holdfast around the aperture to glue itself loosely to rocks (Morris et al., 1980). This allows the snail to hold its position without wasting energy, and it can withdraw into its shell to avoid dessication (Morris et al. 1980). Apparently, the Checkered Periwinkle is less able to tolerate dry conditions (Morris et al., 1980).

Nucella emarginata, commonly known as the Rock Whelk or Dogwinkle, is one of the most common whelks found on the Oregon Coast. Its range is from the Bering Sea to Mexico (Abbott, 1954). It generally prefers to be on rocks at a height of 75-150 cm, where it preys on barnacles (especially the Common Acorn Barnacle, *Balanus glandula*) or mussels (Kozloff, 1993). It is usually found higher intertidally than its close relative *Nucella lamellosa*. This gastropod is usually around 2.5 cm in length. It is short and fat, with a short spire, and usually five whorls. The oval-shaped aperture is large and interiorly is light brown, purple, or purple-brown. It has a smooth inner lip and outer lip. The columella is flat, strongly arched and slightly concave at the bottom. The Rock Whelk is extremely variable in size, color, and pattern. It can be white, gray, yellow, orange, brown, or black. Most of the time however, these snails are banded with dark and light narrow bands. These bands are called spiral cords, and usually alternate between small and large (Kozloff, 1993).

Nucella lamellosa, typically called the Wrinkled Whelk or Wrinkled Dogwinkle, is another common whelk in Pacific Northwest rocky intertidal areas (Morris et al., 1980). It ranges from the Bering Straits to Santa Cruz (Abbott, 1954). This gastropod likes to be on rocks at a height of 100-125 cm, and is usually found lower than the Rock Whelk (Kozloff, 1993). The size, shape details, sculpturing, and color are also variable in this species. The shell has frills or wrinkles if in protected areas or bays. It can have a smooth, eroded shell if it takes abuse from crashing waves (which is usually the case). It can be white, pale brown, orange, or gray. Interestingly, this snail can be banded, which somewhat resembles the Rock Whelk. This species often exceeds 5 cm in length. The spire is higher and more pointed than the Rock Whelk. Axial ribs are often present, the outer lip of the aperture is thick, and the columella is almost vertical, straight and not flattened. The shell of the Wrinkled Whelk often has one or two prominent ridges on each whorl. The Wrinkled Whelk lays eggs in vase-shaped, yellow cases that are about 1 cm long. They are deposited in clusters on rocks. In British Columbia, these clusters of eggs are called "sea oats," (Morris et al., 1980).

Both of these species prey on other organisms by drilling a hole in the shell, and secreting chemicals from an accessory boring organ on the sole of the foot, which softens the shell. A proboscis bearing the radula at the tip is then extended through the hole to allow feeding (Morris et al., 1980). The Bay Mussel, *Mytilus edulis*, seems to be the preferred mussel, and the Common Acorn Barnacle, the preferred barnacle (Morris et al., 1980). Predation on this barnacle species makes room for the Small Acorn Barnacle, *Chthamalus dalli*. The Rock Whelk also preys heavily on the Black Turban Snail, *Tegula funebralis*, and the Eroded Periwinkle, *Littorina planaxis* (Morris et al., 1980).

Nucella canaliculata, the Channeled Dogwinkle, will not be thoroughly discussed here because it is rarely found in bays. It ranges from the Aleutian chain to Monterey, California (Abbott, 1954). It is common intertidally on mussel beds and rocks and its preferred prey is the Bay Mussel and the Thatched Acorn Barnacle, *Semibalanus cariosis*. The Channeled Dogwinkle is usually 2.5 cm in length, is white or orange-brown, and has 14-16 low, flat spiral cords that are separated by narrow grooves bearing tiny scales (Abbott, 1954).

Nucella lima, the File Dogwinkle, ranges from Alaska and Japan to Northern California (Abbott, 1954). It is common intertidally and is similar in appearance to the Channeled Dogwinkle. It is usually less than 2.5 cm in length, and is characterized by 17-20 round-topped spiral cords that often alternate in size. They can be white, or orange-brown, but rarely have colored bands. They have five whorls and a thin outer lip (Abbott, 1954).

Tegula funebralis, the Black Turban Snail, has been observed at Three Graces Rocks. This organism ranges from British Columbia to Baja California (Kozloff, 1993). It is often found in upper mid-intertidal areas, but can be found much lower. Its shell is a purplish-black, with weak spiral lines on the body whorls. There are 4 convex whorls. The shell is almost always eroded near the apex, where the calcareous material shows through (Kozloff, 1993). The head and foot of the Black Turban Snail are black. It can grow to a length of 2.5 cm. It eats algae and it is preyed upon by sea stars such as the Purple Sea Star, *Pisaster ochraceus* (Kozloff, 1993). However, the snail responds to an attack by simply detaching itself from a rock and tumbling away. If it escapes being eaten, the Black Turban Snail may live up to 20-30 years (Meinkoth, 1981).

Olivella biplicata, the Purple Olive Snail, ranges in sandy beach areas from British Columbia to Baja California (Meinkoth, 1981). It is found from the low tide line up to 46 m deep. This snail is obvious to spot, because it is one of the few snails on the Pacific Coast with such a highly polished shell and proportionately long aperture (Kozloff, 1993). The color of its shell is a mixture of gray and purple, with some dark lines defining the edges of the whorls, or crossing them lengthwise (Kozloff, 1993). The shell is sturdy, conical, with a low spire and 4-5 smooth whorls. The siphonal canal is only a notch (Meinkoth, 1981). Large animals are 2 cm long. The Purple Olive Snail has a white or cream-colored foot and mantle (Meinkoth, 1981). It can be seen at the surface of sand, or completely buried, thanks to its plow-like foot. This foot will usually leave a trail or a small dimple in the sand (Kozloff, 1993).

Nudibranchs are sea slugs belonging to the class Gastropoda, of family Mollusca. They have a definite head and usually at least one set of tentacles. Some have one, two, or no gills, and only a few seashore nudibranchs can breathe air (Kozloff, 1993). Most are brilliantly colored to warn potential predators, or to blend in with their surroundings. There are two types of nudibranchs. One group is the "aeolids" or "eolids." These slugs are usually beautiful colors, and are covered with finger-like gills called "cerata" (Snively, 1978). The other group is called the "dorids," which have flat bodies and a ring of feathery gills on their back (Snively, 1978).

The Opalescent Nudibranch, formerly known as *Hermissenda crassicornis*, is now referred to as *Phidiana crassicornis*. This sea slug is a member of the family *Facelinidae*, and is probably the most common of nudibranchs (Kozloff, 1987). It ranges from Alaska to Baja California (Meinkoth, 1981), and in habitats such as tidepools, rocks, pilings, mudflats, floats, and eelgrass beds (Kozloff, 1993). It shares the eelgrass habitat with another sea slug, *Aeolidia papillosa*, the Shaggy Mouse, where it subsists on hydroids. The Shaggy Mouse eats sea anemones so these two species do not compete for food (Kozloff, 1993). The Opalescent Nudibranch can basically be found from the low tide line to water 34 m deep (Meinkoth, 1981).

The Opalescent Nudibranch, as an eolid, is, characterized by the presence of numerous, fleshy, dorsal, cerata, and club-shaped tentacles on its head called "rhinophores" (Kozloff 1993). The cerata have an orange band close to the tip, which are capped with white. The cerata are in clusters on the dorsal surface of a translucent, white body. The brown core visible in each cerata are extensions of the liver-like digestive gland of *Phidiana*. The body is broadest just behind the head, and it tapers to the rear. There is an orange band that runs between the rhinophores, and there is frequently a similar band farther posteriorly. These orange bands are bordered by opaque white or electric blue lines that begin on the first pair of tentacles and run to the tip of the tail (Kozloff, 1993). The second pair of tentacles are usually bluish with raised rings (Meinkoth, 1981). The maximum size of the Opalescent Nudibranch is 5 cm when stretched out (Kozloff, 1993). Hydroids, ascidians, other mollusks, various types of eggs, and pieces of fish are all eaten by this sea slug. It has the strange ability to utilize the stinging capsules it digests when eating hydroids. It does this by moving the capsules to the tips of its cerata, to be stored in a "nonexploded" state (Kozloff,1993). Many eolid nudibranchs can do this, and perhaps it serves a protective function. The Opalescent Nudibranch is also known to be cannibalistic. When two meet, they often fight and tear chunks of tissue from each other (Meinkoth, 1981).

Limpets are gastropods that belong to the phylum Mollusca. They have a large muscular foot and can hold on to rocks by suction. It may take a force of 32-36 kg to pry a limpet off a surface (Snively, 1978). This ability allows limpets to clamp their shell down and protect their soft bodies from wave shock, predators and dessication. They have a rasping tongue called a radula, which they use to scrape algae, and microscopic animals off of rocks (Ruppert and Barnes, 1994). When limpet shells are damaged, the organism can repair the chipped or broken area by laying down new shell material from the inside (Morris et al., 1980). Normal erosion of shells often requires this ability. All limpets seem to harbor immature individuals of commensal amphipods (Morris et al., 1980).

There are six limpet species found in the Tillamook Bay area. We found four of these species at Three Graces Rocks.

Collisella digitalis, is commonly found in rocky shore areas, including the Three Graces Rocks. It ranges from the Aleutian Islands to Baja California (Meinkoth, 1981). This gastropod is typical in the high intertidal splash zone, perhaps 200 cm or higher on a rock face (Kozloff, 1993). It sometimes occurs with periwinkles such as the Checkered Periwinkle, *Littorina scutulata.* Characteristic of this limpet are obvious radiating ribs on its shell. This is the reason for its common name as the Fingered Limpet (Kozloff, 1993). The other most notable characteristic is the apex (highest point on the shell). The apex is positioned so far anteriorly that it is nearly as far as the edge of the shell. The shell is usually concave in front of the apex, and convex behind. The color is variable, but is often brown or olive green, with white blotches or dots. The Fingered Limpet's foot is white or cream-colored, with no markings. The interior of the shell (if the limpet has been removed) has a brown owl-shaped patch in the center. This limpet is generally found on vertical or overhanging surfaces (Morris et al., 1980). Shorebirds and sea stars prey heavily upon this particular species. The maximum length of the Fingered Limpet is 2 cm.

Collisella scabra, the Rough or Ribbed Limpet, is found in the same areas as the Fingered Limpet. It ranges from Cape Arago, Oregon to Baja California, and is rarely seen North of Coos Bay (Kozloff, 1993). This limpet looks similar to the Fingered Limpet in that it also has prominent ribs on its shell. However, the apex of the Rough Limpet is positioned more towards the center of the shell. It is also less tall than the Fingered Limpet. The exterior of the Rough Limpet's shell is often a mottled green or brown, white or gray where eroded, and the interior is white with irregular brown lines and blotches. To distinguish it from the Fingered Limpet, one must observe that the head and foot of this organism are nearly white but peppered with tiny black flecks (Kozloff, 1993). Unlike the Fingered Limpet, the Rough Limpet, which may occupy the same general niche, is generally found on gently sloping or horizontal surfaces (Morris et al., 1980). These two species will compete for food if in the same space (Morris et al., 1980). However, the Rough Limpet prefers the top of bare rocks in the splash zone, where the Fingered Limpet is unlikely to be (Kozloff, 1993). The Rough Limpet survives at this height because it can withstand high temperatures and dessication (Morris et al., 1980). It wanders freely at night and then returns to a "home base" during the day (Kozloff, 1993). It does not exeed 2.5 cm in length.

Another limpet found along the Oregon coast is *Collisella paradigitalis*. This limpet is also common on rocky shores in the mid-intertidal, but is found lower than the Fingered Limpet. This limpet may be difficult to distinguish because it looks intermediate between the Fingered Limpet and the Shield Limpet, *Collisella pelta.* The exterior of the shell can be gray or olive green with bluish-white markings. It has no obvious, raised, ribs radiating from the apex to the margin, but does have slight ribs at the margins of the shell (Kozloff, 1987). The shell may also be pitted. The interior of the shell is white to bluish-white, with irregular dark markings at the edges. There is no prominent dark blotch on the interior of the shell. This limpet prefers to be at a height of 50-75 cm, lower than the Fingered Limpet (Kozloff, 1993). The maximum length of *C. paradigitalis* is 1.5 cm, and is smaller and less tall than *C. digitalis* or *C. pelta* (Kozloff, 1993).

Collisella pelta, the Shield Limpet, is widely distributed along the Pacific Coast on rocky shores. It prefers heights of 125-225cm, and is slightly lower than the Fingered Limpet. The Shield Limpet is an extremely variable species. Usually, it has a tall shell, with the apex almost in the middle rather than at the anterior edge. All slopes of the shell are slightly convex. It may be strongly ribbed and have a wavy margin, or it can be nearly smooth (Morris et al., 1980). Often it is brown, green, or nearly black, and checkered with white or with peripheral rays of white. The maximum length of the common Shield Limpet is 4 cm.

Notoacmea scutum, the Plate Limpet is also quite common in these same areas (175-225 cm), and is often found around the Shield Limpet. It too is found lower than the Fingered Limpet. It has a characteristic low, shield-like shell, with the apex more centrally located than the apices of other limpets (Kozloff, 1993). It is never ribbed, but may be marked with fine radiating lines. The maximum length is 4 cm.

Notoacmea persona, the Mask Limpet or Speckled Limpet, is a gregarious species which prefers to be at a height of 200-400 cm in rocky intertidal areas (Kozloff, 1993). This gastropod likes being under the lower edges of large bolders, especially where the rock meets sand or mud. It is sometimes difficult to identify because it looks similar to the Shield Limpet. All sides of the shell of the Mask Limpet are more convex and give a rather puffy appearance. The maximum length is 5 cm.

Chitons are larger, more abundant, and more conspicuous on the West Coast than anywhere else in the world (Snively, 1978). Chitons are primitive mollusks that bear eight plates on their backs. The plates are hinged, which allows the animal to clamp down onto irregular surfaces to avoid predators or dessication (Snively, 1978). A chiton is very tough to dislodge from a rock. They have no eyes or tentacles, but many have sensitive bumps around their plates that sense light or touch (Snively, 1978). They have a thick muscular foot used for clinging to rocks. Chitons also have a rasping tongue called a radula, which they use to scrape algae off of rocks (Yates, 1988).

A chiton that is sometimes seen on rocky shores of the open Pacific coast, as well as in rocky intertidal situations, is *Mopalia hindsii* . This chiton of family *Mopaliidae* is the one chiton most likely to be found in shallow bays and other somewhat protected areas (Kozloff, 1993). It also likes places where there is more silt than most chitons can stand (Kozloff, 1993).

M. hindsii resembles its relatives *M. ciliata* and the Hairy Chiton, *M. lignosa*. Like *M. ciliata*, *M. hindsii* has a noticable posterior cleft. However, the hairs on the girdle of *M. hindsii* are much more slender, flexible, and sparse. It also has rows of obvious tubercles (bumps) on plates 2-7 seen with low magnification, unlike the Hairy Chiton (Kozloff, 1987). Kozloff (1987) notes that the "lateral areas [of the plates] are separated from the central area

by a series of tubercles that mark the places where more or less longitudinal rows on the central areas meet the oblique rows on the lateral areas,"
(p. 190). *M. hindsii* can be a maximum of 7 cm. All *Mopalia* graze on plant material. However, they also consume hydroids, bryozoans, and other small sessile animals (Snively, 1978).

The chiton *Lepidochitona dentiens* Gould, was found at Tillamook Bay, Oregon. This animal is abundant at low levels in the intertidal, around 25-75 cm high, all along the Pacific Coast (Kozloff, 1993). The upper side of its girdle (tissue around the plates) has a fine granular appearance, when viewed under magnification. The girdle usually has light specks which may be organized into a pattern, such as alternating light and dark bands (Kozloff, 1987). The color of the plates is not too colorful. It is usually brown, but can be brown with green tints, or reddish brown. There are no obvious zig-zag, or wavy patterns on the plates. Each plate except for the first and last one are strongly "beaked." *L. dentiens* has 18-25 gills on both sides of its body (Kozloff, 1987). The maximum length this animal can attain is 2 cm (Kozloff, 1993).

Phylum Annelida

There are three major classes of worms in phylum Annelida. These are Hirudinea, the leeches, Oligochaeta, the earthworms, and Polychaeta, the marine worms. The oligochaetes include most terrestrial and some freshwater worms, the hirudinians include mostly freshwater and a few marine leeches, the polychaetes include most of the marine worms and are the largest group (Kozloff, 1993). Class Polychaeta is further broken down into three smaller groups, errant, burrowing, and tubiculous polychaete worms. Errant worms are worms that crawl or build sand grain tubes or parchment paper-like tubes (Ruppert and Barnes, 1994). Examples of errant worms are *Nereis spp.*, and the Sea Mouse. The burrowing worms such as the Lugworm, build burrows in the sand or mud, and are deposit feeders or predators. Tubiculous worms, such as the Calcareous Tube Worm, make tubes for houses and mostly filter feed plankton. Tube worms are further divided into three groups. The Sabellids secrete leathery tubes and have feathery tentacles, the Terebellids may build sand grain tubes and have long slender tentacles, and the Serpulids build hard calcareous tubes (Yates, 1988).

Polychaetes have a distinct head. In general they are segmented and have fleshy flaps of tissue on the sides of their bodies called parapodia which help some species swim. These can be of many different types. The parapodia of tube dwellers are absent or very small. The swimming or crawling polychaetes may have jaws on a retractable proboscis (Yates, 1988). Some species have specialized bristles called setae, which help them burrow in sand or mud.

Marine worms have some very complex structures that require special terminology for identification purposes. The prostomium in polychaete annelids is the head lobe, which is in front of the mouth. Often there are flaps (called palps), such as the prostomial palp, which is a sensory outgrowth underneath or on the front of the head lobe. Some polychaetes have a long sensory outgrowth or palp on the first true segment of their body. This first true segment on which the mouth is located is called the peristomium. Antennae (which are restricted to the prostomium) are also common. Parapodia normally consist of several lobes, called the neuropodium (the lower lobe) and the notopodium (upper and more towards the back). Neurosetae, in polychaete annelids, are setae arising from the neuropodium. The notopodium setae arise from the notopodium. The acicula of a parapodium, is a chitinous needle-like structure that gives internal support for the lobe of the parapodium. A cirrus is a simple soft appendage that is finger-like or tentacle-like. In segmented polychaetes, each segment is called a setiger, and is numbered from anterior to posterior (Kozloff, 1987).

Nereids are a common group of marine polychaetes. All worms of the *Nereis spp.* have fleshy, obvious parapodia, and setae used to bury in sand and mud. They all have two, sharp, black, chitinous jaws on their retractable proboscis. These jaws are used for tearing off bits of seaweed and grabbing small creatures, including other worms (Yates, 1988). Nereids will also eat bryozoans, sponges, and detritus (Morris et al., 1980).

The most common polychaete found on the Pacific Coast is *Nereis vexillosa*, the Sand Worm. It is found in mussel beds and under rocks or chunks of wood in quiet bays, such as Tillamook Bay. The Sand Worm (family *Nereidae*) reaches a length of 15 cm and is a mixture of gray, blue, and green colors. This worm has numerous tiny paragnaths (teeth) on its proboscis. There are four pairs of tentacle-like cirri on the peristomium. Conspicuous prostomial antennae, prostomial palps, cirri underneath each parapodium, and four eyes are also present on the Sand Worm. It has notopodia with setae and aciculae (Kozloff, 1987).

Nereis vexillosa can be found burrowing in sand just underneath the surface. It has a sexual mature phase where the fleshy parapodia become expanded into paddle-like structures used for swimming (Kozloff, 1993). Periodically during the summer one can see the mature males and females swarming near the surface of the water. Females are distinguishable by having a posterior that is significantly redder than that of the males. When ripe, the Sand Worm will spew out eggs or sperm through openings in its body wall (Kozloff, 1993). The worms do not survive long once this occurs. There is another nereid worm that may occur with *N. vexillosa*. That polychaete is *Nereis brandti*, which is much longer (up to 1 m) and not nearly as common along our coastline. It is in deep water, either subtidal or in the very low intertidal. It has numerous pragnaths (tiny teeth) on its proboscis (Morris et al., 1980). *Nereis grubei* is another related, less common worm that is found on the Pacific Coast. This animal ranges from British Columbia to Mexico and Peru (Morris et al., 1980). It likes habitats in shallow, subtidal, rocky areas or the upper mid-intertidal in mussel beds. It has four pragnaths on its proboscis, arranged in a diamond pattern (Morris et al., 1980).

There are a number of species of worms in the family *Glyceridae* along the Oregon coast. All are carnivores and are different from nereids by their characteristic proboscis. All are of the genus *Glycera* except for *Hemipodus borealis* (Kozloff, 1993). They are common in mudflats, and sandy or gravelly habitats (Kozloff, 1993). These worms have four hook-like, black, jaws (rather than two like nereids) on their retractable proboscis. Another characteristic is their prostomium, which is conical, ringed and tapered to a point. This point is tipped with four small antennae (Kozloff, 1987). This benthic family has two tentacle-like appendages on the tip of its posterior as well. They are capable of shooting out their proboscis quite quickly, in order to burrow, ingest prey, or bite a human handler (Meinkoth, 1981).

Notomastus tenuis, the Thread Worm, is the most common and obvious polychaete in muddy habitats. This worm (family *Capitellidae*) is always present in muddy sand or mud (Kozloff, 1993). It is slender, being 20 cm long and only 1 mm wide when extended. It has small parapodia, and no tentacles. The prostomium has two groups of reddish or blackish eyespots. There are no setae on the peristomium. The notosetae on the first 10-11 setigers are slender. No distinct gills are present on the neurosetae. Eleven setigers make up the thoracic region of the worm, and there are hooded hooks (as parapodia) on the abdominal setigers (Kozloff, 1987).

Not much information is available on the small worm (1 cm or less), *Armandia brevis*, of the family *Opheliidae*. It has a slender body, with a ventral groove running the entire length of the body. There are also numerous lateral eyespots on both sides of its body (Kozloff, 1987). Several of these red and green worms were found at Three Graces Rocks, just under the surface of the sand.

Pista pacifica, the Pacific Terebellid Worm, is an easily identifiable species of worm from British Columbia to Southern California (Kozloff, 1993). This member of family *Terebellidae* prefers muddy sand and eelgrass beds (Meinkoth, 1981). Large specimens are 30 cm long. The Pacific Terebellid Worm makes a durable, sandy tube, that is buried in the sand or mud vertically. Above the surface of the substratum, the tube flares out into a triangular hood. There is a fringe of slender outgrowths on this hood (Kozloff, 1987). When the tide is in, the reddish-brown worm inside spreads its grooved ciliated tentacles over the sand to collect microscopic food particles (Kozloff,1993). This worm has three pairs of branched gills (Meinkoth, 1981).

Spio filicornis, the Long-Horned Worm, is a common polychaete found in protected sandy places, near the low tide line (Meinkoth, 1981). It is found on both coasts of the United States. This polychaete *(*family *Spionidae)* makes a thick-walled but fragile sand tube for itself. This tube rises vertically through the sand, about 6 mm above the surface of the substratum (Meinkoth, 1981). The polychaete is a dull green or yellowish-green, with red gills held erect over its back on all segments. Gills are present over almost the entire length of the body, beginning on setiger 1 or 2 (Kozloff, 1987). There is one pair of tentacles (also called two grooved palps) on its prostomium, and four eyes on top arranged in a square. The Long-Horned Worm is usually 3 mm wide, and can reach a maximum length of 50 mm (Meinkoth, 1981.

Phylum Echinodermata

Sea stars belong to the phylum Echinodermata, which they share with brittle stars, sea cucumbers, sea urchins, and sand dollars. Unique to this phylum, are tube feet and a water hydraulic system which they use in conjunction with muscles to move, or to cling to surfaces or prey. Almost all echinoderms are predators. They eat barnacles, mussels, clams, and other sea stars. Only a small number are filter feeders (Yates, 1988).

The most conspicuous sea star of rocky intertidal areas along the Pacific Coast is *Pisaster ochraceus*, the Purple Sea Star. It ranges from Alaska to Baja California (Meinkoth, 1981). This echinoderm of family *Asteriidae*, can be seen in tide pools at low tide, on floating docks and pilings, in deep water, or well above the low tide line (Meinkoth, 1981). This sea star has five stout, stiff, tapering arms. There are numerous clusters of white spines in a network-like or pentagonal pattern on the dorsal surface of the animal's central disk (Meinkoth, 1981). The spines extend onto the arms. Among the spines, are tiny, stalked, microscopic pincers called pedicellariae. These function in discouraging settlement of larvae or debris on its surface (Kozloff, 1993).

The color of the Purple Sea Star is not always purple. It varies, probably because of environmental differences. For example, in heavy wave action areas where the environment is harsh, this sea star is orange. In more protected or nothern waters, the sea star is purple (Snively, 1978). In Puget Sound and San Juan Archipelago, almost all the *Pisaster* are purple (Kozloff, 1993). The maximum diameter of this organism is 25 cm (Kozloff, 1993).

When on docks or pilings, *Pisaster* prefers to feed on acorn barnacles (such as *Balanus glandula*) and mussels (*Mytilus edulis)*. When in rocky habitats, it eats these organisms, plus limpets, other snails (especially *Tegula funebralis*), and the Sea Mussel, *Mytilus californianus*. It can show a wide vertical distribution when feeding, and stay quite high in the intertidal long after the tide goes out just to feed on certain organisms (Kozloff, 1993). In eating, this sea star is capable of executing a holding and pulling action of its tube feet, combined with a pulling action of its five arms in different directions in order to pry open a bivalve or other shell. It also has the ability to extrude part of its stomach to cover its prey or insert into a crack between its prey's shell halves (Kozloff, 1993). It can then digest the prey while its still in the shell. The digestive process may take two or three days (Snively, 1978).

Phylum Bryozoa

Bryozoans are small sessile (immobile) colonies of very small animals called zooids (Ruppert and Barnes, 1994). Even though the individual animals are small, the overall group they belong to contains 5000 living species (Ruppert and Barnes, 1994). The body of a zooid is usually a trunk, with an eversible structure that bears a lophophore. A lophophore is a circular or horseshoe shaped fold of the body wall that encircles the mouth and bears many hollow, ciliated, tentacles (Ruppert and Barnes, 1994). Each zooid lives in a separate zooecium, or "house" (Kozloff, 1993). The colony builds by asexual reproduction, and protoplasmic connections between the zooids may occur (Kozloff, 1993). Colonies of various species can take many forms such as branching, flat and encrusting growths, leaf-like and attached to substratum in only one point, branching calcareous masses resembling corals, or resembling seaweeds (Kozloff, 1993).

Bryozoans are often confused with hydroids (which belong to Phylum Cnidaria rather than Phylum Bryozoa), because each often has a body stalk and a tentacle-like structure on the end. Another confusion arises because both types of animals have branching colonies (Kozloff, 1993). However, there are major differences. When the zooid of a bryozoan retracts, the whole animal is withdrawn into its zooecium by special muscles (Kozloff, 1993). Hydroids can only bend their tentacles inward, or contract the whole body stalk, because they have no such muscles (Kozloff, 1993). Bryozoans also have another specific set of muscles that can pull the operculum (a protective door) of the zooecium shut (Kozloff, 1993). Also unlike hydroids, bryozoans have no stinging capsules, for they are filter feeders rather than carnivores. For bryozoans, ciliary action moves water through the lophophore, which separates plankton particles of a particular size, and sends them to the mouth (Kozloff, 1993). The u-shaped digestive tract is complete, with the anus being on one side of the lophophore (Kozloff, 1993).

Bryozoan colonies are called “polymorphic,” meaning that individuals within the colony are specialized for different functions. For example, there are individuals that are called avicularia, which resemble the beak of a bird because muscles close one part of a “jaw” against the other (Kozloff, 1993). There is also a type of individual called a vibraculum, which is a structure that is a slender vibratile (moves in a vibrating fashion) projection (Kozloff, 1987). Both of these types of individuals are assumed to discourage settling animals.

Two obvious bryozoans are commonly found along the Pacific Coast. The *Membranipora spp.* of bryozoan is found on blades of kelp or other brown algae. *Membranipora membranacea* , the Lacy-Crust Bryozoan, is a circular encrusting species near the low tide line or below in shallow water (Meinkoth, 1981). It ranges from Alaska, to Baja California (Meinkoth, 1981). Identification of this species is difficult even for experts, due to their simple structure. The zooids are arranged in a radiating pattern consisting of long rectangular cases that branch and rebranch (Kozloff, 1993). The opaque, white lines one sees are the calcified walls of the zooecia (Kozloff, 1993). *Membranipora spp.* are often grazed upon by the Cryptic Nudibranch, *Doridella steinbergae*. This is a tiny sea slug, that is less than 1 cm (Kozloff, 1993). It feeds on the extended lophophores of *Membranipora* (Kozloff, 1993).

Another species of bryozoan found on the Pacific Coast is *Bugula spp.* One species or another of *Bugula* are often present in rocky shore habitat (Kozloff, 1993). It looks lacy and soft, but is actually brittle and gritty due to its partial calcification. A large colony can be 4 or 5cm high, and there is a definite spiral configuration in appearance (Kozloff, 1993). Most of the colony consists of zooecia that no longer contain living zooids. The upper portions of the colony will contain the living, active, tentaculate, individuals along with beaked avicularia (Kozloff, 1993). The dark brown objects one may see in most of the zooecia, are disintegrated organs (Kozloff, 1993).

Bugula californica, the California Spiral-Tufted Bryozoan is a West Coast species that could be seen in Oregon (Meinkoth, 1981). The avicularia of these animals have been observed to pull apart small crustaceans which were then captured by the lophophores (Meinkoth, 1981).

Phylum Cnidaria

Sea anemones are called cnidarians, and are related to jellyfish, corals, and sea pens. Some cnidarians, such as jellyfish, have alternating life stages where they are a non-moving, stalked polyp, or a free swimming animal called a medusa. Sea anemones are always in the polyp stage, and remain attached to substratum unless seriously threatened. Two of probably the best known species of sea anemones are found in Tillamook Bay. Many lesser known species are also seen in Oregon, and along the entire Pacific Coast.

The anemone that everyone seems to recognize first is *Anthopleura xanthogrammica*, the Giant Green Anemone. This anemone ranges from Alaska to Panama, on open coastlines, pilings, rocks, sea walls, and in bays, harbors, and tidepools (Meinkoth, 1981). They are normally in low tidepools and have been found in waters as deep as 15 m (Meinkoth, 1981). They are characterized by a broad, flat, oral disk, where the mouth is located (Kozloff, 1993). This disk as well as the tentacles surrounding it are a subdued or bright emerald green. The diameter of the tentacular crown in an expanded individual might be 15 cm. The column of this animal is usually a drab green or brownish color, that is covered with scattered adhesive projections to adhere shell bits and sand. Some biologists believe that the layer of shell bits and other debris reflects sunlight, holds in moisture and cools the anemone when the tide recedes (Snively, 1978). The Giant Green Anemone is solitary, but may be found near others if the surrounding environment is favorable.

Anthopleura elegantissima the Aggregate Anemone, is also found along rocky shores, from Alaska to Baja California (Meinkoth, 1981). It is commonly found in areas higher than the Giant Green Anemone. These anemones are often in large groups and can practically colonize rocks. They stand about 4 or 5 cm high when submerged, and contract into gritty blobs during low tide times to avoid dessication (Kozloff, 1993). They are an olive green color, with soft pink tentacles. The columns are studded with vertical rows of blue-green tubercles, which also serve to collect foreign particles. The Aggregate Anemone is quite different from other anemones in that all the individuals in a tight colony arose from one parent that asexually divided. Therefore, all the individuals in a group are genetically identical clones (Kozloff, 1993). When one clone encroaches on another's territory, they both engage in a sort of war. At the bases of their tentacles, there are bulbous structures that contain stinging cells called nematocysts. Anemones along the line of aggression fire these at each other until a clear boundary is established between clones (Kozloff, 1993). Studies suggest that the Aggregate Anemones on the peripheral region of a colony are smaller, bear more nematocysts, and act as "warrior" polyps constituting the line of defense against other non-clones. The anemones in the middle of a colony are bigger, have less nematocysts and are the reproductive polyps that must be protected by the warrior polyps (Ayre et al., 1996).

The Giant Green Anemone, as well as *Anthopleura elegantissima,* the Aggregate Anemone, discharges nematocysts onto prey such as crustaceans, dislodged mussels, or any creature that has fallen off a nearby rock (Kozloff, 1993). Once the nematocysts are discharged, the tentacles push the prey into the anemone's mouth. A sucking action is also believed to be involved. Both of these species also contain two distinct types of symbiotic unicellular algae in their tissues. Either one or both zooanthellae and zoochlorellae reside in the gastrodermal layer (the layer of tissue surrounding the gut) of the anemone (Kozloff, 1993). These algal cells contribute to much of the green color of the anemones, however the anemones do produce their own pigments as well. The symbiotic nature of this relationship is that the anemones provide a safe home for the algae, and in turn the algae synthesize organic compounds which the anemones use as food during periods of starvation (Kozloff, 1993).

Phylum Ctenophora

Sometimes people strolling on a beach will find what looks like squishy marbles of clear jelly, that have washed up onto the sand. These gelatinous spheres are animals called comb jellies, and belong to the phylum Ctenophora. They look and feel like jellyfish, but are in fact quite different. There are 50 known species in this phylum, and almost all are hermaphroditic. The phylum name Ctenophora literally means "comb-bearing." Cilia (tiny hairs), are arranged in groups called "ctenes," or combs, in eight meridional rows called comb rows. One cannot see individual cilia with the naked eye, but the shimmery line of a comb row can usually be seen without problem. The cilia help the ctenophore steer slightly and move forward in calm waters. Unlike jellyfish, ctenophores can propel themselves smoothly rather than in a pulsating, jerky motion. Comb jellies cannot move fast and are usually carried by the current (Kozloff, 1993).

Comb jellies have a mouth at one end called the oral end, and an aboral end opposite the mouth. The oral end leads to a sort of stomach, which spreads into canals that make up the rest of the digestive tract. Each canal is directly behind a comb row. At the aboral end, there is an organ of balance which consists of a crystalline mass resting on sensory cilia (Kozloff, 1993). When the ctenophore moves, the cilia move in a particular direction, and the comb jelly adjusts its body orientation in order to be positioned upright. Some comb jellies are the size of a pea, and other deep water individuals are the size of a watermelon (Ruppert and Barnes, 1994). Most ctenophores are transparent, and luminescence is a characteristic of all the species. Light producing cells in the digestive canals cause the comb rows to glow at night (Ruppert and

Barnes, 1994). Most ctenophores have colloblasts, which are sticky cells used to grab prey. Other ctenophores can capture prey directly with their mouths (Ruppert and Barnes, 1994).

The most common comb jelly in Oregon is probably *Pleurobrachia bachei*, The Sea Gooseberry. This creature of family *Pleurobrachiidae*, is also known as Cats Eyes, on the Pacific Coast (Meinkoth, 1981). They often get washed up on shores of the open coast during peak abundance in Summer. They are rare in Winter, and only start peaking in numbers when Spring begins. It ranges from Alaska to Baja, California (Meinkoth, 1981). A large Sea Gooseberry may be 1.5 cm in diameter.

Like all comb jellies, these gelatinous, egg-shaped, animals propel themselves smoothly through calm water by large cilia. There are "tentacle sacs" opening toward the aboral end of the organism (Kozloff, 1987). Two retractable, long tentacles originate here, and when extended, may be 15 cm long. Many fine branches come off each tentacle. The tentacles are extended as the comb jelly swims through the water. Colloblasts are discharged when they touch prey such as copepods or small crustaceans (Kozloff, 1993). The organism will then contract the tentacles to bring the food up to its mouth. Apparently, the Sea Gooseberry is carnivorous and swarms of them have been known to destroy whole schools of young herring (Meinkoth, 1981). Another rarer comb jelly called *Beroe*, a cucumber-shaped animal usually 7 or 8 cm long, will eat its relative *P. bachei* without hesitation (Kozloff, 1993). These creatures are quite harmless to humans.

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Information Theory Analysis, Introduction

The ecological diversity of the invertebrate macrofauna of rocky intertidal and sand/gravel habitats in Tillamook Bay at various times of year is the focus of this report. The array of organisms present in Tillamook Bay's different habitats, or in any type of environment, has several distinct components contributing to the overall impression that might informally be called the "abundance" or "variety" of life present. First and simplest are the actual frequency counts or densities of organisms; how often different organisms are encountered in a given surface area or volume of the habitat. The greater the number of living creatures we see, the greater is our impression of the richness of the habitat. Second to consider is the number of species of organisms present. Intuitively the greater number of different species present, the greater the diversity of life (and all other things being equal the more stable the ecological community due to the multiplicity of trophic relationships present in the more complex food web). Third and finally the evenness or equiprobability of species representation in the data is related to ecological diversity. The more evenly distributed the organisms, or equivalently the lower the divergence from equiprobability of the species distribution, the more diverse are the organisms present. In order to provide a partial description of the invertebrate macrofauna of parts of Tillamook Bay, we will compute and report first-order information theory indices as detailed below, as well as providing actual frequency tables for the invertebrates sampled (for detailed explanations of information theory analyses, see: Kolmes, 1985, Kolmes and Mitchell, 1990; Kolmes and Sommeijer, 1992).

How position in the intertidal range affects the species distribution in Tillamook Bay is another consideration. To examine this, species counts at various heights above the low tide level were taken in a rocky intertidal zone, and information theory indices were employed. In this instance second-order information theory indices expressing the divergence from independence of species identity and height zone were computed. The lower the divergence from independence of the species distribution, the less distinctive are the species found at one height zone from those found at other height zones.

A related question is how different the species prove to be in locations that appear to be superficially very similar to one another in slightly sloped sand/gravel substrates of Tillamook Bay. In order to examine this, species counts in various randomly selected sand/gravel flat quadrats were taken, and again information theory indices were employed. This also involved second-order information theory indices, now expressing the divergence from independence of species identity and quadrat location. The lower the divergence from independence of the species distribution, the less distinctive are the species found in one quadrat from those found in other quadrats in the sand/gravel flats.

Seasonal fluctuations in macroinvertebrates sampled on a rocky substrate in Tillamook Bay will examined by collating data collected from preliminary sampling trips taken in the spring and early summer, and comparing those data to the data collected in the TBNEP supported sampling carried out later in the summer. Macroinvertebrate communities of the intertidal zone share some of the exposure to changing climatic conditions characteristic of terrestrial organisms, but also possess some of the buffering from climatic fluctuations typical of marine organisms. It will therefore be interesting to see how variable across seasons these macroinvertebrate samples are.

In a similar vein, comparisons between the macroinvertebrates sampled on rocky substrates and in sand/gravel substrates will provide some insight into the differences caused by the characteristics of these two types of habitats in terms of protection from wave action, productivity levels, human disturbance for shellfish harvesting, and other differences caused by abiotic factors or human activities.

Overall, the data collected in this project will be analyzed and discussed in order to help describe the strength of vertical zonation on a rocky habitat in Tillamook Bay, the differences between rocky and sand/gravel macroinvertebrates, and the extent of seasonal fluctuations in macroinvertebrates sampled on the rocky substrate. It is hoped that this survey will form the basis for additional sampling in future years, as Tillamook Bay becomes established as a long-term ecological field site for researchers and educators.

Methods

In order to prepare for the invertebrate sampling elements of this project that were supported by the TBNEP, we carried out preliminary field trips to sampling sites at Tillamook Bay in the spring of 1996 with students from the University of Portland’s Invertebrate Zoology class (Biology 436/476) and again during the early summer of 1996 with students from the Marine Biology of the Pacific Northwest (Biology 338/388). These initial trips gave us a baseline data set in order to allow a seasonal comparison with the data collected in the TBNEP supported sampling. The site selected for sampling in the initial field trips was an estuarine rocky intertidal area (the “Three Graces” rocks), and in the TBNEP supported sampling we added a sand/gravel area (the “Garibaldi Flats”) for comparison. Preliminary samples were taken on class field trips in April and June of 1996, and three sampling trips were taken during low tides in July of 1996 by the TBNEP supported researchers. Macroinvertebrate identifications were based on information in Kozloff, 1983, 1987.

A protocol was used involving the sampling of delimited surface areas. For sampling rocky intertidal habitats, the procedure was to place a flexible 25 cm by 25 cm quadrat on a rock as close to the waterline as possible, then to count and identify all of the macroinvertebrates in the quadrat. In the data tables these lowest quadrats are referred to as the 0 - 25 cm zone. For the second sampling quadrat, the grid was first flipped once so that the previous top became the new bottom (25 - 50 cm zone) and macroinvertebrates in this quadrat were not counted. The grid was flipped again as previously, and macroinvertebrates in this quadrat (50 - 75 cm) were once again counted. This procedure was repeated so that samples were taken in alternating 25 cm tall (and 25 cm wide) bands of counted and uncounted rocky face surfaces. Preliminary field trips included sampling as high as 300-325 cm above the low tide line, but it rapidly became clear that most of the interesting data were located closer to the low tide line, so that subsequent sampling was concentrated on the first three (0 - 25 cm, 50 - 75 cm, 100 - 125 cm) and at times four (150 - 175 cm) height zones. Sampling was done at or immediately after low tide. All data tables include the low tide level on the sampling date, to facilitate comparisons between samples.

Sampling on sand/gravel areas was necessarily different since there was not the same sort of vertical zonation to examine. Instead, 25 cm by 25 cm quadrats were placed randomly at between 18 m and 28 m landwards of the low tide line level, with the only caveat being that the habitat sampled was sand and gravel, with areas of eelgrass and large rocks being avoided. The material underneath each of these quadrats to a depth of approximately 25 cm was excavated, and the macroinvertebrates present were counted by carefully sorting through and sieving the substrate. Sampling was done at or immediately after low tide. All data tables include the low tide level on the sampling date.

First-order information theory diversity indices ("Shannon indices", H_1) were computed for the macroinvertebrate faunas of these height zones and habitats. The H_1 and D_1 values (see below) provide an objective measure of the biological diversity present in each type of habitat at each sampling date. Second-order information theory measures, H_2 and D_2 values (see below) provided a way of quantitatively describing the strength of vertical zonation (independence of species found and height above low tide level) for the rocky intertidal habitat. For a more detailed description of how to interpret information theory measures, see Kolmes, 1985; Kolmes and Mitchell, 1990; Kolmes and Sommeijer, 1992.

The equations used in the first-order information theory calculations (where the units are "bits"), for both row and column totals, as well as for first-order measures for individual height zones or summed daily data, are as follows: where pi is the proportion of a specific data set accounted for by the frequency of one invertebrate species, and there are N total species in the species list considered possible for sampling in that location,

a) first-order diversity = H_1 = $-\Sigma p_i \log_2 p_i$
b) maximum first-order diversity = H_{1max} = $\log_2 N$
c) divergence from equiprobability = D_1 = H_{1max} - H_1

The second-order measures (whose units are also "bits") are calculated as follows: where $p_{ij}\log_2 p_{ij}$ is the proportion of a specific invertebrate species (located in a particular rocky intertidal height zone or sand/gravel quadrat) multiplied by the log base 2 of that proportion,

d) second-order diversity = H2 = $-\Sigma p_{ij}\log_2 p_{ij}$
e) maximum second-order diversity = H_{2max} = H_1 for row totals + H_1 for column totals (this computation of H_{2max} parses out first-order unevenness)
f) divergence from independence = D_2 = H_{2max} - H_2

Results

In April of 1996, rocky intertidal sampling was carried out during a (-0.9 ft) low tide. A total of 15,500 macroinvertebrates were recorded in various height zones ranging from 0 - 25 cm above low tide level to 300 - 325 cm above low tide level (Table 1).

The lowest height zone (0 - 25 cm) contained the fewest organisms (184 macroinvertebrates in 22 quadrats), with anemones of two species (*Anthopleura xanthogrammica* and *A. elegantissima*) and thatched barnacles (*Semibalanus cariosis*) predominant (Table 1). The first-order diversity (H_1) for this height zone was 1.935 bits and the corresponding divergence from equiprobability (D_1) was 2.765 bits. Although not a great many individuals were seen in this height zone, it will prove to be one of the more diverse of the rocky intertidal layers, lacking the enormously disproportionate presence of acorn barnacles at most of the greater heights above the low tide level.

The next height zone (50 - 75 cm) contained more organisms (2348 macroinvertebrates in 16 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by goose barnacles (*Pollicipes polymerus*)(Table 1). The first-order diversity (H_1) for this height zone was 0.798 bits and the corresponding divergence from equiprobability (D_1) was 3.902 bits. The disproportionate presence of acorn barnacles was responsible in large part for this low measure of diversity.

The next height zone (100 - 125 cm) contained yet more organisms (4721 macroinvertebrates in 15 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by checkered periwinkles (*Littorina scutulata*)(Table 1). The first-order diversity (H_1) for this height zone was 0.586 bits and the corresponding divergence from equiprobability (D_1) was 4.114 bits. The great frequency of acorn barnacles was responsible in large part for this low measure of diversity.

The next height zone (150 - 175 cm) contained the most organisms (6415 macroinvertebrates in 8 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by checkered periwinkles (*Littorina scutulata*) and goose barnacles (*Pollicipes polymerus*)(Table 1). The first-order diversity (H_1) for this height zone was 0.714 bits and the corresponding divergence from equiprobability (D_1) was 3.985 bits. The high frequency of acorn barnacles was once again responsible in large part for this low measure of diversity.

The next height zone (200 - 225 cm) contained 1296 macroinvertebrates in 3 quadrats, with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by thatched barnacles (*Semibalanus cariosis*)(Table 1). The first-order diversity (H_1) for this height zone was 0.987 bits and the corresponding divergence from equiprobability (D_1) was 3.713 bits. The frequency of acorn barnacles was responsible in large part for this low measure of diversity.

The next height zone (250 - 275 cm) contained 325 macroinvertebrates in 2 quadrats, with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by sand fleas (*Traskorchestia traskiana*) and blue mussels (*Mytilus edulis*)(Table 1). The first-order diversity (H_1) for this height zone was 1.208 bits and the corresponding divergence from equiprobability (D_1) was 3.493 bits. The somewhat greater first-order diversity of this height zone was due in large part to there being two species in addition to the barnacles present in fairly high abundance.

The final height zone (300 - 325 cm) contained 661 macroinvertebrates in 2 quadrats, with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by blue mussels (*Mytilus edulis*) and sand fleas (*Traskorchestia traskiana*) (Table 1). The first-order diversity (H_1) for this height zone was 0.642 bits and the corresponding divergence from equiprobability (D_1) was 4.058 bits. The decline in first-order diversity of this height zone was due in large part to the barnacles once again increasing in their relative abundance.

The second-order information theory measures for the April data set in its entirety had an H_{2max} value of 3.029 bits for a corresponding D_2 of 0.152 bits. The divergence from independence for this data set was therefore quite low. Although the details of the species present at various height zones changed, there was a very high probability that in virtually any location above the sparsely populated lowest quadrats the organisms encountered would be acorn barnacles (*Balanus glandula*), therefore producing relatively weak vertical zonation when the entirety of the data set is considered. It is also of interest that the H_1 and D_1 values are so consistent over such a large height range at the Three Graces rocks.

In June of 1996, rocky intertidal sampling was carried out during a (-0.9 ft) low tide. A total of 3,888 macroinvertebrates were recorded in various height zones ranging from 0 - 25 cm above low tide level to 150 - 175 cm above low tide level (Table 2).

The lowest height zone (0 - 25 cm) contained the fewest organisms (12 macroinvertebrates in 3 quadrats), with green anemones (*Anthopleura xanthogrammica*) predominant (Table 2). The first-order diversity (H_1) for this height zone was 1.958 bits and the corresponding divergence from equiprobability (D_1) was 2.765 bits. Although frequencies of organisms were relatively low in this height zone, it proved to be one of the more diverse of the rocky intertidal samples, lacking the disproportionate presence of acorn barnacles at most of the greater heights above the low tide level.

The next height zone (50 - 75 cm) contained more organisms (395 macroinvertebrates in 3 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by aggregate anemones (*Anthopleura elegantissima*)(Table 2). The first-order diversity (H_1) for this height zone was 0.747 bits and the corresponding divergence from equiprobability (D_1)

was 3.953 bits. The high frequency of acorn barnacles was responsible in large part for this low measure of diversity.

The next height zone (100 - 125 cm) contained more organisms (967 macroinvertebrates in 3 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by aggregate anemones (*Anthopleura elegantissima*)(Table 2). The first-order diversity (H_1) for this height zone was 0.901 bits and the corresponding divergence from equiprobability (D_1) was 3.799 bits. The great frequency of acorn barnacles was responsible in large part for this low measure of diversity.

The final height zone (150 - 175 cm) contained yet more organisms (2514 macroinvertebrates in 3 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by aggregate anemones checkered periwinkles (*Littorina scutulata*)(Table 2). The first-order diversity (H_1) for this height zone was 0.871 bits and the corresponding divergence from equiprobability (D_1) was 3.829 bits. The number of acorn barnacles was responsible in large part for this low measure of diversity.

The second-order information theory measures for the June data set in its entirety had an H_{2max} value of 2.223 bits for a corresponding D_2 of 0.087 bits. The divergence from independence for this data set was therefore quite low. Although the details of the species present at various levels changed, in virtually any location above the lowest quadrats the organisms encountered would very likely be acorn barnacles (*Balanus glandula*), therefore producing relatively weak overall vertical zonation when the entirety of the data set is considered.

In July of 1996, rocky intertidal sampling was carried out during a (-3.0 ft) low tide. The lowest height zone (0 - 25 cm) was a zone not sampled on previous low tides. A total of 5,242 macroinvertebrates were recorded in various height zones ranging from 0 - 25 cm above low tide level to 100 - 125 cm above low tide level (Table 3).

The lowest height zone (0 - 25 cm) contained the fewest organisms (36 macroinvertebrates in 4 quadrats), with anemones of two species (*Anthopleura xanthogrammica* and *A. elegantissima*) predominant (Table 3). The first-order diversity (H_1) for this height zone was 2.189 bits and the corresponding divergence from equiprobability (D_1) was 2.511 bits. Although not a large number of individuals was seen in this height zone, it was one of the more diverse of the rocky intertidal layers, lacking the high frequency of acorn barnacles at most of the greater heights.

The next height zone (50 - 75 cm) contained more organisms (2936 macroinvertebrates in 4 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by blue mussels (*Mytilus edulis*)(Table 3). The first-order diversity (H_1) for this height zone was 0.381 bits and the corresponding divergence from equiprobability (D_1) was 4.319 bits. The high frequency of acorn barnacles was responsible in large part for this low measure of diversity.

The final height zone (100 - 125 cm) contained more organisms (2270 macroinvertebrates in 4 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by blue mussels (*Mytilus edulis*)(Table 3). The first-order diversity (H_1) for this height zone was 0.525 bits and the corresponding divergence from equiprobability (D_1) was 4.175 bits. The large number of acorn barnacles was responsible in large part for this low measure of diversity.

The second-order information theory measures for the June data set in its entirety had an H_{2max} value of 1.565 bits for a corresponding D_2 of 0.067 bits. The divergence from independence for this data set was therefore quite low. Although the details of the species present at various height zones changed, there was a very high likelihood that in any location above the lowest quadrats the organisms encountered would be acorn barnacles (*Balanus glandula*), therefore producing weak overall vertical zonation when the entirety of the data set is considered.

In July of 1996, the Garibaldi Flats were sampled on two low tides (-2.8 ft and -2.2 ft) with five quadrats dug the first day and four quadrats dug the second day. This type of sampling proved to be much slower than simply counting invertebrates on rocky surfaces, since the sand and gravel had to be carefully sieved and sorted through to look for macroinvertebrates.

The first sampling date yielded 16 macroinvertebrates, mostly the Baltic macoma clam (*Macoma balthica*), although six other species were also present in almost even numbers (Table 4). The first-order diversity (H_1) for this sampling date's combined quadrats was 2.092 bits, with a corresponding divergence from equiprobability (D1) of 2.828 bits. Although few in number, these macroinvertebrates of the Garibaldi Flats represented a much more diverse array than the great majority of the samples taken at the Three Graces rocks, where on all three sampling dates divergences from equiprobability were much higher than first-order diversities except in the very lowest height zone.

The second sampling date yielded 25 macroinvertebrates, mostly the soft shelled clam (*Mya arenaria*), although ten other species were also present in fairly even numbers (Table 4). The first-order diversity (H_1) for this sampling date's combined quadrats was 2.996 bits, with a corresponding divergence from equiprobability (D1) of 1.964 bits. Although few in number, these macroinvertebrates of the Garibaldi Flats also represented a much more diverse array than the great majority of the samples taken at the Three Graces rocks.

In April of 1997, rocky intertidal sampling was carried out during a (-0.2 ft) low tide. A total of 7,012 macroinvertebrates were recorded in various height zones ranging from 0 - 25 cm above low tide level to 100-125 cm above low tide level (Table 5).

The lowest height zone (0 - 25 cm) contained the fewest organisms (853 macroinvertebrates in 23 quadrats), with anemones of two species (*Anthopleura xanthogrammica* and *A. elegantissima*) and acorn barnacles (*Balanus glandula*) predominant (Table 5). The first-order diversity (H_1) for this height zone was 2.036 bits and the corresponding divergence from equiprobability (D_1) was 2.050 bits. Although not a great many individuals were seen in this height zone, it will prove to be one of the more diverse of the rocky intertidal layers, lacking the enormously disproportionate presence of acorn barnacles at most of the greater heights above the low tide level.

The next height zone (50 - 75 cm) contained more organisms (1904 macroinvertebrates in 21 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by thatched barnacles (*Balanus cariosis*)(Table 5). The first-order diversity (H_1) for this height zone was 2.361 bits and the corresponding divergence from equiprobability (D_1) was 1.546 bits. The disproportionate presence of acorn barnacles was partially offset by the large number ofthatched barnacles and aggregate anemones in producing this moderately low measure of diversity.

The next height zone (100 - 125 cm) contained yet more organisms (4255 macroinvertebrates in 20 quadrats), with acorn barnacles (*Balanus glandula*) predominant, followed in abundance by thatched barnacles (*Balanus cariosis*)(Table 5). The first-order diversity (H_1) for this height zone was 1.757 bits and the corresponding divergence from equiprobability (D_1) was 2.243 bits. The great frequency of acorn barnacles was somewhat offset by the large numbers of thatched barnacles and blue mussels to produce this moderately low measure of diversity.

The second-order information theory measures for the April 1997 data set in its entirety had an H_{2max} value of 3.290 bits for a corresponding D_2 of 0.133 bits. The divergence from independence for this data set was therefore quite low. Although the details of the species present at various height zones changed, there was a very high probability that in virtually any location above the sparsely populated lowest quadrats the organisms encountered would be acorn barnacles (*Balanus glandula*), therefore producing relatively weak vertical zonation when the entirety of the data set is considered.

Discussion

The "great flood of 1996" saw an unprecedented influx of freshwater into Tillamook Bay early in the year, and some qualitative observations can be made about the effect of that osmotic stress on the macroinvertebrates at our sampling locations. Sponges, never abundant at the Three Graces rocks, had previously been present in low numbers on certain rock faces exposed by tides such as the -3.0 ft tide of our July sampling date (B. Houck, personal communication). In 1996 and 1997 there were no sponges visible at all, and it is likely that, given the intimate exposure of the cells of sponges to the water flowing through them, they were unable to survive the osmotic stress produced by the flood waters. Juvenile sea stars, seen in previous years, were not identified seen in 1996 although one small purple sea star was seen in 1997 (Table 5). Other organisms, like gastropods of the genus *Thais*, remained present in high abundance, with no evidence that they were diminished by the flood. The data collected in these years will provide a useful baseline for the recovery of the macroinvertebrate fauna of Tillamook Bay from what is believed to have been a 50 year or 100 year flood event. Subsequent years of sampling at the same locations should allow us to document the changes in species identity and numerical distribution that take place as the macroinvertebrates pass through successional stages of recovery, as organisms lost to low salinity and high sediment levels reinvade the Bay.

Seasonal comparisons of macroinvertebrate diversity indices show little fluctuation in the distribution of organisms present at the Three Graces rocks. This mathematical result is reinforced by observing the actual data sets (Tables 1,2,3,5) which show that the great majority of the organisms present are sessile (2 species of *Anthopleura*, *Balanus glandula*, *Semibalanus cariosis, Pollicipes polymerus, Mytilus edulis*) and therefore they could not realistically be expected to show any seasonal variations in numbers. Some slow moving organisms were also reliably present in reasonable numbers over the course of the sampling dates (e.g. *Littorina scutulata*). There were differences seen in numbers of some of the less common organisms that are motile (e.g. the fairly large number of Staphylinid beetles seen on the rocks in June) but these were minor fluctuations compared to the great majority of sessile or low-moving organisms seen in approximately consistent numbers over the samples.

The sand/gravel habitat of Garibaldi flats lacked both any one species as dominant as the *Balanus glandula* were on the rocky substrates, and also anything like the number of organisms seen on the rocks. The total number of organisms sampled in sand/gravel quadrats was too low for any firm conclusions to be drawn about how similar in macroinvertebrate communities the similar-appearing quadrats were to one another. The sand/gravel habitat had lower productivity of macroinvertebrates as measured by our samples, and to what extent recreational clam digging over many years has contributed to the low abundances seen in that habitat the present data set cannot say. The lack of protection from physical disturbances for sand/gravel macroinvertebrates may account to some extent for their low numbers. Other factors, such as the effects of the long-term contact between these organisms and any pollutants that settle into the sediments, also need to be considered. Sediment-dwelling organisms may suffer from pollutants that become deposited to a greater extent than do organisms on rocky substrates, which are washed with water with every high tide .

The second-order diversity indices computed for the Three Graces rocks indicate that vertical zonation is relatively weak in this habitat, once again this is due to the strong mathematical effect of the very high numbers of *Balanus glandula*. It can be seen from the raw data that some vertical zonation does occur, with two species of *Anthopleura* present at low heights, and organisms such as *Mytilus edulis* and *Littorina scutulata* , and *Traskorchestia traskiana* emerging at higher levels. However, all of these differences in less common organisms cannot overcome the great dominance of the *Balanus glandula* in our samples and the homogenizing effect these barnacles have on the organisms sampled in different height zones.

Tillamook Bay is a location where a great deal can be learned about the effects of environmental fluctuations and human activities on the life forms and health of an important ecosystem. This survey represents an initial contribution to what we hope will become an ongoing program of ecological research and sampling in future years, as Tillamook Bay becomes established as a long-term ecological field site.

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Tillamook Bay as a Long-Term Ecological Site:

Studies funded by the Tillamook Bay National Estuary Project have the potential to serve as the foundation to establish Tillamook Bay as a long-term ecological site, with benefits to science and to the bay itself. Studies including species identification, species abundance and diversity, invertebrate breeding cycles, larval recruitment and adult mortality can be correlated with environmental and ecological factors over a period of many years. Meaningful data collection requires long-term commitment of three groups:

1) university researchers and students,

2) educators, high school students and community college students from the Tillamook area, and

3) local community members.

Data collection also rests upon adequate resources for species identification in the field, and a central "clearing-house" to maintain and disseminate results.

Contributions in this study from the University of Portland have included identification of some common species found in rocky intertidal areas near the mouth of Tillamook Bay, documentation of these species in a photo CD, collection of baseline data on species diversity in the rocky intertidal zone, and a brief description of identified species. We are quite willing to make a long-term commitment to data collection in the Tillamook Bay area, and we welcome the participation of other researchers, educators, students, and community members in this endeavor. We are willing to volunteer our time and energy to this goal.

We would suggest the following as future projects deserving merit.

1) **Community Volunteers**

In Dr. Houck's seminar presentation in October, 1996, community members in the audience suggested an interest in a "community tide-pool session", an idea that we believe has merit. In such a session, faculty and undergraduate students would work with small groups of interested volunteers to identify species in the rocky intertidal regions of Three Graces Rocks during low summer tides. Methods for recording species abundance and species diversity would be demonstrated. Volunteers would make a commitment to take additional data on future dates and would be provided with data collection sheets. Data would be compiled and analyzed at the University of Portland, with results returned to volunteers. We would be more than willing to organize such sessions next summer, if staff at TBNEP feel it is worthwhile. Community involvement has several benefits, including regular data collection by people with direct access to the Bay on a daily basis, and an educational benefit for those whose lives are most impacted by the health of the bay.

2) **University Studies**

We will continue to supervise studies by University of Portland undergraduates, as well as collect data ourselves, to establish the role of environmental factors such as rainfall/flooding, water temperature, plankton blooms, and public food collection on species diversity in rocky intertidal areas of Tillamook Bay. The flooding of early 1996 and the apparent El Nino event of 1997 mark unusual perturbations of the bay. The effects of either event can only be established by long-term monitoring. Seasonal fluctuations in population size, invertebrate migrations between deep and shallow waters, mortality due to water or air temperature variations or salinity shock, changes in population structure due to public harvest of edible species all could be identified with regular monitoring. We welcome the participation of other interested researchers in such studies.

3) **High School Teachers and Students**

Tillamook Bay offers a unique opportunity for local high school teachers and students to contribute to meaningful data collection in marine biology and ecology. Teachers may choose to work either independently or in collaboration with research personnel. Several teachers have already demonstrated a strong commitment to marine biological studies. All efforts should be made to support these individuals. There is a possibility for outside funding through the National Science Foundation for such initiatives; this possibility should be explored.

4) **Photo CD**

The photo CD produced through this grant represents just the beginning of efforts to document the species present in the bay and make such information available to local educators and community groups. Additional images are needed of organisms common in the rocky intertidal zone, along with photos of species from sandy beach areas and mud flats. Integration of collection data with GIS overlays would be helpful, and an interactive CD could offer additional benefits.

Summary

Tillamook Bay offers a unique setting for long-term ecological and biological studies. The coordinated efforts of researchers, educators and community volunteers could allow such studies to continue after the TBNEP funding has expired. We have been pleased to play a small role in this project, and we remain committed to the twin goals of education and research in Tillamook Bay.

TABLE 1. Invertebrates included in Sampling Tillamook Bay, Three Graces Rocks	April, 1996 tide = -0.9ft	June, 1996 tide = -0.9ft	July, 1996 tide = =3.0ft
Anthopleura xanthogrammica (green anemone)	87	8	11
Anthopleura elegantissima (aggregate anemone)	106	168	50
Urticina (Tealia) lofotensis) (scarlet anemone)	0	0	1
Notoacmea scutum (plate limpet)	13	1	4
Collisella digitalis (fingered limpet)	5	9	11
Collisella pelta (shield limpet)	3	41	29
Littorina scutulata (checkered periwinkle)	556	275	69
Nucella emarginata (rock whelk)	18	0	1
Nucella lamellosa (wrinkled whelk)	4	7	3
Mytilus edulis (blue mussel)	21	28	136
Balanus nubilus (giant barnacle)	1	0	6
Semibalanus cariosis (thatched barnacle)	355	36	8
Pollicipes polymerus (goose barnacle)	425	0	0
Balanus glandula (acorn barnacle)	11614	329	4900
Idotea wosnesenskii (green isopod)	2	1	3
Ligia pallasi (broad black isopod)	11	0	5
Staphylinidae spp. (black beetle)	0	17	1
Hemigrapsus nudus (shore crab)	7	0	0
Pagurus spp. (hermit crab)	3	2	1
Serpula vermicularis (calcareous tube worm)	0	0	1
Nereis vexillosa (sand or pile worm)	3	0	0

TABLE 2. Tillamook Bay, 3 Graces Rock
July, 1996 tide = -2.8ft

	HEIGHT ZONES (cm)		
	0-25	50-75	100-125
Anthopleura xanthogrammica (green anemone)	10	1	
Anthopleura elegantissima (aggregate anemone)	15	34	1
Urticina (Tealia) lofotensis (scarlet anemone)	1		
Diodora aspera (keyhole limpet)			
Notoacmea scutum (plate limpet)		3	1
Collisella digitalis (fingered limpet)			11
Collisella pelta (shield limpet)		17	12
Littorina scutulata (checkered periwinkle)		12	57
Nucella emarginata (rock whelk)		1	
Nucella lamellosa (wrinkled whelk)	1	2	
Olivella biplicata (olive snail)			
Polinices lewisii (moon snail)			
Mytilus edulis (blue mussel)		56	80
Mytilus californianus (sea mussel)			
Clinocardium nuttallii (heart cockle)			
Balanus nubilus (giant barnacle)			6
Semibalanus cariosis (thatched barnacle)	6		2
Pollicipes polymerus (goose barnacle)			
Lepas fascicularis (pelagic goose barnacle)			
Balanus glandula (acorn barnacle)		2800	2100
Cthamalus dalli (acorn barnacle)			
Idotea wosnesenskii (green isopod)		3	
Ligia pallasi (broad black isopod)		5	
Isopoda spp. *			
Staphylinidae spp. (black beetle)	1	1	
Traskorchestia traskiana (sand flea)			
Emerita analoga (mole crab)			
Hemigrapsus nudus (shore crab)			
Hemigrapsus oregonensis (hairy shore crab)			
Pagurus spp. (hermit crab)	1	1	
Petrolisthes cinctipes (porcelain crab)			
Haliclona permollis (encrusting sponge)			
Ophlitaspongia pennata (red sponge)			
Halosydna brevisetosa (scale worm)			

Serpula vermicularis (calcareous tube worm)	1		
Nereis vexillosa (sand or pile worm)			
Dendraster excentricus (sand dollar)			
Evasterias troschelli (mottled star)			
Pisaster ochraceus (purple star)			
total # invertebrates	36	2936	2270

* species unidentified, isopod with flat lateral extensions

TABLE 3. Tillamook Bay, 3 Graces Rock
July, 1996 tide = -0.7ft

	HEIGHT ZONES (cm)			
	0-25	50-75	100-125	150-175
Anthopleura xanthogrammica (green anemone)	6	2		
Anthopleura elegantissima (aggregate anemone)		41	77	50
Urticina (Tealia) lofotensis (scarlet anemone)				
Diodora aspera (keyhole limpet)				
Notoacmea scutum (plate limpet)			1	
Collisella digitalis (fingered limpet)		1		8
Collisella pelta (shield limpet)	1	1	16	23
Littorina scutulata (checkered periwinkle)		1	10	264
Nucella emarginata (rock whelk)				
Nucella lamellosa (wrinkled whelk)	2	4	1	
Olivella biplicata (olive snail)		1		
Polinices lewisii (moon snail)				
Mytilus edulis (blue mussel)		1	13	14
Mytilus californianus (sea mussel)				
Clinocardium nuttallii (heart cockle)				
Balanus nubilus (giant barnacle)				
Semibalanus cariosis (thatched barnacle)			9	27
Pollicipes polymerus (goose barnacle)				
Lepas fascicularis (pelagic goose barnacle)				
Balanus glandula (acorn barnacle)		343	826	2125
Cthamalus dalli (acorn barnacle)				
Idotea wosnesenskii (green isopod)	1			
Ligia pallasi (broad black isopod)				
Isopoda spp. *				
Staphylinidae spp. (black beetle)			14	3
Traskorchestia traskiana (sand flea)				
Emerita analoga (mole crab)				
Hemigrapsus nudus (shore crab)				
Hemigrapsus oregonensis (hairy shore crab)				
Pagurus spp. (hermit crab)	2			
Petrolisthes cinctipes (porcelain crab)				
Haliclona permollis (encrusting sponge)				
Ophlitaspongia pennata (red sponge)				
Halosydna brevisetosa (scale worm)				
Serpula vermicularis (calcareous tube worm)				
Nereis vexillosa (sand or pile worm)				
Dendraster excentricus (sand dollar)				

Evasterias troschelli (mottled star) *Pisaster ochraceus* (purple star)				
total # invertebrates	12	395	967	2514
* species unidentified, isopod with flat lateral extensions				

TABLE 4. Garibaldi sand/gravel/mudflats
July, 1996

	tide = -2.6ft	tide = -2.0ft
Crangon franciscorum (sand shrimp)		2
Upogebia pugettensis (mud shrimp)		
Callianassa californiensis (ghost shrimp)		2
Mya arenaria (soft shelled clam)	1	9
Macoma balthica (baltic macoma)	9	2
Saxidomus giganteus (butter clam)		2
Venerupis staminea (little neck clam)		3
Tresus capax (gaper clam)		
Siliqua patula (razor clam)		
Clinocardium nuttallii (heart cockle)		
Emerita analoga (mole crab)		
Scyra acutifrons (sharp-nosed crab)		
Cancer magister (dungeness crab)		1
Cancer oregonensis (hairy shore crab)		
Scleroplax granulata (pea crab)		1
Amphipoda spp.	1	
Littorina scutulata (checkered periwinkle)	1	1
Olivella biplicata (olive snail)		
Polinices lewisii (moon snail)		
Emplectonema gracile (green nemertean)		
Amphiporus formidabilis	1	
Notomastus tenuis	1	
Nereis vexillosa (pile or sand worm)		
Polynoidae spp.		1
Spio filicornis	2	1
Pista pacifica		
total # invertebrates	16	25

TABLE 5 3 Graces Rock
April, 1997 tide =-0.2 ft

	HEIGHT ZONES (cm)		
	0-25	50-75	100-125
Anthopleura xanthogrammica (green anemone)	85	43	20
Anthopleura elegantissima (aggregate anemone)	106	234	109
Collisella pelta (shield limpet)	3	28	30
Notoacmea scutum (plate limpet)	2	22	16
other limpets		4	7
Littorina scutulata (checkered periwinkle)		6	16
Nucella emarginata (rock whelk)	16		1
Nucella lamellosa (wrinkled whelk)	11	8	
Mytilus edulis (blue mussel)	61	34	522
Mytilus californianus (sea mussel)		11	21
Balanus nubilus (giant barnacle)	5	14	26
Semibalanus cariosis (thatched barnacle)	16	401	1165
Lepas fascicularis (pelagic goose barnacle)		11	
Balanus glandula (acorn barnacle)	516	1083	2318
Idotea wosnesenskii (green isopod)	25	2	
other isopods	2	5	
Traskorchestia traskiana (sand flea)	1		1
Pagurus spp. (hermit crab)	2	3	
unidentified polychaete worm			1
unidentified shrimp			1
Fam. Cocinellidae (ladybird beetle)			1
Tonicella lineata (lined chiton)	1	0	0
Pisaster ochraceus (purple star)	1		
total # invertebrates	853	1904	4255