A Biological Inventory of Benthic Invertebrates in Tillamook Bay

Oregon Department of Fish and Wildlife
Marine Resources Program

Prepared for
The Tillamook Bay National Estuary Project

February 1998

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Prepared for
The Tillamook Bay National Estuary Project
Garibaldi, Oregon 97118

February 1998

Tillamook Bay National Estuary Project Technical Report 01-98
Prepared under Cooperative Agreement #CE990292-1 with the
U.S. Environmental Protection Agency

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EXECUTIVE SUMMARY

The Oregon Department of Fish and Wildlife (ODFW) surveyed Tillamook Bay in the summer of 1996 to inventory the bay's benthic invertebrates. The emphasis of the survey was to estimate clam density and biomass in selected areas and habitats. Clam populations were last surveyed in 1974-76 and 1984-85. More recent information was necessary for the management of both the commercial and recreational clam fisheries. In addition, data were gathered on burrowing shrimp, algae, eelgrass, habitat, and benthic infauna from grab samples.

Clam surveys employed a modified two-stage simple random sampling plan at three subtidal plots and three intertidal plots in the northern section of Tillamook Bay. The plots ranged from 1 to 7.5 hectares in size with 3.4 to 10.7 samples taken per hectare. Data were gathered on adult and juvenile clam size, weight, and age, as well as burrowing shrimp, algae, eelgrass, and habitat at each station. Intertidally, data were gathered using rakes and shovels. Subtidally, SCUBA divers and a dredge pump facilitated data gathering. Additional burrowing shrimp and eelgrass data were gathered throughout the bay and apart from the clam survey. Benthic invertebrates were also surveyed using a Smith-McIntyre grab sampler throughout the bay's channels and flats.

The four major commercial species of clams have the following estimated biomasses in the areas surveyed: butter clams (*Saxidomus giganteus)* 2,023,501 pounds; cockles (*Clinocardium nuttallii)* 628,122 pounds; gapers (*Tresus capax)* 558,682 pounds; and littlenecks (*Protothaca staminea)* 228,745 pounds. Results of the clam survey show the bulk of the clam biomass residing in the subtidal areas, as well as an overall increase in available subtidal clam biomass since the 1975 survey. In 1975, the subtidal clam biomass was estimated at 134,427 pounds per hectare. In 1996, the subtidal estimate was up to 319,864 pounds per hectare. We attribute this increase in biomass partly to an expanded butter clam population and partly to differences in sampling methods. Length frequencies of these four species of clams show the 1996 subtidal populations to be larger in size than clams surveyed in 1975. Gapers averaged nearly 50 mm larger in 1996, indicating poor recruitment over the intervening years. Intertidal areas show a lack of large clams, resulting in a low average size for all four species.

Shrimp survey results show that sand shrimp (*Neotrypaea californiensis*) occur in most habitats throughout the bay, and mud shrimp (*Upogebia pugettensis*) occupy habitats within the lower and middle zones of the bay. Mud shrimp were not found south of a line drawn about 245° SE from Goose Point. The data indicate that burrow densities of both sand and mud shrimp are highest in the middle portions of the bay. More than 75% of the 25 stations sampled throughout the bay had shrimp burrow counts in excess of $16/m^2$, 50% had counts in excess of $80/m^2$, and 25% exceeded $200/m^2$.

The eelgrass/habitat map developed by Earth Designs Inc. provided a good representation of habitats found in the bay, even after a hard winter. Ninety-five percent of the eelgrass density comparisons made were accurate within the scope of our mapping procedure. Eelgrass beds consist primarily of *Zostera marina*. The introduced eelgrass species, *Zostera japonica,* was observed at four roadside sites. Eighty-nine percent of comparisons made between percent algae cover found in the field and the eelgrass/habitat map were in agreement. Eighty-one percent of sediment comparisons concurred. The southern end of the bay showed more sediment changes due possibly to the previous winter's storms.

The benthic invertebrate grab samples resulted in the identification of 154 taxa at 15 grab areas. At least eight of these are introduced species, and six are cryptogenic or of unknown origin. The top five most abundant taxa were: Oligochaetes spp., 49%; the introduced cumacean *Nippoleucon hinumensis,* 8%; the introduced gamarid amphipod *Grandidierella japonica,* 6%; the introduced spionid polychaete *Pseudopolydora kempi,* 5%; and the polychaete *Capitella capitata 'hyperspecies,'* 4%. Thirteen taxa of bivalves were identified through the grab samples, three of which were not seen, and two of which were not quantified in the clam survey. Of the superfamily Corophioidea, juvenile Corophioidea sp., the introduced species *Corophium acherusicum* and *Corophium spinicorne* were identified. Conspicuously absent from samples was *Corophium salmonis*, an important prey species for juvenile salmonids in other estuaries. Future sampling programs should verify this observation. Tidal flat stations had higher numbers of organisms than channel stations, as did the lower bay over the upper bay stations. The lower bay consisted of habitats that were more affected by the oceanic system and thus have higher energy and salinity. These areas contained the main concentrations of clams and also tend to show the highest species richness in the grab samples.

INTRODUCTION

Tillamook Bay encompasses over 9,000 total acres, making it the third largest estuary in Oregon. Over 7,000 of these acres are intertidal area, and over 2,000 acres are subtidal (Cortright *et al*. 1987). Five rivers feed the bay: Miami, Kilchis, Wilson, Trask, and Tillamook Rivers. Principal habitats consist of tideflats, sandbars, river mouths, jetties, channels, eelgrass beds, and oyster beds. The bay supports a large variety of animals and receives intensive human use.

Tillamook Bay has seen and felt the impacts of human land use, yet continues to provide abundant resources. Tillamook Bay supports an active commercial and recreational clam harvest. Commercial bay clams include cockles, butters, gapers, and littlenecks. Other clams such as the softshell and bentnose clams are also found in the bay. On average, Tillamook Bay supplies 72% of the commercial clam harvest in Oregon (Johnson and Wood 1997). At low tide as many as 585 recreational clammers have been counted on Garibaldi Flat alone. Burrowing shrimp populations in Tillamook Bay are biologically and commercially important. Tillamook is one of the most productive bays in Oregon for the catch of sand shrimp taken for the bait market. Sand and mud shrimp are also important biologically to the estuary. Adult and juvenile shrimp are important fish food items for juvenile salmonids in Tillamook Bay as well as for a variety of other fish species (Forsberg *et al.* 1975). Tillamook Bay has historically been the largest producer of cultured oysters in Oregon. Eelgrass (*Zostera marina*) beds cover acres of the bay. They are considered by many to be the single most important and productive habitat available in Tillamook Bay. Eelgrass provides food, shelter, and protection from predators for an enormous number of invertebrates and fish.

Updated assessments of bay clams, burrowing shrimp, and eelgrass beds were necessary in Tillamook Bay due to their biological, social, and economic importance. Bay clams were last surveyed by the ODFW in 1974, 1975, 1976 (Hancock *et al.* 1979), and again in 1984 and 1985 (Gaumer 1985, 1986). Management decisions by ODFW are still being made on the basis of these studies. Since these assessments were done, commercial clam harvest has increased to a high of 149,494 pounds in 1994, with cockles comprising the primary harvested species. In 1995 a quota was set at 10% of the standing cockle clam biomass, and a minimum size limit was set on cockles of 2.25 inches. This equaled 90,000 pounds of cockles, the primary commercial species, annually. A brood stock reserve was set aside in the Ghost Hole area of the bay at this time as well. The harvest levels have decreased over the two subsequent years due to market constraints and decreased effort, as well as the management strategy. The mud shrimp (*Upogebia pugettensis*) and the sand shrimp (*Neotrypaea californiensis*) were partially surveyed in 1974-1976 and quantified in terms of sparse, moderate, and dense (Hancock *et al.* 1979). In 1988, 88,839 pounds of sand shrimp were taken from Tillamook Bay for the bait market. Landings have greatly reduced in recent years, possibly due to a population decline. Oyster growers have concerns that the sand shrimp population is expanding and having a detrimental effect on the industry. Data on the size and locations of eelgrass beds are 20 years old.

ODFW contracted with the Tillamook Bay National Estuary Project (TBNEP) to study these issues during the summer of 1996. The study focused on estimating the current biomass and distribution of bay clams, burrowing shrimp, eelgrass beds, and other benthic invertebrates to provide support for current and future management.

METHODS

The study was divided into four overlapping surveys to meet sampling objectives. The rapid assessment survey served to locate sampling sites for the clam survey and test sampling techniques. The shrimp survey sampled sites throughout the bay specifically for burrowing shrimp density estimates and species distribution. The clam survey estimated the biomass and density of both subtidal and intertidal clams in areas where the rapid assessment survey found the greatest clam concentrations. These areas were located in the northern portion of Tillamook Bay. We also gathered data on eelgrass, burrowing shrimp, percent algae cover, habitat, and sediment in all of the above surveys. The benthic grab survey assessed the presence and abundance of benthic invertebrates other than clams or shrimp. Survey stations were located in tidal flat and channel habitats throughout the bay.

Rapid Assessment Survey

We conducted intertidal and subtidal rapid assessment surveys to locate sampling sites for the clam survey, test sampling techniques, and gather data on burrowing shrimp, eelgrass, and algae cover.

Intertidal Rapid Assessment Survey

We selected intertidal rapid assessment survey sites to provide a broad coverage of the bay. We accessed the sites at low tide using an 18-foot skiff with an outboard motor. Site locations were recorded using a Garmin 45® GPS receiver, and sites were documented with a video camera. Sites were initially sampled using 0.25 m^2, 1 m^2, and 9 m^2 nested quadrats to determine the most efficient quadrat size for clam sampling. Quadrats were located by tossing them randomly. Sampling within the quadrats began with a count of the gaper clam siphons. Then, eelgrass turions were counted, percent algae cover estimated, and shrimp burrows were noted as sparse, moderate, or dense within the 0.25 m^2 quadrat. Substrate was recorded as bedrock, cobble, gravel, sand, sand/mud, mud, shell, and/or debris. From within the nested 0.25 m^2 quadrat, a 0.1 m^2 area was removed to a depth of 25 cm and sieved through a 3 mm screen to sample for clam set, and the remaining area of the 9 m^2 quadrat was raked to remove surface adult clams.

Subtidal Rapid Assessment Survey

The subtidal survey sites were chosen to determine the upper bay limit of heavy concentrations of commercial clams. Surveys began in the lower bay and proceeded up bay in as many channels as possible. Survey locations were accessed at high tide, when visibility was best, using a 21' Glasply inboard/outboard boat with a dive platform. At each survey station, transect lines 300-600 m in length were deployed by anchoring one end to the channel bottom with concrete anchors attached to a marker buoy. The boat pilot then navigated down-current, along a predetermined compass course, as the transect line was fed tautly off the stern of the vessel. The down-current end was anchored and marked with a buoy as well. The position of each end of the transect was recorded using GPS, as for the intertidal stations. Using a live-boat operation, two divers entered the water at the up-current end of the transect line. One carried a clipboard, rake, and quadrat while the other carried the underwater camera. At each 50-meter station along the transect, eelgrass turions and gaper siphons were counted within the 0.25 m^2 quadrat. Algae and shrimp burrows were noted as sparse, moderate, or dense. Substrate was recorded as bedrock, cobble, gravel, sand, sand/mud, mud, shell, and/or debris. The quadrat was then raked for surface-dwelling clams such as cockles and littlenecks. Data were recorded, and the dive team moved on to the next 50-meter mark to repeat the procedure. Using a video camera, divers recorded a view of the bottom along the entire length of the transect. At the end of the transect, the divers and transect lines were picked up and moved to the next site.

Shrimp Survey

Twenty-five intertidal burrowing shrimp survey stations were visited during three successive low tides in July 1996. This survey was in addition to the qualitative shrimp burrow data recorded during the rapid assessment survey and to the counts recorded during the bay clam survey. Survey stations were chosen randomly to sample all the major habitat regions within the bay. Sample sites were accessed using the 18-foot skiff during low tide, and from beach locations where possible. Three 0.25 m^2 quadrats were sampled at each location. Quadrats were placed by randomly tossing the quadrat to three locations from the GPS location for each site. Shrimp burrows and eelgrass turions within each quadrat were counted and recorded. A sediment sample was taken to determine the percent of sand (grain size > 67 microns) at each site. Species composition of the shrimp populations was estimated using two methods. While counting burrows, the holes were examined by feel in an attempt to differentiate between burrows of mud and sand shrimp. Mud shrimp build burrows with a slick or smooth wall lining, where as sand shrimp do not. In cases where the "feel" method was not possible, a sub-sample of shrimp (usually ten) was obtained using a shrimp gun, and the species ratios were estimated.

Field/Map Comparisons

The sites in the intertidal rapid assessment survey and shrimp survey were plotted onto the July 1995 eelgrass/habitat map of Tillamook Bay developed by Earth Design Consultants of Corvallis, OR. A version of the habitat map registered to a standard coordinate system was not available at the time of this publication. Therefore, it was not possible to precisely plot the locations and data of sampling sites using GIS technology. Instead, we estimated the position of the sites by eye, using adjacent geographic features as points of reference. We believe that the plotting technique resulted in potential locational errors of ± 20 meters. Coupled with a GPS error of ± 30 meters, we can estimate the site locations to be accurate to ± 50 meters. As a result, our comparisons between field data and the map assume that any habitat type located within a 50-meter radius of the site can provide a potential match to the field observation.

Bay Clam Surveys

Tillamook Bay clam sampling procedures were designed so as to be as consistent as possible with previous surveys. Procedures described by Hancock *et al.* (1979) were followed for the collection of subtidal and intertidal clam abundance estimates with some modifications. Habitat classifications were modeled after the Cowardin *et al.* (1977) system of habitat classification. Statistical design followed those used by the Canadian Department of Fisheries and Oceans to assess manila clam (*Tapes philippinarum*) densities in British Columbia (Gillespie *et al.* 1995; Kronland *et al.* 1995).

Four intertidal sites and three subtidal sites were sampled (Figure 1 and Table 1). Our goal was to sample intertidal and subtidal sites with a minimum of four quadrats per hectare. We used a modified two-stage random sampling plan made up of first stage sampling unit transects (FSU) and second stage sampling unit stations (SSU) for sampling clams in both intertidal and subtidal sites (Figure 2 and 3). A 'best fit' baseline was designated along one edge of an identified clam bed. The baseline was divided up into N possible one-meter wide FSU transects. Proportional to the area of each site, n of the N possible FSU transects were randomly selected perpendicular to the baseline. Each FSU was divided up into M possible one-meter square SSU stations or quadrats. Larger sites were allocated more FSUs or strips. Within the site, we tried to distribute an equal number (m) of quadrats (SSUs) within each strip (FSU). Within the first section from the baseline the first SSU station was randomly selected. All SSU stations that followed on the FSU transect were systematically placed at the distance of each section from the first randomly placed SSU station. Because starting locations of FSUs were random, we assumed a random distribution of FSUs, even though all subsequent stations after the random starting point were located systematically.

Intertidal Clam Sampling

We began sampling intertidal sites up to two hours before low tide. Baselines were established using 100-meter tapes. The tape was placed parallel to the waterline in a best-fit position to form a straight baseline on the shoreward side of the site. Starting points of FSU transects were marked along the baseline with flagging tape. Another meter tape was anchored at the starting point and laid out following a perpendicular compass course from the baseline down the beach towards the water. We started sampling at the closest station to the waterline to maximize use of the low tide. Using 0.1 m^2, 0.25 m^2 quadrats nested in the lower left corner of the 1 m^2 quadrat, each SSU station on each FSU transect was sampled. The entire 1 m^2 quadrat was first examined for gaper necks or holes. Within the 0.25 m^2 quadrat, eelgrass, and shrimp burrows were counted, and the percent algae cover estimated. Sediment within the 0.1 m^2 quadrat was removed to a depth of 25 cm and sieved through a 3 mm mesh screen to sample for newly settled clams or 'set.' The entire 1 m^2 quadrat was then raked to a depth of 36 cm for adult surface-dwelling clams such as cockles, littlenecks, and butters. Some intertidal sampling sites had SSU stations added to the lower portions of the beach in the field. These sites were stratified into upper and lower sections, each with a distinct sampling effort.

Subtidal Clam Sampling

Layout and selection of subtidal sampling stations followed a modified version of intertidal station selection methods. We identified each subtidal site using the TNEP eelgrass/habitat map overlaid with a UTM coordinate grid. Sampling began with locating the corner of each station with the Garmin 45® GPS receiver and marking it with a heavy, buoyed anchor. A baseline was established by towing a floating line with buoy attached behind the vessel from the corner buoy along the predetermined compass course. The length of the towed line was modified to match the required distance between random FSU transect starting positions. We oriented the baselines of subtidal sites S1 and S3 perpendicular to the channel while the baseline of site S2 was placed parallel to the main navigation channel in the lower portion of the bay to avoid creating a navigation hazard. starting positions. SSU stations within a FSU transect were placed in a similar manner by towing the buoyed line in a compass course perpendicular to the baseline. The first randomly placed SSU station was marked followed by each systematically located station.

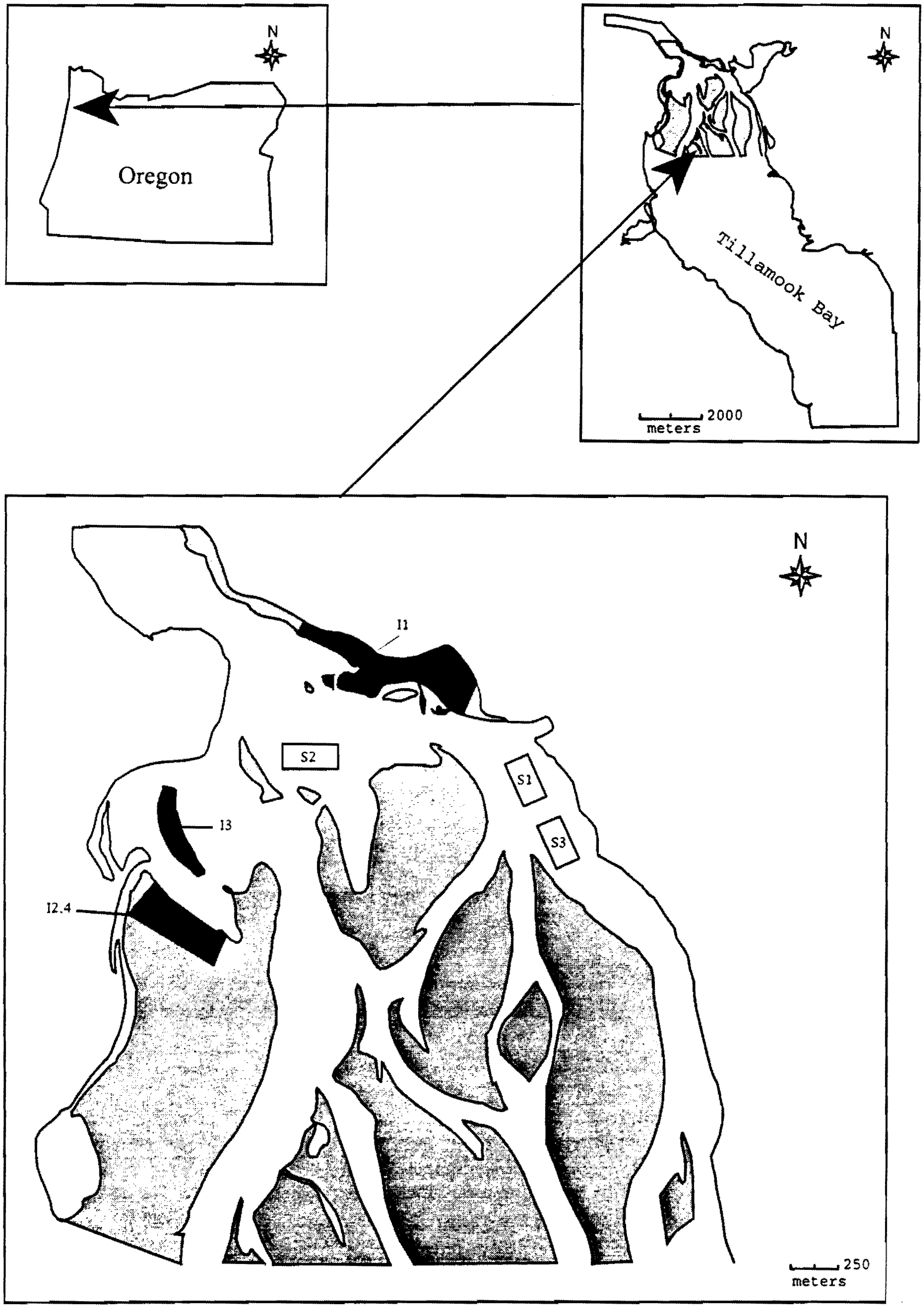


Figure 1. Approximate locations of 1996 Tillamook Bay intertidal and subdital sites. Intertidal sites (I) are shaded and subtidal sites (S) are indicated in rectangular outline.

Table 1. Tillamook Bay site sizes and number of sampling stations per hectare at each site. "I" indicates intertidal sites, and "S" indicates subtidal sites.

Sample Site	Location	Sample Site Size (hectares)	Stations Per Site	Stations Per Hectare
I1-1	Garibaldi Flat	4.46	19	4.3
I1-2	Garibaldi Flat	1.93	10	5.2
I1-3	Garibaldi Flat	4.96	17	3.4
I1-4	Garibaldi Flat	5.18	31	6.0
I2	Crab Harbor	6.00	31	5.2
I3	Crab Harbor	1.00	9	9.0
I4	Crab Harbor	1.50	16	10.7
S1	Hobsonville Point channel	4.50	24	5.3
S2	Garibaldi Flat channel	4.50	24	5.3
S3	Ghost Hole	4.50	24	5.3
averages		3.85	20.5	6.0

At each sample station the dive vessel was anchored as close as possible to the buoy marker. A venturi suction pump dredge was lowered to the substrate and the position marked using both a Garmin 45® GPS receiver and a Corvallis Microtechnology (CMT)® receiver with differential capabilities. Two SCUBA divers dove on the station, recorded shrimp, vegetation, and substrate type and operated the dredge equipment within a 0.1 m^2 ring. Sediment within the sampling ring was removed to a depth of approximately 25 cm into a basket of 3 mm mesh screen. At a signal from the dredging diver, the 3 mm mesh basket was replaced by one with 2.5 cm mesh. Sediment was dredged from within the ring to a depth of approximately one meter. Both baskets were taken to the surface. Material in the 3 mm basket was placed in a bucket to be sorted for set clams. Material in the larger mesh basket was hand-sorted on deck for adult clams. Sample time and depth were recorded, and the depth was adjusted to mean lower low water (0 datum) using Harbor Master® software for tidal predictions for Garibaldi, OR.

Clam Density and Biomass

Average and total clam density and total clam biomass were calculated using unbiased estimators and variances (Kronlund *et al.* 1995) for two-stage sampling using random selection of FSUs and systematic selection of SSUs. Following Kronlund *et al.* (1995), we assumed for purposes of computation that both sampling stages were simple random sampling without replacement (SRSWOR). FSUs for intertidal samples traversed across the depth gradient and tended to maximize variance of quadrats within strips. Concerns that an artificially small variance component might be introduced by treating systematic SSU samples as simple random sampling should also be minimal. In other words, variances should not be underestimated. It is not known whether or not systematic sampling of subtidal plots would have the same or opposite effect, as FSUs did not go across a depth gradient, but were oriented in the direction of the channel.

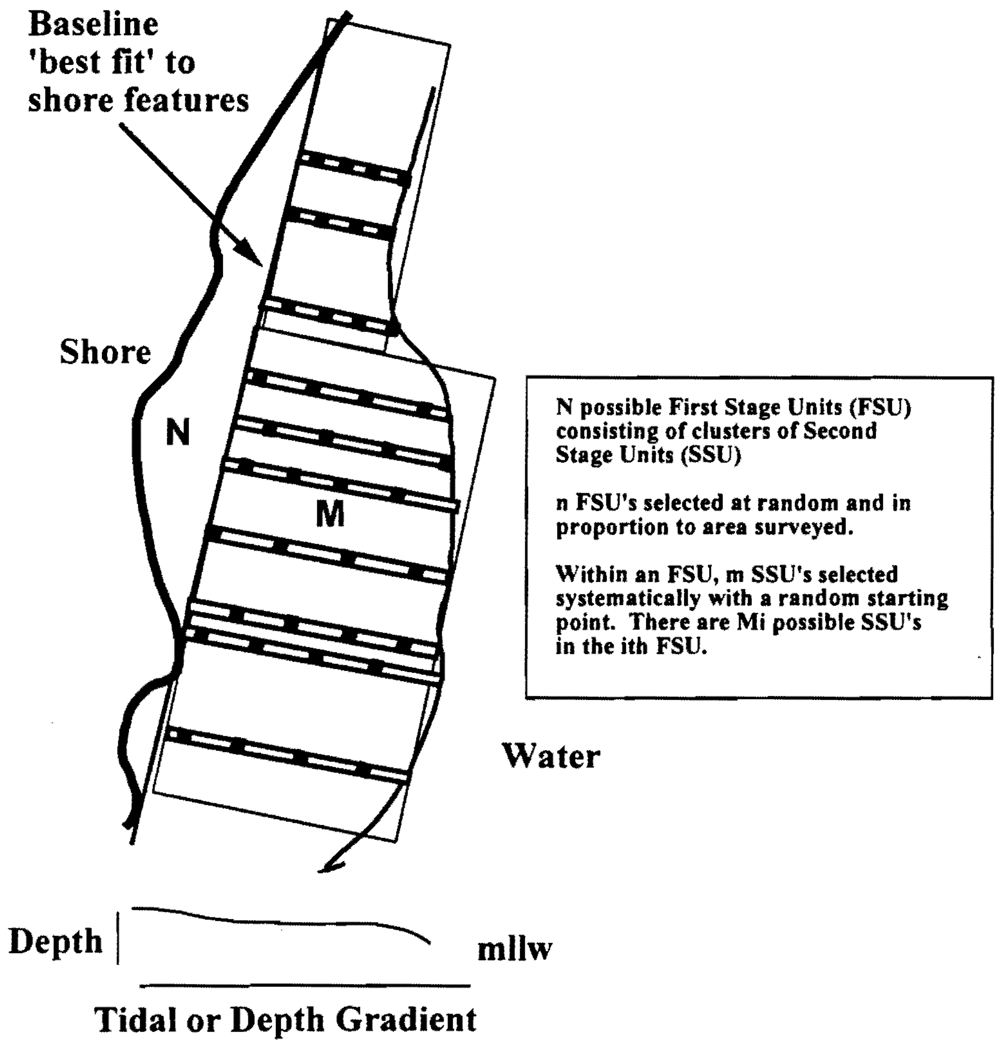


Figure 2. Generalized sampling plan for Tillamook Bay intertidal areas.

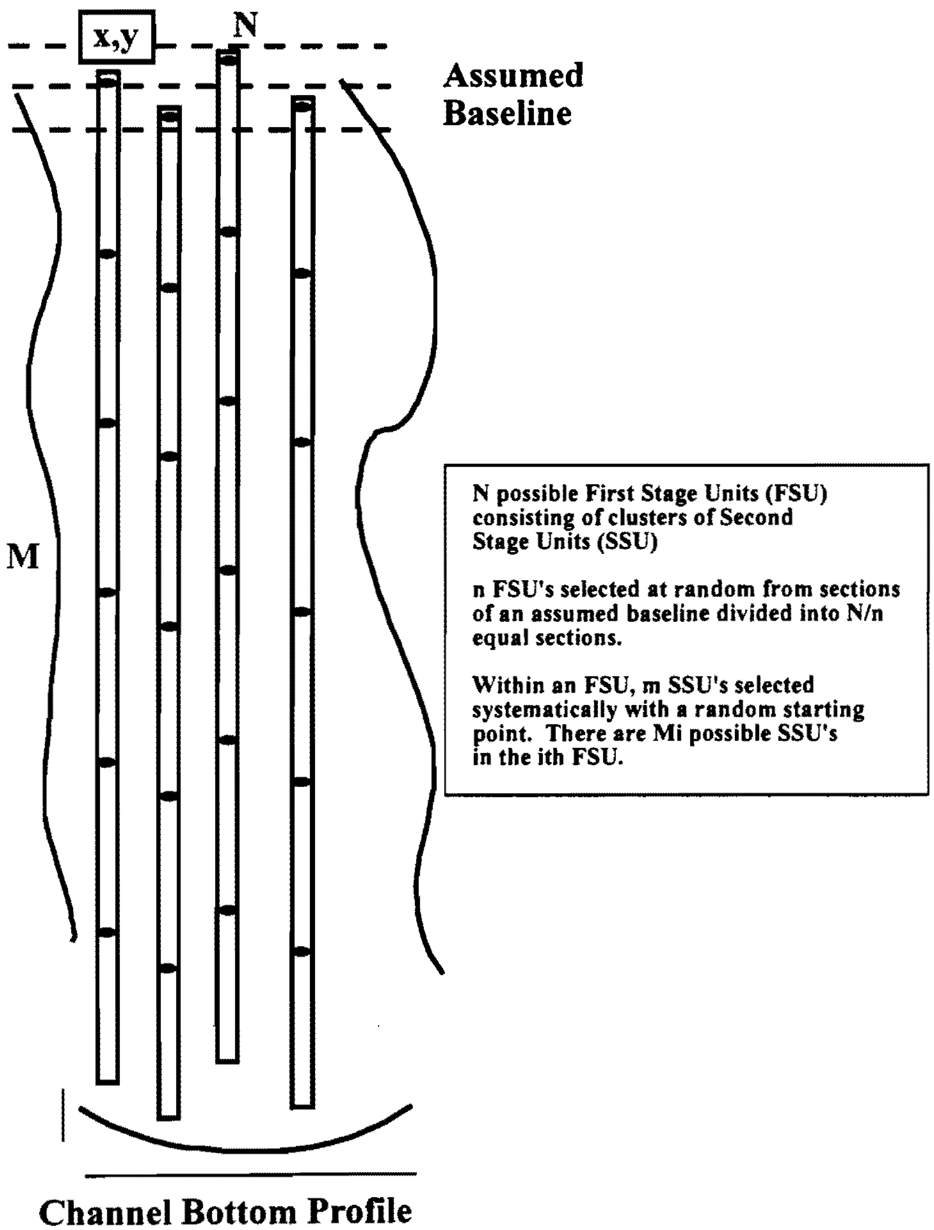


Figure 3. Generalized sampling plan for Tillamook Bay subtidal areas.

Formulas for estimated population mean, total number, total weight, and associated variances used in estimating 95% confidence intervals (CI) follow.

N = the total possible number of FSU's in the plot

n = the number of FSU's randomly selected (strips within plots)

M = the total possible number of SSU's in the plot

M_i = the total possible number of SSU's in the i[th] FSU where i = 1 to n

y_{ij} = the total number or weight of clams in the i[th] FSU and j[th] SSU (quadrat total)

$\hat{y}_{i.}$ = the total number or weight of clams in all j quadrats sampled in the i[th] FSU or strip

$\hat{u}_i$ = the estimated mean number or weight of clams in the plot

$$\hat{u}_i = \left(\frac{1}{n}\right)\sum_{i=1}^{n}\hat{y}_{i.}$$

$\hat{T}$ = the estimated total number or weight of clams in the plot

$$\hat{T} = \left(\frac{N}{n}\right)\hat{y}_{i.}$$

s_b^2 = the variance among FSU totals

$$s_b^2 = \left(\frac{1}{n-1}\right)\sum_{i=1}^{n}\left(\hat{y}_{i.} - \hat{u}_i\right)^2$$

s_i^2 = the variance among SSU's within FSU's

$$s_i^2 = \left(\frac{1}{m_i - 1}\right)\sum_{j=1}^{m_i}\left(y_{ij} - \bar{y}_{i.}\right)^2$$

$V(\hat{u})$ = the variance of the mean number of clams in the plot

$$V(\hat{u}) = \left(\frac{N-n}{N}\right)\left(\frac{n}{n\bar{M}^2}\right)\left(s_b^2\right) + \left\{\left(\frac{1}{nN\bar{M}^2}\right)\sum_{i=1}^{n}\left[\left(\frac{M_i - m_i}{M_i}\right)\left(\frac{s_i^2}{m_i}\right)\right]\right\}$$

$V(\hat{T})$ = the variance of the total number or weight of clams in the plot

$$V(\hat{T}) = N(N-n)\frac{s_b^2}{n} + \frac{N^2}{n}\left[\sum_{i=1}^{n}\left(M_i(M_i - m_i)\frac{s_i^2}{m_i}\right)\right]$$

Upper and lower bounds for the 95% confidence intervals expressed as a percentage of the mean total number and total weight of clams were estimated using the formulas:

$$\hat{u} \pm \frac{1.96\sqrt{v(\hat{u})}}{\hat{u}} \times 100$$

$$\hat{T} \pm \frac{1.96\sqrt{v(\hat{T})}}{\hat{T}} \times 100$$

Biological Sampling

Measurements

All adult clams from each station were measured with calipers to the nearest millimeter across the long axis, parallel to the hinge, and weighed on a top-loading balance to the nearest gram. Cockle clams were an exception to this protocol in that length measurements were taken across an axis perpendicular to the hinge and parallel to the ridges. Commercial-sized clams were defined as follows: gapers > 100 mm, cockles > 50 mm, littlenecks > 40 mm, and butters > 65 mm (Gaumer 1985).

Growth Curves

Growth curves of three of the four commercial species of clams surveyed (butter, cockle, and littleneck) were described using the Von Bertalanffy growth function. A FORTRAN program was used to develop the curve from length and age data. Lengths were collected as described above, and ages were estimated by counting annular rings.

The Von Bertalanffy growth function is defined by the following equation (Ricker 1975):

$$l_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where,

L_∞ = asymptotic length in mm

K = growth completion rate

t = time in years

Recruitment

In both the intertidal and subtidal stations, the top 25 cm of sediment in a 0.1 m^2 sample area was sieved through a 3 mm mesh screen to separate out any juvenile set and small species of clams. Samples were then re-sieved in the lab through a 1cm mesh screen. All clams larger than the 1 cm mesh screen were included in the adult clam data. The < 1 cm portion of the sample was hand-sorted to pick out any small clams. These were preserved by station and identified later. Our species identifications were verified with Susan Weeks of Oikos Co. in Corvallis.

Benthic Grab Survey

The secondary objective of the Tillamook Bay project was to sample the less conspicuous benthic infauna that are important to the ecology of Tillamook Bay's estuarine ecosystem. The total number of samples possible was limited to 75 due to allocation of funds. Our sample design was simplified as consequence, and our efforts directed to obtaining samples from representative gross habitat features of the bay.

Fifteen sites were selected using the TNEP habitat map to represent habitats within the subtidal and intertidal zones of the upper, middle, and lower portions of the bay. Five samples were collected within each site. The five sample locations were randomly placed by positioning a grid of the site within a habitat of interest. Site dimensions were used to create computer-generated, random locations for each of five samples within each site. Sites ranged in size from 30,000 to 160,000 m^2 (Table 2).

Table 2. 1996 Tillamook Bay benthic grab sample site dimensions and sizes in hectares. Site locations are shown in Figure 15.

Area	Dimensions	Area (ha)
G1	300 × 200	6
G2	800 × 175	14
G3	800 × 200	16
G4	800 × 125	10
G5	300 × 100	3
G6	400 × 400	16
G7	400 × 300	12
G8	600 × 250	15
G9	400 × 400	16
G10	400 × 400	16
G11	400 × 400	16
G13	400 × 300	12
G14	400 × 90	3.6
G16	300 × 150	4.5
G17	300 × 150	4.5

In the field, sample sites were located using the pre-determined UTM coordinates and the Garmin 45® GPS receiver. The vessel was anchored as near as possible to the GPS coordinate and allowed to stabilize. Once on the stable location, a true GPS station fix was taken. Time and depth were also recorded. All grab samples were collected during high tide periods to allow for a uniform sampling technique for subtidal as well as intertidal sites.

Benthic samples were collected using a 0.1 m^2 Smith-McIntyre type benthic grab sampler at all but two locations. While anchored over the sample site, the grab sampler was lowered over the side on a davit equipped with a two-speed hand winch. The sampler was lowered slowly to the bottom and allowed to sit on the bottom momentarily to allow the trigger mechanism to spring.

The grab was then winched to the surface slowly and brought on board the vessel. Before processing, the sample was checked to ensure that a good seal had been made and that the sample retained overlaying site water. The sample penetration was measured using a ruler to ensure that an adequate grab depth had been obtained. If a good seal had not been obtained or the penetration inadequate, the grab was rejected and retaken. A penetration depth of ten cm was considered a successful grab; however, if after several grabs, ten cm was not obtainable, a grab depth of less than ten cm was accepted. After acceptance of a grab, sediment type was noted and the sample was emptied into a sieve box with 500 micron mesh Nitrex® screen. The sample was pre-sieved in the field to facilitate sample storage in jars. At two locations in the lower end of the bay, the bottom sediment has a large percentage of shell debris and gravel, preventing the jaws of the grab sampler from closing and retaining a successful sample. At these two stations, samples were collected using scuba equipment and a compressed-air powered airlift dredge developed by ODFW staff. The dredge operated by injecting compressed air into the bottom of the dredge tube, creating a suction to raise the sample into a 500-micron mesh bag affixed at the top of the dredge tube. Sample locations were located using predetermined GPS locations, as were the other benthic grab sites. When the vessel was securely anchored over the sample site, the dredge equipment was lowered to the bottom by divers. The sample was collected from within a 0.1 m^2 sampling frame to a depth of ten cm. The pre-sieved sample was then taken to the surface and processed into storage jars.

For all locations, after sieving the sample through 500 micron screen, the material was placed into sample storage jars. Each sample jar was labeled in the field, both in and on the jar with site number, date, and GPS coordinates. The samples were then preserved in a solution of 10% buffered formalin, rose bengal, and sea water for three days. After three days, the samples were rinsed with water to remove the formalin and stored in 70% isopropyl alcohol until sorted.

Benthic samples were sorted by ODFW staff and Oikos Co. Each sample was rinsed with water to remove preservatives and sorted under the dissecting scope using forceps. Individual organisms were removed and placed into separate vials for polychaetes, molluscs, crustaceans and miscellaneous. These samples were preserved in 70% isopropyl alcohol.

Taxonomy of benthic invertebrates was performed by Marine Taxonomic Services, Corvallis, OR. Information provided by Marine Taxonomic Services included identification and counts of individual taxa and biomass estimates by station. We retained a voucher specimen for each taxon identified (Appendix).

Richness, diversity, and dominance indices were calculated from the data. Richness was calculated as the number of taxa per site. Diversity was calculated using the Shannon-Weaver (H') index (Swartz 1978):

$$H' = \frac{1}{n}\left(N_o \log N_o - \sum_{i=1}^{s} n_i \log n_i\right)$$

n_i = the number of individuals of the *i*th species.

s_o and N_o are the number of species and individuals, respectively, in the sample.

Dominance was calculated using Simpson's diversity index:

$$D = \sum_{i=1}^{s} P_i^2$$

where P_i is the proportion of individuals of the *i*th species that contributes to the total of the sample and s is the total number of species in the community (richness). The resultant value depends on both the species richness and the evenness (equitability) with which individuals are distributed among the species. For a given richness, D increases with equitability, and for a given equitability, D increases with richness (Begon *et al.* 1986).

Project Management

This project was conducted by the following staff of the ODFW:

Program Leader - Shellfish and Marine Habitat	James T. Golden
Project Leader - Shellfish	John A. Johnson
Project Leader - Developmental Fisheries	Jean McCrae
Project Leader - Marine Habitat	David Fox
Assistant Project Leader	David M. Gillingham
Experimental Biological Aides	Vicki Hoover Krutzikowsky Roger Sardiña Steve Hammond

Results and Discussion

Rapid Assessment Survey

The rapid assessment survey consisted of twenty-five intertidal sites and ten 300-600 meter subtidal transects sampled from May-July of 1996. Subtidal surveys revealed that the large subtidal populations of commercial clams were restricted to the lower, northern reaches of the bay. These populations generally occurred north of a line drawn from Hobsonville Point across the bay to the south side of Crab Harbor (Figure 4). Gapers and cockles were found farther up bay on the tide flats and in the channels, however, not in large beds. Softshell clams inhabit the upper part of the bay as well. We concluded that a survey of softshells was out of the scope of the 1996 survey, as they would require sampling areas designed and located specifically for this one species.

In the intertidal surveys, 0.25 m^2, 1 m^2, and 9 m^2 nested quadrats were sampled for clams to gather information on efficiency of different quadrat sizes The 0.25 m^2 quadrats were found to have an average density of 0.5 clams/m^2 ±2.0 (variance), while the 1 m^2 and 9 m^2 quadrats were comparable at 1.4/m^2 ±6.3 (variance) and 1.1/m^2 ±2.3 (variance), respectively. Both the 1 m^2 and 9 m^2 quadrats provided similar estimates of clam abundance, though the 1 m^2 samples had a higher variance. We selected the 1 m^2 quadrat for clam sampling in spite of the higher variance because it was more time- and labor-efficient.

Shrimp Survey

We surveyed shrimp on July 15-19, 1996. Figure 5 shows the 0.25 m^2 counts of both sand (*Neotrypaea californiensis*) and mud shrimp (*Upogebia pugettensis*) burrows combined and the relative proportion of each species' burrows. Shrimp survey results show that sand shrimp occur in most habitats throughout the bay, while mud shrimp occupy habitats primarily within the middle zone of the bay. In our other surveys, small numbers of mud shrimp burrows were observed in the muddy habitats in Miami Cove, the intertidal clam survey sites at Garibaldi Flats, and the subtidal clam survey sites in the channels of the lower bay. Mud shrimp were not found south of a line drawn about 245° SE from Goose Point (Figure 4). The figure indicates that burrow densities of both sand and mud shrimp are highest in the middle portions of the bay. More than 75% of the twenty-five stations sampled throughout the bay had shrimp burrow counts in excess of 16/m^2, 50% had counts in excess of 80/m^2, and 25% exceeded 200/m^2.

The relationship between shrimp burrow counts and number of shrimp present varies both spatially and temporally for sand and mud shrimp (Dumbauld 1994). Dumbauld found that there are fewer burrows per individual *Neotrypaea* in more exposed locations, and that the burrow-to-shrimp relationship varies from state to state for both species. In light of these seasonal and locational variances, Dumbauld suggests surveying the burrow-to-shrimp relationship for each locale in order to use burrow counts for estimating shrimp density, especially *Neotrypaea,* accurately.

Our shrimp burrow survey was conducted during five consecutive days so seasonal variance in the burrow-to-shrimp relationship was not a factor. The sites ranged throughout the bay reflecting a wide range of salinity, sediments, elevations, and vegetation. The sites had from 17-100% sand and fell both within and outside of eelgrass beds. We did not collect data on actual shrimp densities by excavation and removal in Tillamook Bay, so the effect of these environmental variables on the burrow-to-shrimp relationship is unknown. Differences in burrow densities from site to site may not reflect proportional differences in shrimp density.

Field/Map Comparisons

We compared shrimp and intertidal rapid assessment survey field data on eelgrass, benthic macro algae, and sediment type to the data found on the habitat map. Figure 6 shows the sites where comparisons were made. Table 3 outlines eelgrass densities, algae cover, and sediment type found at each shrimp site in the field, compared to what is described by the eelgrass map for the same area. Table 4 outlines the same information for each site in the intertidal rapid assessment survey. Out of 58 sites, there were 58 comparisons of eelgrass densities, 26 comparisons of percent algae cover, and 53 comparisons of sediment

Of the 58 eelgrass comparisons, 55 (95%) were accurate within the scope of our mapping procedure (locational error of ±50 meters). Three (5%) sites did not concur. At site SS3, 0-39 turions/0.25m^2 were counted in the field, but there were no dense eelgrass beds within 100 meters on the map. Site SS24 had 21-41 eelgrass turions/0.25m^2 in the field. The closest eelgrass beds were within 70 meters. Site RI 17 had 9-22 eelgrass turions/0.25 m^2 and the closest eelgrass bed was 60 meters away. *Zostera marina* was the species of eelgrass most commonly observed. At sites RI 14, 20, 23, and 24, *Zostera japonica* was observed and has been noted with a purple 'J.' At all of these sights the *Z. japonica* was on the shore side of the site.

Comparisons between percent algae cover found in the field and the eelgrass/habitat map were drawn at 26 of the intertidal rapid assessment sites. All of these concurred except for three sites, which had sparse algae in the field and no algae described on the map within 100 meters of the GPS location.

Comparisons of 53 sediment descriptions were possible. Of these, 33 sites were analyzed in the field for a percent sand content, and 20 sites were rated qualitatively for sand, mud, shell, gravel, cobble, bedrock, and debris presence. Forty-three (81%) of the total 53 sediment comparisons did concur. The remaining ten (19%) sites did not concur. The mean percent sand found at the seven sites mapped as mud/sand was 78% with a variance of 438.5. The mean percent sand found at the five sites mapped as sand/gravel was 97% with a variance of 8.3. Of those sites described qualitatively, about 80% of the descriptions were in agreement. All of the sites that the map depicted as only mud/sand (tan color) were found in the field to range from 32% - 98% sand. Sites that the map depicted as only sand/gravel (white color) were found in the field to range from 17% - 100% sand. The wide range of percentages of sand in the field for the mud/sand depicted sites on the map could reflect the occurrence of thin layers of mud and silt being deposited over a sand substrate at some sites. It also must be taken into account that sediments in Tillamook Bay are mobile, and in the winter of 1995-96 heavy flooding occurred that could have made dramatic changes in the sediment distribution. When placed on the map using their GPS-derived coordinates, seven intertidal sampling sites appeared to be located in channel areas.

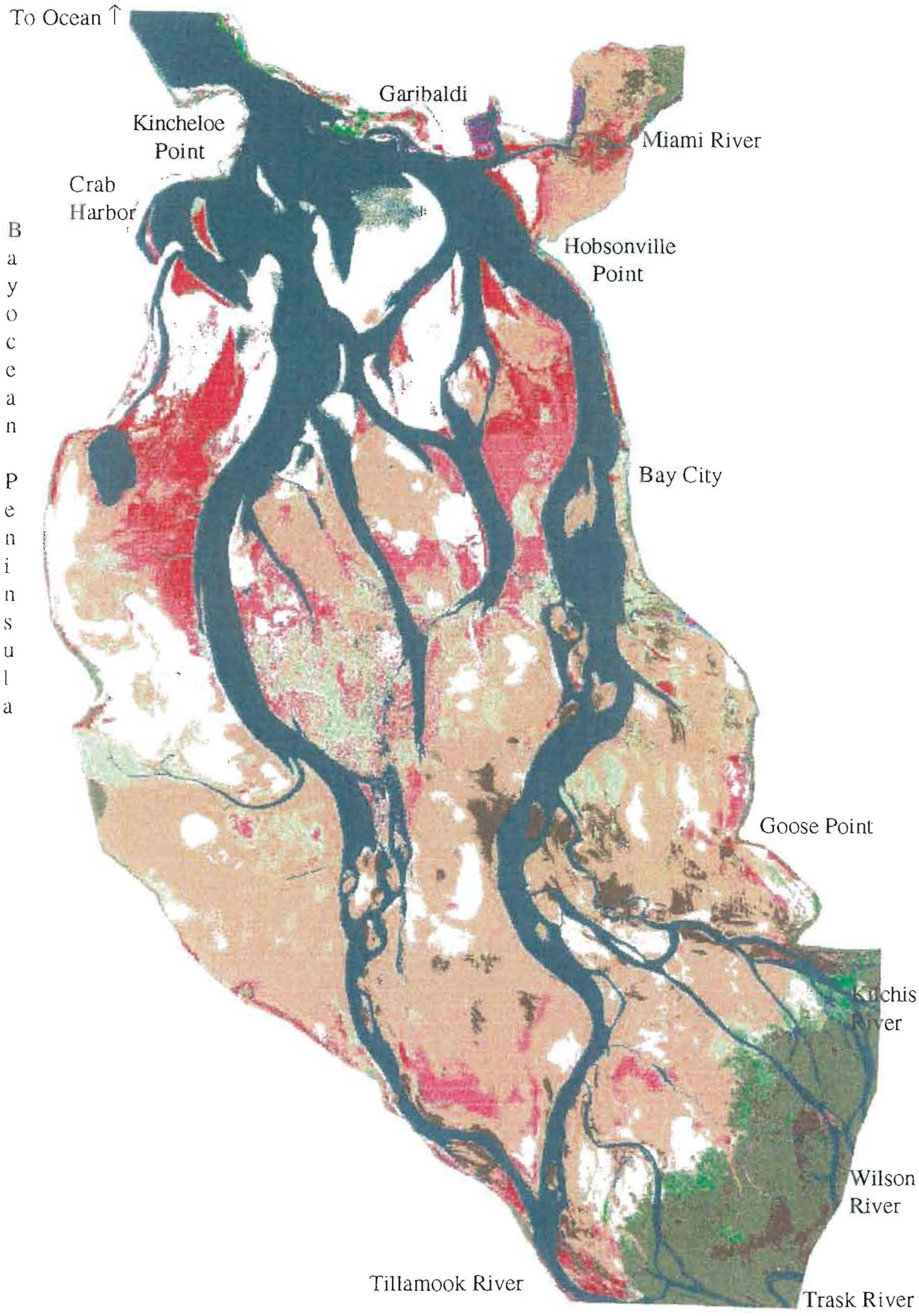


Figure 4. Location names of prominent physical landmarks in Tillamook Bay.

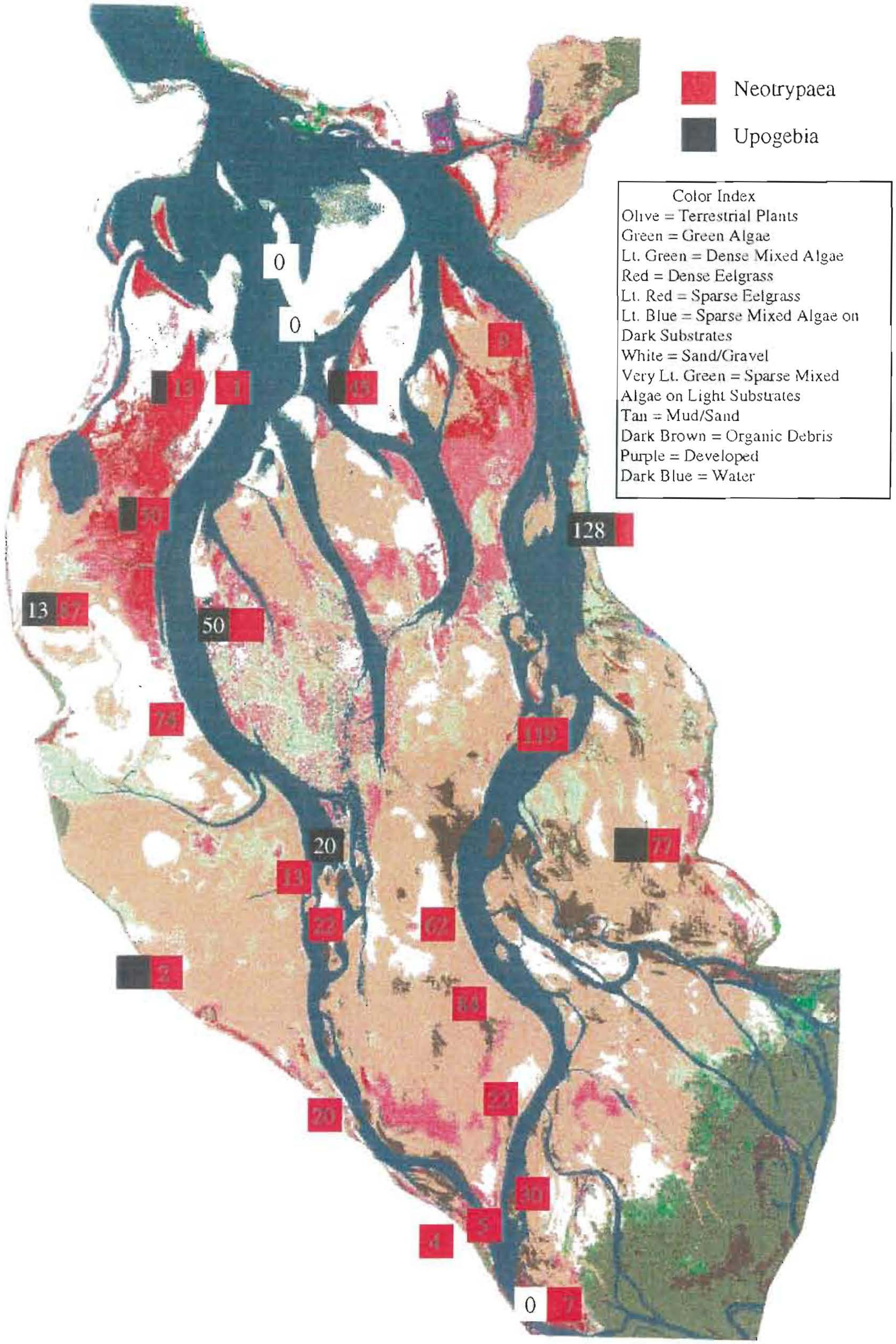


Figure 5. Mean shrimp burrow counts per 0.25 m² for 25 shrimp survey stations in Tillamook Bay. The colors red and black indicate estimated proportions of *Neotrypaea californiensis* to *Upogebia pugettensis*, respectively.

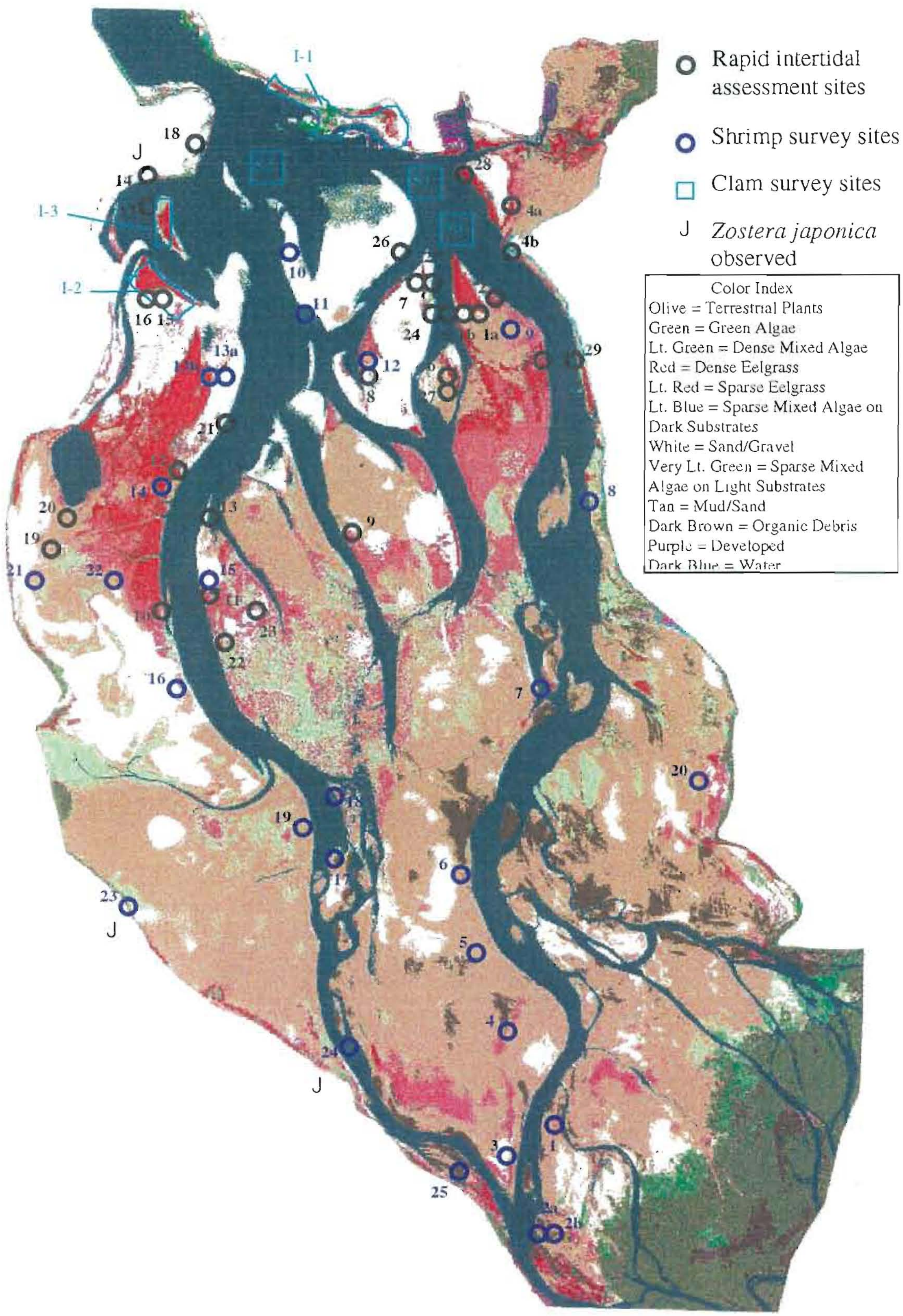


Figure 6. Approximate locations of 1996 Tillamook Bay habitat data sites from the intertidal rapid assessment survey, shrimp survey and clam surveys. See Tables 3 and 4 for comparisons of habitat described by field data and map for each site.

Table 3. Comparisons of eelgrass densities, % algae cover, and observed sediment from 1996 ODFW Tillamook Bay shrimp survey with 1995 Earth Design Consultants multi-spectral eelgrass/habitat map.

SITE	EELGRASS TURION (range)	MAP DESCRIPTION OF EELGRASS (10m radius)	% ALGAE	MAP DESCRIPTION OF ALGAE (10m radius)	FIELD SEDIMENT	MAP DESCRIPTION OF SEDIMENT (10m radius)
SS1	0	0-SPARSE EELGRASS	n/a	NO ALGAE	98% sand	MUD/SAND
SS2A	0	NO EELGRASS	n/a	NO ALGAE	93% sand	MUD/SAND, ORGANIC DEBRIS
SS2B	0	0-SPARSE EELGRASS	n/a	NO ALGAE	n/a	ORGANIC DEBRIS, MUD/SAND
SS3	0-39	0-SPARSE EELGRASS	n/a	NO ALGAE	73% sand	MUD/SAND, SAND/GRAVEL
SS4	0	0-SPARSE EELGRASS	n/a	NO ALGAE	80% sand	MUD/SAND, ORGANIC DEBRIS
SS5	0	NO EELGRASS	n/a	NO ALGAE	85% sand	MUD/SAND
SS6	0	NO EELGRASS	n/a	NO ALGAE	100% sand	MUD/SAND, ORG DEB, SAND/G
SS7	0	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	93% sand	MUD/SAND, ORGANIC DEBRIS
SS8	0	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	88% sand	MUD/SAND, ROCK
SS9	0	SPARSE-DENSE EELGRASS	n/a	NO ALGAE	97% sand	MUD/SAND
SS10	0	NO EELGRASS	n/a	NO ALGAE	97% sand	SAND/GRAVEL
SS11	0	N/A, POINT ON WATER	n/a	N/A, POINT ON WATER	98% sand	N/A, POINT ON WATER
SS12	0-8	0-DENSE EELGRASS	n/a	NO ALGAE	83% sand	MUD/SAND, SAND/GRAVEL
SS13A	0	NO EELGRASS	n/a	NO ALGAE	100% sand	SAND/GRAVEL
SS13B	18-28	0-DENSE EELGRASS	n/a	0-DENSE ALGAE	93% sand	SAND/GRAVEL, MUD/SAND
SS14	8-15	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	92% sand	MUD/SAND
SS15	0	0-SPARSE EELGRASS	n/a	0-SPARSE ALGAE	93% sand	SAND/GRAVEL
SS16	0	0-SPARSE EELGRASS	n/a	0-SPARSE ALGAE	83% sand	SAND/GRAVEL, MUD/SAND
SS17	0-10	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	92% sand	MUD/SAND, SAND/GRAV, ORG
SS18	10	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	92% sand	N/A, POINT ON WATER
SS19	0	0-SPARSE EELGRASS	n/a	0-SPARSE ALGAE	98% sand	MUD/SAND
SS20	0-6	NO EELGRASS	n/a	0-SPARSE ALGAE	77% sand	MUD/SAND
SS21	0	0-SPARSE EELGRASS	n/a	0-SPARSE ALGAE	32% sand	MUD/SAND
SS22	0	0-SPARSE EELGRASS	n/a	0-SPARSE ALGAE	98% sand	MUD/SAND
SS23	0	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	17% sand	SAND/GRAVEL
SS24	21-41	NO EELGRASS	n/a	0-SPARSE ALGAE	47% sand	MUD/SAND, SAND/GRAVEL
SS25	0	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	97% sand	ORGANIC DEBRIS, MUD/SAND

Table 4. Comparisons of eelgrass densities, algae cover, and observed sediment from 1996 ODFW Tillamook Bay intertidal rapid assessment survey with 1995 Earth Design Consultants multi-spectral eelgrass/habitat map. S, M, and D stand for sparse, moderate, and dense, respectively.

SITE	EELGRASS TURION (range)	MAP DESCRIPTION OF EELGRASS (10m radius)	% ALGAE	MAP DESCRIPTION OF ALGAE (10m radius)	FIELD SEDIMENT	MAP DESCRIPTION OF SEDIMENT (10m radius)
RI 1a	36-56	0-DENSE EELGRASS	n/a	NO ALGAE	sand	SAND/GRAVEL,MUD/SAND
RI 1b	9-44	0-DENSE EELGRASS	28	0-SPARSE ALGAE	sand/ mud	SAND/GRAVEL,MUD/SAND
RI 2	0	0-DENSE EELGRASS	0	NO ALGAE	sand/ mud	MUD/SAND
RI 3	M	0-DENSE EELGRASS	S	NO ALGAE	sand/ mud	n/a
RI 4a	0	0-DENSE EELGRASS	0	NO ALGAE	gravel/ sand/cobble	MUD/SAND
RI 4b	0	0-DENSE EELGRASS	0	0-DENSE ALGAE	sand/gravel/cobble	ROCKY,SMOOTH, MUD/SAND
RI 5	9	0-DENSE EELGRASS	S	0-SPARSE ALGAE	sand	MUD/SAND, SAND/GRAVEL
RI 6	15-20	0-DENSE EELGRASS	n/a	0-SPARSE ALGAE	sand	MUD/SAND,SAND/GRAVEL
RI 7	9-24	0-DENSE EELGRASS	n/a	NO ALGAE	sand	SAND/GRAVEL, MUD/SAND
RI 8	18-23	0-SPARSE EELGRASS	S	NO ALGAE	sand, mud	SAND/GRAVEL,MUD/SAND
RI 9	35-38	0-SPARSE EELGRASS	S	0-SPARSE ALGAE	sand, mud	SAND/GRAVEL,MUD/SAND
RI 10	18-29	0-DENSE EELGRASS	0	0-DENSE ALGAE	83% sand	n/a
RI 11	11-24	0-SPARSE EELGRASS	0	0-SPARSE ALGAE	83% sand	MUD/SAND
RI 12	14-20	0-DENSE EELGRASS	n/a	0-DENSE ALGAE	90% sand	MUD/SAND
RI 13	S	0-DENSE EELGRASS	n/a	NO ALGAE	100%sand	MUD/SAND, SAND/GRAVEL
RI 14	0	0-SPARSE EELGRASS	0	NO ALGAE	98% sand	SAND/GRAVEL
RI 15	8-25	0-DENSE EELGRASS	S	0-DENSE ALGAE	98% sand	SAND/GRAVEL, MUD/SAND
RI 16	0	0-DENSE EELGRASS	0	0-DENSE ALGAE	100% sand	SAND/GRAVEL, MUD/SAND
RI 17	9-22	NO EELGRASS	M	0-SPARSE ALGAE	sand/shell	SAND/GRAVEL
RI 18	0	0-DENSE EELGRASS	D	0-DENSE ALGAE	sand/gravel/cobble	SAND/GRAVEL,MUD/SAND
RI 19	2-28	0-DENSE EELGRASS	S	0-SPARSE ALGAE	92% sand	MUD/SAND, SAND/GRAVEL
RI 20	7-17	0-DENSE EELGRASS	S	0-SPARSE ALGAE	75% sand	MUD/SAND,SAND/GRAVEL
RI 21	0	NO EELGRASS	0	NO ALGAE	100% sand	SAND/GRAVEL
RI 22	1	0-SPARSE EELGRASS	0	0-SPARSE ALGAE	mud/ sand	SAND/GRAVEL
RI 23	5	0-SPARSE EELGRASS	0	0-SPARSE ALGAE	sand/ mud	SAND/GRAVEL
RI 24	0-12	0-DENSE EELGRASS	0	NO ALGAE	sand	SAND/GRAVEL, MUD/SAND
RI 25	0-19	0-DENSE EELGRASS	1	NO ALGAE	sand/ mud	SAND/GRAVEL
RI 26	0	NO EELGRASS	0	NO ALGAE	sand	MUD/SAND, SAND/GRAVEL
RI 27	2-5	0-DENSE EELGRASS	3	0-SPARSE ALGAE	sand	MUD/SAND
RI 28	26-31	0-SPARSE EELGRASS	S	0-SPARSE ALGAE	sand/ mud	n/a
RI 29	3-18	0-DENSE EELGRASS	M	0-DENSE ALGAE	sand/mud	SAND/GRAVEL, MUD/SAND

Only one of these sites was not within the 50 meter mapping tolerance of an intertidal flat. However, this could reflect some change in the channel sizes over the course of the year or the tide level at the time the map was made compared to when we surveyed.

Earth Design Consultants relayed to us that there was a high probability that the southern portion of the bay would differ from the 1995 map due to flooding in the winter of 1996. Analyzing the sites in a north/south gradient shows that eight of the 12 (66%) most southern sites where sediment comparisons can be drawn had a noticeably different sediment type than was described on the map. Six of those sites had higher percentages of sand than the map, and two sites had lower percentages of sand. This trend changed north of RI 22. Field data at the northern sites concurred with the map in 28 of 33 (85%) sites.

The eelgrass/habitat map was useful for our study to locate eelgrass beds, and from the data we collected, seems to be fairly representative even after a hard winter. The map was also useful for navigating in the bay using GPS waypoints in the channels plotted from the map's UTM grid. The differences apparent in the habitat comparisons could be explained by site plotting error, GPS error, map error, and/or temporal changes in eelgrass, algae and sediment distribution, and density.

Bay Clam Density and Biomass Survey

Quantitative clam sampling of the estuary was confined to six major clam beds. Intertidal sites I1, I2, I3, and I4 were placed in the lower bay in the main clam bearing habitats. Site I1 spanned Garibaldi Flat and was divided into four separate sections which are represented in the tables as I1-1, I1-2, I1-3, and I1-4. Areas I2 and I4 were combined for statistical purposes as they were adjacent in location and of similar species composition and density. They are referred to as I2,4 when combined in the rest of this report. Three high priority subtidal sites S1, S2, and S3 were identified for dredge survey work in the lower reaches of the bay to provide quantitative estimates of clam abundance in the main commercial clam producing areas.

Clam density information is shown in Table 5. Total clam biomass and commercial (gapers > 100 mm, cockles > 50 mm, littlenecks > 40 mm, and butters > 65 mm) clam biomass results for the sample sites are tabulated in Tables 6 through 9. A biomass estimate for gaper clams is available only for subtidal populations. Gapers in the intertidal survey stations were noted by their siphon holes only and were not excavated, thus biomass data are not available. Total commercial clam biomass, within the sampled sites, for gapers, cockles, butters, and littleneck clams was estimated at 546,788 lb., 609,980 lb., 1,983,639 lb., and 211,755 lb. respectively. Tables 10 and 11 compare the subtidal clam densities and biomass estimates, respectively, with past surveys. Included in the table are the results from a preliminary qualitative survey done in 1995 (Griffin, 1995). This survey indicated a stable overall clam population with shifts in each species contribution. The 1995 survey was not intended to be as vigorous as any of the other surveys. It does support the increase in butter clam biomass seen in 1996. Overall, the 1996 survey results indicate an increase in available subtidal clam biomass since the 1974-75 survey. Subtidal surveys conducted in 1974-75 had a total clam biomass of 134,427 pounds per hectare compared to 319,864 pounds per hectare in 1996. The density and biomass estimates for cockles has stayed constant. Littleneck density and biomass estimates are higher than in 1974-75 and about the same as 1984-85 estimates. Gaper density and biomass estimates have decreased since 1974-75, the density has remained the same since 1984-85, while the biomass has increased.

Butter clam estimates have increased in both density and biomass over the past two decades. Increases in the overall clam biomass appear to be largely due to the increased butter clam population as well as different survey areas. Unsurveyed areas in the lower Tillamook Bay may approach biomass of known survey areas -- thus the 1996 estimated biomass is conservative.

Recruitment

We observed eight species of clams in set samples. The four commercial species surveyed: butter, cockle, littleneck, and gaper clams, as well as four smaller species: bentnose (*Macoma nasuta*), irus (*Macoma inquinata*), balthic (*Macoma balthica*), and false mya (*Cryptomya californica*). The 1 cm mesh did not create a clean length boundary between set and adult clams since we measured all clams except cockles at the widest point across. For analysis, the upper limits of the set clam data were restricted to clams with a length < 15 mm. All clams from set samples 15 mm or greater were added to the adult clam database. The lower size limits of the adult clam database were restricted to clams with a length greater than or equal to 15 mm. The few clams included with the adults that were less than 15 mm were discarded altogether. Results of set clam densities are shown in Tables 12 and 13. Gapers, cockles, butters, and bentnose set were found in very low numbers in the intertidal sites.

Table 5. Summary of clam densities (clams/m²) of subtidal and intertidal adult (>15 mm) clam stocks, Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the mean #/m². Sampling sites are shown in Figure 1.

		GAPERS		COCKLES		BUTTERS		LITTLENECKS	
Site	Site Size (m²)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)
Subtidal									
S1	45,000	5.42	91.2	8.33	79.3	12.50	156.7	2.50	157.0
S2	45,000	2.50	126.1	18.33	61.2	7.08	89.5	2.92	81.4
S3	45,000	3.33	41.5	26.25	69.7	93.75	48.0	46.25	48.0
Intertidal									
I1-1	44,608	0	0	0	0	0	0	0.46	136.5
I1-2	19,264	0	0	1.67	22.0	0	0	4.00	106.1
I1-3	49,600	0.43	82.9	1.87	164.0	2.90	125.5	10.58	62.6
I1-4	66,500	0.20	199.5	0.72	58.6	0	0	1.28	87.0
I2,4	75,000	0	0	3.50	79.4	0	0	0.75	85.5
I3	10,000	0.22	100.9	1.33	76.1	0	0	0	0

Table 6. Summary of total and commercial biomass estimates for gaper clams in Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the biomass.

Site	Biomass Total (lbs)	CI (%)	Commercial Biomass (lbs)	CI (%)
S1	310,275	81.8	310,275	81.8
S2	129,835	137.9	129,835	137.9
S3	118,571	47.1	106,677	66.6
I1-1	0	0.0	0	0.0
I1-2	0	0.0	0	0.0
I1-3	*	0.0	*	0.0
I1-4	*	0.0	*	0.0
I2,4	0	0.0	0	0.0
I3	*	0.0	*	0.0
Subtidal	558,682	56.5	546,788	58.3
Intertidal	*	0.0	*	0.0
Total	558,682	56.5	546,788	58.3

* Gaper clams were evident at these sites, but no weights were collected. See Table 5 for density data.

Table 7. Summary of total and commercial biomass estimates for cockle clams in Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the biomass.

Site	Biomass Total (lbs)	CI (%)	Commercial Biomass (lbs)	CI (%)
S1	116,010	56.2	116,010	56.2
S2	257,090	62.3	256,057	62.3
S3	219,838	43.9	205,548	43.1
I1-1	0	0.0	0	0.0
I1-2	2,207	21.4	2,207	21.4
I1-3	14,102	168.7	12,065	167.9
I1-4	4,115	73.7	3,480	81.9
I2,4	11,835	57.8	11,688	58.4
I3	2,925	70.7	2,925	70.7
Subtidal	592,938	33.4	577,616	33.5
Intertidal	35,184	71.1	32,364	66.9
Total	628,122	32.0	609,980	32.0

Table 8. Summary of total and commercial biomass estimates for butter clams in Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the biomass.

Site	Biomass Total (lbs)	CI (%)	Commercial Biomass (lbs)	CI (%)
S1	331,016	141.2	331,016	141.2
S2	117,952	130.5	115,226	134.1
S3	1,571,407	31.7	1,537,004	33.5
I1-1	0	0.0	0	0.0
I1-2	0	0.0	0	0.0
I1-3	3,126	101.0	393	200.0
I1-4	0	0.0	0	0.0
I2,4	0	0.0	0	0.0
I3	0	0.0	0	0.0
Subtidal	2,020,374	34.7	1,983,246	35.9
Intertidal	3,126	101.0	393	200.0
Total	2,023,501	35.0	1,983,639	36.0

Table 9. Summary of total and commercial biomass estimates for littleneck clams in Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the biomass.

Site	Biomass Total (lbs)	CI (%)	Commercial Biomass (lbs)	CI (%)
S1	10,242	156.4	10,242	156.4
S2	1,445	84.3	1,445	84.3
S3	201,418	27.5	192,869	27.4
I1-1	256	157.4	94	199.9
I1-2	2,363	88.0	1,991	79.8
I1-3	10,481	66.5	3,032	90.5
I1-4	1,673	75.1	1,288	73.8
I2,4	866	103.7	793	107.8
I3	0	0.0	0	0.0
Subtidal	213,106	27.1	204,557	27.0
Intertidal	15,639	47.6	7,198	47.6
Total	228,745	25.0	211,755	26.0

Table 10. Population in clams per hectare for subtidal surveys done in 1974-75, 1984, 1985, 1995, and 1996.

Clams/hectare	1974-76	1984	1985	1995	1996
Cockle	187,980	219,211	280,003	307,000	173,000
Littleneck	163,293	276,901	258,464	121,000	253,000
Gaper	159,068	36,535	43,077	17,000	44,000
Butter	82,191	196,138	312,311	239,000	531,000
Total	592,532	728,785	893,856	684,000	1,001,000

Table 11. Biomass in pounds per hectare for subtidal surveys done in 1974-75, 1984, 1985, 1995, and 1996.

Biomass (lbs)/hectare	1974-76	1984	1985	1995	1996
Cockle	39,881	25,570	39,568	53,620	37,316
Littleneck	7,903	20,192	18,347	6,055	23,518
Gaper	55,733	20,164	20,866	5,712	47,650
Butter	30,910	1,570	87,510	71,550	211,380
Total	134,427	67,496	166,291	136,937	319,864

Table 12. Summary of commercial set clam densities (mean clams/m²) for subtidal and intertidal sites, Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the mean #/m².

		GAPERS		COCKLES		BUTTERS		LITTLENECKS	
Site	Site Size(m²)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)
Subtidal									
S1	45,000	0	0	2.9	130.0	0	0	852.0	198.4
S2	45,000	22.5	77.0	18.8	71.0	4.2	85.0	15.8	97.0
S3	45,000	0.4	200.0	6.7	73.0	0.4	200.0	10.8	104.0
Intertidal									
I1-1	44,608	0	0	0	0	0	0	0	0
I1-2	19,264	0	0	0	0	0	0	0	0
I1-3	49,600	0	0	0	0	0	0	18.8	86.0
I1-4	66,500	0.5	199.9	1.7	108.1	1.5	133.4	3.5	106.7
I2	60,000	0	0	2.2	107.4	0	0	0	0
I3	10,000	0	0	2.2	100.7	0	0	0	0
I4	15,000	0	0	6.7	103.5	0	0	0	0

Table 13. Summary of non-commercial set clam densities (mean clams/m²) for subtidal and intertidal sites, Tillamook Bay, 1996. 95% confidence intervals are reported as a percent of the mean #/m².

		BENTNOSE		IRUS		BALTHIC		FALSE MYA	
Site	Site Size(m²)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)	Mean #/m²	95% CI (%)
Subtidal									
S1	45,000	0	0	0	0	1.3	128.2	0.8	198.4
S2	45,000	2.9	128.0	0	0	0	0	2.1	156.0
S3	45,000	0.4	200.0	8.3	93.0	0	0	7.5	141.0
Intertidal									
I1-1	44,608	0	0	0	0	6.3	101.3	354.2	47.2
I1-2	19,264	0	0	0	0	1.7	199.9	15.8	113.4
I1-3	49,600	0	0	0	0	2.3	125.0	5.7	69.1
I1-4	66,500	0	0	0	0	23.9	46.7	48.9	65.9
I2	60,000	0	0	2.2	126.8	62.2	68.3	34.2	49.6
I3	10,000	2.2	199.9	20.0	58.7	11.1	79.8	7.8	102.5
I4	15,000	0.8	100.0	0	0	37.5	91.1	5.0	132.9

Growth

Length Frequency

Figures 7-10 compare clam length frequencies of the 1996 survey data with the subtidal 1975 data collected by Hancock *et al.* (1979). The 1996 length frequencies were tested for significant difference from the 1995 data using the Kolmogorov-Smirnov Test (Sokal and Rohlf 1969). All four species were found to have significantly ($p < 0.05$) different length frequency distributions in 1975 and 1996. All species had $n > 100$ except for gapers which had $n = 25$ for the 1996 data.

Length frequencies of gaper, cockle, littleneck, and butter clams showed 1996 populations to be larger in size than clams surveyed during 1974-75. Gaper clams averaged nearly 50 mm larger in 1996 and earlier year classes were scarce or not detected, indicating poor recruitment over the intervening years. Mean clam sizes of all four species were larger than those in the 1975 population, consistent with the size frequencies (Figure 11). Length frequency distributions showed a lack of large clams of all species in the intertidal areas. Conversely, a greater abundance of small adult clams were found in the intertidal, compared with the subtidal (Figure 12). It should be noted that the majority of the samples for each species of intertidal clams comes from the Garibaldi Flat sample area. Recreational clam harvest is very high on Garibaldi Flat, where 400 to 600 diggers have been counted on a single day during the summer-month low tides.

Growth Curves

The Von Bertalanffy growth function was used to calculate growth curves of three of the four commercial species of clams surveyed: butter, cockle, and littleneck. Growth curves were calculated for intertidal and subtidal clams, as well as all clams combined plotting length against age in a FORTRAN program (Figures 13 and 14). There were not enough data on gaper clams to estimate a growth curve. Set clams, as well as adult clams, were included to provide for years zero up to two and resulted in a lower K value and standard errors all around (Table 14). The intertidal data included some clams subsampled for age, but otherwise all clams collected were used as data points. Intertidal clams in the older, larger age groups were not evident in our survey, which is reflected in the growth curves for the intertidal areas only. They are essentially straight lines with the exception of cockles, where a growth plateau is reached. Combining the intertidal and subtidal data results in pulling down the L_{∞} value for cockles and littlenecks, which is a consequence of the intertidal areas having a larger abundance of small clams than the older and larger clams. Conversely, the L_{∞} value for butter clams was pushed up slightly as a result of the slope of the intertidal growth curve which only assessed clams aged from zero to five years. The growth curves did not show a conclusive difference in growth rate between subtidal and intertidal populations, although comparisons remain problematical due to age differences.

Clam Habitat Association

We compared densities among four major commercial and recreational clam species in the different habitat types found during the intertidal and subtidal surveys. Table 15 compares clam densities per m^2 for each habitat type. Habitat classifications are taken from Cowardin (1977). It should be noted however, that there were only nine stations within the intertidal shore habitat and four stations in the subtidal aquatic bed habitat. The shore habitats sampled here occurred in

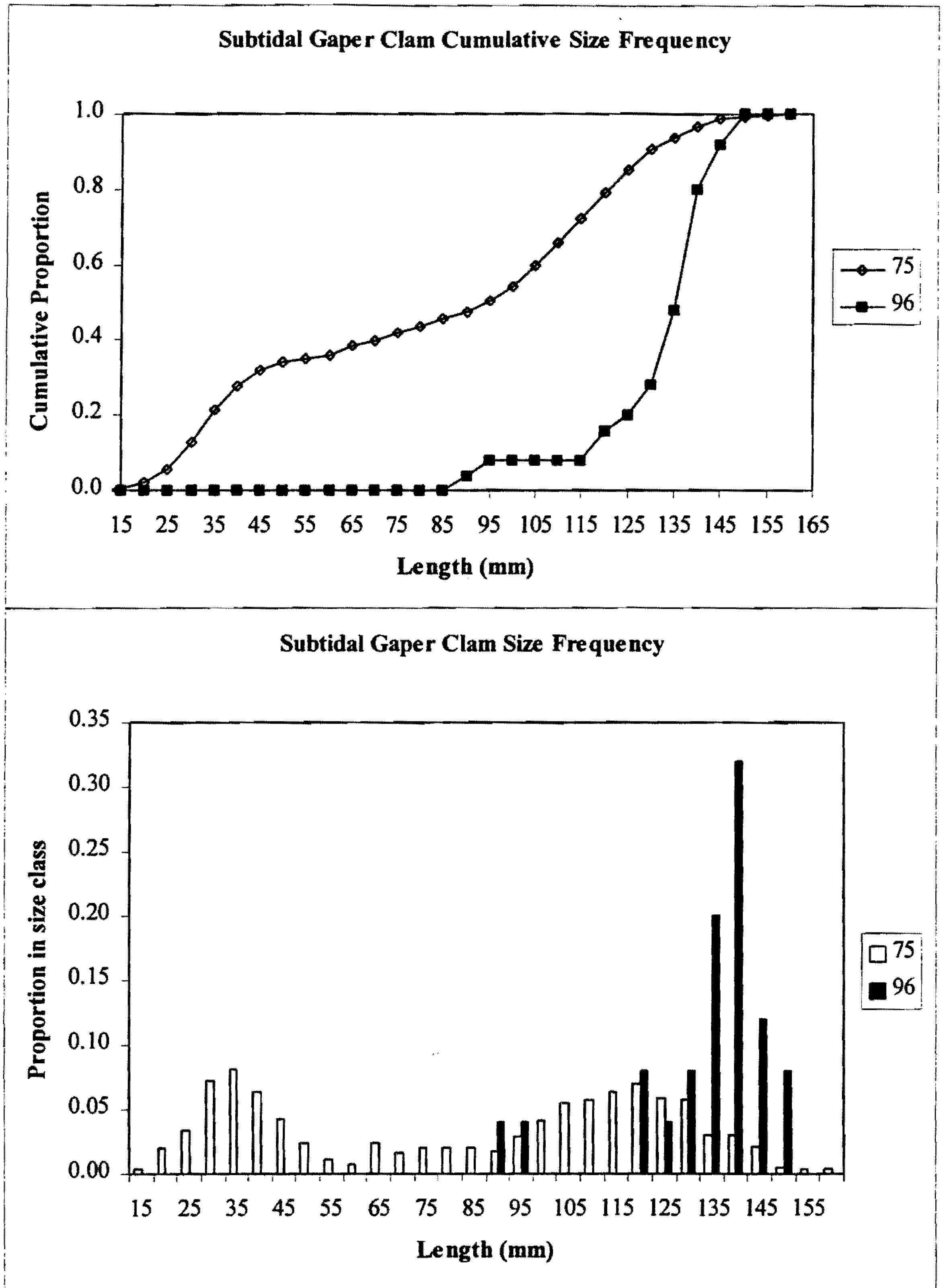
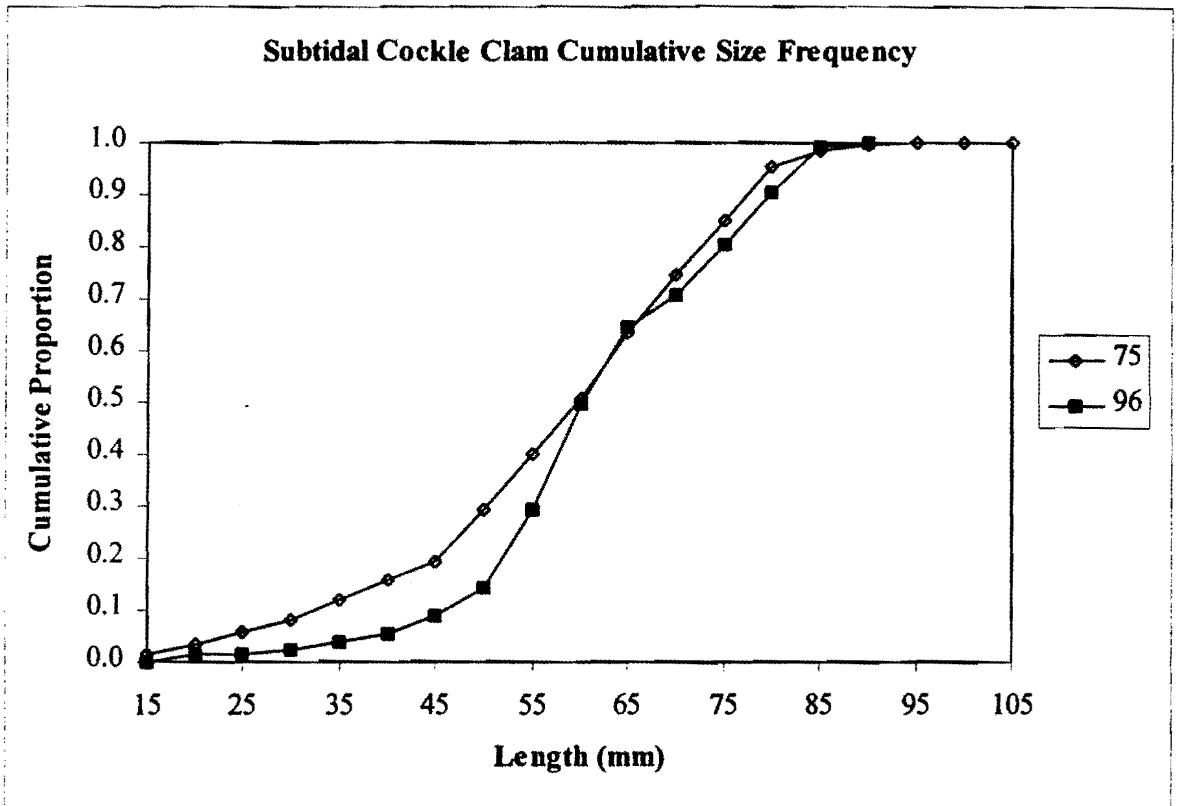


Figure 7. 1975 and 1996 adult gaper clam size frequency. Top figure is a comparison of the cumulative percent of each size class. Bottom figure is a direct comparison of the size frequencies of the 1996 and 1975 data.



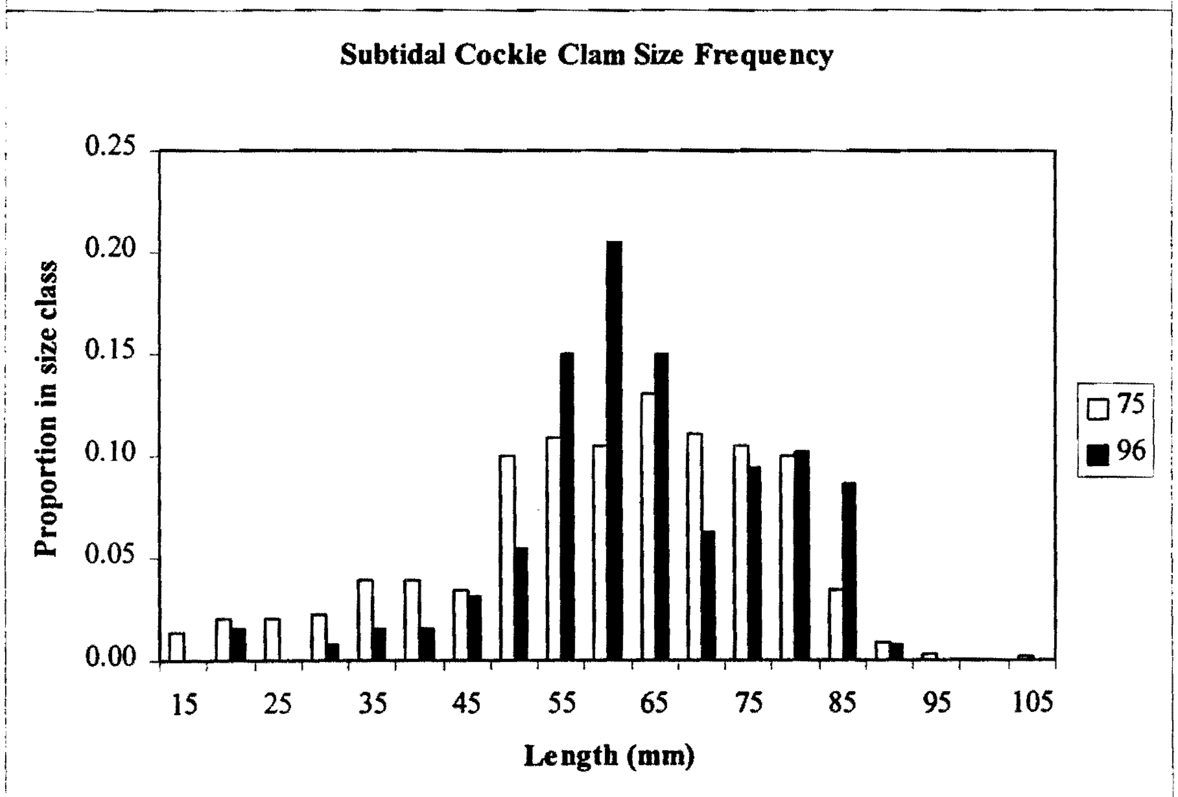


Figure 8. 1975 and 1996 adult cockle clam size frequency. Top figure is a comparison of the cumulative percent of each size class. Bottom figure is a direct comparison of the size frequencies of the 1996 and 1975 data.

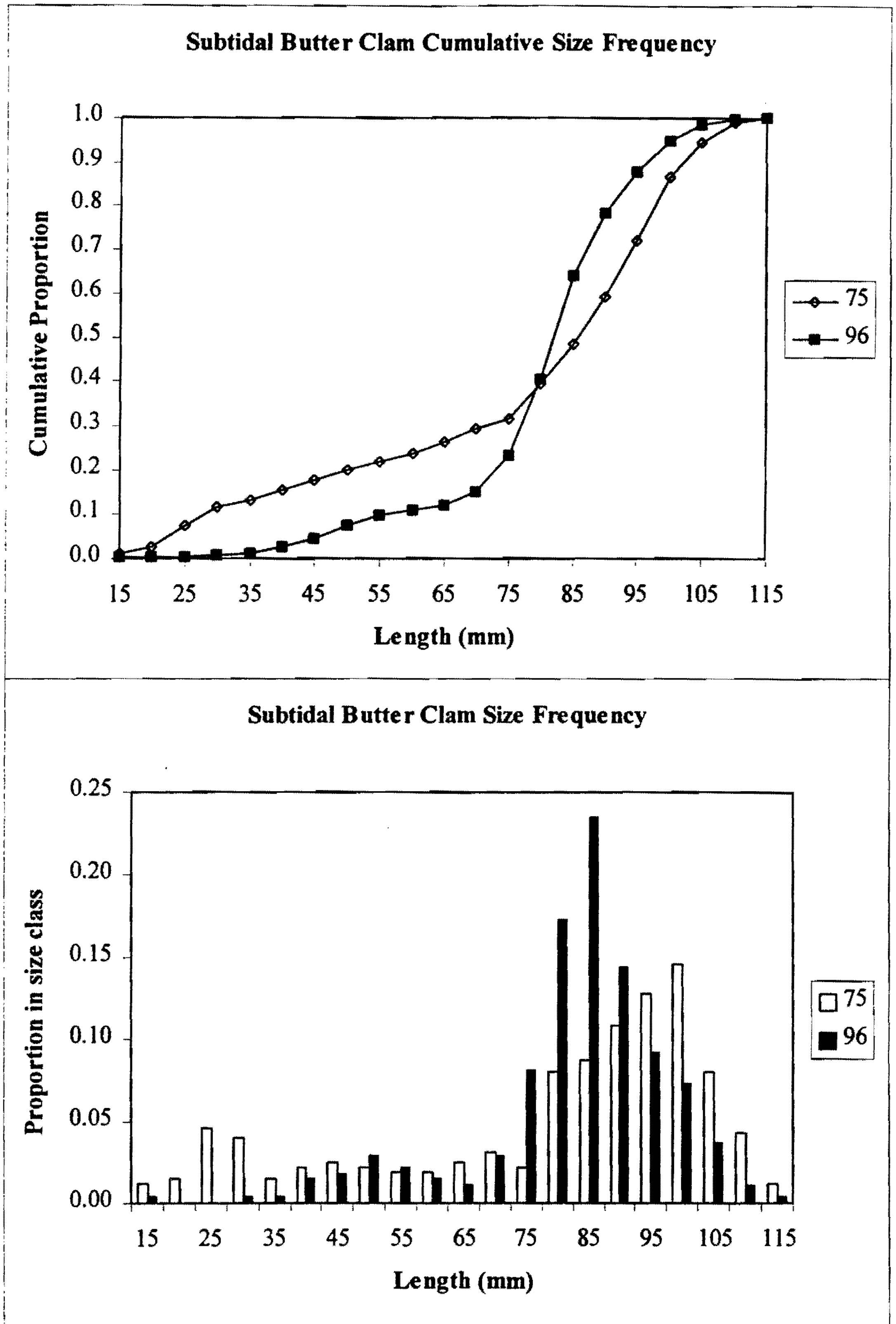


Figure 9. 1975 and 1996 adult butter clam size frequency. Top figure is a comparison of the cumulative percent of each size class. Bottom figure is a direct comparison of the size frequencies of the 1996 and 1975 data.

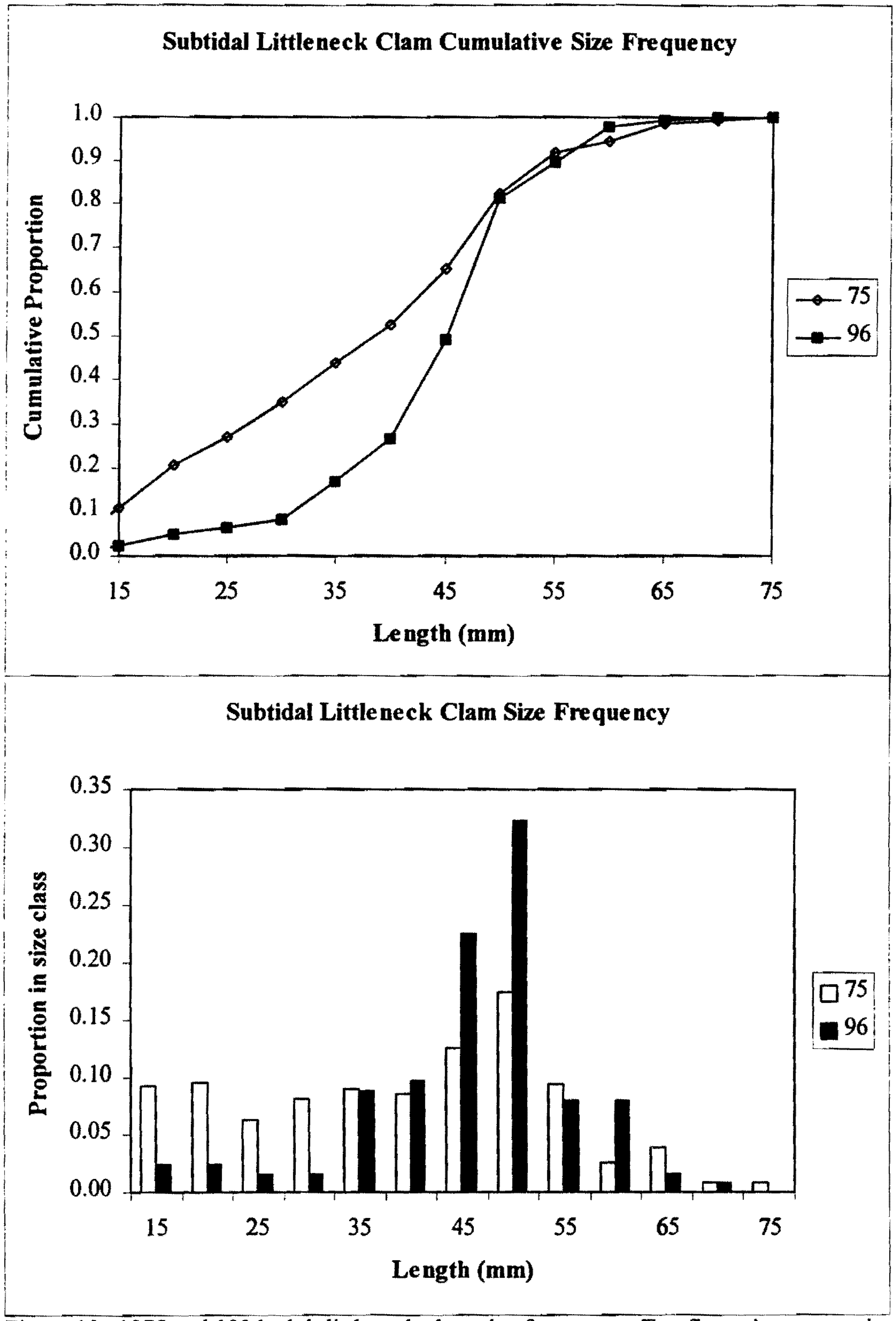


Figure 10. 1975 and 1996 adult littleneck clam size frequency. Top figure is a comparison of the cumulative percent of each size class. Bottom figure is a direct comparison of the size frequencies of the 1996 and 1975 data.

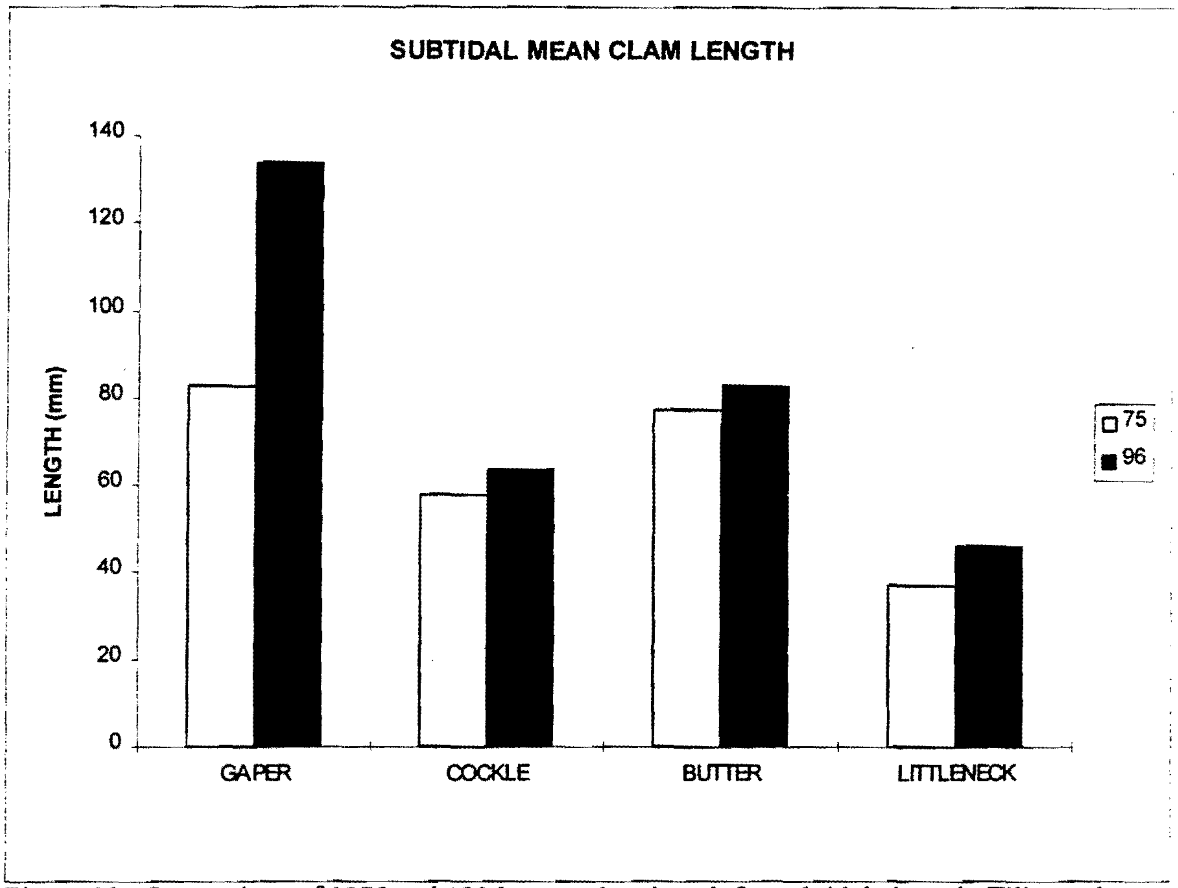


Figure 11. Comparison of 1975 and 1996 mean clam length for subtidal clams in Tillamook Bay.

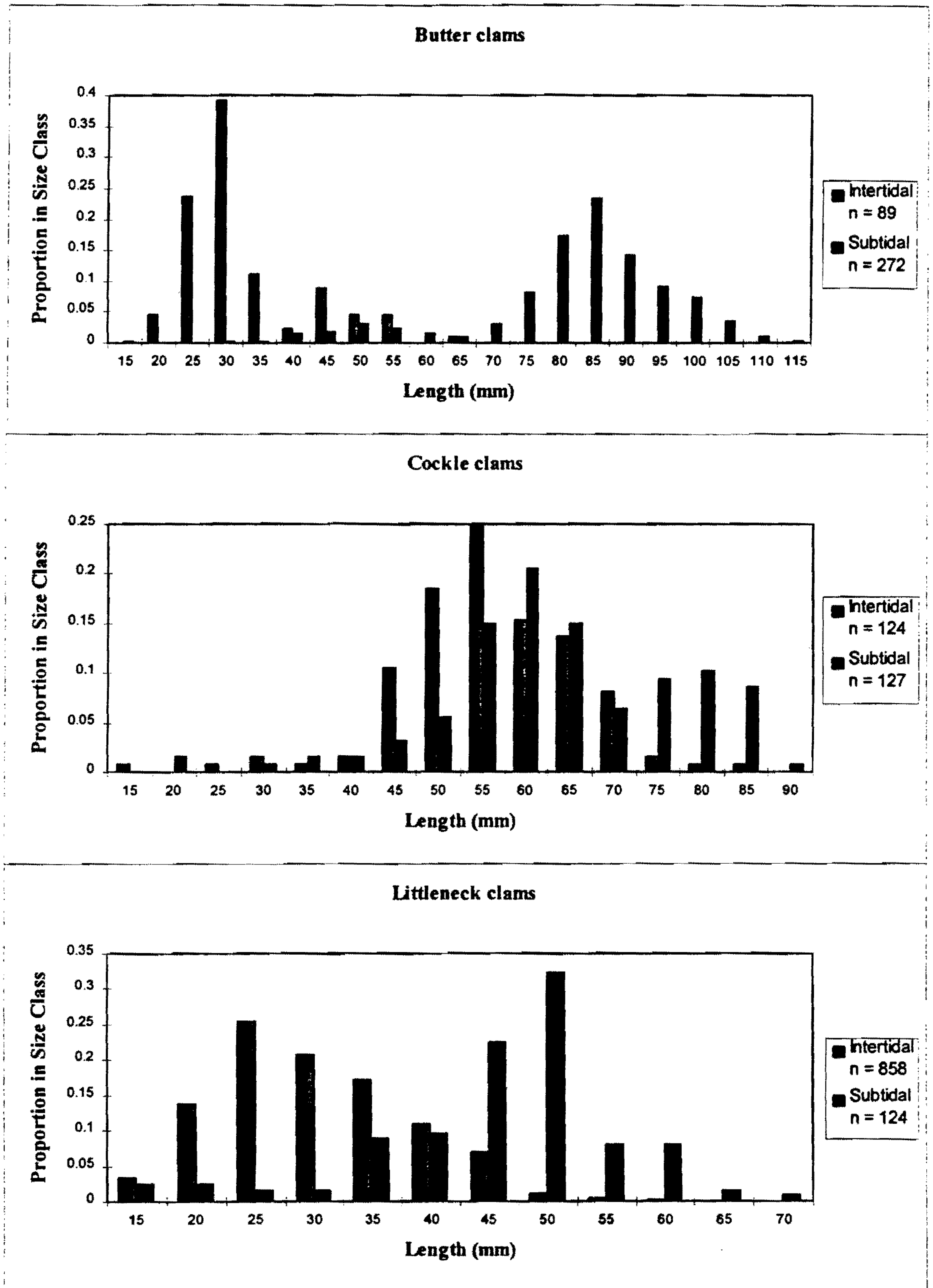


Figure 12. 1996 length frequencies for Tillamook Bay intertidal and subtidal butter, cockle, and littleneck clams.

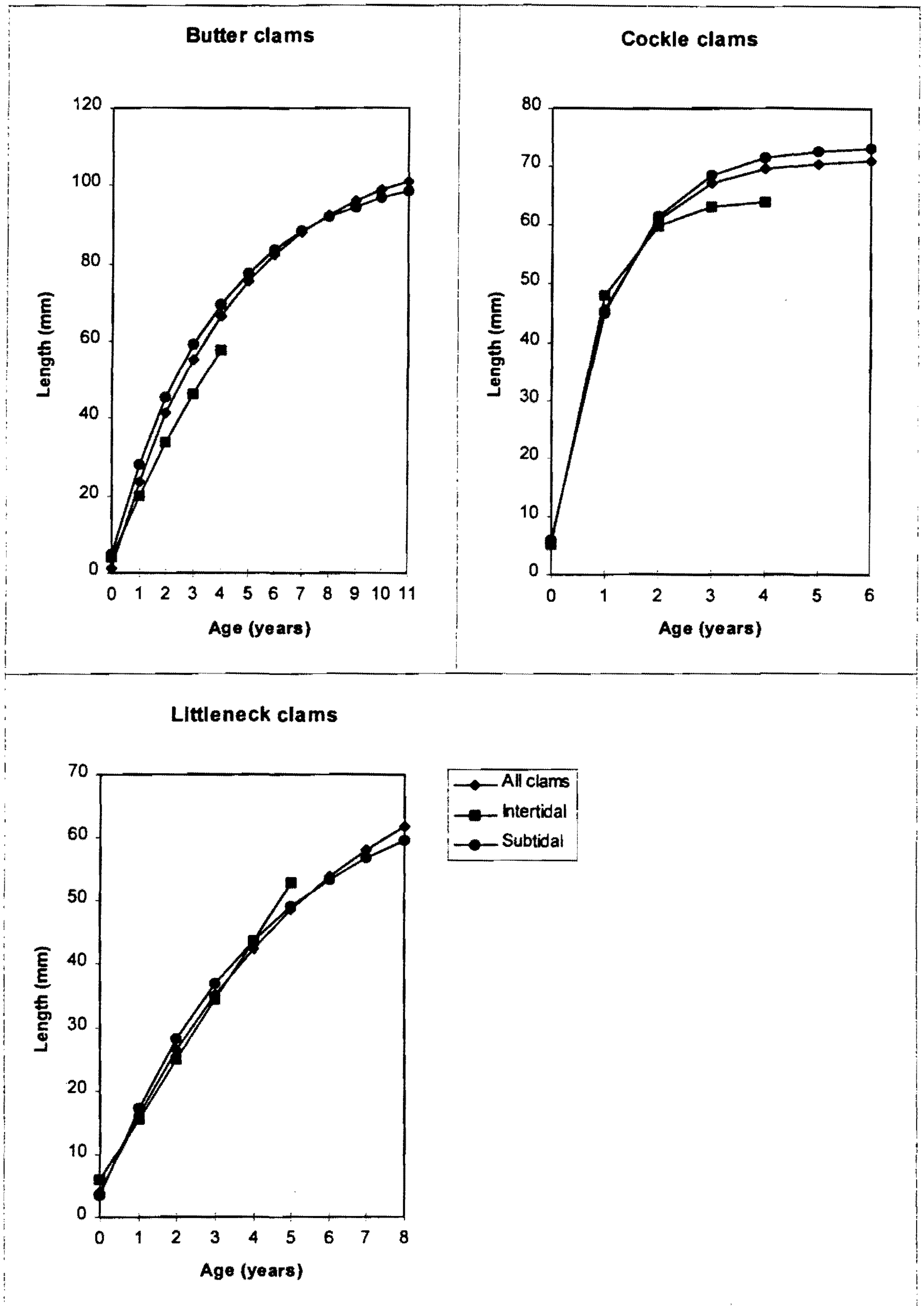


Figure 13. Von Bertalanffy growth curves compared for intertidal, subtidal, and all clams combined.

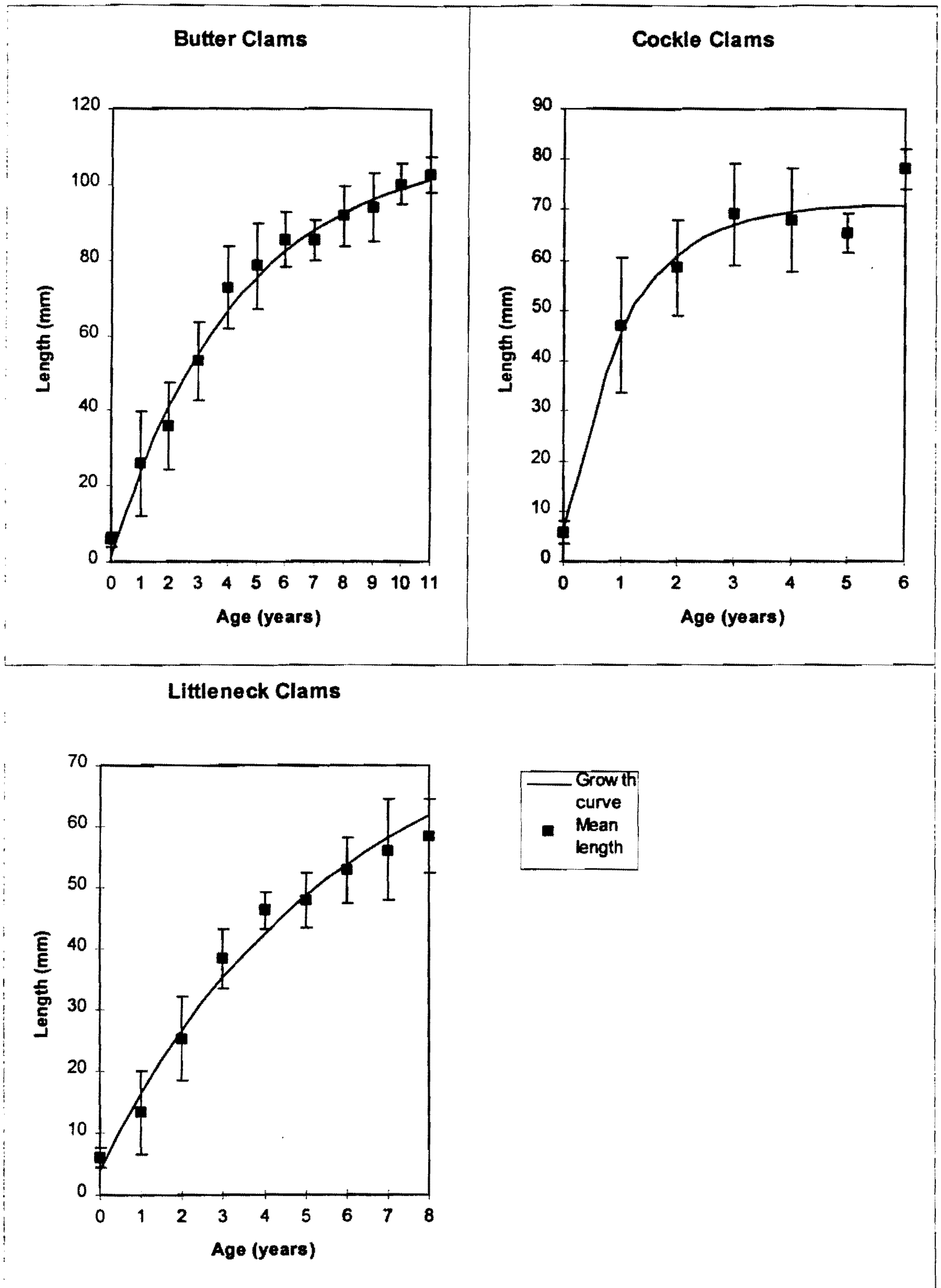


Figure 14. Von Bertalanffy growth curves for three major commercial species found in both intertidal and subtidal areas. The mean of the raw sample data and standard deviations are also plotted.

Table 14. Table of Von Bertalanffy growth curve equation and statistics.

	L (mm)	K	T_0 (years)
Butter Clams	110	0.230	0.955
SE	1	0.071	0.191
Cockle Clams	71	0.935	0.906
SE	6	0.020	0.064
Littleneck Clams	82	0.171	0.701
SE	3	0.019	0.101

Table 15. Comparison of mean clam densities per m² and 95% confidence intervals (%) in sample quadrats for each habitat type.

Habitat	Sample size	Gapers per m²	95% CI (%)	Cockles per m²	95% CI (%)	Butters per m²	95% CI (%)	Littlenecks per m²	95% CI(%)
Intertidal shore	9	0.0	4.9	0.2	29.4	0.0	0.0	0.6	75.5
Intertidal flat	57	0.0	5.7	0.4	30.6	0.1	9.0	1.3	137.5
Intertidal aquatic bed	66	0.2	12.6	1.1	24.6	0.5	63.6	2.5	176.9
Subtidal aquatic bed	4	2.5	79.6	32.5	571.8	5.0	91.9	7.5	79.6
Subtidal unconsolidated	68	3.8	17.3	16.8	56.2	39.7	138.3	17.8	80.6

the Garibaldi Flat sampling area near the estuary entrance. The unconsolidated habitats occurred in the lower bay channels. The unconsolidated sediments consisted of dense sand with large proportions of shell and gravel. As we have already seen, subtidal areas had larger densities of all commercial species of clams. The unconsolidated habitat was especially productive. In the intertidal, the aquatic bed was the most productive habitat for all commercial clam species. Intertidal cockles and littlenecks were found in all three habitats described. The shore habitats were the least productive for all species.

Grab Sampling Results

We collected 75 grab samples at 15 stations between August 15 and September 4, 1996, in Tillamook Bay. Figure 15 shows the approximate locations of each grab station along with a qualitative sediment description. One hundred fifty four taxa were identified, with a total of 79 annelid, 43 crustacean, 27 mollusc, and 6 miscellaneous species (Table 16). Of these, seven were identified as introduced species and 6 as cryptogenic species with unknown origins (Castillo, personal communication, 1997).

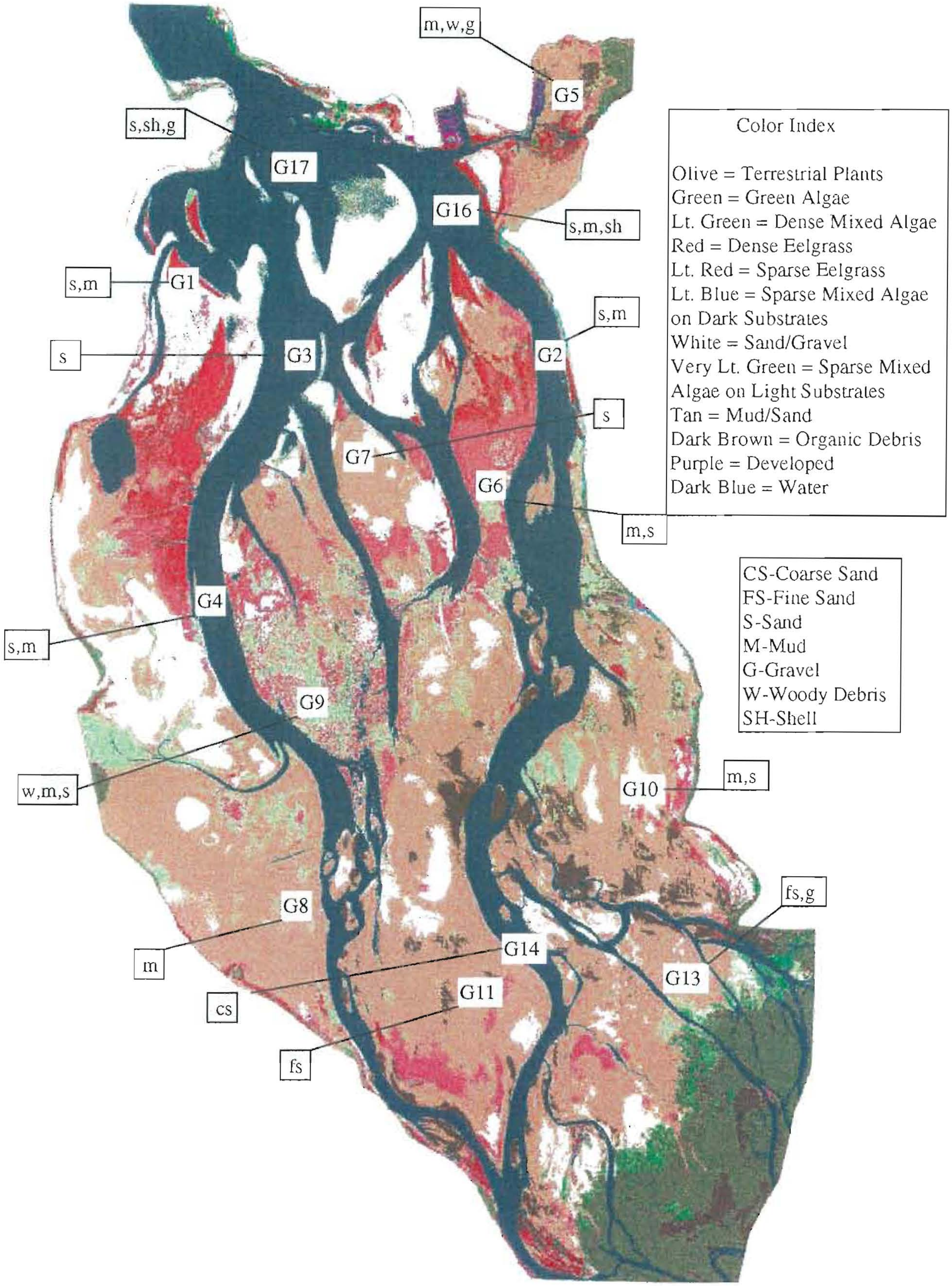


Figure 15. Approximate locations of Tillamook Bay benthic grab samples (G1 through G17) and predominant sediment type.

Table 16. List of species found in grab samples of Tillamook Bay, 1996.

ANNELIDA

Ampharetidae sp. Juv.
Aphelochaeta monilaris
Aphelochaeta sp. Indet.
Armandia brevis
~Capitella capitata 'hyperspecies'
Capitellidae sp. Indet.
Dorvilleidae sp. Juv.
Ehlersia heterochaeta
Eteone sp. Indet.
Eumida longicornuta
Glycera americana
Glycera capitata
Glycera convoluta
Glycera sp. Indet.
Glycinde armigera
Glycinde polygnatha
Glycinde sp. Juv.
~Harmothoe imbricata
Hesionidae sp. Indet.
Hesperone laevis
Heteropodarke heteromorpha
*Hobsonia floridus
Lumbrineridae sp. Indet.
Magelona longicornis
Magelona pitelkai
Magelona sp. Juv.
Manayunkia aesturina
Mediomastus californiensis
Mediomastus sp. Indet.
Micropodarke dubia
Neanthes limnicola
Nephtys caecoides
Nephtys cornuta
Nephtys sp. Juv.
Nereidae sp. Indet.
Nereis sp. Indet.
Nereis sp. Juv.
Notomastus sp. Indet.
Notomastus tenuis
Oligochaeta sp. Indet.
Ophelia limicina
Ophelia sp. Juv.
Opheliidae sp. Indet.
Orbiniidae sp. Indet.
Orbiniidae sp. Juv.
~Owenia fusiformis
Paleonotus bellis
Paraonella platybranchia
Pectinaria californiensis
Pholoe minuta
Phyllodoce hartmanae
Phyllodoce sp. Indet.
Phyllodoce sp. Juv.
Phyllodocidae sp. Indet.
Phyllodocidae sp. Juv.
Platynereis bicanaliculata
Podarkeopsis glabrus
Polychaeta sp. Indet.
Polydora cardalia
*Polydora cornuta
Polydora sp. Juv.
Polynoidae sp. Indet.
Prionospio lighti
Prionospio sp. Indet.
Procerea cornuta
*Pseudopolydora kempi
~Pygospio elegans
Pygospio sp. 1
Pygospio sp. Indet.
Sabellidae sp. Indet.
Scolelepis sp. Indet.
Scoloplos sp. Juv.
Spio sp. Indet.
Spiochaetopterus costarum
Spionidae sp. Indet.
Spionidae sp. Juv.
Spiophanes berkeleyorum
~Spiophanes bombyx
*Streblospio benedicti
Syllidae sp. Indet.

MOLLUSCA

Acanthodoris sp. Indet.
Alvania compacta
Bivalvia sp. Juv.
Clinocardium nuttalli
Clinocardium sp. Juv.
Cryptomya californica
Fartulum occidentale
Gastropoda sp. Indet.
Gastropoda sp. Juv.
Lacuna sp. Juv.
Lacuna vincta
Macoma balthica
Macoma inquinata
Macoma nasuta
Macoma sp. Juv.
Mactridae sp. Juv.
*Mya arenaria
Myidae sp. Juv.
Mysella tumida
Mytilidae sp. Juv.
Nucella canaliculata
Nudibranchia sp. Indet.
Olivella baetica
Protothaca staminea
Saxidomus giganteus
Siliqua sp. Juv.
Tellina sp. Juv.

CRUSTACEA

Achelia sp. Indet.
Ampithoe sp. Indet.
Archaeomysis grebnitzkii
Balanus sp. Juv.
Bathyleberis sp. Indet.
Calanoida sp. Indet.
Cancer magister
Cancer productus
Cancer sp. Juv.
Corophioidea sp. Juv.
*Corophium acherusicum
Corophium spinicorne
Crangon alaskensis
Crangon sp. Indet.
Cumella vulgaris
Cyclopoida sp. Indet.
Decopoda megalops sp. Indet.
Eobrolgus chumashi
Eogrammarus confervicolus
Eohaustorius estuarius
Eohaustorius sp. Indet.
Eohaustorius sp. Juv.
Gnorimosphaeroma oregonensis
*Grandidierella japonica
Grandifoxus grandis
Harpacticoida sp. Indet.
Hemigraspus oregonensis
Hemigraspus sp. Indet.
Heptacarpus brevirostris
Idotea fewkesi
Janiropsis kincaidi
Lamprops quadriplicata
~Leptochelia dubia
Mandibulophoxus gilesi
Neotrypaea sp. Juv.
* Nippoleucon hinumensis
Paguridae sp. Indet.
Pagurus hirsutiusculus
Pantogeneia cf. ivanovi
Parapleustes pugettensis
Tritella sp. Indet.
Upogebia pugettensis
Zeuxo sp. Juv.

MISCELLANEOUS

Anthozoa sp. Indet.
Dendraster excentricus
Nematoda sp. Indet.
Nemertinea sp. Indet.
Ophiuroidea sp. Juv.
Phoronida sp. Indet.

* introduced species
~ cryptogenic species

Data are reported as both count per grab and mean count per station. The Smith-McIntyre grab sampler had a sampling area of 0.1 m^2; therefore, multiplying organisms per grab by ten would translate into number of organisms 'per m^2.'

Numerically Dominant Taxa

The most numerically abundant taxon found was the Oligochaeta spp., making up over 49% of the total animals. The following four dominant taxa were the introduced cumacean *Nippoleucon hinumensis* at 8%; the introduced gamarid amphipod *Grandidierella japonica* at 6%; the introduced spionid polychaete *Pseudopolydora kempi* at 5%; and the polychaete *Capitella capitata 'hyperspecies'* at 4% of the total number of organisms. Eight additional taxa made up 1% each of the total animals: the juvenile gastropod *Lacuna* sp.; polychaete *Glycinde polygnatha*; opheliid polychaete *Armandia brevis*; polychaete *Magelona pitelkai*; polychaete *Mediomastus californiensis*; gamarid amphipod *Eohaustorius estuarius*; Nemertinea spp.; and spionid polychaete *Spiophanes bombyx.*

The Oligochaeta spp. were found primarily in the lower bay, tidal flat stations. The highest densities were found in Miami Cove and Crab Harbor stations, G5 and G1. *Nippoleucon hinumensis* was found only in the tidal flat stations and most abundantly in the Miami Cove station, G5. *Grandidierella japonica* was found almost exclusively in the tidal flat stations and most abundantly in stations G5 and G8 (Figure 16). *Pseudopolydora kempi* was found almost exclusively in the upper bay, tidal flat stations and most abundantly in station G8. *Capitella capitata 'hyperspecies'* was found almost exclusively in the tidal flat stations and most abundantly in station G5. *Lacuna* sp. were found in the low to middle bay zone, most abundantly at station G1 (Figure 17). *Glycinde polygnatha* were ubiquitous throughout the stations, but more abundant in the lower to middle bay. *Armandia brevis* was found primarily in the lower to middle bay tidal flat stations, primarily at station G1. *Mediomastus californiensis* was found primarily in the tidal flat stations, most abundantly at stations G5 and G1 (Figure 18). *Magelona pitelkai* was found ubiquitously in the mid-lower bay. *Eohaustorius estuarius* was found throughout the bay, but most abundantly at station G13 and G11, the two most up-bay stations. *Spiophanes bombyx* was found in the middle to lower bay, most abundantly in the channel station G3 and the tidal flat station G7. Nemertinea spp. were found ubiquitously throughout the bay (Figure 19).

Phyla

From most abundant to least abundant, by phylum, with oligochaetes and polychaetes separated out of Annelida, are: oligochaetes, 49%; polychaetes, 21%; arthropods, 20%; molluscs, 9%; and nemerteans, phoronids, echinoderms, nematodes, and cnidarians all making up less than 1% each of the total number of organisms. All were found more abundantly in the tidal flat stations except for the nemerteans. The oligochaetes were found primarily in the lower bay with the highest densities found in Miami Cove and Crab Harbor stations, G5 and G1 (Figure 16). Polychaetes were found throughout the bay, most abundantly at stations G5 and G8. Arthropods were found throughout the bay, in the highest abundance at station G5, made up largely of *Nippoleucon hinumensis* and *Grandidierella japonica.* Molluscs were concentrated in the lower bay at stations G1 and G7, made up predominantly of *Lacuna* sp., and bivalves (Figure 20). Nemerteans were identified only to phylum and were found throughout the bay (Figure 19). Phoronids were predominantly found in the middle to lower bay especially at stations G5, G1,

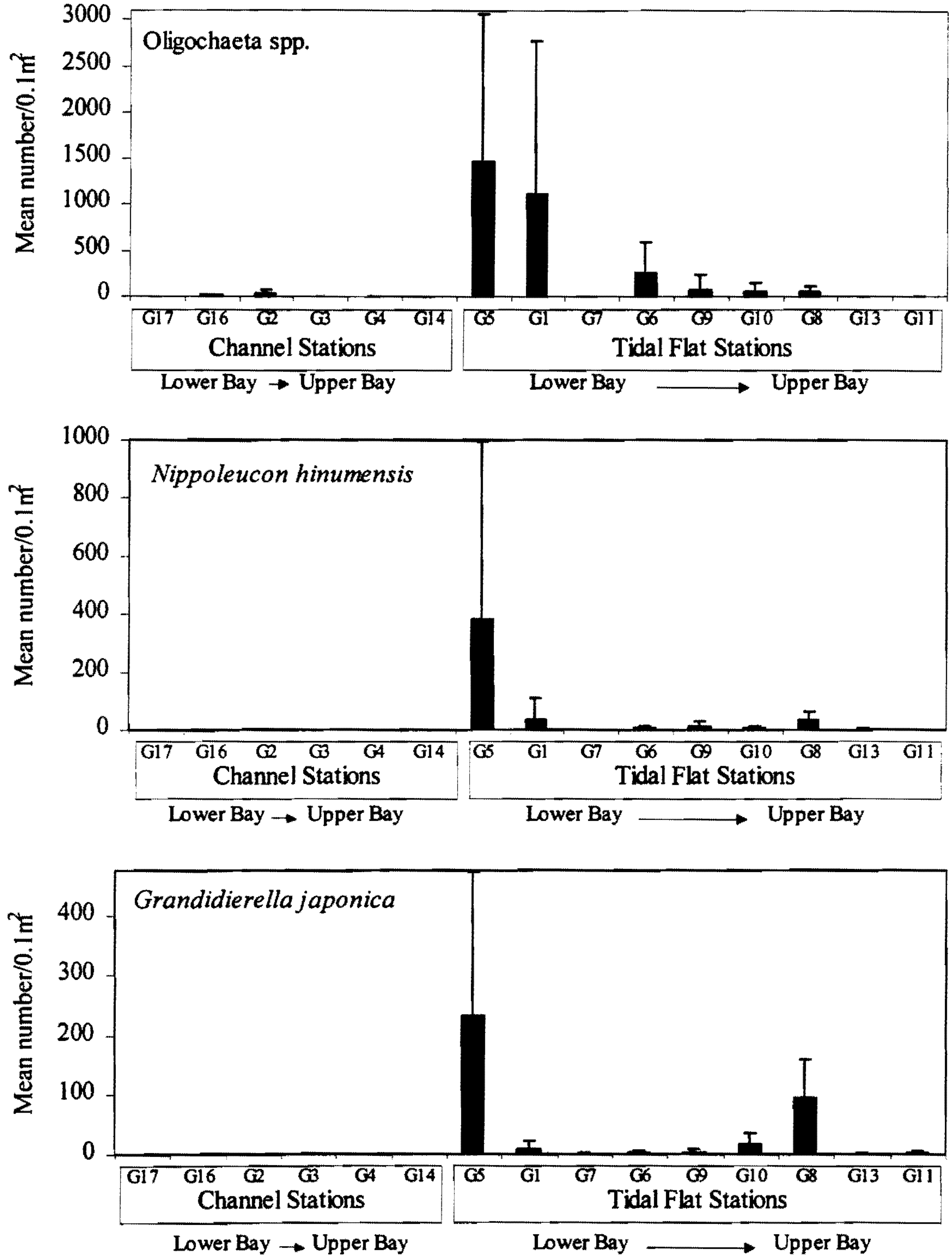


Figure 16. Mean count of 5 grab samples at each station for the three most numerically abundant taxon, Oligochaeta spp., *Nippoleucon hinumensis*, and *Grandidierella japonica*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

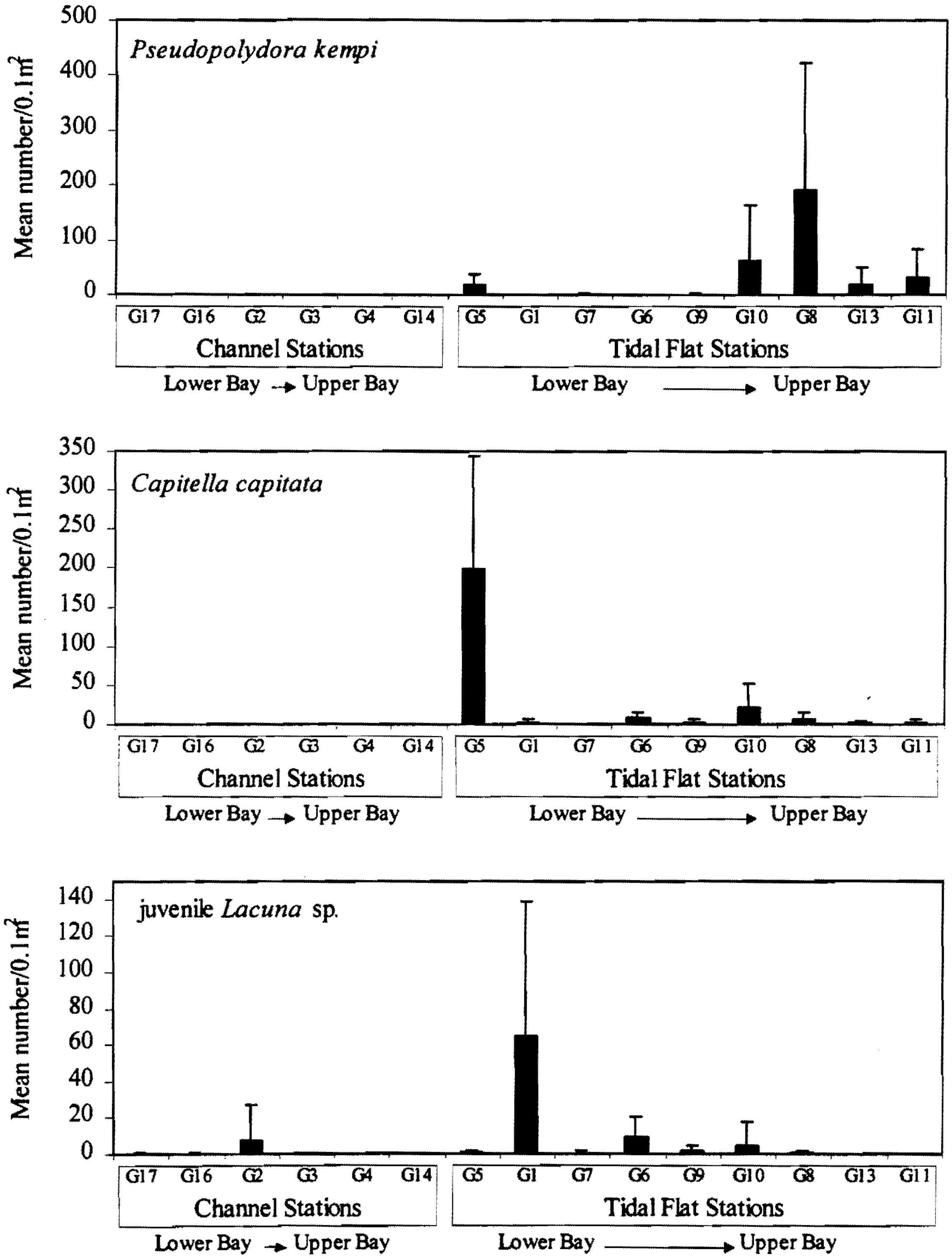


Figure 17. Mean count of 5 grab samples at each station for the 4th through the 6th most numerically abundant taxon, *Pseudopolydora kempi*, *Capitella capitata,* and juvenile *Lacuna* sp. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

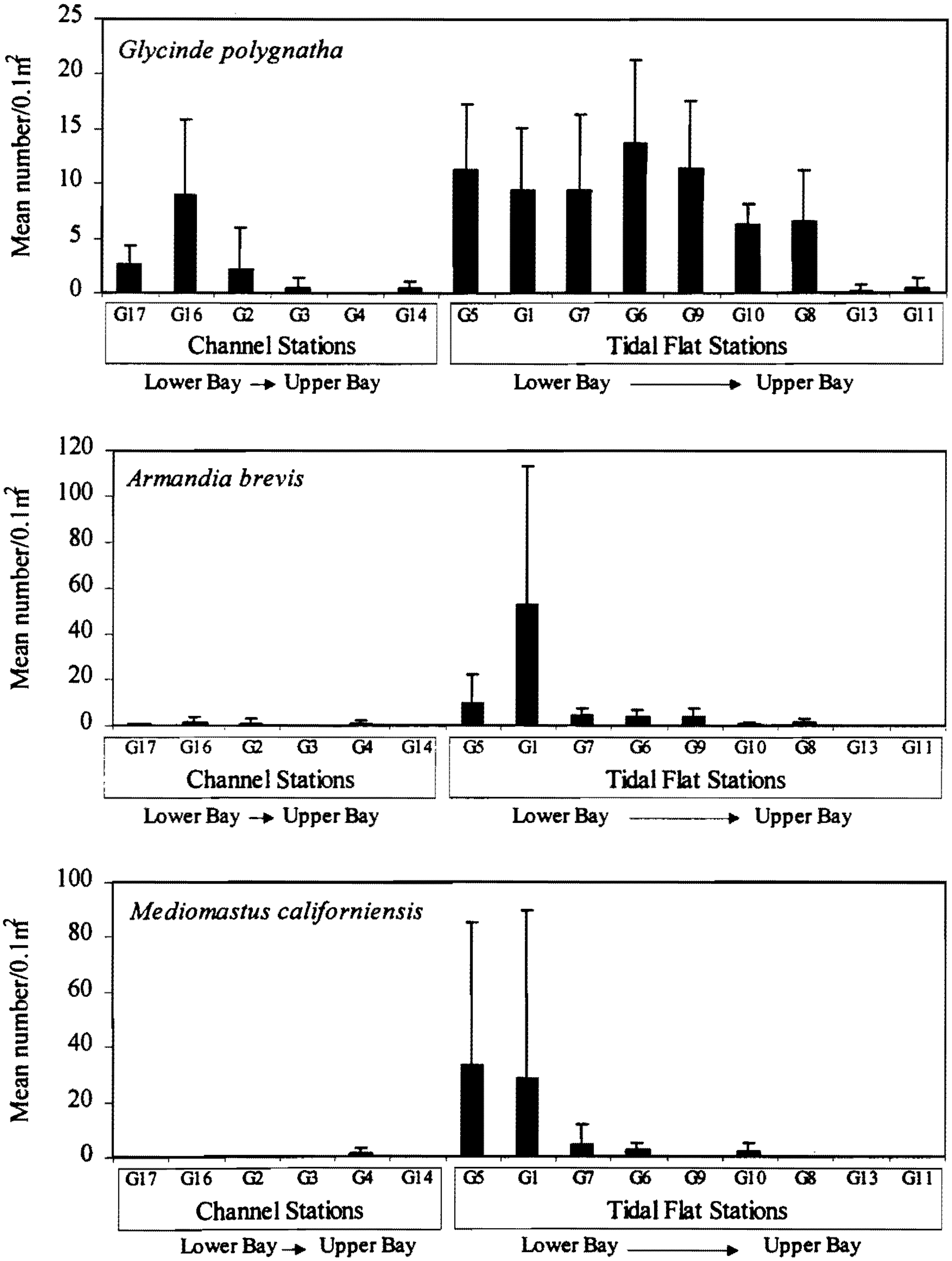


Figure 18. Mean count of 5 grab samples at each station for three species that made up 1% of the total grab survey organisms, *Glycinde polygnatha*, *Armandia brevis*, and *Mediomastus californiensis*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

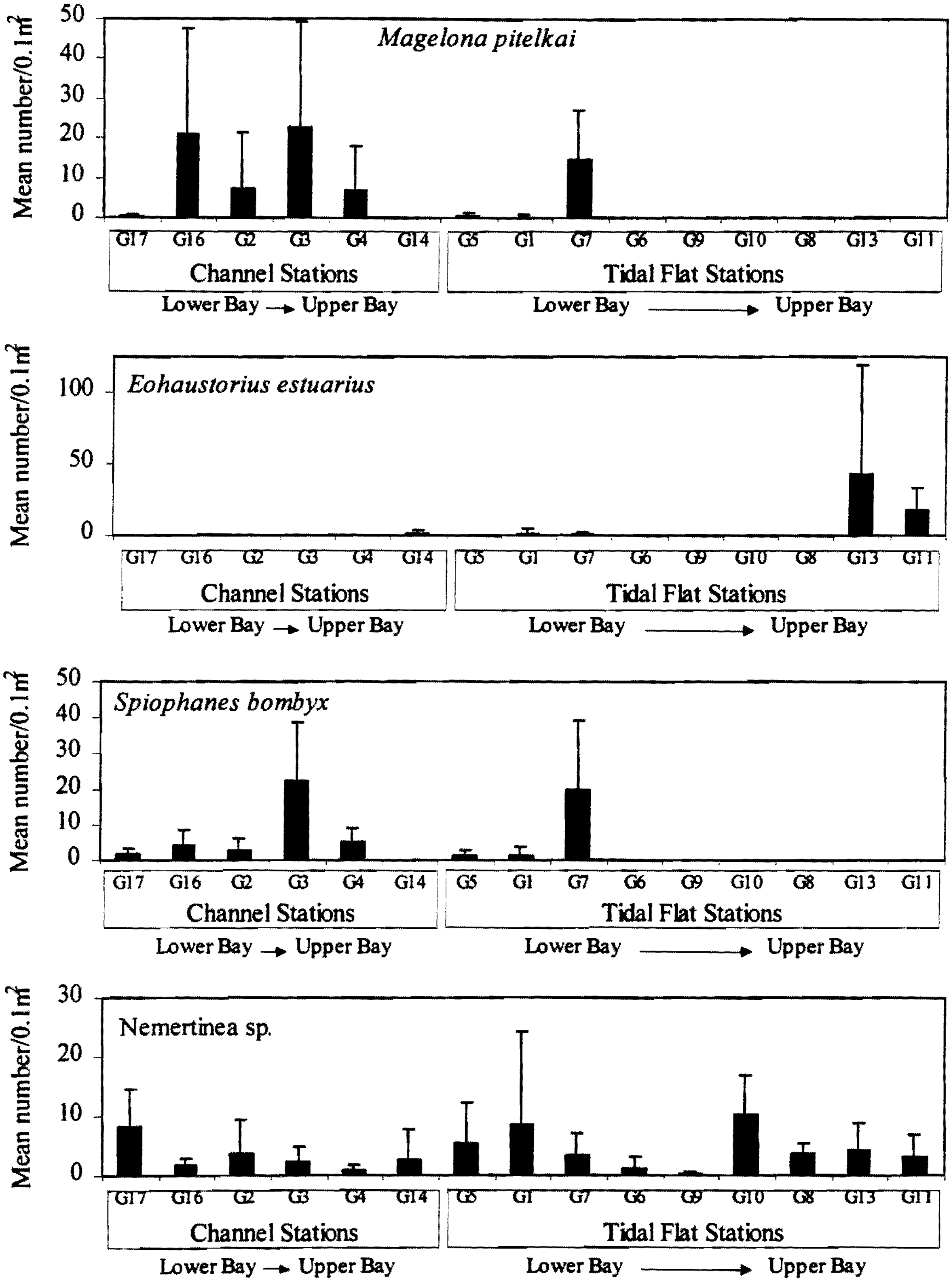


Figure 19. Mean count of 5 grab samples at each station for four species *Magelona pitelkai*, *Eohaustorius estuarius*, *Spiophanes bombyx*, and Nemertinea sp. that made up 1% each of the total grab survey organisms. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

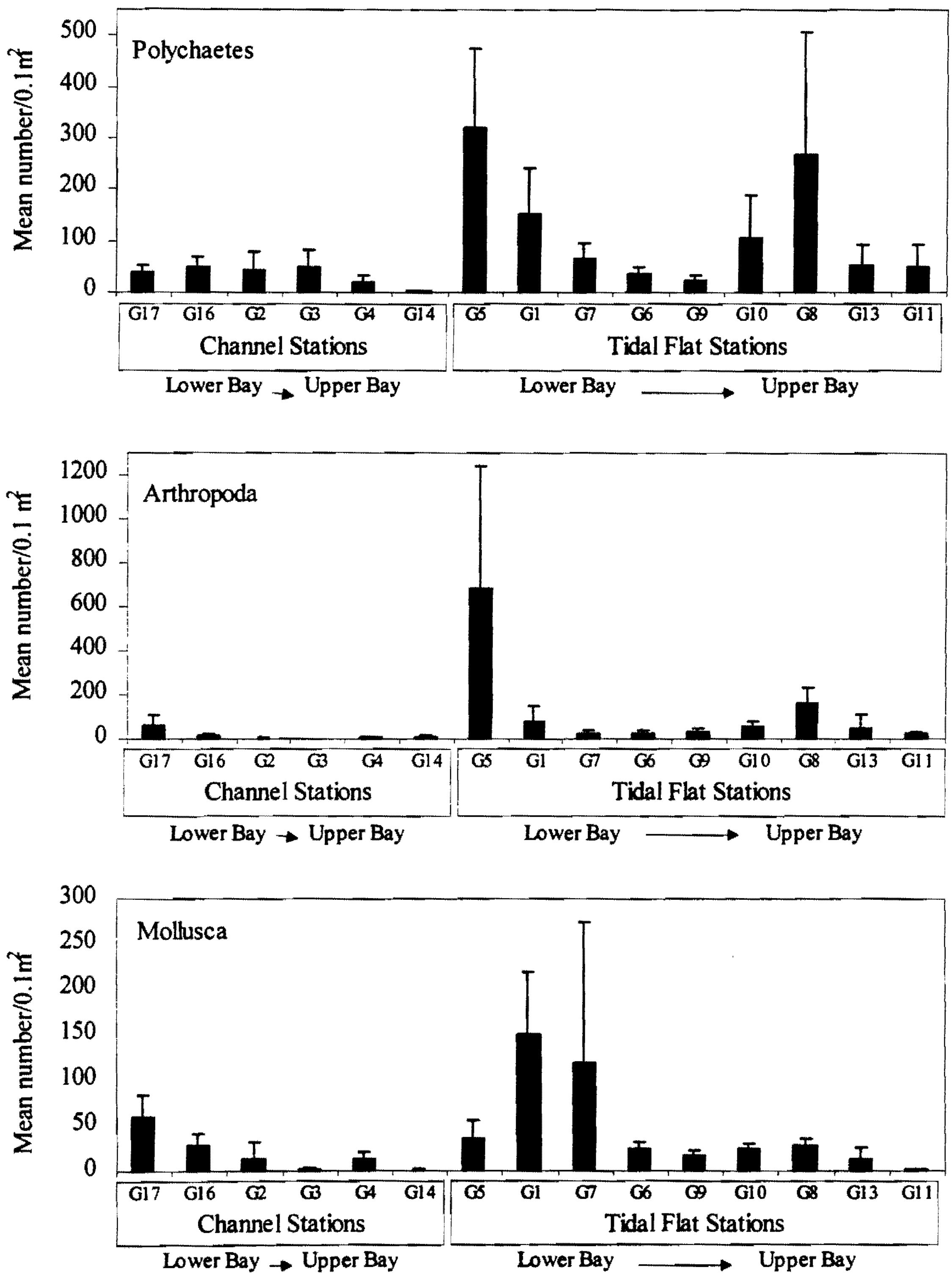


Figure 20. Mean count of 5 grab samples at each station for polychaetes, crustaceans, and molluscs. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

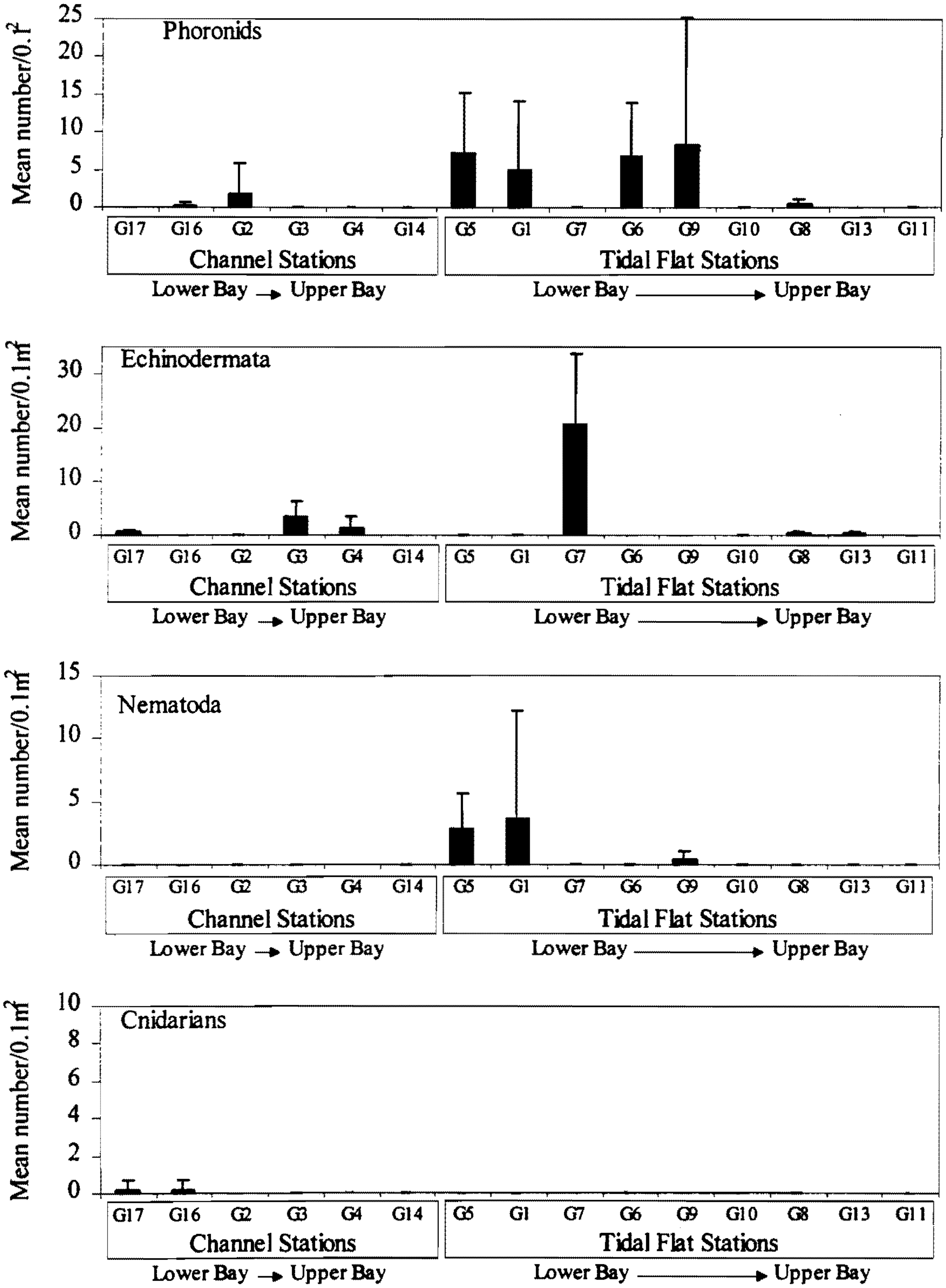


Figure 21. Mean count of 5 grab samples at each station for phoronids, echinoderms, nematodes, and cnidarians. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

G6, and G9. They were identified to the family Phoronidae. Echinoderms included primarily *Dendraster excentricus* found at station G7, but also of Ophiuroidea spp. at stations G13 and G17. Nematodes were identified only to phylum and were found at three middle to lower bay stations, G1, G5, and G9. Cnidarians were represented in the lower bay by Anthozoa spp. at stations G17 and G16 (Figure 21).

Introduced and Cryptogenic Species

Besides the abundant introduced species *Nippoleucon hinumensis, Grandidierella japonica,* and *Pseudopolydora kempi* already mentioned (Figures 16 and 17), five other introduced species and five cryptogenic species made up less than 1% each of the total population. The introduced species include the terebellid polychaete *Hobsonia floridus,* the spionid polychaetes *Polydora cornuta* and *Streblospio benedicti,* the amphipod *Corophium acherusicum,* and the soft-shelled clam, *Mya arenaria.* The cryptogenic species include the polychaete *Owenia fusiformis,* the polynoid polychaete *Harmothoe imbricata,* the spionid polychaetes *Spiophanes bombyx* and *Pygospio elegans,* and the tanaid isopod *Leptochelia dubia.*

Hobsonia floridus was found exclusively in two tidal flat stations, G5 and G8, which fall in the lower and upper bay, respectively. *Polydora cornuta* was found in three tidal flat stations, G1, G9 and G10, in the lower and middle bay regions. *Streblospio benedicti* was found in tidal flat stations, particularly at station G5 (Figure 22). *Corophium acherusicum* was found in almost all the tidal flat stations as well as one channel station. It was interesting to note that of the superfamily Corophioidea, juvenile Corophioidea sp., introduced species *Corophium acherusicum* and *Corophium spinicorne* were identified. Conspicuously absent from samples was *Corophium salmonis,* an often abundant prey species for juvenile salmonids in other estuaries. Future sampling programs should verify this observation. *Mya arenaria* will be discussed in the following bivalve section. *Owenia fusiformis* was found in two tidal flat stations, lower bay station G1, in particular. *Harmothoe imbricata* was found only in lower bay channel station G2 (Figure 23). *Spiophanes bombyx* was found ubiquitously throughout the middle to lower bay stations. The highest densities were found in stations G3 and G7. *Pygospio elegans* was found in two lower bay tidal flat stations, G1 and G6. *Leptochelia dubia* was found at lower bay tidal flat station, G1, only (Figure 24).

Bivalves

Thirteen taxa of bivalves were identified through the grab samples, three of which were not seen and two of which were not quantified in the clam survey. None of the clam taxa identified made up more than 1% of the total organisms in the grab survey. The three not observed in the clam survey were *Mysella tumida,* juvenile *Tellina* sp., and *Siliqua* sp. The two not quantified in the clam survey were juvenile Mytilidae sp. and the aforementioned *Mya arenaria.* The nine species of bivalves that were found in both the clam and grab were *Clinocardium nuttalli,* Mactridae sp. (most likely *Tresus capax*), *Protothaca staminea, Saxidomus giganteus, Macoma balthica, Macoma inquinata, Macoma nasuta,* and *Cryptomya californica.*

Mysella tumida was found in the lower to middle bay in both channels and tidal flats. They were especially abundant at site G7. Juvenile *Tellina* sp. were found in the lower to middle bay in both channels, as well. They were especially abundant at site G1. *Siliqua* sp. were spread

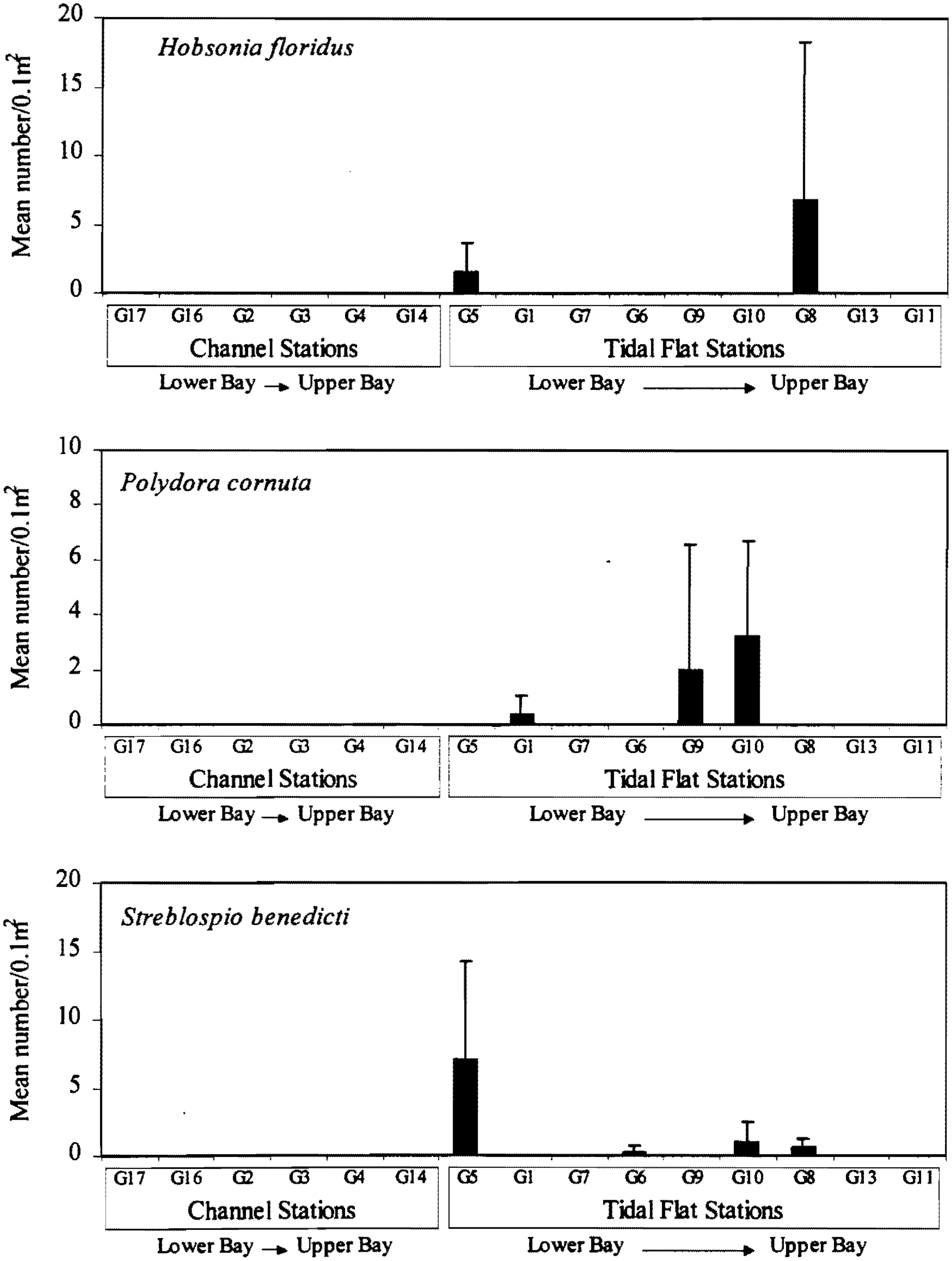


Figure 22. Mean count of 5 grab samples at each station for 3 introduced species *Hobsonia floridus*, *Polydora cornuta*, and *Streblospio benedicti*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

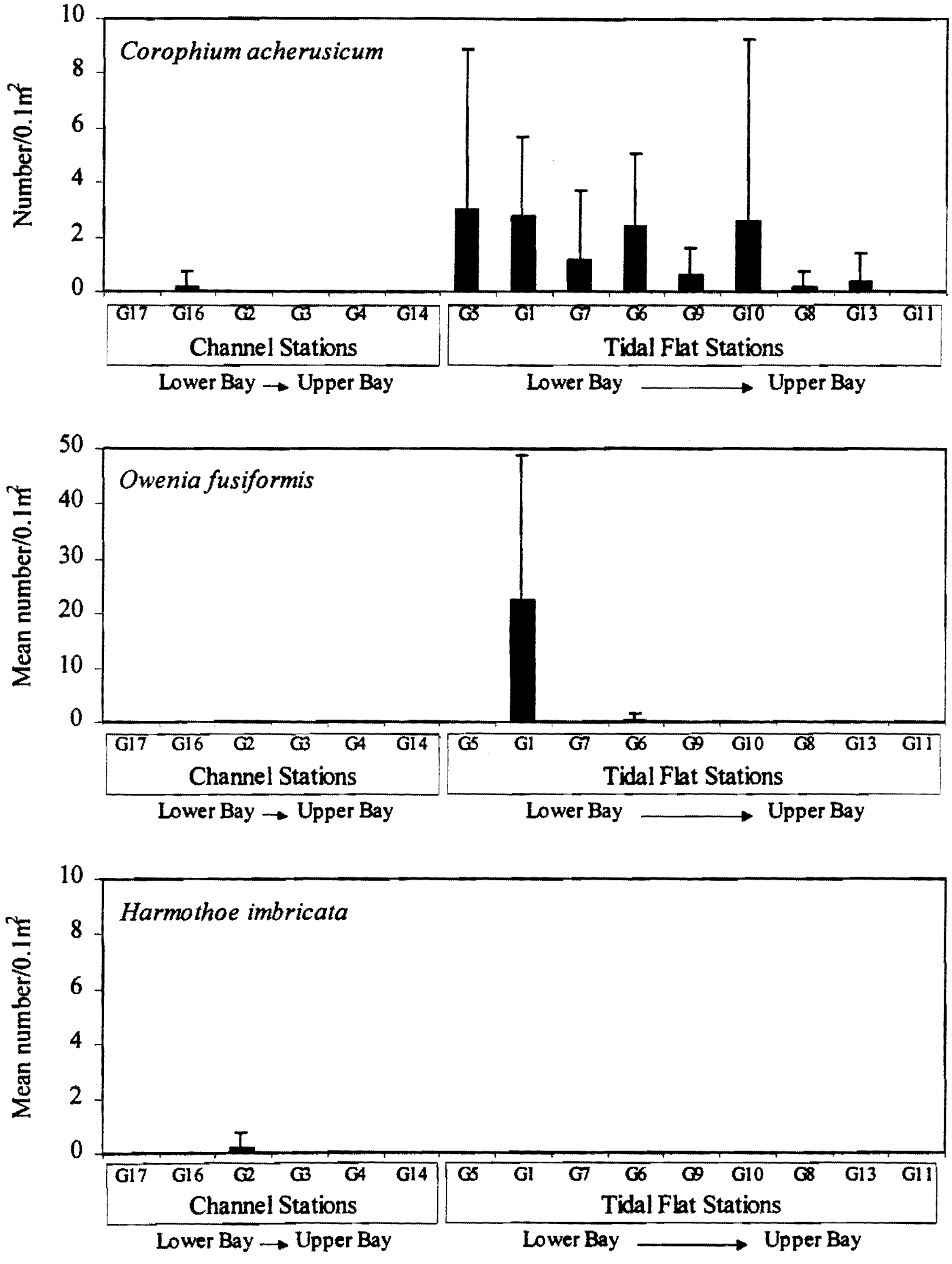


Figure 23. Mean count of 5 grab samples at each station for the introduced species *Corophium acherusicum* and the cryptogenic species *Owenia fusiformis* and *Harmothoe imbricata*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

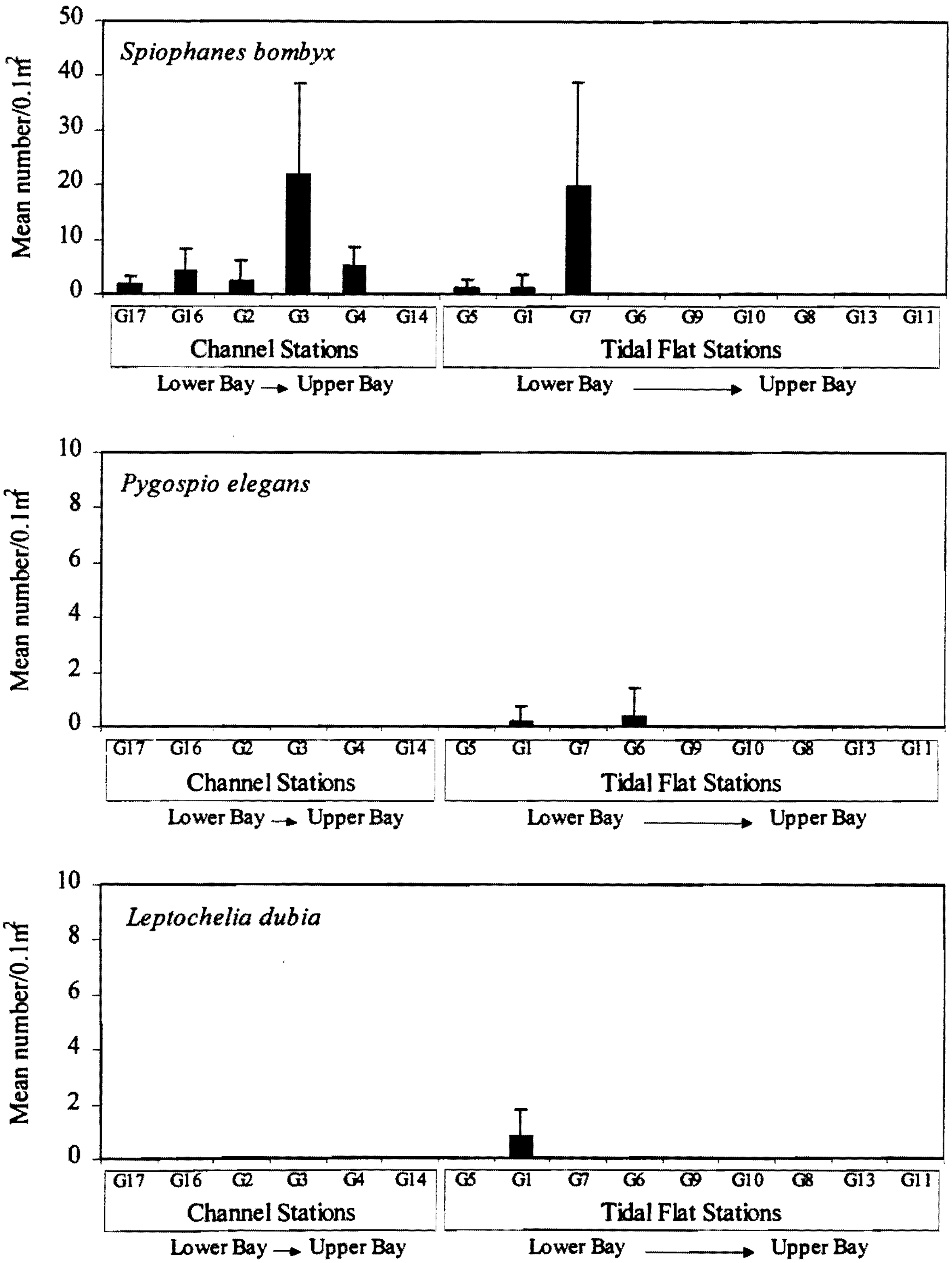


Figure 24. Mean count of 5 grab samples at each station for the cryptogenic species *Spiophanes bombyx*, *Pygospio elegans* and *Leptochelia dubia*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

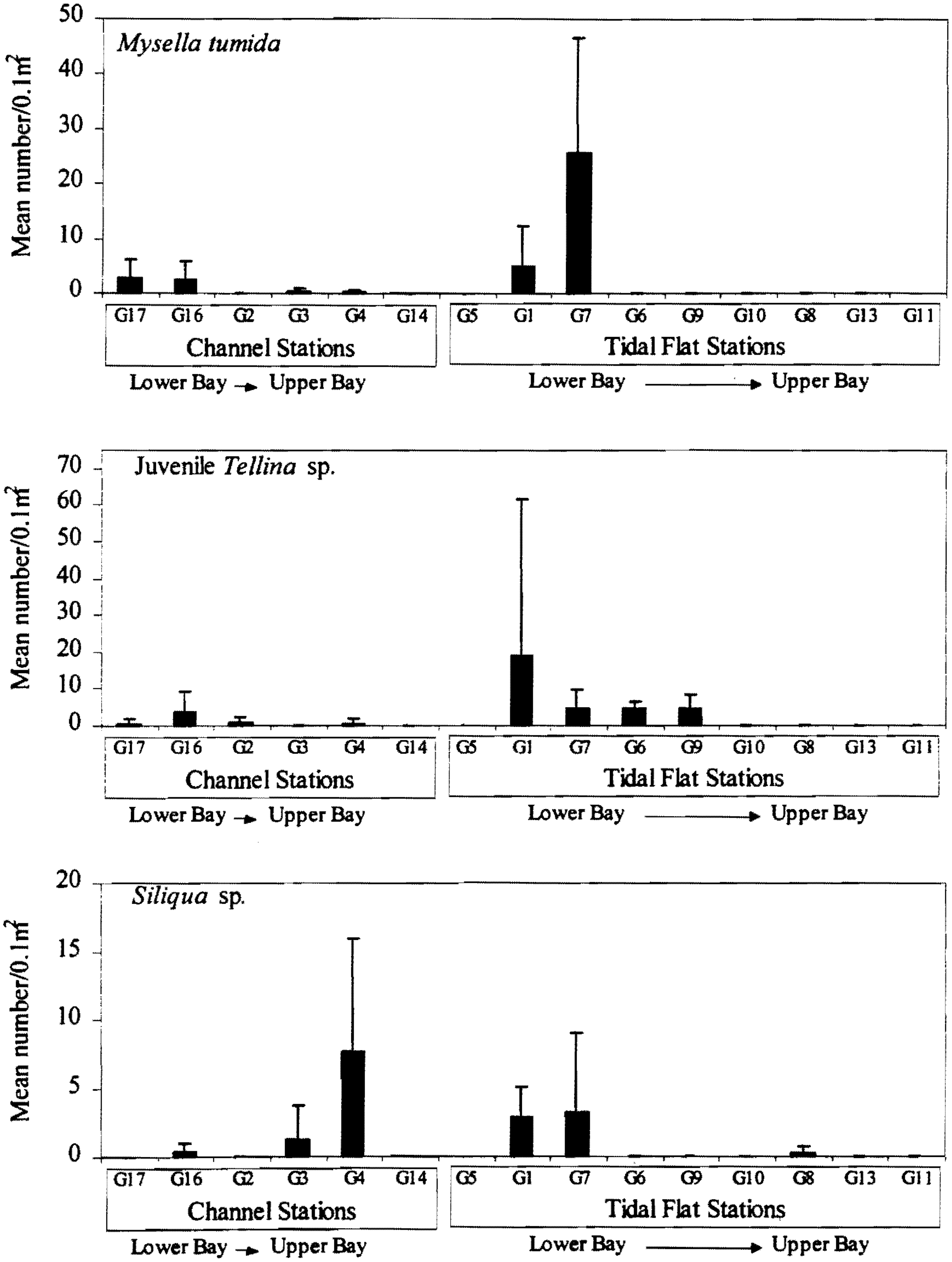


Figure 25. Mean count of 5 grab samples at each station for the bivalves *Mysella tumida*, juvenile *Tellina* sp. and *Siliqua* sp. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

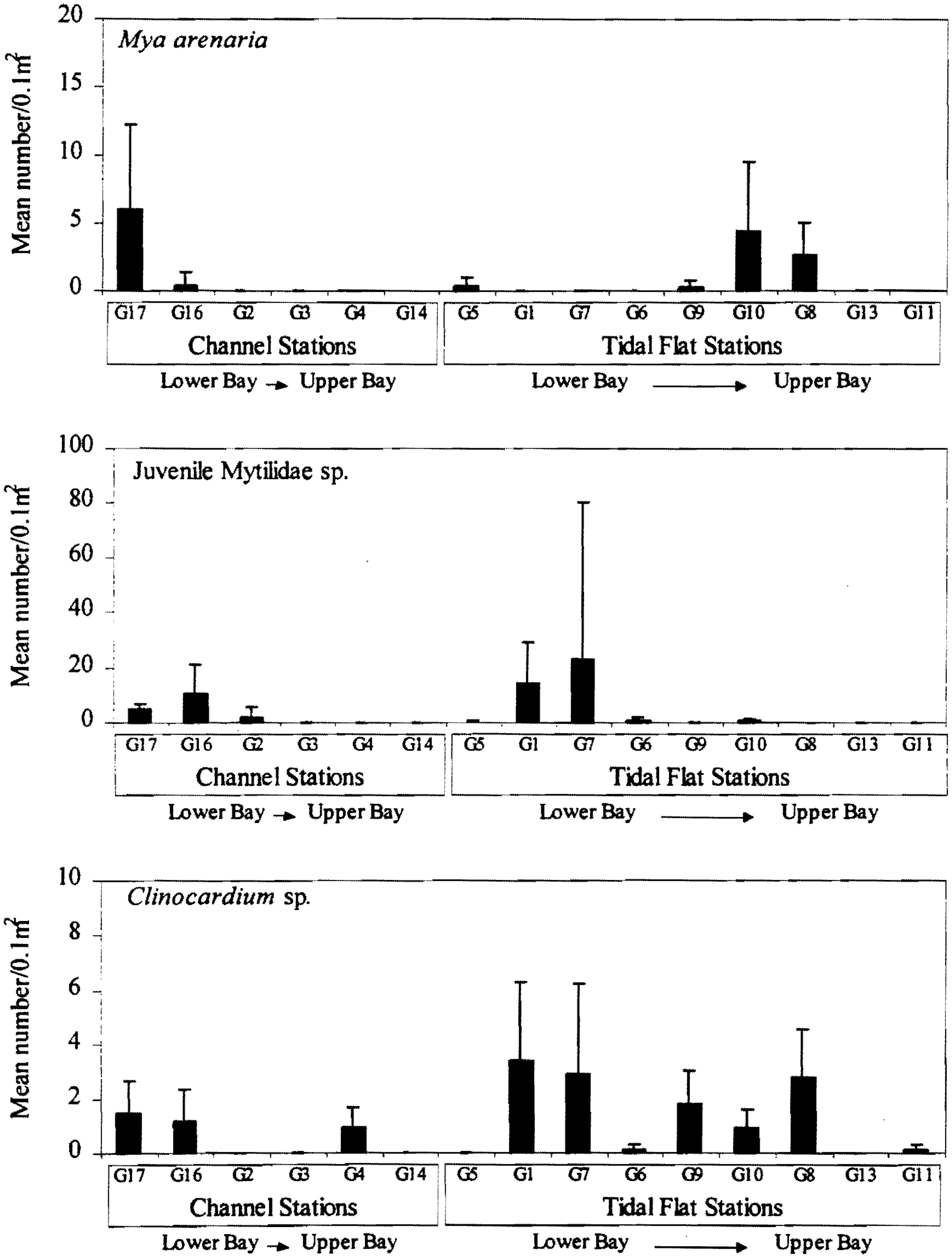


Figure 26. Mean count of 5 grab samples at each station for the bivalves *Mya arenaria*, juvenile Mytilidae sp., and *Clinocardium* sp. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

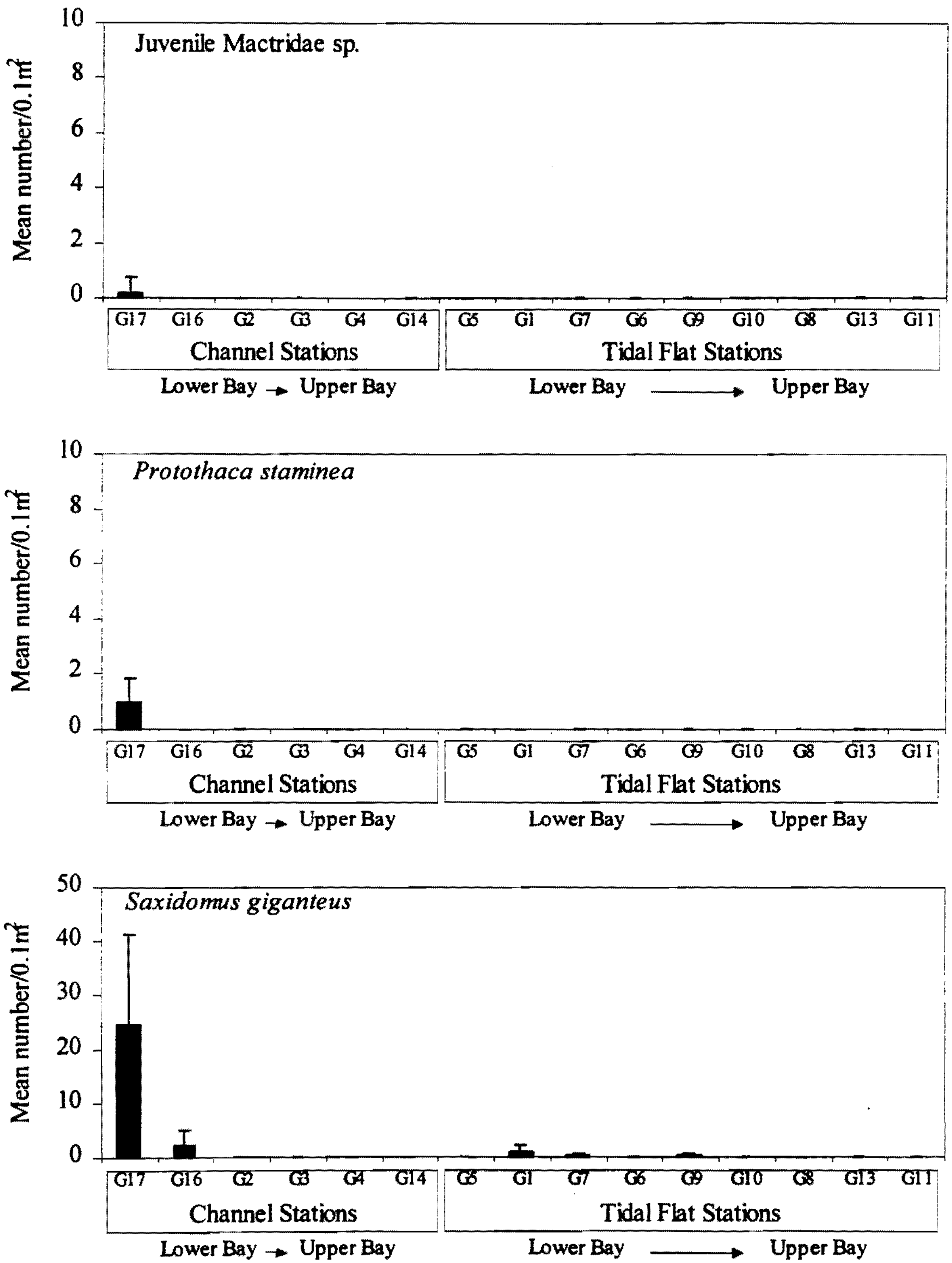


Figure 27. Mean count of 5 grab samples at each station for the bivalves Mactridae sp., *Protothaca staminea*, and *Saxidomus giganteus*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

throughout the south channel and were most abundant at site G4 (Figure 25). *Mya arenaria* was found at six stations throughout the bay, G17, G10, and G8, most abundantly. Juvenile Mytilidae sp. extended into the upper bay along the north channel, but were most abundant in the lower bay. *Clinocardium nuttalli* were found throughout the bay, most abundantly in the tidal flats (Figure 26). Mactridae sp. and *Protothaca staminea* were only found at lower bay, channel station G17. *Saxidomus giganteus* extended into the middle bay, but were found most abundantly at station G17 (Figure 27). *Macoma balthica* were found ubiquitously throughout the tidal flat stations but only at one channel station, G4. They were especially abundant at station G5. *Macoma inquinata* were found in the lower bay at channel stations G17 and G16, and tidal flat station, G1. *Macoma nasuta* were found only at tidal flat stations, G5 and G1, in the lower bay. *Cryptomya californica* was found ubiquitously throughout the stations, most abundantly in the tidal flat stations (Figure 28).

All the bivalves collected in the grab survey were small individuals (<1cm) and do not affect the clam density or biomass estimates calculated from the clam survey. The effects of larval clam transport are evident in the wide dispersion throughout the bay of some species of juveniles, such as *Mya arenaria* and *Clinocardium nuttalli* (Figure 26). Grab stations G17 and G16 correspond with subtidal clam survey sites S1 and S2. Grab station G1 corresponds with intertidal clam survey site I2,4.

Burrowing Shrimp

The burrowing shrimp *Upogebia pugettensis* and juvenile *Neotrypaea* sp. were observed to a limited extent in the grab samples. *Upogebia pugettensis* were found in only one sample at one mid-bay, tidal flat station, G9. Juvenile *Neotrypaea* sp. ranged from 0 to 5 shrimp per sample and made up 0.05% of the grab survey. They were found throughout the tidal flat stations, but only in one channel station, G17 (Figure 29).

Community Indices

Data summaries of the total number of individual organisms, species richness, Simpson's index values of dominance, and the Shannon-Weaver measure of diversity for each grab station are shown in Table 17. Total number, species richness, diversity, and dominance are arranged graphically from lower to upper bay for both channel and tidal flat stations in Figure 30.

Two lower bay, tidal flat stations, G5 and G1, had especially high total numbers of organisms. G5 is located in Miami Cove at the outlet of the Miami River in the Northeast corner of the bay. G5 had a total, for all five grabs, of 12,549 individual organisms with a high richness of 50 different taxa and a low diversity and dominance of 0.668 and 2.68, respectively. Although G5 had a relatively high species richness, the diversity value was low due to the numerical dominance of a few taxa. Five of the ten most numerically dominant taxa were found in high abundances in G5. These include oligochaetes spp., *Nippoleucon hinumensis*, *Grandidierella japonica*, *Capitella capitata*, and *Mediomastus californiensis*. G1 is located in Crab Harbor in the Northwest corner of the bay and correlates to the clam survey site I2,4. G1 had a total, for all five grabs, of 7,550 individual organisms with a high richness of 68 different taxa and a low diversity and dominance of 0.596 and 1.81, respectively. As with G5, the low diversity value at station G1 is explained by the relative numeric dominance of a few taxa. Four of the ten most numerically dominant taxa were found in high abundances in G1. These include Oligochaetes, *Mediomastus californiensis*, *Armandia brevis*, and *Lacuna* sp.

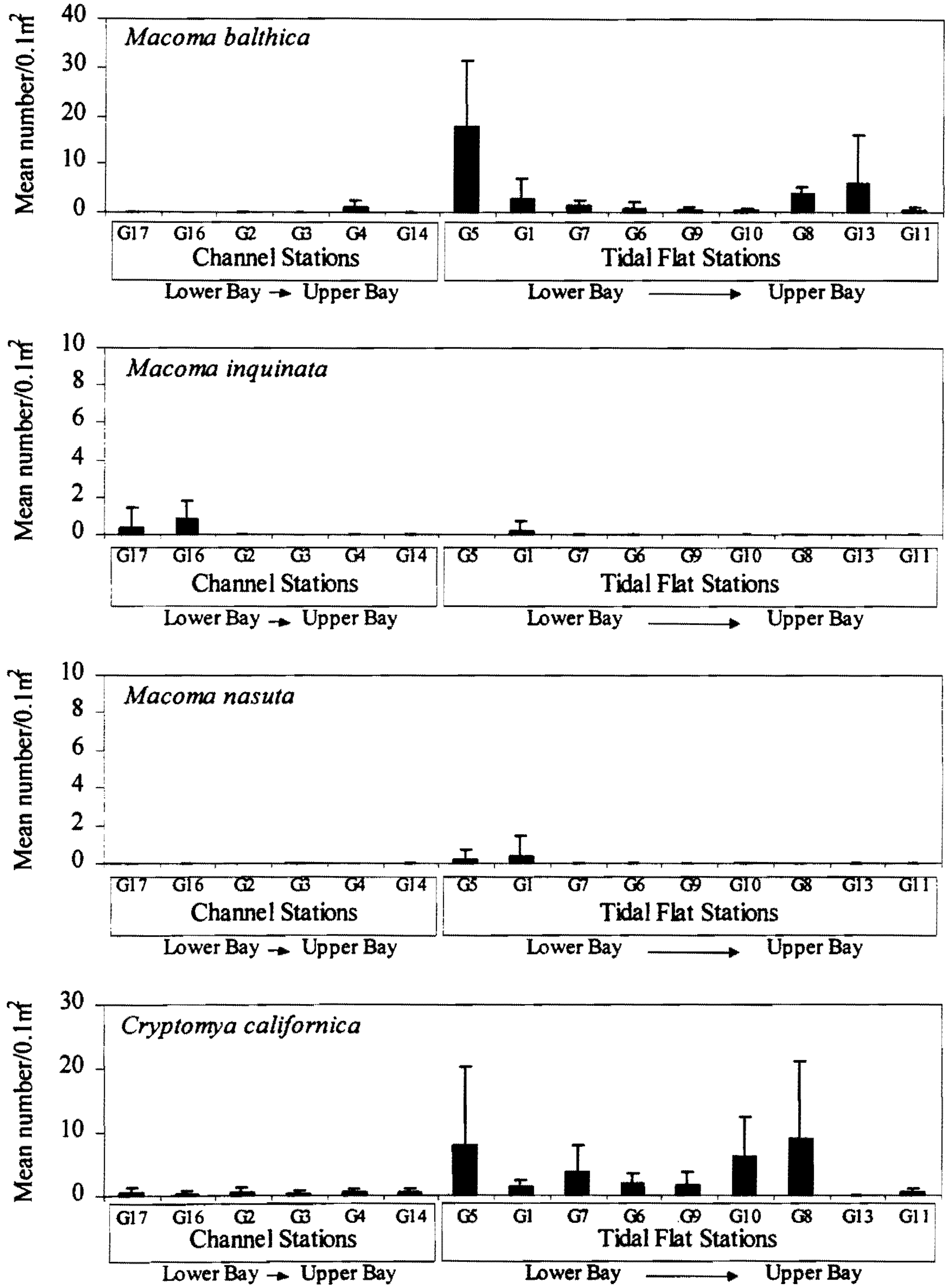


Figure 28. Mean count of 5 grab samples at each station for the bivalves *Macoma balthica, Macoma inquinata, Macoma nasuta,* and *Cryptomya californica*. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

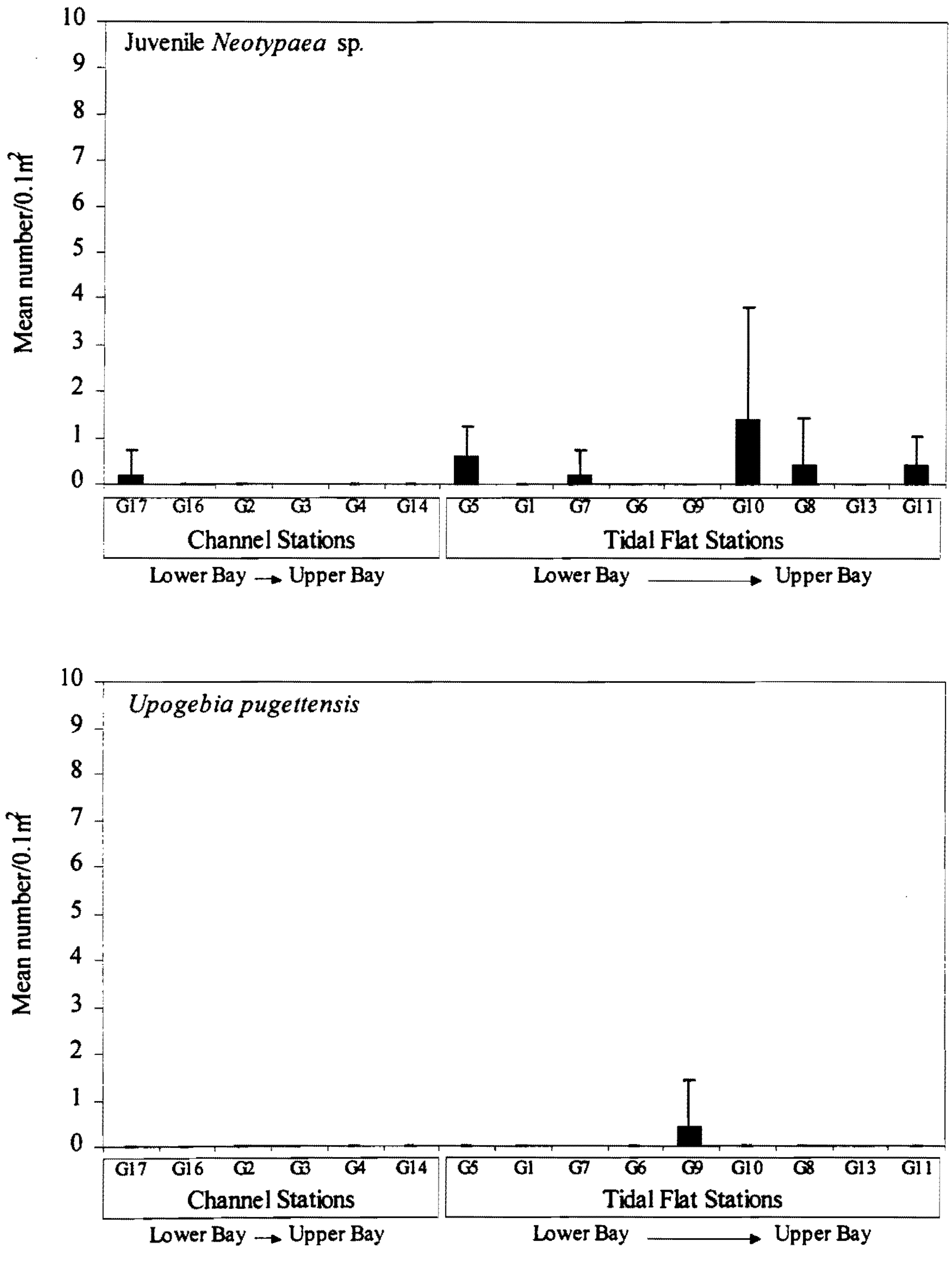


Figure 29. Mean count of 5 grab samples at each station for the burrowing shrimp *Upogebia pugettensis* and juvenile *Neotrypaea* sp. Error bars are 95% confidence intervals. Stations are arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. See Figure 15 for station locations.

Table 17. Summary statistics for grab samples from Tillamook Bay, 1996. There were 5 grabs per station.

Station	**Total # per station**	Mean # per grab	95% CI of mean (%)	**Richness (# of taxa) per station**	Mean per grab	95% CI of mean (%)	**Diversity (H') per station**	Mean per grab	95% CI of mean (%)	**Dominance (S.I.) per station**	Mean per grab	95% CI of mean (%)
G1	7550	1510.0	97.4	68	36.2	15.0	0.596	0.703	38.3	1.81	2.77	56.7
G2	471	94.2	78.1	35	11.4	43.4	0.991	0.648	33.2	5.64	3.74	56.2
G3	291	58.2	65.8	17	8.0	26.8	0.705	0.615	7.9	3.33	3.13	15.4
G4	205	41.0	47.1	29	13.6	16.2	1.201	0.959	4.5	10.39	6.87	13.0
G5	12549	2509.8	35.2	50	29.6	16.6	0.668	0.570	42.0	2.68	2.74	47.4
G6	1716	343.2	81.4	43	23.2	19.9	0.593	0.708	31.9	1.82	3.07	51.6
G7	1149	229.8	58.3	57	26.2	22.1	1.291	1.067	12.7	11.76	8.05	28.9
G8	2550	510.0	64.4	43	26.6	15.9	0.947	0.911	12.0	5.03	5.23	24.5
G9	770	154.0	100.0	35	18.0	13.3	0.926	0.951	22.9	3.75	7.23	47.3
G10	1267	253.4	59.0	39	22.6	18.7	1.107	1.021	14.7	7.18	8.27	37.6
G11	397	79.4	47.5	24	12.0	11.5	0.888	0.706	15.3	4.72	3.31	32.9
G13	600	120.0	45.5	25	11.4	22.2	0.897	0.670	29.8	5.11	3.56	41.4
G14	58	11.6	65.8	15	4.4	67.0	0.971	0.491	65.4	6.65	3.45	63.9
G16	530	106.0	24.0	52	23.8	29.3	1.314	1.084	16.0	12.34	8.90	46.9
G17	844	168.8	25.2	64	30.6	6.3	1.313	1.159	10.3	11.47	9.51	28.5

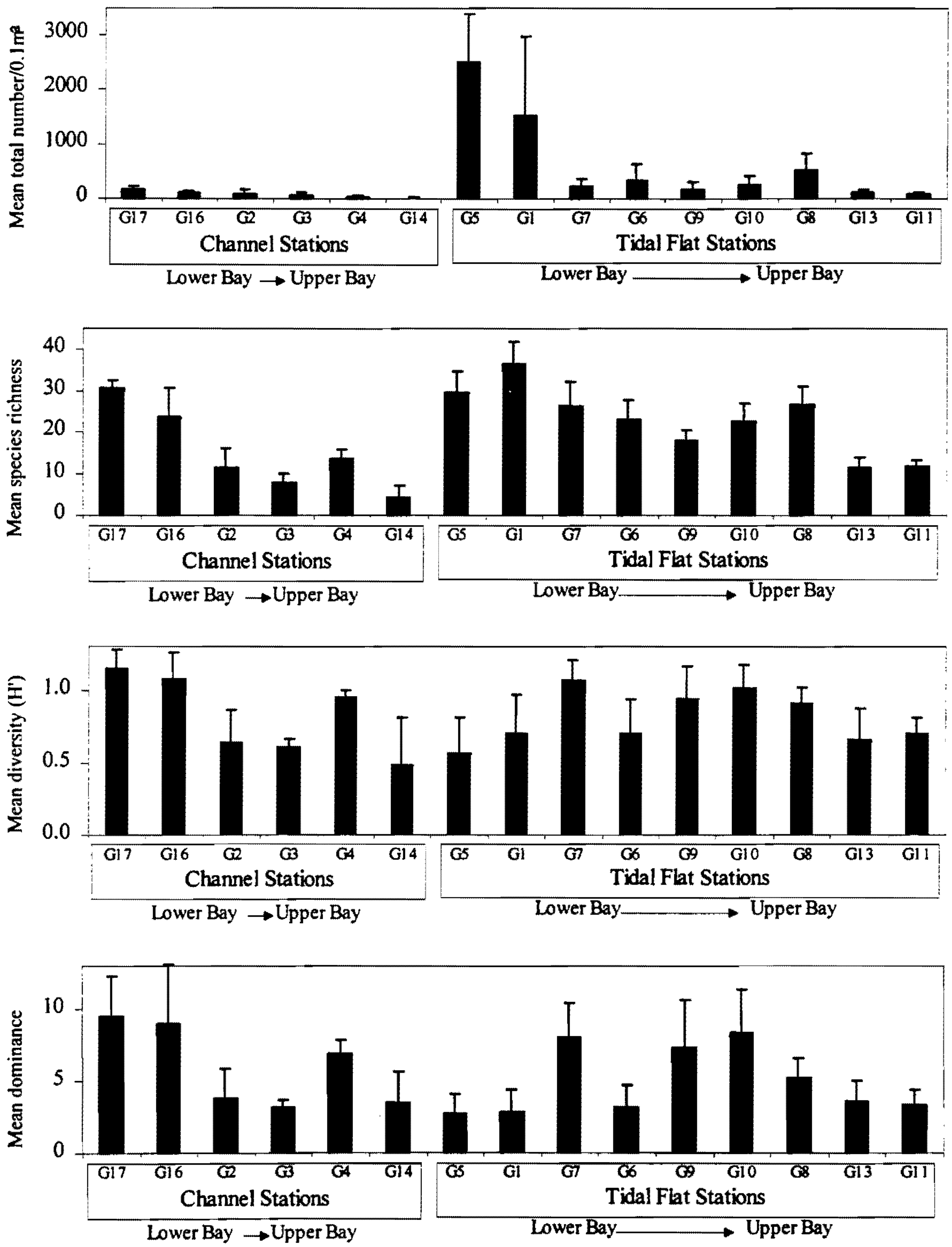


Figure 30. Mean total number per $0.1 m^2$, mean species richness, mean diversity (H'), and mean dominance for grab samples arranged from lower bay to upper bay for channel and tidal flat stations in Tillamook Bay, 1996. Error bars indicate 95% confidence interval. See Figure 15 for station locations.

The other tidal flat stations are described briefly here. G7 is located on a tidal flat near the center of the bay. G7 had 1,149 total individuals with a high richness of 57 taxa, a high diversity of 1.291, and a high dominance of 11.76. *Spiophanes bombyx, Mysella tumida*, Mytilidae, *Lacuna vincta,* and *Dendraster excentricus* were found in their highest abundances in G7. G6 is located on a tidal flat in the middle bay on the eastern side. G6 had 1,716 total individuals a high richness of 43, a low diversity at 0.593, and a low dominance at 1.82. No taxa was found in particularly high abundances in G6. Oligochaetes and *Glycinde polygnatha* were the most abundant taxa in G6. G9 is located on a middle bay tidal flat off of the south channel. G9 had 770 total individuals, a high richness of 35, a high diversity at 0.926, and a low dominance at 3.75. No taxa was found in particularly high abundances in G9. Oligochaetes, *Glycinde polygnatha,* and *Nippoleucon hinumensis* were the most abundant taxa in G9. Oligochaetes and *Pseudopolydora kempi* were the most abundant taxa in G10. Oligochaetes, *Pseudopolydora kempi, Grandidierella japonica, Nippoleucon hinumensis,* and *Pygospio* sp. were the most abundant taxa in G8. *Eohaustorius estuarius, Neanthes limnicola,* and *Pseudopolydora kempi* were the most abundant taxa in G13. *Eohaustorius estuarius* and *Pseudopolydora kempi* were the most abundant taxa in G11.

Compared with the intertidal stations, the channel stations had lower numbers of individuals and species richness values, but comparable species diversity and dominance values. *Parapleustes pugettensis, Saxidomus giganteus,* and juvenile *Balanus* sp. were the most abundant taxa in G17. *Alvania compacta* was found only at station G17. *Magelona pitelkai* and juvenile Mytilidae sp. were the most abundant taxa in G16. *Acanthodoris* sp. were found only in G16. Oligochaetes and *Mediomastus* sp. were the most abundant taxa in G2. *Magelona pitelkai* and *Spiophanes bombyx* were the most abundant taxa in G3. *Siliqua* sp. were the most abundant taxa in G4, though even those were found in densities of only 7.6/m^2. *Calanoida* sp. were the most abundant taxa in G14, though even those were found in densities of only 3.0/m^2.

Sediments

The sediments at each grab station were qualitatively noted during the survey. Figure 15 illustrates the predominant sediments found at each grab location. The lower bay consisted of habitats that were more affected by the oceanic system and thus have higher energy and salinity. These areas contained the main concentrations of clams. They also tend to show the highest species richness in the grab samples (Figure 30). The subtidal substrates consisted of a mix of fine sand, gravel, and shell debris. There was less mud accumulated in the lower bay channels, and there were large channel areas with active sand movement. The intertidal sites in the lower bay consisted of large sand flats. There were many intertidal areas that had a mix of substrates consisting of sand and gravel. The middle portions of the bay were more stable environments with large sand/mud mixed intertidal flats and shallow muddy bottom channels. The large eelgrass and mixed algae beds were more prevalent in this middle portion of the bay. The upper reaches of the bay were more riverine influenced. The sediment in both the intertidal flats and the subtidal channels consisted of courser grain sands. The intertidal flats consisted predominantly of large expanses of sand with little algal growth.

Summary and Recommendations

Rapid Assessment and Shrimp Surveys

- Rapid assessment surveys were effective in locating concentrations of bivalves in Tillamook Bay, comparisons of the habitat map and field observations, and in locating concentrations of mud and sand shrimp.
- Clams appeared to be concentrated in the lower reaches of the bay (with the exception of softshell clams) in areas free of silt and mud, and for the most part in subtidal channels. Cockle and gaper clams occurred farther up the bay on tide flats and channels, although in lower densities.
- The southern-most channel areas appeared to have been affected by recent flooding. Some clam beds had been covered by a silt layer with a depth exceeding 30 cm in some places.
- Mud and sand shrimp were ubiquitous throughout the bay. Some areas had densities higher than 80 shrimp burrows/m^2.
- Multi-spectral scanning images of Tillamook Bay appear to be effective in identifying major eelgrass beds. Information was accurate a year after the flight in which images were created.
- A thorough ground truthing of the multi-spectral image map would require extensive sampling of vegetation and sediment type within a short period of time of image acquisition. This would avoid problems with temporal changes in vegetation or substrate that confound comparisons. In addition, image registration and sampling site location need to be of a spatial precision comparable to the smallest habitat patches on the map. In the case of the habitat map, 1-3 meter accuracy would be needed. Although our comparison provides useful information on the accuracy of the habitat map, it's use is limited to qualitative comparisons due to both temporal changes and spatial inaccuracies.

Clam Surveys

- Using two-stage random sampling to survey specific dense clam beds was more time efficient than the systematic sampling of the bay-at-large used in earlier studies.
- The number of stations per hectare was similar, as were the variances. Pooled estimates across individual survey areas resulted in decreases in variance.
- The areas sampled ranged from 1 to 7.5 hectares in size. Samples taken per hectare ranged from 3.4-10.7.

Clam Biomass

- Two areas, S1 and S3, were located in the Ghost Hole, and a third area of heavy clam populations was identified in the lower bay between Garibaldi and Crab Harbor.
- Overall, the 1996 survey results indicate an increase in available subtidal clam biomass since the 1974-75 survey for two overlapping areas.
- The earlier subtidal survey encompassed 44 hectares with a biomass estimate of 5.7 million pounds of clams, or 130,419 pounds per hectare. In 1996, 13.5 hectares were surveyed (areas S1, S2, and S3) with a biomass estimate of 3.4 million pounds, or 248,745 pounds per hectare.

- Surveys conducted in 1974-75 in similar (overlapping areas S1 and S3) areas had a biomass of 134,427 pounds per hectare compared to 319,864 pounds per hectare in 1996.
- Cockle clams for areas of overlap had a biomass estimate of 37,381 pounds per hectare in 1996 compared to 26,106 pounds per hectare in 1974-75.
- Increases in clam biomass appeared to be due to growth in weight of cockle clams and increased butter clam densities. Different survey methods could contribute to the increase as well.
- Unsurveyed areas in the lower Tillamook Bay may approach biomass of known survey areas – thus, the 1996 estimated biomass is conservative.

Biological Sampling -- Clams

- Length frequencies of gaper, cockle, littleneck, and butter clams showed 1996 populations to be larger in size than clams surveyed during 1974-75. Gaper clams averaged nearly 50 mm larger in 1996, indicating poor recruitment over the intervening years.
- Length frequency distributions showed a lack of large clams of all species in the intertidal areas. Conversely, a greater abundance of smaller clams were found in the intertidal, compared with the subtidal.
- The absence of large clams in the intertidal areas reflect the heavy recreational harvest, especially in the Garibaldi Flat area.

Benthic Grab Samples

- 154 taxa were identified from benthic grab samples throughout Tillamook Bay. Of these, at least 8 were identified as introduced species and 6 as cryptogenic species with unknown origins. The three most abundant organisms identified to the species level were exotic species.
- Stations in Miami Cove and Crab Harbor had the highest number of organisms.
- From most abundant to least abundant, by phylum with Oligochaetes and Polychaetes separated out of Annelida, is: Oligochaetes, 49%; Polychaetes, 21%; Arthropods, 20%; Molluscs, 9%; and Nemerteans, Phoronids, Echinoderms, Nematodes, and Cnidarians all making up less than 1% each of the total number of organisms.
- The top five most abundant taxa were: Oligochaeta spp., 49%; the introduced cumacean *Nippoleucon hinumensis,* 8%; the introduced gamarid amphipod *Grandidierella japonica,* 6%; the introduced spionid polychaete *Pseudopolydora kempi,* 5%; and the polychaete *Capitella capitata 'hyperspecies',* 4%.
- Of the superfamily Corophioidea, juvenile Corophioidea sp., introduced species *Corophium acherusicum* and *Corophium spinicorne* were identified. Conspicuously absent from samples was *Corophium salmonis*, an often abundant and important prey species for juvenile salmonids in other estuaries. Future sampling programs should verify this observation.
- Three taxa of bivalves, *Mysella tumida,* juvenile *Tellina* sp., and juvenile *Siliqua* sp., were identified in the grab survey that were not observed in the clam survey.

Recommendations

- For more precise clam biomass estimates, we recommend doubling sample densities for plots or areas smaller than 5 hectares (e.g., 10/hectare). A minimum sample size of 6 per hectare is recommended for plots greater than 10 hectares in size. In areas with moderate to dense clam populations, 95% confidence limits for estimated biomass should approach $\pm$ 30% of the total.

- There are several management implications that can be made based on survey data. Currently, a 10% of standing biomass harvest guideline is being used to manage the commercial take of cockle clams, coupled with a minimum size restriction and set spawning reserve.
- Existing harvest guidelines appear to be reasonable for cockle clams given increased biomass estimates. One-half of the high density bed surveyed within the Ghost Hole is set aside as a reserve.
- The best prospect for new fisheries appears to be for butter clams, at present.
- Any future expansion of commercial fisheries to other species should be coupled with creation of subtidal reserves to ensure adequate spawning biomass.
- A pre-harvest survey for an area to establish a quota would be advisable prior to exploitation of long-lived species with episodic recruitment
- Currently, the recreational fishery appears to selectively harvest larger clams. Catch, effort, and size of clams harvested should continue to be monitored if funding becomes available, or through volunteer programs.
- Future research should focus on the relationship between populations in subtidal and intertidal habitats.
- Long-term monitoring sites should be established on Garibaldi Flat and in subtidal areas associated with the clam surveys to follow up on survey results. It is recommended that intertidal and subtidal sites be monitored annually towards the end of each summer season for an additional two years. The occurrence of juvenile set clams for each species and the size frequencies of each of the recreational and commercially-important species should be monitored.

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ACKNOWLEDGMENTS

This project could not have been completed without the generous contributions of many people. The authors would like to thank Ralph Garono of Earth Design Consultant, Inc., and Steve Nelson and his staff at the Tillamook Bay National Estuary Project office for their support. Many thanks are due to Don Bacon and his staff at the Port of Garibaldi for their support of vessel moorage needs during the project. The authors would also like to thank Doug Alm for his invaluable knowledge of Tillamook Bay. A special thanks is due to Jean McCrae for her guidance in field sampling technique. Many thanks as well to Gonzalo Castillo and John Chapman for their assistance with identifying introduced benthic invertebrates.

APPENDIX – DESCRIPTION OF PROJECT DATABASES

Data collected by this project are stored on a series of databases available from the Tillamook Bay National Estuary Project. The databases were developed in Microsoft Excel and FoxPro. Information in this appendix describes the content of the following data files:

- Clam Density Data (allcd.dbf)
- Clam Measurement Data (allmd.dbf)
- Set Clam Measurement Data (allset.xls)
- Shrimp Survey (V2shrimp.xls)
- Rapid Assessment Survey (radata.xls)
- Grab Sample Site Summary Data (grab.xls)
- Grab Sample Species List
- Grab Biomass Data (biomas96.xls)
- Grab Invertebrate Count Data (data.xls)
- Grab Species Voucher Collection Data (voucher.xls)
- Grab Species Voucher Quality Assurance Data (voucherqa.xls)

Field Descriptors for Tillamook Bay Clam Density Data.
Foxpro/Excel file allcd.dbf

Field Name	Descriptor
DATE	Date of sampling event
MONTH	Month of sampling event
DAY	Day of sampling event
SITE	Sample Site. An "I" indicates an intertidal site and an "S" indicates a subtidal site. The first number refers to the sample site, and the second number is the subsite (e.g., I13 is Intertidal site 1, subarea 3).
TRANSECT_L	Transect Location. These numbers indicate the distance in meters along the baseline where the transect originates. These are the random starting locations for primary or first stage sampling units (FSUs) along each sample area.
TRANSECT_N	Transect Number. Indicates the sequential number of transects within a sample site area.
STATION_LO	Station Location. Indicates the distance in meters from the baseline for each sample along a transect. The station locations are randomly selected and are the secondary sampling units (SSUs).
STATION_NO	Station Number. Indicates the sequential number of a sample along the transect line. The baseline is the 0 position on the transect line, and the sample stations are numbered away from the baseline.
DEPTH	Sample depth or tidal height based on MLLW.
TIDAL_DEPT	Tidal height prediction for sample time and date. Data obtained from Harbormaster software. All corrections taken from Garibaldi tide predictions.

DEPTH_AT_0	Depth at 0 Mean Lower Low Water. The depth at the time of sampling minus the correction for the time and date of sampling to standardize the actual sample depth at MLLW.
HABITAT	Habitat description based on visual inspection methods used by Bottom *et al.* (1979) after Cowardin *et al.* (1977). UN, RB, AQ, SH, FL, BB, and TM for Unconsolidated Bottom, Rock Bottom, Aquatic Bed, Shore, Flat, Beach/Bar and Tidal Marsh, respectively.
SAND	Substrate Type Sand. The primary substrate is indicated by a one, the secondary substrate by a two, and the next prevalent substrate by a three and so on for all substrate types present in the sample. A zero in this field indicates the absence of that substrate in the sample. Two substrates are marked by a one when they each share an equal occurrence.
MUD	Substrate Type Mud (See definition for Sand).
SHELL	Substrate Type Shell (See definition for Sand).
COBBLE	Substrate Type Cobble (See definition for Sand).
BEDROCK	Substrate Type Bedrock (See definition for Sand).
DEBRIS	Substrate Type Woody Debris (See definition for Sand).
OTHER	Substrate Type Other than Those Listed Above.
ALGAEPERQM	Percent algal cover within sample quadrat. Percent algal cover was determined using a ¼ m^2 quadrat. Data expressed are per 1/4 m^2.
EELGRASSQM	Eelgrass density count per 1/4 m^2 within sample quadrat.
SHRIMPQM	Shrimp burrow count per 1/4 m^2 within sample quadrat.
CHIP	Field reference number to tie field data sheet to data fields for data proofing (numbers are used over on different days.)
GAPER	Gaper clam, *Tresus capax*, density per meter square in intertidal sites and density per 0.1 meter square in subtidal sites.
COCKLE	Cockle clam, *Clinocardium nuttallii*, density per meter square in intertidal sites and density per 0.1 meter square in subtidal sites.
BUTTER	Butter clam, *Saxidomus giganteus*, density per meter square in intertidal sites and density per 0.1 meter square in subtidal sites.
NLN	Native Littleneck, *Protothaca staminea*, density per meter square in intertidal sites and density per 0.1 meter square in subtidal sites.
BNSE	Bentnose clam, *Macoma nasuta*, for all areas except I1 where numbers could reflect *Macoma inquinata* as well. Density per meter square in intertidal sites and density per 0.1 meter square in subtidal sites.
INQUINATA	Irus clam, *Macoma inquinata,* density per meter square in intertidal sites and density per 0.1 meter square in subtidal sites. Irus clams were not separated out from bentnose clams in area I1.
MAC_SP	*Macoma* sp. including *M. nasuta* and *M. inquinata* combined.
EASTING	Latitude location in UTM.
NORTHING	Longitude location in UTM.
DATUM	Map Datum used for coordinates.

Column header descriptors for adult clam measurement database.
Foxpro/Excel file allmd.dbf

Field Name	Descriptor
DATE	Date of sampling effort.
SITE	Sample site. "I" indicates intertidal area, and "S" indicates subtidal sampling area.
TRANSECT_L	Transect Location. The meter distance along the baseline.
TRANSECT_N	Transect Number. Transects are numbered sequentially along the baseline.
STATION_LO	Station Location. The meter distance of each sample station along the transect.
STATION_NO	Station Number. The baseline position is the 0 position of each transect. The stations along the transects are numbered away from the baseline.
CHIP	Field identification number of clam sample to match sample with sample station.
SPECIES	Clam species being measured. LN = NATIVE LITTLENECK, *Protothaca staminea* ML = MANILA LITTLENECK, *Tapes japonica, (only one found in entire survey)* BN = BENTNOSE, *Macoma nasuta* CO = COCKLE, *Clinocardium nuttallii* BU = BUTTER, *Saxidomus giganteus* GA = GAPER, *Tresus capax* INQ = IRUS, *Macoma inquinata*
LENGTH	Individual clam length measured with calipers in millimeters. The length of the shell is measured on the longest dimension of each clam species. All clams measured side-to-side except cockles which were measured from umbo to top.
WEIGHT	The individual weight of each clam measured in grams.
AGE	The age of each clam as determined by counting annular growth rings.
SAMPLE_SIZ	Sample size. Indicates the sample size in meters that each clam came from. One meter samples are from all sample sites. Eight meter samples came from area I13 at the beginning of our sample season when the sample design was still being developed.

*Clams from I13 with no transect or station information but complete length, weight, and age data are a subsample of all I13 clams. Only lengths were obtained for all I13 clams along with their appropriate transect and station information. Column header descriptors for adult clam measurement database.

Column header descriptors for set clam measurement database.
Excel file allset.xls

Field Name	Descriptor
DATE	Date of sampling effort.
SITE	Sample site. "I" indicates intertidal area and "S" indicates subtidal sampling area.
TRANSECT_L	Transect Location. The meter distance along the baseline.
TRANSECT_N	Transect Number. Transects are numbered sequentially along the baseline.
STATION_LO	Station Location. The meter distance of each sample station along the transect.
STATION_NO	Station Number. The baseline position is the 0 position of each transect. The stations along the transects are numbered away from the baseline.
CHIP	Field identification number of clam sample to match sample with sample station.
SPECIES	Clam species being measured. LN = native littleneck, *Protothaca staminea* CO = cockle, *Clinocardium nuttallii* BU = butter, *Saxidomus giganteus* GA = gaper, *Tresus capax* BN = bentnose, *Macoma nasuta* MI = irus, *Macoma inquinata* CM = false mya, *Cryptomya californica* MB = balthic, *Macoma balthica* MS = secta, *Macoma secta* (one unconfirmed identification)
LENGTH	Individual clam length measured with calipers in millimeters. The length of the shell is measured on the longest dimension of each clam species. All clams measured side-to-side except cockles which were measured from umbo to top.
WEIGHT	The individual weight of some clams measured in grams.
AGE	The age of some clams as determined by counting annular growth rings.
COLOR	Color of individual *Macoma balthica*.

Column header descriptors for shrimp survey database.
Excel file v2shrimp.xls

Field Name	Description
SITE	Survey sample site. SS indicates shrimp survey sites.
UTM EASTING	UTM Easting coordinate of sample site.
UTM NORTHING	UTM Northing coordinate of sample site.
GPS DATUM	GPS map Datum used in GPS receiver at sample site.
SHRIMP BURROWS:	
Rep1	Replicate 1, 0.25 m^2 quadrat count of shrimp burrows.
Rep2	Replicate 2, 0.25 m^2 quadrat count of shrimp burrows.
Rep3	Replicate 3, 0.25 m^2 quadrat count of shrimp burrows.
SHRIMP MEAN	Mean shrimp burrow count per 0.25 m^2 at each survey location.
%Species:	
UPO	Percent of *Upogebia* in the shrimp population at shrimp survey sites.
NEO	Percent of *Neotrypaea* in the shrimp population at shrimp survey sites.
EELGRASS#(1/4M):	
Rep1	Replicate 1, 0.25 m^2 quadrat count of eelgrass turions.
Rep2	Replicate 2, 0.25 m^2 quadrat count of eelgrass turions.
Rep3	Replicate 3, 0.25 m^2 quadrat count of eelgrass turions.
EELGRASS MEAN	Mean eelgrass turion count per 0.25 m^2 at each survey location.
%SAND	Percent sand greater than 67 microns in the sediment at some survey sites.

Column header descriptors for intertidal rapid assessment survey database.
Excel file radata.xls

Field Name	Description
SITE	Survey sample site. RI indicates intertidal rapid assessment survey sites.
UTM EASTING	UTM Easting coordinate of sample site.
UTM NORTHING	UTM Northing coordinate of sample site.
GPS DATUM	GPS map Datum used in GPS receiver at sample site.
SHRIMP BURROWS:	
Rep1	Replicate 1, 0.25 m^2 quadrat count or description of shrimp burrows.
Rep2	Replicate 2, 0.25 m^2 quadrat count or description of shrimp burrows.
Rep3	Replicate 3, 0.25 m^2 quadrat count or description of shrimp burrows.
SHRIMP MEAN	Mean shrimp burrow count per 0.25 m^2 or description at each survey location.
EELGRASS# 1/4m^2:	
Rep1	Replicate 1, 0.25 m^2 quadrat count or description of eelgrass turions.
Rep2	Replicate 2, 0.25 m^2 quadrat count or description of eelgrass turions.
Rep3	Replicate 3, 0.25 m^2 quadrat count or description of eelgrass turions.
EELGRASS MEAN	Mean eelgrass turion count per 0.25 m^2 or description at each survey location.
ALGAE 1/4m^2	Percent algae or qualitative description of algae cover in 0.25 m^2 quadrat. S = sparse, M = moderate, D = dense
%SAND	Percent sand greater than 67 microns in the sediment at some survey sites.
SAND	Substrate type sand. The primary substrate is indicated by a one, the secondary substrate by a two, the next prevalent substrate by a three, and so on for all substrate types present in the sample. Method used in most of rapid assessment survey.
MUD	Substrate type mud. (See description of SAND).
SHELL	Substrate type shell. (See description of SAND).
GRAVEL	Substrate type gravel. (See description of SAND).
COBBLE	Substrate type cobble. (See description of SAND).
BEDROCK	Substrate type bedrock. (See description of SAND).
DEBRIS	Substrate type debris. (See description of SAND).

File Structure for Tillamook Bay Grab Sample Data Summary:
Excel 5 grab.xls

Field Name	Description
YEAR	**Year** of sampling event.
MONTH	**Month** of sampling event.
DAY	**Day** of sampling event.
TIME	**Time** of sampling event (PDT).
SITE	Sample **Site.** Indicates the sequential order in which samples were collected.
NUMBER	Sample **Number.** "G11" indicated Grab sample, site 1, replicate 1.
DEPTH	**Depth** of grab corrected for MLLW.
PENETRATION	**Penetration** of grab sample into sediment (cm).
SEDIMENT	**Sediment** type in grab sample. Symbols S, FS, CS, M, G, W and SH for Sand, Fine Sand, Coarse Sand, Mud, Gravel, Woody Debris, and Shell Debris, respectively. Data blanks are indicated with ND.
EASTING	UTM **Easting** coordinate of sample site.
NORTHING	UTM **Northing** coordinate of sample site.
DATUM	GPS map **Datum** used in GPS monitor at sample site.

Tillamook - ODFW
Invertebrate Species Checklist
By Marine Taxonomic Services, Ltd.
January 1997

Phylum Cnidaria
Class Anthozoa
Anthozoa sp. Indeterminate
Phylum Nemertea
Nemertea sp. Indeterminate
Phylum Nematoda
Nematoda sp. Indeterminate
Phylum Annelida
Class Polychaeta
Polychaeta sp. Indeterminate
Order Orbiniida
Family Orbiniidae
Orbiniidae sp. Indeterminate
Orbiniidae sp. Juvenile
Scoloplos sp. Juvenile
Family Paraonidae
Paraonella platybranchia (Hartman, 1961)
Order Spionida
Family Spionidae
Dipolydora cardalia Berkeley, 1927
Polydora cornuta Bosc, 1802
Polydora sp. Juvenile
Prionospio (Minuspio) lighti Maceolek, 1985
Prionospio sp. Indeterminate
Pseudopolydora kempi (Southern, 1921)
Pygospio elegans Claparede, 1863
Pygospio sp. 1
Pygospio sp. Indeterminate
Scolelepis sp. Indeterminate
Spio sp. Indeterminate
Spionidae sp. Indeterminate
Spionidae sp. Juvenile
Spiophanes berkeleyorum Pettibone, 1962
Spiophanes bombyx (Claparede, 1870)
Streblospio benedicti Webster, 1879
Family Magelonidae
Magelona longicornis Johnson, 1901
Magelona pitelkai Hartman, 1944
Magelona sp. Juvenile
Family Chaetopteridae
Spiochaetopterus costarum (Claparede, 1870)
Family Cirratulidae
Aphelochaeta monilaris (Hartman, 1960)

Aphelochaeta sp. Indeterminate

Order Capitellida

Family Capitellidae

Capitella capitata 'hyperspecies' (Fabricius, 1780)

Capitellidae sp. Indeterminate

Mediomastus californiensis Hartman, 1944

Mediomastus sp. Indeterminate

Notomastus (Clistomastus) tenuis Moore, 1909

Notomastus sp. Indeterminate

Order Opheliida

Family Opheliidae

Armandia brevis (Moore, 1906)

Ophelia limacina (Rathke, 1843)

Ophelia sp. Juvenile

Opheliidae sp. Indeterminate

Order Phyllodocida

Family Phyllodocidae

Eteone sp. Indeterminate

Eumida longicornuta (Moore, 1909)

Phyllodoce (Aponaitides) hartmanae Blake and Walton, 1977

Phyllodoce sp. Indeterminate

Phyllodoce sp. Juvenile

Phyllodocidae sp. Indeterminate

Phyllodocidae sp. Juvenile

Family Polynoidae

Harmothoe imbricata (Linnaeus, 1767

Hesperone laevis Hartman, 1961

Polynoidae sp. Indeterminate

Family Sigalionidae

Pholoe minuta (Fabricius, 1780)

Family Chrysopetalidae

Paleanotus bellis (Johnson, 1897)

Family Hesionidae

Hesionidae sp. Indeterminate

Heteropodarke heteromorpha Hartmann-Schroeder, 1962

Micropodarke dubia (Hessle, 1925)

Podarkeopsis glabra (Hartmann-Schroder, 1959)

Family Syllidae

Ehlersia heterochaeta Moore, 1909

Procerea cornuta (Agassiz, 1862)

Syllidae sp. Indeterminate

Family Nereidae

Neanthes (Hediste) limnicola (Johnson, 1903)

Nereidae sp. Indeterminate

Nereis sp. Indeterminate

Nereis sp. Juvenile

Platynereis bicanaliculata (Baird, 1863)

Family Glyceridae
Glycera americana Leidy, 1855
Glycera capitata Oersted, 1843
Glycera convoluta Keferstein, 1862
Glycera sp. Indeterminate
Family Goniadidae
Glycinde armigera Moore, 1911
Glycinde polygnatha Hartman, 1950
Glycinde sp. Juvenile
Family Nephtyidae
Nephtys caecoides Hartman, 1938
Nephtys cornuta Berkeley & Berkeley, 1945
Nephtys sp. Juvenile
Order Eunicida
Family Lumbrineridae
Lumbrineridae sp. Indeterminate
Family Dorvilleidae
Dorvilleidae sp. Juvenile
Order Oweniidae
Family Oweniidae
Owenia fusiformis delle Chiaje, 1844
Order Terebellida
Family Pectinariidae
Pectinaria californiensis Hartman, 1941
Family Ampharetidae
Ampharetidae sp. Juvenile
Hobsonia florida (Hartman, 1951)
Order Sabellida
Family Sabellidae
Manayunkia aestuarina (Bourne, 1883)
Sabellidae sp. Indeterminate
Class Oligochaeta
Oligochaeta sp. Indeterminate
Phylum Mollusca
Class Gastropoda
Gastropoda sp. Indeterminate
Gastropoda sp. Juvenile
Order Mesogastropoda
Family Lacunidae
Lacuna sp. Juvenile
Lacuna vincta (Montagu, 1803)
Family Rissoidae
Alvania compacta (Carpenter, 1864)
Family Caecidae
Fartulum Occidentale (Bartsch, 1920)
Order Neogastropoda
Family Muricidae
Nucella canaliculata (Duclos, 1832)
Family Olividae

Olivella baetica Carpenter, 1864
Order Nudibranchia
Nudibranchia sp. Indeterminate
Suborder Doridoida
Family Onchidorididae
Acanthodoris sp. Indeterminate
Class Bivalvia
Bivalvia sp. Juvenile
Order Mytiloida
Family Mytilidae
Mytilidae sp. Juvenile
Order Veneroida
Family Montacutidae
Mysella tumida (Carpenter, 1864)
Family Cardiidae
Clinocardium nuttalli (Conrad, 1837)
Clinocardium sp. Juvenile
Family Solenidae
Siliqua sp. Juvenile
Family Mactridae
Mactridae sp. Juvenile
Family Tellinidae
Macoma balthica (Linnaeus, 1758)
Macoma inquinata (Deshayes, 1855)
Macoma nasuta (Conrad, 1837)
Macoma sp. Juvenile
Tellina sp. Juvenile
Family Veneridae
Protothaca staminea (Conrad, 1837)
Saxidomus giganteus (Deshayes, 839)
Order Myoida
Family Myidae
Cryptomya californica (Conrad, 1837)
Mya arenaria Linnaeus, 1758
Myidae sp. Juvenile
Phylum Arthropoda
Class Pycnogonida
Order Pegmata
Family Ammotheidae
Achelia sp. Indeterminate
Subphylum Crustacea
Class Ostracoda
Order Myodocopida
Family Cylindroleberididae
Bathyleberis sp. Indeterminate
Class Copepoda
Order Calanoida
Calanoida sp. Indeterminate
Order Harpacticoida

Harpacticoida sp. Indeterminate
Order Cyclopoida
Cyclopoida sp. Indeterminate
Class Cirripedia
Order Thoracica
Suborder Balanomorpha
Family Balanidae
Balanus sp. Juvenile
Class Malacostraca
Order Mysidacea
Suborder Mysida
Family Mysidae
Archaeomysis grebnitzkii Czerniavsky, 1882
Order Cumacea
Family Leuconidae
Nippoleucon hinumensis (identification verified by Les Watling, University of Maine)
Family Nannastacidae
Cumella vulgaris Hart, 1930
Family Lampropidae
Lamprops quadriplicata Smith, 1879
Order Tanaidacea
Family Paratanaidae
Leptochelia dubia (Kroyer, 1842)
Family Tanaidae
Zeuxo sp. Juvenile
Order Isopoda
Family Sphaeromatidae
Gnorimosphaeroma oregonensis (Dana, 1852)
Family Idoteidae
Idotea fewkesi Richardson, 1905
Family Janiridae
Janiropsis kincaidi Richardson, 1904
Order Amphipoda
Family Pontogeneiidae
Pontogeneia cf. ivanovi Gurjanova, 1951
Family Pleustidae
Parapleustes pugettensis (Dana, 1853)
Family Phoxocephalidae
Eobrolgus chumashi Barnard & Barnard, 1982
Grandiphoxus grandis (Stimpson, 857)
Mandibulophoxus gilesi Barnard, 1957
Family Haustoriidae
Eohaustorius estuarius Bosworth, 1973
Eohaustorius sp. Indeterminate
Eohaustorius sp. Juvenile
Family Anisogammaridae
Eogammarus confervicolus (Stimpson, 1856)
Family Ampithoidae

Ampithoe sp. Indeterminate
Family Aoroidae
Grandidierella japonica Stephensen, 1938
Superfamily Corophioidea
Corophioidea sp. Juvenile
Family Corophiidae
Corophium acherusicum Costa, 1857
Corophium spinicorne (Stimpson, 1856)
Family Aeginellidae
Tritella sp. Indeterminate
Order Decapoda
Decapoda megalops sp. Indeterminate
Family Hippolytidae
Heptacarpus brevirostris (Dana, 1852)
Family Crangonidae
Crangon alaskensis Lockington, 1877
Crangon sp. Indeterminate
Family Upogebiidae
Upogebia pugettensis (Dana, 1852)
Family Callianassidae
Neotrypaea sp. Juvenile
Family Paguridae
Paguridae sp. Indeterminate
Pagurus hirsutiusculus (Dana, 1851)
Family Cancridae
Cancer magister Dana, 1852
Cancer productus Randall, 1839
Cancer sp. Juvenile
Family Grapsidae
Hemigrapsus oregonensis (Dana, 1851)
Hemigrapsus sp. Indeterminate
Phylum Phoronida
Family Phoronidae
Phoronida sp. Indeterminate
Phylum Echinodermata
Class Ophiuroidea
Ophiuroidea sp. Juvenile
Class Echinoidea
Order Clypeasteroida
Family Dendrasteridae
Dendraster excentricus (Eschscholtz, 1831)

File Structure for 1996 Tillamook Bay grab biomass data:
Excel biomas96.xls

Field Name	Description
STATION	Grab stations 1-17
REP	Replicate number 1-5 for each grab station.
POLYS	Biomass of polychaetes in grams from that particular replicate.
MOLLUSCS	Biomass of polychaetes in grams from that particular replicate.
CRUSTACEA	Biomass of crustacea in grams from that particular replicate.
MISC.	Biomass in grams of all other species not included in the three previous groupings from that particular replicate.

File Structure for raw 1997 Tillamook Bay grab invertebrate data:
Excel data.xls

Field Name	Description
SPECIES	Species grouped by Polychaeta, Mollusca, Crustacea, Miscellaneous
STATION	Column headings indicate grab stations G1-G17 and replicates 1-5 for each station.

File Structure for 1996 Tillamook Bay grab species voucher collection data:
Excel voucher.xls

Field Name	Description
TAXON	Species grouped by Polychaeta, Mollusca, Crustacea, Miscellaneous.
STATION	Grab stations (1-17) - Replicate number (1-5) for each grab station.
COUNT	Number of that identified species included in voucher collection.

File Structure for 1996 Tillamook Bay grab species voucher qa data:
Excel voucherqa.xls

Field Name	Description
TAXON	Species grouped by Polychaeta, Mollusca, Crustacea, Miscellaneous.
STATION	Grab stations (1-17) - Replicate number (1-5) for each grab station.
COUNT	Number of that identified species included in voucher collection.
ID by ER	Original identification confirmed, accepted or corrected. Corrections indicated by new species name. Comments indicated by *, in hard copy form only.