Chapter 6

Nearshore Biological Communities Prior to Removal of the Elwha River Dams

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Abstract

Increases in sediment delivery to coastal waters are expected following removal of dams on the Elwha River, Washington, potentially increasing sediment deposition on the seafloor and suspended sediment in the water column. Biological communities inhabiting shallow, subtidal depths (3–18 m) near the mouth of the Elwha River, between the west end of Freshwater Bay and the base of Ediz Hook, were surveyed in August and September 2008, to establish baselines prior to dam removal. Density was estimated for 9 kelp taxa, 65 taxa of invertebrates larger than 2.5 cm any dimension and 24 fish taxa. Density averaged over all sites was 3.1 per square meter (/m²) for kelp, 2.7/m² for invertebrates, and 0.1/m² for fish. Community structure was partly controlled by substrate type, seafloor relief, and depth. On average, 12 more taxa occurred where boulders were present compared to areas lacking boulders but with similar base substrate. Four habitat types were identified: (1) Bedrock/boulder reefs had the highest kelp density and taxa richness, and were characterized by a canopy of *Nereocystis leutkeana* ***(bull kelp) at the water surface and a secondary canopy of perennial kelp 1–2 m above the seafloor; (2) Mixed sand and gravel-cobble habitats with moderate relief provided by boulders had the highest density of invertebrates and a taxa richness nearly equivalent to that for bedrock/boulder reefs; (3) Mixed sand and gravel-cobble habitats lacking boulders supported a moderate density of kelp, primarily annual species with low growth forms (blades close to the seafloor), and the lowest invertebrate density among habitats; and (4) Sand habitats had the lowest kelp density and taxa richness among habitats and a moderate density of invertebrates. Uncertainties about nearshore community responses to increases in deposited and suspended sediments highlight the opportunity to advance scientific understanding by measuring responses following dam removal.***

Introduction

Two dams on the Elwha River have reduced sediment transport from the upper watershed to the lower river and coast for nearly 100 years (Duda and others, 2011, chapter 1, this report). Increases in sediment delivery to coastal waters are expected following dam removal, potentially increasing sediment deposition on the seafloor and suspended sediment in the water column. Large increases are expected initially (3–5 years after initiation of dam removal; Czuba and others, 2011, chapter 2, this report) as sediments that have accumulated behind the dams are released. Thereafter, sediment supply likely will decrease but should remain higher than before dam removal due to restored transport of sediments from the upper watershed. Much of the sediment currently impounded by the dams is silt, sand, and clay, which are readily transportable (Czuba and others, 2011, chapter 2, this report). Spatial patterns of suspended and deposited sediment in coastal waters will depend on local physical processes including waves and currents (Warrick and others, 2011b, chapter 5, this report). The amount, timing, and temperature of river water discharged into coastal waters are expected to be little changed by dam removal because the dams have been largely operated as “run of the river” (Duda and others, 2011, chapter 1, this report).

Sediment deposition and suspended sediment can have a variety of effects on nearshore plants and animals. Sediment deposition can affect organisms directly through burial, which can reduce light, oxygen, nutrients, and waste removal; scour, which can injure or dislodge organisms; and replacement of hard, stable substrate with finer particles that inhibit settlement for some organisms (Airoldi, 2003). Sediment deposition also can indirectly affect communities by altering outcomes of competitive and predator-prey interactions among species with different tolerances and responses to sedimentation (Airoldi and Cinelli, 1997; Airoldi and Virgilio, 1998). Suspended sediment increases turbidity, which reduces light penetration and can negatively affect photosynthetic organisms. Seaweeds and sea grasses require high ambient light, account for a large portion of the primary production in nearshore waters, and create three-dimensional structures inhabited by various species (Mumford, 2007); therefore, effects on them may propagate to other parts of the community. Turbidity also can influence competition among plant species with different light requirements, or affect competitive or predatory abilities of animals that depend on vision (Beauchamp and others, 1999). Direct effects of suspended sediment include damage to fish and invertebrate gills, and clogging or damage to feeding structures of filter feeders (Newcombe and MacDonald, 1991). Beds of seaweeds or sea grasses can dampen current velocities, thereby increasing sedimentation and decreasing suspended sediment within the beds (Madsen and others, 2001).

Substrate characteristics, including particle size, stability, and relief, are important for structuring benthic communities. Stable substrates of large particle size, for example bedrock and boulders, support various species adapted to attach to the substrate’s surface (Witman and Dayton, 2001). Fine sediments such as sand and silt do not provide attachment points but do permit burrowing and support various species adapted to living in the sediment (Lenihan and Micheli, 2001). Substrates of intermediate particle size (for example, gravel and cobble) provide some attachment space on their surfaces, but are subject to overturning and displacement by waves and currents, and support different communities compared to more stable rocky substrates (Scheibling and others, 2009). Propagules of some large seaweed species can start to grow on small rocks such as gravel or cobble. Drag on the seaweed increases as it grows, and depending on the size of the rock, the seaweed and the rock it is attached to may be lifted and transported (see Miller and others, sidebar 3.2, this report). A mixture of particle sizes offers a variety of habitats in close proximity. In high current environments, large substrates such as cobble and boulders can dampen current speeds, allowing retention of fine sediments that would otherwise wash away. The presence of fine sediments among larger substrates promotes coexistence of species adapted to different particle sizes. Seafloor relief in rocky habitats provides sloped and vertical surfaces that support different communities than horizontal surfaces. Relief also affects communities by modifying flow patterns (Witman and Dayton, 2001). Effects of sedimentation on benthic communities likely will vary among habitats with different substrate characteristics.

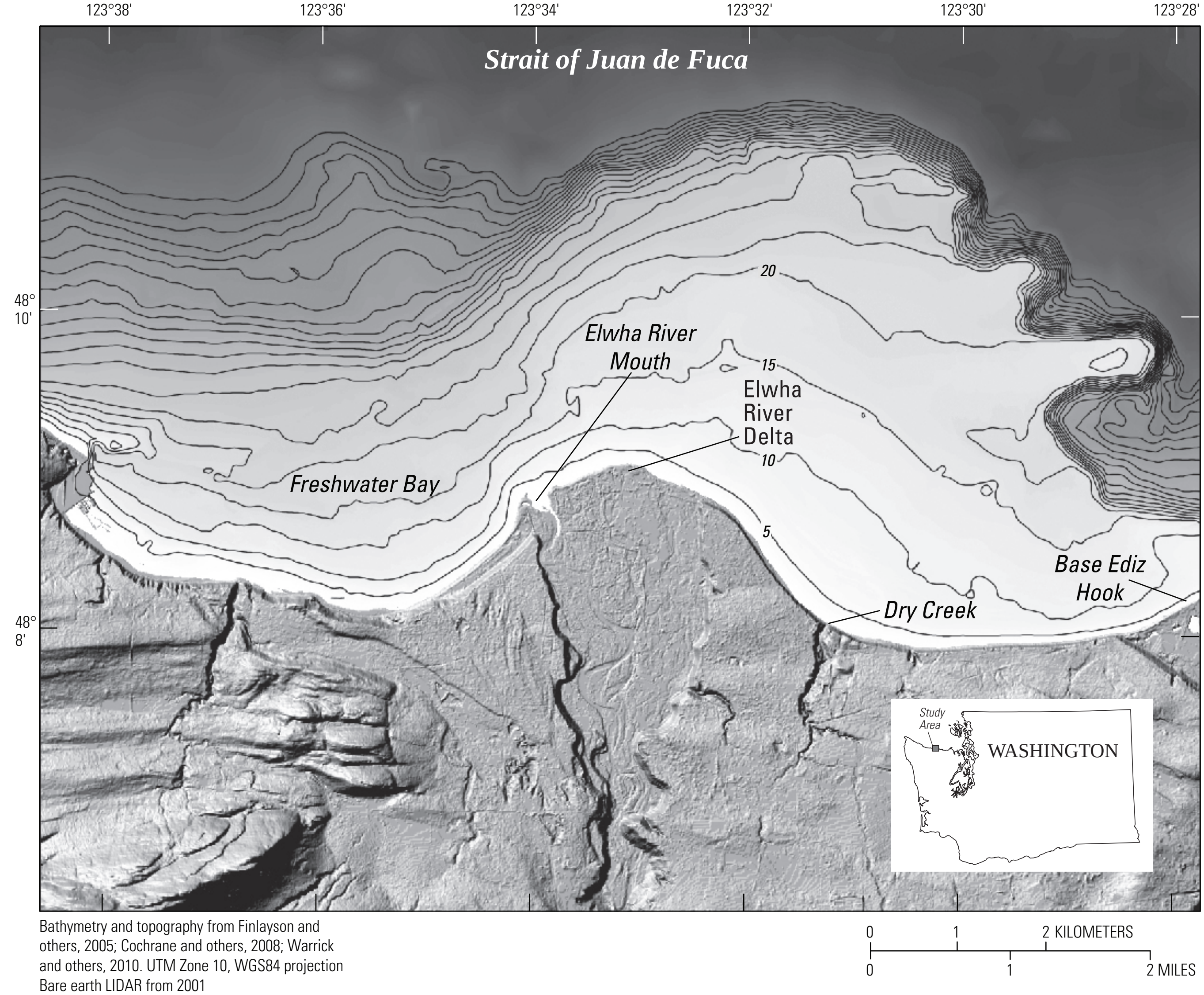
Purpose and Scope

This study was initiated in 2008 to characterize nearshore biological communities prior to removal of the Elwha River dams. The intent was to establish a baseline to measure changes following dam removal. In this chapter, two questions are addressed: (1) What communities currently are present in shallow subtidal areas potentially affected by dam removal? (2) What role does substrate play in structuring these communities?

Study Area

The study area includes shallow depths (3–18 m below mean lower low water [MLLW]) extending from the west end of Freshwater Bay to the base of Ediz Hook, a distance of 15 km (fig. 6.1). This range of depths should include most depths with sufficient light for photosynthesis and where kelp and other benthic macroalgae are dominant given suitable substrate for attachment (Whitman and Dayton, 2001; Mumford, 2007). The length of coast that will be affected by dam removal is not certain, but we expect that the boundaries west and east of the river mouth will include the affected area. They coincide with the boundaries of the Elwha nearshore defined by Shaffer and others (2008) except that their eastern boundary, the tip of Ediz Hook, is 5 km farther east.

Prominent features of the study area are Freshwater Bay, the Elwha River delta, which extends north into the Strait of Juan de Fuca, and the area east of the delta, which is sheltered by the delta to the west and Ediz Hook to the east. High bluffs border much of Freshwater Bay and the shore between Dry Creek and Ediz Hook. Bathymetry is steepest offshore of the river mouth, less steep in mid Freshwater Bay, and most gradual offshore of the eastern flank of the delta (fig. 6.1). Geomorphology of the study area is described in detail in Warrick and others, 2011a, chapter 3, this report.



Bathymetry and topography from Finlayson and others, 2005; Cochrane and others, 2008; Warrick and others, 2010. UTM Zone 10, WGS84 projection
Bare earth LIDAR from 2001

Figure 6.1. Southern waters of the Strait of Juan de Fuca near the mouth of the Elwha River, Washington. Five-meter bathymetry contours also are shown.

Previous Work

Sonar and video surveys were conducted in 2005 in Freshwater Bay and offshore of the Elwha River mouth to map bathymetry and characterize substrate type and distribution (Warrick and others, 2008). Sonar backscatter data and video footage were used to classify substrate as hard (bedrock or boulders), mixed (gravel and cobble), or soft (sand or sand waves) (Cochrane and others, 2008). Most of the hard substrate was in Freshwater Bay, particularly in mid Freshwater Bay close to shore (fig. 6.2*A*). Mixed substrate predominated offshore of the river mouth and in parts of Freshwater Bay. Areas of soft substrate occurred at the west and east ends of Freshwater Bay. The areas farthest offshore were characterized by a combination of mixed and soft substrate. The substrate classifications were integrated with other information, including delineation of bedrock outcrops and counts of boulders visible in the raw backscatter data, to form a substrate type and morphology map (fig. 6.2*B*; Warrick and others, 2008). Bedrock outcrops were apparent in mid Freshwater Bay close to shore. Boulder abundance was high (greater than 10,000/km^2) close to shore and intermediate (10–10,000/km^2) farther from shore in Freshwater Bay. Boulder abundance was low (less than 10/km^2) in a band extending from outer Freshwater Bay to the Elwha River delta.

Aerial photographs taken during 1989 to 2004 were used to map the annual spatial extent of overstory kelp (*Nereocystis leutkeana* [bull kelp] and *Macrocystis integrifolia* [giant kelp], which form a canopy at the water surface) in the Strait of Juan de Fuca (Berry and others, 2005). Kelp was most persistent (present nearly every year) in the area of hard substrate (bedrock outcrops and abundant boulders) in mid-Freshwater Bay (fig. 6.2*C*). Kelp also occurred frequently just to the northeast of the river mouth, where the sonar survey detected little hard substrate in 2005 (Warrick and others, 2008), and in a few patches between Dry Creek and the base of Ediz Hook. Rigg (1915) mapped kelp beds in the Strait of Juan de Fuca in 1911 and 1912.

The entire study area was surveyed in 2006 to map *Zostera marina* (eelgrass), and Freshwater Bay was resurveyed in 2009 (Norris and Fraser, 2009). In both years, a large *Z. marina* bed (23 ha) was present at the west end of Freshwater Bay in a sand-dominated area (fig. 6.2*A*–*B*). In both years a much smaller bed (2 ha) was present in east-central Freshwater Bay. This bed was inshore from the area surveyed for substrate and west of the sandy area identified by the sonar survey at the east end of Freshwater Bay. *Z. marina* was not detected anywhere else in the study area.

Scuba surveys by Seavey and Ging (1995) in 1994 characterized existing marine resources potentially affected by removal of the Elwha River dams. They identified the macroalgae community as a particularly important resource that could be affected by increased sediment load after dam removal. Their study area included depths from 0–15 m and extended from mid Freshwater Bay east to Dry Creek; however, they concentrated their sampling in shallow water (0–9 m) close to the river mouth and did more sampling east than west of the mouth because of their expectation that sediment deposition would be greatest in these areas. They detected high abundance and diversity of macroalgae. Percent cover of macroalgae was greater than 75 percent for 40 percent of their quadrates and greater than 50 percent for 73 percent of their quadrates (*n* quadrates = 836; area of each quadrate = 0.84 m^2). They reported 40 macroalgae taxa (genus or species level identifications) that occurred in at least one quadrate. They also reported 57 taxa of invertebrates and fish that occurred in at least one quadrate and provided density estimates for 15 invertebrate species. They did not provide density estimates for macroalgae. An important component of their results was a set of distribution maps for five macroalgae species and *Z. marina*, for percent cover of macroalgae, and for substrate types (10 classes). *Z. marina* was present in 6 percent of their quadrates.

Shaffer (2000) sampled seasonally (every 3 to 4 months) from March 1996 to April 1997 in two overstory kelp beds (3–6 m depth) in Freshwater Bay, one dominated by *N. leutkeana* and the other by *M. integrifolia*, as well as in a pair of *N. leutkeana* and *M. integrifolia* beds farther west in the Strait of Juan de Fuca. The percentage of cover between the substrate and 1 m above the substrate for three kelp species (*N. leutkeana*, *M. integrifolia*, and *Pterygophora californica*), fleshy red algae, and total vegetation was reported. The density for the three kelp species, *Haliotis kamtschatkana* (northern abalone), *Strongylocentros franciscanus* (red urchins), and *Strongylocentrotus droebachiensis* (green urchins) (*n* quadrates per bed per season = 10; area of each quadrate = 1.0 m^2) also was reported. Percentage of cover of total vegetation in the Freshwater Bay beds was lowest in December (35–55 percent) and highest in June and September (65–95 percent). *P. californica* was the densest of the three kelps in all seasons in the *N. leutkeana* bed in Freshwater Bay; *M. integrifolia* was always densest in the other Freshwater Bay bed. *H. kamtschatkana*, *S. franciscanus* and *S. droebachiensis* were present in the *N. leutkeana* bed (density less than or equal to 2 per m^2 per species) but were nearly absent from the *M. integrifolia* bed in Freshwater Bay.

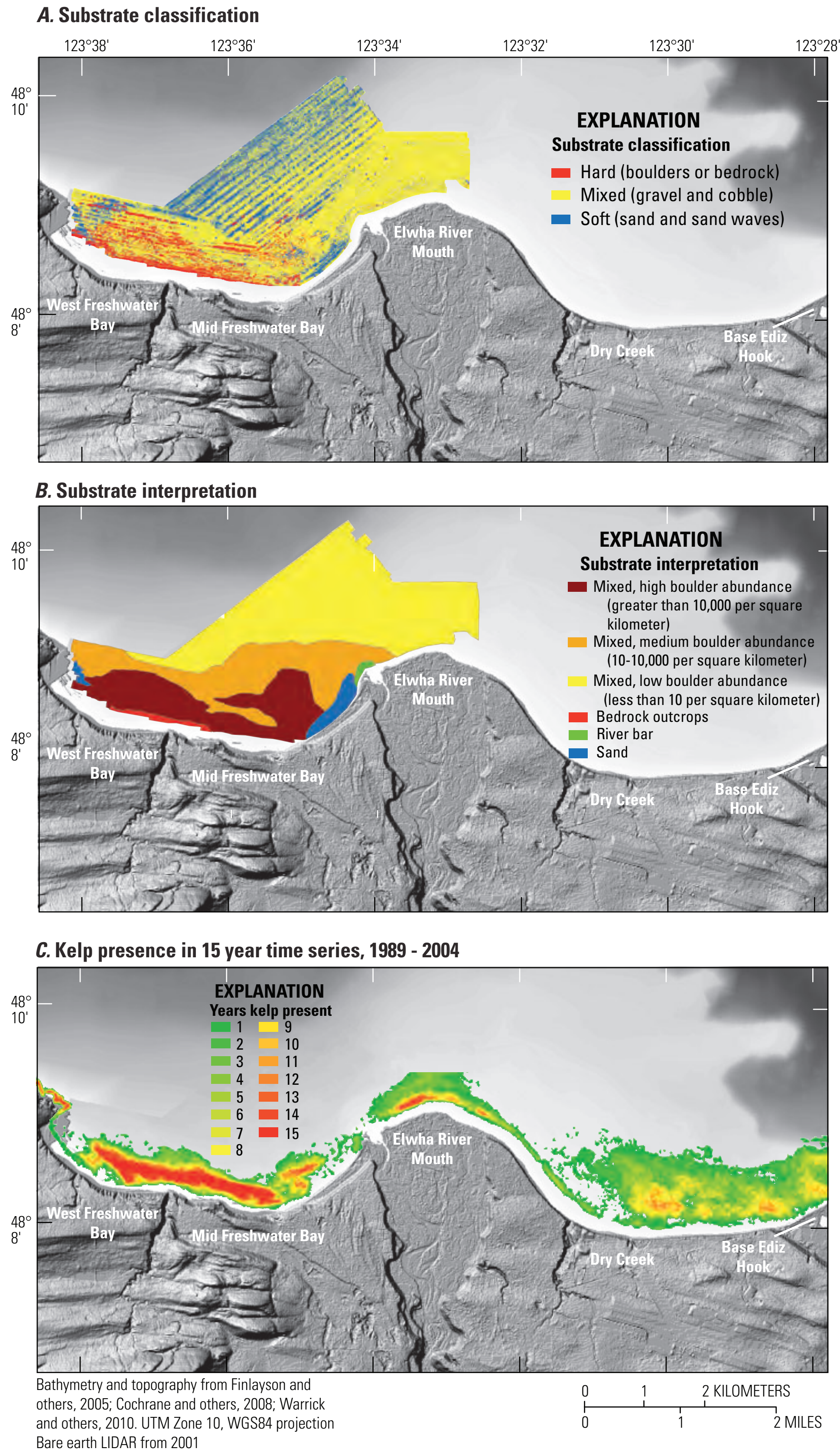


Figure 6.2. Substrates, and the extent of canopy forming kelp, near the mouth of the Elwha River, Washington. (*A*) Substrate classifications from acoustic backscatter data (Cochrane and others, 2008). (*B*) Substrate type and morphology formed by integrating substrate classifications and other information including delineation of bedrock outcrops and counts of boulders visible in the raw backscatter data (Warrick and others, 2008). (*C*) Presence and persistence of surface canopy forming kelp from annual aerial photographs taken in 1989–2004 (Berry and others, 2005).

In 2005 and 2006, the Washington Department of Fish and Wildlife (WDFW) established four permanent sites, marked with metal fence posts driven into the substrate, to assess effects of removal of the Elwha River dams, particularly effects on commercially important shellfish species (Michael Ulrich, Washington Department of Fish and Wildlife, written commun., February 26, 2010). Three sites consisted primarily of large and small boulders, cobble, and solid rock. Two sites were located in Freshwater Bay and considered treatment sites potentially affected by dam removal, and the third was located near Green Point, 21 km east of the Elwha River mouth, and considered a control site unlikely to be affected. One treatment site and the control site were established in 2005 and resurveyed in 2006 and 2007. The other treatment site was established in 2006 and resurveyed in 2007. A treatment site characterized by soft substrate was established offshore of the Elwha River mouth and surveyed in 2006. Sites were rectangular with areas ranging from 140 to 250 m^2. Site depths ranged from 11 to 15 m. Census counts were made for commercially important species including *H. kamtschatkana*, *S. franciscanus*, *S. droebachiensis*, and *Parastichopus californicus* (California sea cucumbers) at the rocky sites, and *Panopea generosa* (geoduck clams) and *Tresus capax* (horse clams) at the soft substrate site. Presence or absence was recorded for other animal and plant species. *S. franciscanus* and *S. droebachiensis* were measured for size. The two rocky treatment sites were recently repurposed and will not be available for resurveying following dam removal; however, pre-removal data from these sites may prove valuable when comparing data collected at other sites with similar habitat.

Study Design

Our study design is based on a Before-After-Control-Impact approach (Underwood, 1994), with sampling effort concentrated in the area expected to be affected by dam removal and in two control areas where effects of dam removal are expected to be minimal. The control areas are offshore of Low Point and Green Point, 20 and 21 km west and east of the Elwha River mouth, respectively. The data reported herein constitute part of the “before” component of the study, and repeated sampling is expected following dam removal (“after”). Analysis of future changes in the control areas compared to changes near the Elwha River should allow for effects of dam removal to be separated from other potential effects such as interannual variability and climate change. Because the purpose of this chapter is to characterize areas potentially affected by dam removal, results from Low and Green points will not be presented.

Site Selection

Sites were randomly selected after stratifying the study area according to three factors: distance from the Elwha River mouth, water depth, and substrate type. Five distance bands were oriented north to south and spaced approximately evenly from the west to the east end of the study area, with the central band straddling the Elwha River mouth (fig.6.3). Three depth strata—3–6, 9–12, and 15–18 m below MLLW—were delineated (fig. 6.3) using the best available bathymetry data (Cochrane and others [2008] for Freshwater Bay and offshore of the river mouth; Finlayson [2005] elsewhere). The intersection of the cross-shore bands and the depth strata produced 15 “bins,” within which areas with different substrate types were identified based on substrate classifications by Cochrane and others (2008) from sonar surveys in Freshwater Bay and offshore of the Elwha River mouth (classifications were hard, mixed, or soft; fig. 6.2*A*), or on the presence of overstory kelp in the two cross-shore bands east of the river mouth that lacked substrate classifications from sonar. Berry and others (2005) mapped the spatial extent of overstory kelp for 15 years during 1989–2004 (fig. 6.2*C*). We inferred substrate type from overstory kelp frequency of occurrence by assuming that kelp were attached to hard substrate; categories were hard (kelp present in 9–15 years), mixed (kelp present in 1–8 years), and soft (kelp never present). Warrick and others (2008) determined that for depths less than 15 m, overstory kelp was present in 58 percent of the area classified as hard from sonar data, but was present in 18–23 percent of the area classified as mixed or soft from sonar data, providing some support for inferring substrate type from kelp presence.

At least one site was randomly selected within each cross-shore band by depth stratum by substrate type combination using a geographic information system. Not all three substrate types were present in every cross-shore band by depth combination (fig. 6.3). One site in the cross-shore band near Dry Creek was placed outside of its intended depth strata; for analyses, it was grouped with the stratum closest to it in depth.

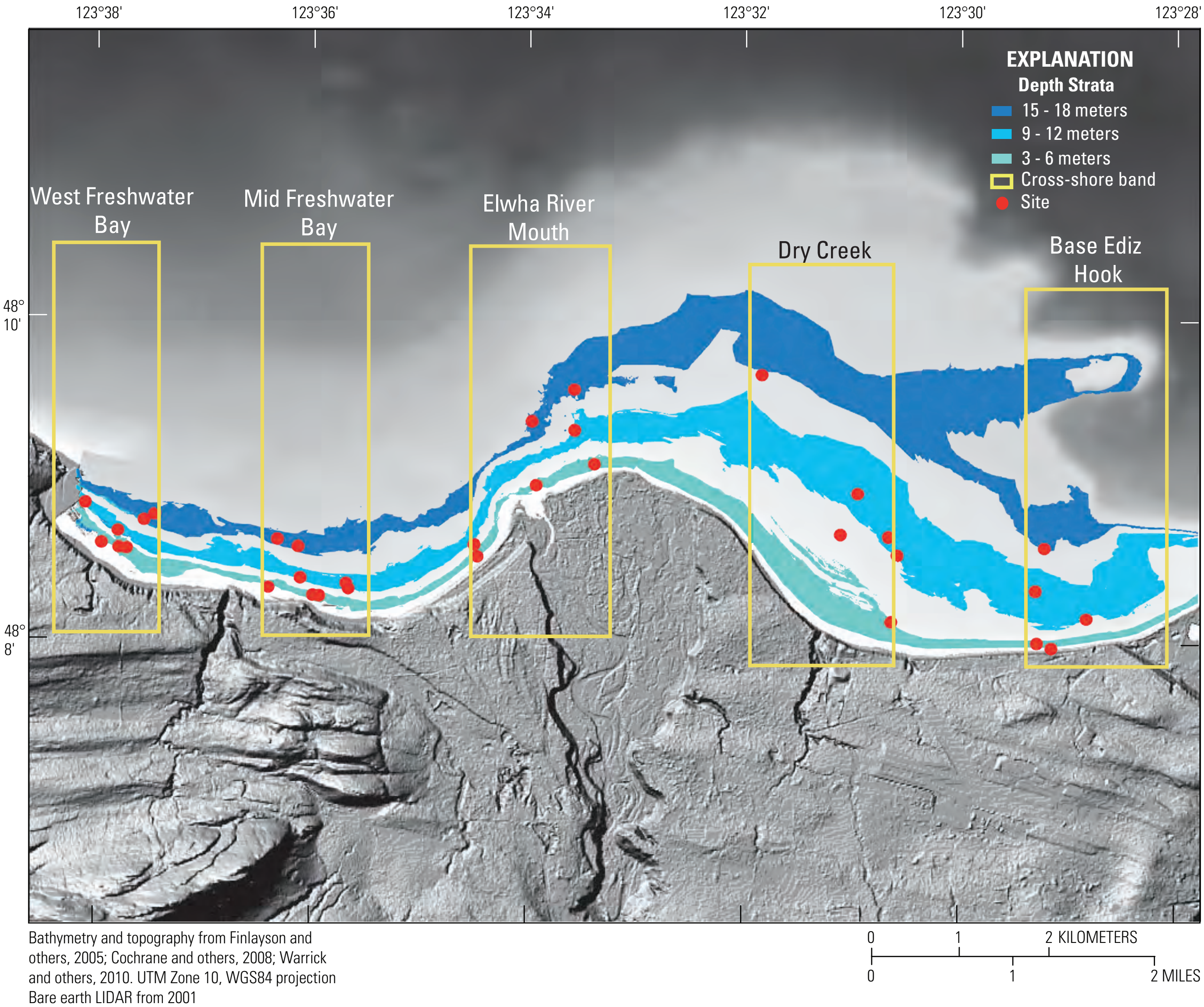


Figure 6.3. Three depth strata and five cross-shore bands at varying distances from the mouth of the Elwha River, Washington. Sites were randomly selected within each of the 15 distance by depth stratum "bins." Data were collected in at least two 30 meter-long shore-parallel transects at each site. One site in the Dry Creek band was placed outside of its intended depth strata; for analyses, it was grouped with the stratum closest to it in depth (3–6 meters).

Data Collection

Data collection methods were adapted from protocols developed by the Partnership for Interdisciplinary Studies of Coastal Oceans (2011) for monitoring ecosystems associated with rocky reef habitats (Carr and others, 2001). Data were collected at 30 m-long transects. Swath surveys were conducted to estimate density. Individual organisms present in a swath of fixed width along the entire transect were identified to the lowest practicable taxonomic level and counted. Measurements taken at discrete points along the transect were used to estimate percent coverage of different substrate types and seafloor relief categories.

We navigated to each randomly selected site using a Wide Area Augmentation System-enabled Global Positioning System (±5 m accuracy) and dropped the boat anchor. Two teams of two divers descended the anchor line and established transects in opposite, approximately shore-parallel directions using compass bearings taken at the surface (fig. 6.4*A*). Water visibility was measured by each team at the anchor as the distance at which one diver could see two fingers held up by the other. Visibility ranged from 4–14 m (mean=8 m) among sites. Depth at transect starting and ending points was recorded from dive computers.

Fish Swath

The fish survey was initiated 10 m from the anchor. One diver swam slightly ahead of the other and counted all conspicuous fish within a 2 m wide by 2 m high swath. The second diver reeled out a measuring tape along the transect line while watching for fish.

Invertebrate and Kelp Swaths

At the 40 m mark, the tape was secured and both divers proceeded back along the transect, one identifying and counting invertebrates in a swath on one side of the tape and the other doing the same for kelp on the other side of the tape (fig. 6.4*B*). Fish observed during the invertebrate or kelp surveys but not observed during the fish survey (typically small, cryptic individuals touching the substrate) were noted and included in fish density estimates. Invertebrate and kelp surveys were either 1 or 2 m wide based on the surveyor's judgment of whether the survey could be completed in a single dive. Surveys were only 2 m wide when organisms were sparse, visibility good, and depth shallow. Invertebrates greater than 2.5 cm (any dimension) for which individuals could be recognized (not encrusting or colonial species) were counted. *N. luetkeana* and *P. californica* with stipes greater than 30 cm long were counted. Other kelp species with combined stipe and blade lengths greater than 24 cm were counted. When *Z. marina* was observed, shoots present in the kelp swath were counted.

A variable area sampling method was used for swath surveys when high densities of invertebrates or kelp were encountered. The transect was divided into three 10 m increments (0–10, 10–20, 20–30). The surveyor counted individuals of a taxon until 30 individuals were counted or the end of the 10 m segment was reached. If 30 were counted before the end, the surveyor recorded the distance along the transect to that point and stopped counting the taxon until the start of the next 10 m segment.

Uniform Point Contact Survey

The uniform point contact (UPC) survey was started when invertebrate and kelp surveys were finished. Both divers participated, each working on separate 10-m segments of the 30 m transect. The UPC involved classifying sediment grain size and seafloor relief at 60 points spaced every 0.5 m along the transect (fig. 6.4*C*). Sediment directly under each point was classified as sand (less than 0.2 cm), gravel-cobble (0.2–25 cm), boulder (25 cm-1 m), or bedrock (greater than 1 m diameter). Relief was measured as the greatest elevation difference within a rectangle 1 m across the transect by 0.5 m along the transect and centered on the transect point (fig. 6.4*C*). Relief classifications were less than 0.1 m, 0.1–1 m, and greater than 1 m.

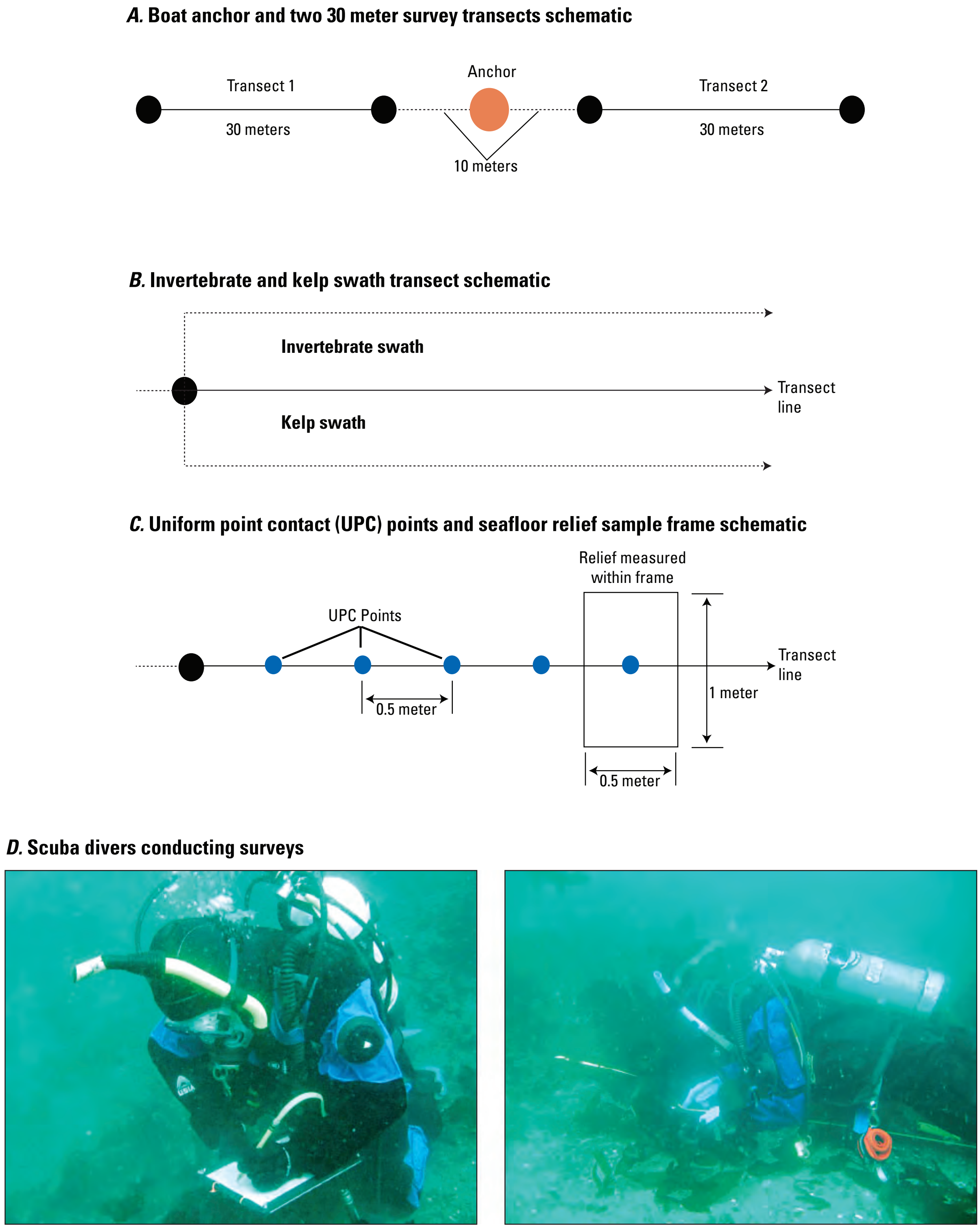


Figure 6.4. Schematic diagrams and photographs showing establishment of transects at a site. (*A*) Boat anchor and two 30 meter transects at one site; (*B*) invertebrate and kelp swaths along a transect; (*C*) uniform point contact (UPC) points spaced every 0.5 meter along a transect, and 0.5- by 1.0-meter rectangles centered on each UPC point. Seafloor relief was measured as the maximum elevation difference within a rectangle; (*D*) Scuba divers at work.

Other Aspects of Data Collection

If divers had adequate air and allowed bottom time, a second transect was done along the same bearing (third or fourth transect at the site), in which case that transect was started 20 m from the end point of the previous transect to maintain a 20 m spacing interval between transects.

Nine sites were surveyed between August 7 and 11, 2008, 14 sites between August 21 and 25, 2008, and 10 sites between September 5 and 7, 2008, for 75 transects completed at 33 sites (table 6.1). Additional sites were surveyed at control locations during these times (data not presented). Diving occurred on dates with low tidal exchanges to minimize current in August–September to optimize favorable weather and wind conditions. Local current predictions generated from current harmonics measured by instruments deployed around the Elwha River delta (Warrick and others, 2011b, chapter 5, this report) assisted with planning dives to coincide with reduced currents. All surveys were conducted during daylight hours. Surveys in 2009 were accomplished using the same methods as in 2008. Data from 2009 are preliminary and are not reported here.

Table 6.1. Completed transects and sites by cross-shore band and depth and substrate stratum, east, west, and at the mouth of Elwha River, Washington, August and September 2008.

[Site locations are shown in figure 6.3]

Cross-shore band	Depth stratum	Substrate stratum	Number of transects	Number of sites
West Freshwater Bay	3–6 meters	Hard	2	1
		Mixed	2	1
		Soft	2	1
	9–12 meters	Hard	2	1
		Soft	3	1
	15–18 meters	Hard	2	1
		Mixed	2	1
Mid-Freshwater Bay	3–6 meters	Hard	6	3
	9–12 meters	Hard	2	1
		Mixed	4	2
	15–18 meters	Hard	2	1
		Mixed	2	1
Elwha River Mouth	3–6 meters	Hard	2	1
		Mixed	2	1
		Soft	3	1
	9–12 meters	Mixed	2	1
		Soft	4	1
	15–18 meters	Mixed	4	2
Dry Creek	3–6 meters	Mixed	3	1
		Soft	2	1
	9–12 meters	Mixed	4	2
		Soft	2	1
	15–18 meters	Soft	2	1
Base Ediz Hook	3–6 meters	Mixed	2	1
		Soft	4	1
	9–12 meters	Hard	2	1
		Mixed	2	1
	15–18 meters	Soft	2	1
Total			**75**	**33**

Data Analyses

Scores were assigned to sediment grain size and relief classifications. Substrate classified as sand, gravel-cobble, boulder, or bedrock received a score of 1, 2, 3, or 4, respectively. A mean and standard deviation (SD) were then computed for each transect as the mean and SD of the substrate scores for each of the 60 UPC points. Relief classified as less than 0.1 m, 0.1–1 m, or greater than 1 m received a score of 1, 2, or 3, respectively; mean and SD relief scores were computed as for substrate.

Analyses were based on site means from data averaged over transects at a site. For purposes of analysis, data were frequently grouped by the cross-shore band and depth strata used in site selection, but to represent substrate type UPC classifications were used rather than the three *a priori* substrate strata.

Pearson's correlation coefficient (*r*; Sokal and Rohlf, 1995), which takes a value between -1 and +1, was used as a measure of association between two variables (for example, kelp density and mean substrate score). Values near 1 indicate that high values of one variable are associated with high values of the other. For example, an *r*-value near 1 for the correlation between kelp density and mean substrate score would indicate that sites with high kelp density also had high mean substrate scores. Values near -1 indicate that high values of one variable are associated with low values of the other, and values near 0 indicate no association between the two variables. Student's *t*-test (Sokal and Rohlf, 1995) was used to determine whether the mean (for example, mean kelp density) for one subset of sites (for example, deep sites) was different from the mean for a second subset of sites (for example, shallow sites). The notation $P<0.05$ was used to indicate that the correlation between two variables or the difference between two means was greater than what would be expected by chance (less than 5 times out of 100 by chance).

Substrate Composition and Relief

Substrate composition at sites ranged from entirely sand (grain size less than 0.4 cm) to mostly coarse grain sizes (boulders or bedrock) (fig. 6.5*A*). Bedrock primarily was at three shallow sites in mid-Freshwater Bay. Boulders were present in Freshwater Bay and offshore of the Elwha River mouth but were rare east of the river mouth. Areas of nearly pure sand were close to shore at the west and east ends of Freshwater Bay and at the base of Ediz Hook. Gravel-cobble substrate dominated at many of the deeper sites, particularly offshore of the Elwha River and Dry Creek.

Seafloor relief at sites ranged from nearly flat (100 percent less than 0.1 m) to moderate (mostly greater than 0.1 m) (fig. 6.5*B*). High relief (greater than 1 m) occurred only at a few sites in Freshwater Bay. Relief greater than 0.1 m was common offshore of the river mouth and to the west but was nearly absent at sites to the east of the river mouth.

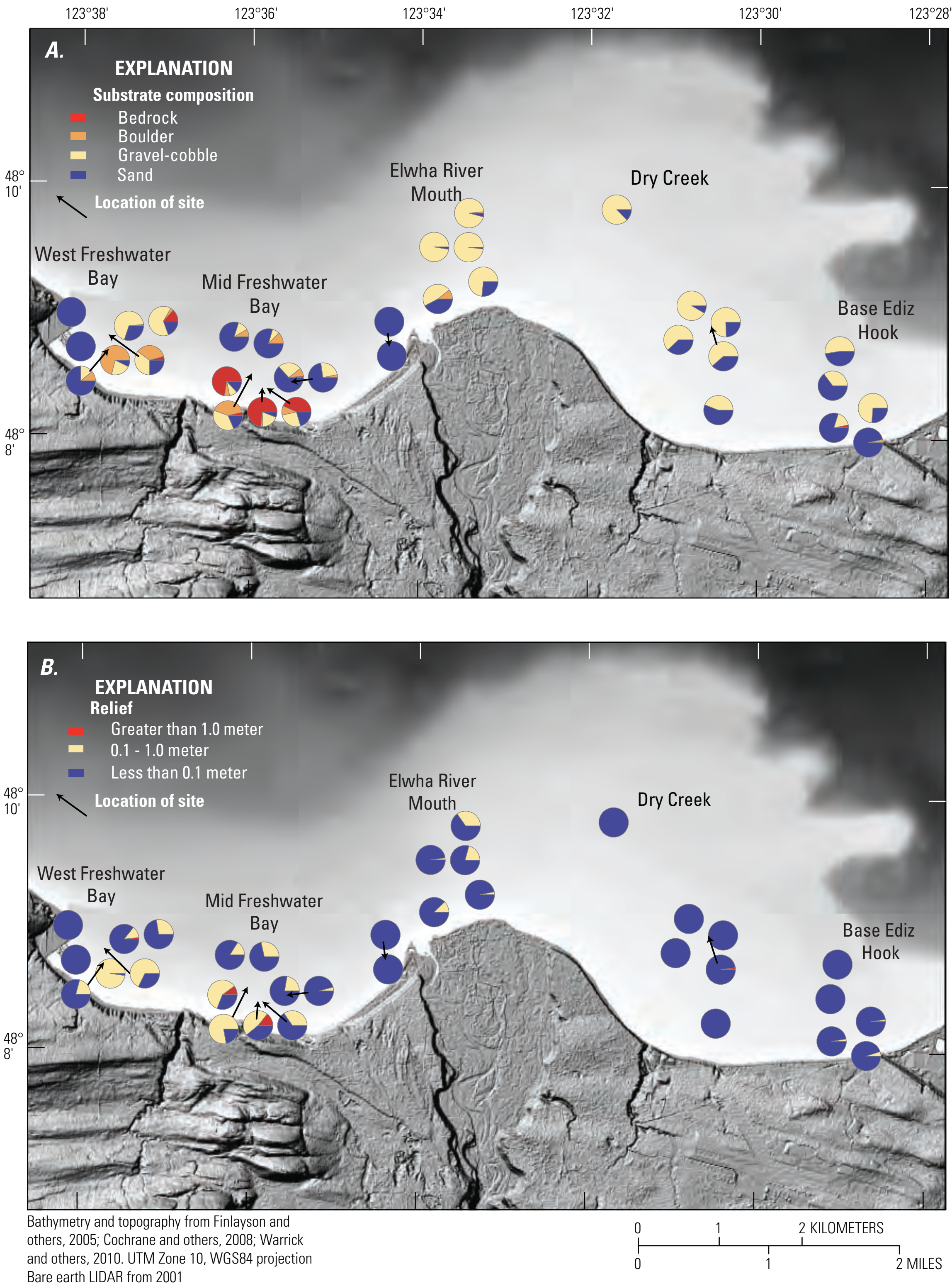


Figure 6.5. Substrate and relief at sites near the mouth of Elwha River, Washington, August and September 2008. (*A*) Substrate composition from classifications made at points spaced every 0.5 meter along 30-meter transects (usually 2 transects and 120 points per site). (*B*) Seafloor relief from classifications made at the same points as substrate classifications. At each point, maximum relief (elevation difference) within a 0.5- by 1.0-meter rectangle centered on the point was measured and binned as shown in the explanation.

Number of Taxa and Mean Density

Density was estimated for 9 taxa of brown algae, 65 invertebrate taxa, and 24 fish taxa (table 6.2). Organisms often were identified to species (67 taxa), but sometimes identification could be made only to genus (7 taxa) or to broader taxonomic categories (24 taxa). All the brown algae were from the order *Laminariales* which contains the large brown algae commonly known as kelp (O'Clair and Lindstrom, 2000; Gabrielson and others, 2006).

Mean density of organisms (averaged over all sites) was 3.10/m^2 for kelp, 2.69/m^2 for invertebrates, and 0.078/m^2 for fish (table 6.2). Mean density within invertebrate subgroups (phyla, subphyla, or classes) ranged from 1.40/m^2 for *Polychaeta* (polychaete worms) to 0.10/m^2 or less for *Cnidaria* (anemones and jellyfish), *Porifera* (sponges), and *Urochordata* (tunicates). High polychaete density was due to high densities of worms that build and live in soft (non-calcareous) tubes constructed from mucous combined with sediment or other local materials (families *Chaetopteridae*, *Maldanidae*, *Onuphidae*, *Sabellidae*, and *Terebellidae*; Lamb and Hanby, 2005). All of these worms were combined into one broad taxonomic category due to difficulties with consistently identifying to lower taxonomic levels. Some of the soft tube worms detected in the study area are shown in figure 6.6. Densities were low for *Cnidaria*, *Porifera*, and *Urochordata* partly because we could not reliably count individuals for the many colonial or encrusting species from these groups. Mean density within fish families ranged from 0.026/m^2 for *Cottidae* (sculpins) to 0.005/m^2 or less for several other families. Fish were combined into broad taxonomic categories (for example, flatfish) either because individuals swam away before they could be identified or because they were difficult to identify visually.

Z. marina (eelgrass) was present only at the west end of Freshwater Bay at two shallow sites with high percentages of sand. Shoot density was 8.9/m^2 at a site with 100 percent sand and 0.5/m^2 at a site with 75 percent sand.

Table 6.2. Number of taxa and mean density (averaged over all sites) from swath surveys for brown algae, invertebrates, and fish at sites near the mouth of the Elwha River, Washington, August and September, 2008.

[**Subgroup:** Order for brown algae, family for fish and mixed for inverebrates (P = phylum, SP = subphylum, C = Class). **Density:** Calculated as number per square meter]

Major group	Subgroup	Common name	Number by taxonomic level				Density
			Species	Genus	Higher	Total	
Brown algae	*Laminariales*	Kelp	**8**	**1**	**0**	**9**	3.10
Invertebrates	*Cnidaria* (P)	Anemones, jellyfish	7	2	1	10	0.10
	Crustacea (SP)	Barnacles, crabs, shrimps	8	0	6	14	0.37
	Echinodermata (P)	Sea cucumbers, stars, urchins	12	0	1	13	0.35
	Mollusca (P)	Chitons, clams, octopi, snails	13	4	5	22	0.42
	Polychaeta (C)	Polychaete worms	0	0	2	2	1.40
	Porifera (P)	Sponges	0	0	1	1	0.02
	Urochordata (SP)	Tunicates	2	0	1	3	0.03
	Total		**42**	**6**	**17**	**65**	2.69
Fish	*Bothidae, Pleuronectidae*	Flatfish	0	0	1	1	0.011
	Chimaeridae	Ratfish	1	0	0	1	0.003
	Cottidae	Sculpins	5	0	1	6	0.026
	Gadidae	Cods	1	0	0	1	0.005
	Hexagrammidae	Greenlings, lingcod	3	0	0	3	0.012
	Pholididae	Gunnels	0	0	1	1	0.015
	Stichaeidae	Pricklebacks, warbonnets	1	0	1	2	0.002
	Other		6	0	3	9	0.004
	Total		**17**	**0**	**7**	**24**	0.078
Total			**67**	**7**	**24**	**98**	**5.87**

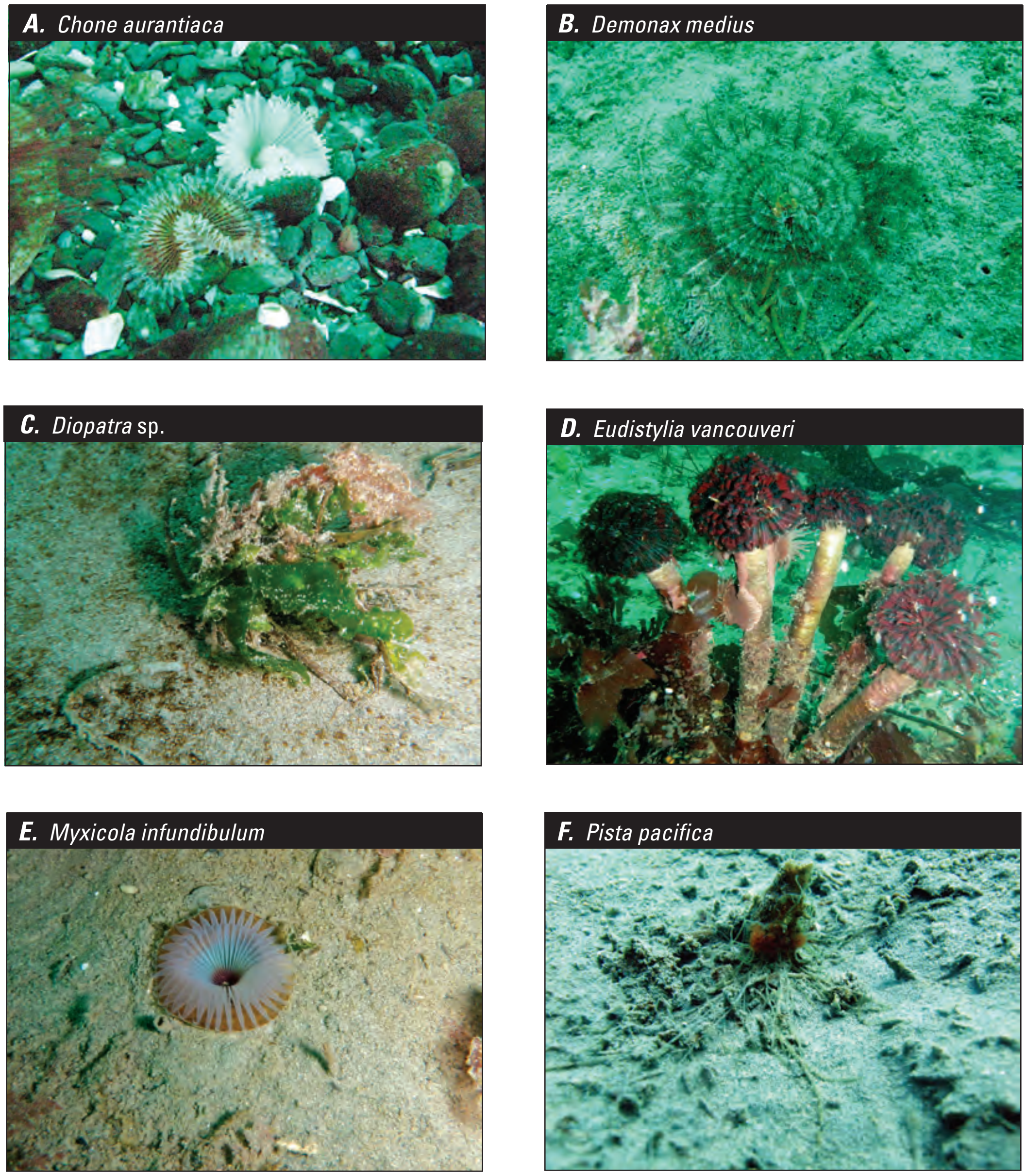


Figure 6.6. Soft tube worms commonly observed near the mouth of the Elwha River, Washington. The tentacular crown, visible for *Chone aurantiaca* (*A*) and several of the other species shown in the figure, serves the dual function of filter feeding and respiration. The crown can be retracted into the tube when the worm senses danger. *Diopatra* worms (*C*) festoon their tubes with local materials, sometimes completely concealing the tube as shown. *Pista pacifica* (*F*) feeds on detritus and small invertebrates on the surface of the substrate by extending the long bucal tentacles, visible here, from its tube. (*J*) The small and large diameter whitish tubes harbor unidentified species.

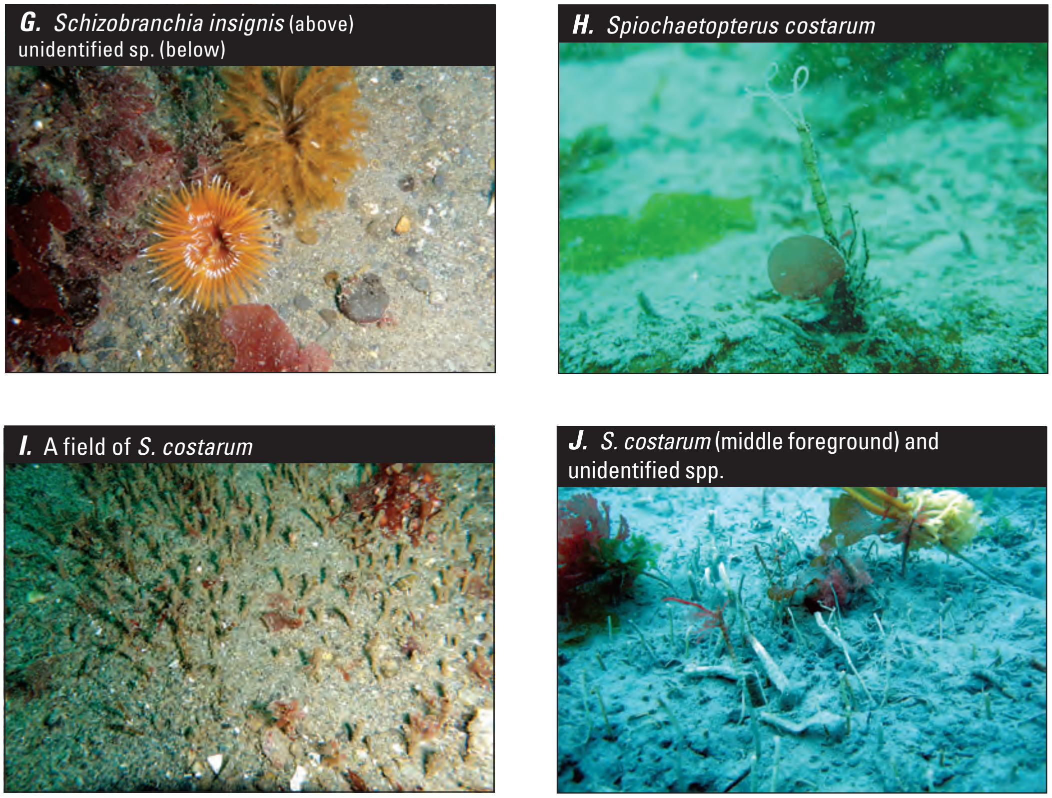


Figure 6.6.—Continued

Abundant Species

Ten species of kelp were observed at the study sites and counted during swath surveys (fig. 6.7). *N. luetkeana* (bull kelp) has a thin, flexible stipe (stem) that extends to or near the water surface, and blades (leaves) that are held there by pneumatocysts (floats). *P. californica* has a rigid stipe that extends upward 1–2 m and blades that can form a dense canopy at that level. The other eight species have short stipes, and their blades lie on or near the seafloor. Counts of *Saccharina latissima* and *Saccharina subsimplex* were combined (as *Saccharina* spp.) because we could not always distinguish small individuals. Both species were observed at the study sites based on characteristics of large individuals. *M. integrifolia* (giant kelp) was observed in the study area at the water surface but not on transects at our sites. Mean density for kelp taxa ranged from 0.91/m^2 for *P. californica* to 0.09/m^2 for *Alaria marginata* (fig. 6.8*A*).

Of the invertebrates identified to species, the 12 species with the highest mean densities across all sites included two crab species, two sea urchins, two sea stars, and one species each of sea cucumber, snail, jellyfish, clam, tunicate, and chiton (fig. 6.9). Densities for these species were an order of magnitude lower than for the kelp species (fig. 6.8*B*). Densities ranged from 0.09/m^2 for *Cancer oregonensis* (pygmy rock crab) to 0.02/m^2 for *Cryptochiton stelleri* (gumboot chiton). Combined density was 0.10/m^2 for the remaining invertebrates identified to species (the species with the 13th through the 42nd highest densities).

Of the fish identified to species, the seven species with the highest mean densities were *Hexagrammos decagrammus* (kelp greenling; 0.007/m^2), *Gadus macrocephalus* (Pacific cod; 0.006/m^2), *Hydrolagus colliei* (spotted ratfish; 0.003/m^2), *Ophiodon elongatus* (lingcod; 0.003/m^2), *Jordania zonope* (longfin sculpin; 0.002/m^2), *Blepsias cirrhosus* (silverspotted sculpin; 0.002/m^2), and *Hexagrammos stelleri* (whitespotted greenling; 0.002/m^2) (fig. 6.10). Combined mean density was 0.006/m^2 for the remaining fish identified to species.

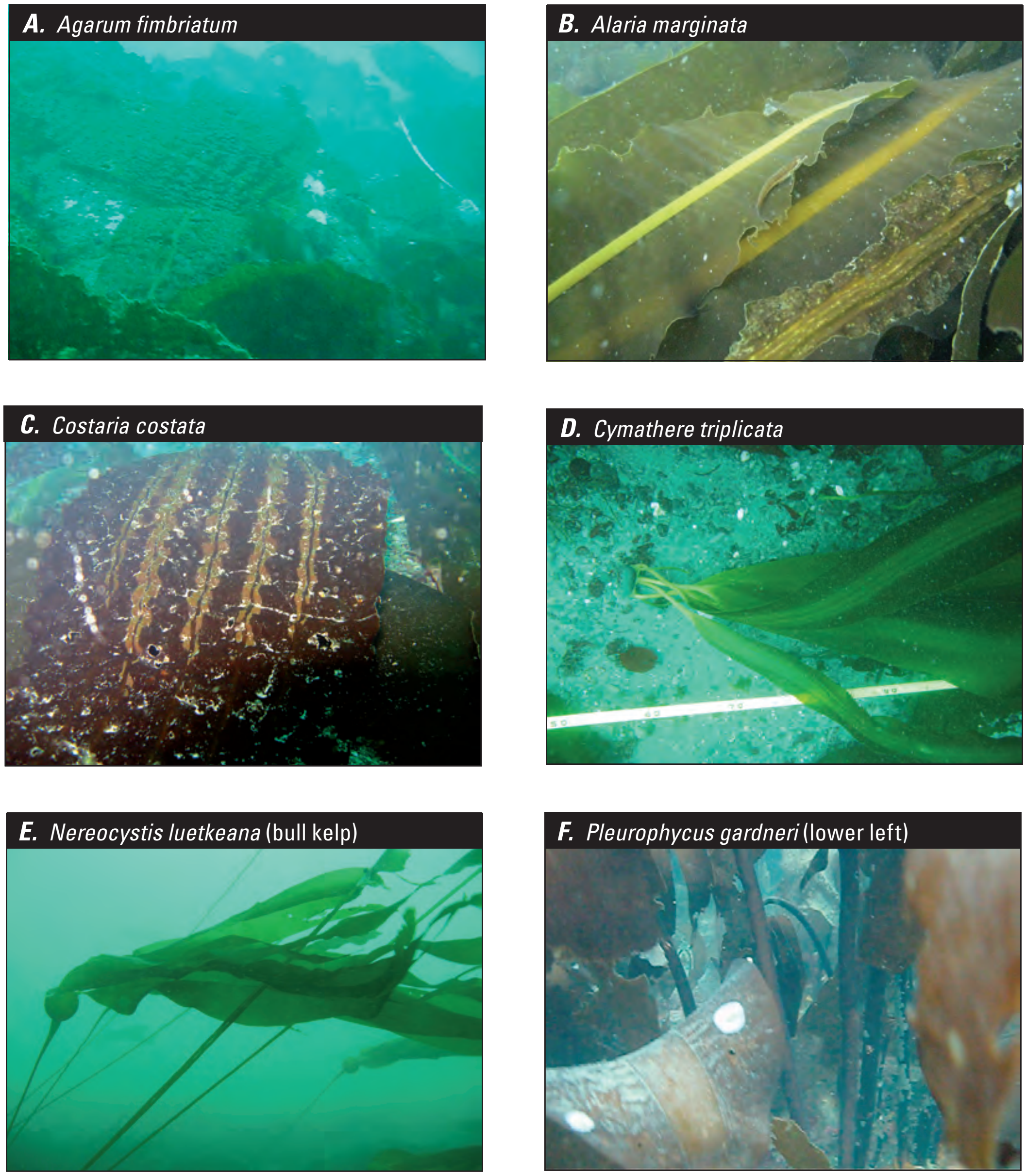


Figure 6.7. Nine kelp taxa (eight species and one genus comprising two species) surveyed for density near the mouth of the Elwha River, Washington. (*B*) Two individuals of *Alaria marginata* are shown (the two blades with light midribs in the center of the image); a *Synchirus gilli* (manacled sculpin) is perched on the upper of the two blades. (*D*) At least five individuals of *Cymathere triplicata* are attached to a single cobble. (*H*) Either *Saccharina latissima* or *S. subsimplex*. These two species sometimes cannot be distinguished without dissection.

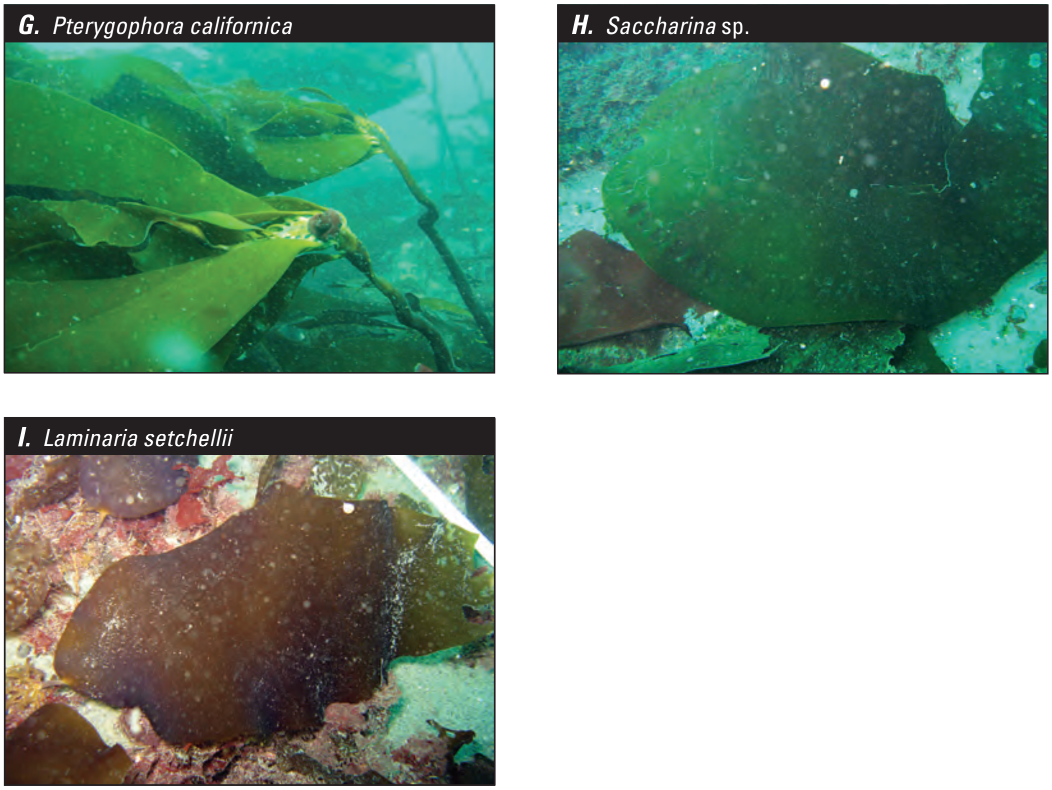


Figure 6.7.—Continued

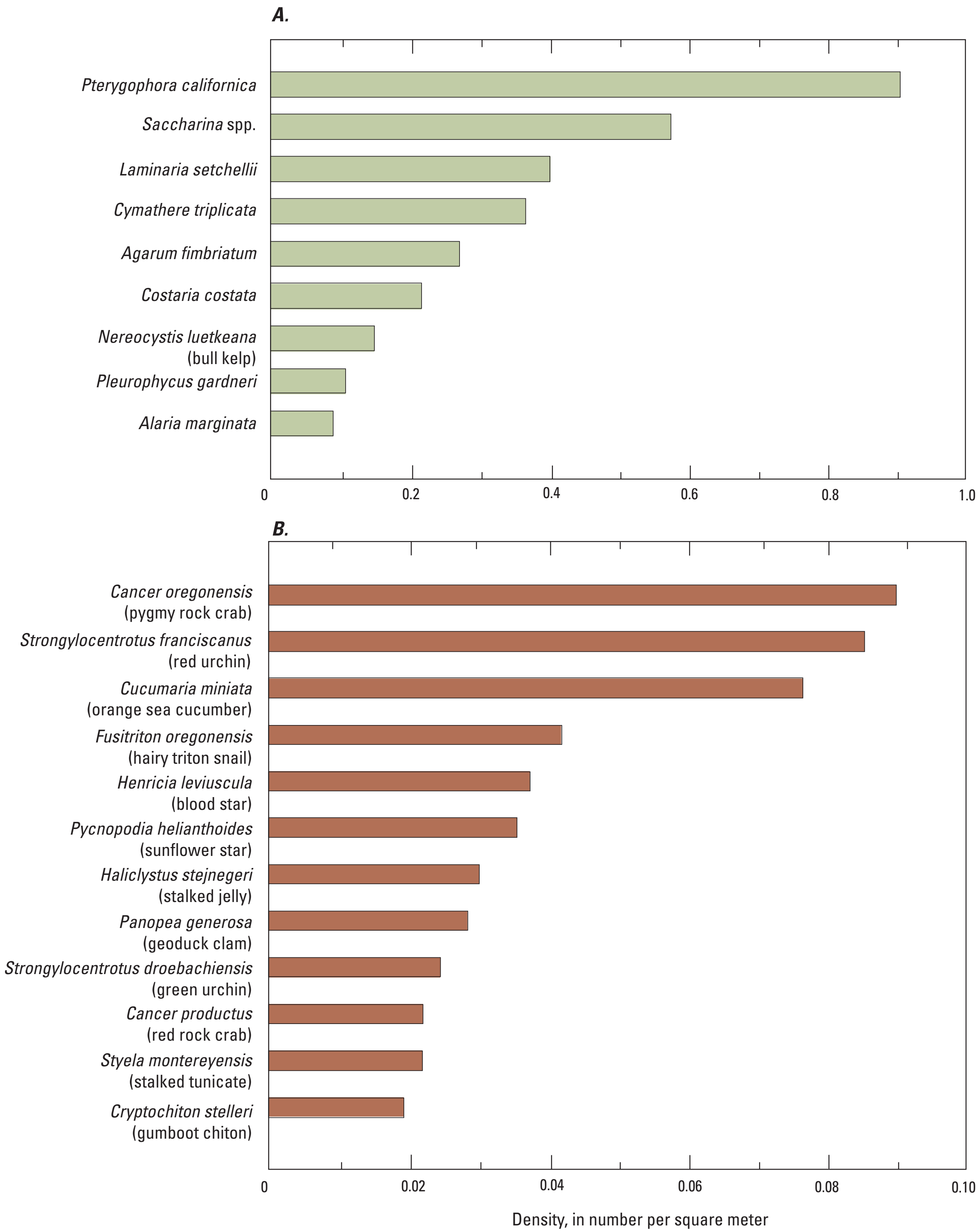


Figure 6.8. Mean density (averaged over all sites) for (*A*) 9 kelp taxa and (*B*) the 12 most common invertebrate species near the mouth of the Elwha River, Washington, August and September 2008. Note that densities are an order of magnitude lower for invertebrates than for kelp. *Saccharina* spp. includes two species, *S. latissima* and *S. subsimplex*, that were difficult to distinguish in the field.

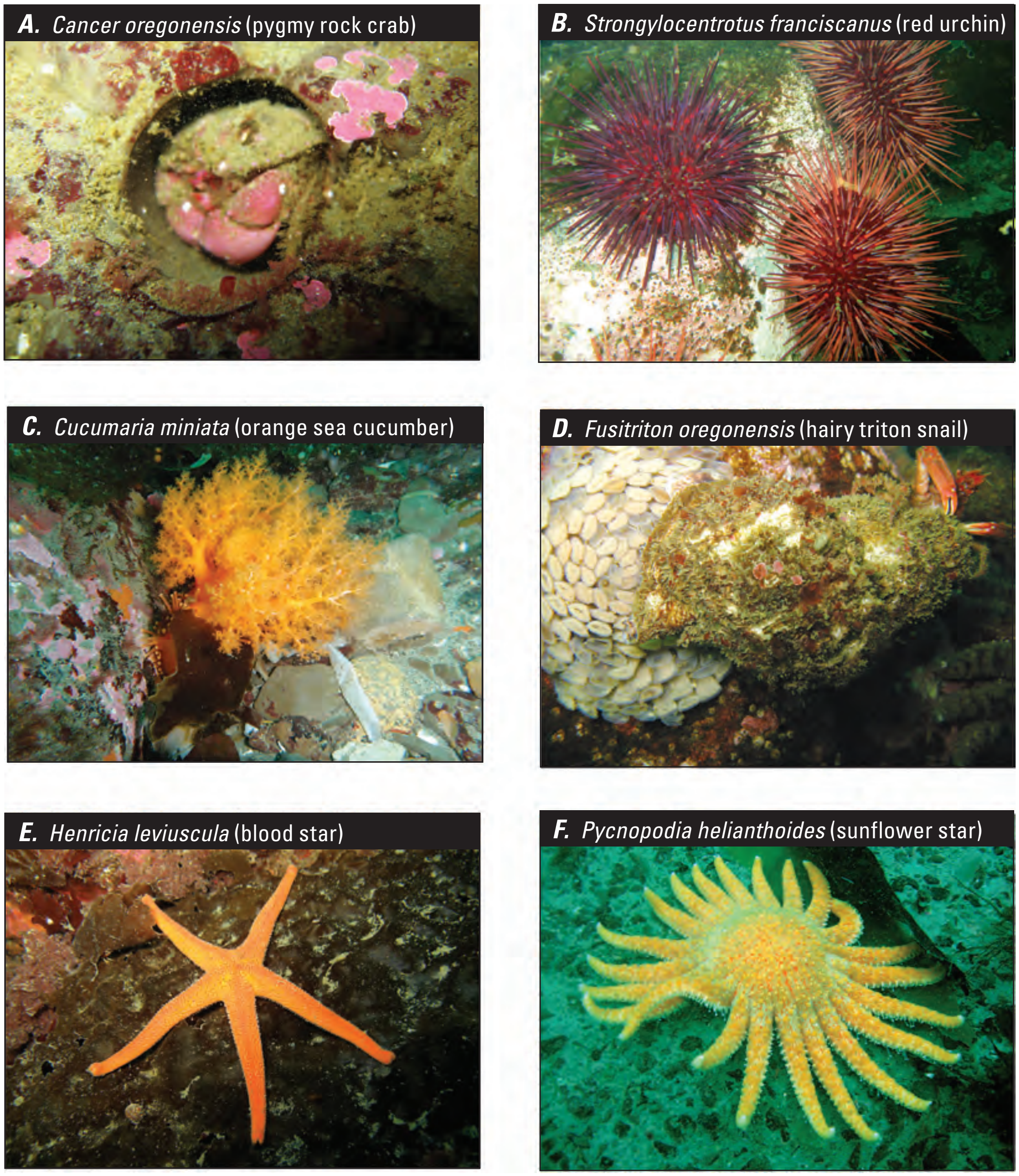
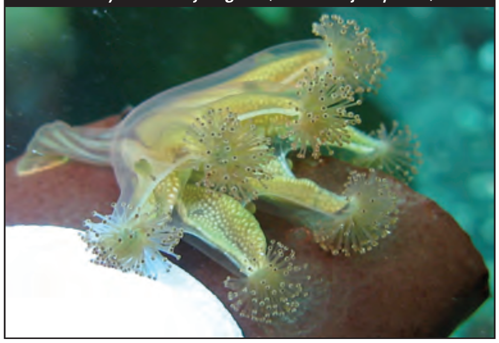


Figure 6.9. Twelve invertebrate species with the highest densities near the mouth of the Elwha River, Washington. Species are shown in order of decreasing density (fig. 6.8*B*). *Cancer oregonensis* (pygmy rock crab; *A*) is shown in a hole excavated in soft bedrock by a burrowing clam. *Haliclystus stejnegeri* (stalked jellyfish; *G*) adopts a sessile lifestyle by attaching to seaweed. *Panopea generosa* (geoduck clam; *H*) is shown with the tips of its siphons protruding from the sand.

G. *Haliclystus stejnegeri* (stalked jellyfish)



H. *Panopea generosa* (geoduck clam)

I. *Strongylocentrotus droebachiensis* (green urchin)

J. *Cancer productus* (red rock crab)

K. *Styela montereyensis* (stalked tunicate)

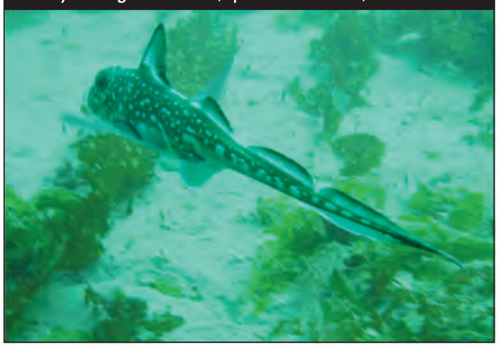
L. *Cryptochiton stelleri* (gumboot chiton)

Figure 6.9.—Continued

A. *Hexagrammos decagrammus* (kelp greenling)

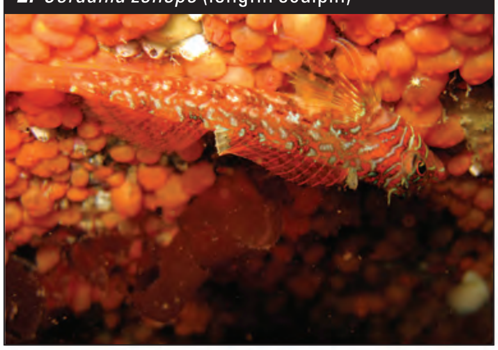
B. *Juvenile Gadus macrocephalus* (Pacific cod)

C. *Hydrolagus colliei* (spotted ratfish)



D. *Juvenile Ophiodon elongatus* (lingcod)

E. *Jordania zonope* (longfin sculpin)



F. *Blepsias cirrhosus* (silverspotted sculpin)

G. *Hexagrammos stelleri* (whitespotted greenling)

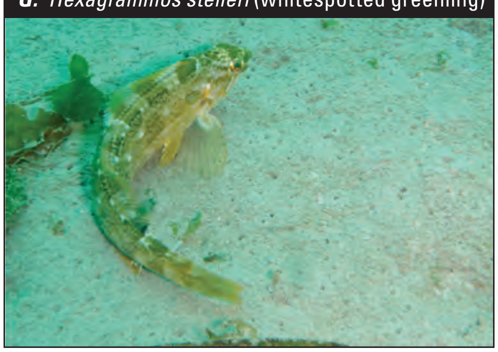


Figure 6.10. Seven fish species with the highest densities near the mouth of the Elwha River, Washington. Species are shown in order of decreasing density.

Spatial Patterns of Density and Taxa Richness

Kelp density was highest in mid- and west Freshwater Bay close to shore (fig. 6.11*A*) at sites with high percentages of hard substrate (bedrock or boulders; fig. 6.5*A*). Kelp density was low off Dry Creek and at two sandy sites southwest of the Elwha River mouth. The site with the highest invertebrate density, 18.5/m^2, was in mid-Freshwater Bay (fig. 6.11*B*). Most invertebrates at this site were polychaete worms with soft tubes (worm density=17.9/m^2). Invertebrate density was 5.8/m^2 at the site with the next highest invertebrate density. Invertebrate density was generally high offshore of the Elwha River mouth and to the west, and generally low off Dry Creek. Fish density was less variable across the study area than either kelp or invertebrate density (fig. 6.11*C*). Taxa richness (total number of taxa for kelp, invertebrates, and fish combined) was higher off the Elwha River mouth and to the west than to the east (fig. 6.11*D*).

Mean density and taxa richness within cross-shore band by depth “bins” are shown in figure 6.12. Kelp density was highest at shallow depths in mid-Freshwater Bay. Invertebrate density was generally higher at mid-depth and deep sites than at shallow sites. Taxa richness tended to be higher at deep sites than at shallow or mid-depths, although the highest taxa richness occurred at shallow depths in mid-Freshwater Bay. Invertebrate density and taxa richness were generally higher offshore of the river mouth and to the west than to the east.

Spatial and depth-related patterns of density varied among kelp taxa (fig. 6.13). *P. californica* achieved high densities at shallow depths in Freshwater Bay and occurred in nearly all combinations of depths and cross-shore bands. *N. luetkeana* also achieved high densities at shallow depths in Freshwater Bay and occurred widely at lower densities, although less widely than *P. californica*. Understory kelp (species with short stipes and with blades lying close to the substrate) exhibited a variety of spatial and depth-related patterns. *A. marginata* was detected at shallow and mid-depths but not at deep sites, and off the Elwha River mouth and to the east but not to the west. In contrast, *Agarum fimbriatum* was most abundant at deep sites, nearly absent at shallow sites, and was detected off the Elwha River mouth and to the west but not to the east. *Cymathere triplicata* was present at shallow and mid-depths but not deep sites in nearly all cross-shore bands. *Laminaria setchellii* was most abundant at deep sites off the mouth and was absent at shallow depths. *Saccharina* spp. was detected across all depths and cross-shore bands with no clear preference for particular depths or regions. Similarly, *Costaria costata* and *Pleurophychus gardneri* were widely distributed although both species were rare at shallow sites east of the river mouth.

Density patterns also varied among abundant invertebrates that were identified to species (figs. 6.14 and 6.15). *C. oregonensis* (pigmy rock crab), the species with the highest mean density across all sites (fig. 6.8*B*), also had the most restricted distribution. It primarily was detected at shallow depths in mid-Freshwater Bay (fig. 6.14), and within that cross-shore band by depth statum it was detected at only the three sites with high percentages of bedrock (fig. 6.5*A*) where it attained a high density (1/m^2). The limited distribution of *C. oregonensis* may have been due to an association with holes in the bedrock. Burrowing clams excavate holes in the relatively soft rock (fig. 6.16*A*). After the clams die, their holes provide daytime hiding places for *C. oregonensis* (fig. 6.9*A*) from which the crabs venture at night to feed (Jensen, 1995).

Most of the other 11 species of invertebrates with high mean densities (fig. 6.8*B*) could be placed into four distribution categories. *Pycnopodia helianthoides* (sunflower star) and *Cancer productus* (red rock crab) were widespread, occurring at nearly all combinations of depths and cross-shore bands (figs. 6.14 and 6.15). *S. franciscanus* (red urchin), *Cucumaria miniata* (orange sea cucumber), *Fusitriton oregonensis* (hairy triton snail), *S. droebachiensis* (green urchin), and *Styela montereyensis* (stalked tunicate) occurred off the Elwha River mouth and to the west, but not to the east, at all depths. *Haliclystus stejnegeri* (stalked jellyfish) was detected primarily at shallow depths where it often attached to vegetation (fig. 6.9*G*). *P. generosa* (geoduck clam) occurred primarily at deep sites. *Henricia leviuscula* (blood star) and *C. stelleri* (gumboot chiton) were harder to place into one of these four distribution categories. *H. leviuscula* was detected off the river mouth, to the west at all depths, and to the east but only at deep sites off Dry Creek. *C. stelleri* was widespread, but less so than *P. helianthoides* or *C. productus*.

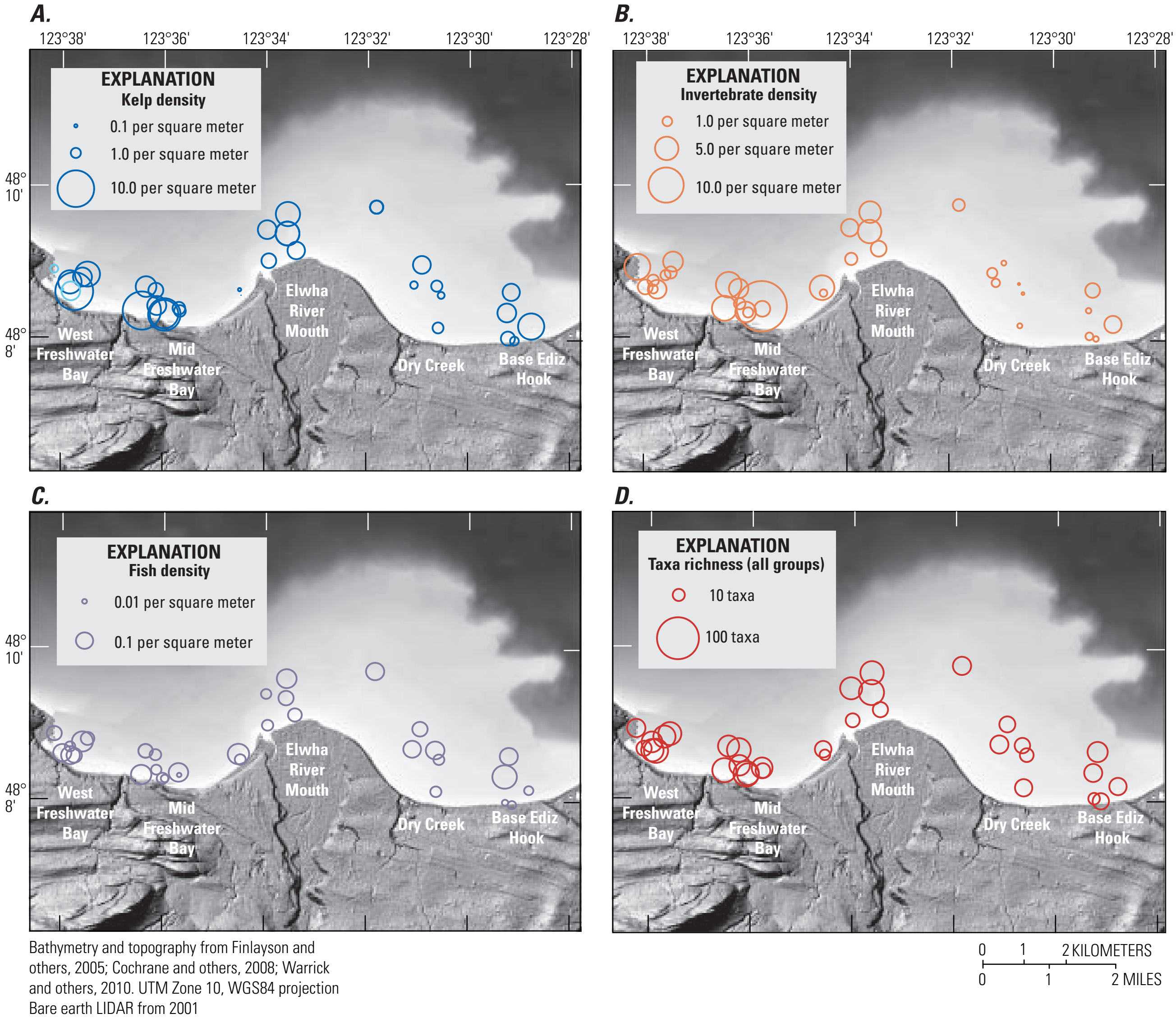


Figure 6.11. Density of (*A*) kelp, (*B*) invertebrates, and (*C*) fish, and (*D*) combined taxa richness for all three groups, at each of the 33 sampling sites near the mouth of the Elwha River, Washington, August and September 2008. Symbol size is proportional to density or taxa richness.

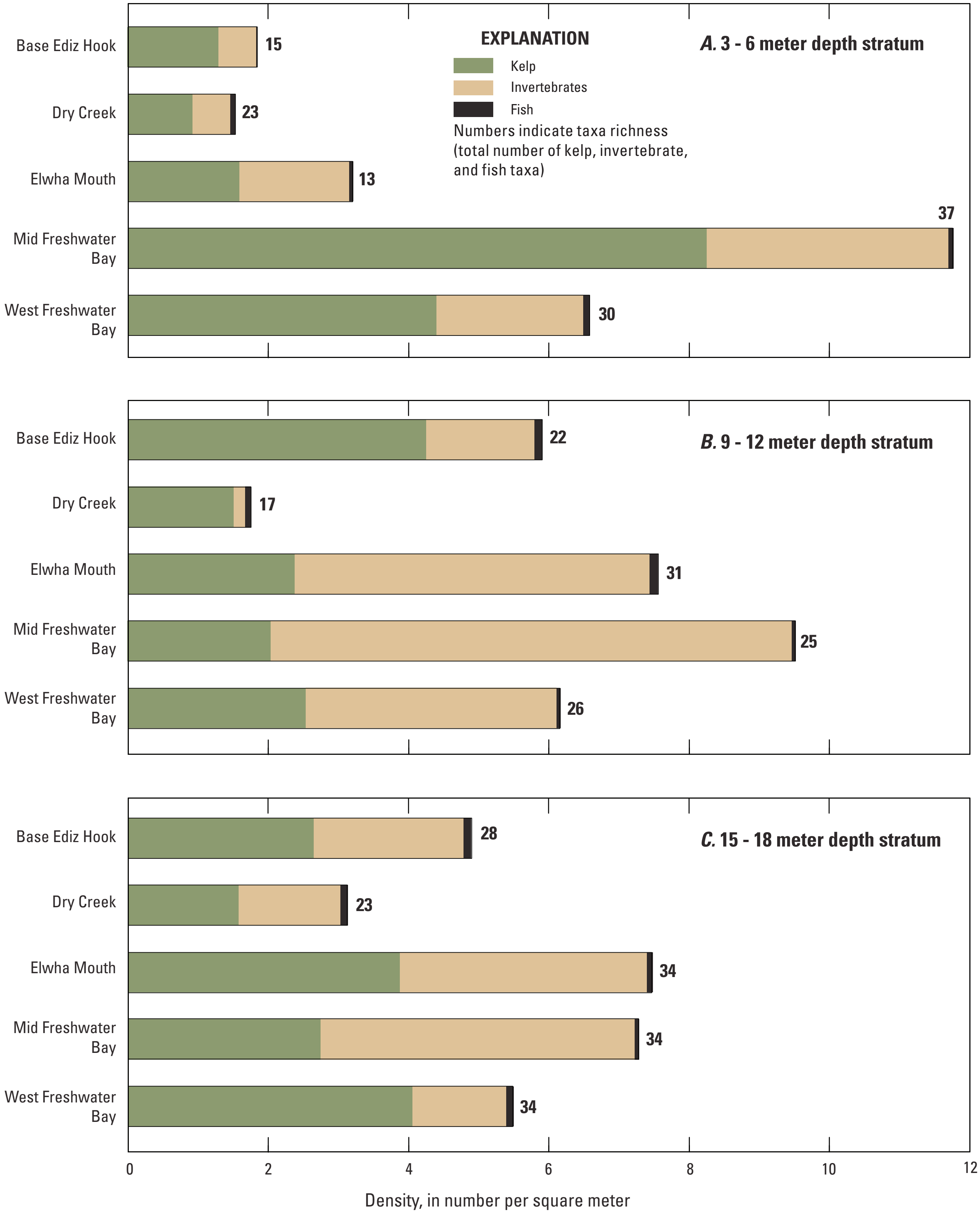


Figure 6.12. Mean densities of the major taxonomic groups (kelp, invertebrates, and fish) in each cross-shore band for (*A*) shallow, (*B*) mid-depth, and (*C*) deep sites near the mouth of the Elwha River, Washington, August and September 2008.

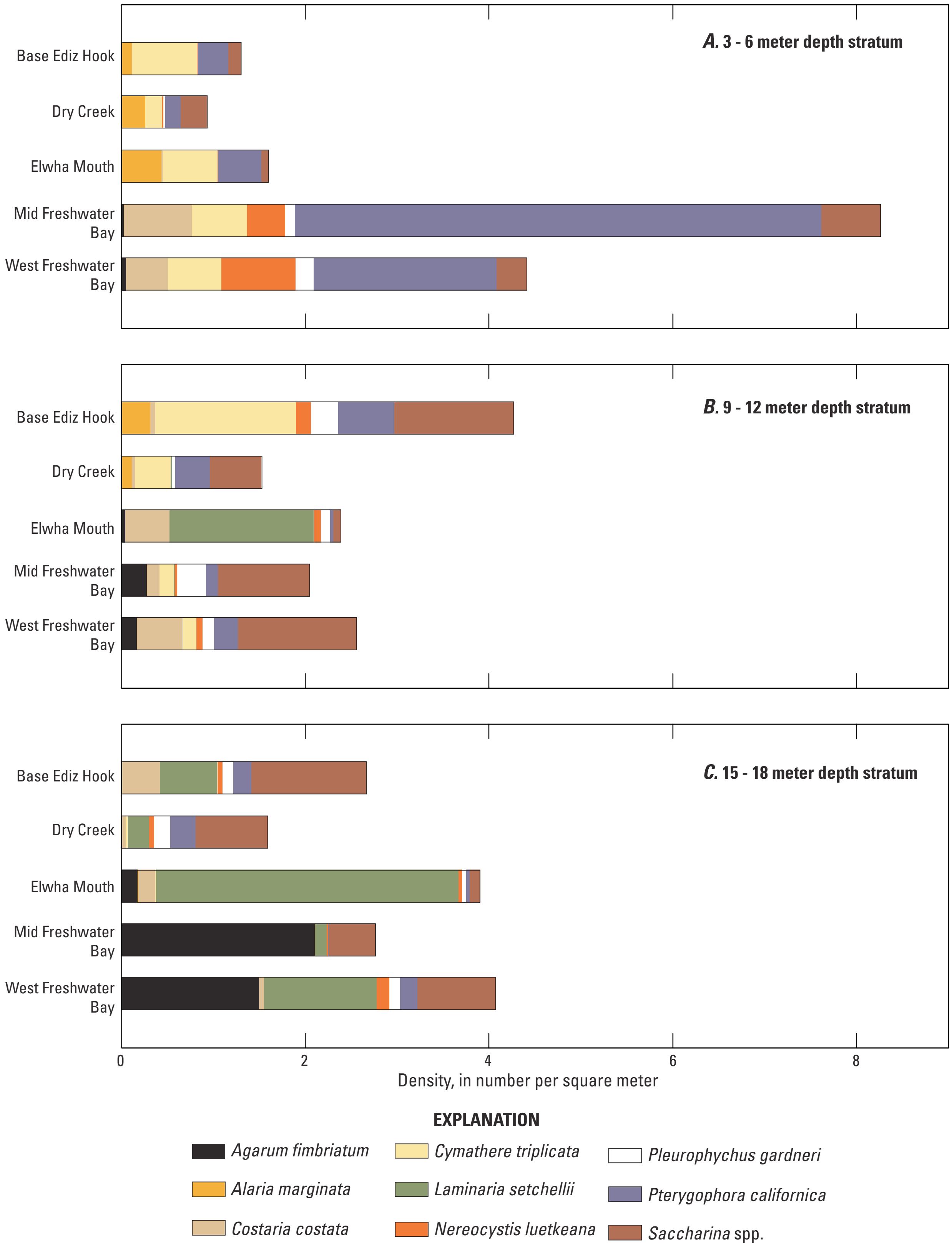


Figure 6.13. Mean densities of the nine kelp taxa in each cross-shore band for (*A*) shallow, (*B*) mid-depth, and (*C*) deep sites near the mouth of the Elwha River, Washington, August and September 2008.

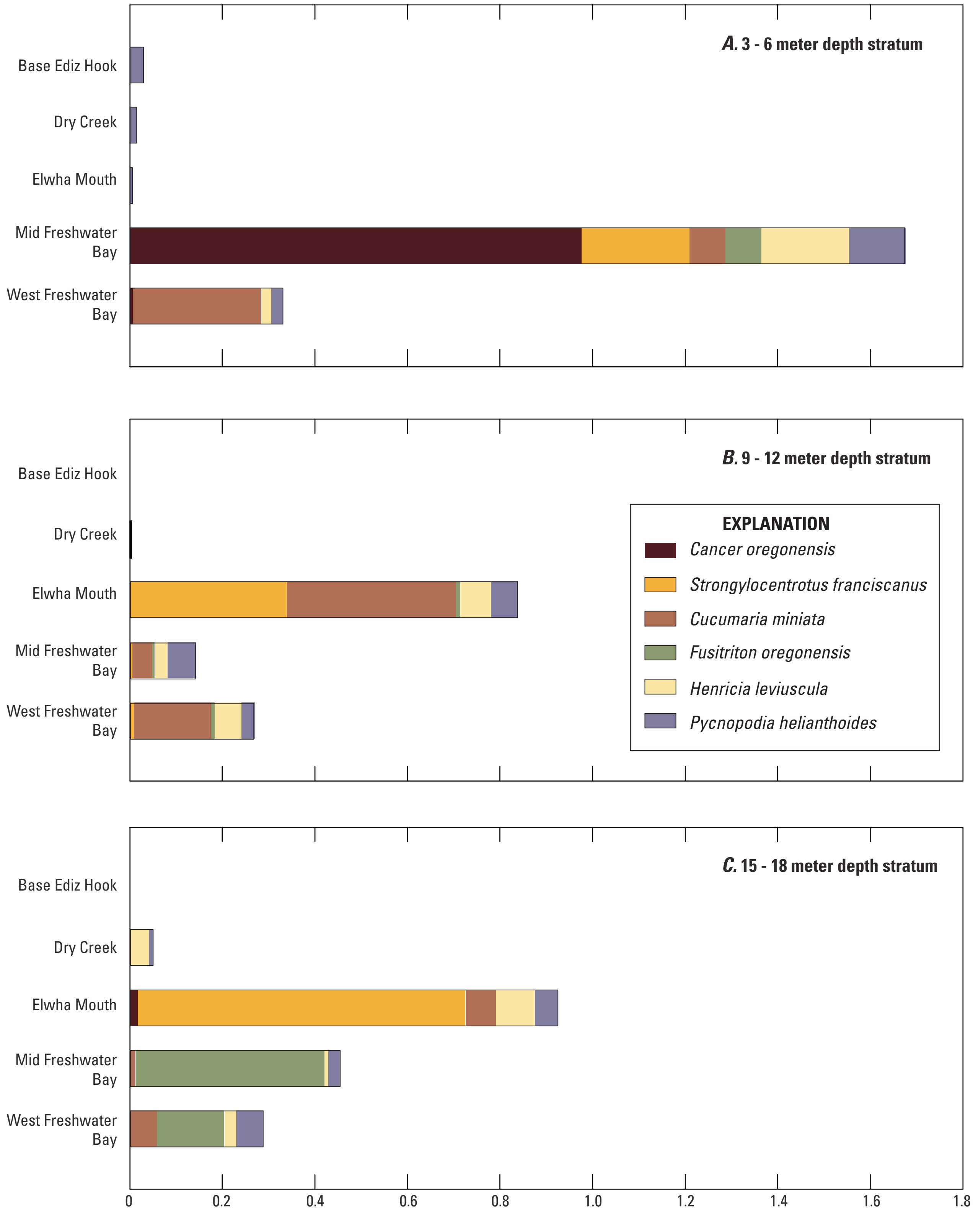


Figure 6.14. Mean densities of the six most common invertebrate species (see fig. 6.8*B*) in each cross-shore band for (*A*) shallow, (*B*) mid-depth, and (*C*) deep sites near the mouth of the Elwha River, Washington, August and September 2008.

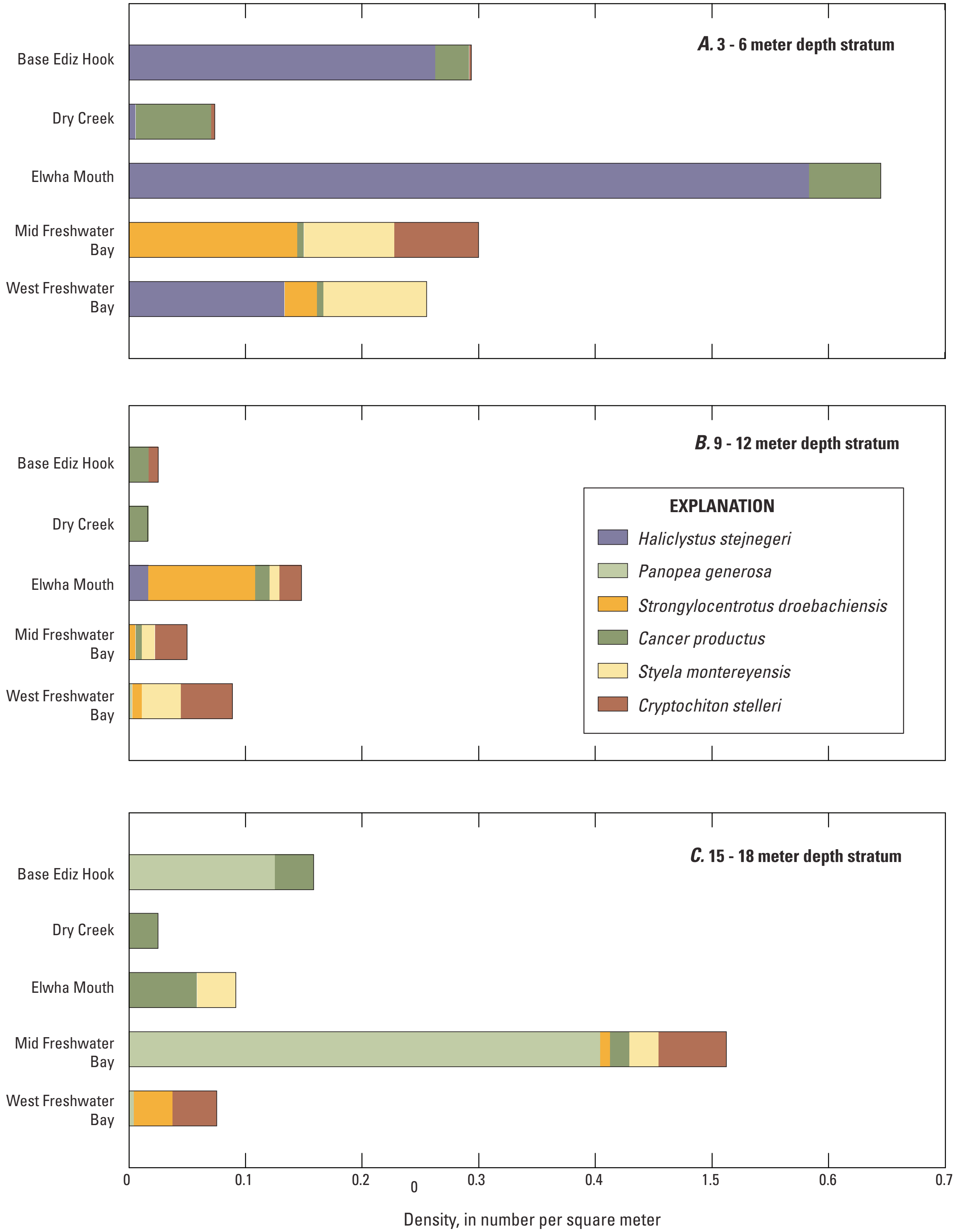


Figure 6.15. Mean densities of the next six most common invertebrate species (see fig. 6.8*B*) in each cross-shore band for (*A*) shallow, (*B*) mid-depth, and (*C*) deep sites near the mouth of the Elwha River, Washington. August and September 2008.

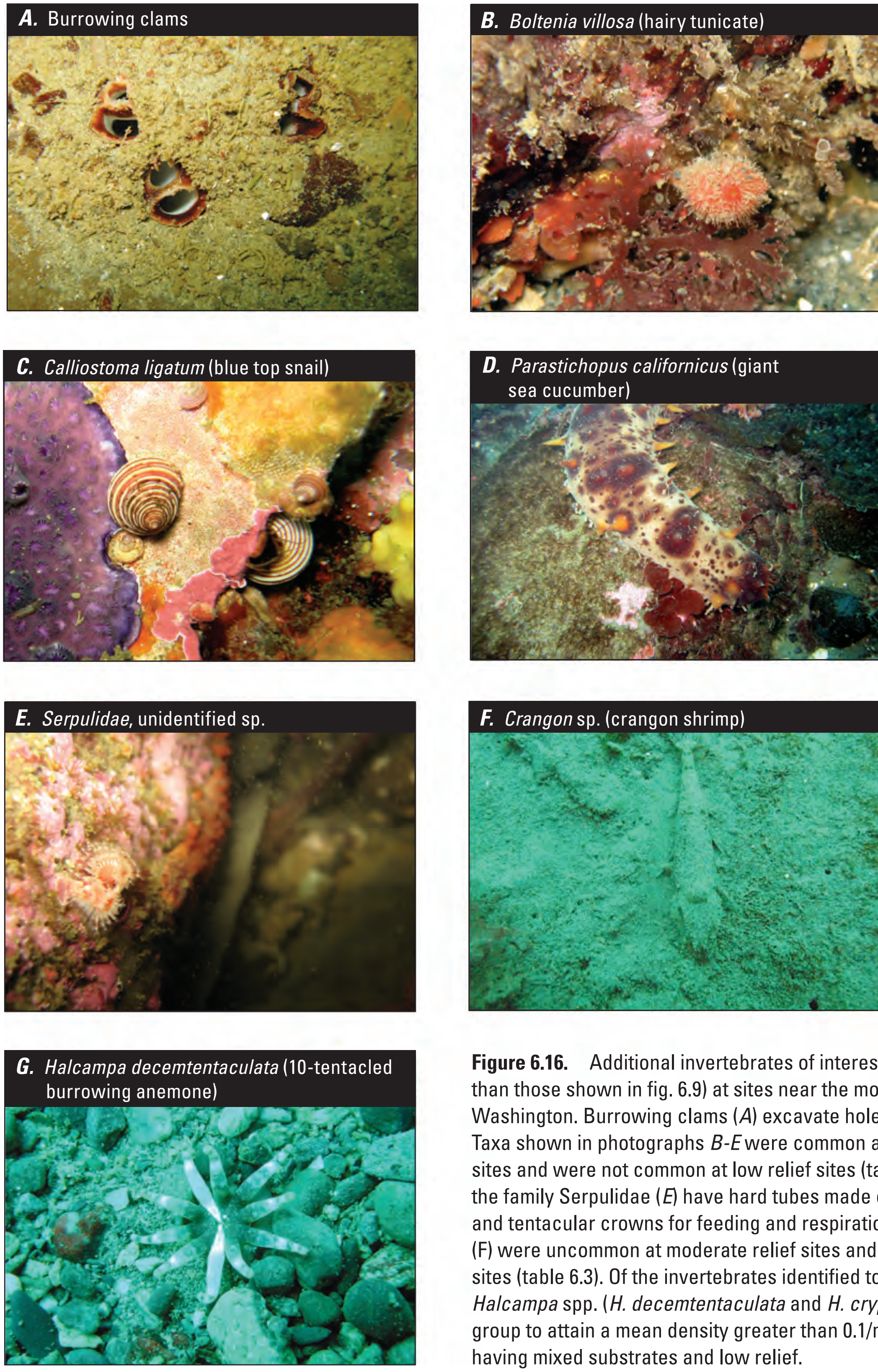


Figure 6.16. Additional invertebrates of interest (invertebrates other than those shown in fig. 6.9) at sites near the mouth of the Elwha River, Washington. Burrowing clams (*A*) excavate holes in soft bedrock. Taxa shown in photographs *B-E* were common at moderate relief sites and were not common at low relief sites (table 6.3). Worms in the family Serpulidae (*E*) have hard tubes made of calcium carbonate and tentacular crowns for feeding and respiration. Crangon shrimp (F) were uncommon at moderate relief sites and common at low relief sites (table 6.3). Of the invertebrates identified to genus or species, *Halcampa* spp. (*H. decemtentaculata* and *H. crypta*) was the only group to attain a mean density greater than 0.1/m^2 at sites classified as having mixed substrates and low relief.

Table 6.3. Taxa common at moderate relief sites and uncommon at low relief sites, and taxa uncommon at moderate relief sites and common at low relief sites near the mouth of the Elwha River, Washington, August and September 2008.

[Only the 22 sites where mean substrate score ranged from 1.25 to 2.15 (fig. 6.20*B*) were included. Mean relief score ranged from 1.12 to 1.35 at moderate relief sites (n = 9) and from 1.00–1.05 at low relief sites (n = 13). **Percent occurrence:** Percentage of total moderate relief sites or total low relief sites where a taxon was detected]

Occurrence-relief category	Percent occurrence		Taxon
	Moderate Relief	Low Relief	
Common-moderate, uncommon-low	88.9	0.0	*Cucumaria miniata* (orange sea cucumber)
	88.9	15.4	*Agarum fimbriatum* (an understory kelp)
	77.8	15.4	*Henricia leviuscula* (blood star)
	77.8	15.4	*Parastichopus californicus* (giant sea cucumber)
	66.7	0.0	*Serpulidae* (calcareous tube worms)
	55.6	0.0	*Boltenia villosa* (hairy tunicate)
	55.6	0.0	*Fusitriton oregonensis* (hairy triton)
	55.6	7.7	*Calliostoma* spp. (top snails)
	44.4	0.0	*Strongylocentrotus droebachiensis* (green urchin)
	44.4	7.7	*Styela montereyensis* (stalked tunicate)
Uncommon-moderate, common-low	11.1	76.9	*Alaria marginata* (an understory kelp)
	0.0	46.2	*Crangon* spp. (crangon shrimps)
	0.0	30.8	*Hexagrammos stelleri* (whitespotted greenling)

Density and Taxa Richness in Relation to Substrate and Relief

Results presented for relations of organism density and taxa richness to substrate and relief characteristics were obtained from analyses of means and SDs of substrate and relief scores rather than from analyses of substrate and relief composition. Mean substrate score is an index of average grain size of sediment. It ranged from 1.0 for sites with 100 percent sand to 3.4 for the site with the most bedrock (fig.6.17*A*). SD substrate score is an index of heterogeneity of sediment grain size. It ranged from 0.0 for sites with only one grain size (100 percent sand) to 1.2 for the site with the most even mixture of the four grain size classes. Similarly, mean and SD relief score are indexes of average relief and variability of relief, respectively (fig.6.17*B*). The analyses were based on means and SDs because they lend themselves to simple statistical techniques and straightforward interpretations of average tendencies and heterogeneity.

Kelp density increased with increasing mean substrate score and was highest at shallow sites with high percentages of boulders or bedrock (fig. 6.18*A*). The positive correlation between kelp density and mean substrate score was greater than would be expected by chance for all sites, for shallow sites (r = 0.91, P<0.05), and for mid-depth sites (r = 0.68, P<0.05), but not for deep sites. Invertebrate density was unrelated to mean substrate score when all sites were considered (fig. 6.18*B*) but was positively correlated with mean substrate score at shallow sites (r = 0.80, P<0.05). Fish density was unrelated to mean substrate score for all sites (fig. 6.18*C*) and within each depth stratum. Taxa richness increased with increasing mean substrate score for all sites (fig. 6.18*D*) and shallow sites (r = 0.81, P<0.05). SD substrate score was less correlated with kelp density and taxa richness than was mean substrate score for analyses conducted with all sites included, suggesting that heterogeneity of sediment grain size was less closely associated with kelp density and taxa richness than was average sediment grain size.

Relations of density and taxa richness to seafloor relief were similar to those for sediment grain size. Kelp density was positively correlated with mean relief score for all sites (fig. 6.19*A*) and shallow sites (r = 0.95, P<0.05). Invertebrate density was unrelated to relief for all sites (fig. 6.19*B*) but was positively correlated with relief at shallow sites (r = 0.80, P<0.05). Fish density was unrelated to relief (fig. 6.19*C*).

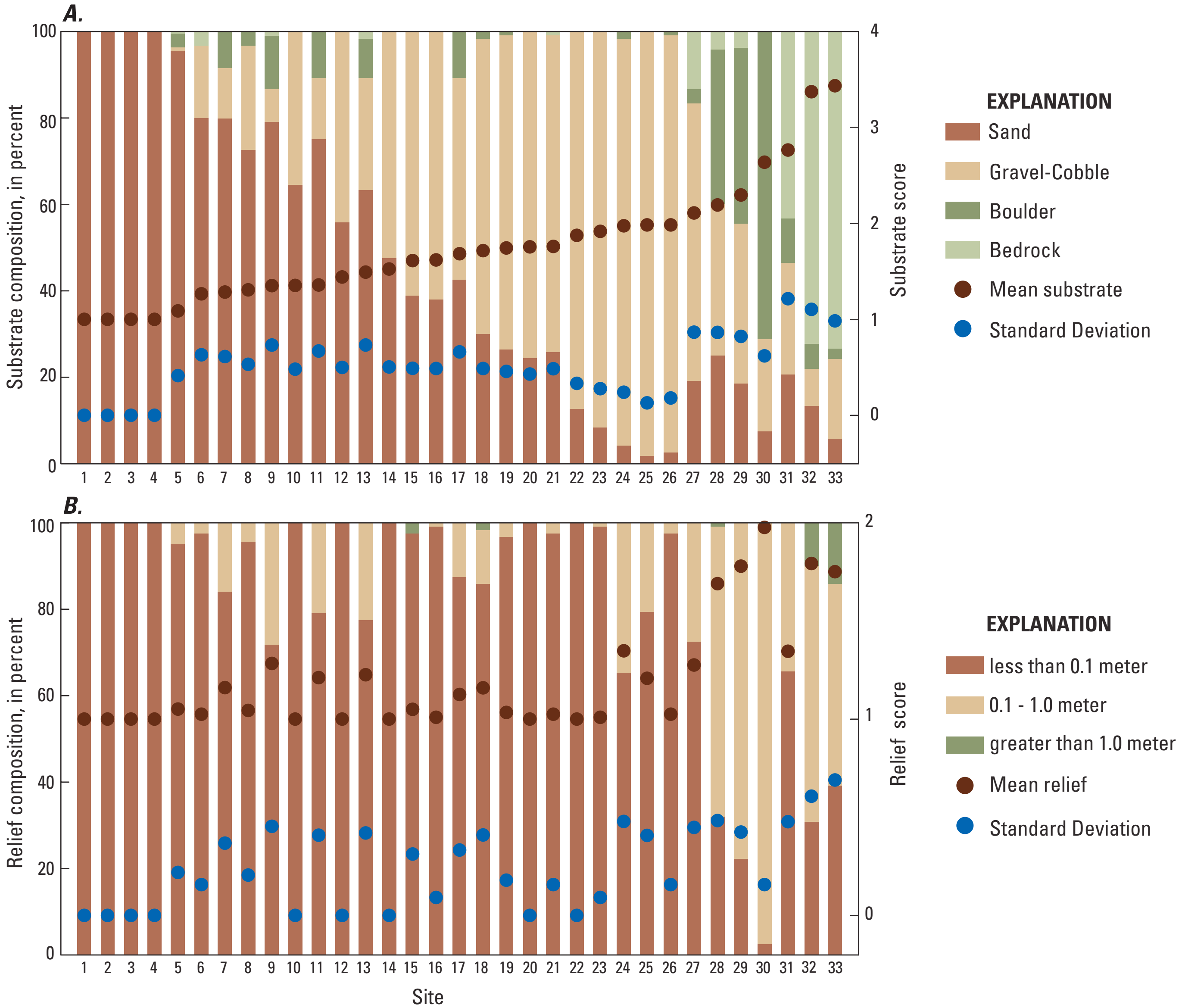


Figure 6.17. (*A*) Substrate composition and mean and standard deviation (SD) substrate score and (*B*) relief composition and mean and SD relief score for each site near the mouth of the Elwha River, Washington, August and September 2008. Sites are ordered from lowest to highest mean substrate score.

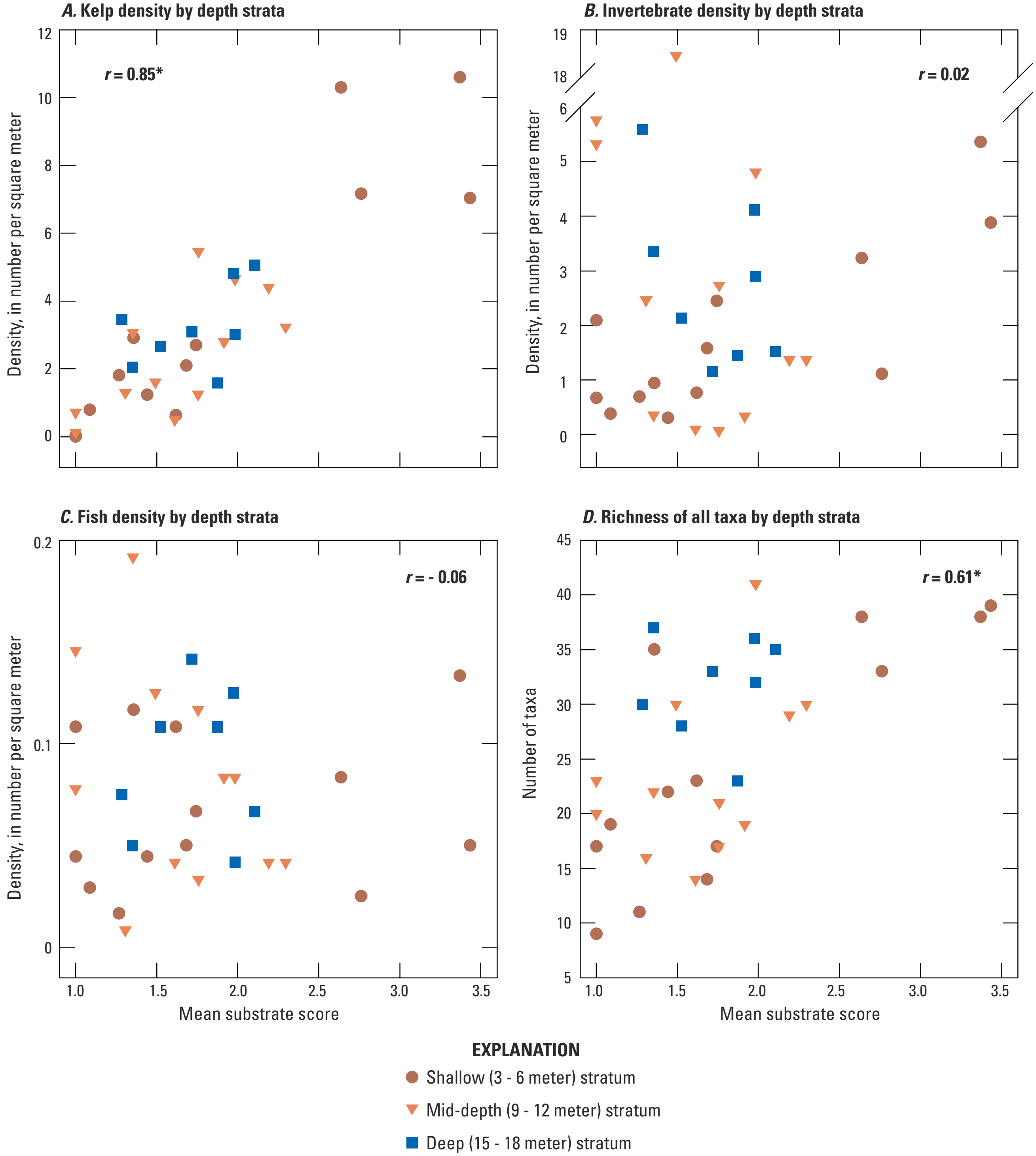


Figure 6.18. Density of (*A*) kelp, (*B*) invertebrates, and (*C*) fish, and (*D*) taxa richness for all three groups combined, in relation to mean substrate score at sites near the mouth of the Elwha River, Washington, August and September 2008. Each data point represents a site (n=33). Pearson's correlation coefficient (r) is a measure of association between two variables, for example, density and mean substrate score. Asterisks indicate that the correlation is stronger than would be expected by chance (P<0.05).

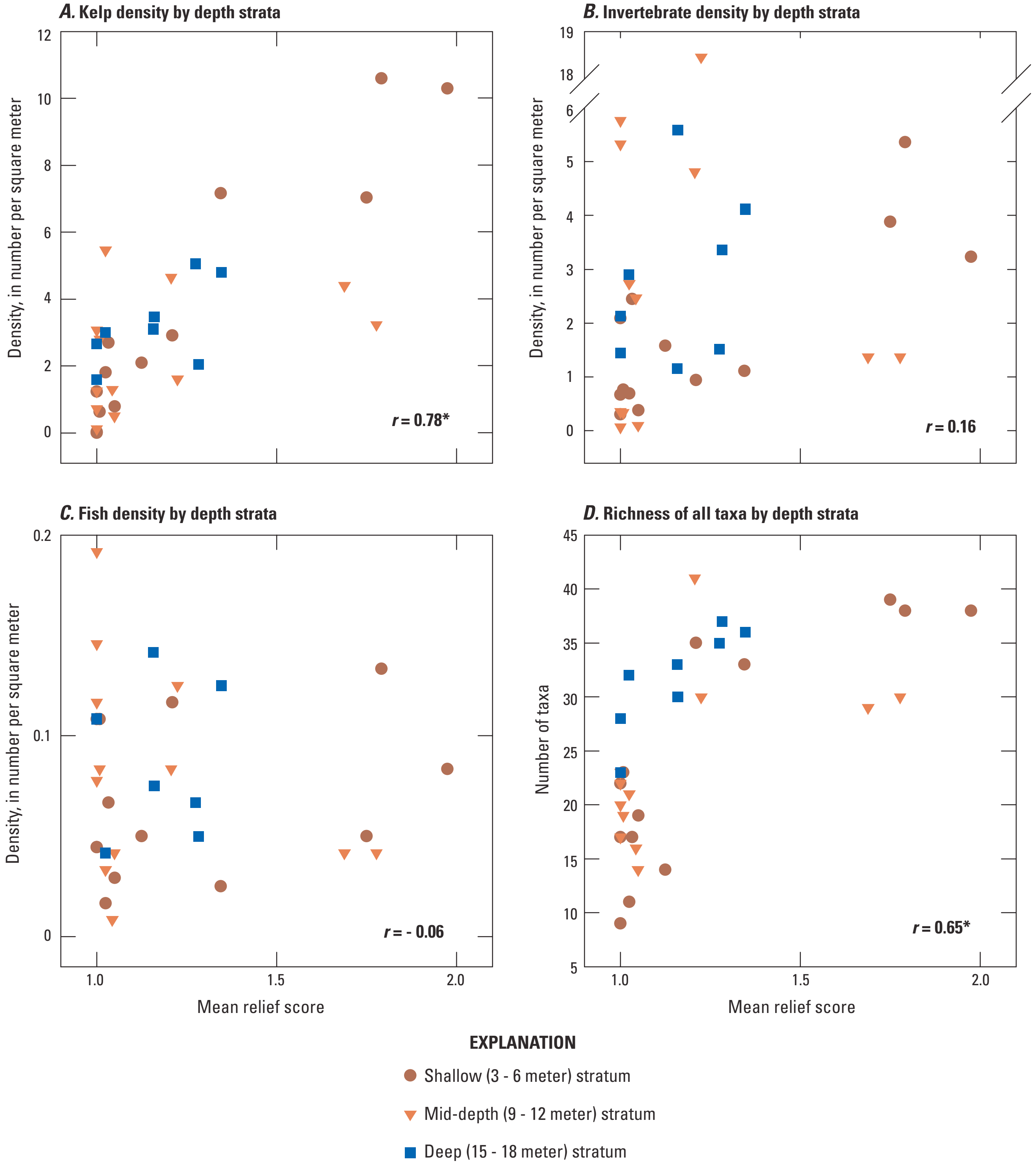


Figure 6.19. Density of (*A*) kelp, (*B*) invertebrates, and (*C*) fish, and (*D*) taxa richness for all three groups combined, in relation to mean relief score at sites near the mouth of the Elwha River, Washington, August and September 2008. Each data point represents a site (n=33). Pearson's correlation coefficient (r) is a measure of association between two variables, for example, density and mean substrate score. Asterisks indicate that the correlation is stronger than would be expected by chance (P<0.05).

Taxa richness was positively correlated with relief for all sites (fig. 6.19*D*), shallow sites (r = 0.84, P<0.05), and deep sites (r = 0.84, P<0.05). In comparison to mean relief score, SD relief score was less correlated with kelp density and nearly equivalently correlated with taxa richness (r = 0.66 between SD relief score and taxa richness) for analyses conducted with all sites included. This suggests that heterogeneity of relief was no more closely associated with kelp density or taxa richness than was average relief.

Mean substrate score was positively correlated with mean relief score (fig. 6.20*A*), indicating that sites with fine sediment also had low relief and sites with coarse sediment had high relief. Therefore, it is not surprising that mean substrate and mean relief were similarly related to density and taxa richness. However, mean substrate score was uncorrelated with mean relief score for the subset of sites with mean substrate scores between 1.25 and 2.15 (fig. 6.20). Some of these sites had low relief (mean relief scores between 1.00 and 1.05) whereas others had moderate relief (mean relief scores between 1.12 and 1.35; fig. 6.20*B*). Density and taxa richness were compared between the moderate and low relief sites to determine whether there was an effect of relief independent from the effect of sediment grain size.

Kelp density was similar between moderate and low relief sites (fig. 6.21*A*). Invertebrate density was higher at moderate relief sites than at low relief sites (fig. 6.21*B*). Mean invertebrate density at moderate relief sites was 1.6/m^2 higher than at low relief sites when one site was excluded (the moderate relief site where density was 18.5/m^2) and 3.3/m^2 higher than at low relief sites when all sites were included. Fish density was similar between moderate and low relief sites (fig. 6.21*C*). The difference in taxa richness between moderate and low relief sites was striking (fig. 6.21*D*). On average, 12 more taxa occurred at moderate relief sites than at low relief sites.

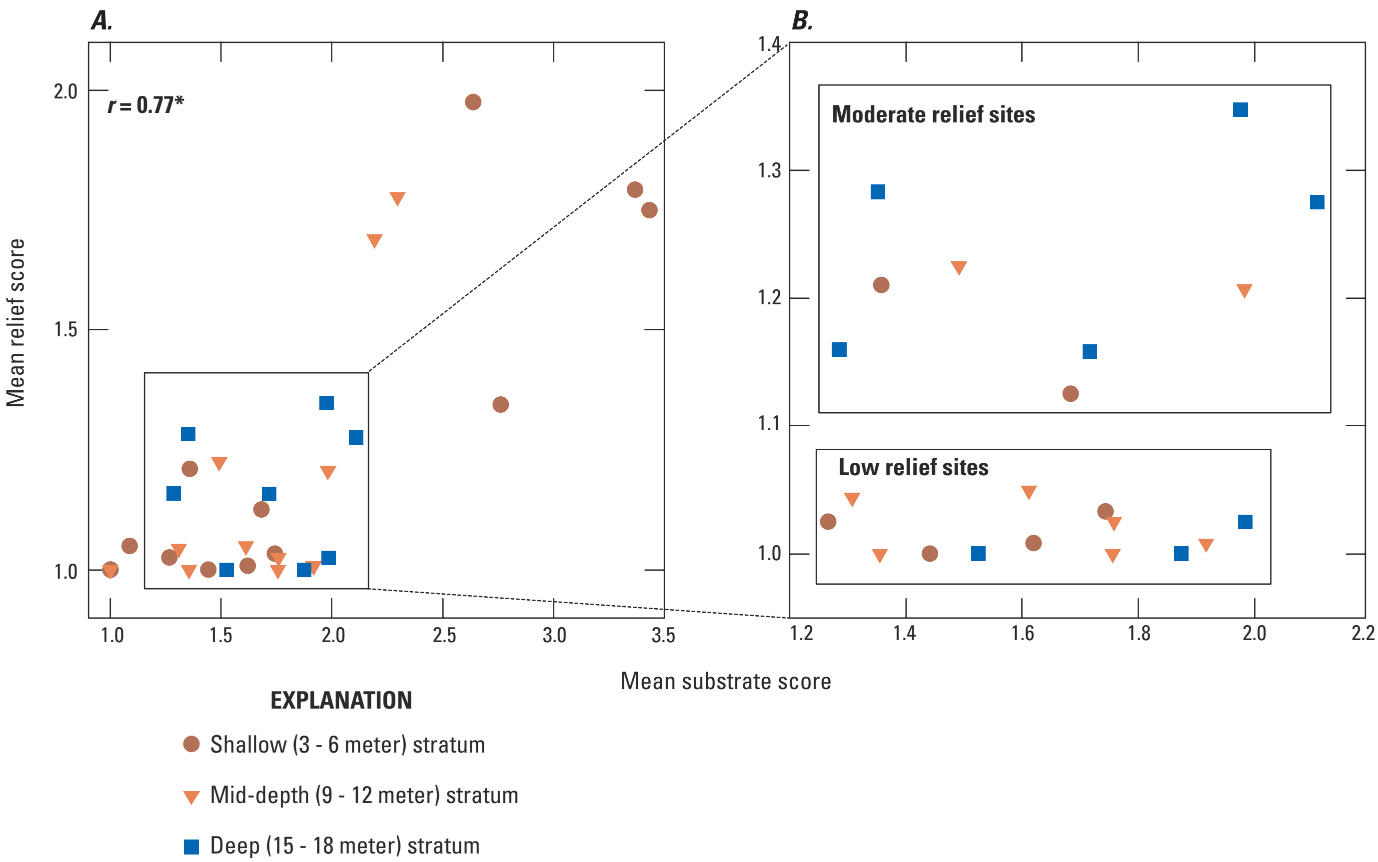


Figure 6.20. Mean relief score in relation to mean substrate score at sites near the mouth of the Elwha River, Washington, August and September 2008. (*A*) All 33 sites. (*B*) The 22 sites with mean substrate scores between 1.25 and 2.15.

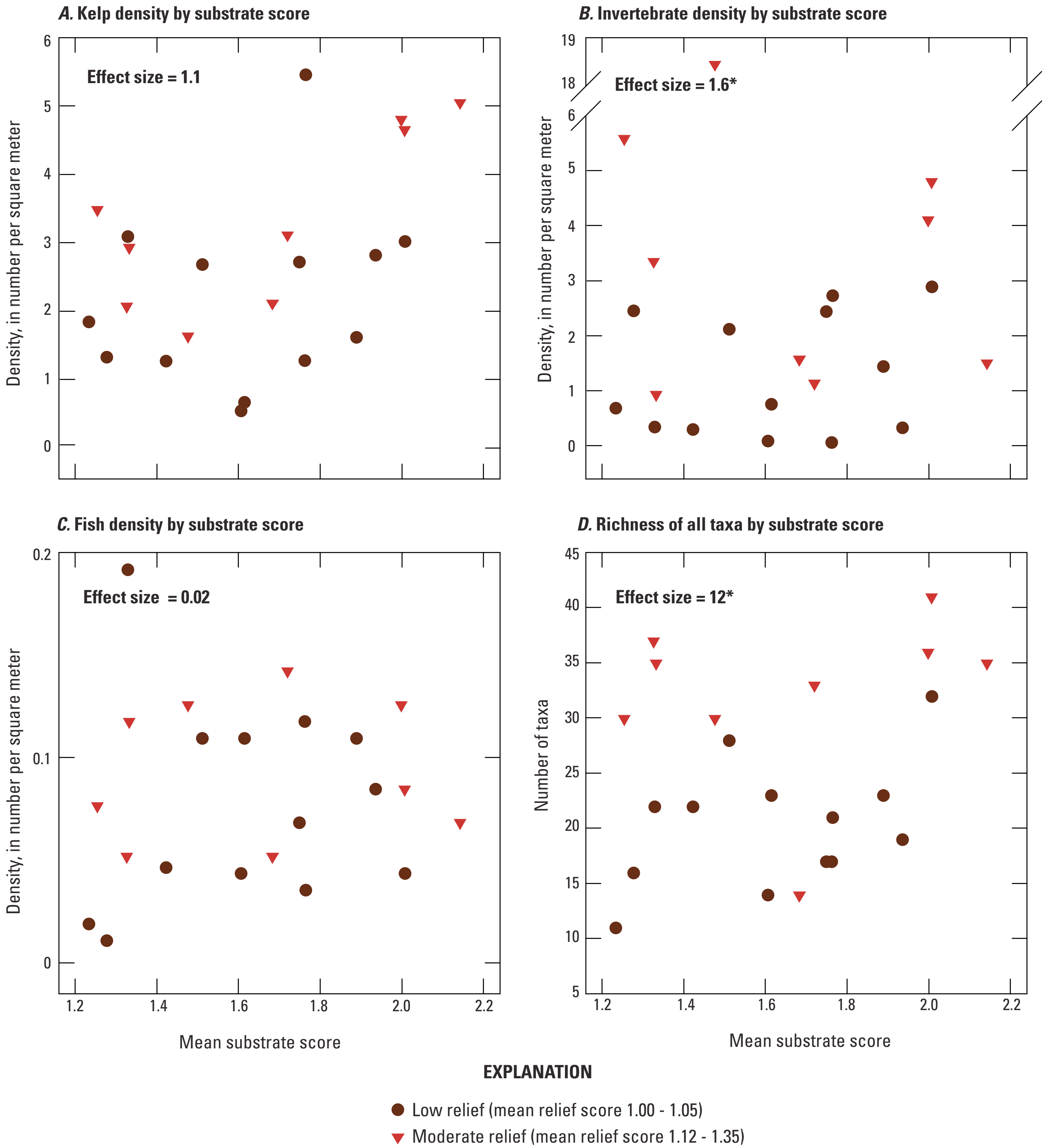


Figure 6.21. Density of (*A*) kelp, (*B*) invertebrates, and (*C*) fish, and (*D*) taxa richness for all three groups combined, in relation to mean substrate score at sites near the mouth of the Elwha River, Washington, August and September 2008. Only the 22 sites with mean substrate scores between 1.25 and 2.15 are shown. Effect size is the difference between the mean for moderate relief sites and the mean for low relief sites. Asterisks indicate that effect size is greater than would be expected by chance ($P<0.05$). Note that for invertebrates, effect size and its asterisk were calculated by excluding the moderate relief site where density was 18.5, much higher than at any other site. Effect size was 3.3 with that site included.

Taxa Associated with Seafloor Relief

The finding that taxa richness was higher at moderate relief sites than at low relief sites was intriguing. It suggests that some taxa preferentially occurred at sites with at least moderate relief, thereby increasing taxa richness at those sites. Further analysis was performed to screen for taxa that were common at the moderate relief sites but uncommon at low relief sites, or the opposite.

Ten taxa were classified as common at moderate relief sites and uncommon at low relief sites, and 3 taxa were classified as uncommon at moderate relief sites and common at low relief sites (table 6.3; fig. 6.7*A–B*; fig. 6.9*C–E*, *I*, and *K*; fig. 6.10*G*; fig. 6.16*B–F*). Thus, more taxa occurred mainly at moderate relief sites than at low relief sites, contributing to the increase in taxa richness with relief. Relief at moderate relief sites usually was provided by a few boulders perched on top of sand or gravel-cobble substrate. Several of the taxa detected mainly at moderate relief sites, including *Serpulidae*, *Boltenia villosa*, and *S. montereyensis*, are sessile and require hard, stable substrate for attachment. Other taxa, notably *F. oregonensis*, were nearly always observed on boulders or bedrock. Thus, the presence of boulders may have allowed the occurrence of species that require or prefer hard substrate, in addition to species requiring or tolerating finer substrates, thereby increasing taxa richness. Of the five common invertebrate species that were detected offshore of the river mouth and to the west but not to the east (figs. 6.14 and 6.15), four (*C. miniata, F. oregonensis*, *S. montereyensis*, and *S. droebachiensis*) were detected mainly at moderate relief sites. Their distribution pattern may have been due to the availability of seafloor relief offshore of the river mouth and to the west and the lack of such habitat to the east (fig. 6.5*B*).

Habitat Types and Associated Taxa

The study sites were qualitatively classified into four habitat types based on physical and biological characteristics (table 6.4 and fig. 6.22).

Bedrock/Boulder Reef

Three shallow sites in central Freshwater Bay were located on a bedrock reef. One shallow site in west Freshwater Bay was included in the same habitat type as the bedrock sites because of its predominantly hard substrate (boulders) and similar species at similar densities. Bedrock/boulder reef habitat supported beds of *N. luetkeana* and *P. californica* that respectively formed nearly continuous canopies at the water surface and 1–2 m above the seafloor, and a diverse assemblage of understory kelp and invertebrates (fig. 6.23*A–B*). It also supported a density of kelp more than twice that for any other habitat type and the highest taxa richness among habitat types (fig. 6.24).

Sand and Gravel-Cobble with Moderate Relief

Most of the mid-depth and deep sites in Freshwater Bay and offshore of the Elwha River mouth had mixed sand and gravel-cobble substrate with sufficient boulder abundance to provide moderate relief (fig. 6.23*C–D*). The relative fractions of sand and gravel-cobble varied considerably within this classification. From a biological perspective, the presence of large boulders, which provided hard, stable substrate and relief that some organisms seemed to depend on, was more important than the composition of the base substrate. Kelp and invertebrate assemblages included species that were rare at sites lacking relief. The mixed substrate-moderate relief habitat type supported the highest density of invertebrates among habitats with taxa richness nearly equivalent to that for bedrock/boulder reefs (fig. 6.24).

Sand and Gravel-Cobble with Low Relief

The substrate was composed of mixed sand and gravel-cobble with little relief at most sites east of the Elwha River mouth, at one deep site offshore of the river mouth, and at one mid-depth site in central Freshwater Bay (fig. 6.23*E–F*). The relative fractions of sand and gravel-cobble varied within this classification but varied less than for the moderate relief classification. Kelp was dominated by understory species, notably *A. marginata* that did not occur west of the river mouth. This habitat supported a density of kelp close to that for the moderate relief classification, but density of invertebrates was the lowest among habitat types and taxa richness was considerably lower than for moderate relief (fig. 6.24).

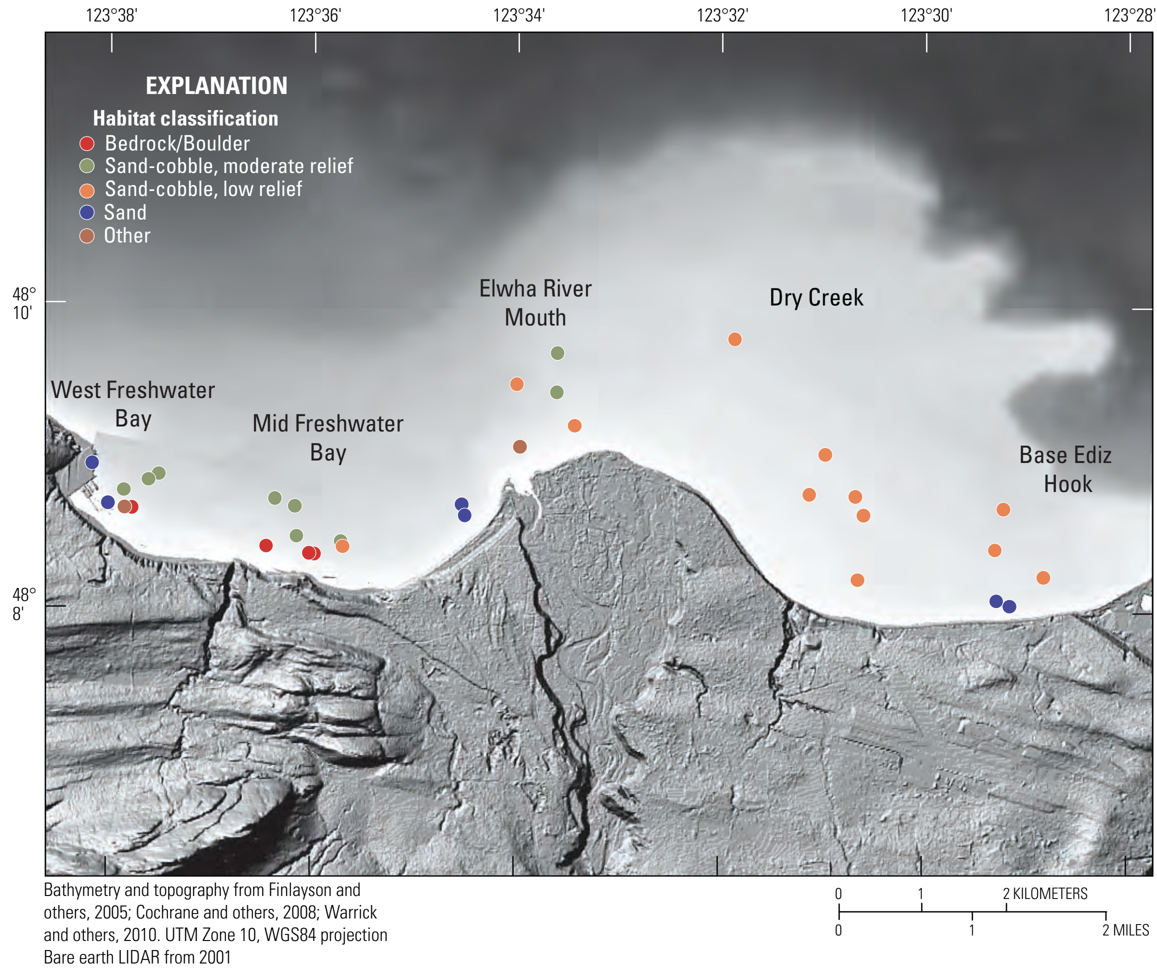


Figure 6.22. Qualitative classification of four habitat types at sites near the mouth of the Elwha River, Washington. The "other" category contains atypical sites that did not fit well into any of the four types. Descriptions of physical and biological characteristics for each habitat type are shown in table 6.4.

Figure 6.23. Opposite page. Four habitat types that were qualitatively classified at sites near the mouth of the Elwha River, Washington. (Characteristics of the habitat types are listed in table 6.4, and locations of the habitat types are shown in fig. 6.22). (*A*–*B*) Bedrock/boulder reef supporting a kelp forest. (*A*) View under the canopy formed by *Pterygophora californica. P. californica* stipes (stems) are attached to bedrock encrusted with pink coralline algae; orange mysid shrimp are visible in the water column. (*B*) View above the *P. californica* canopy. The vertically oriented "ropes" are actually *Nereocystis leutkeana* (bull kelp) stipes that extend from the bedrock to pneumatocysts (floats) at the water surface. Several blades (leaves) grow from each pneumatocyst forming a nearly unbroken canopy at the surface. (*C*–*D*) Mixed sand and gravel-cobble substrate with moderate relief provided by a few boulders. (*C*) A boulder on substrate composed primarily of sand. Macroalgae and a *Cryptochiton stelleri* (gumboot chiton) are visible on the boulder. (*D*) Gravel-cobble substrate and a boulder covered with *Strongylocentrotus franciscanus* (red urchins). (*E*–*F*) Mixed sand and gravel-cobble substrate lacking boulders and therefore showing low relief. (*E*) A mid-depth site offshore of Dry Creek; *Cymathere triplicata* is visible. (*F*) A mid-depth site at the base of Ediz Hook; *C. triplicata*, *Costaria costata*, and *Saccharina* sp. are visible. (*G*–*H*) Sand substrate. (*G*) A *Zostera marina* (eelgrass) bed at the shallower of the two sandy sites in west Freshwater Bay; a *Polyorchis penicillatus* (redeye medusa) is visible in the water column. (*H*) The deeper of two sandy sites in east Freshwater Bay; a *Cancer magister* (Dungeness crab) is visible in the foreground.

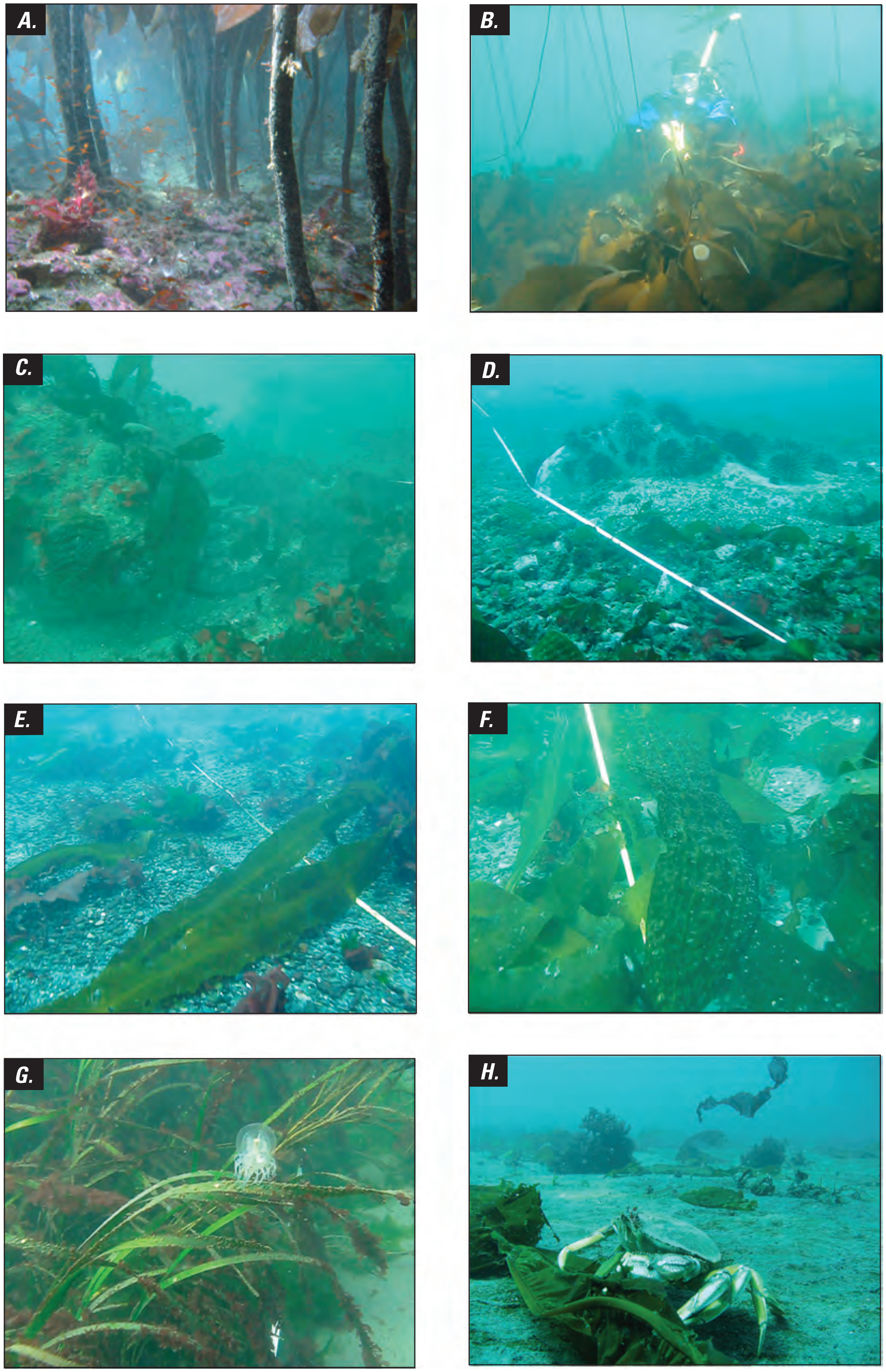

A.
B.
C.
D.
E.
F.
G.
H.

Table 6.4. Qualitative classification of four habitat types based on physical and biological characteristics at sites near the mouth of the Elwha River, Washington.

[Site locations are shown in figure 6.22. Note that two atypical sites were classified as “other” and are not included in this table. Taxa identified to genus or species are listed in order of decreasing mean density. All such taxa with mean density greater than a minimum value (0.17 per square meter for kelp, 0.10 per square meter for invertebrates, 0.005 per square meter for fish) are listed. Of the taxa identified to a broader taxonomic level than genus, the taxon with the highest mean density is listed after the semicolon]

Characteristic	Habitat type			
	Bedrock-boulder reef	Sand and gravel; moderate relief	Sand and gravel; low relief	Sand
		Physical		
Number of sites	4	9	12	6
Depth strata	Shallow	Medium-deep	Shallow-deep	Shallow-medium
Depth[1]	5.3 (3.8–6.1)	13.6 (9.1–16.7)	10.9 (5.4–16.8)	6.4 (3.0–10.4)
Substrate composition[2]	47.2, 22.5, 18.4, 11.8	2.6, 12.6, 49.1, 35.6	0.1, 0.4, 64.7, 34.8	0.6, 0.6, 2.9, 95.9
Substrate score[3]	3.1 (2.6–3.4)	1.8 (1.3–2.3)	1.7 (1.3–2.0)	1.1 (1.0–1.3)
Relief composition[4]	34.5, 59.4, 6.0	65.6, 34.1, 0.3	98.6, 1.2, 0.2	98.8, 1.3, 0.0
Relief score[5]	1.7 (1.3–2.0)	1.3 (1.2–1.8)	1.0 (1.0–1.0)	1.0 (1.0–1.1)
Boulder abundance	Low-high	Medium	Very low	Very low
		Taxa assemblage		
Kelp	*Pterygophora californica, Nereocystis leutkeana, Costaria costata, Cymathere triplicata, Saccharina* spp., *Pleurophychus gardneri*	*Agarum fimbriatum, Saccharina* spp., *Costaria costata, Pleurophychus gardneri*	*Saccharina* spp., *Cymathere triplicata, Pterygophora californica, Alaria marginata*	*Cymathere triplicata*
Invertebrates	*Cancer oregonensis, Cucumaria miniata, Strongylocentrous franciscanus, Henricia leviuscula, Strongylocentrous droebachiensis, Styela montereyensis, Pycnopodia helianthoides;* calcareous tube worms (*Serpulidae*)	*Cucumaria miniata, Strongylocentrous franciscanus, Calliostoma* spp., *Fusitriton oregonensis;* soft tube worms	*Halcampa* spp.; soft tube worms	Soft tube worms
Fish	*Hexagrammos decagrammus, Jordania zonope;* unidentified sculpins	*Hexagrammos decagrammus, Gadus macrocephalus* juveniles; unidentified sculpins[6], gunnels[6]	*Gadus macrocephalus* juveniles, *Hexagrammos decagrammus, Hydrolagus colliei*; unidentified sculpins	*Ophiodon elongatus* juveniles, Blepsias cirrhosus (only in eelgrass); flatfish
Eelgrass				West Freshwater Bay only

[1]Mean (range) in meters, referenced to mean lower low water.

[2]Mean percentage bedrock, boulder, gravel-cobble, and sand, respectively.

[3]Mean (range); substrate score is an index of average sediment grain size.

[4]Mean percentage in three categories: less than 0.1 meter, 0.1–1.0 meter, and greater than 1 meter, respectively.

[5]Mean (range); relief score is an index of average seafloor relief.

[6]Unidentified sculpins and gunnels tied for the highest mean density among taxa identified to a broader taxonomic level than genus.

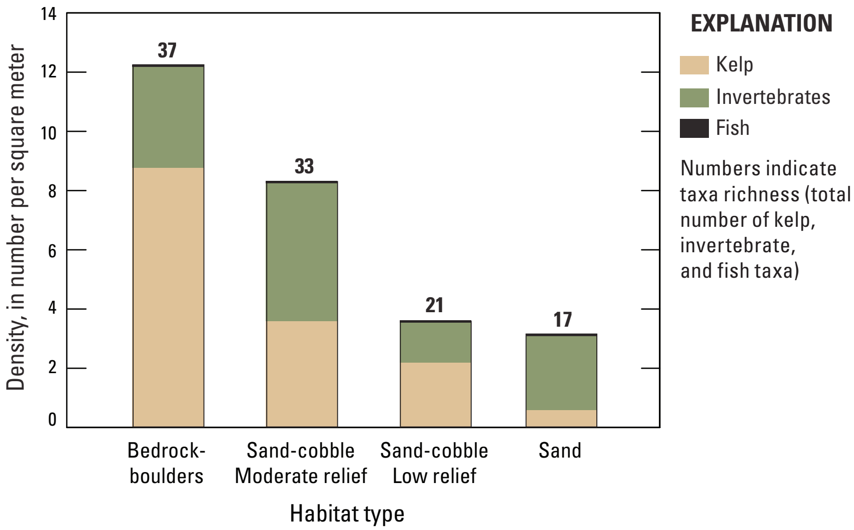


Figure 6.24. Mean densities for kelp, invertebrates, and fish for four qualitative habitat type classifications at sites near the mouth of the Elwha River, Washington, August and September 2008. (Characteristics, locations, and photographs of the habitat types are shown in table 6.4, figure 6.22, and figure 6.23, respectively.)

Sand

Sites dominated by sand were widely dispersed from west to east. Two sites were at the west end of Freshwater Bay, two were at the east end, and two were at the base of Ediz Hook. Eelgrass was interspersed with patches of bare sand at the shallow site in west Freshwater Bay (fig. 6.23*G*). Eelgrass was absent from the other five sandy sites, although it was present at one of the sites classified as "other." Small amounts of substrate allowing kelp attachment (for example, boulders or woody debris), or cobbles with kelp attached that were imported from other areas (Warrick and others, 2011, Chapter 5, sidebar 5.2, this report), were sometimes present at sandy sites, accounting for the occurrence of kelp at low density. Invertebrate density was more twice that for the mixed substrate-low relief habitat and taxa richness was the lowest among habitat types (fig. 6.24).

Other

Two sites were classified as "other" because they did not fit well into any of the four habitat types. The shallow site directly offshore of the Elwha River mouth was a moderate relief site, but it had the lowest mean relief score among the moderate relief sites (fig. 6.20*B*) and a taxa richness considerably lower than for any of the other moderate relief sites (fig. 6.21*D*). A shallow site in west Freshwater Bay was classified as "other" because it was on a boundary between habitat types. One transect was in sand with eelgrass, the other on boulder reef.

Key Findings

The results of this study indicate that biological communities in the study area were partly controlled by substrate, relief, and depth. Communities differed markedly among hard substrate (bedrock or boulders), mixed substrate (sand and gravel-cobble), and sand. The presence of relief (boulders) in areas with mixed substrate increased species richness by providing habitat for species that otherwise would not be represented. Kelp proliferated at shallow depths (3–6 m) given suitable substrate but also was abundant at deep sites (15–18 m). Community composition of kelps and invertebrates varied with depth.

The distribution of substrate, relief, and depth within the study area created a mosaic of habitats and communities. Freshwater Bay was particularly rich. Present at shallow sites in Freshwater Bay, from west to east, were an eelgrass bed, a bedrock/boulder reef supporting a dense and diverse kelp forest, and a sandy area lacking eelgrass but supporting *Cancer magister* (Dungeness crab; fig. 6.23*H*) and juvenile *O. elongatus* (lingcod; fig. 6.10*D*) among other species. At greater depths in Freshwater Bay, mixed sand and gravel-cobble substrate and the presence of boulders supported a distinct community nearly as diverse as the kelp forest. Mid-depth and deep sites directly offshore of the Elwha River mouth merit attention. Diversity was high at these sites (fig. 6.11*D*). Substrate was almost entirely (greater than or equal to 94 percent) gravel-cobble that appeared stable and may have provided habitat for species needing hard substrate even when boulders were absent. Tidal currents here are among the highest in the study area (Warrick and others, 2011b, chapter 5, this report). The distribution of substrate types important for structuring biological communities in Freshwater Bay and offshore of the river mouth is well characterized by the substrate morphology map of Warrick and others (2008) (fig. 6.2*B*).

Mixed substrate lacking boulders predominated at sites east of the Elwha River mouth. The community here was

Sidebar 6.1 Fine Sediments and the Role of Benthic Amphipods

Ian M. Miller, Jeffrey J. Duda, Nancy Elder, Reginald R. Reisenbichler, and Stephen P. Rubin

Although the focus of this study was on benthic invertebrates larger than 2.5 cm, qualitative observations were made of smaller-bodied invertebrates that may play a role in the marine biological community or may serve as useful indicators of change following dam removal, including brittle stars, mysid shrimp, and small tube worms. Of particular interest are benthic amphipods of the genus Ampelisca. These small, tube-building amphipods were abundant at a few sites that included sediments finer than sand.

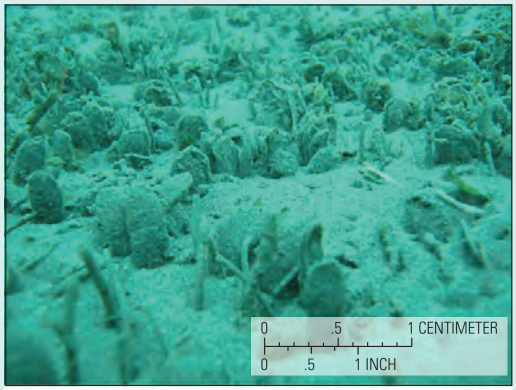
The genus *Ampelisca*, typically associated with bottoms of soft sediments (Dauvin and BellanSantini, 1996), is globally distributed and can be abundant in shallow coastal environments. In Chile, for example, a species of this genus is associated with sediments composed of more than 50 percent silt and clay (Carrasco and Arcos, 1984). Almost all members of this genus build tubes constructed of sediment grains, using the tube as a protection against predatory grazing. During feeding the amphipods extend part of their body from the top of the tube and use their antennae to collect detritus, plankton or other epibenthic invertebrates from the surrounding seafloor or water column (Sheader, 1998). Their tube-building habit modifies the substrate and influences the exchange of material between sediments and the water column. One study from the east coast of the United States suggests that *Ampelisca* tubes provide structure to sea-floor sediments, making them more desirable as a recruitment substrate for commercially important quahog clams (*Mercenaria mercenaria*) (Mackenzie and others, 2006). The abundant amphipods also provide food for a number of larger animals including gray whales (*Eschrichtius robustus*) (Oliver and Slattery, 1985; Darling and others, 1998). *Ampelisca* are thought to be a primary food source for a variety of fish species (Carrasco and Arcos, 1984), in some cases contributing as much as 88 percent of the prey base (Franz and Tanacredi, 1992).

Field observations made during this study and sonar-derived backscatter interpretation from a previous study (Warrick and others, 2008) suggest that sediments finer than sand are rare within the Elwha coastal zone. Sediments usually were composed of coarser sand or a mix of sand and gravel even at sites classified as “soft”. Although fine sediments were generally lacking in the Elwha River nearshore area, tubes of *Ampelisca* were observed at one shallow site at the western edge of Freshwater Bay (fig. S6.1A), in clearings between dense thickets of eelgrass (*Zostera marina*). The substrate at this site was primarily sand, but it may have included silt and clay because these grain sizes often are associated with eelgrass in Puget Sound (Mumford, 2007)

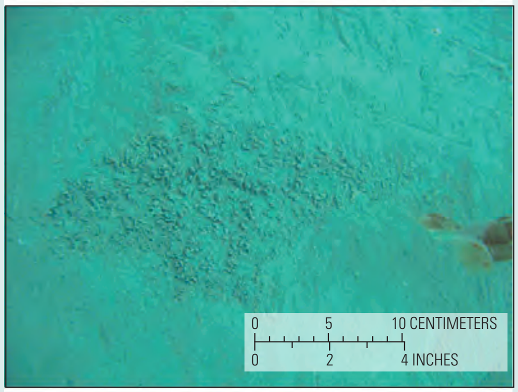
Water visibility, measured by divers, likely can be used as a proxy for the presence of fine sediments, because re-suspension of mud and silt can cloud the water. Mean visibility for all shallow sites at the two control areas (Green Point and Low Point) was lower than for shallow sites in the Elwha coastal zone (fig. S6.2), suggesting the presence of fine sediments in control area substrates. The reduced visibility at Green Point and Low Point was not simply the product of a single low visibility dive skewing the data. Out of 85 visibility measurements made in 2008, the lowest 10 occurred in these two areas.

Ampelisca was observed in abundance at shallow sites offshore of Green Point (fig. S6.1B). Gray whales were observed at these sites exhibiting behavior associated with bottom feeding—repeatedly diving and creating clouds of silt visible at the surface (fig. S6.3A). A year later at the same location trenches were observed in the seafloor, approximately 3 m long, 1–2 m wide and 0.2–0.5 m deep, which were interpreted as gray whale feeding excavations. Along the edges of these trenches, the sediment tubes of Ampelisca and inactive or dead amphipods were observed on the bed

***A. Ampelisca* tubes**



***B.* Flatfish imprint in soft sediment**



***C.* Tube-dwelling amphipods**

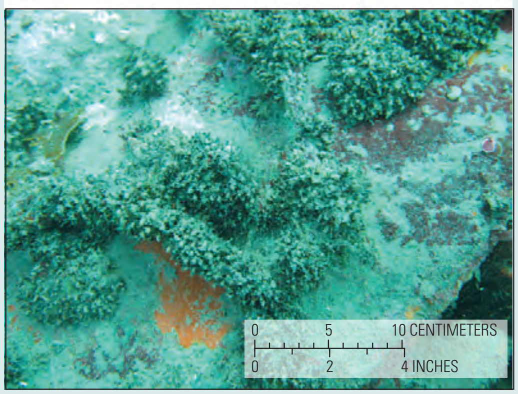


Figure S6.1. (*A*) *Ampelisca* tubes photographed at macro-range in an eelgrass bed at the west end of Freshwater Bay, September 9, 2009. (*B*) Outline of a flatfish in soft sediment off of Green Point, Siebert Creek, Strait of Juan de Fuca. Within the outline are numerous tubes of the amphipod *Ampelisca*, August 12, 2009. (*C*) Tube-dwelling amphipods, perhaps of the genus Ameplisca, attached to a small boulder off shore of Low Point, Lyre River, Strait of Juan de Fuca, September 10, 2009.

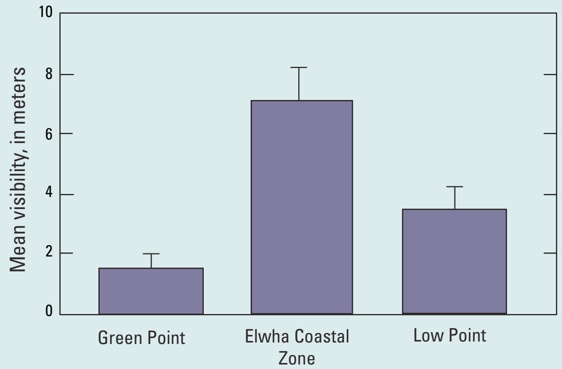


Figure S6.2. Mean visibility at shallow sites for two control areas (Green Point and Low Point) and the Elwha coastal zone. Error bars are one standard deviation.

***A.* Gray whale off of Green Point**

***B.* Edge of whale bite-mark**

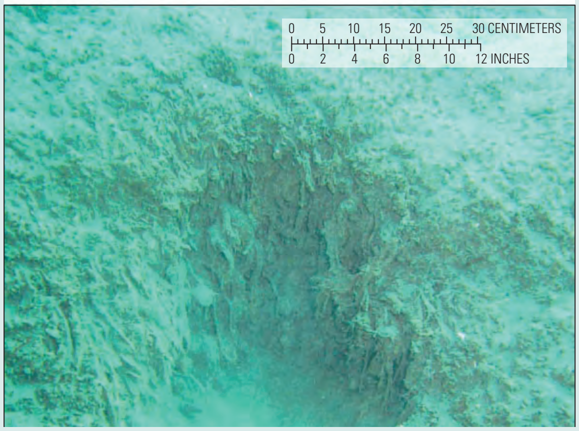


Figure S6.3. (*A*) A gray whale feeding off Green Point, September 4, 2008. Plumes of sediment trailed from this whale as it surfaced after feeding along the bottom. (*B*) An excavated edge cut into the soft substrate off shore of Green Point, likely due to gray whale feeding, September 11, 2009. This illustrates the extent to which soft sediment is used as habitat. Amphipods, annelid worms, and other small invertebrates were observed on and around the excavated bed in these pits.

(fig. S6.3*B*). Previous research in the Strait of Juan de Fuca (Oliver and Slattery, 1985) documented the effects of gray whale feeding on benthic community structure, showing the colonization of feeding excavations by motile scavengers, followed by the return of sessile tube worms in about 2 months. Amphipods also were observed in abundance at Low Point, but with a slightly different growth form, with clumps of tubes attached to boulders (fig. S6.1*C*). It is not clear if these amphipods also are a species of *Ampelisca*, although the tubes apparently were constructed of sediment and individual amphipods were observed at the opening of the tubes.

The role played by *Ampelisca* in supporting upper trophic levels in the Strait of Juan de Fuca is not clear, but this species has been a major dietary item of gray whales feeding elsewhere in the northern Pacific (Oliver and others, 1984; Oliver and Slattery 1985). Whether the removal of the dams on the Elwha River will increase fine sediments in the substrate around the Elwha delta is not known. The configuration of the Elwha delta and its exposure to waves and tidal currents might make it unsuitable for the settlement of silts, mud or clay. We hypothesize, however, that if dam removal results in a shift toward a substrate composed at least partially of fine sediments, development of habitat types and biological communities that are currently sparse may be facilitated in the Elwha coastal zone. We hypothesize that if fine sediments released in the Elwha coastal zone remain after dam removal, they may play a role in restructuring marine habitats by providing one of the essential ingredients for the success of abundant populations of *Ampelisca.*

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less dense and diverse than to the west but nonetheless abundant and distinct. Seavey and Ging (1995) thoroughly surveyed shallow depths between the river mouth and Dry Creek and reported high percentage coverage of macroalgae (74–100 percent) for most of this area. We confirmed their finding that *A. marginata* (fig. 6.7*B*) and *C. triplicata* (fig. 6.7*D*) are dominant kelp species in this area. These species are annuals whose blades grow during the spring and summer months (Mumford, 2007). Therefore, these species avoid damage or dislodgement by winter wave action and can thrive on finer substrate (gravel-cobble) than is required by perennial species like *P. californica* (fig. 6.7*G*). The invertebrate community at mixed substrate sites east of the river mouth was dominated by *Halcampa* spp. (burrowing anemones; fig. 6.16*G*), the most abundant taxon among those identified to genus or species, and soft tube worms including *Eudistylia vancouveri* (northern feather duster worm, fig. 6.6*D*), which was more abundant east than west of the river mouth. *H. Colliei* (spotted ratfish; fig. 6.10*C*) was common in mixed substrate habitat east of the river mouth. Sand habitat was also present east of the river mouth in shallow water at the base of Ediz Hook.

Implications for Effects of Dam Removal

Considerable influx of sediment to the nearshore is expected initially (for 3–5 years after start of dam removal) due to release of sediments that have accumulated in the reservoirs. Thereafter, sediment influx will likely decrease as the natural (pre-dam) rate of sediment delivery is re-established. This temporal pattern of sediment delivery raises a number of questions about biological community responses. What will happen to habitats and biota shortly after dam removal and in the long term? Will the marine system return to its natural, pre-dam condition? How long will restoration (recovery) take? What “services” (for example, kelp production) will be lost or impaired? What services will be enhanced? Our pre-removal survey establishes a baseline for evaluating short- and long-term consequences of dam removal. Follow-up surveys should help answer the questions posed above.

The spatial extent, vertical thickness, frequency, duration, timing (seasonality), and grain size of deposited sediments following dam removal will be important for determining effects on nearshore communities (Airoldi, 2003). Sediment deposition is expected to be greatest east of the Elwha River mouth due to the prevailing direction of coastal currents; however, sedimentation also may occur to the west in Freshwater Bay because currents are occasionally negligible or directed westward (Warrick and others, 2011b, chapter 5, this report). Thus, the community associated with mixed substrates lacking relief (boulders) that currently predominates east of the river mouth may experience the greatest sediment loads following dam removal, but kelp forest and relief-dependent communities to the west also may be affected. Furthermore, each of these communities may respond differently even to similar sedimentation levels. Finally, suspended sediment from riverine inputs as well as from re-suspension of deposited sediments may affect biological communities. These uncertainties highlight the opportunity to advance scientific understanding by measuring responses following dam removal.

Whatever changes come, they will likely involve tradeoffs, favoring some species and disfavoring others in the short term and over the long term as restoration occurs. Kelp may be particularly intolerant of sedimentation because their spores require sediment-free surfaces for settlement, their microscopic gametophyte and young sporophyte life stages are susceptible to burial, and they require high light levels for growth (Mumford, 2007). Even so, some kelp species can persist in areas with fine sediment (Dayton, 1985), perhaps depending on the depth or timing of coverage by fine sediment and the life history traits of the kelp (timing of reproduction; annuals compared to perennials; physiological adaptations). Sediment influx following dam removal may reduce kelp abundance overall, but may favor some species over others. Organisms that can propagate vegetatively, thereby bypassing vulnerable juvenile life stages, may be relatively resistant to sedimentation (Airoldi, 2003). Some turf-forming seaweed can trap sediments, which may discourage grazing or give them a competitive advantage over organisms less tolerant to sedimentation (Airoldi, 2003). If localized accumulations of sediment are great enough, some areas could convert from hard substrate to soft substrate habitat causing dramatic shifts in the benthic community. If dam removal results in accumulations of very fine sediments (silt, mud, or clay), which are currently rare in the Elwha coastal zone (Warrick and others, 2008), a group of small invertebrates that provide food for a number of other organisms may benefit (sidebar 6-1).

Summary

Benthic communities inhabiting shallow, subtidal depths near the mouth of the Elwha River were biologically diverse. They included 10 kelp species with differing growth forms and habitat associations, and a wide variety of invertebrate and fish species. Substrate type, seafloor relief, and water depth were important determinants of organism density and species composition. As such, the spatial distribution of these characteristics created a rich mosaic of habitats and associated communities. The removal of two dams on the Elwha River will release large quantities of sediment, some of which will be discharged into the Elwha River nearshore. The greatest influx is expected during the first 3–5 years after start of dam removal from sediment that has accumulated in the reservoirs. Thereafter, sediment input should decrease but remain higher than before dam removal owing to restored connectivity with the upper watershed. Measuring community responses to short and long term changes in deposited and suspended sediments following dam removal offers an unprecedented opportunity to gain insight relevant to managing these important marine resources.

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