6. FOOD WEB

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A food web is a complex pattern of interlocking food chains in a complex community or between communities, while a food chain is a group of organisms involved in the transfer of energy from its primary source (i.e., sunlight, phytoplankton, zooplankton, larval fish, small fish, big fish, mammals). The types and varieties of food chains are as numerous as the species within them and the habitats that support them. Thus, the food web is analyzed based on knowledge of the food chains that make it up. This can be further complicated because any single species may occupy more than one trophic level within a food chain (Krebs 1972).

To completely describe the food web in Puget Sound is beyond the scope of this report. However, this section describes four major parts of the food web: phytoplankton, zooplankton, benthic infauna, and secondary consumers. Because phytoplankton and zooplankton are essential components of Puget Sound food chains, this section contains information on stressors to these organisms. It also discusses links between food chains and nearshore habitats.

PHYTOPLANKTON

Puget Sound's pelagic food chain, which culminates in fishes, birds, mammals, and humans, begins with phytoplankton (Strickland 1983). Phytoplankton growth in the Sound is regulated by an interaction of the sun, precipitation, nutrients, and forces that move water, including wind. To a great extent phytoplankton production depends on the weather, with mixing and stratification of the water column controlling primary productivity. Strong vertical mixing can have a negative effect on productivity by reducing phytoplankton's exposure to light that is necessary for photosynthesis. However, vertical mixing is also beneficial because it brings nutrients from deep water to the surface where they can be used by phytoplankton. The dominant areas of mixing in Puget Sound occur where the tidally driven current is forced over shallow sills and through narrow constrictions. The major sills in WRIAs 8 and 9 include one at Admiralty Inlet (60 m deep), the north entrance to Colvos Passage (24 m deep) (reach 12), and south of Tacoma Narrows (44 m deep). Puget Sound is also highly productive because of the stabilizing effects of river runoff, which cause a saline stratification of the water column. Thermal stratification reinforces this process, which persists until strong mixing forces intervene. Phytoplankton growth usually begins when the stratification set up by runoff in the winter and spring coincides with an increase in sunlight in the spring. Hence, Puget Sound experiences a highly productive balance of phytoplankton growth, as mixing and stratification alternate, forming patchy distributions in space and time. Most phytoplankton growth in the Sound occurs as dynamic events, with intense blooms usually occurring in the spring and fall, smaller blooms in the summer, and sparse growth in the winter. Phytoplankton studies now under way in the Central Basin indicate smaller scale temporal and spatial correlations among nutrients, chlorophyll, and production exist (R. Shuman, pers. comm.).

The three major types of phytoplankton present in Puget Sound are the diatoms, dinoflagellates, and microflagellates (Rensel Associates and PTI Environmental Services 1991; Strickland 1983). Diatoms occur as either individual cells or chains of cells enclosed in a silica shell. They are the most abundant phytoplankton group (measured by total cell carbon mass per volume of water) in central Puget Sound during the spring bloom and often throughout the summer months. Typically, diatoms are most abundant in coastal areas where a moderate amount of vertical mixing is followed by periods of vertical stratification within the euphotic zone. A spring bloom of *Skeletonema costatum* and other diatom species is typical throughout most of Puget Sound. Smaller blooms may occur in the fall as well.

Dinoflagellates are found in all types of marine waters, but tend to be dominant in less turbulent areas that are vertically stratified and often seasonally depleted of nutrients in surface waters. Vertical density stratification that is largely induced by temperature occurs in some restricted bays and inlets of Puget Sound during summer and fall. Dinoflagellates possess flagella that enable them to move through the water. Thus, some are able to migrate vertically in the water column, obtaining nutrients at depth during the night and using sunlight near the surface during the day for photosynthesis. Dinoflagellates may also dominate the phytoplankton community in relatively well-mixed areas such as central Puget Sound during periods of calm weather and solar heating (Rensel Associates and PTI Environmental Services 1991; Strickland 1983).

Microflagellates, not a taxonomically distinct group, are usually unarmored and unicellular, and are the smallest of the phytoplankton (Strickland 1983). They have been overlooked for many years because their size makes them difficult to capture and preserve. Although they have been known to be numerically dominant during portions of the summer in central Puget Sound (Anderson et al. 1984) and Hood Canal (Rensel et al. 1989), little is known about their biology or behavior.

In most temperate coastal marine environments, including Puget Sound, there is a seasonal pattern of phytoplankton succession (Rensel Associates and PTI Environmental Services 1991). The pattern begins with a community dominated by diatoms in the spring, shifting to one dominated by dinoflagellates or microflagellates in the summer and early fall, and sometimes returning to diatom predominance in the fall. This succession is modified, and sometimes caused, by seasonal water column stratification, water column mixing, surface water replacement by deeper nutrient-rich waters, and zooplankton grazing.

Anderson et al. (1984) found that the time-averaged rate of change of sunlight (intensity and duration) was the most important factor in determining the seasonal abundance and production of phytoplankton in central Puget Sound. Phytoplankton abundance reached a maximum around the time of the summer solstice and a minimum around the time of the winter solstice. Temporal correlations among nutrients, phytoplankton, and zooplankton occurred on a seasonal basis. Correlations on a smaller scale of days and weeks were undetectable because of the large temporal and spatial variation.

Published studies of phytoplankton species distribution and abundance in Puget Sound have generally been restricted to the main channels of the Central Basin (Thompson and Phifer 1936; Chester et al. 1978; Anderson et al. 1984). Dexter et al. (1981) summarized information concerning life histories, major taxa, and spatial and temporal distribution of phytoplankton in Puget Sound.

Stressors

When vertical mixing is severely limited and adequate light is available, nutrients (particularly nitrogen) may become the limiting factor that controls phytoplankton growth in surface waters of Puget Sound. Recent studies show episodic nutrient limitation in the Main Basin of Puget Sound during periods of stability and low nutrient concentrations (Nakata et al. 2000). This is not unexpected in areas that are well mixed and typically have adequate nutrients. However, in some areas of Puget Sound with persistent stratification (i.e., narrow constricted estuaries), restricted circulation may have nutrient levels below a reporting limit for extended periods (Newton et al. 1998). Nutrient-addition experiments conducted as part of focused monitoring by the Department of Ecology showed a substantial increase in phytoplankton production in Hood Canal but not in the Main Basin of Puget Sound (Newton et al. 1994). Nutrient limitation has not been thoroughly studied in Puget Sound waters; however, stratified waters are most likely to respond to nutrient addition. The composition of phytoplankton populations under these conditions may shift from diatoms to dinoflagellate or microflagellate species that are able to vertically migrate to obtain nutrients from subsurface waters. For dinoflagellate populations, shading, tidal advection, grazing, and subsurface nutrient reserves are available in all but the most shallow and isolated embayments of Puget Sound.

Harmful algal blooms or "red tides" are a concern in Puget Sound as the geographic distribution and intensity of PSP has increased since the mid-1970s (Rensel 1993). The two primary species of concern in Puget Sound include the dinoflagellate *Alexandrium catenella*, which causes PSP from a number of saxitoxin derivatives, and the diatom *Pseudo-nitschia* spp., which causes domoic acid poisoning (also called amnesiac shellfish poisoning) (Horner et al. 1997). Almost all of WRIAs 8 and 9 have remained continuously closed to recreational harvesting because of a combination of PSP toxins and fecal coliform levels that remain above allowable health standards. The initiation of *Alexandrium* blooms may be related more to seasonal temperature increases than any other single factor, although some blooms may be prolonged or intensified by increased nutrients (Rensel Associates and PTI Environmental Services 1991).

Reasons for Change

Without long-term data, it is difficult to determine changes in historical distribution. Elevated nutrient loading from human sources (i.e., sewage discharges, non-point pollution, and agricultural runoff) may alter the normal composition of phytoplankton in some areas of Puget Sound. The degree of mixing and the nutrient supply to the surface layer may influence phytoplankton species competition and, hence, community succession. Interannual variations in hydrographic and weather conditions confound the interpretation of short-term monitoring studies for phytoplankton and nutrients in Puget Sound. Strong El Niño events in the early 1980s complicated attempts to characterize phytoplankton conditions during a two-year survey of the Main Basin of Puget Sound (Anderson et al. 1984).

Data Gaps

Long-term data on phytoplankton species abundance in Puget Sound, including harmful and toxic species, are unavailable (Table 5). This data gap precludes an understanding of interannual variations in community structure, and the possible long-term effects of changes in natural and anthropogenic sources of nutrients. Although studies in the Central Basin are beginning to indicate smaller scale temporal and spatial relationships among nutrients, chlorophyll, and production, additional studies are needed to fully understand phytoplankton production. Concurrent monitoring of nutrients, insolation, salinity, water temperature, and dominant zooplankton throughout the water column is needed to clarify nutrient-phytoplankton-zooplankton relationships. All of these factors have been shown to be important in determining species composition and distribution (Takahashi and Parson 1973; Parametrix, Inc. 1984). Despite continuous closures to recreational harvesting in WRIAs 8 and 9, there has been no direct causal link established between nutrient enrichment, eutrophication, and PSP in Puget Sound (Rensel 1993).

Table 5: Data gaps for phytoplankton

Gaps	WRIA 9	WRIA 8
Long-term abundance data	All reaches	All reaches
Interannual changes in community structure	All reaches	All reaches
Long-term effects of changes in natural and anthropogenic sources of nutrients	All reaches	All reaches
Relationships among nutrients, phytoplankton, and zooplankton	All reaches	All reaches

ZOOPLANKTON AND OTHER HETEROTROPHS

In Puget Sound, zooplankton and other heterotrophs (a secondary trophic level of organisms that act as primary consumers/converters of organic matter) in the water column fill an important ecological niche as the link between phytoplankton primary production and fish productivity. Fish that are 50 to 200 millimeters in length, such as juvenile and adult herring, smelt, stickleback, and sand lance, and juvenile salmon, cod, hake, pollock, lingcod, sablefish, and dogfish, derive a major part of their nutrition from zooplankton and other heterotrophs. In addition, these primary consumers are important prey for sculpins, rockfish, basking sharks, some birds, and baleen whales (Strickland 1983). In the Duwamish Estuary (reach 4), Meyer et al. (1981) found that juvenile coho salmon preyed heavily upon gammarid amphipods. The two preferred species were *Corophium salmonis* and *Eogammarus confervicolus*. In addition to gammarid amphipods, juvenile chum consumed calanoid and harpacticoid copepods. Pink salmon juveniles, on the other hand, preferred harpacticoids followed by calanoid copepods. Juvenile chinook relied upon gammaridean amphipods and calanoid copepods in their diet. In early studies, Stober and Pierson (1984) indicated that 85 to 92 percent of the zooplankton in the bay were calanoid copepods.

Technically, the term zooplankton refers to animal forms of plankton, who live in the water column and whose movement is primarily controlled by currents. However, they do have the ability to migrate vertically within the water column and may also migrate horizontally from the shore out to sea during the spring and summer in order to find favorable conditions. The vertical migration creates sonic scattering layers as zooplankton move to the surface at night and to great depths during the day (Strickland 1983). In shallow areas with high turbulence, such as the Narrows, these sonic layers are not observed either because of the high turbulence or because the shallow water inhibits vertical migration. The seasonal horizontal migrations allow zooplankton to follow the phytoplankton blooms, as well as conserve energy by overwintering in protected inlets. In the fall as phytoplankton numbers dwindle, the sonic scattering layers first disappear from reaches 1 and 2 (Main Basin) and then in reach 4 (Elliott Bay), as the zooplankton move to sheltered areas for the winter, such as north of reach 1 (the Whidbey Basin).

Since juvenile salmon feed on large copepods and amphipods, the most efficient food chain for fish productivity consists of three trophic levels: diatoms to large copepods to fish. However, when conditions are unfavorable for diatom growth, such as a highly stratified and low nutrient environment, then small phytoplankton dominate the system. Because of the absence of large diatoms, a second trophic level of heterotrophs is required to produce adequate size food for fish. This "secondary food chain" consists of a small phytoplankton to small copepod/protozoan to ctenophore/medusae to fish progression (Strickland 1983). The secondary food chain has a decreased transfer efficiency and lower nutrition because of the high water content of the medusae. Also, distribution of zooplankton is patchier than the primary food chain. However, microzooplankton help retain nutrients in the surface waters because they have tight trophic coupling to phytoplankton, consuming it before it dies and sinks to the bottom. Therefore, this may allow for a greater population of pelagic fish, whereas the primary food chain may support greater numbers of groundfish due to an abundance of heavy diatoms sinking to the bottom (Strickland 1983). This scenario may apply to the areas in Puget Sound with persistent stratification (reaches 1 and 4) and seasonal stratification (reach 2) (Newton et al. 1995).

In the spring, newly emerged juvenile salmon rely on zooplankton for food in protected nearshore marine waters. As the season progresses, salmon follow the seaward migration of zooplankton into deeper water. However, it is not known how much juvenile salmon are affected by changes in the zooplankton population during their residence in the nearshore waters. Some researchers have attributed a 90 percent decline in the Strait of Georgia coho population to a lack of food during their three-month stay in the inland marine waters (Nevissi et al. 1984). To further support this hypothesis, chum and chinook salmon runs that migrate directly to the ocean have not declined as drastically. Speculation exists that an early arrival of spring freshwater runoff, possibly due to events such as global warming or El Niño, has disrupted the phytoplankton blooms in the Strait of Georgia, which in turn, affect the zooplankton blooms. Significant declines in Puget Sound coho runs have also been attributed to changes in the nearshore environment (Seiler, pers. comm.).

Stressors

Stressors such as shoreline development, climate change, reduced water quality, and natural cycles may be affecting zooplankton in Puget Sound, but historical and contemporary data on species composition and abundance of zooplankton are lacking (Frost, pers. comm.). However, large-scale weather cycles, such as El Niño southern oscillation (ENSO), have had an effect on zooplankton biomass and/or productivity in other waters. For example, a shortened upwelling season caused by the 1997-1998 ENSO reduced biomass and productivity of local zooplankton species off the central Oregon coast (Peterson 1999). Also, a 70 percent decrease in zooplankton volumes in the California current from 1951 to 1993 was attributed to warming of the ocean's surface layers (Roemmich and McGowan 1995). In addition, in Barkley Sound, British Columbia, the 1992 ENSO coincided with a decrease in the biomass and productivity of adult euphausiid, *Thysanoessa spinifera* (Tanasichuk 1998). Also, a link has been found between ocean climate fluctuations on the northeast Pacific continental margin and orders of magnitude shifts in mesozooplankton species composition (Mackas et al. in review).

Another potential stressor to zooplankton species in Puget Sound is the introduction of non-native species from Asia and other regions. Although it appears that no current populations of introduced planktonic copepods are reproducing in Puget Sound (J. Cordell, unpublished data; Cohen et al. 1998; Cordell and Morrison 1996), non-native species have been observed near shipping terminals in Seattle, Washington (reach 4). Also, small epibenthic calanoid copepods indigenous to Asia have successfully established themselves in Puget Sound (J. Cordell, unpublished data). With the abundance of shipping activity in the ports of Seattle, Everett, and Tacoma, a widespread invasion by non-native copepod species in Puget Sound seems highly likely because it has occurred in San Francisco Bay (Orisi and Ohtsuka 1999). One species, *Pseudodiaptomus inopinus*, has already established itself in estuaries along the Oregon and Washington coasts, as well as the Columbia River (Cordell and Morrison 1996). The introduction of *P. inopinus* has diminished the food supply available to juvenile salmon because it outcompetes the juvenile salmon prey copepod *Eurytemora affinis,* but is not suitable food for salmon itself.

Historical Distribution and Reasons for Change

Unfortunately, very few quantitative studies have been completed on zooplankton assemblages in Puget Sound, except for several student theses (Depster 1938; Hebard 1956; Damkaer 1964; Dumbauld 1985). In addition, except for a series of unanalyzed plankton samples collected throughout the 1960s and 1970s by the City of Seattle's wastewater municipality at a single site, no historical data are available to compare with current zooplankton abundance and distribution (Frost, pers. comm.).

Data Gaps

The need for analysis of archived samples described above as well as routine sample collection of present assemblages is essential for understanding the relationship of zooplankton abundance and distribution, human activity, natural cycles, and fish populations in Puget Sound (Table 6). Specifically, useful information would include species composition at varying depths and locations around Puget Sound; seasonal distribution and relationship to human activities; links among salmon, forage fish, and zooplankton; a comparison of fish and zooplankton diets between the late 1970s and early 2000s; and baseline zooplankton data for Puget Sound so that future comparisons can be made (Frost, pers. comm.).

Table 6: Data gaps for zooplankton

	WRIA 8	WRIA 9
Distribution and abundance time-series data	All reaches	All reaches
Species composition at varying depths and locations	All reaches	All reaches
Seasonal distribution and relationship to human activities	All reaches	All reaches
Links among salmon, forage fish, and zooplankton	All reaches	All reaches
Comparison of fish and zooplankton diets in the 1970s versus the early 2000s to assess potential changes	All reaches	All reaches
Baseline zooplankton data	All reaches	All reaches

BENTHIC INFAUNA AND EPIFAUNA

Benthic infauna (organisms that live in the sediments) and epifauna (organisms that live on the sediments) comprise a diverse assemblage of taxa including clams, crabs, worms, snails, shrimps, and fishes. These burrowers, scavengers, predators, and filter feeders are capable of processing vast amounts of phytoplankton, zooplankton, plant matter, sediments, detritus, and other nutrients. They play important intermediate roles in the nearshore food web, acting as converters of organic matter and making it available to higher trophic levels, which contributes to increased productivity of fish and wildlife. Demersal, neretic, and terrestrial predators include fishes such as elasmobranchs (sharks, skates and rays), flatfish and other bottom-dwelling species; shorebirds; marine mammals, including gray whales and sea otters; and humans (i.e., clams support important sport and commercial fisheries).

To completely describe how the various food chains interlock into a coherent food web for benthic communities in Puget Sound is beyond the scope of this report. However, we have briefly described groups of primary and secondary consumers below.

PRIMARY CONSUMERS

The following text describes benthic communities by separating them into the functional feeding groups developed by Word (Word 1990). Organisms within these groups have developed certain methods of obtaining food either by having specialized appendages or by using habitats or niches where their mode of feeding allows them to dominate. The feeding groups described here are based on the particle size of the ingested food item and on the method used to capture the food item.

Benthic community ecologists generally agree that there are four basic types of feeding modes. These include:

- Suspension Feeding: An organism that filters or selects particles (organic and inorganic particles) 50 um or less from the water column.
- Surface Detrital Feeding: An organism that selects organic and inorganic particles from the sediment surface that are 50 um or less in size.

- Surface Deposit Feeding: An organism that selects organic-encrusted mineral grains from the sediment surface that are greater than 100 um in size.

Deposit Feeding (Specialized): An organism that selects organic-encrusted mineral grains from the sediment surface or subsurface that are greater than 100 um in size.

The above groups can be further divided into subgroups based on the method an organism uses to capture its food. One or more of these methods of capture can be found in each of the above modes of feeding. These include:

- Passive Appendage Capture: Food is captured when material comes into contact with an organism's appendages after being carried by water currents.
- Active Appendage Capture: Food is drawn to the organism by movement of body parts, which create water movement, and can be stationary or active.
- Pump and Filter Capture: Food is captured on filters used along with the creation of water movement, which draws particles to the organism.
- Forage Capture: These organisms are highly mobile and actively move to particulate material; this group includes carnivorous and predatory organisms (i.e., secondary consumers).
- Domicile Enhanced: These organisms have tubes, burrows, or mounds that alter the patterns of water movement causing light particulate material to settle.

The distribution of the above feeding groups in Puget Sound is dependent primarily on water movement and secondarily on sediment particle size, which is dependent on the strength and duration of water movement.

The suspension-feeding modes along with organisms associated with the Passive Appendage, Active Appendage, and Domicile Enhances subgroups can be found in high-energy environments where water currents move suspended detrital material through the water column. Sedimentary habitats in these areas tend to be coarse grained. Conversely, the specialized deposit feeding mode along with associated organisms in subgroups that forage capture and pump and filter are found in areas with no water movement and very high levels of organic material. The sediments in these environments tend to consist of fine silt and clays. Except in rare circumstances, organisms in the forage capture and pump and filter subgroups do not coexist in the same area.

Organisms using the surface detrital and surface deposit feeding modes are found in habitats within the extremes of the other two groups. Sedimentary materials can range from silty sand with light to moderate amounts of organic material to sandy silt with light amounts of organic material.

Organisms using the suspension, surface detrital, and surface deposit feeding modes can and do coexist in the same areas. These groups can be found in areas where water movement is slow or where tidal currents cause ebbs and flows in water movement. This results in habitats where some types of suspension feeders can periodically feed and others where surface detrital and surface deposit feeding organisms can periodically feed.

Based on the above modes of feeding and on the relative abundance of organisms found in the different habitats in Puget Sound, Word (1990) arranged the dominant Puget Sound benthic infaunal species into the feeding groups in Table 7.

Table 7: Assignment of Puget Sound benthic infaunal taxa into feeding groups

Feeding Group I: Suspended Detrital Feeders		
Passive Sieve	Domicile Enhanced (Eddy)	Pump and Filter
Owenia spp. (Po) *Sabellidae* (Po) *Serpulidae* (Po) *Amphipolis* (E) *Phoxocephalidae* (A) *Sthenelanella* spp. (Po)	*Maldanidae* (Po) *Onuphidae* (Po) *Ampharetidae* (Po) *Terebellidae* (Po) *Phoronis* spp. (Ph) *Caprellida* (A) *Ampelisca* I (A) *Cucumaria* spp. (E)	*Nemocardium* spp. (Pe) *Crenella* spp. (Pe) *Ampelica* II (A) *Byblis* spp. (A)
Feeding Group II: Surface Detrital Feeders		
Active (Stationary)	Forage Capture	Specialized
Spionidae (Po) *Magelonidae* (Po) *Cirratulidae* (Po) *Myriochele* spp. (Po) *Axinopsida serricata* (Pe) *Mysella* spp. (Pe) *Calyptogena* spp. (Pe) *Photis* spp. (A)	*Orbinidae* (Po) *Capitellidae* (other) (Po) *Mediomastus* spp. (Po) *Decamastus* spp. (Po) *Nephtys* spp. (Po) *Glycera* spp. (Po) *Tanaidae* (A) *Ostracoda* (A) *Euphilomedes* spp. *Cumacea* (A)	*Pectinaria californiensis (Po)*
Feeding Group III: Surface Deposit Feeders		
Active (Stationary)	Forage Capture	
Parvilucina tenuisculpta (Pe) *Macoma carlottensis* (Pe) *Nuculana* spp. (Pe) *Nucula* spp. (Pe) *Yoldia* spp. (Pe)	*Travisia* spp. (Po) *Nereis* spp. (Po) *Bittium* spp. *Mitrella permodesta* *Nassarius* spp.	
Feeding Group IV: Subsurface Deposit Feeders		
Capitella capitata complex (Po) *Armandia bioculata* (Po) *Ophelina acuminata* (Po) *Oligochaeta* (An) *Solemya spp. (Pe)* *Stenothoidae* (A) *Dorvilleidae* (Po)		

Source: Word 1990
A Arthropoda
An Annelida
E Echinodermata
G Gastropoda
Pe Pelecypoda
Ph Phoronid
Po Polychaeta

SECONDARY CONSUMERS

Secondary and higher level consumers, also referred to as predators and carnivores, are animals that prey upon other animals. Typical nearshore carnivores include fish, many epifaunal species such as seastars and snails, shorebirds, seabirds, and marine mammals. No comprehensive study has addressed upper level nearshore food webs in WRIAs 8 and 9. However, a number of studies have examined fish (especially salmon) feeding behavior and prey composition in some nearshore habitats of central and southern Puget Sound. Other studies, such as Birkeland (1974) have examined trophic relationships of epifaunal assemblages.

A number of ecologically important fish species spend the majority of both their juvenile and adult life-history stages within a variety of nearshore habitats in the intertidal and shallow subtidal systems. They include flatfish, surfperch, gunnels, greenlings, poachers, pricklebacks, gobies, and sculpins (Table 8). Members of these taxa use nearshore habitats over a variety of temporal (i.e., seasonal, diurnal) and spatial scales, and vary in their morphological adaptations to tidal fluctuations, preferred prey, and affinities with particular substrate types. All are important components in the nearshore food web (Simenstad et al. 1979; Long 1982).

Table 8: Commonly occurring fish species in nearshore habitats throughout WRIAs 8 and 9

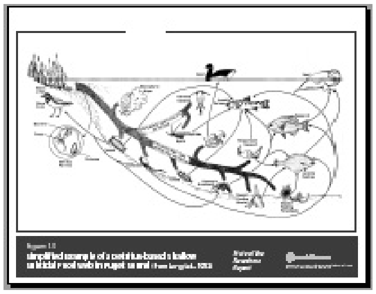
Common Name	Scientific Name
English sole	*Pleuronectes vetulus*
Rock sole	*Lepidopsetta bilineata*
C-O sole	*Pleuronichthys coenosus*
Sanddabs	*Citherichthys* spp.
Starry flounder	*Platichthys stellatus*
Pacific herring	*Clupea harengus pallasi*
Surf smelt	*Hypomesus pretiosus*
Pacific sand lance	*Ammodytes hexapterus*
Bay pipefish	*Syngnathus leptorhynchus*
Crescent gunnel	*Pholis laeta*
Saddleback gunnel	*Pholis ornata*
Penpoint gunnel	*Apodichthys flavidus*
Pile perch	*Damalichthys vacca*
Striped seaperch	*Embiotoca lateralis*
Shiner perch	*Cymatogaster aggregata*
Tidepool sculpin	*Oligocottus maculosus*
Staghorn sculpin	*Leptocottus armatus*
Buffalo sculpin	*Enophrys bison*
Padded sculpin	*Artedius fenestralis*
Lingcod	*Ophyodon elongatus*
Cabezon	*Scorpaenichthys marmoratus*
Whitespotted greenling	*Hexagrammos stelleri*
Rockfishes	*Sebastes* spp.
Tubesnout	*Aulorhynchus flavidus*
Walleye pollock	*Theragra chalcogramma*
Pacific tomcod	*Microgadus proximus*
Chinook salmon	*Oncorhynchys tshawytscha*
Chum salmon	*Oncorhynchus keta*

Adapted fromDonnelly et al. 1984

LINKS BETWEEN FOOD WEBS AND NEARSHORE HABITAT

Two comprehensive studies in northern Puget Sound and the Strait of Juan de Fuca have synthesized biological data and analyzed food web relationships of organisms in nearshore marine habitats (Simenstad et al. 1979; Long 1982). Biological communities in this region bear many similarities to those in central Puget Sound, although the northern habitats generally are less protected and have higher exposure to prevailing hydrologic conditions. Food webs in shallow water nearshore habitats are largely based on the heterotrophic processing of detritus produced by senescing marine algae, estuarine and saltmarsh vascular plants, and especially eelgrass (Figure 13) (Long 1982).

Figure 13 Simplified Example of a Detritus-based Shallow Subtidal Food Web in Puget Sound



Click here to view figure

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In general, food web complexity in these systems increases with decreasing exposure, decreasing sediment particle size, and increasing deposition of algal and vegetative detritus (Simenstad et al. 1979).

Simenstad et al. (1979) constructed composite food webs for seven representative nearshore habitats: neritic, rocky/kelp bed sublittoral, rocky littoral, cobble littoral, and shallow sublittoral zones of gravel-cobble, sand-gravel/eelgrass, and mud/eelgrass habitats. Calanoid copepods and gammarid amphipods were recognized as being critical to upper trophic levels in most shallow sublittoral zones because they provide food resources for important consumer organisms or they convert organic matter to make it available to higher level consumers (i.e., detritus processors). In turn, they are a primary prey of important secondary consumers such as Pacific herring, Pacific sand lance, and juvenile Pacific salmon, which are used by higher-level carnivores.

The principal secondary consumers in shallow neritic habitats (i.e., surface waters and water column of the nearshore region) of northern Puget Sound/Strait of Juan de Fuca are schooling fishes such as juvenile Pacific herring, Pacific sand lance, northern anchovy, longfin smelt, and surf smelt (Simenstad et al. 1979). Almost all marine birds and mammals found in neritic habitats are tertiary consumers that feed on these forage fish species. Secondary consumers in rocky sublittoral and associated kelp habitats are typically demersal or bottom-oriented fishes, including greenlings, gunnels, sculpins, rockfishes, and gobies, and gastropods, octopus, and a variety of seastars. In turn, harbor seals, northern sea lions, California sea lions, and orcas prey upon larger demersal fishes. In gravel-cobble shallow sublittoral habitats, important secondary carnivores are primarily juvenile and adult flatfish, including English sole, sand sole, and rock sole. Benthic-feeding shorebirds, such as greater yellowlegs, sanderling, great blue heron, and sandpipers, are prevalent in this habitat, as well as protected sand/eelgrass and mud/eelgrass habitats. Mud/eelgrass habitats, commonly associated with saltmarsh environments, are considered the most complex and highly connected food webs. Besides many of the fish species already mentioned, juvenile salmon (especially chum), staghorn sculpin, crescent gunnel, pipefish, various flatfish species, and shiner perch are the predominant secondary consumers in these protected shallow water habitats.

Key Findings

- Planktonic, as well as benthic algal and eelgrass-dominated habitats, are highly susceptible to anthropogenic nutrient increases.
- Harmful algal blooms can be intense and result in toxic shellfish as well as other health problems affecting humans and aquatic animals. Harmful algal blooms and elevated fecal coliform levels have closed virtually all WRIA 8 and 9 nearshore habitats to recreational shellfish harvesting.
- El Niño and other anomalous climatic events affect the dynamics of planktonic and benthic habitats.
- There are a large number of introduced benthic and planktonic species that may affect the food web and functions of benthic and planktonic habitats.

- No comprehensive study has addressed food web interactions in WRIA 8 and 9 nearshore marine habitats. However, similar studies in northern Puget Sound and the Strait of Juan de Fuca offer a number of insights into Central Puget Sound processes.
- The food web of shallow nearshore habitats of the region is based upon detritus produced by marine algae, estuarine and saltmarsh vascular plants, and especially eelgrass.
- Gammarid amphipods and calanoid copepods are important primary consumers that convert organic matter to upper trophic levels. Important secondary consumers include herring, sand lance, surf smelt, and juvenile salmon.