19 The seagrasses of THE PACIFIC COAST OF NORTH AMERICA

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The region along the Pacific coast of North America extending from the Baja Peninsula in Mexico through Alaska includes a wide variety of ecosystems ranging from subtropical through arctic in a northerly transect. Given the nature of the leading edge coast and the resultant paucity of large regions where soft sediments can accumulate, one would expect a rather limited diversity of marine angiosperms or seagrasses. However, a reasonably large number of species exist in this region for a number of reasons, related in part to the ability of members of the genus *Phyllospadix* to colonize rocky shores. Eight seagrass species are recognized: *Halodule wrightii, Ruppia maritima, Zostera marina, Zostera japonica, Zostera asiatica, Phyllospadix scouleri, Phyllospadix serrulatus* and *Phyllospadix torreyi*[1-4]. Four of them, *Zostera marina, Phyllospadix scouleri, Phyllospadix serrulatus* and *Phyllospadix torreyi*, have probably been growing in the region since the Pliocene[5]; one, *Zostera japonica*, is a recent addition to the northeast Pacific flora, being introduced as a result of oyster enhancement programs[6]; and little is known about the phytogeographic history of the three other species (*Zostera asiatica, Ruppia maritima* and *Halodule wrightii*).

In terms of ecosystems, members of the genus *Phyllospadix* (the surfgrasses) dominate the rocky subtidal and intertidal zones, where their condensed rhizomes allow them to colonize hard substrates. The three species in the genus *Phyllospadix* (*Phyllospadix serrulatus, Phyllospadix scouleri* and *Phyllospadix torreyi*) are endemic to the Northeast Pacific[2]. Both *Phyllospadix torreyi* and *Phyllospadix scouleri* were widely used in the region by indigenous people before European contact[7]. For example the flowers of *Phyllospadix torreyi* were sucked for sweetness by children of the Makah people who live on the Olympic Peninsula of Washington state, and leaves of the same plant were woven into pouches by the coastal Chumash in the Channel Islands of California.

In contrast, soft-bottom habitats in the subtidal and intertidal zones and estuaries are more commonly associated with plants in the genus *Zostera*, which can form large monotypic stands in the Northeast Pacific estuaries, and mixed stand populations of *Zostera marina* and *Zostera japonica*, and sometimes *Ruppia maritima*, in estuaries from southern British Columbia, Canada, to Coos Bay, Oregon[8,9]. *Zostera marina* provides important habitat for migrating waterfowl, juvenile salmon, resident forage fish, invertebrates and wading birds[8], and *Zostera japonica* is commonly eaten by resident and migratory waterfowl[10]. Noteworthy is the use of *Zostera marina* as substrate for the laying of Pacific herring (*Clupea harengus pallasi*) roe; the roe is also used by humans[8].

Whereas little is known about the primary production rates for *Zostera japonica*, *Zostera marina* productivity can be quite high on an annual basis (84-480 g carbon/m^2/year) and standing stocks may cover many hectares of seafloor[8,11]. For example, the large populations at Izembek Lagoon, Alaska, United States (160 ha) and Laguna Ojo de Liebre, Baja California, Mexico (175 ha), which are the primary staging grounds for migratory waterfowl, may be the largest *Zostera marina* ecosystems in the world[12,30]. In addition, pre-contact First Nations peoples recognized *Zostera marina* and its ecosystems as valuable cultural and food resources. In British Columbia a number of First Nations people (Nuu-chah-nulth, Haida and Kwakwaka'wakw) ate fresh rhizomes and leaf bases or dried them into cakes for winter food[13]. Moreover, the Seri Indians living on the Gulf of California in Sonora, Mexico, used the *Zostera marina* seeds to make flour[14].

Ruppia maritima grows in many of the brackish water coastal lagoons from Alaska south to Mexico[4,14]. Interestingly, *Ruppia maritima* was recognized as a separate species (from *Zostera marina*) by the Seri elders but was not used by them[14].

The last two species, namely *Zostera asiatica* and *Halodule wrightii*, have rarely been the focus of biogeographic investigation within this region. *Zostera asiatica* was found recently at three sites in southern California[3] and, leaving aside some regional studies documenting the presence of *Halodule wrightii* in the Gulf of California[1], there are no studies that discuss the habitat value or autecology of these plants in the Northeast Pacific region.

BIOGEOGRAPHY

Zostera marina (or eelgrass) is the dominant species in terms of biomass and habitats on the Pacific coast of North America, where it grows in:

- the shallow waters of the continental shelf;
- the Gulf of California (Sea of Cortez);
- coastal lagoons such as San Quintin, Baja California, Mexico, and Izembek Lagoon, Alaska[11];
- estuaries formed by tectonic processes like San Francisco Bay;

Case Study 19.1

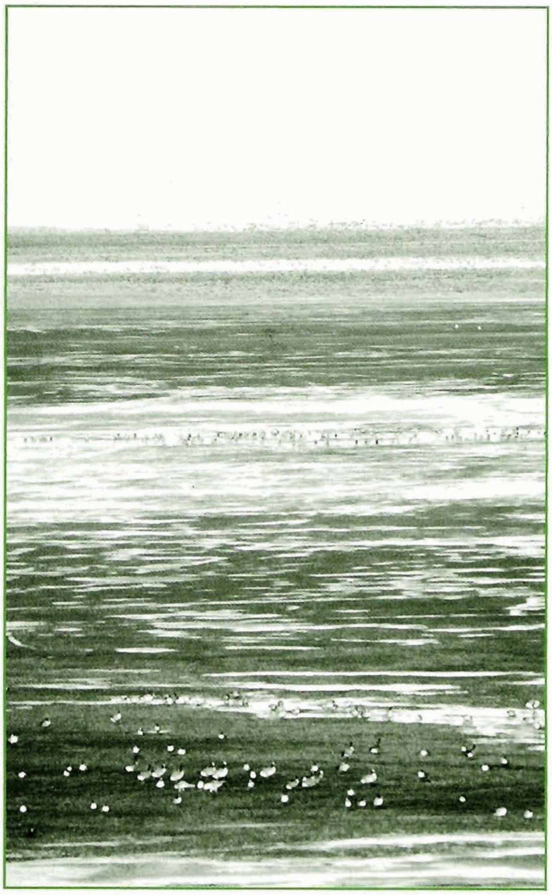
THE LINK BETWEEN SEAGRASS AND MIGRATING BLACK BRANT ALONG THE PACIFIC FLYWAY

Black brant (or sea goose, *Branta bernicla nigricans*) forage on seagrass flats (primarily *Zostera marina*) from Alaska to Mexico. In late August, after raising young in the Yukon-Kuskokwim Delta (61°N, 165°W), flocks gather at Izembek Lagoon (55°N, 163°W) to graze on one of the largest intertidal stands of *Zostera marina* in the world (see photograph below left). In the fall, most of the population moves on a non-stop, three-day transoceanic flight to *Zostera marina* and *Ruppia maritima* beds in Baja California at Bahía San Quintin (30°N, 116°W; see photograph below right), Laguna Ojo de Liebre (27°N, 114°W) and Laguna San Ignacio (26°N, 113°W).

Spring migration coincides with midday maximum low water events, which allow brant daylight opportunities to graze on the extensive seagrass resources growing on the tide flats at locations like Morro Bay and Humboldt Bay, California; South Slough and Yaquina Bay, Oregon; Willapa Bay and Padilla Bay, Washington; and Boundary Bay, British Columbia, Canada. International conservation efforts by the United States, Canada and Mexico are under way at wintering and migration stopover sites along the eastern Pacific Flyway to protect seagrass habitats in coastal embayments and estuaries.

In collaboration with David Ward (US Geological Survey, Anchorage) and Dr Silvia Ibarra-Obando (Centro de Investigaciones Científica y de Educación Superior de Ensenada, Baja California, Mexico).

Photos: D. Ward



Black brant grazing on the *Zostera marina* bed in Izembek Lagoon, United States.

Black brant on the *Zostera marina* and *Ruppia maritima* beds in Bahía San Quintin, Mexico.

- coastal fjords similar to Puget Sound, Washington[8].

It is found along the coast of British Columbia including the coasts of Vancouver Island and Queen Charlotte Islands (Haida Gwaii) in sheltered bays and coves including Bamfield Harbour and Sooke Basin[4]. The species also extends well into Alaskan waters to the Arctic Circle[15]. In the intertidal zone *Zostera marina* can co-mingle with *Zostera japonica* in the Pacific Northwest and *Ruppia maritima* in Baja California[8, 14].

Whereas the majority of *Zostera marina* populations are perennial, annual populations (e.g. Bahía Kino, Gulf of California, Mexico; Yaquina Bay, Oregon, United States) in which 100 percent of the population are generative shoots that recruit from seeds each year have been reported[4, 16]. The appearance of branched reproductive shoots, a dimorphic expression quite distinct from the ribbon-shaped leaves of the vegetative shoots, begins to occur as water temperatures warm in the spring. In the Northeast Pacific, reproductive shoots are visible in February at southern sites such as Baja California, Mexico and southern California; in late March or early April in Puget Sound, Washington; and as late as June in northern sites like Izembek Lagoon, Alaska. Flowering phenology is protogynous and the emergence of stigmas and then anthers effect the release, transport and capture of pollen, which rotate in the shear around stigmas[17]. *Zostera marina* is monoecious; however the release of pollen and its stigmatic capture is separated in time to promote an outcrossing breeding system[17, 18].

In a region-wide analysis of population structure[19], Alberte and colleagues found that:

- there was high genetic diversity among *Zostera marina* populations in the region;
- gene flow restriction existed for populations that were near each other;
- intertidal plants in disturbed environments were less diverse genetically than those in undisturbed sites.

In a subsequent study, focused on San Diego, California, and Baja California, Mexico, Williams and Davis discovered that transplanted *Zostera marina* populations were less diverse genetically than naturally occurring populations[20].

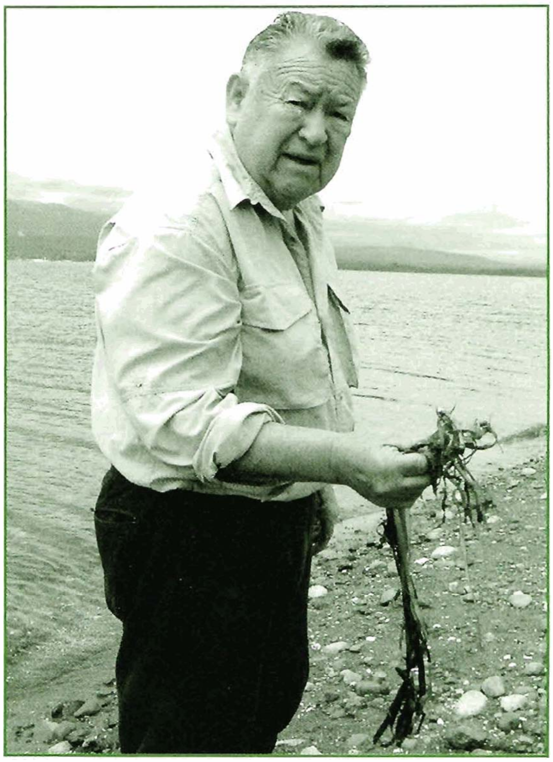
Although *Zostera japonica* is typically smaller than *Zostera marina*, it can be confused with the intertidal growing habit of *Zostera marina* (var. *typica*)[21]. However *Zostera japonica* commonly grows higher in the intertidal zone and has an open (as opposed to tubular) leaf sheath characteristic of its subgenus *Zosterella*[6]. It is a possible invader to the region coming by way of the oyster trade with Japan in

Map 19.1
The Pacific coast of North America

the early part of the 1900s[6]. At several sites from southern British Columbia, Canada, to southern Oregon, *Zostera japonica* co-mingles with *Zostera marina* (and occasionally *Ruppia maritima*[9]) in the intertidal region of many estuaries[6]. *Zostera japonica* is restricted in its northerly extent to the region near the city of Vancouver including Boundary Bay and Tsawwassen, where it is found primarily in the upper intertidal zones in muddy or silty areas[4]. Some unconfirmed reports also exist of the species further

Case Study 19.2
THE LINK BETWEEN THE SEAGRASS *ZOSTERA MARINA* (*TS'ÁTS'AYEM*) AND THE KWAKWAKA'WAKW NATION, VANCOUVER ISLAND, CANADA

Photo K. Recalma-Clutesi



Chief Adam Dick twisting the seagrass (*Zostera marina*) for dipping in eulachon (*Thaleichthys pacificus*) grease. Plants were harvested at Deep Bay on the east coast of Vancouver Island on 28 July 2002.

Chief Adam Dick (Kwaxsistala) and Kim Recalma-Clutesi (OqwiloGwa) are members of the Kwakwaka'wakw Nation on the northeast coast of Vancouver Island, British Columbia, Canada. Both are keenly aware of the value of *Zostera marina* or *ts'áts'ayem* from oral tradition of their nation.

They recall that at Grassy Point or *wáwasalth*, *ts'áts'ayem* is collected with a long thin pole or *k'elpawi* that is stuck into the substrate, rotated to entwine the leaves of *ts'áts'ayem*, and pulled from the bottom to reveal leaves, rhizomes and roots. On removal the plants are peeled exposing the tender soft tissue of the leaf base. The leaves are then wrapped around the rhizome, dipped in *klina* (eulachon (*Thaleichthys pacificus*) grease) and eaten as a ceremonial food.

Whereas Grassy Point has both cultural and ecological value, Chief Dick, Kim Recalma-Clutesi and others of the Kwakwaka'wakw Nation have concern about regional and global practices that threaten the survival of *ts'áts'ayem*.

In collaboration with Chief Adam Dick and Kim Recalma-Clutesi (Kwakwaka'wakw Nation) and Dr Nancy J. Turner (University of Victoria, Victoria, Canada).

north in the Strait of Georgia[4]. Large stands are present in Boundary Bay, southern British Columbia, Canada, and Padilla Bay and Willapa Bay, Washington[10]. The sediments and fauna within *Zostera japonica* beds were found to be largely similar to those found in *Zostera marina* beds in Oregon, although some differences in sediment grain size and organic constituents were observed[22]. *Zostera japonica* has been shown to be important to resident and migratory waterfowl in Boundary Bay[10], and is used as habitat by epibenthic crustaceans in Padilla Bay. To the best of our knowledge, there are no other studies linking *Zostera japonica* to secondary consumers either as a food or habitat in North America.

The three species of the genus *Phyllospadix* are found on exposed rocky coasts in the surf zone and in tide pools in the intertidal zone where their condensed rhizome allows them to attach to hard substrates. Three of the five species in this North Pacific genus are found on the west coast of North America. Turner and Lucas[23] and Phillips and Menez[2] describe the habitat and regional distribution of the three species. *Phyllospadix serrulatus* grows in the upper intertidal zone (+1.5 m to mean lower low water) on the outer coasts of Alaska, British Columbia, Washington and Oregon. Its distribution is often confused with *Phyllospadix scouleri*, which inhabits the lower intertidal and shallow subtidal zone. It can be locally quite common, as on Graham Island (Haida Gwaii)[4], and has a distribution that extends from southeast Alaska to Baja California, although it is reported to be more abundant north of Monterey, California[2, 4]. *Phyllospadix torreyi* grows at greater depths and is generally more abundant on the exposed parts of the coast and even in tidal pools with sandy bottoms, which are typically devoid of the other two *Phyllospadix* species. The distribution of *Phyllospadix torreyi* nearly overlaps *Phyllospadix scouleri*, but it is more abundant south of Monterey, California. The lack of information on its distribution may be related to the difficulty of making collections in energetic habitats where *Phyllospadix torreyi* is found[4]. Whereas little is known about the biogeography of these species, studies have revealed aspects of their autecology and life history such as the adaptations of seeds and roots to cling to surfaces in the rocky intertidal zone[23, 24]. *Phyllospadix* spp. form patches of various sizes in the surf zones, except *Phyllospadix serrulatus*, which is often found in more protected environments[2]. Plants in the genus *Phyllospadix* are largely clonal, and can be of a single sex due to the dioecious nature of the genus in this region.

Few studies have documented the habitat value of *Phyllospadix*; however, infaunal polychaetes are known to live in the rhizome mats of *Phyllospadix scouleri* and *Phyllospadix torreyi*. Surfgrass wrack, identified as *Phyllospadix torreyi*, has also been found in the macrophyte detritus layers in submarine canyons, in southern and central California[25]. This decomposing vegetation provides food and habitat for deep-sea benthic fauna[25]. In terms of commercially important species, researchers in southern California found that in their larval pelagic stage, spiny lobsters, *Panulirus interruptus*, were attracted to experimental treatments containing *Phyllospadix torreyi*.

Ruppia maritima is a variable plant with a number of named varieties with characteristic features, and is found in both freshwater and marine habitats. *Ruppia maritima* var. *spiralis* occurs along the southern coast of Alaska including the Alaska Peninsula, in British Columbia and in California[4]. Varieties *longipes* and *maritima* occur in coastal lagoons and estuaries throughout British Columbia including the Haida Gwaii[4]. Further south *Ruppia maritima* occurs at many sites influenced by saline water in Washington, Oregon, California and northern Mexico[1, 14]. The leaves, rhizomes and seeds of this plant are eaten by resident and migratory waterfowl.

Halodule wrightii is a subtropical species that occurs in the Gulf of California off the coast of mainland Mexico[1, 2], and *Zostera asiatica* is known to occur in three subtidal regions in central California, United States, where it forms underwater forests ca 3 m tall[3]. More work is necessary to elucidate the life history traits and habitat value of these species in this region.

HISTORICAL PERSPECTIVES

Potential changes in the standing crop and areal extent of *Zostera marina* have concerned natural resource managers in the Northeast Pacific for more than two decades[8, 26]. This concern is primarily a function of the habitat value provided by the large ecosystems created by these plants. Changes in the distribution of *Zostera japonica* have received less attention. This species is an exotic but provides valuable waterfowl habitat[10]. Given this, and the fact that *Zostera japonica* has not yet been shown to negatively impact the indigenous *Zostera marina*, prompts some to argue for detailed resource inventories. Information about changes in the local or

Case Study 19.3

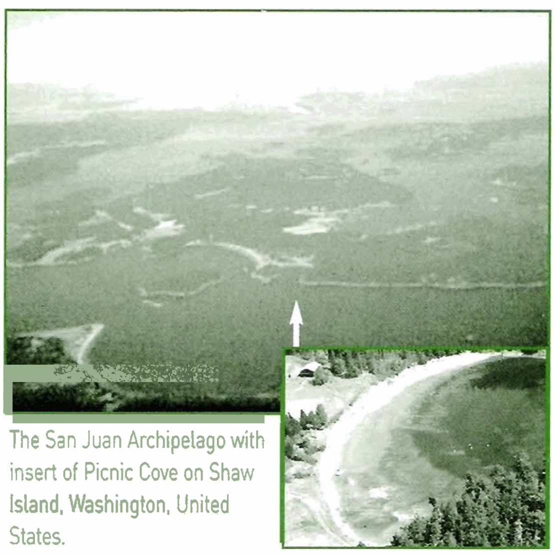
THE LINK BETWEEN SEAGRASSES AND HUMANS IN PICNIC COVE, SHAW ISLAND, WASHINGTON, UNITED STATES

Picnic Cove is a sheltered embayment on the southeast corner of Shaw Island, which is centrally located in the San Juan Archipelago in the Pacific Northwest (see photograph; 48°35'N 122°57'W).

It contains a *Zostera marina* meadow of ca 0.05 km^2 [33] and a very small patch of *Zostera japonica*, in addition to multi-layered shell middens on the low bank at the head of the cove, which indicate historical use by coastal Salish people.

After European contact, Picnic Cove became a favorite picnic spot.

It is now the site of a long-term monitoring station for Washington State Department of Natural Resources' Submerged Vegetation Monitoring Project, and is the location of quadrat-based investigations by S. Wyllie-Echeverria, University of Washington.



Phot s: S. Wyllie-Echeverria

The San Juan Archipelago with insert of Picnic Cove on Shaw Island, Washington, United States.

Table 19.1
***Zostera marina* and *Zostera japonica* basal area cover in the Northeast Pacific**

Country	Region	Area (km^2)
USA	Port Clarence, AK[28, 29]	4.2
USA	Safety Lagoon, AK[28, 29]	9.1
USA	Izembek Lagoon, AK[30]	159.5
USA	Kinzarof Lagoon, AK[28, 29]	8.7
USA	East Prince William Sound, AK[31]	4.4
Canada	Roberts Bank, BC[32]	4*
Canada	Boundary Bay, BC[10]	56*
USA	Puget Sound, WA[34]	200
	Sites within Puget Sound, WA	
	Padilla Bay[29]	32*
	King County[35]	2
USA	Grays Harbor, WA[8]	47.3
USA	Willapa Bay, WA[36]	159*
USA	Netarts Bay, OR[37]	3.4
USA	Yaquina Bay, OR[38]	0.9*
USA	Tillamook Bay, OR[39]	3.6
USA	Coos Bay, OR[9]	0.01*
USA	Humboldt Bay, CA[40]	12.2
USA	Tomales Bay[41]	3.9
USA	San Francisco Bay[42]	1.9
USA	San Diego Bay[43]	4.4
Mexico	Bahía San Quintin[30]	20
Mexico	Laguna Ojo de Liebre[30]	175
Mexico	Laguna San Ignacio[30]	53

Note: * Includes both *Zostera marina* and *Zostera japonica*.

Source: Various sources – see individual references by regions.

regional abundance of the other seagrass species in the Northeast Pacific remains largely unknown[26].

Direct use of seagrasses by humans for food, technology and medicine in the Northeast Pacific was widespread before European contact[7, 13, 14]. However, use now is quite localized and involves the weaving of *Phyllospadix* spp. as a decorative element in small personal baskets and the collection of *Zostera marina* plants for green mulch or the protection of culturally significant sites (see Case Study 19.2). The United States Department of Agriculture investigated the potential use of *Zostera marina* as a cultivar in coastal desert ecosystems during the 1980s, but we are unaware of any projects to further this goal.

It is difficult to ascertain the extent of seagrass losses due to coastal development and population expansion since the beginning of the 20th century, as no baseline data exist prior to the onset of these changes. Any attempt to do so would be conjecture. However, there is anecdotal information to suggest that losses of *Zostera marina* have occurred in the two largest estuaries on the west coast of the continental United States – Puget Sound and San Francisco Bay[27] – and we suspect losses have occurred at other sites as well. Widespread efforts to monitor and map this species in this region should help to determine if local and regional losses continue in the 21st century. More effort is needed to develop a programmatic response for comprehensive resource inventories of the other seven seagrass species[26].

SEAGRASS COVERAGE

Whereas an estimate of the seagrass cover is marginally possible for *Zostera marina*, it is not possible for the other seven species. The conservative estimate for *Zostera marina* is approximately 1 000 km^2 and is based on studies cited in Table 19.1 and our personal knowledge of sites not yet mapped.

THREATS

The following discussion of the present and potential threats to seagrasses is based on some information documented by Phillips[8], Wyllie-Echeverria and Thom[26] and studies therein, as well as a degree of unpublished observation and conjecture.

Coastal modifications and overwater structures in the form of ferry terminals, commercial docks, and smaller residential docks and floats threaten the survival of species that could be shaded in either soft-bottom or rocky littoral zones. Shoreline armoring, which can alter the trajectory of reflected wave energy, may also displace seagrasses. The direct removal of seagrasses through maintenance dredging is a rare occurrence in the Northeast Pacific, but resuspension of sediment associated with activity outside the seagrass zone may reduce transmission of light and/or bury plant populations. The deposition of upland soils into the littoral zone as a result of industrial, commercial and residential development may smother and/or kill seagrass. Moreover, modifications to the coastline projection may alter longshore current patterns resulting in changes to water clarity.

Recreational watercraft (powerboats, jet skis, etc.) may scar seagrasses in soft-bottom environments resulting in the fragmentation of populations and the subsequent loss of wildlife habitat. Whereas larger vessels (ferries, freighters, tankers, etc.) rarely venture into shallow waters, accelerated currents associated with propeller wash connected with landing and getting under way may displace seagrasses and affect current flow during pollen and seed release. The swing of anchor chains, and chains and lines connected to permanent buoys, can uproot plants and leave permanent scars in populations.

Rack and rope culture techniques used in commercial shellfish culture may shade the bottom and alter nutrient regimes and current flow, which may result in the loss of seagrass cover in localized areas. Human trampling associated with the harvest of market-sized oysters from stakes used to set and grow oyster spat can also result in reductions in seagrass cover. Moreover, recreational clam removal using shovels can destroy meters of seagrass cover.

Spills associated with oil production from offshore oil platforms such as those located on the continental shelf of southern California or the transport by oceanic tankers from Alaska to southern ports in Washington and California may result in the death of seagrasses in the littoral zone depending on the intensity and duration of the spill. Proposals for offshore oil development in Canada, the United States and Mexico are most problematic in this regard.

Episodic events such as ENSO (El Niño Southern Oscillation) and interdecadinal variation have the potential to alter ocean temperature and rainfall regimes, which may affect local populations and may also operate on the regional scale. However, a preliminary investigation in Puget Sound found that both biomass and productivity of a subtidal *Zostera marina* population increased during an El Niño year (1991-92) demonstrating the need for time-series data collection to evaluate the status and trend of seagrass ecosystems. Subduction associated with the nearshore plate tectonic activity may alter the shape and size of the littoral zone, reducing or eliminating the seagrass cover, as in the case of the 1964 Alaska earthquake.

The fragmentation of populations caused by natural or anthropogenic disturbance can also provide habitat for introduced species such as the mussel, *Musculista senhousia*, which can in turn prevent regrowth into fragmented areas, potentially leading to a more widespread decline in seagrass cover.

POLICY OPTIONS AND SEAGRASS PROTECTION

It is not clear that federal, provincial or state, or local administrative laws and ordinances recognize the eight seagrass species in the Northeast Pacific. However, in the United States, Canada and Mexico, protection is afforded to *Zostera marina* because the ecosystems provided by this plant are valuable habitat for commercially and recreationally important species such as Pacific salmon (*Oncorhynchus* spp.), Pacific herring (*Clupea harengus pallasi*) and black brant (*Branta bernicla nigricans*)[8]. In Washington state, *Zostera japonica* is also protected, but to the best of our knowledge no other seagrasses are protected by administrative code in the Northeast Pacific.

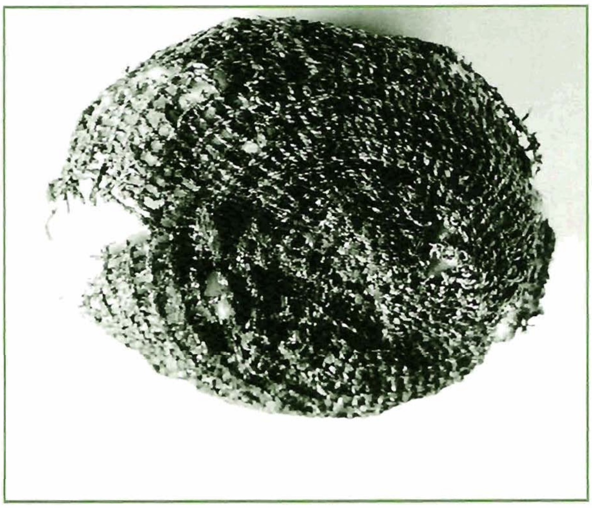


Photo: W.B. Dewey, courtesy of the Santa Barbara Museum of Natural History (cat. no. NA-CA-131.60-4E-1)

Small net bag or flexible basket woven from the leaves of *Phyllospadix torreyi*, found at Santa Rosa Island, California, and dated 1100-1500 in the Common Era.

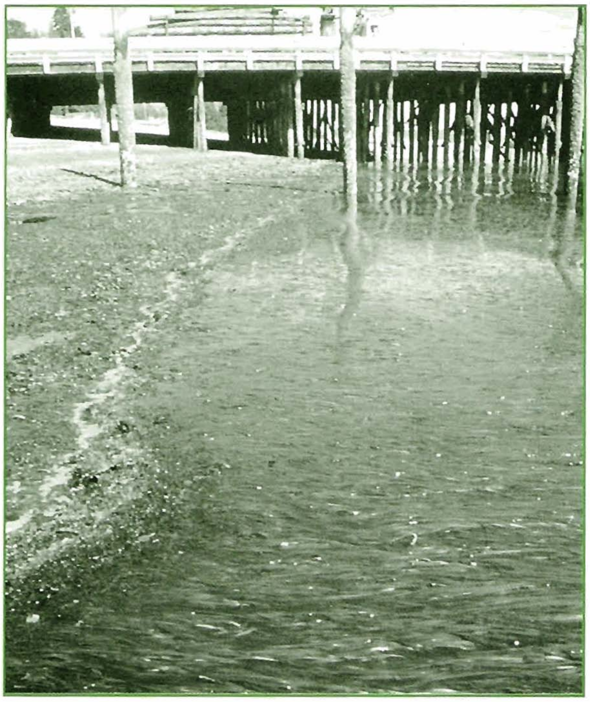


Photo: T. Wyllie-Echeverria

Zostera marina prairie adjacent to the ferry terminal on Whidbey Island in central Puget Sound. Prairie density is influenced by both the overwater structure and ferry propwash.

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