A Literature Review and Life History Summary for Five Bivalve Molluscs Common to the Shoalwater Reservation and Willapa Bay, Washington

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Little Neck Clam - Author

Table of Contents

Introduction

The Shoalwater Bay Tribe (Washington State) has requested the assistance of the United States Army Corps of Engineers (USACE) to prevent erosion of intertidal and upland areas of the Shoalwater Reservation. Located along the northern shore of Willapa Bay, approximately 2 miles east of Cape Shoalwater, the reservation encompasses 1,034 acres, 700 of which are intertidal or subtidal lands. This region has experienced average annual erosion rates in excess of 100 feet per year over the last 147 years. Substantial losses have occurred in recent years to the sand spits from which the tribe harvests bivalve shellfish.

As part of an examination of potential engineering solutions to the erosion problem, USACE is evaluating potential ecological impacts resulting from each of the solutions. Of particular interest are impacts which might affect bivalve species within the reservation or Willapa Bay in general. Willapa Bay supports a major oyster culturing industry as well as recreational fishing for a variety of species. During the initial phase of this effort a total of five bivalve species were identified as being most important to the reservation and Willapa Bay (Table 1):

Table 1. Species List.

Common Name	**Scientific Name**	**Species Profile**
Pacific Razor Clam	*Siliqua patula*	Lassuy and Simons (1989)
Pacific Oyster	*Crassostrea gigas*	Pauley et al. (1988)
Olympic Oyster	*Ostrea conchaphila*	Couch and Hassler (1989)
Native Little Neck	*Protothaca staminea*	Chew and Ma. (1987)
Basket Cockle	*Clinocardium nuttalli*	

In order to assess potential impacts it is essential to understand the biology and ecology of each species. Fortunately, this information was synthesized for 4 of the 5 species in the late 1980's as part of a joint U. S. Fish and Wildlife Service/ USACE series of publications (Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates). Although these reports contain a wealth of information, more than a decade has passed since their publication, so it was deemed prudent to perform a literature search to determine what has been published in the interim.

Literature Search

A total of twenty library databases (Table 2) were queried using sixteen keywords (Table 3) and searched for reports (in English) published later than 1980. The resulting search produced 320 responses, including 47 duplicate listings and three cases where multiple papers were cited as a single reference.

Table 2. Library Databases Searched

Library Databases
NTIS
Compendex
Biosis Previews
Oceanic Abstracts
SciSearch
Dissertation Abstracts
Enviroline
Aquatic Science & Fisheries Abstracts
CAB Abstracts
WasteInfo
GPO Monthly Catalogue
Environmental Bibliography
Life Science Colege, Cambridge
Conference Papers, Cambridge
Water Resourses Abstracts
Zoological Records
LCMARC-Books
British Books in Print

A total of 284 citations remained after the database was edited; these citations and their abstracts (where available) are presented in the Appendix. Further examination of the list yielded far fewer citations of direct relevance to the target species. In fact, only 198 of the 284 references were considered directly relevant. A majority of these references (159) dealt with the Pacific Oyster of which 72% dealt with oyster culture. The remaining Pacific Oyster citations (43) covered a range of topics with heavy emphasis on genetics and physiology.

Table 3. Keyword Search

Biology Key Words	Geography Key Words
Species Name -Common	Washington
Species Name - Scientific	Oregon
Life History	California
Ecology	Alaska
Habitat	British Columbia
Reproduction	Pacific Northwest
Larval Development	Northeast Pacific
Growth	
Aquaculture/Mariculture	

The Razor Clam garnered the second highest number of citations: over half of which were concerned with domoic acid (DA) uptake, depuration, or the biology of the algae that produce it, 5 described clam aquaculture, and 7 described life history characteristics. There were 10 references for the Olympic Oyster, 7 of which dealt with aquaculture. Only 2 citations were found for either the Little Neck Clam or the Basket Cockle.

Life History Information

In the following pages life history information for each of the five species is presented. Where these data have already been summarized (e.g., Species Profiles series), a brief synopsis is included followed by a summary of more recent articles and a list of citations.

Pacific Razor Clam, *Siliqua patula*

Synopsis (Lassuy and Simons, 1989)

The Pacific Razor Clam, *Siliqua patula*, is found from California to the Aleutian Islands on gently sloped, fine sand beaches exposed to ocean swell. The most productive beaches have mean grain sizes averaging 0.16 mm to 0.20 mm. Sexes are separate from birth and reproduction occurs primarily in the late spring and early summer. In the Puget Sound region, water temperatures above 13^{o}C appear to induce spawning although high plankton concentrations have the same effect. Larvae remain in the plankton approximately 10 weeks and settle out predominately in the lower 1/3 of the intertidal zone although large numbers can be found at depths as great as 3.3 m, as evidenced by the distribution of juvenile clams. Once settled, young clams have limited dispersal abilities with lateral movement extending only 30 m away from settlement sites. Adult clams are most abundant in the lower intertidal zone although some can be found subtidally as deep as 6 m (20 ft). While it has been hypothesized that the difference in the distribution patterns of juvenile and adult clams is due to migration of the juveniles, there is no evidence to support the hypothesis. Adult razor clams appear to have limited lateral mobility but can rapidly alter their vertical position. Usually found within 30.5 cm (1 ft) of the sediment surface, they can burrow at a rate of 30.5 cm per minute to a sediment depth of 145 cm.

Like many other bivalves, the razor clam filter-feeds on phytoplankton. Dominant food items include *Chaetoceros armatum*, *Asterionella socialis*, and other surfzone diatoms. The clams themselves are food for a variety of shorebirds, gulls, Dungeness crabs (*Cancer magister*), English sole (*Parophys vetulus*), and sturgeon. They are particularly vulnerable to predation at the post settlement stage. Beach scouring during strong winter storms and diseases are also leading causes of mortality. Approximately 99% of all clams die within the first eight months of life. Maturity is reached within 2

years and the potential life span is approximately 11 years. High levels of harvest and disease-induced mortality have reduced the average life span to 7 years in Puget Sound.

Recent Reports

In one of the few publications since Lassuy and Simons (1989) discussing the life history or ecology of the razor clam, Rickard et al. (1988) examined the depth distribution of a recent set of clams at Copalis Beach, Washington. Density varied directly with increasing depth and inversely with size: at 1.5 m MLLW, average clam size ranged from 8 mm to 12 mm, but densities were only $37/m^2$ while at 12.2 m MLLW, average size was 2 mm and densities were $38{,}000/m^2$. There appear to be two principal hypotheses to explain the difference between settlement rates and adult distributions: 1) the juveniles migrate, or 2) there is strong differential growth and mortality between intertidal and subtidal populations.

Most recent reports on *S. patula* have dealt with the problems associated with domoic acid (DA), a neurotoxic amino acid produced by various species of the diatom genus *Pseudo-nitzschia* (Wright et al., 1989). DA first appeared in Puget Sound clams in 1991, resulting in closure of the clam fishery. The toxin is found throughout the clam tissues but is present in the highest concentrations in muscle (Drum et al., 1993). It depurates from the body very slowly (Horner et al., 1993). Highest body burdens of DA have been detected after storms with tissue toxicities declining in the following order Foot > Siphon > Mantle (Whyte et al. 2000).

DA producing species are common throughout most of the west coast but are only occasionally present in sufficient abundance to create a threat (Villac et al., 1993). Occurrences of *Pseudo-nitzschia* blooms appear to be related to high water column nutrient concentrations and a relaxation of dominant onshore winds (Adams et al., 2000). High nutrient concentrations are generally associated with either coastal upwelling or runoff events. When onshore winds subside concurrent with such events, the DA producing algae have the opportunity to bloom and produce the toxin. Recent studies by Roegner et al. (2002) indicate that offshore processes are important to the import of phytoplankton blooms into Willapa Bay. It can be assumed that under appropriate conditions, deleterious as well as beneficial blooms may be transported into the bay.

Pacific Razor Clam References

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Pacific Oyster, *Crassostrea japonica*

Synopsis (Pauley et al., 1988; Emmett et al., 1991)

The Pacific Oyster, *Crassostrea japonica*, was introduced from Japan in 1903 as an aquaculture species and is presently distributed from California to northern British Columbia. It is a protoandric hermaphrodite: all first year animals are male while in later years they may become male or female. Large numbers of planktonic larvae are produced when water temperatures reach 19.5 ^{o}C (July or August) and they remain in the plankton for 2-3 weeks. Larvae in the eyed-umbone stage settle out and attach to hard substrate, usually old oyster shells. Pacific Oysters are sensitive to salinities less than 20 ppt and are most productive where salinity ranges from 25 ppt to 35 pt. Oysters feed on both phytoplankton and seston and are susceptible to high levels of siltation. Siltation due to Thalassind shrimp burrowing is of particular to concern to oyster culturing operations.

Pacific Oysters have relatively few diseases but do experience mass mortalities, particularly in summer months due to environmental stress (e.g., exposure to high temperatures). Important predators include the Japanese Oyster Drill (*Ceratostoma inoratum*), crabs, and starfish.

Recent Reports

As noted in the introduction, most of the post-1980 literature on the Pacific Oyster, *Crassostrea gigas*, relates to aquaculture. A number of references, although related to aquaculture, contain relevant life history information. Friedman et al. (1998) correlated mass mortalities in summer months with outbreaks of the dinoflagellate *Gymnodinium splendes*. Cheney et al. (1999) verified these results and detected lesions "consistent with an acute toxic effect" while examining the tissues of moribund oysters. Cheney et al. (2000) attribute summer mortality not just to dinoflagellate blooms but also to environmental stress resulting from high temperatures, low dissolved oxygen concentrations, increased tidal exposure, and physiological stress associated with reproduction. Also working with cultured oysters, Brown and Hartwick (1988a) and Brown (1988) studied growth characteristics under different temperature, salinity, and food regimes. Low growth was encountered when salinities were low (<20 ppt), whereas when salinities were high growth was correlated with phytoplankton biomass. Examining the relation between feeding and seston, Barille et al. (1997) found that high concentrations of seston dilute food availability and decrease feeding efficiency.

Hedgecock and Sly (1998) used starch-gel electrophoresis to score genetic differences between natural and cultured oyster populations in Dabob and Willapa Bays and found evidence of loss of alleles in the cultured stocks. Of particular interest to issues involving reproduction and larval availability is the work of Gang and Hedgecock (1998). These authors measured genetic heterogeneity in larvae produced at different times of the year and found that early and late produced larvae were substantially different. Observed differences suggest that relatively few oysters were contributing the bulk of the larvae at any given time.

Righetti (1999; 2000) studied the relative importance of nitrogen excretion by Pacific Oysters to primary productivity and concluded that oysters could supply as much as 58% of phytoplankton nitrogen requirements. The shell habitat of oyster reefs is important to the survival of megalopal stage larvae and young-of-the-year Dungeness Crab, *Cancer magister* (Fernandez et al., 1993). The young crabs are able to escape cannibalism by older crabs.

Although not directly related to oyster ecology, a number of articles have appeared describing infaunal communities associated with oyster beds with emphasis on burrowing shrimp and the effects of Carbaryl, a pesticide employed to control them. Dumbauld et al. (1996; 1997) described the effects of Carbaryl in controlling the two dominant species of burrowing shrimp. They found that sediment characteristics and exposure time were the most important factors in determining the efficacy of the chemical. Ghost shrimp (*Neotrypaena californiensis*) inhabited sandier, more permeable sediments than mud shrimp (*Upogebia pugettensis*). Feldman et al. (1995) reported on the growth of young-of-the-year shrimp after oyster harvesting and found no evidence for impact to the shrimp. Dumbauld et al. (2000) report impacts of pesticide spraying on other members of the oyster bed infaunal community. Small crustaceans such as amphipods were impacted for short periods of time (3 mo) after treatment, molluscs experienced mixed results with *Macoma* sp. being unaffected and decreases in juvenile *Clinocardium nutalli.* Polychaetes were apparently unaffected. Feldman et al. (2000) review the life history of the burrowing shrimps and management implications of Carbaryl treatment. In a related paper, De Grave et al. (1998) sampled infauna associated with suspended oyster culture facilities in Ireland and determined that tramp ling by heavy vehicles employed in maintaining the oyster culture was the dominant disturbance. Shallow burrowing species such as the amphipod *Bathyporeia guilliamsoniana* and the tellinid bivalve *Tellina tenuis* were significantly higher in untrampled controls than underneath the trestles used to support the oysters. Scavenging species such as *Crangon crangon, Palaemon serratus,* and *Carcinus maenas* were most abundant near the trestles.

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Olympic Oyster, *Ostrea chonchaphila (=lurida)*

Synopsis (Couch and Hassler, 1989)

The Olympic Oyster, *Ostrea conchaphila*, also known as *O. lurida* and *Ostreola chonchaphila*, is distributed from Baja California to the Aleutian Islands in protected sites along the outer coast. It is commonly collected on the underside of floats or pilings but can also form beds. It is a protandric hermaphrodite that begins spawning at water temperatures between 13 ^{o}C and 16 ^{o}C and produces either one or two peaks of larvae during midsummer. Larvae remain in the plankton for approximately 2 weeks. Since they are seldom found in nearshore plankton it is assumed they are able to maintain themselves in the same area in which they were spawned. At the end of their planktonic stage they settle onto hard substrates and metamorphoses into spat. Their tendency to settle on the underside of substrates is attributed to the upward position of the foot during swimming. Growth in this species is slow, with shell heights of 35 mm to 45 mm reached only after three years. Maximum size is 75 mm.

Olympia Oysters can survive short pulses of low salinity, but prefer salinities above 25 ppt. They are sensitive to extreme high or low temperatures and are susceptible to siltation or sedimentation. As with the Pacific Oyster, siltation due to burrowing shrimp activities is believed to have a substantial influence on Olympic Oysters. Major predators include the imported Japanese Oyster Drill *Ceratostoma inoratum*, the flatworm *Pseudostylochus ostreophagus*, Rock crabs, shorebirds, and the bat ray. The slipper shell, *Crepidula fornicata*, another introduced species and a part of the fouling community, can compete with Olympia Oysters for food and space.

Recent Reports

As with the Pacific Oyster, most recent articles on Olympic Oysters have concerned aquaculture or the status of the oyster industry (Donaldson, 1981; Chew, 1988; Nosho, 1995; MacKenzie, 1996; Cook, et al., 1998; Robinson, 1998; Stocker and Winther, 1999; Baker and Terwilliger, 2000). The only two references which provide basic biological information on this species are Santos et al. (1992) and Baker (1995). The former describes temperature effects on sexual development: development becomes faster as temperature increases from 12 ^{o}C to 21 ^{o}C. Baker (1995) is a summary of the species' biology similar to but far more detailed than that of Couch and Hassler (1989).

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Littleneck Clam, *Protothaca staminea*

Synopsis (Chew and Ma, 1987; Emmett et al., 1991)

The Common Littleneck, *Protothaca staminea* (previously known as *Venerupsis staminea*) is distributed from Baja California to the Aleutian Islands but is only abundant in Washington State and further north. It grows to a length of approximately 50 mm and is commonly found on intertidal beaches and along rocky shorelines where there is a mixture of coarse sand, gravel, or shell hash. Densities are highest in shelly sediments and lowest in mud and sand. This species is a poor burrower; average depth in the sediment is 15 cm and maximum depth is about 20 cm.

Sexes are generally separate and spawning occurs primarily in late spring. Larvae remain in the plankton around 3 weeks and settle near the lowest level of the tide zone. As with most bivalves, mortality is high in the first year. Growth is highest at sites protected from strong tidal currents and storm-driven waves and where the surface substrate is highly unstable. Estimates of life span vary from 7 years to 15 years with the higher estimates reported from the most northern populations. At least half the clams are mature at the end of their second year and all are mature by the end of their third year.

Little necks are mobile, relocating using their foot; juveniles are thought to move into the higher levels of the intertidal zone as they mature. Major predators include moon snails, octopi, crabs (including Dungeness crabs), and bottom feeding fish such as sculpin, turbot, and halibut.

Recent Reports

Only three citations describing aspects of the biology of *Protothaca staminea* were encountered in the literature search. Harrington (1987) examined characteristics of shell growth of the littleneck and two other species over its entire geographic range. In a study of the burrowing characteristics of a wide range of bivalve molluscs from Oregon, New Jersey, and Scotland, Alexander et al. (1993) classified *Protothaca staminea* as a substrate sensitive burrower. This classification was based on its ability to burrow in a wide range of sediments but at a relatively slow rate. Finally, Parker (2000) discovered significant differences in the genetic makeup of littlenecks from three different populations collected from three different basins within Puget Sound.

Littleneck Clam References

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Basket Cockle, *Clinocardium nutalli*

Synopsis

Commonly known as the Basket, Heart, or Nutall's Cockle, *Clinocardium nutalli* is distributed from San Diego, California to the Bering Sea (Abbot, 1974). It occurs in muddy fine sands of quiet bays and in eelgrass, ranging from the intertidal zone to deep water (Kozloff, 1983). Intertidal zonation is distinct with larger specimens being found at lower levels (Gallucci & Gallucci, 1982). It is a shallow burrower (O'Clair and O'Clair, 1998) and its burrowing habit has been described as substrate sensitive (Alexander et al., 1993). The latter indicates that it is able to burrow in a wide range of substrates but more slowly than substrate generalists.

The Basket Cockle is a simultaneous hermaphrodite- that is, the gonad has functioning male and female follicles (Gallucci & Gallucci, 1982). In the San Juan Islands cockles mature between October and June and spawn between April and November; peak spawning occurs in July and August. It also spawns between July and August in British Columbia (O'Clair and O'Clair, 1998) while in Oregon it spawns from June to October (Robinson & Breese, 1982). The larvae are planktonic. Recruitment may be inhibited by the presence of large amounts of shell hash (Irbarne et al., 1992) and post-recruitment mortality results in uniform distributions in the mid to lower intertidal zone (Gallucci & Gallucci, 1982). Predators include gulls (during daylight low tides), crabs and flatfish (Gallucci & Gallucci, 1982). Animals reach maturity within two years (O'Clair and O'Clair, 1998) and range from 2 inches to 6 inches in length at adulthood (Abbott, 1974).

Although this species feeds by filtering phytoplankton from the water it may also have a symbiotic relationship with algae. Jones and Jacobs (1992) have shown that the largest and oldest cockles are epifaunal in nature and have high concentrations of algae in siphonal and mantle tissues. Recently matured individuals (2 years old) were semi-epifaunal animals have lesser algal concentrations while the smallest animals were infaunal in habit and had no phytosymbionts.

Basket Cockle References

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Appendix . Literature Search Results

Acosta, R. M. De J. & W. M. T. Gutierrez (1996)
Cultivation of *Crassostrea gigas* (Bivalvia: Ostreidae) in a semi-rigid net.
Revista de Biologia Tropical 44: 653-657

A culture system, consisting of a semi-rigid net, with an ABS frame filled with styrofoam was used for the culture of the Pacific oyster *Crassostrea gigas*, from 3.0 mm length seed. The culture system was tested in three locations, two inside San Quintin Bay and one in San Martin Island. The mean monthly growth was 8.69 mm and 8.96 mm in the Bay and 7.33 mm in San Martin Island. These growth rates show that this species can attain commercial sizes in 6 months, using the culture system tested.

Acosta R., M de J, R. Terrazas Gaxiola, B. Farfan, & E. Morales Guerrero (1996)
Growth and condition factor of the Japanese oyster *Crassostrea gigas* (Thunberg) from seasonal seeding in Bahia San Quintin, B.C., Mexico.
Riv. Ital. Acquacolt 31: 151-155

An experiment was carried out to assess growth rates and condition factors of *Crassostrea gigas* from 2 culturing sites inside Bahia San Quintin (Mexico) and from 5 seasonal seeding trials. The oysters attained commercial size in 6-8 months. At the mouth of the bay, C. gigas growth was remarkably consistent; growth rates of .I all 5 seasonal seeding trials ranged from 0.19-0.25 mm day. Comparable growth rates at the head of the bay were obtained during the autumn seedings; these were the lower ones, the highest corresponded to the spring seeding, growth rates in the summer and winter trails were intermediate. In contrast to shell growth, soft tissue growth was favored at the mouth of the bay; here the oysters were fatter, therefore with a better condition factor. The observed differences in growth and condition of *C. gigas* between the experimental sites were related to the prevailing temperature conditions; at the mouth of the bay this variable was consistently lower. The results also show that this location is an alternate culturing site to maintain broodstocks, to improve the condition factor, cleanse gut and shell of the oysters and to keep stocks for later commercialization.

Adams, N. G., M. Lesoing, Mitch, & V. L. Trainer (2000)
Environmental conditions associated with domoic acid in razor clams on the Washington coast.
Journal of Shellfish Research 19: l007-1015

In October 1998, record levels of the neurotoxin domoic acid (DA) were detected in razor clams (*Siliqua patula*, Dixon) resulting in the closure of shellfish harvesting areas along the Washington coast. This toxin was detected in seawater samp les collected at Kalaloch Beach and Second Beach on the central Washington coast using a receptor binding assay and liquid chromatography-tandem mass spectroscopy. Domoic acid levels ranging from 0-2700 ng/L were measured in seawater samples containing fro m 70-100% *Pseudo-nitzschia pseudodelicatissima* (Hasle) at concentrations of 1.0-15X106 cells/L, resulting in maximum levels of cellular toxin of approximately 500 mg/cell. A cultured isolate of this species collected from Kalaloch Beach also produced DA, as determined by the receptor binding assay, during late exponential and stationary stages of growth. The toxic *P. pseudodelicatissima* bloom in the late summer and autumn of 1998 occurred 2-3 weeks after strong coastal upwelling during a period of anomalously low rainfall, typical in post-EI Nino years. Higher toxin levels in seawater at Kalaloch Beach compared to Second Beach were attributed to the periodic nature of upwelling at Kalaloch Beach, demonstrated by a 175-fold increase in nitrate in seawater coincident with a 5degreeC decrease in sea surface temperature on September 1. The upwelling event in September was followed by wind relaxation and reversal at the end of that month, resulting in the transport of toxic cells toward the coast where nutrients were already present to fuel the algal bloom. A pulse of nutrients, either from rainfall or upwelling, to coastal regions that have experienced several weeks of low nutrients, followed by wind relaxation or reversal events that transport cells to inshore re gions, are suggested to be important factors in the initiation of the most toxic Pseudo-nitzschia species blooms on the Washington coast.

Aguilar Ruiz, F. & S. Alvarez Borrego (1982)
Mariculture and ecology of the Baja California coastal lagoons, Mexico.
Cienc. Interam. 22: 52-53

An investigation on mariculture and ecology was done in San Quintin Bay and in Punta Banda estuary and formed part of the Proyecto Nacional de Mexico sobre Desarrollo de la Acuicultura. The objective of this investigation was to initiate aquaculture in Baja California. A study and a mathematical model were made on the coastal lagoon dynamics, and a personnel training project in aquaculture techniques was carried out. Coastal, hydrologic oceanographical and primary production studies were conducted at both places. An aquaculture laboratory was installed for the production of mollusk seed (*Crassostrea gigas* and *Ostrea edulis*) and is now cultivated in San Quintin Bay. *C. gigas* is being produced at a commercial level at this same place.

Alexander R. R., R. J. Jr. Stanton Robert, J. R. Dodd (1993)

Influence of sediment grain size on the burrowing of bivalves: Correlation with distribution and stratigraphic persistence of selected Neogene clams.
Palaios 8: 289-303

Burrowing ability of 21 species of clams from Oregon, New Jersey (USA), and Scotland (UK) was determined in each sieved sediment ranging from fine gravel to mud in half phi increments. A burrowing rate index (BRI), which normalizes burrowing time for specimen mass, was calculated for each species in each sediment. Skewness and kurtosis of the profile of average BRrs across the range of grain sizes was used to categorize species as substrate generalists, substrate sensitive, or substrate specialists. Substrate generalists (*Anadara ovalis, Mercenaria mercenaria, Astarte sulcata, Venerupis decussata, Venus striatula, Venus casina, Mya arenaria*) burrowed slowly into a wide range of grain sizes. Burrowing rate gradually diminished in progressively coarser and finer grained sediments away from the optimum grain size, producing a platykurtic (gently arching) BRI profile. Substrate specialists (*Spisula solida, Nucula sulcata, Cardium edule, Abra alba, Cultellus pellucidus*) burrowed rapidly in a very limited range of grain sizes, but failed to burrow into either or both grain size extremes, thereby producing leptokurtic (peaked) BRI profiles. Substrate sensitive species (*Donax variabilis, D. vittatus, Tellina (Angulus) tenuis, Ensis directus, Clinocardium nuttalli, Protothaca staminea, Petricola pholadiformis, Macoma nasuta, Scrobicularia plana*) penetrated a wider range of grain sizes than specialists, although burrowing rates are slower at the course textured extreme in comparison to generalists. In San Francisco Bay and Mississippi Delta habitats, generalists (*Anadara, Mercenaria, Mya*) occur commonly in most sediment categories and show high mean percent occurrence and low coefficient of variation from the seven and eight sediment-influenced molluscan communities, respectively. Substrate specialists (*Spisula, Nucula*) and some sensitive taxa (e.g., *Petricola*) are sediment-restricted, show fidelity to one or two communities, have low mean percent occurrence, and high coefficient of variation. Substrate generalists (*Anadara trilineata, Mya arenaria*), and species transitional with generalists (*Macoma nasuta*), based on experimental data on either conspecific or congeneric individuals, show high mean percent occurrences and low coefficient of variation in the Pliocene Pecten Zone communities of the San Joaquin Formation of the Kettleman Hills, California. Generalists show stratigraphic persistence, i.e., they are found in 12-14 of 20 successive biostratigraphic units in the Etchegoin and San Joaquin Formations, whereas specialists (*Spisula, Acila (Nucula)*) are never found in more than four biostratigraphic units.

Alvial, A & C. Henriquez, C. (1998)
An update of the abalone aquaculture of Chile
Journal of Shellfish Research 17: 317

For many years the only formal aquaculture activity developed in Chi1e was the mussel production in the south of the country in a very basic and small scale way. The environmental advantages of the Austral region evidenced by these pioneer efforts allowed for the rapid development of the salmon industry which, in less than fifteen years, placed the country as the second largest farmed salmon producer in the world. With the explosive growth of salmon farming in Chi1e, aquaculture potential and its strategic importance

for Chile became obvious. Consequently and considering commercial prospects, Fundacion focused on Turbot, Pacific oyster and California red abalone as new species for Chilean aquaculture. At this point and after the development of Pacific oyster and Turbot up to commercial levels of production, the next stage consisted of commercial abalone development through a Fundacion Chile-CORFO development project. Today, abalone culture in Chile has evolved with the present operation of several Ca1ifornia red abalone (*Haliotis rufescens*) farms: three hatcheries and three ongrowing units (two in the sea and one on land); as well as one hatchery and one ongrowing center of Japanese abalone (*Nordotis discus hannai*). It is expected that California red abalone will grow in the south and center of the country. Meanwhi1e, Japannesse abalone will develop in the north. Projections based on the present development allow for production of 8 mill ion seeds and around 700 ton annual production within the next 2-3 years, making a contribution of around 20 mill ion dollars to seafood exports of the country.

Anderlini, V. C. (1992)
The effect of sewage on trace-metal concentrations and scope for growth in *Mytilus eoulis aoeteanus* and *Perna canaliculus* from Wellington Harbour, New Zealand.
Science of the Total Environment 125: 263-288

Trace metal data are reported for *Mytilus edulis aoteanus* and *Perna canaliculus*, sampled monthly for 16 months from sites at varying distances away from a major municipal sewage outfall at the entrance to Wellington Harbour, New Zealand. The data indicate that the sewage outfall is the most likely input source of Ag, Cu, Pb, and Zn in this region, and that marine communities up to 3 km east and up to 750 m northwest of the outfall are periodically exposed to the effluent. However, only mussels within 750 m of the discharge point have elevated levels of potentially toxic metals and only *M. edulis aoteanus* from within 100 m of the outfall had higher concentrations of Pb and Zn than are permitted in shellfish for human consumption under N.Z. regulations. Scope for growth of both species, determined during a 3-month period, showed that the effluent adversely affected the physiological condition of these species at sites within 750 m of the discharge. Data for *P. canaliculus* from an uncontaminated area of Wellington Harbour transplanted into the effluent at increasing distances from the outfall and analysed for trace metals and scope for growth after 1, 2 and 3 months exposure, also indicated that trace metal levels and scope for growth in these mussels were affected by proximity to the outfall.

Anderson, G.J. and K.K. Chew (1981)
Intertidal culture of the Manila clam Tapes japonica using hatchery-reared seed clams and protective net enclosures
Journal of Shellfish Research 1: 131

Anonymous (1981)
Aquaculture in Baja California.
R & D Mexico vol. 1: 16-20

Experiments carried out in 1973 and 1974 determined that the Japanese oyster (Crassostrea gigas) was suitable for marine culture. Personnel are being trained in techniques for cultivating mollusks, crustaceans and shrimp. The Center for Scientific Research and Higher Education of Ensenada (CICESE) is concurrently engaged in ecological studies in the lagoons and bays of the peninsula with emphasis on the biotic and abiotic environmental variables of importance for bivalve mollusks.

Anonymous (1985)
Alaska Oyster Growers Manual
University of Alaska Sea Grant Program Mar Advisory Bull 17 (212) May 85

Guidelines for operating successful oyster culture ventures in Alaska are compiled. The biology of the Japanese oyster, *Crassostrea gigas*, is briefly described, and economic considerations are discussed. Factors to consider in site selection are identified, and oyster culturing methods are explained. Environmental sanitation, shellfish poisoning, harvesting, shucking, and research needs are also covered.

Anonymous (2001)
Workshop on Possible Pathways of Cadmium into the Pacific Oyster (*Crassostrea gigas*) as Cultured on the Coast of British Columbia, Sidney, British Columbia, Canada, March 6-7, 2001.
Canadian Technical Report of Fisheries and Aquatic Sciences 2405: 21-56

On 6-7 March, 2001 approximately 40 invited participants from Canada, the USA, New Zealand, Australia and Mexico gathered at the Institute of Ocean Sciences in Sidney, BC to exchange information on the possible sources of cadmium in BC cultured oysters. This report comprises informal proceedings of this exchange and includes an outline of ideas for discussion, is provided by the 29 speakers, as well as their presentations on a CD-ROM. A synthesis of the discussions includes the identification of data gaps and contains recommendations on directions for future research.

Arizpe, O. C. (1996)
Secondary production, growth and survival of the Pacific oyster *Crassostrea gigas* (Thunberg) in tropical waters, Bahia de la Paz, Mexico
Journal of Shellfish Research 15: 601-607

Since 1973, when the Japanese oyster was introduced into Mexico, its cultivation has extended into the Northwest Mexican Pacific, yielding the expected profits in only a few areas. The objectives of the project were to determine the mortality, growth, biochemical variables, condition factor, meat yield, and somatic secondary production of *Crassostrea gigas* (Thunberg) in suspended and bottom conditions in Bahia de La Paz and to assess the use of each variable for the cultivation of this resource. Laboratory-reared spat of similar size were introduced with replication into two different areas, both in suspended trays and on the bottom surrounded by a plastic mesh fence. The organisms were checked monthly for almost 2 y. The average growth rates obtained were 6 mm/mo for the first 6 mo and 5.3 mm/mo at 10 mo. The weight gain was 3.6 g/mo for 10 mo. Mortality rates for this period were 35%. The average values of meat yield were 0.35: protein, 50.9%; 1ipids, 8.2%; carbohydrate, 37.7%; and ash, 3.2%. The somatic secondary production of dry weight was 2.5 g per organism during the first year. The results of the multifactorial analysis of variance estimation with each variable obtained led to the conclusion that only somatic production gave statistical elements for selection and culture decision making among all factors tested.

Ayres D. L. & D. Simons (1999)
Razor clam fisheries and status of the razor clam stocks, June 1995 through May 1997.

Washington Department of Fish and Wildlife, Olympia: p 1-55. Report MRD 99-01.

B.C. Salmon Farmers Association (1992)
Aquaculture, British Columbia's future
British Columbia Shellfish Growers Association: British Co1umbia Trout Farmers Association. Report No.: ISBN-0-7726-1508 pp.118

This report describes the aquaculture industry in B.C. and its key opportunities and constraints: provides industry profiles for the salmon, Pacific oyster, manila clams, scallop, mussel, marine plant culture, and the freshwater aquaculture industry: and discusses critical factors necessary for the success of each industry, including product market, the role of the government, environmenta1 factors, production and business viability factors, need for R&D, and general economic trends.

Baker, P. (1995)

Review of ecology and fishery of the Olympia oyster, *Ostrea lurida* with annotated bibliography.
Journal of Shellfish Research 14: 501-518

The Olympia oyster, *Ostrea lurida*, is a small bivalve mollusk species native to the western United States and Canada. It was commercially important in the late 19th century, and was cultured in Washington State unti1 a near-collapse of the industry in the 1950s. Since then it has made a minor commercial comeback, but has been largely superseded by the introduced *Crassostrea gigas*. Most significant literature dates from

prior to the collapse of the industry in the 1950s, and much of this is comprised of state or federal agency reports, or similar obscure 1iterature formats. This document is divided into 2 parts, a review of all important literature to date on the distribution, biology, ecology, taxonomy, and commercial exploitation of *O. lurida*; and an annotated bibliography of known literature pertaining to *O. lurida*.

Baker, P. & N. B. Terwi11iger (2000)
Reestablishment of a native oyster: Implications for population distribution and structure
Journal of Shellfish Research 19: 600

The reappearance of the Olympia oyster, *Ostrea conchaphila (= lurida)* in Coos Bay, Oregon, raises questions about its population structure and dispersal. On the outer coast from Washington to central California, the Olympia oyster occurs only in certain estuaries. This species went extinct in Coos Bay prior to European settlement, and both deliberate and accidental inoculations prior to 1988 failed to reestablish it. Since 1988, the Olympia oyster has become abundant in Coos Bay, with heavy and regular recruitment. Why did the Olympia oyster become reestablished in 1988, but not previously? From where did it reinvade Coos Bay, and how? Coos Bay's geographic isolation may prevent reestablishment of Olympia oyster from other populations by larval dispersal, but does not explain the failure of human introductions. Our research suggests, however, that the Olympia oyster has returned partly because of human modifications to the estuary. Incremental deepening of the bay for navigation has restored a prehistoric salinity regime, making it similar to modern Olympia oyster habitat elsewhere. Olympia oysters currently occur in the most modified portion of Coos Bay, in which modal winter salinities have increased strongly since at least 1950. If this scenario is correct, habitat I imitation, not dispersal, is probably the primary limiting factor for the Olympia oyster in this region. Molecular genetic analysis is underway to determine the source population of the Coos Bay population, and the degree of isolation between Olympia oyster populations. Knowing the source population will also allow us to develop hypotheses for the vector of reestablishment.

Banks M. A., D. J. McGoldrick, W. Borgeson, & D. Hedgecock (1994)
Gametic incompatibility and genetic divergence of Pacific and Kumamoto oysters, *Crassostrea gigas* and *C. sikamea*.
Marine Biology 121: 127-135

Bari11e, L., J. Prou, M. Heral, & D. Razet (1997)
Effects of high natural seston concentrations on the feeding, selection, and absorption of the oyster *Crassostrea gigas* (Thunberg)
Journal of Experimental Marine Biology and Ecology 212: 149-172

Feeding, selection and absorption were determined for the Pacific oyster *Crassostrea gigas* cultivated in the Bay of Marennes-01eron, over a spring/neap tidal cycle. Physiological determinations were related to the highly variable food environment with continuous recordings of turbidity and fluorescence. In this bay, resuspension processes have a major influence on food avai1abi1ity and quality. Seston characteristics experienced by oysters can be summarized by high turbidity levels from 20 to 350 mg.1 (-1) and a predominance of the detritic fraction among the organic fraction (mean C/N ratio = 16.57). Food is diluted by the fine resuspended sediment, and organic content of particulate matter in the water column decreases from 30% to 10% with increasing seston loads. Significant differences (Ancova, $P < 0.01$), due to low retention efficiencies of the smaller particle size range, were recorded between the food quality (estimated by the organic content and the total pigment content) measured in the water column and the fraction retained by the oyster's gi11. Below seston concentrations of 90 mg.l (-1) ingestion rate was regulated by pseudofaecal production. Above 90 mg.1 (-1), a sharp reduction of filtration and rejection rates suggests physical constraints 1imiting food acquisition. The oyster selectively rejects inorganic from organic particles, enriching the ingested fraction. Amongst the potentially nutritive particles, significantly fewer particles containing phytopigments were rejected relative to organic particles (non-linear regressions, $P < 0.001$). The negative influence, through food dilution, of high seston loads on net absorption efficiency was determined, this efficiency decreases with decreasing organic ingested fraction. Scope for growth calculations confirm the negative influence of seston loads, but show, supported by field growth measurements, that resuspended organic particles play an important role in the oyster's nutrition.

Basch, L. V. (1996)

Effects if algal and larval densities on development and survival of asteroid larvae

Marine Biology 126: 693-701

Effects of larval and algal culture density and diet, composition on development and survival of temperate asteroid larvae were studied in the laboratory at Santa Cruz, California, USA, during summer and fall of 1990. Larvae of *Asterina miniata* were reared at two densities, O.S or 1.0 ml (-1), and fed one or two species of cultured phytoflagellates -*Dunaliella tertiolecta* alone or mixed with *Rhodomonas* sp. - at three concentrations of 5xI0(2), SxlO(3), and Sxl0(4) total cells ml (-1). Algal concentration strongly influenced larval development: however, larval density also had a marked effect. Development progressed further with increasing algal concentration. Larval growth and differentiation were sometimes uncoupled, i.e., growth measures were directly related to food level, while differentiation indicators were less so. At the lowest food level, growth was negative and differentiation was arrested at early precompetent stages; these larvae never formed juvenile rudiments or brachiolar attachment structures. Development times of larvae given more food ranged from 26 to 50 d and depended directly on food availability. Development time to metamorphosis at the highest food concentration was similar for siblings fed *D. tertiolecta* alone or mixed with *Rhodomonas* sp. In contrast, when food level was an order of magnitude lower, larvae fed the algal mixture metamorphosed significantly earlier than larvae fed the unialgal diet. This suggests interactive effects of food quantity and food quality. Survival was little affected by larval or food density, except at the lowest ration. Feeding experiments in well-controlled laboratory conditions are useful to predict and compare the physiological or developmental scope of response of larvae to defined environmental factors; however, results from such studies should not be extrapolated to predict rates and processes of larval development in nature.

Bayer R. D. (1984)

Notes on the feeding behaviour of gulls and Crows on clams and crabs at the Yaquina Estuary, Oregon.

Western Birds 15: 35-36.

Beatie, J. H., K. K. Chew, & W. K. Hershberger (1980)

Differential survival of selected strains of Pacific oysters (Crassostrea gigas):

Proceedings of the National Shellfisheries Association 70: 119

Beattie, J. H. (1985)

Effects of growth and mortality differentials on production among selected stocks of the Pacific oyster *Crassostrea gigas* (Thunberg).

Journal of Shellfish Research 5: 49

A selective breeding program to establish stocks of oysters (*Crassostrea gigas*) which would have high survival during summer mortality periods was established in 1976. Oysters produced at the University of Washington Shellfish Laboratory, Manchester, Washington, have exhibited variable survival and growth. In 1982, in Mud Bay, Washington, 24 groups of oysters from an experimental selection project experienced survival of 60-90% while the control group of wild nonselected oysters showed < 40% survival. Mean wet weights of the oyster meats, however, indicated that most of the experimental oysters were smaller than the controls. Inbred groups were particularly small. A production comparison was made by multiplying the mean wet weight by the percent survival. In all cases, except 2 of the inbred groups, the production potential of each experimental group was higher than the controls. Four of the experimental groups had mean wet-meat weights comparable to the controls and also exhibited high (80 to 90%) survival.

Beattie, J. H. , B. Baldeson, L. Wiegardt and W. Breese (1981)

Eyed larvae transport -- is this the way of the future?

Journal of Shellfish Research 1 (Abstract)

Becker, D. D., G. R. Bilyard, & T. C. Ginn (1990)
Comparison between sediment bioassays and alterations of benthic macroinvertebrate assemblages at a marine superfund site Commencement Bay, Washington, USA
Environmental Toxicology and Chemistry 9: 669-686

Laboratory sediment bioassays and alterations of benthic macroinvertebrate assemblages were evaluated at 43 stations in Commencement Bay, Washington, and at 4 stations in Carr Inlet, Washington (a reference embayment). Three bioassays were evaluated: the amphipod mortality test using *Rhepoxynius abronius*, the oyster larvae abnormality test using *Crassostrea gigas* and the Microtox test using *Photobacterium phosphoreum*. Alterations of benthic assemblages were determined using numerical classification analysis. Bioassay responses and alterations of benthic assemblages were closely related to chemical contamination, suggesting that most biological effects resulted from chemical toxicity. Although all three bioassays were reasonably successful in predicting the presence or absence of moderately to severely altered benthic assemblages, considerable differences were found in the ability of the tests to identify only the altered assemblages. The Microtox bioassay successfully identified the highest percentage of altered benthic assemblages. By contrast, the oyster larvae abnormality bioassay falsely predicted the lowest percentage of altered assemblages. Tiered application of results of both the Microtox and oyster larvae tests improved the accuracy with which altered assemblages were identified.

Becker, D. S., T. C. Ginn, & G. R. Bilyard (1989)
Comparisons between sediment bioassays and alterations of benthic macroinvertebrate assemblages as measures of sediment toxicity.
Oceans 89. Part 2: Ocean Pollution p461-466

Laboratory sediment bioassays and alterations of benthic macroinvertebrate assemblages were evaluated at 43 stations in Commencement Bay, Washington (a chemically contaminated embayment) and at four stations in Carr Inlet, Washington (a relatively uncontaminated reference embayment). Three bioassays were evaluated: the amphipod mortality test using *Rhepoxynius abronius*, the bivalve larvae abnormality test using the oyster *Crassostrea gigas*, and the Microtox test using the bacterium *Photobacterium phosphoreum*. Alterations of benthic macroinvertebrate assemblages were determined using numerical classification analysis. In general, bioassay responses and alterations of benthic macroinvertebrate assemblages were closely related to chemical contamination, suggesting that most biological effects resulted from chemical toxicity. Although all three bioassays were reasonably successful in predicting the presence or absence of moderately to severely altered benthic assemblages, considerable differences were found in the ability of the tests to identify specifically only the altered assemblages. The Microtox bioassay was the most sensitive of the three tests because it successfully identified the highest percentage of altered assemblages. By contrast, the oyster larvae abnormality bioassay was the most efficient of the three tests because it falsely predicted the lowest percentage of altered assemblages. By using the results of the Microtox and oyster larvae abnormality bioassays in a tiered design, the strengths of both tests were combined to improve the accuracy with which altered assemblages were identified.

Becker, P. (1983)
Out of and into the 80's: The American shellfish industry 1890-1983
Proceedings of OCEANS 83. 2: 857-859

The American shellfish industry is on the brink of disaster. Some segments, (particularly Hood Canal, Washington, a small sport and commercial shrimp fishery, and Kodiak Island, Alaska, a large commercial shrimp fishery), have been managed to a state of near revival. Others, like the Olympia oyster fishery, collapsed long ago, or like the Delaware Bay oyster fishery, collapsed in relatively recent years. The attributable causes are a litany: human and industrial pollution of the water resource, domestic and imported predators and disease, destruction of marshland habitat, and overharvest. Although many people in the public and academic sectors are familiar with recreational aspects of the industry, they remain totally ignorant of the spectra of problems and policies which have historically beset the commercial aspects of the industry.

Boese, B. L. (2002)
Effects of recreational clam harvesting on eelgrass (*Zostera marina*} and associated infaunal invertebrates: *In situ* manipulative experiments.
Aquatic Botany 73: 63-74

The effect of recreational clam harvesting on eelgrass (*Zostera marina* L.) was experimentally tested by raking or digging for clams in experimental $1m^2$ plots located in a Yaquina Bay (Newport, OR) eelgrass meadow. After three monthly treatments, eelgrass measures of biomass, primary production (leaf elongation), and percent cover were compared between experimental and control (undisturbed) plots. Benthic macro (retained on 0.5 mm mesh sieve) and mega (retained on 3 mm sieve) infauna1 samples were also taken to compare species number and abundances. Results indicated that clam raking did not appreciably impact any measured parameter. In contrast, clam digging reduced eelgrass cover, above-ground biomass and below-ground biomass in measurements made 1 month after the last of three monthly treatments. Although differences between control and treatment plots persisted 10 months after the last clam digging treatment, these differences were not statistically significant. Approximately 10% of the eelgrass of Yaquina Bay is subjected to recreational clamming and as this activity is generally less intense than that employed in this study, it is un1 ike1y that recreational clamming has a major impact on eelgrass beds in the Yaquina estuary. This conclusion should be viewed with caution as multi-year disturbances were not investigated and there are differences in sediment characteristics and clam abundances between experimental sites and those sites that are intensively harvested by the public.

Boese, B. L., M. Winsor, H. Lee, S. Echols, J. Pellitier & R. Randall (1995)
PCB cogeners and hexachlorobenzene biota sediment accumulation factors for Macoma nasuta exposed to sediments with different total organic carbon contents
Environmental Toxicology and Chemistry 14: 303-310

Deposit-feeding marine clams (*Macoma nasuta*) were exposed for 119 d to three sediment types that varied in total organic carbon (TOC) from 0.8 to 2.5%. Sediments were spiked with equal concentrations of 13 polychlorinated biphenyl congeners and hexachlorobenzene. Tissue residues were measured, and steady-state bioaccumulation factors (BAFs), the corresponding 1ipid, and TOC-normalized biota sediment accumulation factors (BSAFs) were determined. The BSAFs were less variable than were the BAFs with the exception of compounds with log K(ow) > 7. Many of the BSAFs exceeded 1.7, which is a calculated maximum value based on partitioning alone. Although BSAFs varied with sediment type and compound, the use of a BSAF of 4 as a screening level for neutral organic compounds in assessing dredge materials is supported by the present study.

Bohn, R.E. (1989)
Transferring oyster hatchery technology: Can the East Coast learn from the West Coast?
Journal of Shellfish Research 8: 479

Oyster hatcheries, and the aquaculture systems which have resulted from their success, dominate the industry on the West Coast and are reaching national markets with their products. A combination of aggressive research and development, a compliant regulatory atmosphere, and the biological necessities of a non-native oyster have resulted in a flourishing and stable oyster growing industry from Alaska to California. Other areas of the country find their powerful commercial fisheries, faltering natural resources, and strict regulatory approaches hindering the development of a similar growth. Valuable lessons which led to the success of the West Coast industry, and their application to other parts of the country, are presented. Variations in the biology of the Pacific oyster (*Crassostrea gigas*) and the American oyster (*C. virginica*), and their implications in culture methods are also discussed.

Bonar, D. B. (1991)
Cultchless oyster production and enhanced setting with epinephrine and i-dopa IN Nosho, T.Y.; Chew, K.K. (eds.); Remote Setting and Nursery Culture for Shellfish Growers: Workshop Olympia, WA (USA) 19 Feb 1991 pp. 14-21, 1991 Washington Sea Grant Program, University of Washington, Seattle, WA.

In the last twenty years, growers and researchers have identified specific chemicals that enhance settlement behavior and/or metamorphosis of bivalves and can be used in nursery or field situations. The information presented outlines the practical application of laboratory-based studies done on the neurophysiological control of settlement and metamorphosis in *Crassostrea gigas* and *C. virginica*. Most of this work has been performed in conjunction with Coast Oyster Company in Quilcene, Washington, and with St. Georges Oyster Company in Piney Point, Maryland.

Boom, J. O. G, E. G. Boulding, & A. T. Beckenbach (1994)

Mitochondrial DNA Variation in Introduced Populations of Pacific Oyster, *Crassostrea gigas*, in British Columbia.

Canadian Journal of Fisheries and Aquatic Sciences 51: 1608-1614

Crassostrea gigas, a species native to Japan, was transplanted in very large numbers from the Miyagi Prefecture from 1927 to 1977 to British Columbia coastal waters. We examined the genetic structure and diversity of wild British Columbian populations of C. gigas using restriction enzyme analysis of mitochondrial DNA. Forty-four mtDNA haplotypes were identified in 141 animals from the populations sampled, implying the existence of considerable genetic diversity. The frequency distribution of these haplotypes is unusual in that only two haplotypes predominate whereas 34 are represented by a single individual and five by two individuals. The four British Columbia populations sampled all shared the two common haplotypes in roughly the same frequencies and a third haplotype at low frequencies. Between 9 and 11 haplotypes were found uniquely in each of the four British Columbia populations sampled, but 34 of those 40 private haplotypes were observed only once. Much larger sample sizes would be required to conclude that those haplotypes are indeed 'private' and not present in low frequencies in all populations. We conclude that there is substantial genetic variation in these introduced populations, but there is little evidence of genetic divergence between them.

Boulding, E. G., J. O. G Boom, A. T. Beckenbach (1993)

Genetic variation in one bottlenecked and 2 wild populations of the Japanese Scallop (*Patinopecten yessoensis*) – empirical parameter estimates from coding regions of mitochondrial DNA.

Canadian Journal of Fisheries and Aquatic Sciences 50: 1147-1157

Restriction analysis of the mitochondrial genome of 16 Japanese scallop (*Patinopecten yessoensis*) provided unique genotypes for each individual, mostly due to length variation. Fragment length variation was common, probably because randomly repeated elements of noncoding mtDNA mutate to a different number of copies at high rates. To accurately estimate genetic diversity, we used the polymerase chain reaction (PCR) to selectively amplify coding mtDNA fragments and performed restriction analysis on these. Four pairs of PCR primers were used to amplify fragments encoding: (1) most of ATP synthetase subunit 6 and most of cytochrome c oxidase subunit 3, (2) part of cytochrome b apoenzyme, (3) tRNA for threonine, and (4) most of the large (16S) ribosomal gene. We used this technique to compare the genetic diversity of a population bred in a small experimental hatchery in British Columbia for three generations with its wild source population at Mutsu Bay, Aomori, Japan, and with a second wild population at Uchiura Bay, Hokkaido, Japan. The three populations were similar in the frequency distributions of the 11 Mitochondrial clonal1ines. This suggests that the experimental hatchery stock was not severely inbred and that gene flow between the two wild Japanese populations has been sufficient to prevent divergence.

Bourne, N. & J. R. Brett (1984)

Aquaculture in British Columbia.

Proceedings of the National Aquaculture Conference- Strategies for aquaculture development in Canada. Department of Fisheries and Oceans, Ottawa, Onto (Canada). Sci. Info Publ. Br, Can. Spec. Publ. Fish. Aquat. Sci. 75: 25-41

This paper presents an overview of the current status of aquaculture in British Columbia. To date, total production from the culture of invertebrates, vertebrates, and marine plants has been small and disappointing; it has generally decreased in recent years. In 1981, oyster production was about 1,400 metric

tons (t) and farmed salmon only 180t. Reasons for this low production are presented. The future of aquaculture in British Columbia nevertheless remains promising and there is the potential to establish a viable mariculture industry in the Province. Research and development needed to achieve this goal are discussed.

Bower, S. M. (1987)
Pathogenicity and host specificity of *Labyrinthuloides haliotidis* protozoa Labyrinthomorpha a parasite of juvenile abalone.
Can. J. Zool. 65: 2008-2012.

Infections with *Labyrinthuloides haliotidis*, an ach1orophyllous, eucaryotic protist, were lethal to almost all juvenile abalone (*Halitotis kamtschatkana* and *Haliotis rufescens*) less than 6 months of age in an abalone mariculture facility in British Columbia, Canada. In laboratory experiments, *L. ha1itodis* isolated from infected abalone or grown in axenic nutrient medium was infective for abalone (*H. kamtschatkana*) less than 4.0 nm in shell length and 140 days of age. Ten days after exposure to at least 104 parasites in 20 ml of sea water, about 90% of these abalone died with numerous parasites throughout the tissues of the head and foot. By about 190 days of age, regardless of shell size, abalone mortalities were reduced to less than 50% after exposure to about 105 parasites. Finally, by about 340 days of age, most juvenile abalone (4.0 to 10.5 mm in shell length) did not succumb after three consecutive exposures, 13 days apart, to between 2 times. 105 and 5 cntdot. 106 *L. ha1iotidis*. Larger abalone (15 to 25 mm in shell length) did not become infected following intramusc1ar in jections of about 1.5 .cntdot. 104 *L. ha1iotidis*. Small juvenile scallops (*Patinopecten yessoensis*) and juvenile oysters (*Crassostrea gigas*), both less than 8 months of age, were also resistant to infection. However, two of the oysters with badly cracked shells became infected. This suggests that if *L. ha1iotidis* can gain access, it is capable of using 1iving oyster tissue as a source of nutrients for growth and mu1tip1ication.

Bower, S. M. (2000)
Hazards and risk management of *Microcytos mackini* in oysters.
Risk analysis in aquatic animal health. Proceedings of an international conference, Paris, France, 8-10 February, 2000. p.164-166.

The parasite *Microcytos mackiniis* listed as a notifiable disease in the Office International des Epizooties (OlE) International Aquatic Animal Health Code. To date, this pathogen has been reported only in British Columbia, Canada, where it has caused approximately 40% mortalities among older *Crassostrea gigas* at low tide levels and unsightly lesions in oysters which survive the infection. From the perspective of risk assessment, *M. mackini* represents a hazard to global oyster production because of its lack of host specificity and cryptic biology. Experiments indicate that *M. mackini* is pathogenic for all species of oysters tested (*C. gigas, C. virginica, Ostrea edulis* and *O. conchaphila*). The only available method for detecting infection is microscopic screening at high magnification (1000x) of stained tissue imprints or histological sections. However, the small size of this parasite (approximately 2 micro m in diameter) makes 1ight infections difficult to detect. In addition, experimental evidence suggests that most infections are subclinical. The pathogen *M. mackini* is only capable of causing disease in oysters held at less than 10 deg C for at least three months and is detectable in the field only during spring (March to May). However, subclinical infections could occur in field oysters throughout the year because experimentally exposed oysters, held at 18 deg C, can retain the parasite at subclinical levels for at least six months. Thus, when assessing the risk associated with this pathogen, it is vital to acknowledge the possibility that infection may not be detected, using current surveillance techniques, for about nine months of the year. The development of a sensitive DNA-based diagnostic test will improve the ability to detect subclinical infections. Such a test is vital in the establishment of an effective risk management strategy for *M. mackini*.

Bower, S. M. & G. R. Me yer (1999)
Effect of cold water on limiting or exacerbating some oyster diseases
Journal of Shellfish Research 18 (Abstract)

Like most other pathogens, agents of oyster diseases are influenced by environmental conditions. Information accumulated to date indicates that some parasites are only pathogenic when water temperatures are cold for extended periods while others do not produce disease when temperatures are low. For example, controlled laboratory studies revealed that *Microcytos mackini*, the agent of Denman Island disease *in Crassostrea gigas*, did not develop in oysters held at >15 degree C and temperatures <10 degree C were required for at least 3 months for the development of disease and associated mortalities. This temperature requirement explains the occurrence of the disease only in the spring of the year and its absence in oysters south of British Columbia despite the extensive historic relocation of potentially infected oysters to the Pacific United States. Conversely, other oyster diseases seem to be curtailed by cold temperatures. For example, *Nocardia* sp. has been detected in *C. gigas* in British Columbia throughout the year. However, nocardiosis occurs only towards the end of exceptionally warm summers. The 1iterature also indicates that *Ostracoblabe implexa*, the agent of oyster shell disease, requires >22 degree C for more than two weeks to proliferate and optimum growth occurs at 30 degree C (Alderman & Jones 1971, Trans. Br. Mycol. Soc. 57:213-225). This requirement for warm temperatures probably explains why this fungus is not a problem in British Columbia although we have detected it in a few oysters. Diseases caused by *Perkinsus marinus* and *Bonamia ostreae* have not been detected in Canada possibly because these parasites require warm temperatures to replicate. The question that research must now address is how long can these pathogens survive in hosts held at temperatures not suitable for their pathogenic expression before potential carriers can be certified as free of infection.

Brake, J. W., J. Davidson, & D. J Davis (1999)
Triploid production of Mytilus edulis in Prince Edward Island--an industrial initiative.
Journal of Shellfish Research 18 (Abstract)

The mussel aquaculture industry in Prince Edward Island (PEl), Canada is a well established major contributor to the island economy. In 1997 farm gate value exceeded $12 M (Can) and export value exceeded $24 M (Can). The industry currently supports over 1250 full and part time jobs. Harvesting and marketing during the spawning season is currently an area of concern for the industry. Mussels that have recently spawned have a low (less appealing) meat yield, while those close to spawning can spawn out en route to the market from processors. In both cases the potential exists to increase consumer dissatisfaction with the product. Triploids have very poorly developed gonads, thus more energy can be used for meat production instead of gonad production, allowing for the possibility of larger meat yields than normal diploids during the spawning season. The production of triploid mussels might therefore alleviate these problems, allowing the marketing of a high quality product year round. The production of triploid Pacific oysters (*Crassostrea gigas*) is currently extensively practiced in the Pacific Northwest. Triploid clams (*Ruditapes philipparum*), scallops (*Placopecten magellanicus*), and mussels (*M. galloprovincialis*) have all been produced as well as others. Identified methods of triploid induction (used at different levels or in combinations) in shellfish include temperature and/or pressure shocking and the use of chemicals such as caffeine, cytochalasin B, or 6-dimethylaminopurine. The mussel industry has recognized the potential of harvesting triploid mussels during the spawning season. The objective of this study is to elucidate the best triploid induction methods for commercial use in PEl by the use of a matrix of previously identified triploidy induction methods. These combinations of methods will be ranked by % induction and % survivorship, as well as feasibi1ity in order to determine the best method. Hatchery techniques will be fine tuned for the species, then the performance of triploids in the field will be evaluated to find when it might be more or less advantageous to utilize them

Brake, J. W., J. Davidson, & D. J Davis (2000)
Triploid production of *Mytilus edulis* in Prince Edward Island
Journal of Shellfish Research 19 (Abstract)

The mussel aquaculture industry in Prince Edward Island (PEl), Canada is a well established major contributor to the island economy. PEl mussel production in 1998 was approximately 12,500 MT, with farm gate value exceeding $15.1 M (Can) and export value exceeded $30 M (Can). The industry supports over 1250 full and part time jobs. The production of non-reproducing harvestable triploid mussels has been investigated for harvesting during the spawning season, when product quality and shipping are both

problems, allowing the marketing of a high quality product year round. Many species have been produced and reared successfully as triploids and the production of triploid Pacific oysters (Crassostrea gigas) is currently extensively practiced in the Pacific Northwest. Identified methods of triploid induction (used at different levels or in combinations) in shellfis h include temperature and/or pressure shocking and the use of chemicals such as caffeine, cytochalasin B, or 6-dimethylaminopurine. The mussel industry has recognized the potential of harvesting triploid mussels during the spawning season. The objective of this study is to elucidate the optimal triploid induction methods for commercial use in PEl by the use of a matrix of previously identified triploidy induction methods. These combinations of methods are ranked by % induction and % survivorship, as well as feasibility in order to determine the best method. To date, inductions trials with a % triploid induction of >90% have been obtained, however, survival has been lower than expected. A new attempt to investigate the exact treatment timing window is being investigated in an attempt to improve survivorship. This method involves epifluorescent microscopy and the timing of treatment based upon the chromosome separation rather than polar body formation. The current methodology being used for triploid induction optimization and successful growth trials will be discussed along with some of the results obtained to date.

Bresse, W. P. & A. Robinson (1981)
Razor clams *Siliqua patula* gonadal development induced spawning and larval rearing
Aquaculture 22: 27-34

Maturation of ova and oocytes was described for populations along the central Oregon [USA] coast. A new method was developed for inducing spawning of the razor clam *S. patula* (Dixon). One-celled marine algae at a concentration of 2-2.5 million cells/ml caused spawning in clams, mussels and oysters. Growth rates were estimated for the larval stage of the razor clam.

Brooks, C. & C. Langdon (1998)
Is the laboratory performance of Pacific oyster spat, Crassostrea gigas, exposed to varying salinities, predictive of performance in the field?
Journal of Shellfish Research 17 (Abstract)

Broodstock selection of oysters is a lengthy process which may take up to three years. In an effort to study the feasibility of shortening this time period, 72 representative oysters from each of the 14 full-sib families available were individually tagged as 7-10 mm spat. Commercially available Kumamoto, triploid and tetraploid oysters were included for comparison. Spat were placed into uncrowded upwellers and fed to excess on a diet of *Chaetoceros calcitrans,* and *Isochrysis galbana*. Whole wet weights and survival were measured approximately bi-monthly for 11 months. Half of the oysters were exposed to increasingly severe (i.e., 30ppt-5ppt) salinity fluctuations that simulated typical winter tide cycles and a 1996 storm event in Oregon's Yaquina Bay. The pre-flood family rankings of specific growth rate and survival were similar between fluctuating and constant salinity conditions, based upon Spearman Rank Correlation, (rho = 0.893, 0.833 respectively). Mean family SGR values ranged from 4.56% to 1.3%. The five families with the highest pre-flood mean SGR were the tetraploids, followed by diploid families #106, #108, #105 and the triploids. Results of the family rankings in the laboratory environments compared with their rankings at two different grow-out sites in the Yaquina Bay estuary wi11 be presented.

Brown, J. R. (1988)

A habitat suitability index model for the aquaculture of the Pacific oyster, *Crassostrea gigas*

Journal of Shellfish Research 7: 112

A Habitat Suitability Index (HSI) model was developed in order to evaluate the suitability of coastal areas in British Columbia for the aquaculture of *Crassostrea gigas.* In the model the effects of abiotic and biotic factors upon oyster growth and mortality are quantified through the use of a relative index. Fundamental to the model is the comparison of existing habitat conditions to the optimum conditions of the habitat variables for the oyster as described in the literature. The performance of the model was evaluated utilizing environmental and oyster production data collected from 10 field sites over a 14 month period. Site-specific HSI values derived from the environmental data were found to be significantly correlated with the increase

in shell length of two groups of oysters. The use of the HSI model in the selection of sites for aquaculture operations and in the management of coastal areas will be discussed.

Brown, J. R. (1988)
Multivariate analyses of the role of environmental factors in seasonal and site-related growth variation in the Pacific oyster *Crassostrea gigas*
Marine Ecology Progress Series 45: 225-236

Monthly increases in shell height were measured for 2 age classes (Years 0 and 1) of a common broodstock of oysters *Crassostrea gigas* in 10 locations in British Columbia. Canada over 14 mo. Measurements were also taken of several environmental variables known to affect oyster growth. Based on comparisons of shell height growth curves sites were grouped into low medium and high growth categories which were similar for both age classes of oysters. According to discriminant function analysis differences in salinity and particulate organic matter (POM) concentration distinguished low growth sites from medium and high growth areas. Medium and high growth areas were segregated solely on the basis of food-related variables: POM. carotenoid concentration and Secchi depth.

Brown, J. R. & E. B. Hartwick (1988a)
Influences of temperature, salinity, and available food upon suspended culture of the Pacific Oyster, *Crassostrea gigas* I. Absolute and allometric growth
Aquaculture 70: 231-252

Growth of oysters was measured at 10 locations in British Columbia, Canada over a 14-month period. Three categories of site-related growth were defined by comparisons of growth curves for different body variables. In high growth sites, oysters had greatest increases in shell height and weights of whole oyster, shell and dry meat which were attributed to high phytoplankton biomass (chlorophyll a) and suitable temperature and salinity regimes. Oysters in medium growth sites had significantly lower growth in shell height and dry meat weight but equivalent whole and shell weight growth to high growth sites. Temperature and salinity regimes were suitable for oysters at these sites but overall phytoplankton biomass was low. At low growth sites, growth in all body variables were reduced because periods of high food availability coincided with suboptimal salinity conditions « 20 ppt). Comparisons of site-specific allometric regression equations fitted to 10glO transformed dry meat weight and shell weight data were not different between low and high growth sites, however, oysters at I' medium growth sites had significantly less dry weight in relation to shell weight. We suggest that under prolonged periods of low food supply, oysters preferentially partition energy resources toward increasing shell weight and thickness over body tissue weight. This response may be inhibited under conditions of low salinity because of reduction of assimilated ration and possible 1imitations upon the supply of minerals essential to shell formation.

Brown, J. R. & E. B. Hartwick (1988b)
Influences of temperature, salinity, and available food upon suspended culture of the Pacific Oyster, *Crassostrea gigas* II. Condition index and survival
Aquaculture 70: 253-268

Condition indices, dry meat weight:dry shell weight ratio and dry meat weight:internal volume ratio, and survival rate were determined for a common broodstock of oysters grown in 10 locations in British Columbia, Canada, over a 14-month period. Year 0 oysters (20-30 mm initial shell height) had lower overall survival rates (31.5-57.3%) than Year I oysters (40-50 mm shell height) (63.2-89.7%) although for a given age-class, differences in survival between most sites were not great. Most oyster mortalities occurred in the initial 2-3 months according to seasonal and annual instantaneous mortality rates. Monthly dry meat weight:internal volume condition index values did not appear to be related to site-related trends in growth rate. Dry meat weight:dry shell weight ratio was a more suitable index for assessing the condition of oysters provided available food and water temperature were the principal factors affecting growth. Slow growing oysters from areas with low salinity « 20 ppt) had dry meat weight:she11 weight ratios equivalent to those of rapidly growing oysters from areas with conditions of high salinity and abundant food supply. Intra-site correlations between the two condition indices were poor. Multiple regression analysis revealed

that dry meat weight:internal volume ratio was primarily correlated to whole weight and secondarily to water temperature, salinity and chlorophyll a concentration (r2 = 0.39, P .ltoreq. 0.001). Dry meat weight:dry shell weight ratio was correlated to the same environmental factors but not whole weight (r2 = 0.41, P .ltoreq. 0.001). Ecophysio1ogica1 studies of oysters should not rely extensively upon results of condition index analysis, particularly involving volume measurements, unless there are collaborating growth and environmental data.

Brown, J. R. & E. B. Hartwick (1988c)

A habitat suitability index model for suspended tray culture of the Pacific Oyster, *Crassostrea gigas* Thunberg

Aquaculture and Fisheries Management 19: 109-126

A habitat suitability index (HSI) model for suspended tray culture of the Pacific oyster, Crassostrea gigas Thunberg, was constructed from existing information in the literature on oyster-environment relationships. I the model, biophysical data are used to rate aquaculture potential of coastal areas on a scale from 0.0 to 1.0, where 1.0 represents optimal conditions for growth and survival and 0.0 represents totally unsuitable habitat conditions. The model was tested with environmental, growth (increase in shell height) and secondary production (g .cntdot. 100 oysters -l .cntdot. day-l) data collected over a 14-month period for two age-classes of oysters transplanted to 10 locations along the coast of British Columbia, Canada. Regressions of HSI values calculated from entire study environmental data against oyster growth and secondary production were highly significant for both age-classes. Environmental data subsets representing short sampling programmes (1-3 months) resulted in HSI values significantly correlated to oyster growth, provided that some sampling occurred during periods of high food availability. HSI modeling techniques have potential application in site selection and coastal management of aquaculture.

Buroker, N. E. (1983)

Sexuality with respect to shell length and group size in the Japanese oyster *Crassostrea gigas.*

Malacologia 23: 271-279

Burreson E. M., N. A. Stokes & C. S. Friedman (2000)

Increased virulence in an introduced pathogen: *Haplosporidium nelsoni* (MSX) in the eastern oyster *Crassostrea virginica.*

Journal of Aquatic Animal Health 12: l-8

The protistan parasite *Haplosporidium nelsoni* has caused extensive mortality in the eastern oyster *Crassostrea virginica* along the mid-Atlantic coast of the United States since 1957. The origin of H. nelsoni has remained unresolved. Molecular diagnostic tools were used to examine the hypothesis that a haplosporidian parasite in the Pacific oyster *C. gigas* is *H. nelsoni*. A DNA probe specific for H. nelsoni reacted positively in *in situ* hybridizations with haplosporidian plasmodia from *C. gigas* collected in Korea, Japan, and California. Primers that specifically amplify *H. nelsoni* DNA in the polymerase chain reaction amplified product from California *C. gigas* infected with the haplosporidian parasite. The DNA sequence of the 565-base pair amplified product was identical to the *H. nelsoni* sequence except for a single nucleotide transition, a similarity of 99.8%. These results are conclusive evidence that the parasite in *C. gigas* is *H. nelsoni* and strongly support previous speculation that the parasite was introduced into Californian populations of *C. gigas* from Japan. Results also support previous speculation that *H. nelsoni* was introduced from the Pacific Ocean to *C. virginica* on the East Coast of the United States, likely with known importations of *C. gigas.* These results document greatly increased virulence in a naive host-parasite association and reinforce potential dangers of intentional, but improper, introductions of exotic marine organisms for aquaculture or resource restoration

Caceres-Martines, C. & S. Garcia Bustamante (1990)

Pilot culture of the oyster *Crassostrea gigas* in bags on posts in the intertidal zone of Magdalena Bay, B.C.S.: Stocking density effects on growth. IN The Aquaculture in Mexico: From Concepts to Production. Lanza Espino, G de la; Arredondo Figueroa, J (eds) pp.316.

Three different stocking densities were used for the culture of *Crassostrea gigas* in bags, these were: 500, 1000 and 1500 oysters/bag. Monthly measures were realized. Growth and the condition index were evaluated. It was concluded the intertidal oyster culture in bags is not affected by the stocking density. Finally, the stocking of 1000 oysters/bag for the fattening period and of 250 oysters/bag for the culture period were recommended for commercial activities.

Caceres-Martinez J., P. Macias-Montes De Oca, & R. Vasquez-Yeomans (1998)

Polydora sp. infestation and health of the pacific oyster *Crassostrea gigas* cultured in Baha California, NW Mexico.
Journal of Shellfish Research 17: 259-264

The culture of the Oyster *Crassostrea gigas* Thunberg is the most important aquaculture activity in the state of Baja California, NW Mexico. Its production is obtained from Bahia Falsa, at South of the state, reaching 2,500 metric tons per year and is sold in national and international markets. However, there is a lack of information on commensals and parasites affecting cultured oysters. A survey of worm blister on the inner valves of cultured oysters was performed from May 1996 to April 1997. Two locations were sampled: the outer and inner areas of the bay, at three depths. Direct counts of worm blisters and quantification of the area occupied by worm blisters on the inner valves were used as evaluation methods. The burrowing worm belonged to the genus *Polydora* (Polychaeta: Spionidae). Its prevalence was higher in oysters from the outer relative to the inner locations, and was also higher in oysters placed near the substrate relative to those near the surface of the water. There was a trend of lower condition index and higher mortality in oysters placed near the muddy bottom. The placement of culture oysters away from the bottom and exposed to air during low tides may reduce the prevalence of *Polydora* sp. and oyster mortality.

Cajal Medrano, R. (1980)

DDT and its metabolites in two genera of cultured oysters from Baja California, Mexico. IN Memoirs of the 2nd Latin American Symposium on Aquaculture vol. 1 p. 449-487

3 months after the seeding of *Crassostrea gigas* and *Ostrea edulis* in the Punta Banda Inlet and San Quintin Bay, Mexico, samples were taken on a monthly basis during 7 months. The organisms were measured longitudinally and their soft parts were homogenized to be analyzed by gas chromatography in order to detect DDT and its metabolites. The highest concentrations of total DDT detected were of 11.23 and 12.58 ppb for the Punta Banda inlet and 2.82 and 3.75 ppb for the San Quintin Bay. For both zones the more conspicuous metabolite was p,p'DDE. Since the highest concentrations recorded did not exceed the maximum value permitted by the U.S. Food and Drug Administration (7 ppm), the organisms were considered as suitable for human consumption but unsuitable for oyster growth, and they could also be harmful for other parts of the ecosystem.

Cantera, J. R., R. Contreras, F. Borrero, E. Buttkus, & F. Zapata (1980)

Natural history of the mangrove gastropod *Thais kiosquiformis* Duclos 1832, on the Colombian Pacific coast. IN Memoirs of the Seminar on the Scientific Study and Human Impact on the Mangrove Ecosystem. p. 170-194

Thais kiosquiformis is a common predator of oysters, cirripeds and other gastropods, which inhabits on the roots and trunks of red mangrove (*Rhizophora mangle, R. brevistyla*), rocky shores and man-made constructions, from Baja California to Peru, including Colombian localities with mangrove ecosystem from Ensenada of Catripe (4 degree 251 N and 77 degree 181 W) to Tumaco (1 degree 501 N and 78 degree 44'W). The average length of specimens for the six localities was found to be 36.36 mm. *Thais kiosquiformis* preys upon cirripeds, *Ostrea conchaphila, Littorina zebra, Littorina varia* and *Cerithidea valida*. The ovigerous masses can be round or elongated, with a length of between 5.0 cm and 23 cm; width between 7.9 and 9.8 cm. The females deposit the masses individually or communally on shaded surfaces. The growth was, in average, 0.54 mm in length and 0.29 grams in weight per month.

Cardwell, R. O., S. J. Olsen, M. I. Carr, and E. W. Sanborn (1980)
Biotic water quality and hydrologic characteristics of Skyline Marina North Puget Sound Washington State USA in 1998.
Washington Department of Fisheries Technical Report (54). I-VII, 1-103

Fish, zooplankton and water quality characteristics of Skyline Marina in north Puget Sound were compared to the marina's source water in monthly surveys conducted from March-Oct. 1978. A companion study defined the marina's flushing properties. Fish were indexed mainly by purse seining and the food habits of 7 spp. of salmon (*Oncorhychus* spp.) and baitfish juveniles [*0. kisutch, O. tshawytscha, O. gorbuscha, O. keta, Hypomesus pretiosus, Ammodytes hexapterus* and *Clupea harengus pallasil* in terms of ontogenic-seasonal variation. Water quality was described through measurements of general parameters (e.g., temperature, phytoplankton, nutrients), heavy metal and organic concentrations in sediments, heavy metal residues in adult Pacific oysters (*Crassostrea gigas*) and acute toxicity of ambient waters to Pacific oyster larvae. Predation on brachyurans, copepods, siphonophores and tunicates, diversity and density were examined. Heavy metal toxicities, possibly from antifouling paints, and their effects were discussed.

Carlson, B. K. (1982)
Settlement and subsequent survival of commercially-reared eyed-pediveliger larvae of the Pacific oyster *Crassostrea gigas* (Thurnberg).
Journal of Shellfish Research 2: 116

A series of factorial experiments were conducted using eyed-pediveliger oyster larvae (*Crassostrea gigas* (Thurnberg)) reared at a commercial hatchery in Netarts, Oregon. Experiments on the combined effects of temperature and salinity indicated that temperature had a highly significant effect on the setting of Pacific oyster larvae. At temperatures from 15 degree to 30 degree C, the percentage of larvae setting during a 48-hour period increased as temperature increased. There was no significant difference in setting at salinities from 15 ppt to 30 ppt, and there was no evidence of a temperature-salinity interaction.

Carlton J. T. (1999)
Molluscan invasions in marine and estuarine communities.
Malacologia 41: 439-454

The distributions of many species of marine and estuarine mollusks have been altered dramatically by human movements over the past 2,000 and more years. Vectors have included vessels, mariculture, the aquarium trade, intentional or accidental releases into the wild, and canals. Most marine mollusk distributions are held to be natural prior to the 19th century, whereas mollusk distributions during or since the 19th century are held to be potentially subject to human modification. However, that pre-19th century invasions occurred is clear, suggesting that the antiquity of human-mediated mollusk introductions has been extensively underestimated. The Asian oyster *Crassostrea gigas* was introduced to Europe by the 1500s, the Northern Hemisphere mussel Mytilus may have arrived in the Southern Hemisphere by the early 1500s, and shipworms have similarly been widespread by shipping. A subset of 38 Northern Hemisphere introduced mollusks reveals distinct geographic patterns: 63% originate in the North Atlantic Ocean/Mediterranean area, while 37% originate in the North Pacific Ocean. Within the Atlantic Ocean, the western Atlantic is a significantly stronger donor area, accounting for 75% of those North Atlantic taxa that have dispersed globally. Similarly, the western Pacific Ocean is also a strong donor region, exporting 93% of all those originating in the Pacific. Ecologically, in San Francisco Bay, California, the introduced infaunal or near-surface bivalves *Mya, Gemma, Venerupis, Musculista* and *Potamocorbula* may be sufficiently abundant as to control water column productivity. The European snai1 *Littorina littorea* (Linnaeus, 1758) has had vast and complex impacts on intertidal hard and soft bottom communities from Canada to the mid-Atlantic America. In general, far more attention must be paid to experimentally demonstrating the impacts of invasive species.

Cary, S. C., C. F. Phleger, and D. L. Leighton (1982)

Advances in culture of the purple-hinge rock scallop (*Hinnites multirugosus*);

Journal of Shellfish Research 2: 116-117

Casti, G. C. (2000)

Benthic biological invasions in two temperate estuaries and their effects on trophic relations of native fish and community stability

Dissertations International v. 61/08-B p. 3958, pp251

The extent of biological invasions, their role on the feeding of native fishes and their impact on community stability were investigated in Alsea Bay and Yaquina Bay, two estuaries on the central Oregon coast, USA. Most nonindigenous species (NIS) introduced in these intermediately invaded estuaries are considered byproducts of culturing introduced Atlantic and Pacific oysters. Secondary potential vectors of NIS in Yaquina Bay are external fouling of ship hulls and ballast water. Native benthic invertebrates and native fishes dominate in density, catch per unit effort (CPUE) and richness in both estuaries. Three of the 11 benthic NIS of invertebrates in Yaquina Bay and one of the eight NIS in Alsea Bay are among the 10 most dominant benthic invertebrate species. The NIS of invertebrates are concentrated in habitats with above average water temperature, salinity, and macrophyte density at high-tide. The CPUE of fishes and decapod crustaceans are associated with above average water temperature, salinity and macrophyte density but are not consistently correlated with invertebrate density in sediments. Biological invasions have caused significant prey shifts in intertidal food webs of Yaquina Bay. Diets of two species of native juvenile flatfishes (*Pleuronectes vetulus* and *Platichthys stellatus*) included mainly polychaetes, crustaceans and bivalves and each of these taxa are represented in the diet by native species and NIS in each estuary. Both flatfish species are generalist predators and had no consistently higher selection for either native species or NIS. Prey selection experiments indicated that two native and two introduced amphipod prey (Corophium spp.) are acceptable prey for juvenile English sole. Thus, predator-prey coevolution plays no significant role on prey selection. Interspecific prey selection may depend on prey exposure, water visibility, substratum type, and species diversity of available prey. Modeling of functional-group interactions for the intertidal benthic community of Yaquina Bay suggested reduced community response to invasions or removal of fish predators as indicated by the community tendency to zero overall-feedback. However, the increased risk of stability decline of invaded community models implies that further human-mediated biological invasions should be avoided.

Cheney, D. P., R. Elston, R. & B. MacDonald (1998)

Summer mortality in Pacific oyster: Observations on the influences of water quality and culture methods Journal of Shellfish Research 17 (Abstract)

Pacific oysters (*Crassostrea gigas*) account for the bulk of the oysters produced on the west coast of North America. Virtually, all of these oysters originated from seed stocks imported from Japan between the 1920's and 19701s. Culture of the Pacific oysters began in a small number of rural sites and spread rapidly so that today commercial culture is carried out in many non-urban embayments in Washington, Oregon, northern California, northem Mexico, southern British Columbia and portions of Alaska. While oyster production on the U.S. west coast has not experienced the catastrophic losses from disease plaguing the east coast, mass mortalities periodically occur on commercial farms. Oysters from growing areas in Washington, Oregon and California sporadically experience larger than expected die offs in summer months. Sharp increases in mortality from Puget Sound, Washington from June to September are considered the classic example of west coast summer mortality. More recently, losses of seed oysters in Europe have also been attributed to summer mortality. Work began in early 1998 on a Oyster Disease Research Program study to more precisely characterize summer mortality in a variety of culture conditions and locations, definitively describe the relationship to infectious diseases, and identify water quality and seasonal patterns. Additionally, both a field component that investigates oyster thermal stress response and an assessment of induced thermal tolerance to reduce oyster mortalities are underway. Management practices for commercial cultivation are also being evaluated as possible measures to reduce the frequency and extent of oyster losses.

Cheney, D., R., Elston, B. MacDonald, G. Cherr, A. M. Hamdoun, and J. J. Jacobsen (1999)
An update on the ongoing oyster summer mortality study: mortality of the Pacific oyster, *Crassostrea gigas* health screening, environmental links and management options.
Journal of Shellfish Research 18: 685

Cheney, D., B. F. MacDonald, & R. A. Elston (2000)
Summer mortality of Pacific oysters, *Crassostrea gigas* (Thunberg): Initial findings on multiple environmental stressors in Puget Sound, Washington, 1998.
Journal of Shellfish Research 19: 353-359

A study was begun in late 1997 in Puget Sound, Washington, and Tomalas Bay, California, to characterize more precisely the summer mortality of the Pacific oyster (*Crassostrea gigas*) in a variety of culture conditions and locations and to describe definitively the relationship of summer mortality to infectious diseases. Water quality and seasonal factors also were identified. A field component investigated the oysters thermal stress response and assessed induced thermal tolerance as a means to reduce mortalities. In addition, management practices for commercial cultivation were evaluated as measures to reduce the frequency and extent of oyster losses. Our evaluation of the 1998 data from the summer mortality project supports earlier reports on the rate and timing of mortality events. There were differences in the mortality rates among the varieties of oysters tested, with triploid oysters having consistently higher mortality rates than diploid oysters planted in comparable plots. Trends in mortalities were toward higher rates at or immediately after neap tides when dissolved oxygen was lowest and during periods of elevated air and water temperatures. Relative densities of the phytoplankton *Gymnodinium splendens, Ceratium* spp., and *Psuedo-nitzschia* spp. were higher during the late summer; dissolved oxygen concentrations were correspondingly low, and oyster mortalities were high during this same period. It is likely that Pacific oysters at the study sites experienced varying degrees of chronic stress attributable to multiple environmental factors. Evaluations of effects of those stressors and development of oyster health management strategies are continuing.

Cheney, D., R., Elston, B. MacDonald, K. Kinnan, & A. Suhrbier (2001)
Summer mortality of the Pacific oyster *Crassostrea gigas*: Influences of culture methods, site conditions, and stock selection

Aquaculture 2001. World Aquaculture Society, LSU, Baton Rouge, LA.

During the late summer to early fall period, Pacific oysters cultured on the west coast of the United States and elsewhere may experience high levels of mortality In the 1960ls to 801S, this condition was subject to intensive investigation focusing on broad areas of disease pathology, genetics, physiology and the environment. Results of these studies were largely inconclusive, or pointed to a poorly defined etiology. Although several factors, such as a bacterial and herpes-like virus infections could be I inked to certain mortality events, no clear picture emerged. Recent studies in Puget Sound, Washington USA and Tomales Bay, California USA center on the influence of multiple stressors and their affects on oyster survival, physiology and pathology. The goal of this research is to identify possible modifications in culture practices, brood stock selection or grow-out location to increase survival of Pacific oysters. Field observations indicate oysters are subject to extreme variations in a number of parameters during intertidal cycles. Annual or seasonal variations in those parameters and differing culture practices likely play major roles in oyster survival. An increased rate of oyster mortality and modified physiological response appears to be strongly correlated with both elevated temperatures and extended periods of depressed DO. A long period of neap tides with low and slack water during the evening was observed to result in daily and successive reductions in DO to levels ranging from 0.5 and 2 mg/L. The DO reductions are sometimes coupled with heavy macroalgae blooms and high phytoplankton densities. This and other work also indicate oyster summer mortality rates are strongly influenced by ploidy and broodstock origin/stock selection. These observations have renewed interest in testing stocks selected for reduced rates of summer mortality, and which retain desirable characteristics of good growth and meat yield. This research is supported by grant numbers NA86RGOO15 and NA96RG0488 from the National Sea Grant College Oyster Disease Research Program and matching contributions from West Coast shellfish farmers.

Cherr, G. & C. S. Friedman (1998)

Investigation of a Mass Mortality of Pacific Oysters, *Crassostrea gigas*, in Tamales Bay, California California Sea Grant Coll. Program, La Jolla, CA. Report Number: R-044 p. 167-172

Pacific oysters, *Crassostrea gigas*, from two suppliers in Washington State and Humboldt Bay, California, were out planted in Tomales Bay, California, at three different locations: north, central, and south. Oysters were planted in Willapa Bay, Washington, as a control. Each location received approximately 10,000 oysters from Washington State and 13,000 oysters from Humboldt Bay. The oysters were planted at a tidal level of +1.5.

Chew, K. K. (1985)

A review of West Coast oyster fisheries and the present impact of remote setting of oyster seed.

Journal of Shellfish Research 5: 33

A brief account is given on the trends in the oyster fisheries. The present fishery centers almost exclusively around the fresh market. In recent years, the demand for oysters on the East Coast of the United States has had some impact on production in the Pacific Northwest. The demands from both the East and West coasts have, in part, created a situation in which oysters may be harvested at an earlier age to accommodate the market. To complicate the situation further, the recent EI Nino may have caused significant setbacks in the harvest of Pacific oysters from coastal bays such as Willapa Bay in Washington State, historically one of the most productive bays on the west coast. Problems and situations related to this climatic phenomenon will be discussed. Remote setting of eyed larvae for the West Coast is a reality and adjustments by many of the oyster growers are being made to accommodate this latest technique for securing Pacific oyster seed. The potential of remote setting has essentially taken away most of the guess work related to securing adequate seed for growing in most of the areas along the Pacific coast of the United States.

Chew, K. K. (1988)

Oyster aquaculture in the Pacific Northwest. IN Keller, S. (ed.) Proceedings of the 4th Alaska Aquaculture Conference, November 18-21, 1987, Sitka, Alaska, USA Univ. Alaska Sea Grant Program, Fairbanks, AK (USA) Alaska Sea Grant Report, No. 88-4, p. 67-75

The main area for oyster production on the West Coast is in the state of Washington, USA. The two principal species grown in the Pacific Northwest are the Japanese or Pacific oyster (*Crassostrea gigas*) and the smaller native or Olympia oyster (*Ostrea lurida*). There was good oyster production in the 1950s because of large shipments of the Japanese seed. Production went into a slump during the 1970s and there is a general increase now in the 1980s. During the 1960s and 1970s Maryland, which borders the Chesapeake Bay, was the number one oyster growing state, Louisiana along the Gulf of Mexico was the second largest, and Washington in the Pacific Northwest was third. As of 1986, the American oyster (*Crassostrea virginica*) fishery in the Chesapeake Bay area has fallen below Louisiana and Washington. Pollution and disease have contributed to the demise of the oyster fishery not only in Chesapeake Bay but Delaware Bay also. As a result of the decline of the East Coast oyster fishery, the Pacific coast oyster producers are beginning to ship oysters to the eastern seaboard to fill the market demands. Because of these demands the West Coast production scheme has also changed as the growers harvest their crops earlier instead of waiting 3-4 years to let the oyster get larger. There is good potential for an oyster industry in Alaska.

Chew, K. K. (1988)

Littleneck clam aquaculture in the Pacific Northwest

IN Keller, S. (ed.) Proceedings of the 4th Alaska Aquaculture Conference, November 18-21, 1987, Sitka, Alaska, USA Univ. Alaska Sea Grant Program, Fairbanks, AK (USA) Alaska Sea Grant Report, No. 88-4, pp. 99-102, 1988

The Manila 1ittleneck clam (*Venerupis japonica*) is having a major impact on commercial clam harvest in Washington State, USA. It started out slowly in the 1950s and has built to a production level of over four

million pounds by 1986. The native littleneck clam (*Venerupis staminea*) production dropped below the Manila clam in the mid-1970s. In Puget Sound, Washington, clam growers have in the past used the Japanese technique for enhancing the settlement of 1ittleneck clams by staking brush in the intertidal area where natural sets could be caught. This was not found to be a reliable way to catch seed.

Chew, K. K. (1996)

Update on the Pacific Oyster Mortalities in the Pacific Northwest
Aquaculture Magazine 22: 87

The status of Pacific oyster (*Crassostrea gigas*) mortality in Puget Sound and other Pacific Northwest areas is reviewed. Mortality issues have been a concern since the late 1940s when pulp mill effluent caused declining oyster populations near outfalls. More recent mass mortalities in cultivated oyster beds in the 1980s have been blamed on stress induced mortality via reproductive failure and on pathogenic bacteria. Studies of these hypotheses have been inconclusive. Growers have reported that extensive mortalities are occurring earlier than was previously reported and have spread to areas that previously had no significant problems. The Pacific Coast Oyster Growers Association is sponsoring a project to better understand the mortality patterns and possible associated environmental parameters.

Chew, K. K. (1997)

Status of Shellfish Culture in Alaska
Aquaculture Magazine 23: 79

Shellfish aquaculture is emerging as an important industry in coastal areas of Alaska. Aquaculture development will require appropriate political moves and reform of state regulation since competition with commercial fisheries of wild species is a contentious issue in Alaska. Shellfish species that are currently being cultured or are candidates for culture in Alaska include Pacific oysters, mussels, little neck clams, butter clams, rock scallop, and geoduck clams. The current status and future prospects for each of these species is summarized, based on information provided by the state and by a Univ. of Alaska Fairbanks aquaculture specialist. Other issues that are reviewed include development and implementation of hatchery technology in Alaska, the occurrence of marine toxins in shellfish, regulatory reform, and growth in the Alaska Shellfish Growers Assn.

Chew, K. K. (1998)
Update on the green crab's movement up the Pacific coast of North America
Aquaculture Magazine 24: 89-90

It was considered a given that the Green crab (*Carcinus maenus*) would eventually make its way across the Oregon border to Washington State. Its northward march from the first sighting in San Francisco Bay in 1989 ended in Coos Bay, Oregon in 1997 (see recent article titled Green crab Alert on the Pacific Coast, Aquaculture Magazine, March/April, 1998, page 96). Concern was expressed and a special workshop was organized by the Oregon and Washington Sea Grant Programs on February 9-10, 1998 in Vancouver, WA, where there was a discussion on the Green crab's movement and potential impact on the Pacific Northwest. At the time several of the researchers noted that it would just be a matter of time before this predatory species would probably show up in the State of Washington, and apparently it might have! Although alive specimen was not found, scientists have found inch-long molt, or shed shell, of a male Green crab in Willapa Bay, located in the southwest corner of the State of Washington. This is a small signal that could mean a huge problem for the Washington shellfish industry, as over 50% of e state's production of Pacific oysters (Crassostrea gigas) come from this important bay. The average annual production over the past five years for the State of Washington is over 8 million pounds (meat weight only).

Chislick, G. (1981)
The British Columbia Oyster Industry -- long 1ine and raft string culture
Journal of Shellfish Research 1 (Abstract)

Cochrane, M. (2001)

Dairy waste impacts on tribal shellfish: The cow to clam connection

Aquaculture 2001, World Aquaculture Society, LSU, Baton Rouge, LA.

The Northwest Indian College and the Lummi Nation have been involved in water quality monitoring of the Nooksack River watershed in Whatcom County Washington lover the last three years with a project that has studied non-point source pollution responsible for the loss of over 40% of tribal commercial shellfish harvest sites. The study has involved three years of extensive fecal co1iform monitoring as well as tidal drift determinations to quantify the effects of dairy nutrient management on Tribal shellfish beds. This presentation discusses the results of fecal co1iform monitoring as they apply to the development, integration, and expansion of a watershed wide monitoring plan, pub1ic and agency participation in the development and implementation of the monitoring plan, point and non-point source identification, and fecal coliform transportation dynamics. It will also discuss the problems related to identifying a IICOW to c1amr connection. The fecal co1iform problem described appears to be mostly a problem of adjacent regulatory standards. It takes a fecal co1iform count of over 200 to violate Class A water quality standards at the mouth of the Nooksack River. It only takes a fecal coliform count of 44 to violate Shellfish growing water standards three miles downstream. Therefore, while the mouth of the Nooksack River can be in comp1iance due to improved dairy management practices, water quality violations that result in closures can sti11 occur on Tribal shellfish beds. This presentation will be of special interest to those individuals who would like to know more about the role that a Federally recognized Treaty Tribe could play in focusing attention and resources on water quality issues.

Connolly, T. J. (1995)

Archaeological evidence far a former bay at seaside, Oregon.
Quaternary Research (Orlando) 43: 362-369

Conte, F. S. (1984)

Economic impact of paralytic shellfish poison on the oyster industry in the Pacific
United States.

Aquaculture 39: 331-343

The oyster industry on the west coast of the continental United States extends from Morro Bay, California, north to and including Puget Sound, Washington. Periodic outbreaks of paralytic shellfish poison caused by dinoflagellates of the genus *Gonyaulax* have resulted in reported symptoms and even death from consumption of contaminated shellfish. Although no deaths and only two reported outbreaks have affected commercial oysters, the fear of paralytic shellfish poison results in seasonal depressions in oyster markets, even when outbreaks are not present. This study reviews the economic impact of paralytic shellfish poisoning, the factors that increase the impact beyond the normal response, and requirements necessary to lessen the impact on the oyster industry.

Cook, A. E., J. A. Shaffer, B. R. Dumbauld, & B. E. Kauffman (1998)

Olympia oyster stock rebuilding strategy for Washington State

Journal of Shellfish Research 17 (Abstract)

The Olympia oyster (*Ostrea lurida*) is native to the state of Washington. Once the basis for a thriving, state wide oyster industry, its numbers were drastically reduced by the mid 19401s. Water quality and overharvesting are thought to be the major factors in its near demise. The Pacific oyster (*Crassostrea gigas*) has since replaced the Olympia oyster in Washington and world markets. The Washington Department of Fish and Wildlife is now developing an Olympia oyster stock rebuilding strategy. The goal of the strategy, to restore the Olympia oyster within its historical geographic range, is quite simple, but offers many challenges. Key elements of the draft strategy include historical and current distribution of, habitat and water quality impacts to interspecies interactions with, and Tribal co-management of the Olympia oyster. Partnering with local commercial shellfish interests and the general public provides new opportunities for

restoring the native oyster, and is a top priority for state management of this species. Suggested priorities for implementation of the strategy will be discussed.

Cook, A. E., J. A. Shaffer, B. R. Dumbauld, & B. E. Kauffman (2000)
A plan for rebuilding stocks of Olympia oysters *Ostreola conchaphila*, Carpenter 1857 in Washington State.
Journal of Shellfish Research 19: 409-412

The Olympia oyster (*Ostreola conchaphila*) is native to the state of Washington. Once the basis for a thriving, statewide oyster industry, its numbers were drastically reduced by the mid 1940s. Water quality and overharvesting are thought to be the major factors causing its near demise. The Pacific oyster (*Crassostrea gigas*) has since replaced the Olympia oyster in Washington and world markets. Concern over the much reduced status of the stocks of native oysters led the Washington Department of Fish and Wildlife to develop a plan to rebuild them. The goal of the strategy, to restore the Olympia oyster within its historical range, is quite simple, but offers many challenges. Key elements of the draft strategy presented here include a description of the historical and current distribution, habitat requirements, and current problems associated with restoring stocks of the native oyster in Washington State. Partnering with Tribal co-managers, local commercial shellfish interests, and the general public provides new opportunities for restoring the Olympia oyster, a top priority for state management of this species. Suggested priorities for strategy implementation are also discussed.

Couch, D. & T. J. Hassler (1989)

Species Profiles. Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest). Olympic Oyster
Fish and Wildlife Service, Washington, DC; Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab. Report No.: FWS-82/11.124 Dec 89 pp16.

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal aquatic species. They are designed to assist in environmental impact assessments. Olympia oysters initially spawn as males then alternate their functional genders. Spawning begins at ljr-16 C and occurs from spring to fall. After a short planktonic stage, larvae attach to the substrate. Olympia oysters thrive at salinities of 25 ppt or above; they are killed by freezing temperatures. Olympia oysters once supported large sustenance and commercial fisheries. Olympia oysters have not returned to pre-exploitation population levels which declined because of pollution and loss of habitat.

Cox, R. K. (1984)
Preliminary report on deepwater culture of *Crassostrea gigas* Thunberg at seven sites in British Columbia.
Journal of Shellfish Research 4: 109

Seven coastal sites in British Columbia were assessed for deep-water culture of the Pacific oyster *Crassostrea gigas* using a variety of hanging culture techniques. Seed oysters from the 1980 Pendrell Sound set (mean shell length = 8 mm) were suspended at experimental sites from February to July 1981. Additional oysters were suspended at one site in October 1981 using beach-hardened, 1980 Pendrell oysters. A total of 14,000 grow-out strings were placed at the 7 sites. Shell growth, fouling, condition index, temperature, and salinity were monitored from July 1981 to August 1983. Shell growth averaged 60 mm in 1981 and 30 min in 1982. Shell length at harvest averaged 108 mm. Condition indexes at all sites were high in mature oysters and generally higher than values reported for bottom-cultured oysters. Condition indexes showed large variations. The blue mussel *Mytilus edulis* was the predominant fouling organism at all sites. A further 45 species of fouling organisms were identified. Fouling increased flotation requirements significantly at some sites and reduced growth rate.

Cox, R. K. (1989)
The Japanese oyster drill, *Ceratostoma inoratum*, in British Columbia

Journal of Shellfish Research 8: 319

The Japanese oyster dri11, *Ceratostoma inoratum* was introduced into British Columbia along with early imports of the Japanese oyster, *Crassostrea gigas.* By the 1930's it had become well established at a number of locations within the Strait of Georgia. Currently, 6 areas of the B.C. coast are under restrictions that prohibit movement of shellstock and equipment to prevent the spread of the drill. In order to provide more detailed information a comprehensive survey of one restricted area, Comox Harbour, was undertaken in May, 1988. Results showed that adult drills and egg clusters were present in high numbers but distribution was strongly clumped. The observed aggregated pattern was 1ikely associated with egg laying. Survey data indicated the continuing necessity of regulatory control and suggest operational constraints for shellstock movement.

Cross, S. F. & B. C. Kingzett (1992)
Biophysical criteria for shellfish culture in British Columbia: A site capability evaluation system
British Columbia. Aquaculture and Commercial Fisheries Branch. Courtenay Corp pp62

This document presents a set of shellfish biophysical criteria that are appropriate for a general evaluation of the capability of a potential beach or off-bottom (deep-water) site for the culture of Pacific oyster. Japanese scallop and Manila clam. The report discusses the environmental variables important in the selection of a site for the biological requirements of each species. A numerical criteria system is developed that provides the basis upon which areas can be categorized for probable culture capability using tolerances and optima for each species. An example of how the system may be used in an evaluation of site capability is presented and the limitations and subjectivity of the proposed

Da Silva, A. S. (1995)
The development of a GIS based site suitability model for suspended oyster culture in Maeres Island, Clayquot Sound, British Columbia (*Crassostrea gigas*).
Dissertations International V. 34/04 of Masters. p. 1471 pp116

The management of coastal resources in B.C. has become a difficult task for resource managers as the pressure from diverse resource uses increases and availab1e coastal areas decrease. Concerns about the identification and protection of suitable areas for aquaculture activities have been recognized, and the allocation of such areas has been considered as a vital step for the growth and competitiveness of the aquaculture industry. A comprehensive and practical site selection approach would help the industry and resource managers find biophysically, economically and socially suitable sites. Habitat Suitability Index (HSI) and Culture Suitability Index (CSI) models reflecting habitat and economic factors have been applied for aquaculture site selection in B.C. One specific objective of the study is to improve HSI-based models by adding a novel socio-political component. The improved model was named a Site Suitability Index (SSI) and consists of biophysic, economic and socio-political variables related to the suspended oyster culture of *Crassostrea gigas* Thunberg. The model accounts for sociopolitical factors that could influence or that could be influenced by suspended oyster culture operations. Another objective was to test the feasibility of inserting the SSI model into a Geographic Information System (GIS) to generate Suitability Index results in a spatial format. Pre1iminary results of the final model coverage show that if comprehensive data sets for relevant resource industries and for socio-political values are available, a complete and single model can be constructed to facilitate sitting studies and proactive planning for aquaculture by providing a selection of optimum habitats and non-conflict zones.

Davis, J. (1998)
Bivalve aquaculture in the pacific northwest: Current farming methods and research activities. IN Barber, B (ed) Northeast Aquaculture Conf. & Expo. Proceedings s of the First Annual Northeast Aquaculture Conference and Exposition , Rockport, Maine (USA) 18-19 Nov 1998.

Bivalve aquaculture in the Pacific Northwest is focused on a variety of species which take into account the variety of habitats found there, and the economics of rearing bivalves in relatively cool and productive northeast Pacific waters. A dichotomy of farming methods exists with suspended mussel and oyster culture

making up only a small percentage of the farmed product, as intertidal clam and oyster culture dominate the focus of activity. Specifically, hatchery reared Mediterranean mussels (*Mytilus galloprovincialis*), Pacific oysters (*Crassostrea gigas*) and European flat oysters (*Ostrea edulis*) are currently reared using standard suspended culture methods from rafts and surface long 1ines. Intertidal oyster culture is dominated by Pacific oysters, although Kumomoto oyster (*C. sikamea*) culture is practiced where intertidal conditions are suitable. On-bottom culture, intertidal longline, on-bottom longline and rack and bag culture are all current methods in use. Intertidal clam culture is focused on the Manila clam (*Tapes philippinarum*) and the geoduck clam (*Panope abrupta*). Manila clam culture is focused on harvesting clams originating from sets produced from naturalized populations and enhancement of beaches with gravel and other substrates using hatchery reared seed. Geoduck culture is rapidly evolving and uti1izes intensive, high density culture practices and hatchery reared seed, exclusively. Finally, scallop culture (*Patinopectin caurinus, P. yessoensis*, and *Crassodoma giganteus*) are in their infancy with respect to the rest of the shellfish industry and are currently 1imited by bottlenecks in hatchery production.

Davis, J. P. (1989)
Growth rate of sibling diploid and triploid oysters, *Crassostrea gigas*
Journal of Shellfish Research. 8: 319

The rate of growth was compared between diploid and triploid Pacific oysters (*Crassostrea gigas*) over 2 years. Sibling diploid and triploid oysters were produced in the hatchery and grown in suspension culture in Quilcene Bay and Westcott Bay, Washington. Internal cavity volume, dry weight and wet weight was measured in individual oysters at approximate 3 month intervals. At both sites, triploids outperformed diploids after 24 months. In both bays, the growth rate of triploids exceeded that of diploids during the spring and summer months. At Quilcene Bay, a productive site with peak water temperatures exceeding 20 degree C in July and August, the growth rate of triploids relative to diploids was greater than in Westcott Bay, a productive but cooler site where peak water temperatures only reach 16 degree C. This pattern of growth is discussed with respect to energetic considerations relating to the observation that oysters generally spawn every year at Quilcene Bay. In Westcott Bay, oysters develop an extensive gonad, generally do not spawn and resorb gametes during the fall and winter months.

Davis, J. P. (1989)
Costs of reproduction in Pacific oysters
Journal of Shellfish Research 8: 431-432

Research was conducted to examine somatic growth over three years in hatchery populations of Pacific oysters (*Crassostrea gigas*) transplanted into two grow-out environments in Washington state differing significantly in total organic seston load and temperature during the period of gametogenesis (spring and early summer). Hatchery produced Pacific oysters were placed in Westcott Bay and lower Quilcene Bay as juveniles. Age and size specific changes in reproductive output and glycogen storage patterns relative to somatic growth were measured. Both somatic and germinal production were reduced in Quilcene Bay transplants relative to Westcott Bay oysters. In Westcott Bay, somatic growth in tagged oysters continued during the period of gametogenesis, whereas in Quilcene Bay oysters, shell growth slowed or ceased during the late spring coincident with peak gametogenic activity. Glycogen content in Qui1cene Bay oysters at peak gametogenesis was significantly lower than glycogen content in Westcott Bay oysters at peak gametogenesis. Physiological rate changes in oysters were measured in the laboratory over the course of an artificial conditioning period where temperature and food levels were controlled. Results are discussed with reference to the integrated growth response (i.e. somatic and germinal production) during gametogenesis in Pacific oysters.

De Grave, S. S. J. Moore, & G. Burnell.
Changes in macrofauna associated with intertidal oyster, *Crassostrea gigas* (Thunberg) culture.
Journal of Shellfish Research 17: 1137-1142.

Decho, A. W. & S. N. Luoma (1991)
Time-courses in the retention of food material in the bivalves *Potamocorbula amurensis* and *Macoma balthica* – significance to the absorption of carbon and chromium-
Marine Ecology Progress 78: 303-314

Time courses for ingestion, retention and release via feces of microbial food was investigated using 2 bivalves with different feeding strategies, *Potamocorbula amurensis* and *Macoma balthica*. The results showed 2 pathways for the uptake of food material in these clams. The first is represented by an initial label pulse in the feces. The second pathway operates over longer time periods. Inert Cr-51-labeled beads were used to determine time frames for these pathways. The first pathway, involving extracellular digestion and intestinal uptake, is relatively inefficient in the digestion of bacterial cells by P. amurensis but more efficient in *M. balthica*. The second pathway, involving intracellular digestion within the digestive gland of both clams, was highly efficient in absorbing bacterial carbon, and was responsible for most chromium uptake. Differences in the overall retention of microbial Cr-51 and c-14 relate not to gut-passage times but to the processing and release strategies of the food material by these 2 clams.

Dickson, F. (1992)
Aquaculture conflicts in Pacific Canada. Shellfish and marine plant aquaculture in
British Columbia -- conflicts and solutions
World Aquaculture 23: 28-29

The shellfish aquaculture industry in British Columbia is dominated by production of Pacific oysters (*Crassostrea gigas*). There is growing participation in intertidal manila clam (*Tapes phillipinarum*) culture due to diminishing supplies of wild clams and in development of Japanese scallop (*Patinopecten yessoensis*) off-bottom culture. Marine plant culture continues to develop slowly with recent interest shown in culturing Nori (*Porphyra* spp). There are a number of conflicts arising with the development of shellfish and marine plant aquaculture in British Columbia. Conflicts, or perceived conflicts with other resource users, have been greatly exacerbated by the rapid expansion of salmon culture in British Columbia in the last five years. The environmental concerns, both real and imagined, associated with salmon have 'tainted' any form of off-bottom aquaculture such as scallops and marine plants. These problems are accentuated where other resource use is high. Siting conflicts due to floating culture operations, such as scallop and nori farmers, include displacement of other site users (recreational boaters, commercial and sport fishermen, and commercial marine operators), upland owners who have aesthetic concerns, water access rights, and native Indian concerns about loss of aboriginal rights. Bottom culture operators, particularly oyster and clam growers, face siting conflicts primarily with commercial and recreational fishermen who wish to harvest wild clams on the same beaches.

Dickson, F.V., R. K. Cox & N. Bourne (1991)
Shellfish and marine plant aquaculture in British Columbia. Conflicts and solutions
Journal of Shellfish Research 10: 235

The shellfish aquaculture industry in British Columbia is dominated by production of Pacific oysters (*Crassostrea gigas*). There is growing participation in intertidal Manila clam (*Tapes philippinarum*) culture due to diminishing supplies of wild clams and in development of Japanese scallop (*Patinopecten yessoensis*) off-bottom culture. Marine plant culture continues to develop slowly with recent interest shown in culturing nori (*Porphyra* spp.). Development of these culture operations has been hampered by conflicts particularly for clam culturists, and for scallop and nori farmers. Joint government programs have been developed to provide special reserves for recreational clam fishermen. A co-operative federal/provincial government program is being finalized allowing for structured development of clam culture to complement the wild clam fishery. Coastal Resources Information Studies initiated by the government of British Columbia have been completed for five zones in the province. The maps identify conflict areas such as critical fish habitats, underwater archaeological sites, parks, Indian Reserves, anchorages, navigation channels and important fishing grounds where initiation of aquaculture activities wi11 be 1imited or prohibited.

Donaldson, J. (1981)
Hatchery rearing of the Olympia oyster *Ostrea lurida*.

Journal of Shellfish Research 1: 131

The Olympia oyster (*0. lurida*) industry was once a thriving industry on the western coast of North America and especially in the state of Washington. Depleted populations, lack of recruitment, the Japanese oyster drill, and the flatworm each played a role in the decline of the now decimated populations. Hatchery-grown seed is the only apparent method to restore beds to production levels. Hatchery techniques are described for rearing this species from the brooding larval phase through to setting size. Three groups of brood stock in different quantities were maintained in a closed system at different times of the year to determine the desirable number of adults needed for hatchery production. Larval-rearing techniques are described which resulted in growth periods of 15 to 23 days from 1iberation to setting. Setting was successful; however, a high mortality occurred in the first 2 weeks after setting for all groups.

Donaldson, J. (1988)

Overview of an operating oyster hatchery. IN Keller, S. (ed.) Proceedings of the 4th Alaska Aquaculture Conference, November 18-21, 1987, Sitka, Alaska, USA Univ. Alaska Sea Grant Program, Fairbanks, AK (USA) Alaska Sea Grant Report, No. 88-4, pp. 77-81

Coast Oyster Company has the largest hatchery in the world with four remote setting sites: Quilcene, Willapa Bay and southern Puget Sound in Washington; and Humboldt Bay, California, USA. Production, combined with one other hatchery in Oregon, supplies 70 to 80% of all the oyster needs on the West Coast, from California to British Columbia, Canada. Coast Oyster Company has 20,000 acres of primarily intertidal oyster ground. Most of that is owned, and some is leased (by subtidal lease) from the Department of Natural Resources. Only 2,500 to 3,000 acres, or 15%, is used to cultivate and propagate oysters. A lot of that ground could be brought into production by using alternative methods, but a good part of it is held for buffer. The hatchery system started in 1974 to supply Pacific oyster seed on a regular basis.

Donaldson, J. (1998)
Basic methods of seed production Clam and Oyster Farming
Sea Grant Program Report Number: WSG-WO-98-01 p. 11-12

There are two basic types of molluscan larval hatcheries. One is a seed production facility that produces relatively small numbers of larvae, usually less than a bi 11 ion total of all species combined, and concentrates on production of single seed of oysters, clams or scallops. The other is a larval production facility that produces large numbers of larvae and 1ittle or no single seed, but sells larvae extensively to others who set and grow seed to plantable size. All hatchery systems for algal culture, broodstock conditioning, larval rearing and larval setting can easily be adapted to suit the culture of any molluscan species and the form or product desired. The following is a brief general description of the systems currently employed in the industry for both Manila clams and single Pacific oysters, the two most dominant species presently cultured in the Pacific Northwest.

Dortch, Q., R. Robichaux, S. Pool, O. Milsted, G. Mire, N. N. Rabalais, T. M. Soniat, G. A. Fryxel1, R. E. Turner, & M. L. Parsons (1997)
Abundance and vertical flux of *Pseudo-nitzschia* in the northern Gulf of Mexico
Marine Ecology Progress Series 146: 249-264

Many species of the ubiquitous pennate diatom genus *Pseudo-nitzschia* have recently been discovered to produce domoic acid, a potent neurotoxin which causes Amnesic Shellfish Poisoning (ASP). Pseudo-nitzschia spp. were extremely abundant (up to 10(8) cells 1 (-1); present in 67% of 2195 samples) from 1990 to 1994 on the Louisiana and Texas, USA, continental shelves and moderately abundant (up to 10(5) cells 1 (-1); present in 18% of 192 samples) over oyster beds in the Terrebonne Bay estuary in Louisiana in 1993 and 1994. On the shelf there was a strong seasonal cycle with maxima every spring for 5 yr and sometimes in the fall, which were probably related to river flow, water column stabi1ity, and nutrient avai1abi1ity. In contrast, in the estuary there was no apparent seasonal cycle in abundance, but the time

series of data is relatively short and the environment highly variable. At one site on the shelf, where sediment traps were deployed from spring to fall and sampled at frequent intervals in both 1990 and 1991, approximately 50% of the Pseudo-nitzschia spp. cells present in the water sank into sediment traps. Pseudo-nitzschia spp. were also abundant in surficial sediments. The species of Pseudo-nitzschia present, during this study were not routinely identified with the methods employed. However, toxin-producing *P. mu1tiseries* has been identified previously from Galveston Bay, Texas, and cells from a bloom on the shelf in June 1993 were identified by scanning electron microscopy as *P. pseudode1icatissima*, which is sometimes toxic. Although there have been no known outbreaks of ASP in this area, historical data suggests that *Pseudo-nitzschia* spp, abundance may have increased on the shelf since the 1950s. It is hypothesized that the increase is due to doub1ing of the nutrient loading from the Mississippi and Atchafa1aya rivers and increased eutrophication on the shelf.

Doty, D. C., D. A. Armstrong, & B. R. Dumbauld (1989)

The benefits of improved refuge associated with commercial oyster culture for the survival of juvenile Dungeness crab

Journal of Shellfish Research 8: 319-320

Ground culture of the Pacific oyster (*Crassostrea gigas*) in Washington State estuaries such as Willapa Bay and Grays Harbor appears to benefit the Dungeness crab (*Cancer magister*) resource, and possibly the fishery, by providing critical habitat for 0+ crab newly settled to the intertidal zone of such estuaries. However, culture practices over the last 25 years have included the use of an insecticide Sevin sprayed to control burrowing shrimp whose activities inhibit oyster survival and growth. There is growing evidence that crab loss during treatment with Sevin are substantially replaced during subsequent years of oyster culture by virtue of an increase in optimal shell habitat for 0+ crab. Measurements of intertidal 0+ crab density suggest that shell habitat supports higher densities (2-16 crab/m super (2)) of crab than does eelgrass (0-3 crab/m super (2)) or open ground. In addition, growout beds with 2-3 year old oyster support higher densities of crab than do newly planted seed beds.

Doui11et P. & C. J. Langdon (1993)

Effects of marine bacteria on the culture of axenic oyster *Crassostrea gigas* (Thunberg) larvae.

Biological Bulletin (Woods Hole) 184: 6-51

Bacteria-free oyster larvae (*Crassostrea gigas*) were cultured under aseptic conditions; they were fed axenic algae (*Isochrysis galbana*), and the medium was inoculated with isolated strains of marine bacteria. Twenty-one bacterial strains were tested, and most were detrimental to larval survival and growth. However, additions of strain CA2 consistently enhanced larval survival (21-22%) and growth (16-21%) in comparison with control cultures that were fed only algae. Size-frequency distributions of populations of larvae cultured for 10 days on axenic algae were skewed due to the poor growth of many individuals, whereas size-frequencies from populations of larvae fed axenic algae supplemented with CA2 bacteria were distributed normally. Strain CA2 may therefore make a nutritional contribution to the growth of oyster larvae. *I. galbana* did not grow under the 1ight intensities used for larval culture; thus the improvement in larval growth cannot be attributed to bacterial enhancement of algal growth and, consequently, food availability. Naturally occurring microflora from Yaquina Bay, Oregon, (USA) depressed survival or growth of larvae-fed 1ive algae.

Downing, S. L. (1988)

Comparing adult performance of diploid and triploid monospecific and interspecific *Crassostrea* hybrids

Journal of Shellfish Research 7: 549

A complete factorial design was used in 1986 to produce diploid and triploid monospecific and interspecific hybrids between *Crassostrea gigas* and *C. rivularis*. Triploid percentages of spat and adults were not significantly different except for the monospecific C. rivularis cross, in which they rose form 55 to 77%. While growing on long lines in California or suspended off the dock, all the crosses grew equally.

However, bottom culture favored those crosses containing at least 2 chromosomal sets from *C. rivularis*. Triploids devoted less effort to reproduction and consequently had significantly higher glycogen levels than diploids during gametogenesis. So far, the sex ratios have been different among the crosses: at one extreme, *C. rivularis* has yielded 100% males while the diploid *C. gigas* has been 55% female and 45% male. The hybrids have been intermediate with the triploid *C. rivularis* by *C. gigas* being 85% male and the diploid cross lower at 78% male.

Drinkwaard, A. C. (1998)

lntroductions and developments of oysters in the North Sea area: A review.
Helgolaender Meeresuntersuchungen 52: 301-308

To replenish the exploited native stocks of *Ostrea edulis*, imports from almost all European coasts have arrived in the North Sea, particularly in the Dutch Oosterschelde estuary. The American oyster *Crassostrea virginica* and the Portuguese oyster *C. angulata* have also been imported into the North Sea several times. However, only the introductions of various genetic strains of the Pacific oyster *C. gigas* have been of lasting success. Spat from British Columbia (Canada) was first imported to the Oosterschelde in 1964. First spatfalls in this area took place in the warm summers of 1975 and 1976. Further larval outbursts occurred in 1982 and 1989, and good settlements took place on culture plots as well as along the dikes of the Oosterschelde. Since 1977 no more cupped oysters have been imported from overseas. The population maintained itself and was able to spread in a northern direction along the Dutch North Sea coast. In Britain, hatchery-produced *C. gigas* were transferred to several sites, in the 1970s including the British North Sea coast. Here, occurrence in the wild seems to be rather 1imited up to now. Into the German Wadden Sea, *C. gigas* larvae and spat from a Scottish hatchery have been introduced since 1971, as were medium-sized oysters from a variety of European sources in the 1980s. Strong spatfalls on intertidal mussel beds in the northern German Wadden Sea occurred in 1991 and 1994. For the introductions of *C. gigas* along the west European coasts, precautionary measures to minimize unintentional transfers of associated organisms, as recommended by the ICES Code of Practice in 1994, came too late.

Drum A. S; T. L. Siebens, E. A. Crecelius, & R. A. Elston (1993)
Domoic acid in the Pacific razor clam *Siliqua patula* (Dixon, 1789).
Journal of Shellfish Research 12: 443-450

In the fall of 1991 domoic acid was discovered in coastal Pacific razor clams *Siliqua patula* (Dixon, 1789) in Washington and Oregon states at levels higher than acceptable for safe human consumption, thereby forcing a closure of the recreational harvest. Tissue distribution data indicated the clams maintained these elevated levels from fall through early summer of 1992 in the edible muscular tissues (mantle, siphon, adductor muscles, and muscular foot) with concentrations of toxin averaging from 23.3-50.7 mu-g/g. The concentration in the non-edible tissues (gill, digestive gland, gonad, and siphon tip) ranged from trace amounts to 8.4 mu-g/g. Clams that were dissected into edible and non edible pooled portions contained 36.4 t 22.6 and 13.7 +- 7.6 mu-g/g, respectively. On an additional sampling date, clams were sampled fresh or were frozen whole before sampling. The concentration in the edible portion of the fresh clams averaged 16.8 +- 11.6 mu-g/g, while the blood and dissection fluids contained only trace amounts of toxin. The domoic acid concentration of the frozen edible portion averaged 12.6 +- 6.9 mu-g/g with meltwater levels reaching 4.2 mu-g/g and the dissection fluid containing up to 10.0 mu-g/g. Clams collected in December 1991 with elevated levels of toxin (47.9 +- 12.7 mu-g/g) that were held on Strait of Juan de Fuca seawater for three months maintained this level of contamination (44.3 +- 19.8 mu-g/g). Razor clams from Alaska held under identical conditions during this time period did not contain detectable levels of toxin. Razor clam tissues collected in 1985, 1990, and the summer of 1991 revealed only trace levels of toxin.

Dumbauld, B. R., D. A. Armstrong, D. R. Gunderson, & A. R. Black (1988)
The importance of intertidal shell as nursery habitat for young-of-the-year Dungeness crab in Grays Harbor, Washington
Journal of Shellfish Research 7: 115

Studies of juvenile Dungeness crab (*Cancer magister*) ecology and population dynamics in Grays Harbor (1983-85) show that intertidal areas, particularly those with an overlying shell substrate, playa critical role in the survival of newly recruited 0+ crab. Optimal habitat in Grays Harbor consists of shell deposits of the eastern softshell clam *Mya arenaria* and live commercial oyster beds (*Crassostrea gigas*). Although initial settlement densities in May of 1983 were as high as 362 crabs/m super (2), numbers fell to much lower but relatively stable levels of 15-20 crabs/m super (2) in June and 5-10 crabs/m super (2) in July and August of all 3 years. Even at these densities, population estimates were much higher for 0+ crabs in the intertidal subtidal areas where 1+ juveniles are prevalent. Crabs greater than 40 mm carapace width were rarely found in the intertidal indicating that they 1) physically outgrow the shell habitat; 2) leave due to agonistic behavior and displacement and/or; 3) can no longer find suitable prey. This exodus from the intertidal to the subtidal in late summer may be the source of distinct increases in subtidal 0+ populations in September and October.

Dumbauld B. R, D. A. Armstrong, K. L. Feldman, & J. R. Skalski (1996)
Field experiments on thalassinid shrimp control for oyster culture in Washington State.
Journal of Shellfish Research 15: 487

Dumbauld B. R, D. A. Armstrong, & J. R. Skalski (1997)

Efficacy of the pesticide capbaryl for thalassinid shrimp control in Washington State oyster (*Crassostrea gigas*, Thunberg, 1793) aquaculture.
Journal of Shellfish Research 16: 503-518

The pesticide carbaryl is applied to intertidal oyster beds in Washington State to control burrowing thalassinid shrimp. We studied efficacy and found a significant dose response relationship for both ghost shrimp, *Neotrypaea californiensis*, and mud shrimp, *Upogebia pugettensis*. A threshold response was observed, suggesting that reducing the commercial application rate below 5.6 kg ha-1 would decrease efficacy and increase variability of resulting kill, particularly for *Upogebia*. Exposure time (time between application at low tide and flood tide) significantly affected the relationship, suggesting that even lower rates (e.g., 2.5 kg ha-l) could be effective when exposure time is sufficiently long (> 2-3 h). Typical oyster beds are exposed from 2 to 6 h during minus spring tides. Carbaryl persisted slightly longer (40-45 days) in muddier substrate where *Upogebia* is present than in the well-drained sand inhabited by *Neotrypaea*. However, given rapid initial decline after application (1 ppm in 24 h), reducing application rate would not greatly influence persistence at levels toxic to nontarget species. This study suggests that growers should be aware of the species of shrimp present on individual oyster beds, because *Neotrypaea* causes much higher initial oyster seed mortality than does *Upogebia*. No oysters survived beyond 300 days on untreated or treated plots where *Neotrypaea* was present. Because of seasonal recruitment of postlarvae to the estuary in late summer and early autumn, *Neotrypaea* is also able to reinfest treated plots immediately, suggesting that long-term control for this species is more problematic.

Dumbauld, B.R., K. M. Brooks, & M. H. Posey (2001)

Response of an estuarine benthic community to application of the pesticide carbaryl and cultivation of Pacific oysters (*Crassostrea gigas*) in Willapa Bay, Washington
Marine Pollution Bulletin 42: 826-844

Oyster culture operations on the West coast of North America have developed into complete farming operations for the introduced Japanese oyster, *Crassostrea gigas*, which now covers vast areas of the intertidal landscape, particularly in Washington State where the pesticide carbaryl has also been used to control burrowing thalassinid shrimp for more than 30 years. Field experiments were conducted to examine the effects of these habitat modifications on the benthic community in Willapa, Bay Washington where 50% of the state's oyster production occurs. Results indicated that the primary long-term effect of carbaryl application was removal of the two species of thalassinid shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*), which dominated the community at the start of the experiment and clearly influenced community composition themselves. Small peracarid crustaceans like the amphipods *Corophium acherusicum* and *Eohaustorius estuarius* experienced the most significant short-term mortalities, but

generally recruited back to treated sites within 3 months, and were often more abundant on treated than untreated sites 1 year after carbaryl application. Results for molluscs were mixed, with no significant effect on *Macoma* spp, but a significant effect on the commensal clam *Crytomya californica* and mixed results for the cockle *Clinocardium nutalli*. Polychaetes were the least susceptible to carbaryl and with the exception of a short-term effect on oligochaetes, no significant negative effects were observed. The addition of oysters did not affect the infaunal community in this study, however greater abundance of epifaunal organisms like mussels, scaleworms, and the amphipod *Amphithoe valida*, which builds tubes in algae attached to shells, was observed. Carbaryl, which is currently applied to roughly 242 ha (less than 6% of the intertidal) in Willapa Bay on an annual basis, has a variable but relatively short-term effect on the benthic community, which should be viewed in the context of other oyster culture operations 1ike the addition of oysters themselves to a community often dominated by burrowing thalassinid shrimp which clearly control its dynamics.

Else, P.V. (1985)

Alaska oyster grower's manual. Second edition
Frady, T. (ed.) Alaska Univ., Fairbanks (USA). Alaska Sea Grant Program, Marine Advisory Bulletin 1985

Elston, R. A. (1985)

Pathology and diagnosis of oyster velar virus disease (OVVO).
Journal of Shellfish Research 5: 52

Oyster velar virus disease (OVVD) has been previously described in hatchery-reared larvae of the Pacific oysters *Crassostrea gigas* and the lesions of the disease have been observed in wild larvae. Resultant hatchery mortalities can be substantial, occur primarily in 170- to 190- mu m shell-height larvae and are most severe from April to June. Lesions were studied in over 800 larvae by differential interference contrast microscopy, histological, and electron microscopial methods from 4 episodes of hatchery disease over a 2-y period. Viral inclusion bodies in the velum were observed by histological methods in 38% of larvae collected from tank bottoms of affected groups and 28% of larvae collected from the water column. Animals exhibited signs of the disease before infectious viral particles were formed. The findings suggest that the disease may be widely distributed and vertically transmitted.

Elston, R. (1991)

Shellfish health management and maintenance IN Nosho, T.Y.; Chew, K.K. (eds.);
Remote Setting and Nursery Culture for Shellfish Growers: Workshop Olympia, WA (USA) 19 Feb 1991 pp. 41-42, 1991. Washington Sea Grant.

Hatchery and nursery diseases can cause mortality and reduce production, growth rate, and product quality. Disease effects can be insidious since the result is not always obvious as a distinct mortality episode. Often, poor management results in poor health of animals. Such effects are easily remedied by correcting the management procedures. This paper presents a brief mention of specific infectious diseases and the locations at which they occur. Vibriosis. A 'management' disease. It can enter and be amplified through algal stocks, seawater, or broodstock. Oyster velar virus disease (OVVD) of Pacific oysters. A manageable disease transmitted from the broodstock. Diseases caused by parasites such as the geoduck larval amoeba. Washington State is establishing regulations first within the state followed by regional cooperation for the control of shellfish diseases: rewrite of WAC-220-77-040 under way with shellfish industry participation. Cooperative approach with members of Pacific Marine Fisheries Commission. Procedures for "routine" movements within West Coast Commerce Area, procedures for new species introductions, and various operational guidelines.

Elston, R. A. & D. Cheney (1998)

Shellfish health management for enhancement, restoration and culture on the West Coast
Journal of Shellfish Research 17 (Abstract)

Pacific and kumamoto oysters (*Crassostrea gigas* and *C. sikamea*) and manila clams (*T. philippinarum*) are widely cultured on the west coast of North America. Native bivalve culture is relatively limited by several species such as the geoduck clam (Panope abrupta) and native littleneck clam (*Protothaca staminea*) are part of an emerging technology that supplies seed and adult shellfish for enhancement, restoration, and commercial production. It is essential that health management procedures be in place to prevent the dissemination of infectious diseases during these activities and to reduce operational costs. Studies on cultured seed stock in Washington, Oregon, California and Hawaii revealed opportunistic but significant bacterial pathogens and several other conditions. No diseases considered certifiable were found. A broader mortality and health study of adult oyster stocks is underway to elucidate causes of periodic mortality and establish an ongoing program of health surveillance. Developing technology for new species in culture must include health management and dis ease prevention in the intensive culture facilities. Morphologic pathology is the basis of disease evaluation but needs to be supplemented by microbiological and molecular methods for diagnosis and characterization of infectious diseases. Shellfish health programs for commercial producers are under development in order to better understand the disease process related to shellfish mortalities and product losses, and to foster practices that will enhance shellfish health. The health program consists of standards for brood stock management, hatchery and grow out operations, a response plan for disease outbreaks, record-keeping requirements and standards for evaluation and training.

Elston, R & D. Cheney (1998)

Oyster seed diseases and health management in intensive mollusc culture
Journal of Shellfish Research 17: 324

Since the late 19701s, the technology for mass production of larvae and spat of many species of bivalve molluscs, particularly oysters, has been commercialized. A variety of opportunistic viral, bacterial and parasitic diseases have been described from intensively culture bivalve larvae and to a large extent, these diseases have been eliminated or significantly reduced by improvements in hatchery management. Losses of seed bivalves are much more significant in terms of cost and the study of seed diseases has not received a great deal of attention. Therefore we undertook a project to characterize healthy Pacific oyster, Crassostrea gigas, seed microanatomy, seed oyster diseases and the management of such diseases in Washington and California in 1996 and 1997. Four intensive oyster seed production Erf facilities took part in the program. From the time of larval settlement until a shell height of approximately 1 cm, seed oyster anatomical development is transitional between the larval and adult forms. During this period there is a rapid increase in the number of gill folds, extensive growth of vesicular connective tissue cells to fill the coelomic cavity of the larvae, increase in the number of circulating hemocytes, elaboration of the digestive diverticula, and the formation of kidney tissue, among other developmental changes.

Elston R. A., J. H. Beattie J. H., C. Friedman, R. Hedrick, & M. L. Kent (1987)

Pathology and significance of fatal inflammatory bacteraemia in the Pacific oyster, *Crassostrea gigas* Thunberg.
Journal of Fish Diseases 10: 121-132

Elston, R. A., P. Fre1ier, & D. Cheney (1998)

Systemic Gregarine-like protozoa in juvenile Pacific oysters, *Crassostrea gigas* (Thunberg 1793).
Journal of Shellfish Research 17: l177-1181

During a detailed survey of Pacific oyster, *Crassostrea gigas*, juvenile health at intensive rearing facilities during 1996 and 1997, systemic Gregarine-like protozoa were found in seed oysters planted on certain nursery beds. The organisms were never found in seed oysters from intensive production tank faci1ities. The infections were not associated with morbidity and mortality and appeared to be of 1imited pathologic significance. The organisms occurred systemically in seed oysters and were most commonly found in vesicular connective tissue with minimal to no associated host response. Oyster seed planted on three nursery bed areas in Washington became infected but those planted in Arcata Bay, California never became infected. Infection intensity and prevalence initially increased after planting, then dec1ined. The organisms are extremely rare in adult oysters and the data suggest that juvenile oysters essentially outgrow the

infections without detectable clinical pathologic effects. Spore stages were never observed and a definitive taxonomic affinity could not be established.

Elston. R. A., P. Frelier, & D. Cheney (1999)
Extrapallial abscesses associated with chronic bacterial infections in the intensively cultured juvenile Pacific oyster *Crassostrea gigas.*
Diseases of Aquatic Organisms 37: 115-120

During a detailed survey of Pacific oyster juvenile health at intensive rearing facilities in Washington State and California (USA), an episode of persistent morbidity and mortality occurred over an 8 week period in 1997. Affected oyster seed were typically between about 1.0 and 2.4 mm in shell height. Abscesses were formed in the extrapallial space resulting from invasion by (unidentified) straight bacterial rods along the inner shell surface. The abscesses contained host cells and bacteria. The infection appeared to be chronic, was associated with relatively low numbers of bacterial cells, and caused alterations of the underlying mantle and abnormal shell deposition. No signs of any other type of infectious agent were found associated with the lesions. After a chronic time course, 2 outcomes were possible: either the mantle was breached, leading to an overwhelming terminal bacterial infection or, in some cases, host cell debris and bacteria were sequestered by new shell deposition and the infection was resolved. It is concluded that the condition can cause mortality and significant loss of growth in intensively cultured juvenile oysters.

Elston, R. A., D. Cheney, P. Fre1ier, & D. Lynn (1999)
Invasive orchitqphryid ciliate infections in juvenile Pacific and Kumamoto oysters, *Crassostrea gigas* and *Crassostrea sikamea*.
Aquaculture 174: l-14

During an extensive survey of juvenile oyster health from shellfish nursery facilities in Washington state, USA, a primary invasive ciliate disease was discovered. Ci1iates invaded the extrapallial space and coelomic cavity of juvenile Pacific and Kumomoto oysters (*Crassostrea gigas* and *Crassostrea sikamea*) which had a shell height of from 0.5 mm to 2.0 mm. Both diploid and triploid oysters were affected but no infections were found in oysters larger than 3.0 mm shell height. The invasion was initiated when ciliates were able to bypass the outer mantle lobe and gain entry to the extrapallial space. Subsequently, the thin mantle tissue separating the extrapallial space from the coelomic cavity was breached. Once the extrapallial space was invaded in these small shellfish seed, the infection appeared to be irreversible. Cumulative mortality in affected cultures usually exceeded 50%, and the infection was considered a serious although sporadically occurring problem for nursery production of early stage seed. The ciliates were ovoid with a tapered anterior end and round in cross section with an estimated maximum body width averaging 18 um and body length averaging 32 um. The ciliates were holotrichously ciliated with a modal number of somatic kineties for these samples of 13. The cytoplasm of the ciliates was typically full of food vacuoles, which appeared to contain debris and in several cases what appeared to be entire nucleated cells. The invasive ciliates have an obvious anterior oral cavity and cytostome with at least two oral polykinetids and a paroral. Based on the shape of the oral cavity, they belong in the Order Scuticociliatida and can be most easily placed in the Family Orchitophryidae. In contrast to a previous report describing ciliates in oyster seed cultures, this infection was considered primary but opportunistic. Strategies for preventing and managing the infection are discussed.

Evans J. W. (1988)
Cockle diaries: the interpretation of tidal growth lines.
Endeavour (Oxford) 12: 8-15

Everett R. A., G. M. Ruiz, & J. T. Carlton (1995)
Effect of oyster mariculture on submerged aquatic vegetation: An experimental test in a Pacific Northwest estuary.
Marine Ecology Progress Series 125: 205-217

The effects of commercial culture of oysters, *Crassostrea gigas*, on submerged aquatic vegetation (SAV), *Zostera marina*, were examined with replicated field experiments in the South Slough estuary, Oregon, USA. Both stake and rack methods of oyster culture resulted in significant decreases in the abundance of SAV compared to undisturbed reference areas. SAV cover in both stake and rack treatments was less than 25% of that in reference plots after 1 yr of culture, and was absent from rack treatments after 17 mo of culture. Field experiments using marked plants revealed no difference in growth between plants in stake and reference plots. Comparisons of sediment surface topography demonstrated that oyster culture resulted in significantly greater sediment deposition in stake plots and greater erosion in rack plots. Silt-clay fractions and carbon content of sediments tended to increase with stake culture and decrease with rack culture, but only for carbon content at racks were the differences significant between culture and reference plots. Stake culture 1ikely affected SAV via increased sedimentation and direct physical disturbance during placement and harvest, while increased erosion and perhaps shading resulted in the marked decrease in SAV coincident with rack culture. These results indicate the potential for significant loss of SAV from estuarine ecosystems where these methods of oyster culture and SA V coincide.

Farfan, C., A. M. E. Peralta, & O. T. Vazquez (1998)
Egg laying delay in *Modiolus capax* (Bivalvia: Mytilidae)
Revista de Biologia Tropical 46: 633-641

The capacity of *Modiolus capax* to delay spawning and to hold mature gametes for long periods, was analyzed in sexually mature organisms subjected to cold water and food rations higher than those for maintenance. The experimental group, 200 mussels collected in August from Bahia de los Angeles, Baja California, Mexico, was subjected to 19+/-2 degrees C temperature comparable to that In the natural environment during autumn and early winter; the daily food rations, delivered in open flow, were equivalent to 0.5-1.0% of the mussel IS dry soft body weight. The effectiveness of the experimental treatment was verified every month in a sample of 16 mussels; for contrast, a sample from Bahia de los Angeles was also analyzed. The assessed variables were general condition and gonadosomatic indices and for the histological study of the gonads, a maturity scale with eight stages was designed. In September the mussels from the natural environment were in the initial phase of post-spawning; by December they were in late post-spawning or rest. In the experimental group there were no spontaneous spawnings and general condition and gonadosomatic indices remained consistently higher than in the natural environment, however, by the eight-week of treatment the gonads showed evidences of incipient reabsorption. It is proposed that the natural reproductive cycle, mass spawning in summer and rest in late autumn and early winter, might be 1imiting the mussel is capacity to retain mature gametes.

Farley, C. A., D. L. Plutschak, & G. Krantz (1991)
Crassostrea gigas disease exposure to *Haplosporidium nelsoni* and *Perkinsus marinus* in Chesapeake Bay waters
Journal of Shellfish Research 10: 306-307

A population of native *Crassostrea virginica* collected from a low salinity habitat was diagnosed by hemanalysis to be free of *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* in the spring of 1989. A sample of 100 Japanese oysters, *C. gigas*, ranging 45-105 mm, was received from Puget Sound, Washington, in May 1989 and diagnosed as above. Both populations were placed in a quarantined running seawater system at the Deal Island hatchery for natural exposure to both disease over the summer. Both MSX and *Perkinsus* developed, intensified, and killed most of the 320 native oysters. Japanese oysters did not show any MSX infections but did show low level infections of *Perkinsus* which did not intensify. In 1990, 3 groups of *C. gigas* seed produced by Rutgers University staff and a new population of native; oysters were added to the original C. gigas population in the exposure system. By the fall of 1990, surviving native oysters were found to be 97% infected by *P. marinus* but showed no MSX. Only 14 of the original *C. gigas* survived and 5 animals exhibited low level *Perkinsus*. *C. gigas* seed experienced 90-99% mortality and did not grow in ambient salinity that ranged 10.5-18 ppt.

Feldman, K. L., D. A. Armstrong, B. R. Dumbauld, & C. J. Langdon (1995)

Controlling populations of burrowing thalassinid shrimp on oyster culture grounds: Effects of harvesting and shell configuration on recruitment of young-of-the-year

Journal of Shellfish Research 14: 265

Survival and growth of the Pacific oyster *Crassostrea gigas* along the Pacific coast of the United States are adversely affected by burrowing shrimp *Neotrypaea californiensis* and *Upogebia pugettensis*. In Washington State (USA), the insecticide carbaryl has been applied to oyster beds to control populations of shrimp for more than 30 years. While carbaryl removes adults from oyster grounds, it does not discourage reinvasion by young-of-the-year (YOY) shrimp. We initiated a study to examine how the harvest and culture of oysters affects recruitment success of burrowing shrimp. Young-of-the-year abundance was quantified prior to and 2 wks after dredging a mature oyster bed to assess whether active methods of disturbance, such as harvest operations, might kill YOY shrimp residing in shallow burrows. We found no conclusive evidence, however, that dredging had a significant impact on shrimp density distinct from natural mortality. Young-of-the-year shrimp were also quantified in areas of oyster culture and dense epibenthic shell cover to determine if shell configuration (i.e., structure and percent cover of shell) affects recruitment success. Mean densities of *N. californiensis* were significantly lower in a mature oyster bed and an area of dense epibenthic shell than in a seed bed and an open mudflat. Results of field and laboratory experiments indicate that epibenthic shell hinders recruitment of *N. californiensis* by acting as a physical barrier to settlement and harboring high densities of YOY Dungeness crab, *Cancer magister*, which prey on newly settled shrimp. In contrast to *N. californiensis*, however, mean densities of YOY U. pugettensis were significantly higher in epibenthic shell habitats than open mudflat; mechanisms underlying their patterns of distribution currently are being investigated. It is hoped that information on shrimp recruitment will aid in developing an integrated pest management plan to achieve more effective long-term management of shrimp populations in areas of bivalve culture. (DBO)

Feldman, K., D. A. Armstrong, B. R. Dumbauld, T. H. DeWitt & D. C. Doty (2000)

Oysters, crabs, and burrowing shrimp: Review of an environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries.

Estuaries 23: 141-176

Washington State's coastal estuaries are productive shallow water environments that support commercial fisheries for Dungeness crabs (*Cancer magister*) and English sole (*Parophrys vetulus*) by providing 0+ (settlement to age 1) populations with critical refuge and foraging habitats unti1 subadults migrate to the nearshore coast. Intertidal mudflats also constitute prime areas for commercial oyster (Crassostrea gigas) culture, an important industry for the coastal communities of Willapa Bay and Grays Harbor that supply much of the nation's oysters. Conflicts over natural resources and estuarine utilization have arisen over the last 37 yr due to the use of carbaryl (an organocarbamate pesticide) by oyster growers on their grounds to control populations of burrowing thalassinidean shrimp (Neotrypaea californiensis and Upogebia pugettensis). Burrowing shrimp, which have an indirect negative effect on oyster survival and growth through bioturbation and sediment destabilization, are killed by carbaryl, as are 0+ and subadult Dungeness crabs, 0+ English sole, and other non-target species present on the tideflats at the time of application. The pesticide is delivered at 9 kg ha-l directly to the mudflat as a wetable powder during low tides in July and August. Commercial crabbers and other groups who have economic, recreational, and environmental interests in the estuaries have generally opposed use of the chemical that oyster growers maintain is essential to sustain production levels. For years, government natural resource agencies that regulate the use of carbaryl lacked critical information needed to effectively manage the program. An Environmental Impact Statement (EIS) and Supplemental EIS have provided much of that data and helped shape management decisions with regard to establishing carbaryl concentration rates and total allowable spray area. Additional research is needed to develop more economically and environmentally sound policies for shrimp control based on burrowing shrimp -oyster interactions on an estuarine-wide scale. In this paper we review issues pertaining to oyster culture, the use of carbaryl to control burrowing shrimp populations, and effects on non-target species, drawing upon research from published articles as well as unpublished data collected by the authors. We also discuss what is known of burrowing shrimp 1ife history and ecology and emphasize the importance of integrating information on shrimp, such as timing of recruitment. variability

in year class strength, and patterns of habitat use, into carbaryl control policies or alternative strategies that may be developed in the future. We recommend controlled experimentation be done to examine the ecological effects of delaying carbaryl application to some ghost shrimp beds until October after peak recruitment of 0+ ghost shrimp has occurred, allowing the number of hectares treated each year to vary based on fluctuations in pest population densities, and modifying the substrate by applying a dense layer of oyster shell to the mudflat (shell pavement) to reduce recruitment of ghost shrimp.

Fernandez, M. D., Armstrong, D., & O. Iribarne (1993)
First cohort of young-of-the-year Dungeness crab, *Cancer magister*, reduces abundance of subsequent cohorts in intertidal shell habitat.
Canadian Journal of Fisheries and Aquatic Sciences 50: 2100-2105

Fernandez, M., O. Iribarne, D. Armstrong (1993)
Habitat selection by young-of-the-year Dungeness crab (*Cancer magister*) and predation risk in intertidal habitats
Marine Ecology Progress Series 92: 171-177

Habitat selection by megalopae, and habitat preference and relative mortality of young-of-the-year (YOY) Dungeness crab Cancer magister were evaluated in 4 habitat types: bivalve shell middens (Crassostrea gigas), eelgrass *Zostera marina*, mud with scattered shell and bare mud. Under laboratory conditions shell was the most preferred habitat by megalopae and YOY; eelgrass ranked second. Field tethering experiments showed that shell habitat provided the best protection from predation, and that the proportion of crab eaten was highest on bare mud. Field tethering experiments using small hooks attached to tether lines and glued to the crab showed that the sculpin *Leptocottus armatus* was the most important fish preying on YOY crab in this area. Cannibalism by larger instars of YOY, 1+ and 2+ Dungeness crab also may account for part of the YOY mortality. Most evidence suggests that intertidal shell habitat enhances Dungeness crab survival during the first several months of benthic 1ife.

Franklin, H. L. & S. L. Downing (1989)
Effects of culling and temperature on family contribution in hatchery reared Pacific oysters
Journal of Shellfish Research 8: 447-448

The commercial oyster industry in the Pacific Northwest relies heavily on hatchery-produced seed. Experiments were run to test the combined effects of culling and temperature, and the effect of culling alone. Full-sib families were reared at 3 temperatures with culled and nonculled treatments at each temperature. Larval results indicate that groups reared at 30 degree Chad 50% fewer survivors to straight hinge than groups reared at 20 and 25 degree C. Preliminary results indicate that the 30 degree C groups are predominantly represented by 2 families. In the 20 and 25 degree C groups, certain families are also disproportionately represented, but the families are different than the ones making a larger contribution to the 30 degree C groups. In the second experiment spat counts indicate that the culled treatments have fewer spat set per shell than the non-culled treatments (53.3 and 71.1 spat/shell, respectively).

Friedman, C. S. (1990)
Nocardiosis of the Pacific Oyster, *Crassostrea gigas* Thunberg (Oyster).
Dissertations International V. 51/11-B p. 5096.

The relationship between a bacterial infection and summer mortality of Pacific oysters, *Crassostrea gigas* Thunberg was investigated. A bacterium was isolated from both the hemolymph and adductor muscle pustules of infected 2 yr or older animals from four locations in Washington, U.S.A and British Columbia, Canada (Chapter 1). The fi1amentous bacterium stained gram-positive and acid-fast, produced catalase, shared common antigens with nocardia1 bacteria and was emarginated with a trilaminar cell wall. These characteristics indicate that the bacterium belongs in the genus *Nocardia* and the disease is best designated Pacific oyster nocardiosis (PON). Experimentally-induced infections of oysters showed similar gross and microscopic signs as natural infections with the bacterium. Intracardiac injections of 1.44 $\times$ 10$\sP5$ cfu/ml of the bacterium resulted in a 47% mortality of adult oysters held in seawater (32 ppt) at

21 C within 34 d. Pacific oyster nocardiosis co-occurred with periods of mortality of C. gigas in certain embayments in Washington and British Columbia (Chapter 2) in which water temperatures and nutrient levels became elevated during the summer. Six culture sites contained oysters with PON. Overall, more males and reproductively immature oysters than female oysters contained bacterial foci during an infection season and Oakland Bay, Washington oysters showed a peak prevalence of infection during September. These data suggest a causal relationship between PON and summer mortality in certain embayments. Analysis of morphological, physical and biochemical properties of *Nocardia* sp. from oysters showed that the bacterium contained chemotype IV cell walls which consisted of meso-diaminopimelic acid, arabinose, galactose and nocardomycolic acids as major cell wall components and an average base composition of 68.8 mol % G + C. The bacterium was most similar to N. asteroides (antigenical1y) and N. seriolae (biochemically). However, unlike N. seriolae, Nocardia sp. from oysters contained large amounts of C 16:0 and only trace amounts of C 15:0 and C 17:0 as major methyl ester pyrolytic products of cell wall mycolic acids. In addition, the oyster bacterium did not grow with gluconic acid, grew poorly with Tween 80 as sole carbon source, did not grow with ornithine as sole carbon and nitrogen source, was resistant to 5-fluorouracil, sensitive to isoniazid and mitomycin C, and did not grow with 5% salt. Based on these unique properties of the oyster bacterial isolates, we propose a new species of *Nocardia: N. crassostreae sp. novo*

Friedman, C. S. (1996)
Haplosporidian infections of the Pacific oyster, *Crassostrea gigas* (Thunberg), in California and Japan.
Journal of Shellfish Research 15: 597-600

Haplosporidian infections were observed in adult and seed Pacific oysters, *Crassostrea gigas* (Thunberg), in Drakes Estero, CA, and in seed Pacific oysters from Matsushima and Watanoha Bays, Japan. Up to 7% of domestic Pacific oysters and those imported from Japan that were examined from Drakes Estero had mild systemic or localized haplosporidian infections. Plasmodia were observed within the gills and connective tissues surrounding the stomach and intestine or, more commonly, within the epithelium of the heart. An inflammatory response was observed in response to plasmodia within connective tissues; inflammation was not observed in infections within the heart. Multinucleated plasmodia were also observed in the heart of 1-3% of seed oysters examined from Matsushima and Watanoha Bays, Japan. Results from this study suggest that haplosporidia are established at very low levels in Pacific oysters reared in Drakes Estero, CA. These data also suggest that Pacific oysters imported into Drakes Estero from Matsushima Bay, Japan, were a likely source of the introduction of the haplosporidian in California

Friedman C. S., J. H. Beattie, R. A. Elston, & R. P. Hedrick (1991)
Investigation of the relationship between the presence of a gram-positive bacterial infection and summer mortality of the Pacific oyster, *Crassostrea gigas* Thunberg.
Aquaculture 94: 1-15

The occurrence of Pacific oyster nocardiosis (PON) was found to correspond with peak periods of summer mortality as described for Pacific oysters, *Crassostrea gigas*, reared in certain bays in Washington State and British Columbia. Areas in which 2-year or older Pacific oyster historically experience summer mortality and bacterial infection are embayments where water temperatures and nutrient levels become elevated during the summer months. Pacific oysters reared in three sites in both Washington State and British Columbia, Canada, contained the bacterial pathogen. An examination of the seasonality of the bacterial disease in Oakland Bay, Washington State, showed a peak prevalence of infection during the month of September. Although the ratio of male:female oysters was generally 1:1 at most locations sampled, between late August and November bacterial foci were more often found in males and reproductively immature oysters than in females. However, approximately equal numbers of male and female oysters were infected in early summer. Diseased oysters contained an infiltration of hemocytes surrounding tufts of Gram-positive bacteria of the genus *Nocardia*. Injection of the bacterium isolated from diseased oysters into healthy oysters resulted in infections with the same characteristic histopathological changes as observed in individuals with PON. The seasonal coincidence and involvement of older oyster containing bacterial foci suggests that PON is a causal factor in summer mortality in certain areas.

Friedman, C. S., A. Shamseldin, P. G. Pillai Murali;, G. N. Cherr , S. A. Jackson, E. Rifkin, K. R. Uhlinger K R, and J. S. Clegg (1997)

Summer mortality and the-stress response of the Pacific oyster, *Crassostrea gigas* Thunberg.
Journal of Shellfish Research 16: 335

Gaffney, P. M., D. Hedgecock, & A. Robinson (1998)
Identifying the Kumamoto oyster: A first step in broodstock restoration and improvement
Journal of Shellfish Research 17 (Abstract)

The Kumamoto oyster, *Crassostrea sikamea*, is a valuable part of the oyster industry in the Pacific Northwest, where it was introduced inadvertently with shipments of seed oysters (*C. gigas*) from Japan earlier this century. Although a number of growers have broodstock Kumamoto oysters, previous work has raised concern that their genetic integrity may be threatened by two factors: hybridization with the Pacific oyster *C. gigas*, and loss of genetic variability as a result of small effective population sizes. As the first step towards preserving and improving the existing Kumamoto broodstock population, growers want to identify non-destructively oysters that are pure *C. sikamea* and separate them from *C. gigas* or hybrid oysters. Analysis of DNA markers amplified by the polymerase chain reaction (PCR) is an attractive alternative method that can be applied to small tissue snips, eggs and larvae. Previously, Banks et al. (1993) demonstrated the use of PCR-amplified mitochondrial genes to distinguish between Pacific and Kumamoto oysters. However, this approach cannot be used to identify hybrids, which possess only the maternal mtDNA geno-type. For this reason, we developed a nuclear gene marker that can discriminate between the two species and their Fl hybrids. We have typed several hundred biopsied oysters supplied by growers. Some lots contained substantial numbers of Pacific oysters, while others were almost pure Kumamoto. Although the relationships among surviving Kumamoto populations are not yet known, the prospects for a broodstock restoration program are good. To date, no hybrids have been found. This suggests either that hybridization was never that extensive, that growers have learned to be more discriminating, or possibly that hybrids do not survive well in the field.

Gallucci, V. F. & B. B. Gallucci (1982).
Reproduction and ecology of the hermaphroditic cockle, *Clinocardium nuttali* (Bivalvia: Cardiidae) in Garrison Bay.
Marine Ecology Progress Series 7: 137-145.

Gang L. & D. Hedgecock (1998)

Genetic heterogeneity, detected by PCR-SSCP, among samples of larval Pacific oysters (*Crassostrea gigas*) supports the hypothesis of large variance in reproductive success
Canadian Journal of Fisheries and Aquatic Sciences 55: 1025-1033

Differences in genetic composition among samples of larvae produced during a single spawning by a semi-isolated population of Pacific oysters (Crassostrea gigas) in Dabob Bay, Washington, confirm a specific prediction of the hypothesis that this and other marine animals have large variances in reproductive success. To study the genetics of single larvae, part of the mitochondrial genome was cloned and sequenced and polymerase chain reaction (PCR) primers to amplify four segments developed totaling nearly 2300 base pairs, or 13% of the genome. PCR products were digested with restriction enzymes into smaller fragments, which were then screened for single-strand conformational polymorphisms (SSCp). Seven plankton samples, taken between 10 and 21 August 1993, showed a common composite PCR-SSCP haplotype that comprised from 53 to 85% of samples. Exact probability and permutation tests reveal that early and late samples from north Dabob Bay differed significantly from the rest. These differences cannot be ascribed to spatial variation and are consistent with the hypothesis that larvae are produced by relatively few adults, in accord with previous observations of substantial genetic drift in this large population.

Gang, L. & D. Hedgecock (1996)
Mitochondrial DNA variation within and among larval cohorts of Pacific oyster, Crassostrea gigas, detected by PCR-SSCP analysis

Journal of Shellfish Research 15: 511-512

Detailed studies of genetic composition within and among cohorts of larvae produced by a semi-isolated population of Pacific oysters in Dabob Bay, Wa, are needed to test the hypothesis that large variance in reproductive success causes a previously reported 10 super (4)-fold discrepancy between effective and actual population sizes. We cloned and sequenced part of the mitochondrial genome of Crassostrea gigas and developed PCR primers to amplify, from individual larvae, four fragments totaling about 2.3 kb in length, or 13% of the genome. Each fragment was digested into smaller pieces and screened for nucleotide-sequence variation by methods for detecting single-strand conformation polymorphism (SSCP). Three temporal plankton samples from Quilcene Bay and two from north Dabob Bay (total N = 519) were surveyed by PCR-SSCP. A common haplotype is shared by 70-84% of all larvae sampled, so Monte-Carlo contingency chi-square methods are used to test the independence of haplotype frequency and sample. Qui lcene Bay larval samples are homogeneous, but the north Dabob Bay larval samples are not. Haplotype frequencies in a cohort of larvae produced after mid-August in north Dabob Bay differ from those in a cohort that appeared in early August in both sites

Gang, L. & D. Hedgecock (1998)
Genetic heterogeneity, detected by PCR-SSCP, among samples of larval Pacific oysters (*Crassostrea gigas*) supports the hypothesis of large variance in reproductive success.
Canadian Journal of Fisheries and Aquatic Sciences 55: 1025-1033

Differences in genetic composition among samples of larvae produced during a single spawning season by a semi-isolated population of Pacific oysters (*Crassostrea gigas*) in Dabob Bay, Washington, confirm a specific prediction of the hypothesis that this and other marine animals have large variances in reproductive success. To study the genetics of single larvae, we cloned and sequenced part of the mitochondrial genome and developed polymerase chain reaction (PCR) primers to amplify four segments totaling nearly 2300 base pairs, or 13% of the genome. PCR products were digested with restriction enzymes into smaller fragments, which were then screened for single-strand conformational polymorphisms (SSCP). Seven plankton samples (total N = 877), taken between 10 and 21 August 1993, showed a common composite PCR-SSCP haplotype that comprised from 53 to 85% of samples. Nevertheless, exact probability and permutation tests reveal that early and late samples from north Dabob Bay differed significantly from the rest. These differences cannot be ascribed to spatial variation and are consistent with the hypothesis that larvae are produced by relatively few adults, in accord with previous observations of substantial genetic drift in this large population.

Garcia E. J., A. Gonzalez, N. Ayala Sanchez & S. C. F. Feliz Sanchez (1982)
Japanese oyster seed production, *Crassostrea gigas* in Erendira Ejido, Baja California, Mexico
Rev. Latinoam. Acuiculto. 13: 52-56

In the mollusc reproduction laboratory in Ejido de Erendira y Bahia de San Quintin, Baja California, which was set up with the help of The Bahia Falsa Common Lands Fish Farming Cooperative Society, work was carried out into oyster seed (*Crassostrea gigas*) production. The main purpose of the mass reproduction of Japanese oyster seed in the laboratory is to achieve a production line, using trained Mexican personnel, to become self-sufficient firstly in the provision of raw materials to the oyster farms of Baja California, and then to achieve self-sufficiency at national level.

Garcia-Esquivel, Z, M. A. Gonzalez-Gomez, M A& D. L. Gomez-Togo (1999)
Growth, mortality and biochemical content of the Pacific oyster, Crassostrea gigas, during spat-adult development
Journal of Shellfish Research 18 (Abstract)

Changes in shell height, tissue dry weight (TOW), mortality and biochemical content were evaluated in Crassostrea gigas during the spat to adult development. In San Quintin Bay (SQB) , NW Mexico. Shell growth rate was 1.5x greater at the mouth (0.36 mm/d) than the head of SQB and tissue growth rate was

also 5-fold higher at the mouth (8.6 mg TDW/d). Oysters located at the head of SQB consistently suffered longer emersion periods (17%) than the ones at the mouth. The market size (9 cm) was reached after 8 mo. (mouth) and 13 mo (head) post-setting. Cumulative mortality during the study ranged between 63 and 87% but the highest mortality (50 to 60%) took place within the first mo. post-setting, during the rearing period. Proteins, 1ipids and carbohydrates were present in proportions of 48-64%; 2-9% and 1-22% respectively, with lower values associated to winter months and longer aerial exposure. Proteins and 1ipids were the most abundant biochemical components during early spat development, but 1ip ids were replaced by carbohydrates as the main energy source in the Fall, when oysters reached 50 to 64 mm. Based on the growth rates and biochemical patterns, it is concluded that site-specific differences in developmental rates were mainly due to longer emersion times at the head of SQB.

Garcia-Esquivel, Z, M. A. Gonzalez-Gomez, D. L. Gomez Togo, M. S. Galindo Bect & A. M. Hernandez (2000)

Microgeographic differences in growth, mortality, and biochemical composition of cultured Pacific oysters (*Crassostrea gigas*) from San Quintin Bay, Mexico.
Journal of Shellfish Research 19: 789-797

Changes in shell height, tissue dry weight (TOW), mortality, and biochemical composition of *Crassostrea gigas* were evaluated at two commercial sites in San Quentin Bay (SQB), Mexico, during the first 9 mo post-settlement. Shell growth rates were 1.5[xl higher at the mouth (0.36 mm d-1) than the head of SQB (0.23 mm d-1). Tissue dry weight was also 7- to 8-fold higher in oysters from the mouth (2.1-2.16 g TOW oyster-1) than the head of SQB (0.23-0.33 g TOW oyster-1) at the end of the 9-mo experiment. Market size (9 cm) was reached after 9 mo at the mouth and at an estimated age of 13 mo at the head of the bay. Highest mortality occurred within the first month post-settlement (50%-60%) and reached approximately 63% to 87% throughout the whole study period. Proteins (48%-64%) and 1ipids (2%-9%) were the most abundant biochemical components during early spat development. When oysters reached a size between 48 and 55 mm (shell height) in the fall, glycogen (1%-22%) replaced lipids as the main energy depot. The changeover occurred earlier in oysters at the mouth than in oysters from the (cont. next page) head of the bay. It is suggested that between-site differences in growth and biochemical composition in oysters are the result of longer immersion/feeding period experienced by oysters at the mouth of SQB.

Gee, A. & R. A. Elston (1997)

PCR detection of the bacterial pathogen in oyster nocardiosis.
Journal of Shellfish Research 16: 264

Gonzalez, T. A, L. A. Martinez, I. Rego, J. Ausio, & J. Mendez (2000)

DNA content, karyotypes, and chromosomal location of 185-5.85-285 ribosomal loci in some species of bivalve molluscs from the Pacific Canadian coast
Genome 43: l065-1072

The DNA content of 10 species of bivalve molluscs from British Columbia coast was determined by image analysis, and the karyotypes of the horse clam *Tressus capax*, the bent-nose macoma *Macoma nasuta*, and the nuttallls mahogany clam *Nuttallia nuttallii* are described here for the first time. We also have analyzed the location of rDNA loci using a 28S-5.8S-18S probe in four of these species: *Mytilus californianus, M. trossulus, Macoma nasuta* and *N. nuttallii*. Results obtained report new data about cytogenetic characteristics of bivalve molluscs.

Gray, A. E., T. J. Mulligan, & R. W. Hannah (1997)

Food habits, occurrence, and population structure of the bat ray, *Myliobatis californica*, in Humboldt Bay, California.
Environmental Biology of Fishes 49: 227-238

Grizel, H. & M. Heral (1991)
Introduction into France of the Japanese Oyster *Crassostrea gigas*
Journal du Consei1 International pour Exploration de la Mer 47: 399-403

The Japanese oyster (*Crassostrea gigas*) has been introduced in France on a large scale to replace cultivation of the Portuguese oyster (*Crassostrea angulata*), affected by a viral disease. The importation took place from 1971 to 1975, with broodstock coming from British Columbia (Canada) and spat from Japan. Good growth rate and success of the natural setting on the French Atlantic coast attested to the success of this implantation, with a production which reached 80 000 t by 1976. The precautionary measures associated with this transfer 1imited the implantation of an introduced fauna, 15 years after, to: *Balanus amphitrite*, *Aiptasia pulchella* and, on the Mediterranean coast, *Undaria pinnatifida* and *Laminaria japonica*. The authors also discuss the possible role of *Crassostrea gigas* in spreading the viral disease

Gunther, A., J. Davis, D. Hardin, J. Gol d, D. Bell, J. Crick, & G. Scelfo (1999)
Long-Term Bioaccumulation Monitoring with Transplanted bivalves in the San Francisco Estuary
Marine Pollution Bulletin 38: 170

A number of transplanted bivalves have been used by researchers working for the Califo rnia State Mussel Watch and the Regional Monitoring Program for Trace Substances as part of biomonitoring efforts targeting trace elements and organic contaminants in the San Francisco Estuary. The transplanted bivalves used in these projects included *Mytilus californianus*, *Crassostrea gigas*, and *Corbicula fluminea*). Data detailing substantial declines in contaminant levels in M. californianus for the period 1980-96 are detailed for a range of problematic pollutants, including PCBs, cis -chlordane, dieldrin, and silver. Concurrent increases in the Cr contents of M. californianus during the same period were documented. Limitations on the use of these transplanted bivalves for biomonitoring efforts are detailed.

Guo, X., W. K. Hershberger, K. K.; Chew, S. L. Downing, & P. Waterstrat (1988)
Cell fusion in the Pacific oyster, Crassostrea gigas: Tetraploids produced by blastomere fusion
Journal of Shellfish Research 7: 549-550

This report presents results of research investigating the use of PEG treatment to induce the fusion of two blastomeres to produce tetraploid oysters (*Crassostrea gigas*). Eggs and sperm were obtained by stripping conditioned adult oysters and fertilization was conducted in artificial seawater (ASW). After the majority of the developing emb ryos reached the two-cell stage, they were treated with 50% PEG (w/w in ASW) for 1, 2, and 5 minutes. Treated embryos were rinsed with ASW and then cultured in natural seawater. Fusion of the blastomeres was assessed by microscopic examination. Analysis of chromosome preparations from trochophore larvae revealed 1-4% tetraploidy. The highest level of tetraploid production occurred in the 2-minute treatment group. Additional studies are being conducted to refine the treatment procedures and to increase the yield from a very promising approach to tetraploid production in Pacific oysters.

Gutierrez G. E, G. Flores Munoz, R. Pro Garcia, J. A. Vi1laescusa Celaya, J. A. Gonzalez Armenteros (1991)
Heavy metals in tissues and in sedimentary biodeposits of the oyster *Crassostrea gigas* from the aquaculture zone of San Quintin Bay, Baja California, Mexico.
Invest. Mar. Cicimar. 6:176-186

The monthly variation of concentrations of heavy metals bioavailable in the total tissue of the oyster, *Crassostrea gigas*, of comme rcial size (90-136 mm) and in the period of growth (51-99 mm) was studied in the oyster culture region of San Quintin Say, Baja California, during February to July 1989. The enrichment of heavy metals in the bioavailable fraction of the sedimentary biodeposit of the cultured oysters was also studied. The results show higher concentrations (mu g g-l dry weight) of AI, Cd, Cu, Mn and Zn in the oysters in the period of growth (643.5, 10.3, 40.4, 101.7 and 232.9) than in the commercial size oysters (306.2, 7.7 26.8, 64.7 and 203.8). A kinetic accumulation of AI > Zn > Mn > Cu > Cd was

observed for both sizes. The study indicates that the temporal variation in the accumulation of these elements in the oysters cultured in San Quintin Bay is related to physiological variations (weight) and productivity (chlorophyll a, seston). This study indicates that the sedimentary biodeposits in the culture region of San Quintin Bay contribute to the enrichment of AI, Cd, Cu, Mn and Zn in the sediments.

Gutierrez G. E, J. A. Vi11aescusta; G. F. Munoz, & J. L. Sericano (1996)
Organic contaminants in sediments from San Quintin Bay, Baja California, Mexico.
Marine Pollution Bulletin 32: 378-381

Habict, C., J. E. Seeb, R. B. Gates, I. R. Brock, & C. A. Olito (1994)

Triploid Coho salmon outperform diploid and triploid hybrids between Coho Salmon and Chinook Salmon during their first year
Canadian Journal of Fisheries and Aquatic Sciences 51: 31-37

Sterile hybrid and triploid fish may provide hatchery programs with a tool to reduce the risk of genetic contamination of wild stocks, provided these fish have acceptable performance characteristics. We examined growth, survival, and deformities in diploid and triploid families of coho salmon (*Oncorhynchus kisutch*) and hybrids between coho salmon females x chinook salmon (*0. tshawytscha*) males. Data were collected from the half-sibling families through day 387. A reparameterized Gompertz growth model showed that conspecific coho salmon grew faster than hybrids, regardless of ploidy. No difference in growth rates was found between diploids and triploids. Abnormalities were significantly associated with the male parent but not with ploidy component, in contrast to previous observations of reduced deformity occurrence in triploid hybrids. Food conversion was better for conspecifics than hybrids during initial feeding, but not different during the second half of the experiment. No ploidy or cross x ploidy interaction effects on food conversion efficiency were observed. Finally, conspecifics had better posthatching survival than hybrids, regardless of ploidy. Of the treatments studied, conspecific triploid coho salmon may be the most viable alternative for sterile fish production: they performed as well as the conspecific diploids and better than either diploid or triploid hybrids.

Harbo, R. & R. Webb (2000)
Management strategies far commercial intertidal clam fisheries in British Columbia, Canada
Journal of Shellfish Research 19 (Abstract)

There are a number of intertidal clam fisheries in B.C. including First Nations fisheries for food, social and ceremonial purposes, commercial fisheries and recreational fisheries managed by the federal Department of Fisheries and Oceans. The four commercially harvested species (landings in 1998) are Manila clams, *Venerupis phi1ippinarum* (1,115 tonnes), native 1itt1eneck clams *Protothaca staminea* (50 t), mixed (118 t), butter clams *Saxidomus gigantea* (40 t) and razor clams *Si1iqua patu1a* (40 t). The commercial fishery has historically been managed by minimu m size 1imits and time and area closures. Fisheries are monitored in-season against historical landings and effort, and once these ceilings are reached in any given fishing area, the fishery may be closed. Extensive consultation takes place and an effort to develop Community Management Boards has been initiated in two areas. The fisheries are designed to allow openings throughout the year in order to deal with market demands. Area management (1989) divided the coast into 7 areas. License limitation (1998) reduced the number of harvesters from approximately 2000 to a fixed number of 1160. Approximately 50% of these license holders are First Nations participants. First Nations also participate in the co-management of beaches fronting or immediately adjacent to Reserves and pilot projects in the north coast. Harvests for depuration are managed experimentally by quotas, setting a variety of exploitation rates (0 to 50%). A collaborative agreement was developed with industry that supports surveys and stock assessment programs and a fishery manager. Five plants are licensed to depurate in B.C.; harvesting >400 t in 1998 from vacant crown foreshore. Additional harvests from aquaculture leases in open and contaminated areas are managed by the province.

Harrington, R. J. (1987)
Skeletal growth histories of *Protothaca staminea* Conrad and *Protothaca grata* Say throughout their geographic ranges Northeastern Pacific
Veliger 30: 148-158

The skeletal growth histories of only a few bivalve species have been documented throughout most or all of their latitudinal ranges. This paper considers growth parameters based on new growth measurements made throughout the geographic ranges of two bivalve species, *Protothaca staminea* (Conrad) and *P. grata* (Say). Growth data for a third species, *Siliqua patula* (Dixon, 1788) by Weymouth et al. are employed extensively in the study for comparative purposes. The collective range of all three species extends from the Gulf of Alaska to Panama. The parameters studied include: shell height vs. age (Ht), the rate of decrease in growth rate with ontogeny (defined as the slope of Walford plots and as e-k in the von Bertalanffy growth equation), mean maximum height (Ha), and mean maximum longevity of individuals. Latitudinal trends in the number of daily growth increments formed during the first full season of growth are contrasted for individuals of both *Protothaca* species. All three species exhibit similar over ontogeny, and live longer than do southern phenotypes. High initial growth rates correspond to more rapid decreases in annual growth rate. The rate of growth deceleration is highly correlated with mean annual sea-surface temperatures. The number of daily growth increments formed during the first full season of growth is apparently related to the planetary gradient in sunlight and productivity. The latitudinal rate of change in the number of daily growth increments is not affected across species boundaries.

Harrison, F. L., J. P. Knezovich, & J. S. Tucker (1981)
The Sensitivity of Embryos of the Pacific Oyster Crassostrea gigas to Different Chemical Forms of Copper Nuclear Regulatory Commission, Washington, DC. Office of Nuclear Regulatory Research. Report No.: UCRL-52725 Jul 81 pp37.

The effects of copper on the development of Crassostrea gigas embryos were determined with a 48-h static bioassay. In filtered, sterilized seawater from Bodega Bay, California, the LC100 occurred at 20 micrograms copper/L (micrograms of copper per 1iter), and the LC50 occurred at 12 micrograms copper/L. Destruction of the naturally occurring dissolved organic material in the culture water by UV oxidation reduced survival at 10 micrograms copper/L. The addition to seawater of any of five organic chelators--ethylene-tetraacetic acid (EDTA), sodium citrate, glycine, and oxalate--at approximately 1 x 10 to the minus 6th power M, and humic matter at 2 mg/L increased embryo survival. EDTA and humic matter were the most effective chelators; EDTA significantly increased survival at 100 micrograms copper/L and humic matter at 40 micrograms copper/L. The ability of a chelator to increase survival was related to the stability constant of the copper-chelator complex.

Heath, W A. & S. Dobie (2000)
Shellfish production on British Columbia's north coast: An industry in transition.
Bull. Aquacu1t. Assoc. Can. 100: 14-22

The North Coast area of British Columbia produces over $50 million in annual shellfish landings, representing more than 50% of the province's total commercial shellfishery harvest, including geoduck, razor clams, Dungeness crab, spot prawns, red sea urchins and sea cucumbers. In this biologically rich region, the farming of shellfish has not yet developed to a commercial scale, although there is considerable interest in it. A series of projects was initiated to explore the feasibility, training and planning issues around shellfish farming in this frontier region and to address other constraints, such as provision of marine biotoxin monitoring. In the current project, experimental trials with the Japanese scallop (*Patinopecten yessoensis*) were conducted at sites in the Queen Charlotte Islands/Haida Gwaii, starting in November 1997. At two off-bottom culture sites (Skidegate Inlet and Rennell Sound), favourable results for scallop growth (609 mm/month) and survival (over 90%) indicate that subsurface suspended culture is biologically feasible in these areas, but is not advisable in the more brackish Masset Inlet. Experimental growout of Pacific oysters (Crassostrea gigas) at a near-surface suspended (tray) culture site in Renne11 Sound yielded favourable growth rates (up to 17.4 mm/month), but the issues of access (rough logging road), heavy biofou1ing (e.g., by the mussel, *Mytilus trossulus*) and settlement of sea stars will be significant factors to

manage in any development of commercial shellfish culture. Additional regional constraints to commercial shellfish culture on the North Coast, such as community planning, growing-water classification, marine biotoxin monitoring, training, and transportation issues as are being addressed through special projects and development of a strategy for regional shellfish development. Shellfisheries in this region will continue to be important, but in the near future shellfish farming may contribute to seafood industry diversification and sorely needed economic opportunities for north coastal communities in British Columbia.

Hedgecock, D. (1994)

Does variance in reproductive success limit effective population sizes of marine organisms? p: 122-134 IN Beaumont, A.R. [Ed.l. Genetics and evolution of aquatic organisms. Chapman & Hall. London, Glasgow. 534p

Hedgecock, D. (1998)

Crossbreeding to improve Pacific oyster broodstocks: Update of USOA-WRA project

Journal of Shellfish Research 17 (Abstract)

This collaborative project has four major objectives: (1) to test the performance of hybrids made by crossing inbred 1ines, at a commercial scale, (2) to make new inbred 1ines from select pedigreed fami1ies in Oregon State University's Molluscan Broodstock Program, (3) to synthesize trip10ids and eventually tetrap10ids from WRAC inbred 1ines and test their performance, and (4) to enable early detection of metabolic potential for growth by determining the metabo1ic basis of hybrid vigor. Four hybrid spawns have been carried out at the Taylor Resources, Inc., hatchery on Dabob Bay, each yielding 8-10 mi 11 ion seed, which have now been planted in Thorndyke and Samish Bays. In the hatchery, two mixed-hybrid groups grew faster and settle 2-7 days earlier than larvae from typical commercial spawns. DNA markers will be used at harvest to determine the relative performances of different hybrids in these mixed groups and thus the best inbred lines for further crossbreeding. DNA markers are also being used to map genes causing growth heterosis in F2 and F3 hybrid populations. New inbred lines were initiated by sib-mating within the nine, top-performing MBP families grown in Tomales Bay. Seventeen triploid groups have been synthesized with one-, two-, and three-way combinations of inbred-line genomes.

Hedgecock, D. & J. P. Davis (2000)

Improving Pacific oyster broodstock through crossbreeding

Journal of Shellfish Research 19: 614-615

Hedgecock, D. & F. Sly (1990)

Genetic drift and effective population sizes of hatchery propagated stocks of the Pacific Oyster *Crassostrea gigas*

Aquaculture 88: 21-38

Using starch-gel electrophoresis, we scored genetic differences for 14 polymorphic enzymes among individuals from three Pacific oyster populations: natural set from Dabob Bay, Washington, and two cultivated stocks. The stocks were each derived from the Dabob Bay wild population and reproductively isolated from this population and from each other for three generations via hatchery propagation and separate rearing on commercial growout beds in Willapa Bay, Washington, and Humboldt Bay, California. Compared with the wild population, one of the two cultivated stocks had significantly fewer alleles per locus, but proportions of polymorphic loci and average heteozygosities were not statistically different among the three population samples. Hatchery-propagated stocks differed markedly in allelic frequencies from each other and from the wild population at most loci. Allelic frequencies in the Dabob Bay sample are assumed to represent those in the progenitors of the hatchery stocks. Average per locus allele-frequency variances between the progenitor and derived hatchery populations are normally distributed after appropriate transformation, indicating that divergence of hatchery stocks from Dabob Bay population owes to random genetic drift. Based on the inverse relationship between the magnitude of random genetic drift and effective population size (Ne), the per-generation effective sizes of the two commercial oyster stocks

are calculated to be only 40.6 .+-. 13.9 (s.d.) and 8.9 .+-. 2.2 (s.d.) for the Willapa Bay and Humboldt Bay stocks, respectively. These estimates account well for the loss of alleles in these hatchery-propagated stocks. Analysis of allele-frequency drift is recommended over simple comparisons of genetic diversity for revealing the extent and nature of genetic change in reproductively isolated aquaculture stocks

Hedgecock, D., K. Nelson, & M. A. Banks (1991)
Does variance in reproductive success limit effective population sizes of marine organisms? A proposed test in the Dabob Bay population of Pacific oysters, using enzymatic amplification of mitochondrial DNA
Journal of Shellfish Research 10: 237

Estimates of long-term effective population sizes (N sub (e» derived from studies of biochemical genetic variation are several orders of magnitude less than actual population sizes for most organisms, including marine fish and shellfish species. Two independent estimates of N sub (e) for the American oyster *Crassostrea virginica*), for example, are on the order of 10 super(5), in contrast to annual landings of 10 super (10) individuals. Large variance in reproductive success, made possible by great fecundity and mediated by sweepstakes recruitment success of broods, would explain such discrepancies. This hypothesis predicts (1) lower genetic diversity in cohorts of larvae or spat than exists in the adult breeding population and (2) temporal variance in allelic frequencies owing to random genetic drift. Drift of allozyme frequencies and a 10 super (4)-fold discrepancy between effective and actual population sizes have been observed for Pacific oysters (*C. gigas*) in Dabob Bay, WA. The polymerase chain reaction (PCR) was used to amplify maternally inherited mitochondrial DNA sequences from single larvae, spat and adult Pacific oysters; these genes are being sequenced to determine polymorphic nucleotide sites suitable for typing using sequence-specific o1igonucleotide probes.

Hedgecock, D. & A. M. Robinson (1992)
Report of the Kumamoto Brood Stock Workshop. Held in Portland, Oregon on January 24,1992. Oregon State Univ., Corvallis. Sea Grant Program. Report No.: ORESU-W-92-002 1992 22p

United States The west coast oyster industry should take immediate steps to preserve the genetic integrity and diversity of its Kumamoto oyster brood stocks. Employing currently available diagnostic methods, the initial steps for identifying pure Kumamoto brood stock would be: (1) strict selection of candidates with Kumamoto morphology and growth history; (2) nondestructive (thermal) induction of spawning; (3) testing of sperm for inability to fertilize Pacific oyster eggs; (4) sampling of larvae for mitochondrial DNA typing; (5) sampling of progeny at an early juvenile stage for enzyme typing; (6) conservation of brood stock whose progeny are diagnosed as pure Kumamoto and culling of those individuals whose progeny carry Pacific oyster genes.

Hedgpeth, J. W. & S. Obrebski (1981)
Willapa Bay: A Historical Perspective and a Rationale for Research Fish and Wildlife Service, Washington, DC. Office of Biological Services. Report No.: FWS/OBS-81/03 Apr 81 pp63

Willapa Bay on the Washington coast has been a principal center for production of oysters since the 1850's. Previous research is discussed and several research issues are considered. These include the importance of eelgrass, the effect of drainage basin runoff, effects of dredge and fill, why certain areas favor oyster production, and the significance of microorganisms

Henderson, B.A. (1982)
Practical methods of handling and setting eyed-pediveligar larvae of the Pacific oyster *Crassostrea gigas* (Thurnberg);
Journal of Shellfish Research 2: 119-120

Heritage, G. D. (1981)
Blue mussel (*Mytilus edulis*) culture in south coastal British Columbia
Journal of Shellfish Research 1: 132-133

Heritage, G. D. & N. Bourne (1980)

Sampling Pacific oyster *Crassostrea gigas* Thunberg larvae and predicting spatfall in Pendrell Sound, British Columbia.

Proceedings National Shellfisheries Association 70: 126

Hershberger, W. K., J. A. Perdue, & J. H. Beattie (1984)

Genetic selection and systematic breeding in Pacific oyster culture

Aquaculture 39: 237-245

Oyster (Crassostrea gigas) culture in the Pacific Northwest has seen many technological improvements in the past 5 years. Among the most important of these improvements are the ones that have made possible an increased reliance on hatchery-produced seed. Because of these developments various sources predict that by 1985 virtually 100% of the seed uti1ized in the Pacific Northwest will come from hatcheries. This increased reliance on hatchery-produced seed and industry diversification suggests that a more organized approach to genetic strain development would be beneficial. The benefits of such an approach are illustrated by the results of a program currently underway at the University of Washington.

Hershberger, W. K., J. H. Beattie, N. Pongthana, & K. K. Chew (1988)

Genetic improvement of the Pacific oyster (*Crassostrea gigas*) far commercial production

Journal of Shellfish Research 7: 163

Genetic research at the University of Washington has investigated several approaches to the enhancement of production traits in Pacific oysters. First, a selection and breeding approach developed stocks of oysters resistant to summer mortality. These stocks have only been minimally employed in commercial production. As a side benefit of this program, lines were produced that exhibited increased levels of glycogen, compared to natural, or non-selected hatchery stocks. Further genetic work with this trait indicated it is highly heritable and could potentially be valuable to increasing product quality. The second approach used has been interstock breeding to determine the influence of heterosis on growth and other production traits. Results suggest that genetic differences are consistent over environments, although there are some genotype X environment interactions.

Hodgson, C. A., W. A. Heath, N. Bourne, & W. Heath (eds.) (1992)

Shellfish culture in British Columbia

Bull. Aquacult. Assoc. Can., No. 92-4

Shellfish farming in British Columbia is in a growth phase, with steadily increasing production of Pacific oysters, the main cultured species, and recent diversification into culture of Manila clams, Pacific scallops and mussels. Oyster production reached 4,500 tonnes with a farmgate value of C$3.5 mill ion in 1991. Clam farm production was only 60 t, valued at C$175,000 in 1991, but will increase rapidly as 70 licensed clam tenures come into full production. Commercial culture of Pacific or Japanese scallops and blue mussels are in the early stages of development with minimal reported production. Although there are several limiting factors to further development of shellfish culture in BC, the prospects of continued growth and economic development are very good.

Holliday, J. E., G. L. Allen, J. Frances, & L. P. Diver (1993)

Evaluation of commercially-used collectors for Sydney Rock Oysters, *Saccostrea commercialis* and Pacific Oysters, *Crassostrea gigas.*

Aquacultural Engineering 12: 63-79

Ten types of commercially-used collectors were evaluated for natural settlement and retention of juvenile Sydney rock oysters (*Saccostrea commercialis*) and barnacles (*Balanus* spp.), over 271 days in Port Stephens, NSW, Australia. Juvenile Sydney rock oysters (spat) from six collector types were then removed and on-grown in timber and PVC mesh trays for 14 days, to assess whether collector type affected post-harvest survival Retention and growth of Sydney rock oysters to market size were also assessed 843 days

after deployment, on five types of collectors used for on-growing. Nine of the collector types were also evaluated as substrates for settlement of Pacific oysters (*Crassostrea gigas*) in Port Stephens. Density at settlement and retention of juvenile and adult oysters was higher on PVC collectors than on traditionally-used tarred sticks. Density of Sydney rock oyster spat, was higher ($P < 0.05$) on five types of PVC collectors, and the bioresin slats than on tarred sticks. Retention of spat on four types of PVC collectors was also higher ($P < 0.05$) than on tarred sticks between 172 and 271 days. There was a significant relationship ($p < 0.001$) between oyster density at day 172 and spat losses at day 271. More barnacles settled on tarred sticks than on other substances ($P < 0.05$). Post-harvest survival of single Sydney rock oyster spat 14 days after removal from collectors was high (89-94%) and similar ($p > 0.05$) for four types of PVC collectors and tarred sticks ($p < 0.05$). However, survival of spat removed from bioresin slats was lower (66.8%). At harvest (day 843), the highest ($p < 0.05$) number of market size Sydney rock oysters were retained on four types of PVC sticks and the lowest number on tarred sticks. With the exception of flat spiky PVC sticks, which had a higher percentage loss than round spiky PVC sticks ($P < 0.01$), oyster losses between day 1 72 and harvest for all five types of on-growing collectors were uniformly high (range 92.6-96.5%; $P > 0.05$), despite the differences in initial spat density. Spat density of Pacific oysters was higher ($p < 0-001$) on three types of PVC collectors than on tarred sticks, PVC slats and bioresin slats.

Horner, R. A., D. L. Garrison, & F. G. Plumley (1997)
Harmful algal blooms and red tide problems on the US west coast
Limnology and Oceanography 42: 1076-1088

On the U.S. west coast, the main toxin-producing algal species are dinoflagellates in the genus *Alexandrium* that cause paralytic shellfish poisoning (PSP) and diatoms in the genus *Pseudo-nitzschia* that produce domoic acid and cause domoic acid poisoning (DAP). Other harmful species, including the raphidophyte *Heterosigma nkashiwo* and the diatoms *Chaetoceros convolutus* and *Chaetoceros concavicornis*, kill fish at aquaculture sites, but are not harmful to humans. Water discolorations (red tides) caused by nontoxic dinoflagellates also occur throughout the area. Early records, partially based on local native lore, suggest that algal toxins have been present along this coast for hundreds of years, but actual scientific information is sparse. We review what is now known about harmful algal blooms in this vast area, including the hydrographic regimes that induce and (or) support blooms, bloom dynamics, and the biology of the causative species.

Horner, R. A , M. B. Kusske, B. P. Moynihan, R. N. Skinner, J. C. Wekel1 (1993)

Retention of domoic acid by Pacific razor clams, *Siliqua patula* (Dixon, 1789): Preliminary study.
Journal of Shellfish Research 12: 451-456

Domoic acid concentrations up to 160 mu-g g-l shellfish meat were reported in razor clams on the Washington/Oregon coasts in the fall of 1991. Toxin levels in the clams remained above the regulatory closure level of 20 mu-g g-l for at least 6 months. In summer, 1992, razor clams, averaging about 10 mu-g g-l of domoic acid toxin, were maintained under laboratory conditions to determine how long it would take them to be free of the toxin. Periodically, edible (foot, siphon, and mantle) and non-edible (gi II, digestive gland, and gonad) parts were tested for domoic acid. After 86 days, toxin levels remained near the original levels, but at least one clam in each group of six tested contained ca 22 mu-g g-l reflecting the clam-to-clam variabi1ity in their natural habitat. It appears that razor clams are able to depurate domoic acid in their natural environment, but may maintain a low level of domoic acid for long periods.

Horner, R. A & J. R. Postel (1993)
Toxic diatoms in Western Washington waters (US West Coast)
Hydrobiologia 269: 197-205

Members of the planktonic diatom genus *Pseudonitzschia* H. Peragallo, *P. pungens* (Grun.) Hasle *f. multiseries* (Hasle) Hasle and *P. austral* is Frenguelli, that may produce the marine biotoxin, domoic acid, have been recognized in western Washington waters. Their distribution is not well-known in this area, probably because they often have been misidentified. However, they appear to be relatively common and

may be abundant, especially in late spring and summer. Domoic acid, a potent neurotoxin, was found at levels up to 154 mu g g(-l) wet weight in razor crams, *Siliqua patula* Dixon, and *Dungeness crabs*, Cancer magister Dana, on the Pacific coast of Washington in late October 1991. It was also found in trace amounts in blue mussels, *Mytilus edulis* L., and oysters, *Crassostrea gigas* Thun., in the inland waters of northern Puget Sound in summer 1992. The presence of these potentially toxic diatoms signals the need for regular phytoplankton monitoring and additional shellfish monitoring to ensure that seafood is safe for human consumption. Further, studies are needed on the physiological ecology of the diatoms to determine the causative factors leading to production of the toxin.

Horner R. A & J. R. Postel (1993)
Domoic acid in western Washington waters.
Journal of Shellfish Research 12: 141-142

Humphries, M. (1980)
The Mariculture of Oysters: A Grower's Point of View. IN Lorimer, R & S. E. McMullin, (eds) Canada and the Sea, I. Resources of the Marine Environment: East and West Coast. Canadian Issues. Association for Canadian Studies, Willowdale, Ontario (Can). 3: 63-67

A system of oyster (*Crassostrea gigas*) culture was developed by private growers in British Columbia. The raft-culture approach offers a number of advantages over conventional bottom culture but requires a high initial capital equipment cost and is labour intensive. The potential for development is great for mariculture but depends upon there being a healthy marine environment.

Imber B. E., J. A. J. Thompson, & S. Ward (1987)
Metal-binding protein in the Pacific oyster, *Crassostrea gigas*: assessment of the protein as a biochemical environmental indicator.
Bulletin of Environmental Contamination and Toxicology 38: 707-714

Inclan Rivadeneira, R. & M. J. Acosta Ruiz (1989)
The fouling community on rafts for the culture of the Japanese oyster *Crassostrea gigas* in Bahia San Quintin, Baja California, Mexico.
Ciencias Marinas 15: 21-37

From November 1984 to July 1985, an experimental study was carried out using rafts for the culture of *Crassostrea gigas*. Oysters 0.3 cm in length were placed on two rafts in each site; one received a cleaning treatment and the other was left without treatment. Monthly samples of 40 individuals from each raft, morphometric measurements of length and width were obtained. Highly significant differences in length and in width were found by means of a Kruskal-Wall is analysis. Plates made from the same material as the culture system were also placed in order to obtain monthly and accumulative records of the fouling organisms and their biomass. The mechanism through which some species and certain colonization processes manage to cause a negative effect on the growth rates of the cultured oyster is discussed. The biomass of the fouling organisms did not cause problems during the study. However, recommendations are made on the maintenance of this type of culture method.

Iribarne O., D. Armstrong, P. Palacios & M. Fernandez (1992)
Ecological effects of adding bivalve shell to intertidal soft-bottom areas.
Northwest Environmental Journal 8: 153-154

Assemblages of bivalve shells found in the intertidal zone of Grays Harbor estuary (WA) are important habitat for young-of-the-year Dungeness crab (*Cancer magister*). Such assemblages are mostly composed of soft-shell clam (*Mya arenaria*) and cultivated oyster (*Crassostrea gigas*) shells. We observed high densities of small (1 to 2 cm width) juvenile Dungeness crab in existing intertidal shell habitat, and proposed construction of additional shell habitat designed to enhance settlement and survival of small crab. The idea was for this to mitigate for losses of larger Dungeness crab killed during dredging of the Grays

Harbor navigational channel by the Army Corps of Engineers. Experimental shell plots ranging from 100 m super (2) to *4,000* m super (2) were deployed in several parts of the estuary in 1990 and 1991 to evaluate the feasibility *of* this mitigative technique. Eight hectares *of* shell, as full-scale crab mitigation, were deployed in Grays Harbor during the spring *of* 1992. Whether or not addition *of* shell also affects local biodiversity is imp ortant from a management perspective. Controlled field experiments were carried out during 1991 on small patches *of* bivalve shell placed at different densities in several parts *of* the estuary. Results show that construction *of* intertidal shell habitat enhances settlement *of* bivalve species that live on hard substrate (e.g., mussels), but successful settlement varied with soft-bottom clam species like *Mya arenaria, Macoma balthica, M. nasuta,* and *Clinocardium nuttalli*. Physical processes, such as passive accumulation or transport *of* larvae by currents, or impacts *of* predators within the shell may explain differences in survival *of* the soft-bottom clams. Small-scale field experiments show higher mortality *of* adult bivalves (*Mya arenaria* and *Macoma balthica*) when transplanted to artificial intertidal shell habitat in contrast to mud plots on open tideflats. Predation rates by juvenile crab on *Mya arenaria* are sufficiently high to eliminate the newly settled clam population and, consequently, *Mya* is restricted to high intertidal areas where crab predation is very low.

Islas, 0. R., V. Guardado, & A. M. Perez (1982)

Crecimiento y sobrevivencia del astian japones (*Crassostrea gigas*} en la Laguna Manuela; B.C., Mexico.
Ciencias Marinas 8: 47-54

Johnson, K. & D. Skidmore (1982)

Puget Sound mussel studies (cultured);
Journal of Shellfish Research 2: 120

Jones, D. S. & D. K. Jacobs (1992)

Photosymbiosis in *Clinocardium nuttalli* implications for tests of Photosymbiosis in fossil molluscs
Palaois 7: 86-95

The endosymbiotic association between the heart cockle, *Clinocardium nuttalli*, and an endosymbiotic green alga (zoochlorella) was investigated in the field and laboratory. Specimens were obtained from False Bay, San Juan Island, Washington [USA]. Infaunal clams did not contain symbionts while slightly larger and older semi-infaunal individuals harbored algae in siphonal and mantle tissues. Epifaunal clams were the largest and oldest (up to six years old) and contained the greatest concentration of algae. The three mode-of-1ife groups apparently represent an ontogenetic continuum with progressive emergence from the substrate related to the acquisition of algal symbionts after the clams' second year of life. No symbiont-induced effects were observed on either shell growth rates or on oxygen and carbon isotopic composition of shell carbonate. Several aspects of the photosymbiotic relationship of C. nuttalli (and other photosymbiont-bearing bivalves) contradict ecological, morphological, geochemical, and life history characteristics traditionally used to recognize such associations in the fossil record. While these characteristics remain valid as supporting arguments for suspected cases of paleophotosymbiosis, paleontologists are cautioned that numerous photosymbiotic taxa do not display these characteristics and hence many cases of paleophotosymbiosis probably go undetected. Paleontologists are encouraged to develop better criteria for recognizing photosymbiotic molluscan hosts.

Jones, G. & B. Jones (1988)

Advances in the remote setting of oyster larvae.
Ministry of Agriculture and Fisheries, Victoria, B.C. (Canada) pp88.

The emphasis of this report is on the tank setting of artificial cultch of Pacific oyster, *Crassostrea gigas.*

Jones R R., C. Schwarz & L. Lee (1998)
Intertidal population estimate of razor clams (*Siliqua patula*) at beaches near Nasset, Naida Gwaiil Queen Charlotte Islands, and applications to fishery management.

Canadian Special Publication of Fisheries and Aquatic Sciences 125: 199-211

Jones, T. O. & G. K. Iwama (1989)
The influence of a commercial salmon farm upon suspended culture of the Pacific oyster, Crassostrea gigas
Journal of Shellfish Research 8: 413-414

The objective of this study is to determine the suitability of culturing Pacific oysters and salmon in one site. This project investigates the possible effects of a salmon culture facility on oyster growth by monitoring any variations in temperature, salinity and available food. Absolute Growth, Condition Indices, Dry Meat Weight:Dry Shell Weight Ratio and Survival Rate were determined for a common broodstock of oysters grown in Jervis Inlet, British Columbia, Canada over a 3 month period. Six stations were utilized at the salmon grow out facility and 2 controls were implemented at traditional oyster culture sites. The potential for bioaccumulation of antibiotics will be analysed during the fall by establishing measurement techniques for antibiotic residues from oysters collected during the study.

Jones, T. O. & G. K. Iwama (1990)
Polyculture of the Pacific oyster, *Crassostrea gigas* (Thunberg), with chinook salmon, *Oncophynchus tshawytscha*
Aquaculture Association of Canada Conf. Halifax, N.S. (Canada) 10 Jun 1990 pp. 79-82

The growth and condition indices of year-one oysters (*Crassostrea gigas*) were compared over a 5-mo period between stations located at a commercial chinook salmon (*Oncorhynchus tshawytscha*) farm and at control stations located at commercial oyster leases away from any salmon farm. Increase in shell heights of oysters suspended at the salmon farm were as great as 3 times ($p < 0.01$) those at the control stations.

Jones, T. O., J. N. C. Whyte, L. D. Townsend, N. G. Ginther; & G. K. Iwama (1994)
The effects of domoic acid on haemolymph pH, PCO-2 and PO-2 in the Pacific oyster, Crassostrea gigas and the California mussel, *Mytilus californianus.*
Canadian Technical Report of Fisheries and Aquatic Sciences 2016: 19

Kaysner, C. A. (1989)
Vibrio species of the USA West Coast
Journal of Shellfish Research 8: 449-450

Kilbride, K. M. & F. L. Pavegio (2001)
Long-term fate of glyphosate associated with repeated Rodeo applications to control smooth cordgrass (*Spartina alterniflora*) in Willapa Bay, Washington.
Archives of Environmental Contamination and Toxicology 40: 179-183

Cordgrasses (*Spartina* sp.) are exotic, invasive species that threaten to degrade the intertidal zones of estuaries along the West Coast of North America. Integrated pest management (IPM) strategies primarily focus on the use of aerial and ground applications of Rodeo(R) in conjunction with mowing, but IPM treatments over multiple years usually are necessary to control *Spartina*. Although information exists regarding the short-term fate and effects to marine biota of a single Rodeo(R) application to control *Spartina*, 1ittle information is available regarding the fate and biotic effects associated with repeated Rodeo(R) applications necessary for control. Consequently, we conducted a 3-year study to assess the short- and long-term fate and potential effects to marine biota associated with repeated applications of Rodeo(R) to control smooth cordgrass in la southwestern Washington estuary. At each of three intertidal locations In Willapa Bay, we established plots on exposed mudflats and along the edge of a *Spartina* meadow that were hand sprayed with Rodeo(R) (5% solution) and LI-700(R) (2% solution) during July 1997 and 1998. Glyphosate concentrations in sediment from mudflat plots declined 88% to 96% from 1 day

post-treatment in 1997 to 1 year after the second Rodeo(R) applications in 1999. In contrast, glyphosate (cont. next page) concentrations in Spartina plots increased 231% to 591% from 1997 to 1999 because *Spartina* rhizomes 1ikely did not readily metabolize or exude it. Comparison of concentrations from mudflat and *Spartina* plots with toxicity test values for marine biota indicates that under worst-case conditions short- and long-term detrimental effects to aquatic biota from repeated application of Rodeo(R) for *Spartina* control would be highly unlikely.

Kittel, M. T. (1998)
Comparative analysis of Tasmanian Pacific oysters, *Crassostrea gigas*, after growout in Washington State.
Journal of Shellfish Research 17: 329

Kittel, M. T. (1999)
Tasmanian Pacific oysters, *Crassostrea gigas*, in Washington state: A morphological, physiological, and molecular genetic analysis of an introduced population
Dissertations International v. 60/11-B, p. 5262. pp221.

Domestication by selective breeding requires specific knowledge of performance-related traits in commercially exploited aquaculture species. A small number of deep-cupped Pacific oysters, *Crassostrea gigas*, were transferred from a Tasmanian shellfish hatchery to Washington state. Thirty-four of these were spawned to estab1ish an Fl generation. Fl Tasmanian oysters were grown in the field in comparative growout trials and their survival, growth rate, and shell morphology were monitored. During the second year of the experimental growout, Tasmanian F_l and control oysters were examined for patterns of gonadogenesis and glycogen storage. A110zyme frequencies were calculated for 21 loci to assess genetic variabi1ity and the magnitude of a possible founder effect. Nuclear and mitochondrial DNA sequences were amp1ified by the polymerase chain reaction (PCR) and examined for restriction fragment length po1ymorphisms (RFLPs) and sequence variation. The Tasmanian Fl oysters experienced 40% fewer mortalities and attained significantly greater shell length and higher whole weight and volume than controls. Seasonal pro1iferation of gonadal tissue and dec1ines of glycogen stores showed no significant differences. There was no overall heterozygote deficiency or decreased heterozygosity or polymorphism among Tasmanian Fl oysters. However, there was a 19% overall reduction in a11e1ic variation due to the loss of ten previously described rare alleles in the Fl generation. Restriction of a 2,100 bp fragment of the nuclear rDNA array with 45 endonucleases produced no population-specific haplotype. Partial sequencing of the mitochondrial cytochrome b gene revealed a C→T transition with a frequency of 50% among Tasmanian Fl oysters. The introduced oysters may increase productivity as a pure stock in areas of high mortality or through hybrid vigor in crosses with selected 1ines of local C. gigas. Adequate numbers of broodstock animals should be used in maintaining the Tasmanian oyster population to prevent further erosion of genetic variability.

Kittel, M. T. & K. K. Chew (1995)
Experimental growout of F-l Pacific oysters, *Crassostrea gigas*, from Tasmania in Washington state waters.
Journal of Shellfish Research 14: 579

Kittel, M. T. & K. K. Chew (1996)
Tasmanian Pacific oysters, Crassostrea gigas, in Washington State: Characterization of a transplanted population
Journal of Shellfish Research 15 (Abstract)

In 1995, 32 Pacific oysters from Tasmania, Australia, were artificially spawned in quarantine in the state of Washington and the resulting F sub(l) generation was outplanted at three different locations of Puget Sound. We have begun studies to characterize these oysters at several levels. Survival, growth rates and shell morphology of oysters grown under different environmental regimes are determined and compared to similar data from C. gigas of local origin. Patterns of gametogenesis and glycogen storage will be examined from histological sections of oysters taken over the period of one growing season. The ability of the

imported oysters to form viable hybrids with C. gigas of local origin and closely related species such as C. sikamea will be determined from reciprocal crosses between selected oysters. Molecular analysis of the transplanted oysters will focus on establishing their species identity and genetic relatedness to local C. gigas populations. Preliminary findings of some of the ongoing studies wi11 be presented.

Kittel, M. T. & K. K. Chew (1998)
Survival, growth, and patterns of sexual maturation of Tasmanian Pacific oysters, *Crassostrea gigas*, in Washington State
Journal of Shellfish Research 17

The F sub(l) generation of Tasmanian Pacific broodstock oysters, *Crassostrea gigas*, transferred from Tasmania to Washington state in 1994, was studied in comparative growout trials and laboratory analyses. Survival, growth, and shell morphology data were collected over an 18-month period from the Tasmanian oysters and control C. gigas of local origin. Seasonal changes in gonadal proliferation and glycogen storage were determined by quantifative histological examination and biochemical analysis of glycogen content. Results of these studies show that the F sub(l) progeny of the introduced oysters experienced significantly fewer mortalities at one of the experimental growout sites. In addition, the Tasmanian oysters attained a significantly greater shell length, whole volume, and whole weight than the controls. Patterns of gonadogenesis and glycogen storage are presented. A molecular genetic analysis by allozyme electrophoresis and PCR-RFLP methodology to characterize the introduced oysters as a distinct population is in progress. Based on their performance during the experimental grow-out, these Tasmanian oysters may be of value to oyster growers as distinct stocks or as broodstock for intraspecific hybridization.

Kittel , M. T. & K. K. Chew (2000)
Growth, shell morphology, reproductive physiology, and molecular genetic analysis of Tasmanian Pacific oysters, *Crassostrea gigas*, in Washington State.
Journal of Shellfish Research 19: 615-616

Konar, B. & M. D. Stephenson (1995)

Gradients of subsurface water toxicity to oyster larvae in bays and harbors in California and their relation to mussel watch bioaccumulation data.

Chemosphere 30: 165-172

Crassostrea gigas larval toxicity tests were conducted on subsurface water samples collected from various California harbors ranging from San Francisco Bay to Newport Bay in southern California. The purpose of this study was to evaluate this test as an ambient toxicity monitoring tool and to attempt correlation of toxicity data with tissue contaminant concentrations. Los Angeles, Moss Landing and Richmond harbors showed trends of increasing toxicity with distance from the mouth of each harbor. These results were also compared to synthetic organic and metal tissue contaminant data collected by the California State Mussel Watch program. Increasing toxicity was significantly correlated with increasing tissue concentrations of lead, copper, silver, zinc, chlordane, endosulfan, dieldrin and PCB in some harbors (Richmond, Moss Landing, Los Angeles and Newport). Other harbors (Monterey, Santa Cruz and Redwood Creek) showed no correlations. However when data from all the harbors were combined there were no significant correlations between bioassay toxicity and contaminants found in mussels. For individual harbors, it is recommended that both accumulation data and bioassay data should be used in conjunction to assess toxicity in harbors.

Kruzynski, G. M. (2000)

Cadmium in BC farmed oysters: A Review of available data, potential sources, research needs and possible mitigation strategies
Canadian Stock Assessment Secretariat, Ottawa (Ontario). Research document no. 2000/10437p

In response to a request by the Canadian Food Inspection Agency (CFIA), the Department of Fisheries & Oceans undertook to investigate the potential reasons for apparently elevated cadmium levels in British Columbia cultured Pacific oysters (*Crassostrea gigas*). Earlier in the year, CFIA reported that several shipments of BC farmed oysters had been rejected by the Hong Kong market for being in excess of their cadmium concentration limits. A preliminary literature search was conducted, contacts were made with shellfish growers & processors, both Government & academic researchers were consulted, and the resulting information is synthesized in this report. Since there are no historical baseline data on cadmium residues in BC cultured oysters, residue data on wild intertidal oysters collected over 1973-99 were used as a comparison. These were mapped & overlaid on current CFIA 2000 oyster data to determine the source of the cadmium & suggest factors involved in the cadmium concentration levels observed in the oysters. Maps showing the relationship of BC coastal geology & existing stream sediment cadmium data to oyster-growing areas are provided. Several hypotheses on cadmium pathways from both marine & terrestrial sources were gleaned from the literature, and potential applications to the British Columbia situation are proposed.

Kuiper, T. (1991)
Shellfish production: Some do's and don'ts IN Nosho, T.Y.; Chew, K.K. (eds.);
Remote Setting and Nursery Culture for Shellfish Growers: Workshop Olympia, WA
(USA) 19 Feb 1991 pp. 34-41, (1991). Washington Sea Grant Program, Seattle, WA

Kuiper Mariculture, Inc., has been producing oyster and clam seedlings for commercial sale since 1980 and bay mussel seed since 1986. They supply more than a hundred farms in the Pacific Northwest, Mexico, and Europe with about 150 million seed per year. Their niche in the shellfish industry is to supply small seed (5-30 mm) that is suitable for further nursery rearing by growout companies. Most of the farms supplied have their own nurseries, either for cultch setting or, in the case of single seed, for adding growth to the seed to reach a size for final growout. The focus this paper is to share some experiences, both good and bad, describing the development of nursery techniques over the last eleven years. Topics detailed include: larval setting of Manila clams, Pacific oyster, and mussels; seed culture after settlement; nursery culture; and planning and management.

Landsberg, J. H. (1996)
Neoplasia and biotoxins in bivalves: Is there a connection?
Journal of Shellfish Research 15: 203-230

In the past 25 years, there has been an increase in the frequency of two major types of cancer in bivalves: disseminated neoplasia and germinomas, which cause debilitation and mortality in shellfish stocks. Disseminated neoplasia is common in softshell clams, *Mya arenaria*; the cockle, *Cerastoderma edule*; and blue mussels, *Mytilus trossulus*; and less common in edible oysters, *Ostrea edulis*; macomas, *Macoma balthica*; blue mussels, *Mytilus edulis*; and Olympia oysters, *Ostrea conchaphila*. Germinomas occur more frequently in northern quahogs, *Mercenaria mercenaria*, and softshell clams, *Mya arenaria*. Certain geographical locations, especially along the northwest Pacific and northeast Atlantic Coasts of North America and the Atlantic Coast of Europe, are “hotspots” for neoplasia. A genetic susceptibility of bivalves to tumor formation has been suggested, and the etiologies proposed include chemical carcinogens, viruses, and other transmissible agents. However, no clear cause-and-effect relationship has yet been conclusively demonstrated, nor has the potential role of biotoxins as etiological agents been examined. In the past 25 years, there has also been an increase in the frequency with which humans have been poisoned by consuming toxic bivalves. Filter-feeding bivalves accumulate biotoxins produced by toxic microalgal blooms. This study traces the worldwide distribution of paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning, and venerupin shellfish poisoning and of the microalgae and bivalve species associated with the poisonings and then compares these distributions with the distribution of neoplasia in bivalves. The incidence of disseminated neoplasia in some affected bivalve species appears to parallel, both spatially and temporally, outbreaks of PSP that are associated with the toxigenic dinoflagellates *Alexandrium tamarense, A. minutum, A. fundyense*, and *A. catenella*. Shellfish that have accumulated potent saxitoxin and its derivatives (neosaxitoxin and

gonyautoxins) produced by these dinoflagellates are highly toxic to humans. The presence of disseminated neoplasia parallels the presence of certain toxin derivatives in both the bivalve and the *Alexandrium* spp. to which the bivalves are exposed. Disseminated neoplasia is common in softshell clams, M. arenaria, that have apparently been exposed to and have accumu lated gonyautoxins, (GTX) , and in particular GTXl and GTX4, that are produced by *A. tamarense* or *A. fundyense. M. mercenaria* is apparently not affected by disseminated neoplasia and does not usually accumulate toxins associated with *A. tamarense* or *A. fundyense*. Bivalves that accumulate high concentrations of saxitoxin or neosaxitoxin, such as butter clams, *Saxidomus giganteus*; surf clams, *Spisula solidissima*; sea scallops, *Placopecten magellanicus*; and California mussels, *Mytilus californianus*, are apparently not affected by disseminated neoplasia or germinomas. In *M. arenaria*, the incidence of germinomas appears to be related to the distribution of *Alexandrium* spp. blooms. In *M. mercenaria*, however, the distribution of germinomas is not related to those *Alexandrium* spp. that are commonly associated with PSP. The incidence of disseminated neoplasia and germinomas is not correlated with PSP outbreaks associated with *Pyrodinium bahamense var. compressum* or *Gymnodinium catenatum.* Although the epizootiological evidence presented here for a correlation between dinoflagellate toxin profiles, the deposition of toxins in bivalve tissues, and the presence of neoplasia in such bivalves is circumstantial, it should be investigated in field and laboratory experiments.

Langdon C. J, D. P. Jacobson, F. Evans, E. & S. E. Matson (2000)
Development of a specific-pathogen-free (SPF) hatchery and nursery for production of Pacific oyster seed.
Journal of Shellfish Research 19: 688

Langdon C. J. & A. M. Robinson (1991)
Development of the commercial aquaculture of the Suminoe oyster (*Crassostrea rivularis*)
Journal of Shellfish Research 10: 238

The Suminoe oyster (*Crassostrea rivu1aris*) has been introduced from Japan in several localities on the west coast, USA. The species is not widely cultivated, despite its reported high growth rate in the Yaquina Bay, Oregon. The potential value of the Suminoe oyster as a commercial species on the west coast, USA, was examined. In the Yaquina Bay, female Suminoe oysters became sexually mature in late summer with peak gonadal maturation occurring in October. In contrast, female Pacific oysters were mature in May with peak gonadal maturation occurring in September. Sexual maturation of adult Suminoe oysters could be successfully accelerated by collecting broodstock oysters from the Yaquina Bay in mid-March and holding them in flowing seawater at 20 degree C for 4 to 6 weeks. Larvae were successfully raised to setting and metamorphosis by culturing them for 3 weeks in 0.7 mu m-fi1tered seawater on a mixed diet of the flagellate *Pseudoisochrysis paradoxa* and the diatom Chaetoceros calcitrans. Growth of planted hatchery-raised Suminoe spat was superior to that of same-age Pacific oyster spat in several localities on the west coast. Comparative tests indicated that the appearance of the Suminoe oyster on the half-shell was preferred to that of the Pacific oyster.

Langdon C. J. & A. M. Robinson (1996)
Aquaculture potential of the Suminoe oyster *Crassostrea ariakensis* Fugita 1913).
Aquaculture 144: 321-338

Oyster production on the West coast of the USA is almost entirely dependent on the culture of the Pacific oyster Crassostrea gigas. Commercial production of the Suminoe oyster *Crassostrea ariakensis* is presently 1imited to a few bays in Washington, Oregon and California. The objective of the present study was to determine the aquaculture potential of the Suminoe oyster for the West coast, USA. Female Suminoe oysters became sexually mature about 3 months later than Pacific oysters in Yaquina Bay, OR. Suminoe oyster broodstock could be successfully conditioned at 20 degree C for spawning from mid-March until mid-October. Larvae were cultured and successfully set by feeding them on a microalgal diet of the flagellate *Pseudoisochrysis paradoxa* (VA-12) during the first 7 days of culture and then a diet made up wholly or partly of the diatom species Chaetoceros calcitrans during subsequent weeks of culture. Growth and setting of larvae were greatest at a salinity of 15 to 20 ppt. No successful settlement occurred at 35 ppt

salinity. Both Suminoe and Pacific oyster spat grew best at 25 degree C and a salinity of 25 to 35 ppt. Growth of Suminoe oyster spat was less sensitive to sub-optimal temperature and salinity conditions than Pacific oysters. In grow-out trials conducted from 1989 to 1993 on the West coast, USA, final shell lengths of Suminoe oysters were significantly less than those of Pacific oysters, but there were no significant differences in tissue dry weights. Both Suminoe and Pacific oysters reached market size for the half-shell trade (60 to 70 mm shell length) 12 to 18 months after planting. Consumer acceptability tests indicated that Suminoe oysters were equal or superior to Pacific oysters in appearance, taste and texture

Langdon, C. J. (1998)
Update on the molluscan broodstock program
Journal of Shellfish Research 17 (Abstract)

The primary focus of the Molluscan Broodstock Program (MBP) is the genetic improvement of Pacific oysters through genetic selection. Pairs of oysters from either Willapa or Dabob Bay 'wild' populations were crossed to produce about 150 full-sib fami1ies. The families were planted at five commercial sites along the West coast, U.S.A. Survival, growth and meat yields of planted fami1ies will be compared when they reach market size and top performing fami1ies will be used to produce the next MBP generation. Interim 1ive weights of fami1ies planted in 1996 were measured at sites in south Puget Sound and Willapa Bay in summer 1997 to determine if it will be possible to predict final rankings of fami1ies at market size from their relative 1ive weights after about 10 months of growth. At both sites we have found significant differences in 1ive weights of families, with some families weighing almost twice as much as other families at the Puget Sound site. Six families were ranked among the top 15 families of both sites, indicating that these families performed well at both sites, despite environmental differences.

Langdon, C., D. Jacobson, S. Matson, F. Evans, & M. Blouin (2001)
Genetic-environment interaction effect on yields of Pacific oysters planted at subtidal and intertidal sites
Aquaculture 2001, World Aquaculture Society, LSU, Baton Rouge, LA.

Crosses were made in 1998 among nine families showing the highest yields (live weight per bag) of 48 fami1ies planted at an intertidal site in Tomales Bay California. The resulting 40 full-sib fami1ies were planted in bags at an intertidal site (I) in Totten Inlet, Puget Sound, Washington, and in lantern nets at a subtidal site (S) in Yaquina Bay, Oregon. In addition, full-sib families derived from crossing non-selected "wild" oysters were planted at these sites as well as groups of oyster seed from various commercial sources. After about two years of growth, oysters were harvested and average family yields determined. The estimated realized heritabilities for yield were 0.42 (I) and 0.37 (S). Family yields varied greatly depending on the parental cross, with the average yield of inbred families being significantly less ($p<0.05$; Fisher's PLSD) than that of out-bred families at both sites. There was no significant difference ($p>0.05$; Fisher's PLSD) between the average yield of industry oysters and that of families from selected broodstock; however, the average yields of the top nine families from selected broodstock were 28% (I) and 20% (S) greater than that of industry oysters. Genetic-environmental interaction effect was determined by comparing family yields at the two sites by regression analysis. There was a significant relationship ($p = 0.049$) between family yields at the two sites, indicating that the genetic-environment interaction effect was small. Six of the top ten families at each site were common to both sites. However, there were exceptions, with the relative performance of some families changing dramatically between sites. Based on these results, it should be possible for industry to significantly improve oyster production by crossing specific selected families as part of a long-term breeding program. Inbreeding should be avoided as it results in significantly reduced yields. The small genetic-environmental interaction effect found in this study indicates that it should be possible to develop generalist families that produce high yields across a wide range of different grow-out environments.

Lannan J. E.; Robinson A.; Breese W. P. (1980)
Broodstock management of *Crassostrea gigas* 2. Broodstock conditioning to maximize larval survival.
Aquaculture 21: 337-345.

Lapota, D., D. E. Rosenberger, M. F. Platter-Rieger, & P. F. Seligman (1993)
Growth and survival of *Mytilus edulis* larvae exposed to low levels of dibutyltin and tributylin
Marine Biology 115: 413-419

Two studies were conducted to observe effects of dibutyltin (DBT) and tributyltin (TBT) on larvae of *Mytilus edulis* for an exposure period of 25 d. Endpoints for evaluation were shell growth and mortality measured at 33 d. Larvae were cultured in a new laboratory assay chamber in a recirculating static test. The control, 2, 20, and 200 mu g/l DBT-treated populations had mean shell lengths of 527, 523, 417, and 180 mu m, respectively. Survival was 1% for the 200 mu g/l DBT-treated population, but ranged from 73 to 83% for controls, 2, and 20 mu g/l treatments. The no-observed-effect concentration (NOEC) was 2 mu g/l for DBT, while the lowest-observed-effect concentration (LOEC) was 20 mu g/l. The chronic toxicity value was 6.3 mu g/l. In the TBT bioassay, mean shell lengths for the control, 0.006, 0.050, and 0.130 mu g/l-treated populations were 565, 437, 385, and 292 mu m, respectively. Control survival was 74%, whereas TBT-treated populations survival ranged from 52 to 58%. The NOEC for TBT was 0.006 mu g/l TBT and the LOEC was 0.050. A chronic toxicity value of 0.017 mu g/l was calculated.

Lassuy, D. R. & D. Simons (1989)
Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest) Pacific Razor Clam
Fish and Wildlife Service, Washington, DC.; Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab. Report No.: FWS-82/11.89; WES/TR/EL-82-4.89 pp24.

Species profiles are literature summaries of the taxonomy, morphology, distribution, 1ife history, ecological role, fishery (when appropriate), and environmental requirements of coastal aquatic species. They are prepared to assist coastal managers, engineers, and biologists in the gathering of information pertinent to costal development activities. The Pacific razor clam has a long history of human consumption on the west coast. Turn-of-the-century commercial canning operations have given way to today's extensive recreational fishery. Razor clams spawn in late spring and early summer in the Pacific Northwest and recruit to flat, sandy beaches in late summer. Greatest densities of large clams occur in the lower intertidal zone. Razor clams grow and mature faster but attain a lower maximum size and age in the southern part of their range. They are noted for their unusual ability to dig very rapidly through the subsurface sand. Silt-generating activities should be avoided in the vicinity of razor clam beaches, as juveniles are susceptible to suffocation.

Leclair, L. L. & S. R. Phelps (1994)
Genetic characteristics and relationships of five Razor clam (*Siliqua patula* Dixon) populations along the Pacific coast of North America.
Journal of Shellfish Research 13: 207-216

We electrophoretically examined razor clams (*Siliqua patula* Dixon) from five intertidal locations along the Pacific coasts of Alaska, British Columbia, Washington, and Oregon to determine the level of genetic variation within the species and among regions. All five locations exhibited high levels of within population genetic diversity. The average heterozygosity ranged from 0.25 to 0.27 and the mean number of alleles per locus ranged from 3.4 to 4.6, based on 24 loci. We found no reduction of genetic diversity within the Washington populations compared to populations that had not experienced large mortalities due to the pathogen NIX. The genetic diversity among regions was low, and alleles that occurred at a frequency of 0.05 or greater in one collection, were generally observed in all other collections. However, we found significant differences in allele frequencies among collections. The most genetically similar populations were the two from Washington, while the greatest genetic differences occurred when the two Washington collections were combined and compared to the Alaska sample. Differences in the susceptibility of razor clams to NIX among locations may have a genetic basis.

Lewis, A. G. & A. Metaxas (1991)
Concentrations of total dissolved copper in and near a copper-treated salmon net pen
Aquaculture 99: 269-276

Total dissolved « 0.45-mu-m) copper was measured inside and outside a copper-treated salmon net pen at the mouth of Jervis Inlet, British Columbia. Collections were made from each of three depths, several times over an incoming tide. The concentration inside the pen was 0.54 (+/- 0.37 s.d.) mu-g 1-1 2 days after a freshly dipped net was installed (July 1988) and 0.54 (+/- 0.20 s.d.) mu-g 1-1 a month later (August). Copper concentrations immediately outside the net were 0.55 (+/- 0.37) and 0.55 (+/- 0.24) mu-g 1-1 on the two sampling dates. Concentrations over the same depth range at a station approximately 700 m away from the net pen were 0.38 (+/- 0.39) mg 1-1 in July and 0.37 (+/- 0.30) mu-g 1-1 in August. Differences between the means (net pen and station) are not significant (to.05). Tidal exchange is suggested to be important in maintaining low dissolved copper concentrations in and near the net pens, by preventing accumulation of copper leached from the nets.

Lilja, J. (1981)
Paralytic shellfish poisoning in Washington State, 1979-1980
Journal of Shellfish Research vol. 1: 133

MacKenzie, C. L, Jr (1996)
History of oystering in the United States and Canada, featuring the eight greatest oyster estuaries
Marine Fisheries Review 8: 1-78

Oyster landings in the United States and Canada have been based mainly on three species, the native eastern oyster, *Crassostrea virginica*, native Olympia oyster, *Ostreola conchaphila*, and introduced Pacific oyster, *C. gigas*. Landings reached their peak of around 27 million bushels/year in the late 1800's and early 1900's when eastern oysters were a common food throughout the east coast and Midwest. Thousands of people were involved in harvesting them with tongs and dredges and in shucking, canning, packing, and transporting them. Since about 1906, when the United States passed some pure food laws, production has declined. The causes have been lack of demand, siltation of beds, removal of cultch for oyster larvae while harvesting oysters, pollution of market beds, and oyster diseases. Production currently is about 5.6 million bushels/year.

MacKenzie, C. L., V. G. Burrell, A. Rosenfield, & W. L. Hobart (1997)
History, Present Condition, and Future of the Molluscan Fisheries of North Central America and Europe. Volume 2, Pacific Coast and Supplemental Topics
National Marine Fisheries Service, Woods Hole, MA. Northeast Fisheries Science Center. Report No.: NOAA-TR-NMFS-128 Dec 97 pp226.

History, Present Condition, and Future of the Molluscan Fisheries of Panama; Mussel Fishery and Culture in Baja California, Mexico: History, Present Status, and Future; The Shellfish Industry of California--Past, Present, and Future; Molluscan Fisheries in Oregon; Past, Present, and Future; The Fisheries for Olympia Oysters, *Ostreola conchaphila*; Pacific Oysters, *Crassostrea gigas*; and Pacific Razor Clams, *Siliqua patula*, in the State of Washington; Molluscan Fisheries of British Columbia; The Molluscan Fisheries of Alaska; The Importance of Shellfisheries to Coastal Communities; Environmental Challenges Facing the Shellfisheries to Coastal Communities; Environmental Challenges Facing the Shellfishing Industry; U.S. Regulatory Strategies for Ensuring the Safety of Molluscan Shellfish; Resource Economics Issues Concerning Molluscan Fisheries in the United States; Mollusk Statistical Data Collection in the United States; Shellfish Marketing in the United States: Past, Present, and Future; United States Trade in Bivalve Mollusks in 1990 and 1991; and Markets for Bivalve Mollusks in the European Community.

Manders, J. C. (1997)
A current analysis of the status and prospects for the culturing of the Pacific oyster, *Crassostrea gigas* (Thunberg) in British Columbia, Canada
Dissertations Internantional 36/03 of Masters p. 741. pp197.

The purpose of this study was to identify the main issues influencing the current status and prospects of a commercial operation for the production of the Pacific oyster (*Crassostrea gigas*) in British Columbia, Canada. In today's increasingly competitive and global market the need to apply an integrated approach has never been more important. The success of an oyster production operation will require certain knowledge and skills, including such things as knowing the level and nature of the international production, understanding the biology and the physical steps to cultivate the Pacific oyster, comprehending the strengths and weaknesses of the marketplace, and managing the financial requirements of a solvent operation. This study had the following objectives: to describe the existing markets for Pacific oysters, internationally and locally; to describe the biology and culturing issues affecting the production of B.C. Pacific oysters; to assess the marketing opportunities and constraints of B.C. Pacific oysters; and to assess the financial issues affecting B.C. Pacific oyster producers. The study included: a 1iterature and trade statistics review; a survey of Pacific oyster producers in the Pacific Northwest; a survey of B.C. Pacific oyster buyers; a consultation process with industry, and attendance at the British Columbia Shellfish Workshop 196, Courtenay and the World Aquaculture 197 Conference, Seattle. The B.C. Oyster production industry could easily be described as being in the early stages of growth. There are some definite weaknesses and constraints, but these are balanced with some great strengths and opportunities. An operation which builds on its strengths and establishes a good reputation is likely to secure a healthy future in this rapidly evolving industry.

Manning, T. A. & J. A. Cahalan, J.A. (1996)
Growth of the Pacific oyster, *Crassostrea gigas* (Thunberg) at 18 sites in Puget Sound and Hood Canal
Journal of Shellfish Research 15: 787-788

A mark and recapture study was conducted at 18 beaches in Hood Canal and Puget Sound, Washington to obtain accurate estimates of Pacific oyster growth rates. These population parameter estimates will be used in developing harvest models which are used to manage the resource.

Martin, M., K. E. Osborn, P. Billig, & N. Glickstein (1981)
Toxicities of 10 metals to *Crassostrea gigas* and *Mytilus edulis* embryos and *Cancer magister* larvae
Marine Pollution Bulletin 12: 305-308

Pacific oyster (C. gigas) embryos, bay mussel (*M. edulis*) embryos and Dungeness crab (*C. magister*) zoea I stage larvae were exposed to As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag and Zn salts. The 2 bivalve species were exposed through the completion of embryogenesis (48 h) and the effects of the metals on abnormal development were monitored. The crab larval stages were exposed to the metal solutions for 96 h. Concentrations (mu.g/l) which caused 50% abnormal development in the 2 spp. of bivalve larvae and LC50 of the crab larvae ranged from 5.3 (oyster) to 49 (crab) for Cu; 5.8 (mussel) to 8.2 (crab) for Hg; 14 (mussel) to 55 (crab) for Ag; 119 (oyster) to 456 (crab) for In; 232 (crab) to 3000 (mussel) for As; 247 (crab) to 1200 (mussel) for Cd; 349 (oyster) to 4360 (crab) for Ni; 476 (mussel) to 758 (oyster) for Pb; 3440 (crab) to 4538 (oyster) for Cr6+; and Se > 10,000 for the 3 spp. The acute toxicity testing of *C. gigas* embryo with 2 California [USA] native species confirmed its usefulness for predicting toxicity to the latter species.

McLachlan, A., J. E. Dugan, O. Defoe, A. D. Ansell, O. M. Hubbard, E. Jaramillo, & P. E. Penchaszadeh (1996)
Beach Clam Fisheries
Oceanography and Marine Biology: An Annual review 34: 163-232

The biology, ecology, and fisheries of 15 species of clam from exposed ocean beaches are reviewed and contrasted. The species, representative of four families of bivalves, are *Tivela stultorum* and *Siliqua patula* from North America, *Tivela mactroides, Donax denticulatus* and *D. striatus* from the Caribbean, *Mesodesma mactroides* and *M. donacium* from southern South America, *Donax trunculus* from Europe, *D. serra* from southern Africa, *D. cuneatus* and *D. faba* from Asia, *Donax deltoides* from Australia, and

Paphies ventricosa, P. subtriangulata and *P. donacina* from New Zealand. These clams tend to fall into two categories: generally larger temperate species that dominate the: macrofauna community biomass on beaches of the dissipative type, and generally smaller tropical species, mostly donacids, found on reflective beaches. Some species have intertidal distributions, but most are centered in the swash zone or shallow subtidal. Vertical distribution appears to be related to latitude and temperature with lower temperatures leading to a more downshore distribution. Subtidal species are more difficult to exploit because of the protection afforded by high energy surf zones. All are filter feeders, playing important roles in the trophic structure of beaches. Most species have extended spawning, often with two peaks in the year. In many cases recruitment occurs in a different zone from the adult populations with subsequent migration up or downshore. Life spans range from 1-3 yr for the smaller, warm water species to >20yr in the larger temperate species, but most species 1ive for 2-8yr and have relatively rapid growth to maturity. Many populations exhibit resurgences-considerable fluctuations in abundance coupled to variable recruitment and/or mass mortalities. Exploitation of beach clams is sometimes constrained by the accumulation of toxins, such as those associated with blooms of toxic algae, that can render them unsafe for human consumption.

Masui, Y., T. Yoshikawa, Y. Naito, Y. Boku, T. Fujii, H. Manabe & M. Kondo (1998)
Effect of *Crassostrea gigas* extract (dCOE) on cell growth in gastric carcinoma cell lines.
Functional foods for disease prevention II: medicinal plants and other foods. IN Shibamoto. T., J. Terao. & T. Osawa (eds). Symposium at the 213th National Meeting of the American Chemical Society. San Francisco. California. April 13-17. 1997. p.50-57 ACS Symposium Series 702 Publisher: American Chemical Society , Washington, DC.

Mazon Suastegui, J., V. Rios Arias, J. Rivera Lucero, & M. Aviles Quevedo (1990)
Oyster seed production at the aquaculture center of Magdalena Bay, Baja California SUI, Mexico (1987-1988)
Ser. Cient. Univ. Auton. Baja California. Sur.II, 1: 30-37

A description of the installed facilities, operation and techniques for the production of oyster (*Crassostrea gigas*) seed at the Magdalena Bay aquaculture center, is presented. The need for a major cooperation between the different seed production centers in Mexico and between these and the fishermen cooperatives devoted to aquaculture activities was remarked.

McGoldrick, D. J. & D. Hedgcock (1995)
Hybrid vigor in Pacific oysters: An experimental approach using crosses among inbred lines
Journal of Shellfish Research 14: 229

In order to document and analyze the genetic basis of growth and survival in Pacific oysters (*Crassostrea gigas*), five 2 x 2 crosses were conducted in the summer of 1993 and 2 in the summer of 1994. The outcomes of these experiments have substantial implications for genetic improvement because they demonstrate that cross-breeding can improve traits valuable to production. To confirm pedigrees and levels of inbreeding in the parents of each cross, allozyme markers were utilized. These markers detected contamination of broodstock in 3 of our 5 experiments. In 1 of the 1993 crosses there was significant hybrid vigor for survival and shell length. Hybrid vigor for shell length persisted and increased from larval to adult stages. In addition, reciprocal cross differences for shell length, which were statistically significant on days 7 and 14, disappeared by day 340, consistent with the action of a diminishing maternal effect. Density had no effect on larval shell length although larval density varied over 4 orders of magnitude. Therefore, factors independent of larval density and correlated to the parents must have increased the performance of the hybrid groups. This is consistent with previous observations of non-additive genetic variance in similar traits. In another experiment, hybrid larvae survived better than inbred larvae (thus exhibiting heterosis). Curiously, however, hybrids in this experiment were smaller than inbreds at both larval and juvenile stages. The two 1994 experiments await statistical analysis. Further studies using pairwise intercrosses of Fl hybrid groups, and molecular markers (microsatellites) can now be utilized to uncover and map the genetic basis of the demonstrated heterosis in Pacific oysters. (DBO)

Meyers, T.R. (1989)
Certification policy for importation of *Crassostrea gigas* spat into the state of Alaska
Journal of Shellfish Research 8: 323

In Alaska, the Japanese oyster is the only shellfish species permitted by state regulations for import and does not include stocks from Korea, the Gulf of Mexico and the Atlantic coast of North America. Any grower within Alaska having intent to import Japanese oysters of a particular stock is required to submit a Fish Transport Permit application for approval by the ADF&G. Current pathology policy allows only spat or seed (animals < 1 yr-old) to be imported due to the increased risk of transporting exotic diseases which may infect the older and larger animals. Certification procedures follow American Fisheries Society guidelines regarding sample sizes. Sixty adults of the parent stock, 200 spat and about 1-2 ml of larvae (if available) are the required samples. Renewal of certification is on a yearly basis, requiring examination of 60 spat from the year class to be imported, and an updated disease history and hatchery performance review of the hatchery stocks from the vendor for the previous growing season. A certification will become invalid if a disease outbreak occurs within stocks at the facility, or if an uncertified stock is brought into the rearing faci1ity or grow-out area.

Meyers, T. R. & S. Short (1990)
Summer mortalities and incidental parasitisms of cultured Pacific oysters in Alaska.
Journal of Aquatic Animal Health 2: 172-176

Morse, D. E. (1980)
Recent advances in biochemical control of reproduction, sett1ing, metamorphosis and development of abalones and other molluscs: app1icabi1ity for more efficient cultivation and breeding:
Proceedings of the National Shellfisheries Association vol. 70:132

Mueller, K. W. & A. Hoffmann, A. (1996)
Effect of freshwater immersion on attachment in the Japanese oyster drill, *Ceratostoma inornatum*: Implications for shellfish transfers in Washington State
Journal of Shellfish Research 15 (Abstract)

Currently, Washington Department of Fish and Wildlife has a permit process in place to monitor shellfish movements between waters classified by the department as restricted or unrestricted with respect to the presence or absence of the Japanese oyster drill, *Ceratostoma inornatum.* Conditions of shellfish transfers between these areas include freshwater washdowns, which help dislodge and remove drills from the shellfish and equipment used during the transfer. To determine time to detachment in freshwater, individual drills (size = 5.7-50.5 mm shell length) were placed on a single oyster shell valve and allowed to attach themselves. The valve and snail were then placed in freshwater. Detachment was indicated by drills rolling off the valve; time to detachment was measured using a digital stopwatch. A 1inear regression analysis of the log-normal time to detachment on size showed a positive size effect. Therefore, the amount of time required for freshwater washdowns should be governed by the larger drills. Since the purpose of washdowns is to dislodge all drills, attention was focused on the largest animals (50 mm shell length).

Nosho, T. (1989)
Small-Scale Oyster Farming for Pleasure and Profit
National Sea Grant Coll. Program, Rockville, MD. Report No.: WSG-AS-89-1 Jan 89 pp14.

Increasing numbers of waterfront property owners are becoming interested in starting small oyster farms or in improving their existing operations. The report provides information on the species and varieties of oysters that are appropriate for farming in the Pacific Northwest. It discusses beach ownership, water quality considerations, and ground type necessary for such operations to be successful. The report also explains various growing methods: bed culture, stake culture, use of longlines, single oyster production, rack and bag culture, floating culture, and suspended nets. Legal aspects are discussed, and a 1ist of state agencies to contact is given, as well as a list of shellfish suppliers and an extensive reading 1ist.

Nosho, T. Y. (1995)
The Pacific coast oyster industry - Factors contributing to its longevity and sustainability
Journal of Shellfish Research 14: 273

Pacific oyster, *Crassostrea gigas*, farming is a sustainable process requiring the planting of seed, growth to maturity, processing and marketing and so is similar to the cultivation of other farmed products like corn or wheat. Oyster farming is a light industry that is highly compatible with the environment and produces virtually no pollution. Energy requirements are minimal with highest energy usage in the hatchery and juvenile nursery phases. Various algal cultures are used to feed larval and early juvenile oysters, but most of the growth occurs as the oyster feeds from natural sources. Thus, feed costs are minimal. The industry essentially began in 1922 when the first shipment of oyster seed arrived from Japan to the Rock Point Oyster Co. in Washington. All subsequent shipments were made from the same area in Japan, Miyagi Prefecture. Prior to this introduction, Olympia oysters (*Ostrea lurida*) were farmed extensively in Washington. Only small amounts of Olympia oysters are farmed today. At the time *C. gigas* was introduced, no other *Crassostrea* species existed on the Pacific coast except for the imported eastern oyster *C. virginica* which never did well on commercial beds. Because *Crassostrea* species on the west coast are lacking, the potential for disrupting gene pools of natural populations is non-existent. Currently, this shellfish industry is one of the most sophisticated in the world. Key elements contributing to sustainability are tideland ownership, water quality, technology and innovation, marketing, and entrepreneurship. Principal concerns within the industry include: potential declines in growing area water quality, the issue of burrowing shrimp control, increasing regulations and user fees, and the media. (DBO)

Nosho, T. Y. & K. K. Chew (eds.) (1991)
Remote setting and nursery culture far shellfish growers: Workshop Record
Remote Setting and Nursery Culture for Shellfish Growers: Workshop Olympia, WA (USA) 19 Feb 1991
Washington Sea Grant

Pacific oyster growers in the Pacific Northwest largely depend on seed produced in hatcheries to provide them with the stock to produce a crop. The advent of remote setting and nursery culture of oysters and other bivalves has propelled the industry a great step forward. Seed producers and growers no longer have to ship seed on heavy cultch to the growout site; now just the tiny larvae - millions of them wrapped in wet gauze the size of a baseball - can make the journey, saving shipping and maintenance costs. As a result, however, the setting and nursery activities that once took place at a centralized hatchery are now dispersed about the countryside and are conducted by individual growers rather than hatchery operators. During the past several years, the need has grown to have a special meeting of shellfish growers, regulators, and scientists to address the problems of survival of oyster and clam seed through the nursery period prior to placement into growout faci1ities or natural shellfish beds. 20 presentations are included under the headings setting procedures, shellfish nurseries - commercial approaches, and shellfish nursery rearing. Each paper is indexed separately.

Olsen, S. (1981)
New candidates with aquaculture potential in Washington State: pinto abalone (*Haliotis kamtschatkana*), weathervane scallop (*Pecten caurinus*), and purple-hinge rock scallop (*Hinnites multirugosus*)
Journal of Shellfish Research vol. 1: 133

Paniagua-Chavez, C. G. & M. De J. Acosta-Ruiz (1995)
Gonadal development of *Crassostrea gigas* in Bahia San Quintin, Baja California,
Ciencias Marinas 21: 225-242

The reproductive cycle of the Pacific oyster, *Crassostrea gigas* (Thunberg), presents significant differences (S (alpha = 0.05)) in September and October in the La Boca and Mina Vieja locations. The maximum gonadal index (GI) occurred in May and August at Mina Vieja with 32 and 34%, respectively and the minimum of 8% in October. In La Boca, the highest GI value of 37% was obtained in September and October while the lowest, 7%, was observed in April. Partial spawnings were observed from July through October in La Boca and from July to September in Mina Vieja, located in the internal area of Bahia San

Quintin. An asynchrony was observed in both spawning and maturation between male and female oysters. The male:female ratio was 7:3 and hermaphroditism was less than 3%.

Parker, M. S. (2000)
Population genetics of *Protothaca staminea* and *Macoma balthica* in Puget Sound, WA.
Journal of Shellfish Research 19: 686

Pauley, G. B., B. Van Der Raay, & D. Troutt (1988)

Species Profiles: life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest), Pacific Oyster

US Army Engineer Waterways Experiment Station, Vicksburg, MS.; Fish and Wildlife Service, Washington, DC. Report No.: Fws-82/11.85 pp.28

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal aquatic species. These are designed to assist in environmental impact assessments. The Pacific oyster is found in the estuarine waters of California, Oregon, Washington, and British Columbia. It is sought both commercially and recreationally. Washington leads all other areas combined with a commercial production of 5.5 million pounds valued at $3.8 million. This is 26% of Washington State's total shellfish production value. These are very prolific animals, releasing up to 70 million eggs per year. Larvae are sensitive to a variety of environmental conditions, primarily temperature and salinity, and to pollutants including sulphite waste liquor. Growth is rapid and most noticeable in the third and fourth years. Along with other shellfish, Pacific oysters may accumulate toxin from *Gonyaulax cantenella* (responsible for paralytic shellfish poisoning), but they lose the toxin more rapidly than other shellfish. Optimum water temperature for adults is 20 C and optimum salinities are above 20 ppt for adults. Ambient temperature is the single most critical item to breeding success in the Pacific Northwest.

Pastorok, R. A., J. W. Anderson, M. K. Butcher, J. E. Sexton, G. Cherr, P. Dinnel, R. Caldwell, & P. Chapman (1995)

lnter- and intralaboratoy variability of marine chronic toxicity test methods

Proceedings of the 1995 International Environmental Conference. Atlanta, GA

Biomonitoring of effluents is being incorporated into National Pollutant Discharge Elimination System permits for industrial wastewater discharges in Washington State. This study evaluated inter- and intralaboratory variability of EC50 values in four chronic marine bioassay protocols that may be used to evaluate the toxicity of complex effluents: 1) bivalve larval developmental abnormality, using the oyster *Crassostrea gigas* or the mussel *Mytilus* sp., 2) echinoderm fertilization, using the sand dollar *Dendraster excentricus* or the sea urchin *Strongylocentrotus purpuratus*, 3) fish growth, using the inland silverside *Menidia beryllina*, and 4) kelp sexual reproduction, using the brown alga *Laminaria saccharina*. Five commercial laboratories conducted several round-robin tests of fresh effluent samples from two pulp and paper mills (representing a bleached kraft process and a bleached sulfite process) and two reference toxicants (CdCl//2 and lyophi1ized effluent from a pulp and paper mill). Monthly testing of the two reference toxicants was performed for 13 months using the bivalve and echinoderm tests. The bivalve test was usually less variable than the echinoderm test. Hypothesis tests using analysis of variance on EC50 values for these two tests revealed significant (p less than equivalent to 0.05) differences between species within the bivalve and echinoderm phyla. The kelp reproduction test usually provided results, although both inter- and intralaboratory variability were high. The fish growth test did not yield sufficient numbers of EC50 estimates for an analysis of inter-and intralaboratory variability. Overall, the order of assay sensitivity, from most to least sensitive, was *C.gigas* abnormality, *Mytilus* sp. abnormality, *D. excentricus* fertilization, *S. purpuratus* fertilization, *L. saccharina* reproduction, and *M. beryllina* growth.

Paust, B. C. & R. Ralonde (1997)
Guidelines for shellfish farming in Alaska
Alaska Univ., Fairbanks (USA). Alaska Sea Grant Aquacult. Note, no. 16, pp21.

Shellfish aquaculture in Alaska can be a perilous career choice for the new entrepreneur. It can also be exciting and profitable for the person wil1ing to work hard and deal with the issues and risks. This manual has practical guidelines, strategies, and warnings about entry into shellfish farming business in Alaska and other coldwater regions. The information was collected by extension workers who have worked closely with Alaska shellfish farmers over the past two decades. It can be adapted to farming several bivalve species in the North in many parts of the world. The book addresses the culture of the Pacific oyster (Crassostrea gigas) in Alaska. In Alaska, shellfish aquaculture methods include suspended culture, such as lantern nets hung from surface longlines, and to a lesser extent intertidal zone methods, such as rack-and-bag culture which can be used in areas where winter freezing is not a problem. Suspended culture methods are most frequently used to culture single oysters for the half-shell market, but can also be applied to the production of shucked oysters. Even though Alaska shellfish farmers have experienced constraints ranging from biological concerns to complex sociopolitical difficulties, the Alaska shellfish farming industry is making significant progress. Most of the growth in shellfish culture in Alaska came only a few years ago, after the Alaska State Legislature passed the Aquatic Farm Act of 1988. This single initiative enabled the expansion of aquatic farms in several Alaska regions. During 1990-1994, Alaska went from a few aquatic farms to sixty-four. With farms permitted to culture shellfish on nearly 200 acres of state tidelands, the industry has grown from production totaling a few thousand dollars in 1988, to several times this amount at the end of 1994. This growth has taken Alaska beyond experimental shellfish culture industry. The Alaska industry is now poised for a period of significant growth. In spite of progress made to date, shellfish farming remains a risky business. An important function of this manual is to decrease the rate of business failure associated with the industry.

Perdue, J. (1980)

A physiological approach to the summer mortality problem of Pacific oysters in Washington State.
Proceedings of the National Shellfisheries Association 70: 133-134

Perdue, J. A. (1982)

Gametogenesis and growth of the Pacific oyster *Crassostrea gigas* (Thurnberg) stocks in two bays in the State of Washington.

Journal of Shellfish Research 2: 105-106

As is true with many bivalves, the reproductive cycle dominates the life of the Pacific oyster *Crassostrea gigas.* Extensive gonad proliferation occurs in environments characterized by warm temperatures and high productivity. Condition indices typically exceed values of 16 under these conditions with gonadal products occupying 40 to 50% of the dry tissue weight. Whereas some bivalves partition energy reserves to different areas during gametogenesis, the Pacific oyster appears to direct an extensive amount of energy toward the annual reproductive cycle. A comparison of two different gametogenic patterns in two different bays revealed how shell growth, as one energy partition, was dependent on the gonadal cycle in the Pacific oyster, and not upon either temperature or food conditions, as in some other bivalves.

Perdue, J. A. & G. Erickson (1984)

A comparison of the gametogenic cycle between the Pacific oyster *Crassostrea gigas* and the Suminoe oyster *Crassostrea rivularis* in Washington State.
Aquaculture 37: 231-237

The gamotogenic cycle of the Suminoe oyster, *Crassostrea rivularis,* was compared with that of two groups of Pacific oysters (*Crassostrea gigas*) on an intertidal oyster bed in Oakland Bay, Washington. The Pacific oysters exhibited an earlier and more extensive development of gonad relative to *C. rivularis*. Resulting carbohydrate depletion was much greater in *C. gigas* relative to *C. rivularis*. Both groups of Pacific oysters spawned completely in mid-August. *C. rivularis* did not spawn but, rather, initiated phagocytosis of gametes by leucocytes. The implications of the results on the development of a marketable summer oyster are discussed.

Perdue J. A., J. H. Beattie J. H. & K. K. Chew (1981)

Some relationships between gametogenic cycle and summer mortality phenomenon in the Pacific oyster (*Crassostrea gigas*) in Washington State.
Journal of Shellfish Research 1: 9-16

Perdue, J. A., J. H. Beattie, W. Hershberger, & K. K. Chew (1984)
Selective breeding for improved meat quality in the Pacific oyster *Crassostrea gigas* (Thunberg) in Washington State.
Journal of Shellfish Research 4: 98

The University of Washington has conducted a selective breeding program with the Pacific oyster *Crassostrea gigas* since 1976. In 1979, one experimental F sub(2) generation was found which exhibited significantly less gonadal development during the early summer months. The carbohydrate content of this experimental group was consistently higher than any of the other groups monitored during the summer of 1979. In an effort to determine if this trait of reduced gonadal development and increased carbohydrate content could be selected for the breeding program, this experimental group was crossed with three other groups in a rotational linecrossing design in 1980. In 1982, the 2-year-old progeny (F sub(3)) were monitored for gonadal development, carbohydrate content, and growth. Early gonadal development was significantly reduced and the resulting carbohydrate content significantly increased in those groups bred from the high carbohydrate broodstock. Implications of these results on the development of a summer oyster stock are discussed.

Perdue, J. A., J. H. Beattie, W. Hershberger, & K. K. Chew (1984)
Selective breeding for improved meat quality in the Pacific oyster Crassostrea gigas in Washington State.
Journal of Shellfish Research 4: 111

The University of Washington has conducted a selective breeding program with the Pacific oyster (*Crassostrea gigas*) since 1976. In 1979, one F sub(2) experimental group was found which exhibited significantly less gonadal development during the early summer months. The carbohydrate content of that experimental group was consistently 50% higher than any of the other groups monitored during the summer of 1979. To determine if this trait of reduced gonadal development and increased carbohydrate content could be selected for in the breeding program, that experimental group was crossed with 3 other groups in a rotational, linecrossing design in 1980. In 1982, the 2-year-old progeny (F sub(3» were monitored for gonadal development, carbohydrate content, and growth. Early gonadal development was significantly reduced and the resulting carbohydrate content significantly increased in those groups that were bred from the high carbohydrate broodstock.

Pierson, K. B., B. D. Ross, C. L. Melby, S. D. Brewer, & R. E. Nakatani (1983)

Biological Testing of Solid Phase and Suspended Phase Dredged Material from Commencement Bay, Tacoma, Washington
Washington Univ., Seattle. Fisheries Research Inst. Apr 1983 pp71.

Sediments from nine sites in Blair and Sitcum Waterways, Commencement Bay, Tacoma, Washington, were tested for potential acute chemical toxicity using chinook salmon smolts, Pacific oyster larvae, and phoxocephalid amphipods. Survival of salmon smolts was not affected by 96 hr exposure to elutriates of up to one part per thousand by volume from 5 sites. Oyster larvae developed abnormal shells following 48 hr exposure using undiluted water drained from defrosted sediment from 4 sites, but were not affected by 1:5 dilutions of artificially prepared elutriates. Two hundred four hr exposure to sediments from each of the nine sites neither decreased survival of amphipods nor altered the time spent in the sediment or the amphipod's abi1ity to rebury in sand. Ammonia-nitrogen concentrations in artificially prepared 1:5 elutriates at ambient pHs would be potentially toxic to salmonids and other fishes; therefore dredging methods that dilute the elutriate are recommended. An elutriate dilution of 1:1000 was shown to be safe; elutriate concentrations greater than 1:1000 could be toxic to salmonids and other fishes. Amphipod

bioassays should not be used to assess potential chemical toxicity of dredged sediments unti1 further research clarifies confounding factors such as anoxia and starvation.

Pogson G. H. (1991)
Expression of overdominance for specific activity at the phosphoglucomutase-2 locus in the Pacific oyster, *Crassostrea gigas.*
Genetics 128: 133-141

Poland, W. G. & T. A. Broadley (1989)
Investigations into remote setting Pacific oyster larvae
Journal of Shellfish Research 8: 415-416

In 1987, investigations were initiated to increase the percentage of larvae *Crassostrea gigas* that metamorphosed on cultch and to create an even distribution of these larvae on cultch in the setting tanks. The 1988 studies focused on defining criteria for siting natural nursery areas that would facilitate good growth and survival of spat oysters. The proportion of larvae setting was affected by temperature, salinity, feeding levels, water circulation rate, and cultch type. Distribution on cultch was related to water circulation rate and pattern and method of adding larvae to tanks. Growth at nursery sites was related to water temperature or chlorophyll a. Nursery survival was related primarily to cover of fouling animals. A procedure manual for remote setting has been written based on these results.

Pouvreau, S., A. Gangnery, J. Tiapari, F. Lagarde, M. Garnier, A. Bodoy (2000)
Gametogenic cycle and reproductive effort of the tropical blacklip pearl oyster, *Pinctada margaritifera* (Bivalvia: Pteriidae), cultivated in Takapoto atoll (French Polynesia)
Aquatic Living Resouces 13: 37-48

The gametogenic cycle and the reproductive effort of the blacklip pearl oyster, *Pinctada margaritifera*, cultivated in Takapoto lagoon were studied for a 1-year period (March 1997-April 1998) by bimonthly observations of gonadal sections, dry tissue weights and gonadal index in a population of pearl oyster composed of three age-groups. pearl oysters attained sexual maturity in the end of their first year (height approximate to 40 mm), implying that *P. margaritifera* is a late-maturing species in comparison with other Pteriidae. This species was also confirmed to be a marked protandrous successive hermaphrodite in culture, with 100 % of males at first maturity and 75 % in older pearl oyster (height> 120 mm). The general pattern of gametogenic activity, fairly synchronous in both sexes, was comparable with that of other tropical bivalves: reproduction occurs continuously throughout the year with a maximal activity during the warm season (November-May). No resting period was observed. Quantitative growth data showed that *P. margaritifera* exhibits an annual synchronised polymodal spawning pattern, with two spawning peaks in age-group I (height approximate to 70 mm) and five in age-groups II (height approximate to 100 mm) and III (height approximate to 120 mm). Spawning was sometimes incomplete, nevertheless a clear relationship between gamete production (P-R, g) and size (height H, mm) was obtained: P-R = S.26 x 10(-7) H-2.91 (R-2 = 0.99, p < O.OS). Estimation of P-R was used to calculate the annual reproductive effort in *P. margaritifera*. Reproductive effort (%) was similar to those calculated for temperate species and showed a progressive increase with the age of pearl oyster, from 7 % in age-group I to 38 % in age-group III. This study showed that, in a fairly stable tropical environment such as the Takapoto lagoon, *P. margaritifera* is a multiple spawner, which uses an opportunistic reproductive strategy, allowing investment all year around, of any surplus energy into gamete production. Surplus energy is ensured by the high pumping rates developed by this non-symbiotic bivalve to succeed in low seston conditions.

Quayle, D. B. (1988)
Pacific oyster culture in British Columbia Canada
Canadian Bulletin of Fisheries and Aquatic Sciences 218: 1-241

Of the three species of oysters (*Crassostrea gigas, Crassostrea virginica*, and *Ostrea lurida*) that occur in British Columbia, only the exotic Japanese species (*C. gigas*) the Pacific oyster, in now cultured. The

anatomy of C. gigas is described in some detail as well as the reproductive process. Successful breeding of the species in most British Columbia waters is erratic except for certain areas such as Pendrell Sound, Hotham Sound, Ladysmith Harbour in Georgia Strait, Pipestem Inlet and Nootka Sound on the west coast of Vancouver Island. Collection of seed, particularly in Pendrell Sound is described in some detai1. Methods of culture include intertidal and subtidal bottom culture, suspended string, stake, tray, and both suspended and intertidal stick culture. Harvesting, processing, and storage methods are described. The problems of Pacific oyster culture include industrial and sewage pollution, paralytic shellfish poisoning along with predators and disease. How these may be dealt with is discussed. Administrative aspects of this industry are reviewed.

Ralonde R. (1993)
Shellfish aquaculture in Alaska and the potential of interaction with wild species.
IN ColIie M. R. & J. P. McVey (Eds) Interactions between cultured species and naturally occurring species in the environment. Twenty-Second US-Japan Aquaculture Panel Symposium Homer, Alaska, USA August 21-22, 1993 Alaska Sea Grant College Program, University of Alaska Fairbanks, Alaska

Ralonde, R.L. (1998)
Application of floating upwelling system (FLUPSY) for improved survival and growth of Pacific oyster seed (*Crassostrea gigas*) in Alaska
Journal of Shellfish Research 17 (Abstract)

Alaska regulations allow only Pacific oysters *Crassostrea gigas* less than 20 mm in shell length to be imported into the state for aquaculture. The influences of Alaska1s northern latitude and small size of the Pacific oyster seed cause high variability in growth and survival that severely hampers expansion of the oyster farming industry. Application of floating upwelling system (FLUPSY) nursery technology was tested on S mm Pacific oyster seed with the objectives to evaluate changes in seed survival and growth, develop improvements in FLUPSY design and operation, and measure the economic impacts of nursery culture on oyster farm operation. With application of FLUPSY nursery technology farmers wil1 experience a 10-30% reduction in mortality, improved uniformity in growth, and an estimated 40% reduction in farm construction and operation costs. Reduced variabi1ity of growth and survival improves production inventory estimates and access to larger, more secure markets. Continuing research is directed toward developing and refining design criteria and operation protocols for efficient application of FLUPSY nursery technology.

Ralonde, R (1998)
Larvae sampling and setting experiences with pink/spiny scallops. Clam and Oyster Farming IN Nosho, T (ed) 7th Conf. for Shellfish Growers: Clam and Oyster Farming. Sea Grant Program Report Number: WSG-WO-98-01 p. 39-42

Culture of shellfish species other than Pacific oysters is not feasible because the state prohibits importing species other than oysters, and the state lacks a shellfish hatchery to produce the seed. Along with shellfish seed production, research and development is necessary to produce an in-state oyster broodstock and technology to culture other species for production on Alaska aquatic farms. As a partial solution to these problems, $3.2 mill ion was appropriated from Exxon Valdez litigation funds to construct a Mariculture Technical Center and shellfish hatchery in Seward. Construction is now underway and the facility is expected to be completed in April 1997. Of the alternate species being proposed for development, scallop is a preferred option for aquatic farmers. Initial investigation into scallop culture in Alaska began in the mid-1980s from a State of Alaska/Japan cooperative program to attempt capture of weathervane scallop (*Patinopectin caurinus*) spat from the wild by app1ication of a technique successfully used in Japan for collection of Japanese scallop spat (*Patinopectin yessoensis*). With help from the Overseas Fisheries Cooperation Foundation of Japan, the Alaska Department of Fish and Game conducted a project around Kodiak Island starting in March 1987. Completed in 1989, the project was not successful in collecting weathervane scallop spat, but captured primarily spat of the smaller species of pink (*Ch1amys rubida*) and spiny (*Ch1amys hastata*) scallop spat (OFCF 1989).

Ralonde, R, J. Cochran, J. Hetrick, M. Soares, M Ostasz, & J. Burleson (1993)
Promise and constraints of shellfish aquaculture in Alaska
Journal of Shellfish Research 12: 147-148

In 1989, Alaska Senate Bi II 514 revitalized the shellfish culture industry by improving aquatic farm permit processing. The changed regulations have caused an influx of permit applications that resulted in 72 aquatic farms. The new shellfish culture industry faces major challenges. The State of Alaska has conservative species import regulations, and does not have an operating shellfish hatchery, requiring farmers to buy spat from hatcheries outside the state. High operating cost, lack of a track record, and inexperience of the farmers makes financing difficult. The Pacific oyster is an attractive species for aquaculture in Alaska because it grows very well on the abundant, high quality food. Cold, clean water also prevents bacterial contamination extending the shelf life, and retards sexual maturation resulting in high quality half shell oysters being available year around. Blue mussels, and scallops are also being cultured at experimental levels. Littleneck clams, urchins, abalone, and seaweeds are potential farm candidates. Each of these species has its own set of constraints and promises for aquaculture. The constraints to shellfish aquaculture in Alaska may seem substantial, but the prospects for success are rapidly improving. Technological innovations are being developed to address some of the constraints, and construction of an Alaskan shellfish hatchery is receiving substantial attention. Alaska holds a major advantage not found in other states, pristine water quality. Currently, Alaska is the only state with no restricted waters for shellfish harvest. While the amount of non-restricted and open shellfish harvest areas around the United States are decreasing, Alaskan marine aquaculture is expanding. Pristine water quality, technological improvements, and high sanitation standards will make Alaskan shellfish a viable industry.

Ramirez F. D., V. J. Chavez, & M. C. Caceres (1990)
Oyster culture in bags on posts at the intertidal zone at La Paz Bay, B.C.S.: A comparison between the suspension culture respect growth and resistance. IN Lanza Espino, G de la & F. J. Arredondo Figueroa (eds) The Aquaculure in Mexico: From Concepts to Production.
Area Cienc. Mar., Univ. Auton. Baja California Sur. La Paz. pp316.

The oyster *Crassostrea gigas* was cultured in two different systems, baskets and bags with the aim of obtain the better performance for this culture. Growth (weight and length) and resistance (camera number and valves width) were the measured parameters. Results showed that both parameters, growth and resistance were higher for the oyster cultured in bags, also these oysters showed lesser mortality, higher yield and a better handling resistance.

Rangel. D. C. (1989)
Final Report of the Meeting on Marine Molluscs Culture in Northwest Mexico. La Paz, Baja California Secretaria de Pesca, Mexico City (Mexico). pp35.

An account is given of topics discussed at the Meeting, which covered the development of molluscs culture in Northeast Mexico. Principal species involved in the culture industry are *Crassostrea gigas, C. corteziensis, Mytilus edulis, M. californiensis, Ruditapes, Haliotis* and *Argopecten circularis*.

Reynoldson, T. B. (1987)
lnteractions Between Sediment Contaminants and Benthic Organisms
Hydrobiologia Vol. 149, p 53-66

Interactions between contaminated sediments and benthic invertebrates in marine and freshwater systems are reviewed using selected examples from the available literature. The most obvious impact on marine and freshwater invertebrates from contaminated sediments is direct acute toxicity. Data also exist which suggest that contaminants may cause alterations in genetic structure or aberrations in genetic expression in organisms such as Chironomidae and Oligochaeta. High rates of neoplasm have been identified in marine biota in association with urban discharges -- e.g., blue mussels and Olympia oysters in Oregon, clams in Chesapeake Bay, and soft-shell clams in Maine. Changes in benthic invertebrate community structure

resulting from sediment contamination may be directly-induced or may be mediated indirectly for example, increased chironomid numbers in response to contamination by crude oil can be related to enhanced algal growth. Processes by which benthic organisms transfer contaminants from sediments to other components of the aquatic system include (1) bioaccumulation, which is restricted to uptake of contaminants via sediment ingestion (2) trophic transfer, which is the movement of contaminants through the food web and the accompanying biomaginfication effects (3) migration, which incorporates the possible implications of spatial movement in which organisms move into and out of contaminated sediment (4) biodegradation, which refers to the metabolism of contaminants by benthic invertebrates and (5) bioturbation, which is the effect that physical movement and alteration of the sediments (by organisms) may have on contaminants. The significance of these processes wi11 have to be considered in any attempt to manage contaminated sediment material whether it be the benthic populations themselves because because of their economic importance (e.g., shellfish industry), their activity in biomagnification, or in the transfer of contaminants to economically-important fish stocks. It is apparent that the concept of the sediment as a sink for contaminants is not acceptable and that significant interactions occur between benthic invertebrates (and other organisms) and sediment materials.

Rice, D. W., C. P. Se1tenrich, R. B. Spies, & M. L. Keller (1993)
Seasonal and annual distribution of organic contaminants in marine sediments from Elkhorn Slough, Moss Landing Harbor and nearshore Monterey Bay, California.
Environmental Pollution 82: 79-91

This 3-year study provides data on the spatial, seasonal and annual variability of hydrocarbons and total organic carbon present in marine sediments at three sites: Elkhorn Slough, Moss Landing Harbor and nearshore Monterey Bay in the vicinity of Moss Landing, California. The study provides baseline information that could be used to evaluate the potential impacts of future fuel oil releases occurring in the Moss Landing area. Groups of hydrocarbons were chosen to represent the hydrocarbon inputs into the Moss Landing area. These included the pesticide dichlorodiphenyltrichloroethane (DOT), polychlorinated biphenyl (PCB), phthalic acid ester (PAE), polycyclic aromatic hydrocarbon (PAH) and combustion PAHs (sum COMBs). For sum DOTs, sum YPCBs, sum PAEs, sum PAHs and sum -COMBs, the major sources of variabi1ity were between sites and random effects. Subsites within each site contributed 1itt1e variability. No significant seasonal differences in any chemical contaminant group were found at any site. Significant seasonal differences in total organic carbon (TOC) and significant annual differences in sum PCBs, sum PAHs, sum COMBs and sum PAEs were found at the nearshore Monterey Bay site. Significant annual differences in sum PAEs and TOC were found within Moss Landing Harbor, and significant annual differences in sum PAEs were found within the E1khorn Slough site. Imp1ications for future samp1ing designs in the Moss Landing area are that given the current baseline conditions (a stable, low rate of hydrocarbon input), a variability of 75-150 m-2 may not need to be heavily sampled. Spatial variability, not seasonal or annual variability, is the major source of hydrocarbon variabi1ity in Moss Landing sediments, although 3 years may not be long enough to establish tong-term annual trends. Further research to determine the sum PAH spatial sampling scale for oil spills is needed.

Rickard, N. A. & R. A. Newman (1988)
Development of technology for harvesting and transplanting subtidal juvenile Pacific razor clams, Siliqua patula Dixon, along the coast of Washington State.
Journal of Shellfish Research 7: 131.

In 1979, the Washington Department of Fisheries initiated a research project to determine the feasibility of enhancing the unstable and heavily exploited harvestable populations of intertidal Pacific razor clams, *Si1iqua patula*, along the Washington coastal beaches by harvesting subtidal seed clams and transplanting them to sparsely populated intertidal locations. Early technological development centered around two independent mechanical harvesting systems: a small hydraulic surf clam harvester and a small sled mounted airlift harvester. A subsequent evaluation of the project's technical capabilities combined the excavating efficiency of the hydraulic harvester and the sorting capacity of the airlift harvester to produce a mechanical hydraulic-airlift harvesting system. The potential of this integrated harvesting system was

demonstrated during the summer and early fall of 1985 when over 125 mill ion juvenile razor clams were harvested from a subtidal area northwest of Copalis Beach. Washington. More than 90 million of these were successfully transplanted intertidally to Washington's Twin Harbors Beach and the Long Beach Peninsula.

Rickard, N. A., A.D. Rickard, & D. D. Simons (1988)
Aspects of the early subtidal life history of the Pacific razor clam. Siliqua patula Dixon, off the coast of Washington State.
Journal of Shellfish Research. 7: 131-132

In early August of 1985. the Washington Department of Fisheries discovered an extremely large subtidal population of juvenile Pacific razor clams, *Siliqua patula* off the Washington coast. Greatest abundance was centered 4.8 kilometers northwest of Copal is Beach, Washington. Abundance of juvenile razor clams within these confines was conservatively estimated at 28 bi11ion. Density of juveniles was demonstrated to vary directly with increasing depth and inversely with mean size. Results support the hypothesis that settlement of post metamorphosed larval S. patula occurs subtidally at very high densities. Subsequent intertidal settlement of juveniles at lower densities is hypothesized to be the result of a mechanism involving growth, movement and mortality.

Righetti, L (1999)
Nitrogen excretion by the Pacific Oyster, *Crassostrea gigas*, as a contributor to estuarine nutrient cycling in Tamales Bay, California.
Journal of Shellfish Research. 18: 726-727

Righetti, L. (2000)
Nitrogen excretion by the Pacific Oyster, *Crassostrea gigas*; a contributor to estuarine nutrient cycling in Tamales Bay, CA.
Journal of Shellfish Research 19: 611

Rio-Portilla, M. A., A. D. del Re-Araujo, & D. Voltolina (1992)
Growth of the pea oyster *Pteria sterna* under different thermic and feeding conditions
Marine Ecology Progress Series 89: 221-227

The combined influence of temperature and food concentration on *Pteria sterna* growth was determined, using 3 temperatures and 3 food concentrations. During 15 wk, the shell was measured weekly along the axis of maximum growth. The 2 higher growth rates (4.8 and 4.2 mm/mo) were obtained with the highest ration, at 30 and 25 degree C, while with the lowest food concentration growth was not temperature dependent. By the response surface analysis, a synergistic effect of temperature and food concentration on growth was found. Food concentration, but not temperature, had an important influence on condition index (ash free meat dry weight/shell dry weight x 100).

Robinson, A. (1992)
Gonadal cycle of *Crassostrea gigas kumamoto* Thunberg in Yaquina Bay, Oregon and optimum conditions for broodstock oysters and larval culture
Aquaculture 106: 89-97

The reproductive cycle of Kumamoto oysters collected from commercial oyster grounds in Yaquina Bay, Oregon, was determined monthly over a 3-year period. Gonads contained some ripe gametes throughout the year. Maximum frequency of sexually mature oysters occurred in August-September and declined rapidly in October-November to a minimum in March. Gametogenesis commenced in May and the first mature ova appeared in June-July. Conditioning for spawning trials was conducted at 20 degree C and 24 degree C four times a year. At 24 degree C production of gametes occurred 2 to 4 weeks earlier than at 20 degree C. By beginning conditioning in Mayor June, the conditioning period in the laboratory could be reduced by 2 to 6 weeks. Larval survival and number of spat collected was also increased by reducing the

laboratory conditioning period. In experiments carried out at five temperatures and five salinities, the optimum conditions for larval rearing ranged from 24 to 28 degree C and from 20 to 25.

Robinson, A. M. (1998)
Oyster culturing in Oregon
Journal of Shellfish Research 17: 337

The native oyster *Ostrea conchaphila* is the only oyster species native to the west coast of the United States. It was abundant in the bays and estuaries from Alaska to California. Coastal Indians consumed oysters that they could reach during low tides. White settlers began to harvest native oysters in the mid-1800s, and by the end of the century their numbers had decreased to levels too low for commercial harvesting. The west coast oyster industry depends on the introduced Pacific oyster Crassostrea gigas. Seed for the Pacific oyster is produced in hatcheries, since the water temperature of most estuaries is too cold for natural reproduction. Oregon has four major estuaries: Tillamook Bay, Netarts Bay, Yaquina Bay, and Coos Bay. Pacific oysters are commercially grown at each estuary. Oregon has had a commercial oyster hatchery since 1975 located at Netarts Bay. Annual larval production is in the billions, with larvae being shipped to oyster growers from Alaska to Mexico. Tillamook Bay has six oyster growing companies with an annual production of 5,000 gallons; Netarts Bay has three companies with an annual production of 3,000 gallons; the one Yaquina Bay company produces 11,000 gallons annually; and Coos Bay, with four companies, has an annual production of 40,000 gallons.

Robinson, A. (2000)
Kumamato oyster broodstock
Journal of Shellfish Research 19 (Abstract)

Kumamato oysters (*Crassostrea sikamea*) were brought to the west coast of the United States in 1947. Experimental seed was planted at various locations in Washington, Oregon and California. Plantings were successful and this encouraged several oyster growers to purchase commercial quantities of Kumamato seed oysters yearly. By 1953, a total of 3181 cases of seed were imported and grown for the cocktail oyster market. Once the hatchery technology was developed, Kumamato oyster seed was produced in hatcheries on the west coast of the United States. In the early seventies, in the first commercial oyster hatchery in California, Kumamato and Pacific oysters were crossed in the hope of producing a large, deep-cupped oyster with good meat quality. However, the cross (called Gigamoto) grew up to be anything but what was hoped for. Since commercial oyster growers had mixed the cross with the rest of the Kumamato oyster seed, it was difficult to separate true Kumamato oysters from the cross. It was not until 1990 that genetic technologies became available to distinguish Kumamato oysters from Pacific oysters. Accordingly, the differences in the DNA pattern of true Kumamato oysters have been identified and commercial hatcheries have been provided with true Kumamato broodstock oysters so that they can produce pure Kumamato seed.

Robinson, A. M. & W. P. Breese (1982).
The spawning season of four species of clams in Oregon.
Journal of Shellfish Research 2: 55-57

Robinson, A. & H. Horton (1987)
Environmental effects on the growth of sibling Pacific oysters *Crassostrea gigas* Thunberg and overwintered spat
Journal of Shellfish Research 6: 49-54

The growth of hatchery-reared *Crassostrea gigas* siblings and over-wintered spat was measured on commercial oyster grounds at three locations on Oregon and Washington [USA] coasts: Coos Bay, Oregon; Willapa Bay, Washington; and Oyster Bay, Shelton, Washington. Samp1ing was carried out at four month intervals at each location from November 1984 through June 1986. After two years on commercial grounds oysters showed similar growth measured by shell length and width although wet and dry weights of the

meat varied considerably between locations. The spat, overwintered in a nursery, showed the lowest mortality on the commercial grounds, but did not show better yield of meat than year younger oysters.

Robinson A. & J. Johnson (1997)

Native oyster restorations in Oregon.

Journal of Shellfish Research 16: 337

Robinson, A. M. & C. J. Langdon (1993)

The suminoe oyster-candidate for the half-shell trade?

Journal of Shellfish Research 12: 152

Over the last four years, research funded by the National Coastal Resources Research and Development Institute at the Hatfield Marine Science Center, Oregon State University, has focused on development the aquaculture of the Suminoe oyster *Crassostrea rivularis*. This species was probably introduced to the West coast, USA, with importations of Pacific oysters (*Crassostrea gigas*) from Japan. We successfully reared Suminoe oyster larvae on algal diets containing diatoms of the genus *Chaetoceros* and at salinities of 15 to 20 ppt. Usually 20 to 25% of larvae (initially present in cultures) successfully metamorphosed to produce spat. Percent set was significantly increased by exposure of competent larvae to 2 x 10 super (-4) M epinephrine, which also resulted in production of cultchless spat. These hatchery procedures have been successfully adopted by a commercial hatchery. Laboratory growth experiments indicated that both Pacific and Suminoe juvenile oysters grew fastest at a salinity of 25 ppt, and there was no evidence that juvenile Suminoe oysters were more tolerant of lower salinities than Pacific oysters. Pacific oysters grew faster than Suminoe oysters when planted at most of the grow-out sites tested on the West coast, as determined by increase in shell length and dry tissue weight. The commercial value of the Suminoe oyster wi11 depend on both its good flavor and its attractive appearance on the half-shell.

Roland, W. G. & K. J. Albrecht (1990)

Production of Pacific British Columbia Canada oysters *Crassostrea gigas* Thunberg from wild-caught and hatchery-produced seed at several densities on oyster shells.
Aquaculture & Fishery Management 21: 31-39

Production of Pacific oysters was studied under pilot-scale conditions in Baynes Sound, British Columbia, using common bottom culture strategies. Four seeding treatments, each with a different seed per cultch density were cultured: wild-caught seed 5 mm in shell height at 10 seed per cultch piece and hatchery produced seed 1-2 mm in shell height at densities of 11, 40 and 105 per cultch piece. The cultch material for all treatments was Pacific oyster shell. All seed was reared for approximately 1 year in a seed nursery located at the 2.2-m tidal level then transferred to a l-m tidal level grow-out plot until harvest 4 years later in May 1988. Clusters of large numbers of oysters were separated and evenly distributed within the plots when the oysters attained a shell height of 60-100 mm. During the first year, growth was low and mortalities were relatively high. All treatments produced oysters of similar size at harvest. The proportion surviving at harvest was substantially higher for the wild oysters which were initially larger at time of planting. Within the hatchery treatments proportion survival per cultch piece was inversely related to initial density on the shell; however, total production per cultch piece was positively related to initial density. Most efficient use of seed is attained at lower densities per shell; however, most efficient use of cultch and effort to handle cultch is attained at high densities.

Roland, W. G., T. A. Broadley & I. R. Sutherland (1989)

Solving problems with remote setting Pacific oyster larvae in British Columbia

Journal of Shellfish Research 8: 324

Remote setting of oyster larvae is widely recognized as the key to solving the chronic need for a reliable and economical source of seed oysters in British Columbia. The strategy to solve problems associated with remote setting has included: publications and courses on the use of the process; annual workshops for

problem identification and exchange of new technology; a standardized data collection method for industry to use in assessing their success; and, experimental investigations of variables that affect the percentage of larvae setting, their distribution on cultch, and post-set survival of spat. These initiatives should provide a sound basis for future growth of oyster culture in British Columbia.

Ruesink J. L., C. Roegner, B. Dumbauld & D. Armstrong (2001)
Spatial variation in the performance of an introduced oyster in a west coast estuary.
Ecological Society of America Annual Meeting 86: 194

Ruesink, J. L. (1998)
Physical and biological impacts on growth and mortality of *Crassostrea gigas*
Journal of Shellfish Research 17 (Abstract)

What 1imits the spread of introduced Pacific oysters? On the west coast of North America, *Crassostrea gigas* rarely occurs outside of warm, protected bays, and ranges may be constrained by physical and/or biological factors that change over a gradient of wave exposure. In Barkley Sound, Vancouver Island, the presence of oysters is inversely related to the abundances of strongly-interacting intertidal species. I transplanted spat to wave protected and exposed areas and performed a 2x2 factorial experiment manipulating competitors and predators. In early summer 1997, growth and survival were higher at protected than at exposed sites. Predator exclusion improved survival of oysters, but removal of competitors actually reduced survival. Microhabitat appeared extremely important for oyster growth, as all spat on a single piece of cultch tended to be affected similarly.

Sager, G. (1980)
Increase functions of the type DW-DT equals KW-M-T plus T-O-P and their integrals
Anatomischer Anzeiger 147: 445-457

The testing of a dozen functions for the length of the Alaskan [USA] razor clam *Siliqua patula* (Bivalvia) was discussed. An equation was proposed after a series of investigations into mathematical properties of organic growth. The resulting growth function was restricted to vanishing values of the birth length, as is practically the case with the razor clam measuring 0.01 cm at birth and reaching 15-16 cm at 12 yr of age. When the quotient of initial and final length or weight increases in future investigations with other species, the increase function must be modified, giving quite different solutions for some parameters. The properties of the growth functions were discussed, and an evaluation of the parameters was shown

Sager, G. (1980)
The testing of growth functions for the length of *Siliqua patula* Bivalvia
Anatomischer Anzeiger 148: 446-461

The razor clam *S. patula* from the Alaskan [USA] coast seems well fitted because of the number of length measurements and the existence of an inflexion point of the growth curve. Nonlinear regressions are used following the Paul method. Results are within the predicted parameters. The number of parameters of the functions will not necessarily increase the quality of the approximation.

Santos, J. M., S. L. Downing & K. K. Chew (1992)
The effects of water temperature on the sexual development of adult Olympia oysters, *Ostrea lurida.*
Journal of Shellfish Research 11: 556

Schiechte, J. W. (1996)
Stage structure analysis and modeling of the Pacific Razor Clam (*Siliqua patula*) in a changing environment: Investigation of population dynamics and harvest strategies using process models and simulation (Washington, Nucelobacter Siliqua, Nuclear Inclusion X, Recruitment)
Dissertation International v.57/12-B: p. 7328. pp330.

The Pacific Razor Clam (*Siliqua patula*) populations along the Washington coast have experienced massive fluctuations in abundance since the 1950s. Since the 1980s, it has been hypothesized that some of the declines in abundance might be related to the disease NIX (Nuclear Inclusion X; Nucleobacter siliqua). This study investigated the relationships between NIX and the processes of survival, growth and recruitment for razor clams along the Washington coast. This study suggests that NIX has not detrimentally affected the razor clam populations along the Washington coast. Contrary to the findings concerning NIX, this study suggests that the processes investigated were affected by the environmental conditions. In particular, survival and growth both showed seasonal components. Similarly, recruitment was correlated to the maximum mean-temperature. However, the degree and direction of the recruitment relationship was beach-specific. Simulation models were constructed to determine whether alternative management strategies could provide greater harvest with 1 itt1e to no change in risk of extinction or loss of recreational harvest opportunity. The current management strategy is a harvest rate strategy in which 25.4% of all clams $>$3.5 inches may I be harvested. The simulations suggested that the constant harvest rate strategy was a preferred strategy, but that the rate of harvest could be increased to 80% of the adults with little to no risk to the populations.

Schoener, A. & D. F. Tufts (1987)
Changes in oyster condition index with El Nino-Southern Oscillation events at 46 degree N in an eastern Pacific bay

Journal of Geophysical Research 92: 14429-435

In 31 years of monitoring the condition index of temperate northeast Pacific oysters (*Crassostrea gigas*), the lowest annual index value was recorded during the 1982-1983 El Nino-Southern Oscillation (ENSO) event. Cross-spectral analyses of monthly fluctuations of the condition index with sea level height indicate that there are significant correlations between them, although out of phase. Coherent signals with an approximately 2-year period have been detected in the data in the interval between ENSO events. We conclude that sea level height fluctuations may indirectly influence oyster growth, through alterations in productivity, and the availability of planktonic food resources.

Scholz, A J; Cooke, W A; Cooper, K L; Donaldson (1985)
Beach setting of eyed oyster larvae *Crassostrea gigas* (Thunberg) in Puget Sound, Washington.
Journal of Shellfish Research 5: 53

Eyed larvae of *Crassostrea gigas* were spread at three intertidal beach locations during low tide exposure to determine if setting would occur. No setting occurred at Bywater Bay when the incoming water temperature was 10 degree C. Setting occurred at both Lilliwaup and Penrose Point where incoming water temperatures were about 21 degree C. Laboratory experiments tested setting at 5 degree C increments from 5 degree to 25 degree C. Significant levels of setting occurred at 15 degree C, 15%; 20 degree C, 39%; and at 25 degree C, 67% after 24 h. Further experiments indicate that 20% setting will occur after 6 h at 18 degree C when larvae are refrigerated prior to setting trials.

Schumacker, E. J., B. R. Dumbauld, & B. E. Kauffman (1998)
Investigations using oyster condition index to monitor the aquatic environment of Willapa Bay Washington
Journal of Shellfish Research 17 (Abstract)

Natural set and hatchery reared Pacific oysters, *Crassostrea gigas*, were transplanted to two sites within and just outside the mouth of the Willapa River. Samples from each of the four groups were taken monthly and oyster condition index (CI) determined on individual oysters using a gravimetric method and the Westley volumetric method which has been used by the Washington Department of Fish and Wildlife (WDFW) since the early 19601s. Findings from this study have shown that the gravimetric and Westley volumetric methods are 1inearly correlated when performed on the same oysters and that the less time consuming and more precise gravimetric method can be used as an accurate gauge of oyster CI. Relationships between oyster CI and short-term and long-term variations in aquatic conditions such as temperature, salinity, chlorophyll a content, and nutrient levels are being determined through ANOVA and

multiple regression. Placement of the oyster test sites was also done to monitor watershed activities (esp. storm events) and their effects on oyster CI. Goals for this investigation include the standardization of the methods for determining oyster CI the use of this index as an indicator of conditions and trends in an estuarine environment, and determining if responses differ for hatchery reared and natural set oysters.

Smith, D. R., M. D. Stephenson, J. Goetz1, G. Ichikawa, & M. Martin (1987)
Use of transplanted juvenile oysters to monitor the toxic effects of tributyltin in California waters
Oceans 87 - Proceedings: The Ocean, An International Workplace. Halifax, NS

Juveni1e cu1ch1ess oysters (*Crassostrea gigas*) were transplanted to locations within several major bays and harbors in California known to contain elevated water levels of tributyltin (TBT). Once retrieved, the oysters were measured and sectioned to determine shell growth and the presence of shell chambering. The percentage of oysters in a sample that exhibited chambering was used as an indication of TBT toxicity. Oysters from every bay and harbor sampled exhibited at least some degree of stunted growth and/or shell deformation (chambering). The results from this study suggest that transplanted juvenile oysters can be used in routine monitoring programs to study the toxic presence of TBT in marine waters.

Stephenson, M. (1991)
A field bioassay approach to determining tributyltin toxicity to oysters in California.
Marine Environmental Research 32 (Special Issue) 51-59

Stephenson, M. D., D. R. Smith, J. Goetz1, G. Ichikawa, & M. Martin (1986)
Growth abnormalities in mussels and oysters from areas with high levels of tributyltin in San Diego Bay.
Oceans 86 - Washington, DC, USA

Culched and cu1chless oysters (*Crassostrea gigas*) and two species of mussels (*Myti1us edulis* and *M. californianus*) were transplanted to San Diego Bay, California, along a gradient of known seawater tributyltin (TBT) concentrations. Reduced shell growth in all three species was noted at stations with the highest levels of TBT. Oysters exhibited a shell thickening response that has been identified in studies in France and England as indicative of high levels of TBT in seawater. Study results suggest that mussels and oysters can be used in routine monitoring programs to study the environmental effects of TBT in marine waters.

Stevens, B.G., R. Cusimano, & D. A. Armstrong (1982)
Feeding habits of the Dungeness crab *Cancer magister* Dana in Grays Harbour, Washington.
Journal of Shellfish Research 2: 121

Stocker, M. & I. Winther (1999)
Report of the PSARC Invertebrate Subcommittee meeting, June 7-10, 1999
Canadian stock assessment proceedings series no. 99/16 Pacific Scientific Advice Review Committee (Canada). Invertebrate Subcommittee. Meeting (1999: Pacific Biological Station), Ottawa (Ontario). Canada. Dept. of Fisheries & Oceans. Science, Ottawa (Ontario). pp44

Reports proceedings of a meeting of a subcommittee that reviewed eight working papers and ten fishery updates on invertebrate fisheries. For each working paper, subcommittee comments, discussion, and recommendations are provided along with a summary of the paper. Topics of the papers include biology and fisheries of the purple sea urchin (*Stongylocentrotus purpuratus*), box crab (*Lopholithodes foraminatus*), and pink & spiny scallops; sea cucumber and shrimp trawl fisheries; management of the red sea urchin fishery; ecosystem-based management of marine invertebrates; and the status of the Olympia oyster (*Ostrea conchaphila*). The updates cover the sea cucumber, squid, geoduck, green sea urchin, scallop, octopus, horse clam, crab, intertidal clam, and razor clam fisheries.

Svrjcek. R. S. (1991)

Marine Ranching

Proceedings of the U.S.-Japan Meeting (17th) on Aquaculture held in Ise, Mie Prefecture, Japan on October 16-18, 1988. Satellite Symposium: October 20 National Marine Fisheries Service. Seattle. WA. Northwest and Alaska Fisheries Center. Report No.: NOAA-TR-NMFS-l02 May 91 178p

The document presents 23 papers delivered at the Seventeenth U.S. - Japan Meeting on Aquaculture Ise. Mie Prefecture. Japan October 16, 17, and 18. 1988 Satellite Symposium: October 20. Papers inc1ude: Efficient techniques for producing masu sa1mon smo1t and improving adult returns from outp1antings; Recent advances in halibut (*Hippoglossus* spp.) culture; Reproductive steri1ity in trlp1oid Pacific oysters; Sa1monid carrying capacity: Estimates and experiences in the Great Lakes of North America; Farming techniques for bay sca11op, *Pecten (Notovo1a) a1bicans*, in the western regions of the Japan Sea; Large-scale cu1ture system for attaching microalgae; The importance of smolt development to successfu1 marine ranching of Pacific sa1mon; Control of skin u1cers in young b1uefin tuna in fish farming; and The use of aquaculture for enhancement of the common property fishery in Oregon, Washington, and A1aska.

Szarzi, N. J., T. J. I. Quinn, & D. N. McBride (1995)

Assessment of shallow-water clam resources: Case study of razor clams, eastern Cook Inlet, Alaska.
ICES Marine Science Symposia 199: 274-286

Taylor, B. E., G. Jamieson, & T. H. Carefoot (1992)

Mussel culture in British Columbia – the influence of salmon farms on growth of *Mytilus edulis*

Aquaculture 108: 51-66

Salmon farms as sites for mussel culture were investigated with respect to possible advantages of nutritional enrichment. Mussels were cultured at different distances around two salmon farms. Three growth parameters: condition index, carbohydrate content, and crude protein content were monitored at 3-6-week intervals from September 1988 to August 1989. Distinct seasonal differences were observed in all parameters, but distance from the farm did not substantially influence mussel growth, nor did the farms increase available food for mussels. Measures of seston and chlorophyll concentration, made concurrently with mussel collections, indicated that neither a direct contribution of nutrients in the form of fish feed and faeces, nor an indirect contribution of waste nitrogen to augment phytoplankton production, occurred. This was despite currents flowing at least part of the time in a direction from the farms to the mussels.

Taylor, B. E. (1989)

Mussel culture in British Columbia: The influence of salmon farms on growth in mussels

Journal of Shellfish Research 8: 416

The present study investigated the possible advantages, through nutritional enrichment, of salmon farms as sites for mussel culture. Mussels are being cultured at different distances around 2 salmon farms on the east coast of Vancouver Island. Three parameters of mussel growth (condition index, polysaccharide content and nitrogen content), were monitored at 3-6 wk intervals. While distinct seasonal differences in the 3 growth parameters were observed, up to spring 1989 there has been no significant difference in any parameter between mussels with respect to their proximity to a farm. It is expected, however, that such a difference may become evident during the summer months--typically a time of increased growth and reproduction. Contrary to prediction, the farms have not appeared to influence the availability of foodstuffs for mussels. Neither a direct contribution of nutrients in the form of feed particles, nor an indirect contribution of waste ammonia augmenting phytoplankton production, has so far been made by the salmon farms.

Thompson, B., B. Anderson, J. Hunt, K. Taberski, B. Phillips (1999)
Relationships between sediment contamination and toxicity in San Francisco Bay.
Marine Environmental Research 48: 285-309

Sediment contamination and toxicity were monitored at 14 sites in San Francisco Bay between 1991 and 1996. Sediment contamination patterns were different in the major reaches of the Bay, and at each site. Several contaminants were consistently above concentrations previously associated with toxicity at most sites. Bulk sediment bioassays using the amphipod *Eohaustorius estuarius* and sediment elutriate bioassays using larval bivalves (*Mytilus spp., Crassostrea gigas*) also indicated different patterns of sediment toxicity in space and time. Sediments were most toxic to the amphipods at Redwood Creek (90% of the tests), and were toxic in at least half the tests conducted at five other sites. Sediment elutriates severely reduced normal bivalve larval development at the San Joaquin and Sacramento Rivers in all samples, but toxicity occurred in less than a third of the tests in the Central and South Bays. Toxicity could not be statistically related to seasonal freshwater flow or rainfall in the Bay, but seasonal variation in contaminant concentrations and toxicity was observed. Amphipod toxicity was inversely and significantly related to the mean effects range-median quotient, suggesting that cumulative concentrations of several contaminants were related to toxicity. Further analysis identified suites of specific contaminants at each site that were variably related to amphipod toxicity at each site. Chlordanes, cadmium, and silver were significantly related to amphipod survival in the North Bay. Seasonal patterns in low, and high molecular weight polycyclic aromatic hydrocarbons (PAHs) were related to toxicity at Alameda, and metals and PAHs were related to toxicity at Castro Cove. Larval bivalve toxicity was associated with metals in bulk sediments, but elutriate chemistry was not measured, and relationships with toxicity could not be examined. Hypotheses about effective concentrations of several individual contaminants and mixtures of contaminants were posed.

Thompson, D. S. (1989)
An overview of the Washington Department of Fisheries Puget Sound enhancement plan for *Crassostrea gigas* and *Tapes philippinarum*
Journal of Shellfish Research 8: 416-417

Pacific oyster *Crassostrea gigas* and Manila clam *Tapes phi1ippinarum* enhancement is proceeding throughout Puget Sound in response to the increasing harvest of these species by tribal and nontribal user groups. Pacific oyster enhancement is by traditional seeding methods. Test plots are established on exposed beaches to determine the feasibi1ity of planting single seed, which can lodge between rocks; and spreading larvae which can attach to stable rock surfaces. Manila clam enhancement is by two methods. The first, beach graveling, is being used to create new clam habitat on mud and mud/sand beaches. The second method is to enhance natural gravel beaches by planting seed or spreading larvae. Beaches chosen for the study are beaches with good clam habitat that have a low natural recruitment of clams; and good clam producing beaches that are heavily harvested.

Thompson, P. A., M. Guo, & P. J. Harrison (1993)
The influence of irradiance on the biochemical composition of three phytoplankton species and their nutritional value far larvae of the Pacific oyster (*Crassostrea gigas*)
Marine Biology 117: 259-268

Three species of phytoplankton grown at high (HL) or low 1ight (LL) were fed as saturating rations to laboratory-reared larval *Crassostrea gigas.* Larval C. gigas fed diets of HL grown *Chaetoceros gracilis* and HL grown *Isochrysis aff. galbana* grew faster than those fed LL grown cells of the same phytoplankton species. Faster growth of *C. gigas* larvae was consistently associated with increases in the percent composition of short chain saturated fatty acids (FA) 14:0 + 16:0 in the HL grown cells. There were no consistent and significant differences between HL and LL grown phytoplankton cells in their content of carbon, nitrogen, protein, lipid or carbohydrate. Intraspecific increases in percent composition of essential fatty acids (EFAs), 20:5 omega 3 and 22:6 omega 3, in the phytoplankton were not associated with improvements in the growth or survival of the oyster larvae. Oyster larvae fed diets of *Phaeodactylum*

tricornutum with a relatively high proportion of EFAs grew more slowly than those fed *C. gracilis.* In this experiment the proportion of dietary EFA 20:5 omega 3 was negatively correlated with oyster growth rates. The faster growing oyster larvae contained relatively more of the FAs 14:0 + 16:0 which may be useful as measures of larval oyster condition. After a diet of one phytoplankton species for ca. 10 d, oyster larvae acquired distinctive FA profiles resembling that of their phytoplankton prey.

Van Veldhuizen, H. D., R. Markel, R. & P. Carpenter (1989)
Ocean dumping of municipal incinerator ash by Akutan, Alaska.
Oceans 89. Part 2: Ocean Pollution, Seattle, WA, USA

The community of Akutan (population approximately 100) purchased a municipal incinerator and applied for a permit to dump the bottom ash at sea. The Environmental Protection Agency's ocean dumping site designation regulatory program required an Environmental Impact Statement, including chemical and biological testing of the ash, on the proposed action. Metal concentrations were generally low compared with typical municipal incinerator bottom ash. Total dioxins were measured at 547 parts per trillion, with 2,3,7,8-TCDD detected at 6.2 parts per tri11ion. PCBs and other priority pollutant organics were not detected. Suspended particulate phase bioassays using mysids and speckled sanddabs yielded 96-h LC//5//0 of 20.7% elutriate from a 60% ash-sediment mixture. A 48-h EC//5//0 of 15.5% was determined for Pacific oyster larvae development. Mysids, clams, and polychaete worms showed no significant mortality after 10-day exposure in sol id-phase bioassays with a 60% ash-sediment mixture. Clams exposed to the 60% ash-sediment mixture for 10 days showed statistically significant bioaccumulation of copper (2-fold), lead (5-fold), and zinc (1.25-fold). Dynamic wind and wave conditions and vigorous tidal flushing through nearby Akun Strait (2 nmi away with tidal currents in excess of 5 m/s) are expected to rapidly disperse and dilute ash in the water column. Analysis of potential environmental impact indicates that incinerator ash from small communities can be safely disposed of in the dynamic environment of the Bering Sea.

Villarreal, G. (1995)
Alterations in the structure of the macrobenthic community at Bahia Falsa, Mexico, related to the culture of *Crassostrea giga*s
Ciencias Marinas 21: 373-386

The changes in macrobenthic communities in Bahia Falsa, Baja California, induced by an oyster culture are evaluated, in order to understand the actual status of the ecological system and provide the basis for a future management in the area. The study was conducted between 1987 and 1990 in a 15-point grid covering the lagoon. Data obtained were processed for community ordination by a principal components method, and a biological value index was also obtained. The results indicate that the community, in general, and the *Zostera marina* meadow, in particular, do not show symptoms of alteration and that the annelid community composition is similar to that reported 3 and 21 years ago. Only the area directly associated with the culture installations shows marked eutrophication and a community characteristic of organically polluted areas.

Villac, M. C., D. L. Roelke, F. P. Chavez, L. Cifuentes L & G. A. Fryxell (1993)
Pseudonitzschia australis Frenguelli and related species from the west coast of the USA.: Occurrence and domoic acid production.
Journal of Shellfish Research 12: 457-465

Awareness of the threat of the phycotoxin domoic acid, the cause of Amnesic Shellfish Poisoning(ASP), reached the U.S.A. west coast in the fall of 1991. Domoic acid in razor clams, mussels, and Dungeness crabs led to the closure of fisheries along the coasts of California, Oregon, and Washington. The death of pelicans that had fed on contaminated anchovies in Monterey Bay, California, set off the alarm by mid-September. The diatom *Pseudonitzschia australis* Frenguelli, detected in high concentrations in Monterey Bay at that time, was found to be a source of domoic acid. The present survey shows that, during the fall of 1991, P. australis and other *Pseudonitzschia* spp were also observed in other sites on the westcoast from Southern California to the mouth of the Columbia River (Newport, Coos Bay, and Ilwaco). In the fall of 1992, besides P. australis, other *Pseudonitzschia* spp. were present in Monterey Bay: *P. americana* and *P. pungens,* Along with the known domoic acid producers *P. delicatissima, P. pungens f. multiseries,* and *P.*

pseudodelicatissima. There was no report of domoic acid outbreak in the Bay in1992. There is strong evidence from the 1iterature that, except for *P. americana*, all *Pseudonitzschia* species found in 1991 and 1992 have been part of the diatom community of the U.S.A. west coast at least since the 19401s. The study of their distributional patterns can provide a predictive tool for the future onset of potential harmful blooms, and hence help protect the consumer and the seafood industry. Clones of *P. australis* from Monterey Bay, Coos Bay and Ilwaco were established in 1991, and clones of *P. australis, P. americana, P. delicatissima, P. pungens,* and *P. pungens f. multiseries* from Monterey Bay were established in 1992. Domoic acid was detected in P. australis (0.02-0.4 pg cntdot cell-l) and in *P. pungens f. multiseries* (0.06-1.5 pg cntdot cell-l) while *P. americana, P. delicatissima*, and *P. pungens* tested negative. The low toxicity found for these *Pseudonitzschia* clones may be attributed to testing the cell contents only and to growth and harvesting conditions in the lab. The implications of background levels of domoic acid to shellfish contamination in the field and, therefore, to long-term exposure of low concentrations of this toxin to consumers have yet to be explored.

Wachsmuth, L (1983)

Disaster ahead for the Yaquina Bay oyster industry?

Journal of Shellfish Research 3: 115

After 11S years of fishing and farming, the future of Yaquina Bay is as uncertain and bleak as ever, with one exception. The current crisis seems to be of major proportions and threatens the future of oyster farming. Giant Pacific oysters, as of 8 years ago, became stunted after the second year of growth, only putting on thick layers of blistered shells that were filled with a foul-smelling exudate. They seldom reached 'medium' size even after 6 years. A change species of oysters to the Japanese oyster, *Crassostrea ariakensis* (Wakiya) (= *Ostrea/Crassostrea rivularis*), which shows the following advantages: (1) SO% faster growth than *C. gigas*, thereby shortening the growth cycle by one year; (2) good flavor; (3) absence of the stunting and blistering problem; (4) larger maximum size than *C. gigas*; (S) higher spawning temperatures resulting in a firm and tasty meat during August and September; and (6) uniform shell shape and attractive interior shell surface is considered.

Walker, T.A. (1993)

Island scallops: Farming the Japanese scallop in British Columbia

Aquaculture Magazine 19: 38-49

While working as a consultant along the British Columbia westcoast, marine biologist Rob Saunders had an opportunity to work with a number of aquatic species. Saunders was involved in projects ranging from kelp to abalone and two exotic or nonindigenous species - Manila clams and Pacific oysters. But it was the work of Department of Fisheries and oceans researcher Dr. Neil Bourne, with another exotic species that caught Rob's attention. Dr. Bourne, working out of the DFO Pacific Biological Station in Nanaimo, on Vancouver Island, spent from 1980 to 1988 developing hatchery techniques for *Patinopecten yessoensis*, the Japanese scallop.

Ward, J., J. Word, & L. D. Antrim (1989)

Biological Testing of Sediment for the Olympia Harbor Navigation Improvement Project, 1988: Geoduck, Amphipod, and Echinoderm Bioassays

Battelle Pacific Northwest Labs, Richland, WA. May 89 pp91.

The Olympia Harbor Navigation Improvement Project requires the dredging of approximately 330,000 cubic yards (cy) of sediment from the harbor entrance channel and 205,185 cy from the turning basin. Puget Sound Dredged Disposal Analysis (PSDDA) partial characterization studies were used to plan a full sediment characterization in which chemical analyses and biological testing of sediments evaluated the suitability of the dredged material for unconfined, open-water disposal. The US Army Corps of Engineers (COE), Seattle District, contracted with NOAA/NMFS, Environmental Conservation Division, to perform the chemical analysis and Microtox bioassay tests, and with the Battelle/Marine Sciences Laboratory (MSL) in Sequim to perform flow-through sol id-phase bioassays utilizing juvenile (8 to 10 mm) geoduck

clams, *Panopea generosa*, and static solid phase bioassays using the phoxocephalid amphipod, *Rhepoxynius abronius*, developing embryos and gametes of the purple sea urchin, *Strongylocentrotus purpuratus*, and the larvae of the Pacific oyster *Crassostrea gigas*. When the results of the biological tests were evaluated under PSDDA guidelines, it was found that all the tested sediment treatments from Olympia Harbor are suitable for unconfined open-water disposal.

Ward, J. A. J. Q. Word, M. R. Pinza, H. L. Mayhew, & E. S. Barrows (1992)

Ecological evaluation of proposed discharge of dredged material from Oakland Harbor into ocean waters (Phase 3 A of -42-foot project). Volume 1, analyses and discussion
Technical Report Battelle Pacific Northwest Labs. Report Number PNL-8302 -Vol. 1, vol. 1 99.169, Sep 1992

The Battelle/Marine Sciences Laboratory (MSL) conducted a study to determine whether dredged sediments from Oakland Inner and Outer Harbors were, suitable for ocean disposal. Nineteen test treatments, six reference treatments, and control treatments were tested for physical/chemical parameters, water column effects, dredged sediment-toxicity, and bioaccumulation potential. Physical/chemical parameters were analyzed at each site and each composite sediment to a depth of -44 ft MLLW. These parameters included analysis for geological characteristics, conventional sediment measurements (grain size, total volatile sol ids, total organic carbon, oil and grease, and total petroleum hydrocarbons), metals, polynuclear aromatic hydrocarbons (PAHs), pesticides, butyltins, and polychlorinated biphenyls (PCBs). Physical/chemical data were used in support of the toxicological and bioaccumulation testing, but were not used in the decision-making criteria described it in the Draft Implementation Manual under Tier III testing. To evaluate water column effects, MSL conducted suspended-particulate-phase (SPp) tests using the mysid shrimp *Holmesimysis sculpta*, speckled sanddab *Citharichtys stigmaeus*, and larvae of the pacific oyster *Crassostrea gigas*- Both a 48-h and a 96-h test were performed. The MSL evaluated dredged sediment toxicity by conducting a total of eight solid-phase toxicity tests using the following organisms: the bivalve clam *Macoma nasuta*, the polychaete worm *Nepthys caecoides*, the speckled sanddab *C. stigmaeus*, and the amphipod *Rhepoxynius abronius*. Test duration ranged From 10 to 28 days. Bioaccumulation potential was evaluated in the 28-day *M. nasuta* and *N. caecoides* solid-phase exposures by measuring the Contaminants of concern present in their tissues after exposure to test, reference, and control sediments.

Ward, J. A. J. Q. Word, M. R. Pinza, H. L. Mayhew, & E. S. Barrows (1992)

Ecological evaluation of proposed discharge of dredged material from Oakland Harbor into ocean waters (Phase 3 A of -42-foot project). Volume 2, appendixes
Technical Report Battelle Pacific Northwest Labs. Report Number PNL-8302-Vol.2 pp685., Sep 1992

The Battelle/Marine Sciences Laboratory (MSL) conducted a study to determine whether dredged sediments from Oakland Inner and Outer Harbors were suitable for ocean disposal. Nineteen test treatments, six reference treatments, and three control treatments were tested for physical/chemical parameters, water column effects, dredged- sediment toxicity, and bioaccumulation potential. Physical/chemical parameters were analyzed at each site and each composite sediment to a depth of -44 ft MLLW. These parameters included analysis for geological characteristics, conventional sediment measurements (grain size, total volatile solids, total organic carbon, oil and grease, and total petroleum hydrocarbons), metals, polynuclear aromatic hydrocarbons (PAHs), pesticides, butyltins, and polychlorinated biphenyls (PCBs). Physical/chemical data were used in support of the toxicological and bioaccumulation testing, but were not used in the decision-making criteria described in the Draft implementation manual under Tier III testing. To evaluate water column effects, MSL conducted suspended-particulate-phase (SPp) test using the mysid shrimp *Holmesimysis sculpta*, speckled sanddab C*itharichtys stigmaeus*, and larvae of the pacific oyster *Crassostrea gigas*. Both a 48-h and a 96-h test were performed. The MSL evaluated dredged-sediment toxicity by conducting a total of eight sol id-phase toxicity tests using the following organisms: the bivalve clam *Macoma nasuta*, the polychaete worm *Nepthys caecoides*, the speckled sanddab *C. stigmaeus*, and the amphipod *Rhepoxynius abronius*. Test duration ranged from 10 to 28 days. Bioaccumulation potential was evaluated in the 28-day M. Nasuta and

N. caecoides solid-phase exposures by measuring the contaminants of concern present in their tissues after exposure to test, reference, and control sediments. This report contains the data and test results.

Wekell, J. C, E. J. Gauglitz Jr, H. J. Barnett, C. L. Hatfield, & M. Eklund (1994)
The occurrence of domoic acid in razor clams (*Siliqua patula*), dungeness crab (*Cancer magister*), and anchovies (*Engraulis mordax*).
Journal of Shellfish Research 13: 587-593

In September 1991, waterfowl died in Monterey Bay, CA, after eating anchovies (*Engraulis mordax*) contaminated with domoic acid. Analysis revealed that the anchovies contained up to 485 ppm domoic acid in their viscera. This was the first reported incidence of domoic acid-related mortality of any organism in the United States. After this reported outbreak we obtained frozen samples of anchovies that were harvested near Newport, CA, in April 1991 and found they contained 270 ppm domoic acid in their viscera. By May, average domoic acid levels in frozen anchovy samples from this same area were less than 1 ppm. In October 1991, domoic acid was detected in razor clams (*Siliqua patula*) from
Oregon and Washington and appeared to peak (an average of 106 ppm for all Washington State beaches) in the first week of December 1991. The averages then declined to less than 20 ppm without 6 months. However, domoic acid was sti11 present at low levels (averages It 5 ppm) in razor clams from Washington state beaches in December 1993. Dungeness crab (*Cancer magister*) in Washington and Oregon were also found to contain domoic acid, but only in their viscera. Domoic acid concentrations in the raw viscera of individual crabs from Washington state in December 1991 averaged 13 ppm and ranged from 0.8 to 90 ppm. The highest average levels of domoic acid in Washington state crabs were in the Grays Harbor and Willapa Bay samples, 32 and 31 ppm, respectively. By 1992 domoic acid level averages were It 5 ppm in preseason samples of Dungeness crab taken along the Oregon and Washington coasts, ranging from 0 to 71 ppm. The highest levels of domoic acid in 1992 (36-71 ppm) were recorded in samples taken early in that year (January through Apri1).

Wekel1, J. C., E. Gauglitz Jr, H. Barnett, C. Hatfield, D. Simons & D. Ayres (1994)
Occurrence of domoic acid in Washington State razor clams (*Siliqua patula*) during 1991-1993.
Natural Toxins 2: 197-205

The presence of domoic acid in aquatic species was reported for the first time in the United States in the late summer of 1991 in Monterey Bay, California. By October of 1991, domoic acid was found in razor clams (*Si1iqua patula*) and in the viscera of Dungeness crab (*Cancer magister*) along the coasts of Washington and Oregon. In response to this outbreak, the National Marine Fisheries Service, in cooperation with the Washington State Department of Fisheries began analysis of Washington State razor clams for the period from November 1991 to June 1993. This survey indicated that domoic acid levels in the edible portion of the razor clams peaked in December of 1991 (average of all Washington state coastal sites: 106 ppm) and followed a slow decline to the present day low levels (It 5 ppm). Sixteen months after the maximum level, domoic acid has not completely disappeared from the razor clams from the Washington State beaches. Unlike mussels (*Mytilus edulis*), where the toxin is found only in the viscera, domoic acid distributes itself throughout the various body parts of the razor clam. The highest concentration occurs in the foot or 'digger' and the lowest in the siphon or "neck". The concentration of domoic acid in the razor clam foot reached a high of 230 ppm.

Wekell, J. C., R. A. Horner, C. L. Hatfield, H. J. Barnett, E. J. Gauglitz Jr;, J. A. Lund & V. L. Trainer (1996)
Domoic acid on the west coast of the United States.
Canadian Technical Report of Fisheries and Aquatic Sciences 2138: 78-81

Wekell, J. C., V. Trainer, D. Ayres, & D. Simons (2000)

The distribution of domoic acid concentrations in Razor clams as a function of elevation between high and low tides at Kalaloch Beach Washington.
Journal of Shellfish Research 19: 638

Wellborn, J. R. (1994)

Biochemical studies of seawater chemistry and invertebrate larvae from Antarctic and temperate regions
Dissertations International v. 55/12-B: p. 5224

A method was developed for measuring picomole amounts of sugars in seawater using high-performance 1iquid chromatography (HPLC). This method was then used to measure sugar uptake from seawater into molluscan larvae. Bivalve veligers take up glucose, maltose, cellobiose, and cellotriose but not L-rhamnose or maltotriose. Gastropod veligers take up glucose and maltose, but not L-rhamnose or maltotriose. Bivalve veligers transport glucose and maltose by separate pathways and the influx of $\sp{14}$C-labeled glucose was equal to the net flux (measured with HPLC). Thus, molluscan larvae can utilize part of dissolved organic material in the sea, a part not previously identified as an energy source available to larvae. HPLC was used to measure seasonal changes in concentrations of individual dissolved free amino acids and sugars in antarctic waters (McMurdo Sound) and temperate waters (California). Amino acids in surface and water-column samples from a receding ice edge in Antarctica were low (73 nM, mean, total concentration) during austral spring, then increased (675 nM) by summer. Sugar concentrations were low during spring (47 nM), increasing by summer (125 nM). Amino acids were low (19 nM) in water-column samples taken under annual sea ice during spring, increasing in summer (151 nM), while sugars showed no seasonal increase. Temperate samp les showed no summer increase in either free amino acids or sugars, and concentrations were low (below 50 nM). Glucose, fructose and sucrose were the dominant sugars measured in all samples. During development, gastropod larvae (*Haliotis rufescens*) maintained taurine content (measured with HPLC) while bivalve larvae (*Crassostrea gigas*) increased taurine content 43-fold. Taurine was not measurable, as determined with HPLC, in bivalve larval foods (microalgae). Taurine synthesis from cysteine was not measurable in unfed bivalve larvae or larvae exposed to hyperosmotic seawater. Larvae fed algae synthesized taurine from cysteine or methionine, and synthesis was up-regulated ll-fold by feeding the larvae. Algal proteins (*I. galbana*) contain 5 fmol cell$\sp{-l}$ of cysteine and methionine. Calculations show that larvae feeding on algae can obtain enough precursors to meet taurine requirements during growth if 41% of the precursors are metabolized into taurine. This finding contrasts with previous research on adults which show that taurine is an essential amino acid.

Whyte, J. N. C., N. G. Ginther, & L. Townsend (1994)

Seasonal variation in content and distribution of domoic acid in the razor clam, Siliqua patula, from different geographic locations in British Columbia.
Canadian Technical Report of Fisheries and Aquatic Sciences 2016: 65

Whyte, J. N. C., R. J. Beamish, N. G. Ginther, & C. E. Neville (1993)

Nutritional condition of the Pacific Lamprey (*Lampetra tridentate*) deprived of food for periods of up to 2 years.
Canadian Journal of Fisheries and Aquatic Sciences 50: 591-599

The anadromous parasitic Pacific lamprey (*Lampetra tridentata*) does not feed during metamorphosis or its spawning migration. To assess the utilization of body reserves, we compared the compositions of an adult lamprey held for 2 yr without food, recently metamorphosed lampreys, and lampreys starved for 6 mo. Moisture was higher and soluble ash and 1ipid levels in tissue of the 2-yr-starved than in metamorphosed lampreys (2.67 and 3.39 kJ.g-l, respectively). Fatty acid profiles of 2-yr-starved and metamorphosed lampreys were qualitatively similar except for the presence of 15:0 in the latter. Substantially lower levels of 14:0 and 16:1n7 and higher levels of polyunsaturated fatty acids occurred in starved lampreys. Changes in composition of lampreys starved for 6 mo were similar to changes between the 2-yr-starved and metamorphosed lampreys. Maintenance energy in a normalized l-g lamprey starved for 6 mo was derived from catabolism of 71% lipid and 29% protein; total loss was 2.56 kj or 49% of the original energy. The

ability to survive extended periods on endogenous reserves, which may have allowed *L. tridentata* to survive past environment catastrophes, allows it to migrate considerable distances to spawning areas in the headwaters of rivers.

Wiegardt, L. J. & N. Bourne (1989)
Introduction and transfer of molluscs in the Northeast Pacific
Journal of Shellfish Research 8: 467

Several species of molluscs have been introduced to the west coast of North America either intentionally or unintentionally. The most famous introduction was the Pacific oyster, *Crassostrea gigas*, which now supports a large industry in the northeast Pacific. The manila clam, *Tapes philippinarum*, which was introduced with the Pacific oyster also supports a multimillion-dollar industry. However, deleterious organisms were introduced with Pacific oysters and a brief review of the advantages and disadvantages of the introduction is given. The advent of hatcheries with quarantine facilities now makes it possible to introduce exotics or transfer molluscs from area to area on a large scale with minimal danger of introducing pests, parasites or diseases with them. The need for further introductions of molluscan species and transfer of species to other areas of the northeast Pacific is reviewed. Mechanisms control1ing introductions and transfers of molluscs (and other organisms) are discussed. The general conclusion is that any further introductions should be carefully reviewed and controlled and regulations tightened to control movement of molluscs into or throughout the northeast Pacific.

Wiley, K. & J. Zahradnik (1981)

Performance evaluation of a suspension tray system for the culture of pacific oysters, Crassostrea gigas, in Trevenen Bay, British Columbia.
Journal of the World Mariculture Society 12: 64-75

The system consists of 5 trays, each with a holding capacity of 0.658 m2 and capable of growing 100-150 oysters. The trays are based on a circular frame and are .91 m in diam., 5.1 cm in height with a 0.5 cm net mesh attached to the frame. Spacing between the trays is 15.2 cm. Two units were tested, 1 in a sheltered location and one in a natural tidal raceway. The units performed similarly at both sites, exhibited 1ittle variation in shell growth in the series of 5 trays, retarded fouling and were economically viable for commercial use.

Wolfe D. A., M. M. Krahn, E. Casillas, S. Sol, T. A. Thompson, J. Lunz, & K. J. Scott (1996)
Toxicity of intertidal and subtidal sediments contaminated by the Exxon Valdez oil spill.
Proceedings of the Exxon Valdez oil spill symposium, American Fisheries Society Symposium 18: 121-139

Word, J., J. Ward, & D. L. Woodruff (1990)
Results of bulk sediment analysis and bioassay testing on selected sediments from Oakland Inner Harbor and Alcatraz disposal site, San Francisco, California Battelle Pacific Northwest Labs., Richland, WA. Department of Energy, Washington, DC. Report No.: PNL-7586 Sep 90 pp217.

The Battelle/Marine Sciences Laboratory (MSL) was contracted by the US Army Corps of Engineers, San Francisco District, to perform bulk sediment analysis and oyster larvae bioassays (elutriate) on sediments from Inner Oakland Harbor, California. Analysis of sediment characteristics by MSL indicated elevated priority pollutants, PAHs, pesticides, metals, organotins, and oil and grease concentrations, when compared to A1catraz Island Dredged Material Disposal Site sediment concentrations. Larvae of the Pacific oyster, Crassostrea gigas, were exposed to seawater collected from the Alcatraz Island Site water, and a series of controls using water and sediments collected from Sequim Bay, Washington. Exposure of larvae to the Alcatraz seawater and the 50% and 100% elutriate concentrations from each Oakland sediment resulted in low survival and a high proportion of abnormal larvae compared to Sequim Bay control exposures. MSL identified that field sample collection, preservation and storage protoco1s used by Port of Oakland contractors were inconsistent with standard accepted practices.