Padilla Bay
National Estuarine Research Reserve

Technical Report No. 24

Padilla Bay Estuarine Profile: Contribution No. 1

Padilla Bay Molluscs: A Review, With Emphasis on the Bivalves

Paul A. Dinnel

September 2000

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Padilla Bay Molluscs

A Review, With Emphasis on the Bivalves

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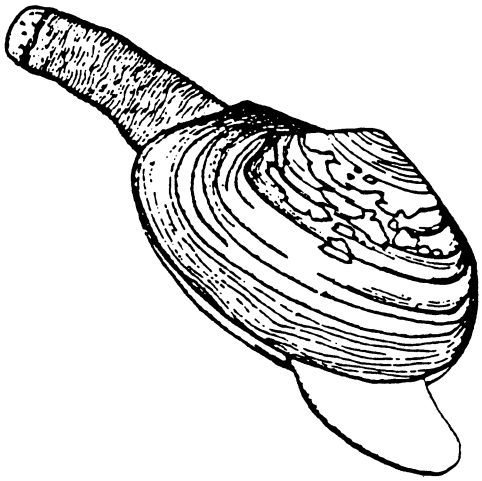
For

Padilla Bay National Estuarine Research Reserve

September 2000



Abstract

This report provides a review of all scientific investigations and aquaculture work associated with molluscs found in Padilla Bay, Washington, with special emphasis on the bivalve species. Forty-seven data sources dating back to the early 1930s were evaluated. Past sampling programs have identified 133 mollusc species plus an additional 18 molluscs identified to genus only. However, identifications of four of the bivalve species are questionable. This report also provides overviews of the oyster industry in Padilla Bay, the impacts of various sources of pollution, and a brief review of the biology and ecology of Padilla Bay bivalves. Detailed information about each Padilla Bay bivalve species is provide in a "Species Profile" that discusses the biology, distribution, habitat and fishery/aquaculture potential of each species. A bibliography covering many of the bivalve species is also appended to aid further species-specific research.

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Introduction

A list of the molluscan fauna of Padilla Bay has gradually been assembled by Riggs (1997) from data presented in various studies dating back to 1947. But aside from a simple listing of species previously reported, no integrated, critical treatment of Padilla Bay molluscs has been undertaken. Molluscs from Padilla Bay have been identified from 47 previous studies conducted since the early 1930s. The object of this report is to tabulate all mollusc species identified by these studies and provide a more intensive review of the bivalves. For the bivalves, I provide a critical review of the data, and provide basic information about taxonomy, range, habitat, biology and ecology in a series of Species Profiles.

Background on Molluscs

Phylum Mollusca

The term mollusc (also mollusk) is derived from Aristotle's word for cuttlefish, and is considered to mean soft-bodied. In abundance of species, molluscs comprise the largest invertebrate phylum aside from the arthropods. Almost 100,000 living mollusc species have been described. In addition, because of the hard shells of bivalves and gastropods, the fossil record is rich, with over 35,000 fossil species dating back to the Cambrian Period. Molluscs have adapted themselves to most habitats, including marine, freshwater and terrestrial, to depths of 35,000 feet, mountains, deserts, and the Arctic.

Since earliest times man has used molluscs as food, as witnessed by great prehistoric shell middens in many parts of the world, and for tools, money, jewelry and dyes. Phylum Mollusca comprises a very diverse group of animals, ranging in size from a few mm to giant squid that may rival the length of whales and weigh up to two tons. While molluscs may generally be identified by their soft bodies, many (e.g., clams and snails) have strong external shells, some (e.g., squid, chitons, pteropods) have internal shells, and some (e.g., octopuses, nudibranchs) have no shell at all. A few exist only as parasites or as specialized commensals.

Molluscs apparently arose from an ancestral stem that also produced the annelids, as evidenced by the extremely similar pattern of spiral cleavage in developing embryos of the more primitive members of these phyla. In each group, a larva of the trochophore type is produced. In molluscs, the trochophore then develops into a ciliated straight-hinged larva called a veliger, based on the presence of a ciliated vellum. At settlement, the vellum is cast off as the mollusc begins its benthic phase (Fig. 1). Most larval development takes place in the water column as part of the zooplankton. However, some molluscs brood their young in the mantle cavity and release partially- or fully-formed juveniles. The cephalopods, however, lay external egg cases from which fully formed juveniles hatch. Most mollusks are dioecious (separate sexes), although some are hermaphrodites, either simultaneous or sequential (e.g., protandrous – first male, then changing to female).

Molluscan Taxonomy

The classification and identification of molluscs is as complete as a phylum can be, especially in view of the fact that most molluscs have well-developed shells that serve as the basis of their classification and identification. Indeed, shell collecting has been a favorite pastime for many centuries. However, many molluscs (e.g., the opistobranchs) require dissection of the soft tissues or reproductive systems to identify them. Molluscan taxonomy is roughly split into two divisions: 1) malacologists – those who study the soft tissue anatomy, and 2) conchologists – those who collect and study shells. Molluscs are divided into six classes, as described below:

1. Class Monoplacophora. These are primitive limpet-like molluscs. Only five living species are presently known, all deep-sea residents.

2. Class Amphineura. This class is divided into two subclasses: Polyplacophora (chitons) and Aplacophora, which are a small group of aberrant, worm-like animals no more than 25 mm in length.

3. Class Gastropoda. Literally meaning "stomach-foot," gastropods are essentially snails in their various forms. There are about 80,000 species of gastropods. Gastropods are usually univalves, although some species do not have shells. In all gastropods, the later embryonic stage undergoes a twisting of 180° called "torsion." Gastropods are usually divided into three subclasses:

    - Prosobranchia -- typical marine and aquatic snails

    - Opisthobranchia – nudibranchs, techtibranchs, sea hares, bubble snails, all marine

    - Pulmonata – land and some aquatic snails, all of which have a modified "lung" structure to facilitate air breathing

4. Class Bivalvia (Pelecypoda). These are molluscs with two hinged shells and, often, a "hatchet foot" (hence, Pelecypoda). Varieties of bivalves include clams, mussels, scallops, jingles, pen shells and oysters. Bivalves are divided into five orders:

    - Palaeoconcha – Awning clams. Have filibranch-like gills, but lacks siphons, toothless hinge and flat-ended foot.

    - Protobranchia – Primitive clams (e.g., *Nucula, Yoldia, Solemya*). Gill filaments not folded; foot with flattened ventral surface; palpal proboscides frequently present.

- Filibranchia –Mussels, scallops, oysters, ark shells. Gills are long curtains folded back against themselves.

- Eulamellibranchia – Most clam species. Gill filaments folded and adjacent filaments attached by ciliary or tissue junctions.

- Septabranchia – Dipper clams. Gills modified as a pumping septum between inhalant chamber and suprabranchia cavity

5. Class Scaphopoda. These animals are commonly called tusk or tooth shells. The shells resemble miniature elephant tusks that can be up to 125 mm long. They typically reside in marine bottoms buried in mud.

6. Class Cephalopoda. These are the squid, octopuses, cuttlefish and nautilus', of which only about 400 species have been described. Cephalopods are represented by two subclasses:

    - Nautiloidea – primitive chambered nautilus' of the Pacific Ocean, which have substantial external chambered shells

    - Coleoidea – squids, cuttlefish and octopuses. Where present, shells are much reduced and internal, ranging from the cuttlefish chalky "bone" to flat, thin squid "pens"

Survey of Historical Studies Reporting Molluscs in Padilla Bay

Almost 50 primary data sources were investigated for the review presented in this report, although only a portion of these were original studies; the rest were simply compilations or reviews of previous field work. Following is a description of each of the field studies, databases, and compilations reviewed and the type of data available from each. The sources are listed in chronological order and indicate the order in which molluscs were first reported in Padilla Bay. Mollusc data gleaned from each of the following sources are summarized in a Padilla Bay mollusc inventory list (Table 1).

Pacific Fisherman Articles, 1932-44

As far as can be determined, the first published notation regarding molluscs in Padilla Bay (ignoring the fact that they're non-indigenous) concerned the initial planting of 15,000 cases of Pacific oyster (*Crassostrea gigas*) seed in south Padilla Bay in 1932 by the Padilla Point Oyster Company. Further notations about additional plantings and harvests of Pacific oysters appear in subsequent issue of *Pacific Fisherman.*

Shelford et al. 1935

As part of a larger study, Shelford et al. (1935) sampled two sandy intertidal stations on the shore of Samish Island, one each on the north and south shore (his Stations 114 and 115). However, his sampling map and brief results presented for these stations did not provide enough information to discern which of the two stations was located in Padilla Bay. Mollusc species identified from these two stations were the bivalves *Cardium corbis* (= *Clinocardium nuttallii*), *Saxidomus giganteus*, *Macoma nasuta* and *Paphia* (= *Protothaca*) *staminea*. All of these species are common and probably occurred at both of the Samish Island stations.

Early Oyster Investigations, 1948-63

Other early work with Pacific oysters in Padilla Bay concerned their poor growth and the possibility that they were being adversely affected by pulp mill pollution. In 1948, Saxton and Young investigated the possible effects of sulfite waste liquor on oysters in Padilla Bay. Another pulp mill pollution study conducted of Orlob et al. in 1950 specifically discusses the condition of Pacific oyster beds in both Padilla and Fidalgo Bays. Others, including Neale (1952) and Westley (1958, 59, 60, 61, 62, 63) issued follow-up reports on the condition of Pacific oyster beds in south Padilla Bay, both as a function of pollution and natural physical factors.

Sylvester and Clogston 1958

The first actual survey of Padilla Bay biota was conducted by Sylvester and Clogston (1958), who conducted both intertidal and subtidal benthic sampling in the Fidalgo-Padilla Bay region for the Texas Company Refinery. They identified 21 species of molluscs and six other molluscs identified to genus only. However, identifications of two molluscs in their report are questionable: 1) *Mercenaria* sp. would most certainly allude to *Mercenaria mercenaria*, the East Coast cherrystone clam or quahog, the only species of *Mercenaria* reported to reside on the West Coast. However, this species, introduced from the East Coast in the 1800s, has only been reported from the Los Angeles area and Humboldt Bay in northern California (Morris et al. 1990). Hence, this was probably a case of mistaken identity. 2) The butter clam, *Saxidomus nuttallii*, is also a probable case of mistaken identity. This species, which is very similar to the locally abundant (but smaller) *Saxidomus giganteus*, has a reported range of Humboldt Bay, California to Baja California (Morris et al. 1990). It is highly probable that the *S. nuttallii* of Sylvester & Clogston is actually *S. giganteus*.

Pacific Ocean Farms 1973

In July 1973, Northwest Environmental Consultants, hired by Orion Corporation, surveyed Padilla Bay for the abundances of shellfish resources. They primarily recorded the existence of commercial/sport species of clams. All had been recorded from previous studies. Their final report (Pacific Ocean Farms 1973) details relative abundances of common clam species at 34 sampling stations throughout the bay.

Goodwin 1973

As part of a Washington Department of Fisheries Puget Sound-wide survey of subtidal hardshell clam resources, Goodwin (1973) surveyed five subtidal stations (9 to 23 foot depths, sand and mud substrates) between Hat Island and Samish Island. However, he failed to find either commercial or sport densities of clam resources at these stations.

Webber et al. 1975

Webber and colleagues at Western Washington University conducted a year-long survey of intertidal and subtidal habitats in 1974-75 for the Washington Department of Ecology's Oil Baseline Study of North Puget Sound. They identified 24 molluscs to species plus a number of other molluscs only to genus. Twenty of these molluscs had not been identified by the previous field study by Sylvester and Clogston (1958).

Jeffrey 1976

Jeffrey (1976) produced a summary inventory of biota collected from Padilla Bay. However, his inventory did not reflect any new sampling on his part, but rather a review of previous collecting efforts by others (primarily Sylvester and Clogston [1958] and Webber et al. [1975]). His report contains a listing of 28 molluscs, not all identified to the species level.

Smith and Benedict 1977

Smith and Benedict (1977) described the benthic biota of Fidalgo and Padilla Bays relative to anticipated impacts of construction of the Anacortes navigation channel. Their list of molluscs adds 15 new species and three new genera to those previously known.

Smith and Webber 1978

Smith and Webber (1978) is essentially a continuation of the Ecology Oil Baseline Sampling Program in North Puget Sound initiated by Webber in 1974. Smith et al. identified three additional molluscs not reported by previous investigators.

U.S. Army Corps of Engineers 1981

The Army Corps of Engineers (ACOE 1981) published a Final Environmental Impact Statement for Swinomish Channel maintenance dredging in 1981 that lists fauna collected from various stations, including three from Padilla Bay. A few molluscs, all bivalves, were collected, but, with the exception of *Transenella tantilla*, all were poorly identified (i.e., identified to genus only or as "clam sp. x").

Barreca 1982

In a 1982 Western Washington University Masters Thesis aimed at assessing petroleum-degrading bacteria in Padilla Bay, Barreca also described the benthic communities associated with the bacterial fauna via benthic grab samples. Barreca described 27 molluscs to species and four others to genus only. Eleven of the identified species had not previously been recorded for Padilla Bay. However, identification of one species, the northern razor clam, *Siliqua patula*, is questionable. This species is generally found on open ocean beaches with lots of surf action. While it is possible that larvae of this species could be carried into Puget Sound and settle and survive as juveniles, this identification should be treated as questionable. It is possible that this specimen could actually have been a juvenile jackknife clam, *Solen sicarius*.

Huxley 436, 1983

A 1983 Environmental Impact Assessment class (Huxley 436) at Western Washington University prepared an Environmental Impact Statement related to possible future development on southwest Padilla Bay tidelands. As part of the document, students prepared a list of marine animals identified from previous studies, as noted above. Thus, no new data were presented. Their list of molluscs previously identified from Padilla Bay included 50 molluscs identified to species and eight others identified to genus only or as "unidentified sp."

Riggs 1983

In 1983, Riggs conducted field work in Padilla Bay related to faunal communities associated with the eelgrasses *Zostera marina* and *Z. japonica* for a student research paper in Biology 407 at Western Washington University. She reported finding nine molluscan species in Padilla Bay samples, of which only one species (*Haminoea vesicula*) was previously unreported.

Washington Department of Ecology 1984

Another compilation of existing data was prepared in 1984 (WDOE 1984) as part of a Padilla Bay National Estuarine Sanctuary Management Plan. This document records 48 different molluscs identified from Padilla Bay prior to 1984, although a few were identified only to the genus level.

Antrim 1985

In a Western Washington University Masters Thesis, Antrim (1985) measured trace metals in five species of molluscs collected from Padilla Bay (Pacific oyster, *Macoma* sp., mussels, cockle and the snail *Batillaria*). None of these species were new additions to the known fauna.

Pantalone 1985

As a University of Washington student research project, Pantalone (1985) investigated the feeding habits of the staghorn sculpin, *Leptocottus armatus*, from Padilla Bay. The only molluscs that he found in the sculpin stomachs were a unidentified gastropod and clam siphons. Hence, no new species were added by this study.

Wissmar 1986

In a study prepared for the Padilla Bay Reserve, Wissmar (University of Washington) collected several mollusc species (*Clinocardium*, *Macoma nasuta*, *Saxidomus*, *Mytilus*, and the bubble snail *Haminoea vesicula*). None of these were new additions to the known faunal database.

Nyblade 1986

As part of the Swinomish Marina Environmental Impact Statement preparation, Nyblade (1986) conducted a benthic sampling program from which he reported nine species of bivalves (all common) and two gastropods identified only to genus.

Cheney and Mumford 1986

In their book describing shellfish and seaweed harvests of Puget Sound, these authors indicate that small amounts of Pacific octopus (*Octopus dofleini*) have been harvested from Padilla Bay in the past. This is the first and only report of any cephalopod species being found in Padilla Bay. Source of the harvest records is probably WDF files.

Bureau of Indian Affairs et al. 1987

The Bureau of Indian Affairs together with the Swinomish Tribal Community and the U.S. Army Corps of Engineers (BIA et al. 1987) prepared a draft Environmental Impact Statement for a potential Swinomish Tribal marina at a southwest Padilla Bay site. Only a few common bivalves were identified from some brief sampling in and around the marina site. All of these species had previously been identified from Padilla Bay.

Ruckelshaus 1988 and Ruckelshaus 1988, 1990, 1993

In a series of articles, including her Masters Thesis, Ruckelshaus and colleagues at the University of Washington investigated the effects of habitat characteristics and food sources on the growth of the blue mussel *Mytilus* (*trossulus*) *edulis* in Padilla Bay. Although the mussels used in the study were probably transplanted into Padilla Bay from an outside location, the authors do mention that mussels are a common Padilla Bay species on rocky and piling substrates. In general, the authors found that many biotic stress factors (e.g., food quantity and quality, temperature, salinity, submergence time) can affect mussel growth, that primary production from eelgrass and macroalgae did

supplement phytoplanktonic food sources, and that mussel growth was generally greatest in beds of the eelgrass, *Zostera marina*.

Riggs 1989

Riggs identified molluscs collected in a habitat study in Padilla Bay around 1989, but maintained the data as an unpublished database. During this study, she identified 25 molluscs to species and 10 others to genus only. From this study, three new species (*Tellina carpenteri*, *Cypraeolina pyriformis* and *Urosalpinx cinerea*) and one genus (*Barleeia*) were added to the list of Padilla Bay molluscan fauna.

Gibson and Chia 1989

Gibson & Chia (1989) described a new species of bubble shell, *Haminoea callidegenita*, and compared it to a closely related species, *H. vesicula*. Both of these organisms were collected offshore of Rock Point, Samish Island, which, presumably, is off the western end of Samish Island and at the boundary between Samish and Padilla Bays. If Rock Point is further north, then this new species has not been found in Padilla Bay yet.

Pfaff 1990

Pfaff (1990) identified molluscs collected in a habitat study of Padilla Bay in 1989 and reported finding six mollusc species, all common and previously reported.

Dinnel et al. 1990

Dinnel et al. (1990) analyzed gut contents of 18 species of fish caught in Padilla Bay in 1987-88. Although they found molluscs in the stomachs of various fish, the authors only recorded molluscs as "bivalve," "gastropod," or "clam siphon." Hence, no species information is available from this source.

Pepe and Plews 1991

These investigators collected native littleneck clams (*Protothaca staminea*) from various sites around Puget Sound, including March Point, to assess the magnitude of both microbiological and chemical contamination in this species of clam. Clams collected from March Point were apparently only assessed for contamination from six metals. All tissue concentrations of Ar, Cd, Cu, Hg, Pb and Zn appeared to be low.

Lepla 1991

Along with other animals associated with eelgrass beds, Lepla (1991) collected data on Taylor's sea hare (*Phyllaplysia taylori*). This species was already on the list of known molluscs.

Woolrich 1992

In a letter to Doug Bulthuis, Woolrich (1992) provides chemical data analyses for native littleneck clam (*Protothaca staminea*) tissues assessed for a variety of metal and organic contaminants.

Kahler 1994

Kahler (1994) compared infaunal communities associated with eelgrass, *Zostera marina*, versus non-vegetated soft sediments in Padilla Bay as part of a Western Washington Student Paper. He identified nine mollusc species in his samples, eight previously identified from Padilla Bay, and one (*Macoma yoldiformis*) new to the Padilla bay mollusc inventory.

Shaw 1994

In his Western Washington University Masters Thesis, Shaw (1994) investigated the distribution of eelgrass grazers in Padilla Bay, including the opisthobranchs, *Phyllaplysia taylori* and *Haminoea vesicula*, neither new to the known molluscan faunal list.

USFWS 1994

The U.S. Fish and Wildlife Service analyzed metals and PAHs in native littleneck clams, softshell clams and Pacific oysters from six sites in Padilla Bay and three sites in Fidalgo Bay. They concluded that the occurrence of "elevated chemical residues were few and localized," primarily in softshell clams sampled from March Point. No new taxonomic data are provided in this report.

Johnson and Davis 1996

Johnson and Davis (1996) reported on concentrations of pesticides and PCBs in mussels (*Mytilus trossulus*) collected from Padilla Bay. Nothing new taxonomically.

Palm 1996

In another Western Washington University Masters Thesis, Palm (1996) investigated the diet of the Manila clam, *Venerupis philippinarum*. Again, nothing new here taxonomically.

Bulthuis 1996

Bulthuis (1996) authored a review of "Coastal Habitats in Padilla Bay" for the U.S. Army Corps of Engineers. This review paper covered many of the previous ecological studies conducted in Padilla Bay and provided lists of flora and fauna reported by those authors. Since this is a compilation of previous studies, it does not contain any new molluscan data.

Cooper 1997

Cooper (1997), in a Friday Harbor Laboratory (University of Washington) student paper, investigated the ecology of the non-native turret snail, *Batillaria zonalis* in Padilla Bay. No new taxonomic information here.

Ray 1997

Ray (1997) conducted a recent study of the benthic assemblages of Padilla Bay. In this report he identified 24 mollusc species and three additional molluscs identified only to genus (plus two completely unidentified bivalves). Most of these species were already on the Padilla Bay faunal list, but Ray's list did contain seven new species (*Pandora bilirata*, *Admete gracilior*, *Alia tuberosa*, *Cyclostremella concordia*, *Cylichna attonsa*, *Solariella peramblis*, and the first Scahopoda identified so far, *Dentalium rectuis*). The bivalve genus *Corbula* also appears on his list for the first time. Although both Ray and Smith & Benedict (1977) list *Solen peramblis*, it should be noted that this may be a questionable identification, as virtually no information on this species has been located in Pacific Coast (or world) taxonomic literature. It may be possible that this was a typographical error, *Solen* being substituted for the gastropod *Solariella peramblis*.

Riggs 1997

Riggs (1997 -- with a 1998 update dated 2/22/98) has compiled the most complete list of molluscs collected from Padilla Bay so far. She lists (in the 1998 update) 95 distinct species, 30 additional identified to genus only and two as "unidentified species." A few of these molluscs have resulted from her own sampling programs in Padilla Bay, but most come from other studies.

Harley 1998

Harley (1998) investigated the ecology of a variety of rocky intertidal sites ranging from Tatoosh Island off the entrance of the Strait of Juan de Fuca to Saddlebag and Dot Islands in Padilla Bay. The only bivalves discussed in his study were *Mytilus californianus* and *M. trossulus*. Only *M. trossulus* was found at the Padilla Bay sites.

de Heij 1999

A Saddlebag Island food web researcher, de Heij (1999) identified four molluscs to the species level, of which two were new to the Padilla Bay faunal list. These two species were the chitons, *Katharina tunicata* and *Tonicella lineata*.

DeLorenzo 1999

During a Western Washington University Masters Thesis study of the ecology of the sea hare, *Phyllaplysia taylori*, in Padilla Bay eelgrass beds, DeLorenzo (1999) collected other organisms as well. She reported finding 10 species of molluscs in her samples,

three of which were new to Padilla Bay: *Alia carinata*, *Lottia alveus* and *Eubranchus olivaceus*.

Yates 1999

As part of an undergraduate research project at the Shannon Point Marine Center, Yates (1999) conducted sampling at Bay View State Park in Padilla Bay to assess the abundance and ecological relationships of a new invasive species, the purple varnish clam, *Nuttallia obscurata*. *Nuttallia* was first introduced to this coast at Vancouver, B.C. in the late 1980s or early 1990s, probably via ballast water. A native of Japan and Korea, this clam probably became established in Padilla Bay in the mid-1990s and is now abundant in Samish, Padilla and Fidalgo Bays. *Nuttallia* is a new addition to the Padilla Bay faunal list.

WDOE/NOAA 1999

A combined sampling effort by the Washington Department of Ecology and the National Oceanic and Atmospheric Administration in 1997 focused on collecting sediment triad data (chemistry, benthic infauna and bioassay) for a substantial number of stations in North Puget Sound, including six stations in Padilla Bay. These data have been summarized in a report (WDOE/NOAA 1999) and made available as raw data files by the Puget Sound Ambient Monitoring Program (PSAMP 1999). The PSAMP database for molluscs collected in Padilla Bay with a grab sampler includes information on species identified together with number of individuals found in each sample. The PSAMP species list for Padilla Bay contains 12 species and two genera new to the Padilla Bay faunal list.

Giver 1999

In her Master's Thesis, Giver (1999) analyzed the "Effects of the invasive seaweed *Sargassum muticum* on native marine communities in Northern Puget Sound, Washington." One of her sample sites was on the eastern shore of Hat Island in Padilla Bay. During her study, Giver identified 11 gastropod and one bivalve species from the Hat Island site. One of the gastropod species, *Onoba* (*Alvania*) *carpenteri* was new to the Padilla Bay molluscan list.

Huxley College of Environmental Studies 2000

A summer course taught by Dr. Bill Summers at Western Washington University adopted a project to assess the environmental impacts associated with WDNR's establishment of an Aquatic Reserve in the southern portion of Fidalgo Bay. Since few historical sampling data are available for Fidalgo Bay, the students incorporated historical sampling data from Padilla Bay into their Environmental Impact Assessment (EIS). Thus, this report contains only compilations of past data and no new information.

Nolan 2000

As part of an undergraduate research project at the Shannon Point Marine Center, Nolan (2000) assessed the habitat value of the small Pacific oyster bed located at Bay View State Park. Nolan reported finding four gastropod, seven bivalve and one limpet species. All of these species had previously been reported from Padilla Bay

Invertebrate Type Specimen Collections

Dr. Herbert Webber and colleagues at Western Washington University have conducted a substantial amount of ecological research in the north Puget Sound region since the 1970s. Their ecological and taxonomic work was supported by the formation of a substantial invertebrate (and algal) type collection that received expert care and maintenance. Recently, Dr. Webber retired, leaving his specimen type collection in the care of the Shannon Point Marine Center. However, his specimen collection is simply being held in storage at this time, and there are no firm plans regarding its long-term care or storage. This is a very valuable taxonomic resource for the North Sound region and should be preserved intact. However, the collection will require a long-term home and designation of a curator who can reorganize the collection and provide needed maintenance (e.g., replacing preservative fluids, updating records).

In addition, Riggs (1989) reported that a representative sample of each species collected (including 17 gastropods and 18 bivalves, excluding *Tellina modesta*) during her 1989 habitat survey in Padilla Bay is contained in a reference collection presently housed in the Padilla Bay Reserve research barn.

Summary of Molluscs Reported From Padilla Bay

One goal of this report was to review all historical sampling data for molluscs found in Padilla Bay, identify the sources of data, and provide an updated inventory list (Table 1). As of September 2000, the final tabulation of the number of species/genera of molluscs found in Padilla Bay is:

	Identified to Genus Only	Identified to Species
• Class Bivalvia	8	56
• Class Gastropoda	10	69
• Class Amphineura	0	5
• Class Scaphopoda	0	2
• Class Cephalopoda	0	1
Total	18	133

However, as mentioned above, the following molluscs must be considered suspect identifications at this time: *Mercenaria* sp., *Saxidomus nuttallii*, *Siliqua patula*, and *Solen peramblis*.

The Oyster Industry in Padilla Bay

Ironically, the mollusc that has garnered the most attention in Padilla Bay in the past is the non-native Japanese import *Crassostrea gigas*, the Pacific or Japanese oyster. In the 1800s and the early 1900s, there used to be a thriving population of the native oyster, *Ostrea lurida*, in Samish Bay (although none have ever been reported from Padilla Bay). The Samish Bay native oyster reefs were fished to virtual (perhaps literal) extinction by the early 1900s when they were often transported by the ship load to San Francisco and other Pacific ports. This story was replayed throughout Puget Sound and Willapa Bay, which left the oyster industry hurting. Gradually, the Pacific oyster filled the void left by the native oyster when seed oysters were imported from Japan (and later cultured in Washington State hatcheries). Many locations in North Puget Sound, including Samish Bay, proved to be good growing areas for the new import. In the early 1930s, the Padilla Point Oyster Company was formed and Pacific oyster seed was first planted on south bay beds in 1932. Thereafter followed additional plantings, with harvested oysters being taken to canning plants in Everett, Anacortes or on Samish Island.

Early seed plantings in Padilla Bay included 14,500 cases in 1932, 18,800 cases in 1933, and 47,700 cases in 1934. In 1935, Padilla Point Oyster Company attempted to catch natural oyster spat in Willapa and Quilcene Bays, and at Ladysmith Harbour, B.C., but failed. They did, however, catch a good set in 1936, the cultch then being replanted into Padilla Bay in 1937 (*Pacific Fisherman* 1932-1944).

Oyster harvests from the Padilla Bay beds began in 1933, when 6,844 standard cases (case = 4 dozen 5 oz. cans) of oysters were canned in Everett. Production then grew to 24,600 cases in 1936, but apparently dropped to essentially zero from 1937-1942 due to poor oyster condition and growing financial problems. In 1938, the Padilla Bay Oyster Company was liquidated and reorganized as the Pioneer Oyster Company. Shortly thereafter, the Pioneer Oyster Company sued the Puget Sound Pulp and Timber Company of Bellingham and Anacortes claiming that their sulfite waste liquor effluents were responsible for high mortalities and poor growth and condition in their south Padilla Bay beds. The initial suit requested damages in the amount of $2,125,000, a staggering amount in that era. However, in September 1941 Pioneer lost the case when Federal Court judge John C. Bowen ruled that the oyster problems were primarily the result of overcrowding (40-60+ seed cases/acre), the resulting starvation, and the generally poor condition of the growing grounds (*Pacific Fisherman* 1932-1944).

However, in about 1943 the Anacortes Pulp Mill was closed following orders from the Washington Pollution Control Board, and about six months later Pioneer harvested 20,000 gallons of shucked oysters from the south Padilla Bay beds and transferred another 15,000 bushels to other growing areas. From 1952 to 1955, approximately 16,300 cases of seed oysters were again planted in Padilla Bay, all in the southern portion of the bay, except for one test plot at the mouth of Joe Leary Slough (Table 2, Fig. 2). An additional 16,000 bushels of oysters were transplanted to Joe Leary Slough in 1952 and

another 8,000 bushels transplanted in 1957 (Table 2). Oyster culture in south bay apparently continued without much further fanfare until about 1960, when production finally ceased.

Various investigations (Saxton and Young 1948; Orlob et al. 1950; Westley 1958, '59, '60, '61, '62 '63) were conducted to assess factors that might be responsible for the poor growth and condition of Padilla Bay oysters. Some of the factors given included:

- Temperature – both freezing winter conditions and summer high temperatures
- Overcrowding -- Density of seed planting too high for the conditions, thus causing starvation due to food competition
- Wave action that transported oysters to undesirable locations
- Predation by oyster drills and crabs
- Excessive growths of algae, especially sea lettuce, *Ulva lactuca*
- Smothering by sediments in some locations
- Pulp mill effluents (reduced condition factor and growth)
- Presence of parasites (e.g., *Mytilicola*)

Despite all of these factors (and ignoring the fact that Padilla Bay is now a National Estuarine Research Reserve), portions of Padilla Bay are still deemed to be quite satisfactory for oyster growth. Indeed, in the late 1970s, Joe Engman of Dungeness Oyster Company approached Orion Corporation with a proposal to plant 2,000 bags of seed oyster on their intertidal lands and share the profits with them (Orion declined) (Fagergren et al. 1989). In 1989, Orion conducted their own shellfish aquaculture assessment (primarily aimed at oysters) for their intertidal lands (Fagergren et al. 1989). Fagergren et al. concluded that there were potentially up to about 1,000 acres that might be used for oyster culture (i.e., acreage without complete eelgrass cover) and that some unknown portion of those lands would probably grow oysters successfully. However, the authors finally concluded that the overall prospects for commercial oyster culture in Padilla Bay were economically marginal, especially considering the magnitude of the past growth and condition problems.

Today, only remnants of Pacific oyster culture remain in Padilla Bay. There may be isolated areas where oysters or shell from past culture activities remain. The only active aquaculture today is reported to be by a small tidelands owner who is growing oysters for personal use via long-line culture on the shore of March Point. A small WDFW recreational enhancement plot of oysters also exists at Bay View State Park, where the remaining oysters have grown as large as 12 inches or more in shell length.

Opportunities may exist for further enhancement of recreational plots in the bay. Small plots could provide enhanced shellfish gathering opportunities for the public as well as provide research opportunities for scientists evaluating the potential for living oysters to enhance certain habitat types. Pacific oysters (live or dead shell) may also provide eventual settling substrate for natural spawning Pacific oysters or native oysters, should native oyster restoration in North Sound become a reality, as proposed by WDFW (Cook et al. 1998) and others.

Pollution Effects on Molluscs in Padilla Bay

The effects of pollution in Padilla Bay on molluscs can be divided into two major areas: 1) Pollution that adversely affects the abundance, health or reproductive success of the animals themselves, and 2) Pollution that does not adversely affect the organisms, but does limit their use as human food resources.

Pulp Mill Pollution

Examples of effects of pulp mill pollution on the animals are relatively few. The most obvious of these is the asserted effects of pulp mill effluents on oyster growth, condition and reproduction. Pulp mills in Anacortes and Bellingham discharged virtually untreated sulfite waste liquor (SWL) into Fidalgo and Bellingham Bays from about the mid-1930s through the mid-1970s. At times, concentrations of Bellingham-derived SWL in surface waters of north Padilla Bay reached as high as about 20 ppm (Fig. 3; Shea et al. 1981; WDF 1960). Concentrations of SWL in Padilla Bay resulting from Anacortes discharges are unknown. Bioassay work by Woelke (1960) found that concentrations of SWL >5 ppm can have an adverse effect on survival and normal development of oyster larvae. Cardwell and Woelke (1979) have also shown that Pacific oyster embryo bioassays of ambient water collected from north Padilla Bay was intermittently toxic to oyster embryos during the 1960s and 1970s (Fig. 4). However, demonstration of intermittent water toxicity in bioassays, even if strongly correlated with SWL concentrations, is not a conclusive demonstration of actual effects on population levels of resident animals. In fact, no population effects have ever been demonstrated for any animals (including cultured oysters) in Padilla Bay.

There were, however, strong assertions by the oyster industry that SWL in Padilla Bay was causing adverse effects to cultured oyster growth and condition. While these assertions were never proven or upheld in court challenges, there seems to remain a distinct possibility that SWL did act as one additional stress among many that adversely affected oyster growth and condition in Padilla Bay.

Industrial Effluents

Other than the historical presence of pulp and plywood mills in Anacortes, the primary industrial effluent sources in the Padilla Bay area have been from the March Point oil refineries and their associated industries. There is little, if any history of ambient water quality sampling in the Padilla and Fidalgo Bay region that can be used to evaluate past pollution from these sources. Some sediment and shellfish tissue data do, however, exist. Generally, these data provide indications of only slight accumulations of industrial chemicals in the Padilla Bay region, and most of the stations showing signs of past contamination are in the Fidalgo Bay/March Point area (Pepe and Plews 1991; USFWS 1994; WDOE/NOAA 1999; Johnson 2000). One exception to this rule is that a WDOE/NOAA (1999) sediment sample in inner Padilla Bay sampled in 1997 registered a state "Sediment Quality Standard" (SQS) exceedence for 4-methylphenol and phenol,

and a "Cleanup Screening Level" (CSL) exceedence for 4-methylphenol. Johnson (2000) also identified arsenic as exceeding Washington Department of Health (WDOH) Office of Environmental Health Assessments (OEHA) screening levels in clams, oysters and crab tissues from the Padilla/Fidalgo Bay region. However, the significance of this is unknown, as arsenic concentrations in shellfish from other areas of Puget Sound are generally as high or higher than those found in Padilla and Fidalgo Bays.

Bioassays of sediment samples collected from Padilla Bay have generally shown sediments to be nontoxic to test animals, although occasional samples have suggested slight to moderate toxicity (Gardiner 1992; Wiggins 1992; USFWS 1994; WDOE/NOAA 1999; Fitzpatrick 1999). In no cases, so far, have industrial chemical concentrations in shellfish tissues from Padilla Bay been found to exceed limits established to protect human health (e.g., Antrim 1985; Woolrich 1992; WDOE/NOAA 1999).

Oil Spills

There have been occasional oil spills from the March Point oil refineries in the past, the largest being a spill of No. 2 diesel oil from the Texaco refinery in April 1971 (Chia 1971; Clark and Finley 1973). In all cases so far, the spills have been confined to the March Point/Fidalgo Bay area or the oil has been carried westward by currents into the San Juan Archipelago region. However, only a continued high level of vigilance and prevention will prevent an eventual oil spill that might be carried into Padilla Bay by incoming tidal currents and/or westerly winds.

Sewage Contamination

There are no indications that Padilla Bay is significantly contaminated by human sewage. There are no sewage treatment plants that discharge into Padilla Bay and the low density of residential development on the uplands suggest only low probability of sewage pollution from failing on-site septic systems. However, significant fecal coliform contamination has been shown to exist in the bay in several areas, but especially in the area of Joe Leary Slough (Luce 1986; Bulthuis, pers. comm.). This fecal coliform contamination is almost certainly the product of poorly managed dairy cattle waste, not human sewage (Bulthuis, pers. comm.). In some cases, waste discharges from cattle from Joe Leary Slough may be high enough to deplete dissolved oxygen in water and sediments in the slough or near the mouth of the slough, possibly leading to mortality of estuarine fauna, including some molluscs.

Given occasional significant concentrations of fecal coliforms in the water of Padilla Bay, it follows that care should be used when harvesting and consuming filter feeding bivalves from the bay, especially those collected near Joe Leary Slough. To date, the Washington Department of Health does not routinely sample for fecal coliforms in shellfish from Padilla Bay since it is not a commercial shellfish growing area. Thus, Padilla Bay is presently "uncertified" for commercial shellfish harvesting (versus "certified" or "decertified") (WDOH 1992).

Agricultural Pesticides and Herbicides

One study by Mayer and Elkins (1990) tested for the presence of 14 pesticides and herbicides in Padilla Bay and its surrounding sloughs following their summer applications to upland agricultural areas. They found that only two of the herbicides, dicamba and 2, 4-D, could be detected in any of the water or sediment samples, and then only after a period of substantial rainfall in one of the two summers tested. In Padilla Bay, only dicamba was found in water samples at concentrations ranging from 50-90 μg/liter (ppb). No pesticides or herbicides were found in any of the Padilla Bay sediment samples. Mayer and Elkins calculated that it would require about 100 times the concentration of dicamba found in Padilla Bay waters to affect algae growth. Being a herbicide, its effects on faunal life would be even less.

Three studies have investigated pesticide concentrations in shellfish tissues collected from Padilla Bay. Oyster (*Crassostrea gigas*) tissues were sampled for DDE, DDD and DDT in 1966 by the Washington State Shellfish Laboratory (WSSL 1966). They consistently found only trace amounts (≤12 ppb) of DDE and DDT, and an occasional sample with DDD. A second sampling program in 1995 by the Washington State Pesticides Monitoring Program (Johnson and Davis 1996) collected mussels (*Mytilus trossulus*) from Padilla Bay and other more urbanized embayments. The mussel tissues were analyzed for 20 pesticides and three isomers of PCB. Only trace amounts (≤0.57 ppb) of six pesticides (4, 4'-DDT, 4, 4'-DDE, 4, 4'-DDD, endosulfan I, alpha BHC and hexachlorobenzene) were detected. The only isomer of PCB detected was PCB-1254 at a concentration of 2 ppb. These pesticide/PCB concentrations were substantially less than concentrations in mussel tissues from the Duwamish or Hylebos Waterways, and probably below concentrations of concern for either molluscan or human health. A third sampling program by WDOE (Johnson 2000) measured pesticides in Dungeness crab, native littleneck clams and Pacific Oysters from several Padilla Bay sites. Several pesticides (primarily DDT breakdown products) were detected in oysters from Bay View State Park. However, most pesticide concentrations were near the lower chemical detection limits and not considered to be of significant human health concern.

In summary, molluscan fauna in Padilla Bay have probably suffered little, if any, impacts caused by anthropogenic contaminants, especially subsequent to the closure of the Anacortes pulp and plywood mills and initiation of higher SWL treatment levels at the Bellingham pulp mill. There also seem to be few concerns about human consumption of molluscan shellfish from Padilla Bay, with the possible exception of fecal coliforms originating from dairy cattle and occasional paralytic shellfish poisoning (PSP) closures during periods of toxic algae blooms.

Biology and Ecology of Bivalves in Padilla Bay

The biological and ecological characteristics of each of the bivalve species found in Padilla Bay (except those whose identifications are suspect) are covered in detail in the species profiles found in Appendix 1. Where available, information on distribution, habitat type, depth range, shell and anatomical characteristics, reproductive biology and general ecology are given. Where applicable, fishery and aquaculture information is included, and, for a few species, the historical effects of anthropogenic impacts. The information and illustrations contained in Appendix 1 were gleaned from many sources, including Abbott 1968, 1974; Armstrong et al. 1992; Behrens 1980; Bernard 1983; Gotshall 1979; Johnson and Snook 1967; Keen 1963; Keep 1935; Kozloff 1983 a, b; Lie 1968; Light 1967; Morris 1952, 1966; Morris et al. 1990; Oldroyd 1924a, b; Quayle 1960; Ricketts and Calvin 1968; Rudy 1979). Appendix 2 contains selected species-specific references for many of the molluscs found in Padilla Bay.

Most of the investigators that have described bivalves collected from Padilla Bay have done so in conjunction with general surveys or incidental to another primary study focus. One of the first general surveys of Padilla Bay fauna was by Sylvester and Clogston (1958), who described eight species and 4 genera of bivalves from the bay. Other studies general survey or incidental studies that have added to the present bivalve taxonomic list include work by Smith and Benedict 1977, Barreca 1982, Riggs 1983 and 1989, Wissmar 1986, Nyblade 1986, Pfaff 1990, Kahler 1994 and Giver 1999.

Several investigators have assessed faunal zonation and community structure in or near Padilla Bay. Each investigator had a unique way of describing faunal characteristics, including associations based on substrate type, tidal height or depth, floral associations or predator-prey interactions. One of the earliest bivalve ecological studies in the Padilla Bay area was by Shelford et al. (1935) who classified community associations into two broad classes: 1) those dependent on slow water movement and soft mud or sand bottoms, and 2) those found on hard bottoms in areas of high current or wave action. With the exception of mussels, the abalone jingle (*Pododesmus*), and perhaps scallops, almost all bivalve mollusks found in Padilla Bay fall in Shelford et al's first class. Shelford et al. breaks this first class into two "biomes": 1) the *Pandora-Yoldia* biome, which is essentially associate with subtidal soft mud or mixed sand/mud bottoms, and 2) the *Macoma-Paphia* (= *Protothaca*) biome, which is primarily associated with intertidal sand and mud bottoms.

Bivalve species common in the *Pandora-Yoldia* biome include: *Pandora filosa*, several species of *Yoldia*, *Nucula* sp. and *Pecten* sp. Many other bivalve species also occur in this biome; these are identified by their depth ranges in the species profiles (Appendix 1). Bivalves common in the *Macoma-Paphia* biome include: many species of *Macoma*, *Protothaca staminea*, *Mya arenaria*, *Clinocardium nuttallii*, *Saxidomus giganteus*, *Tresus* sp. and, in recent years, *Venerupis philippinarum*, *Nuttallia obscurata* and *Crassostrea gigas*.

Webber et al. (1975) and Smith and Webber (1978), Yates (1999) and Nolan (2000) all conducted intertidal infaunal sampling on the eastern shore of Padilla Bay. Each of these investigators identified bivalves that are characteristic of mid- to upper-intertidal habitats in North Puget Sound (i.e., a *Macoma-Protothaca-Venerupis-Mya* "biome"). Sampling by Yates (1999) focused on the ecology of the new invasive purple varnish clam (*Nuttallia obscurata*), which has now become a dominant species in the mid- to upper-intertidal area in selected locations in Padilla Bay. Nolan's (2000) sampling in the small Pacific oyster bed at Bay View State Park found that bivalves were about twice as abundant under growing oysters compared to a control plot (bare mudflat), probably because the overlying oysters afforded extra protection from crab, fish and bird predators.

Ray (1997) was perhaps the first to investigate bay-wide faunal habitat associations in Padilla Bay using a well-designed experimental approach. He collected 15 random samples from eight different habitat types in Padilla Bay, with depth as a co-variable. For bivalves, he found 19 species (+ 14 gastropods) (Table 1), which were most plentiful (in terms of number of taxa) in beds of *Zostera japonica*. Bivalves were also plentiful in *Z. marina* beds and were dominate in unvegetated areas at intermediate (5-20 m) and deep (>20 m) water depths. Small clams were also abundant in English sole (*Pleuronectes vetulus*) and blackbelly eelpout (*Lycodes pacificus*) stomach samples from all depths sampled.

Overall, the ecology of bivalves in Padilla Bay is similar to many other eelgrass-dominated estuaries in the Pacific Northwest, as described and reviewed by Shelford et al. (1935) and Phillips (1984). The sand and mud flats of Padilla Bay are dominated by the usual indigenous bivalve genera (*Protothaca*, *Macoma*, *Saxidomus*, *Clinocardium*, *Tresus*, *Tellina*) as well as by a generous mix of non-native invasive species (*Mya arenaria*, *Venerupis philippinarum*, *Nuttallia obscurata* and, in past years, cultured Pacific oysters, *Crassostrea gigas*). The one unusual aspect about Padilla Bay bivalve ecology is the obvious lack of the geoduck (*Panope generosa*), which is quite ubiquitous in Puget Sound and present in intertidal areas of Samish Bay (Bill Dewey, pers. comm.). The author of this report has spent a considerable amount of time looking for signs of *Panope* presence in intertidal areas of Padilla Bay, but without any success. It is possible that juvenile geoduck are missing because they may be highly susceptible to predation by crabs, which are highly abundant in the bay. It is also possible that some geoducks are present in deeper subtidal areas of the bay, but have yet to be located.

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Table 1. Molluscs reported from Padilla Bay, Washington as of September 2000. Names in ( ) indicate cases where there has been a change in taxonomic names or where a varient of the proper name has been used in some reports.

Species Name	Common Name	References
Class Bivalvia		
Acila castrensis	Sculptured or divaricate nut clam	5, 6, 8, 9, 13, 17, 38, 41, 45, 47
Axinopsida serricata	Silky axinopsis	2, 5, 6, 9, 13, 16, 17, 38, 41, 45
Cardita sp.	Clam	1, 3, 9, 45
Cardium sp.	Clam	1, 3
Chione sp.	Clam	9
Clinocardium californiense	California cockle	2
Clinocardium nuttallii	Heart cockle, basket cockle	1, 2, 3, 5, 6, 8, 9, 13, 16, 17, 26, 27, 33, 37, 38, 41, 47
Compsomyax subdiaphana	Translucent compsomyax	5, 9, 16, 38
Corbula sp.	Clam	8
Crassostrea gigas*	Japanese oyster, Pacific oyster	6, 9, 17, 21, 23, 27, 29, 31, 35, 36, 37, 40, 41, 43, 45
Crenella sp.	Clam	6, 9, 13, 17, 41
Cryptomya californica	False mya	2, 6, 9, 13, 17, 37, 41
Humilaria sp.	Clam	1, 3, 9, 45
Kellia laperousii	Laperouse's Kelly-shell	38
Kellia suborbicularis	Globose Kelly-shell	9
Lucinoma annulata	Ringed lucine	9, 17, 47
Lucinoma (Lucina) tenuisculpta	Fine-lined lucine	5, 8, 9
Lyonsia californica	California lyons-shell	2, 5, 6, 8, 9, 38, 41
Lyonsia striata	Dipper clam, striate lyonsia	6, 9, 17, 41
Macoma balthica	Baltic macoma	2, 4, 6, 9, 13, 15, 17, 37, 41, 42, 47
Macoma calcarea	Chalky macoma	5, 9
Macoma carlottensis	Charlott's macoma	38
Macoma eliminata	Clam	38
Macoma inquinata	Irus clam, Polluted macoma	6, 7, 9, 13, 17, 38, 41, 42, 47
Macoma nasuta	Bent nose clam	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 13, 16, 17, 18, 26, 27, 33, 38, 41, 42, 45. 47
Macoma (incongrua) obliqua	Incongruous macoma	5, 6, 9, 13, 17, 38, 41

Species Name	Common Name	References
Class Bivalvia, continued		
Macoma secta	White sand clam, giant macoma	2, 4, 6, 9, 17, 41
Macoma yoldiformis	Yoldia-shaped macoma	9, 16
Megacrenella (Vitrinella, Crenella) columbiana	Clam	38
Mercenaria sp.**	Quahog, cherrystone clam	1
Musculus sp.	Mussel	38
Mya arenaria*	Soft shell clam	2, 3, 4, 5, 6, 9, 11, 13, 15, 18, 33, 37, 38, 41, 43, 45, 47
Mya truncata	Blunt soft shell clam	4, 5, 6, 9, 17, 41
Mysella tumida	Tumid mysella	2, 5, 6, 8, 9, 13, 17, 38, 41, 45
Mytilus edulis (now M. trossulus)	Blue mussel, bay mussel	1, 3, 6, 9, 10, 17, 22, 26, 34, 37, 38, 39, 40, 41, 45, 46, 47
Nucula tenuis	Thin nut clam	2, 5, 6, 9, 13, 17, 38, 41, 45
Nuculana hamata	Hooked hamata	6, 8, 9, 13, 17, 41
Nuculana minuta	Clam	2, 6, 9, 13, 17, 38, 41
Nuttallia obscurata*	Purple varnish or mahogany clam	11
Pandora bilirata	Clam	8, 9
Pandora filosa	Clam	38
Pandora punctata	Spotted pandora	5
Parvilucina sp. (now Lucinoma)	Clam	9, 13, 47
Pecten hindsii	Navigator scallop	1, 3, 9
Pododesmus macroschisma	Rock oyster, abalone jingle	1, 3, 6, 9, 14, 17
Protothaca staminea	Native littleneck	1, 3, 5, 6, 7, 9, 11, 16, 17, 30, 33, 37, 38, 40, 41, 42, 43, 44, 45, 47
Protothaca tenerrima	Thin-shelled littleneck	5
Psephidia lordi	Lord's pebble shell	2, 5, 6, 9, 13, 17, 37, 38, 41, 45
Pseudopythina (Orbitella) rugifera	Rough prawn-shell	9, 17, 37, 47
Saxidomus giganteus	Butter clam, Washington clam	6, 9, 13, 17, 26, 33, 41, 45, 47
Saxidomus nuttallii**	Butter clam, Washington clam	1, 3, 9
Siliqua patula**	Northern razor clam	5
Solen perambilis**	Clam	8, 9, 13
Solen sicarius	Jackknife clam, sickle razor clam	5, 6, 9, 17, 41, 47
Tellina carpenteri	Pink tellin	9, 47

Species Name	Common Name	References
Class Bivalvia, continued		
Tellina modesta	White tellin	5, 6, 8, 9, 13, 17, 18, 41, 45, 47
Tellina nuculoides	Salmon tellin	9
Transennella tantilla	Little transennella	2, 3, 4, 5, 6, 8, 9, 13, 14, 16, 17, 18, 37, 41, 45, 47
Tresus capax	Horse clam	6, 9, 13, 17, 41
Tresus nuttallii	Horse clam	1, 3, 9
Venerupis philippinarum (Tapes japonica)*	Manila clam, Japanese littleneck	2, 4, 6, 7, 9, 11, 17, 18, 32, 33, 41, 42, 47
Yoldia limatula	File yoldia	5
Yoldia myalis	Clam	8, 13, 38
Yoldia scissurata	Clam	5, 13
Yoldia thraciaeformis	Broad yoldia	5, 6, 9, 13, 17, 38, 41
Class Gastropoda		
Acmea digitalis	Keyhole limpet	1, 3, 45
Acmea pelta	Shield limpet	1, 3, 45
Acmea persona	Mask limpet	1, 3
Acmea scutum	Limpet	1, 3
Acteocina harpa	Barrel bubble shell	9
Admete gracilior	Snail	8, 9
Alia carinata	Keeled dove-shell	12, 38
Alia gausapata	Frieze-covered dove-shell	9, 17, 39
Alia tuberosa	Tubercuate dove-shell	8
Alvania compacta	Snail	38
Alvania (Alvinia) sp.	Snail	5, 13
Amphissa sp.	Snail	9, 17, 47
Archidoris sp.	Sea lemon	1, 3, 9
Assiminea californica	Snail	6, 9, 17, 41
Barleeia (Bartreeia) sp.	Snail	7, 9, 47

Species Name	Common Name	References
Class Gastropoda, continued		
Batillaria zonalis (now B. attramentaria)*	Turret snail	1, 2, 3, 4, 6, 7, 8, 9, 17, 18, 24, 27, 41, 42, 45, 47
Bittium (Lirobittium) sp.	Snail	2, 9, 17, 38, 41, 47
Calliostoma ligatum	Blue top snail	6, 9, 17, 41
Callistoma costatum	Turban snail	1, 3, 9, 45
Calyptraea fastigiata	Nudibranch	1, 3, 9
Cecina manchurica	Snail	9, 17, 41
Ceratostoma foliatum (Purpurea foliata)	Leafy hornmouth	1
Collisella digitalis	Finger limpet, ribbed limpet	6, 9, 17, 41
Collisella pelta	Shield limpet, helmet limpet	2, 6, 9, 17, 41
Colus jordani	Snail	5
Crepidula adunca	Hooked slipper shell	2, 6, 8, 9, 17, 41
Crepidual fornicata*	Atlantic slipper shell	9, 17
Cyclostremella concordia	Snail	8, 38
Cylichna attonsa	Small bubble shell	8, 9
Cypraeolina pyriformis	Pear-shaped marginella	9, 47
Dialula sandiegensis	Ringed nudibranch	9
Diaphana sp.	Snail	38
Didora aspera	Keyhole limpet	3, 6, 9, 17, 41, 45
Dirona abolineata	Frosted nudibranch	9
Eubranchus olivaceus	Nudibranch	12
Granulina margaritula	Snail	38
Haminoea callidegentia	Bubble shell	9, 20, 47
Haminoea vesicula	Blister paper bubble shell	8, 9, 12, 18, 20, 25, 26, 38, 39, 47
Hermaea vancouverensis	Vancouver's sacoglossid	9, 12
Hermissenda crassicornis	Opalescent nudibranch	6, 9, 12, 17, 41
Kurtziella crebricostata	Snail	38
Lacuna carinata	Carinate lacuna	5
Lacuna marmorata	Chink shell	9, 17

Species Name	Common Name	References
Class Gastropoda, continued		
Lacuna porrecta	Wide chink shell	8, 9, 17
Lacuna variegata	Chink shell, variegated lacuna	6, 9, 12, 39, 41, 45, 47
Lacuna vincta	Common northern lacuna	9, 17, 39
Lirularia lirulata	Lirulate margarites	2, 9, 38, 39
Littorina saxatilis	Northern rough periwinkle	38
Littorina scutulata	Checkered periwinkle	9, 10, 13, 17, 39, 41
Littorina sitkana	Sitka periwinkle	1, 2, 3, 4, 6, 9, 10, 17, 39, 41, 45
Lottia alveus	Limpet	12
Lottia lirulata	Limpet	2
Margarites marginatus	Snail	9, 17, 39
Margarites pupillus	Little margarite shell	6, 9, 13, 17, 39, 41, 47
Melanochlamys (Aglaja) diomedia	Diomede's aglajid	4, 9, 13, 16, 17, 41
Melibe leonina	Hooded nudibranch	9, 12
Mitrella (Astyris) gausapata	Frieze-covered dove-shell	38
Nassarius mendicus	Lean basket shell	2, 5, 9, 13, 18, 47
Nassauius fraterculus (fraticularis ?)*	Basket shell	4, 6, 8, 9, 17, 18, 41, 42
Notoacmea persona	Large varigated limpet	2, 6, 9, 17, 41
Notoacmea scutum	Plate limpet	2, 6, 9, 17, 41
Nucella emarginata	Emarginate dogwinkle	10
Ocenebra (Tritonalia) japonica*	Japanese oyster drill	1, 3, 6, 9, 17, 41
Odostomia sp.	Odostome	5, 8, 9, 13, 38, 47
Oenopota sp.	Snail	5, 9
Olea hansineensis	Hansine sea slug	9
Onoba carpenteri	Snail	9, 17
Phyllaplysia taylori	Taylor's sea hare	6, 9, 12, 13, 17, 25, 28, 38, 41, 45
Phytia (Ovatella) myosotis*	Bristle-bearing ear shell	6, 9, 17, 41
Polinices lewisii	Lewis' moon snail	9
Polinices (Euspira) pallida	Snail	38

Species Name	Common Name	References
Class Gastropoda, continued		
Retusa (Acteolina) harpa	Barrel bubble shell	6, 9, 18, 41
Sealesia dira	Dire whelk	9, 17, 47
Solariella perambilis	Lovely Pacific solarelle	8, 9
Thais lamellosa	Wrinkled thais	1, 3, 6, 9, 17, 41, 45
Trichotropis (Trichitrophus) sp.	Snail	1, 9
Triopha carpenteri	Orange-spotted nudibranch	9
Turbonilla sp.	Snail	5, 8, 9, 38
Urosalpinx cinerea*	Atlantic oyster drill, eastern drill	9, 47
Class Amphineura		
Ischnochiton (Lepidozoma) cooperii	Cooper's chiton	3, 9
Ischnochiton (Lepidozoma) mertensii	Merton's chiton	3, 9
Katharina tunicata	Black chiton	34
Mopalia muscosa	Mossy chiton	1, 3, 6, 9, 17, 34, 41, 42, 45
Tonicella lineata	Lined chiton	34
Class Cephalopoda		
Octopus dofleini	Giant Pacific octopus	19
Class Scaphopoda		
Dentalium rectuis	Tooth or tusk shell	8, 9
Pulsellum salishorum	Tooth or tusk shell	38

* Non-native, introduced species (Cohen et al. 1998; WDFW 2000)
** Doubtful identification

References for Table 1:

1 = Sylvester & Clogston 1958
2 = Webber et al. 1975
3 = Jeffrey 1976
4 = Smith and Webber 1978
5 = Berreca 1982
6 = Huxley 1983
7 = Pfaff 1990
8 = Ray 1997
9 = Riggs 1997, updated 1998
10 = Harley 1998
11 = Yates 1999
12 = DeLorenzo 1999
13 = Smith & Benedict 1977
14 = ACOE 1981
15 = BIA et al. 1987
16 = Kahler 1994
17 = WDOE 1984
18 = Riggs 1983
19 = Cheney and Mumford 1986
20 = Gibson and Chia 1989
21 = Neale 1952
22 = Johnson and Davis 1996
23 = Orlob et al. 1950
24 = Cooper 1997
25 = Shaw 1994
26 = Wissmar 1986
27 = Antrim 1985
28 = Lepla 1991
29 = Westley 1958-63
30 = Woolrich 1992
31 = Saxton and Young 1948
32 = Palm 1996
33 = Pacific Ocean Farms 1973
34 = de Heij 1999
35 = McMillin 1957
36 = *Pacific Fisherman* 1932-44
37 = Nyblade 1986
38 = PSAMP 1999
39 = Giver 1999
40 = Johnson 2000
41 = Huxley College 2000
42 = Nolan 2000
43 = USFWS 1994
44 = Pepe and Plews 1991
45 = Bulthuis 1996
46 = Ruckelshaus 1988; Ruckelshaus et al. 1988, '90, 93
47 = Riggs 1989

Table 2. Oyster beds seeded or transplanted in Padilla and Fidalgo Bays, 1952 to 1957. See Figure 2 for oyster bed locations. From Sylvester and Clogston 1958.

Bed Number	Company	Acres	Year Planted	Cases Seeded	Bushels Transplanted
1	Similk Beach*	?	1955	700	
2	Similk Beach*	?	1956	77	
3	Similk Beach*	4	1954	200	
4	Similk Beach	9	1955	300	
5	Pioneer	82	1952	4,000	
6	Pioneer	32	1952	Total	
7	Pioneer	30	1952	for all three beds	
8	Pioneer	50	1955	2,250	
9	Pioneer	100	1953	4,750	
10	Pioneer	12	1954	5,000	
11	Pioneer	21.5	1954		
12	Pioneer	30	1954	Total	
13	Pioneer	5.5	1954	for all seven beds	
14	Pioneer	8	1954		
15	Pioneer	10	1954		
16	Pioneer	7.5	1954		
17	Pioneer	Test Bed	1952	---	16,000
17	Pioneer	Test Bed	1957	---	8,000

* Fidalgo Bay beds, all others are in Padilla Bay

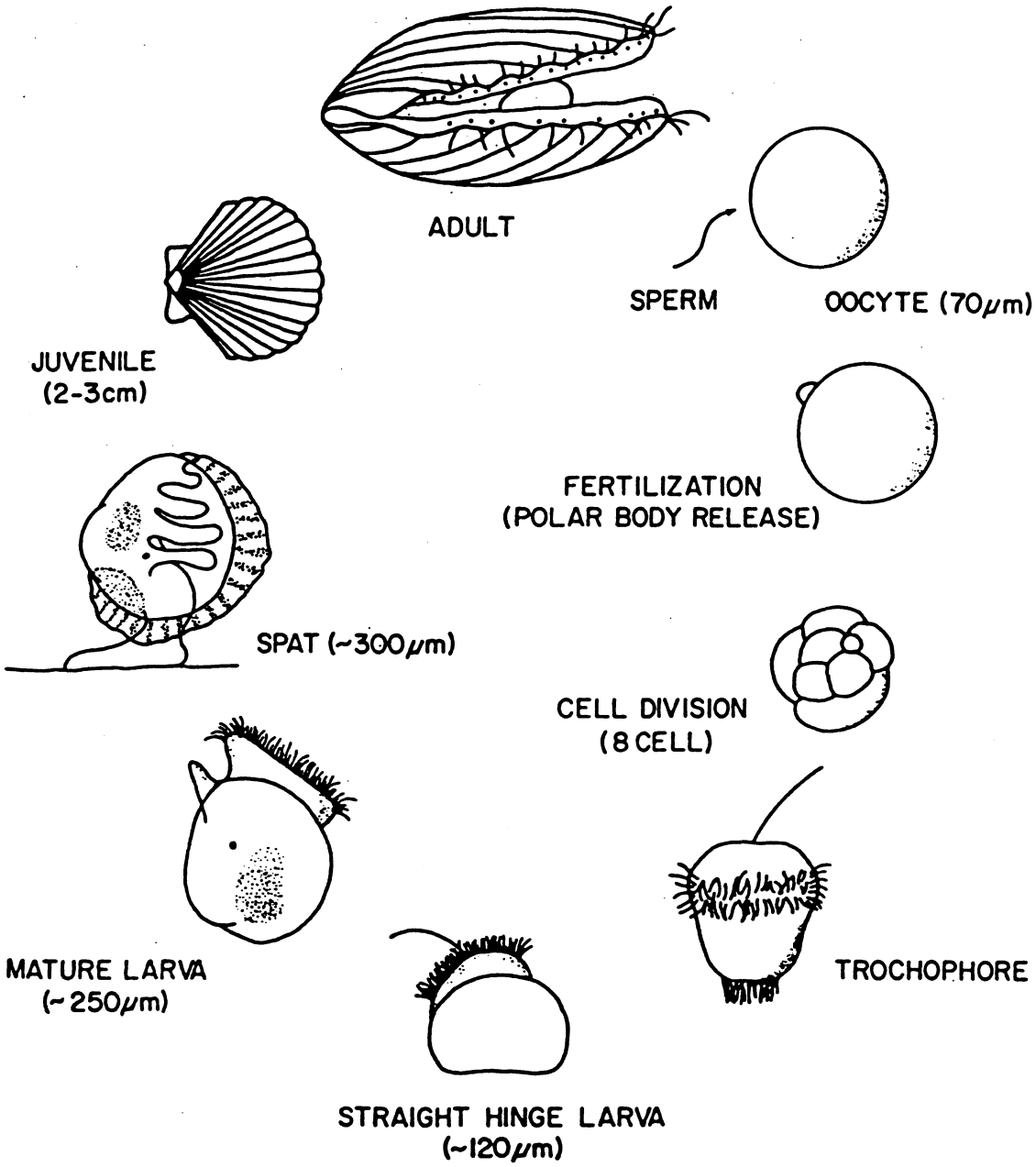


Figure 1. Generalized bivalve life cycle.

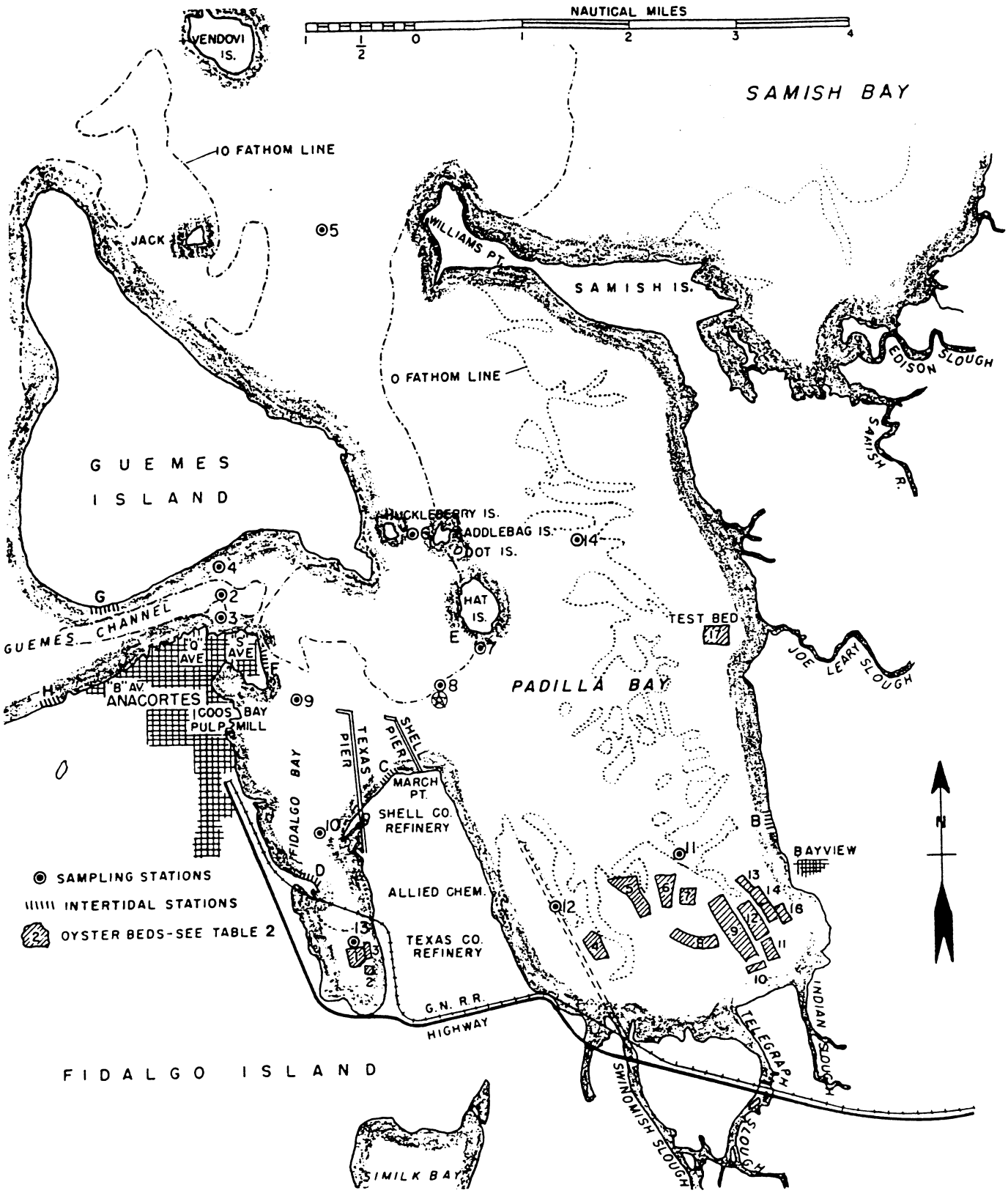


Figure 2. Locations of Pioneer and Similk Oyster Company Pacific oyster beds in Fidalgo (Beds 1-3) and Padilla Bay (Beds 4-17), 1952-1957 (from Sylvester and Clogston 1958).

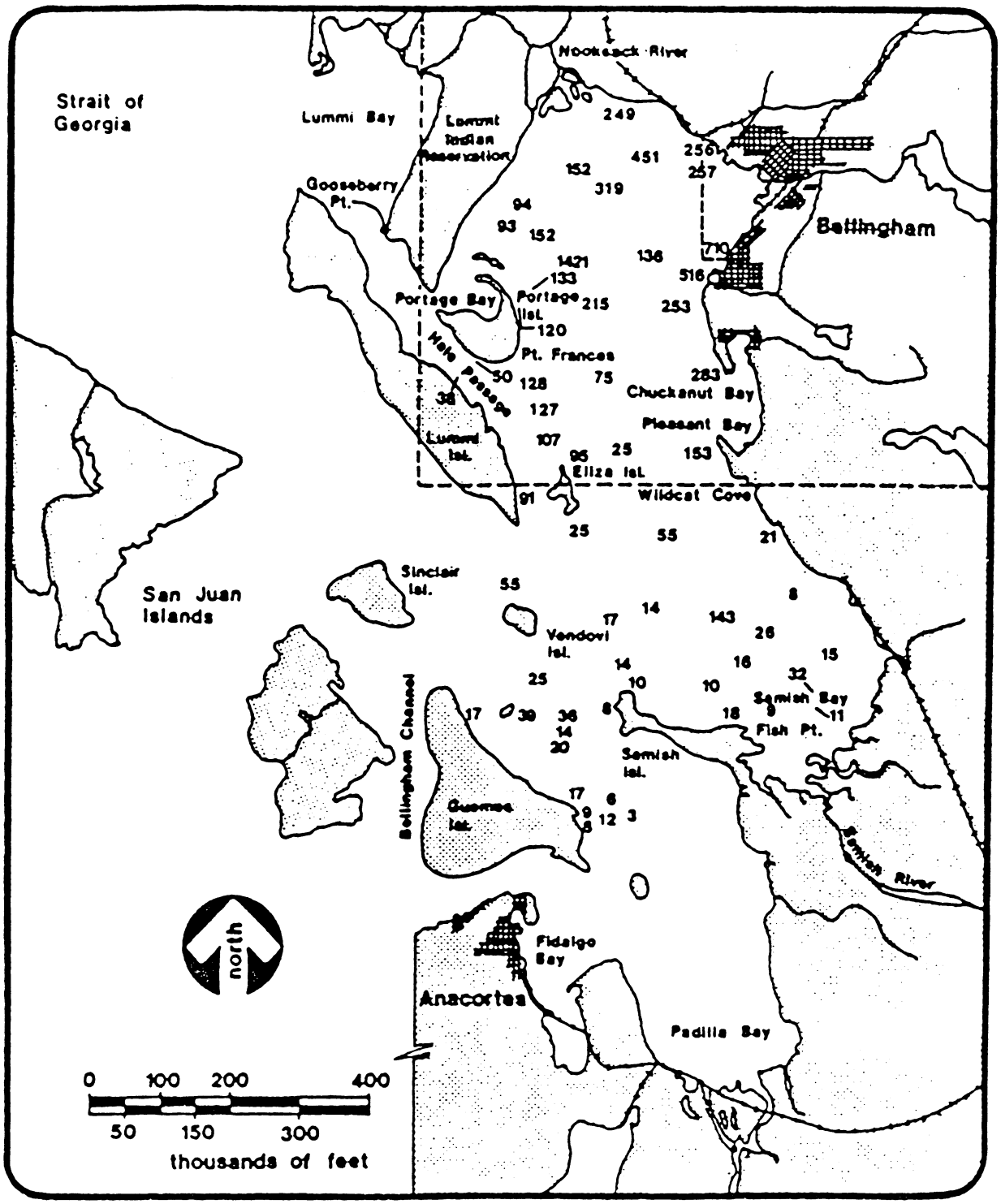


Figure 3. Maximum sulfite waste liquor concentrations (ppm) observed in surface waters of Bellingham, Samish and Padilla Bays from 1956 to 1964 (from Shea et al. 1981).

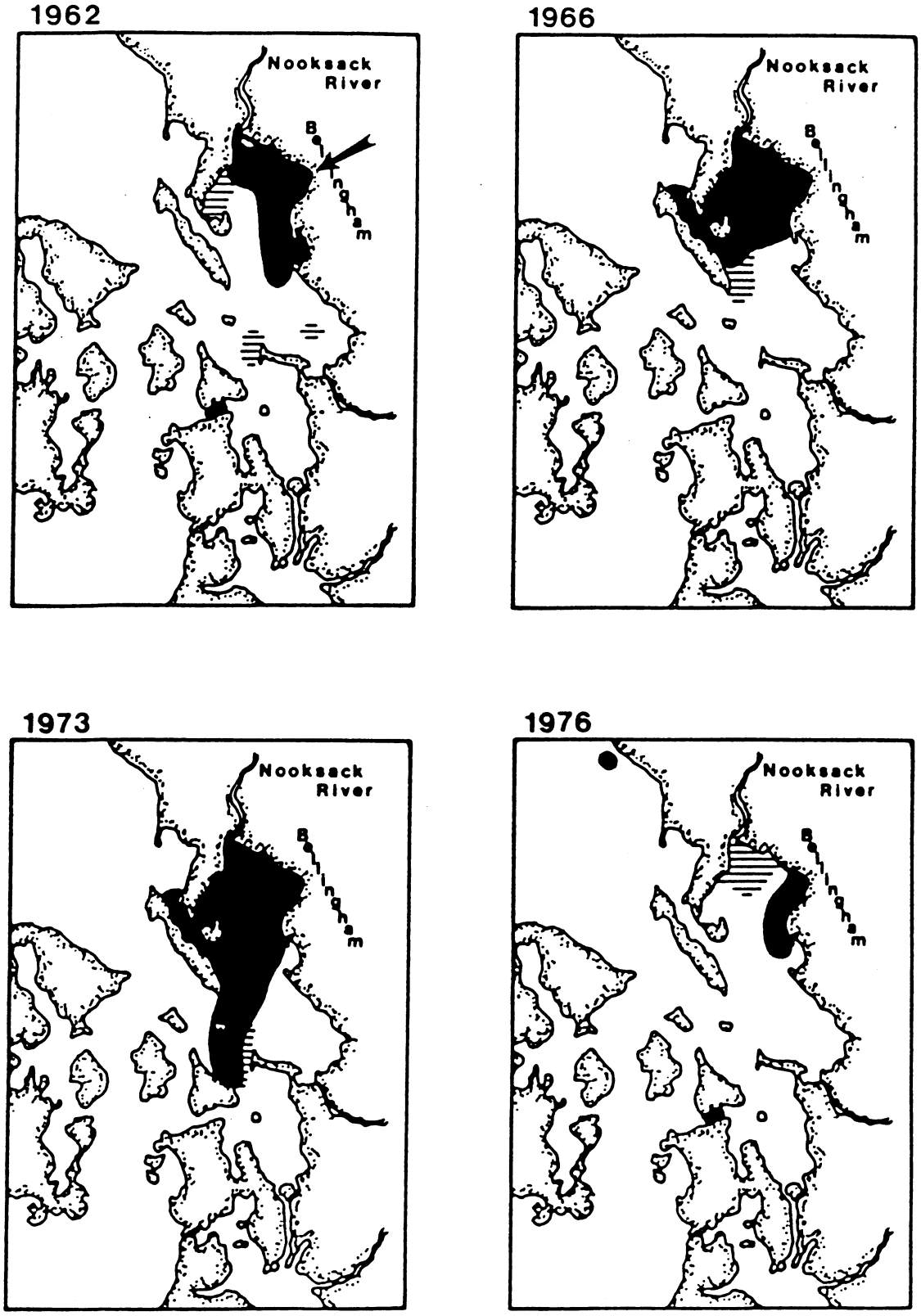
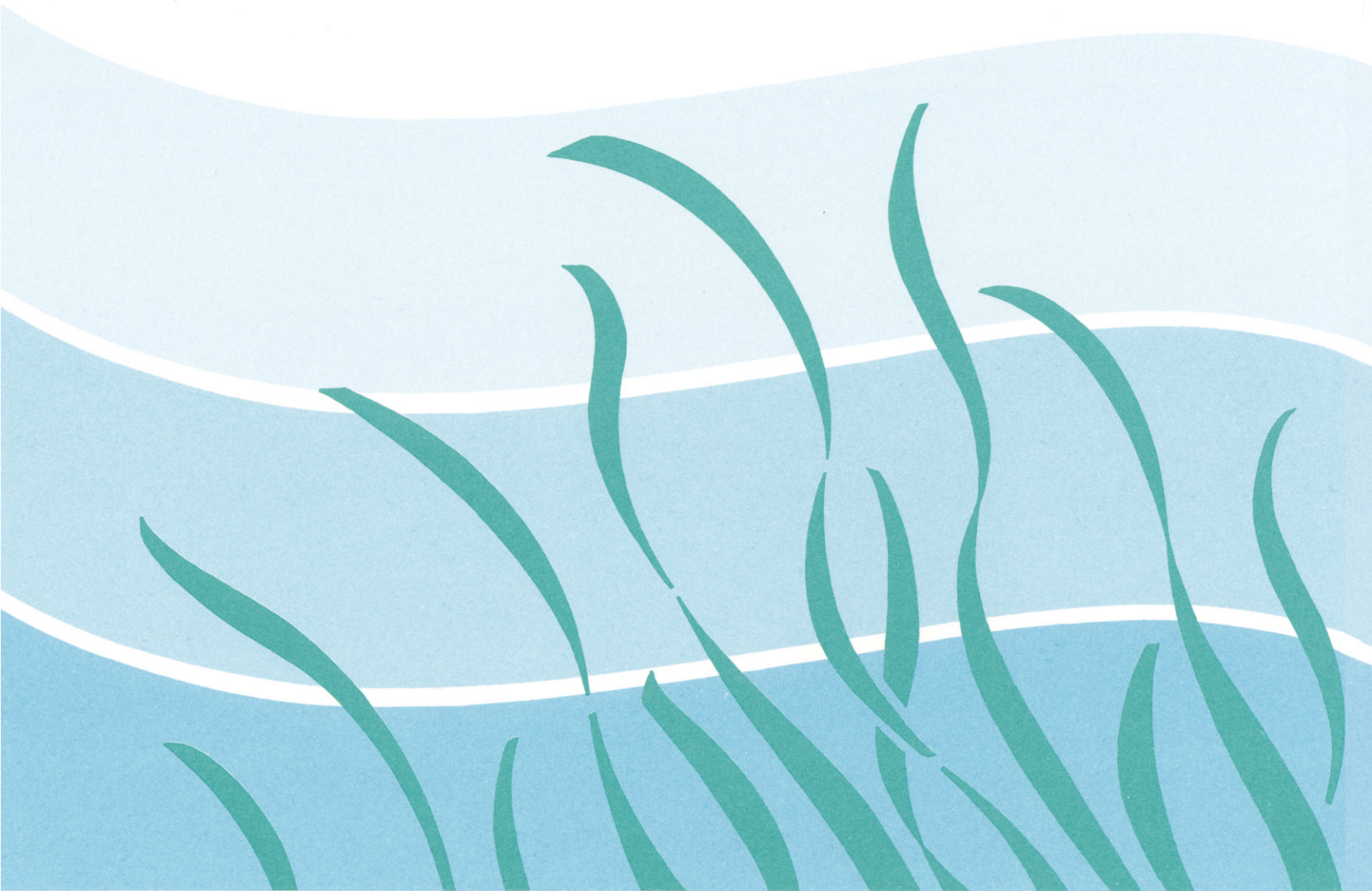


Figure 4. Representative maps of the toxicity of marine waters to oyster larvae (% abnormal larvae) in Bellingham, Samish and Padilla Bays during the 1960s and 1970s (from Cardwell and Woelke 1979).

>50%

5-49%