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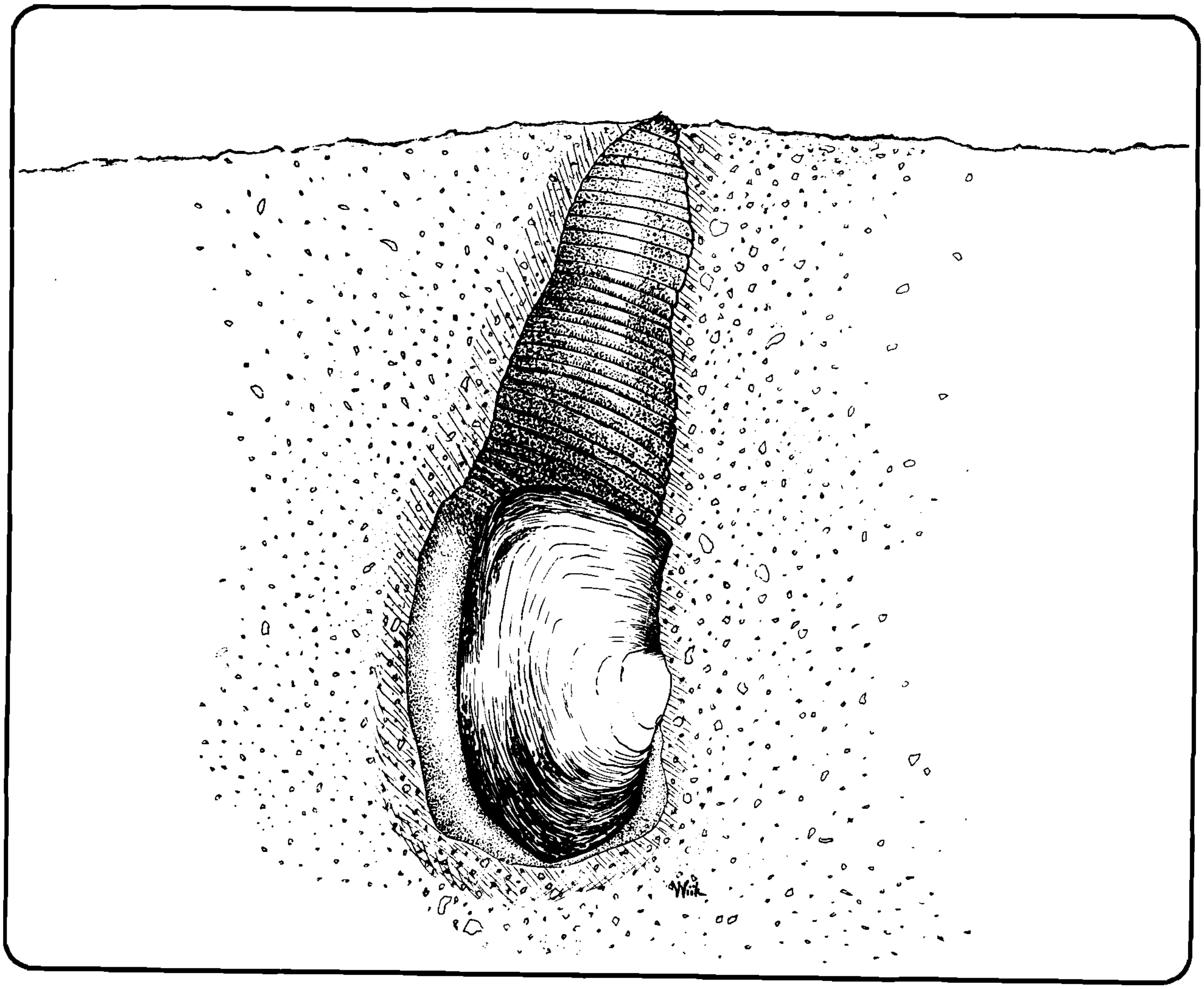
PACIFIC GEODUCK CLAM



Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fish and Invertebrates (Pacific Northwest)

PACIFIC GEODUCK CLAM

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	*By*	*To Obtain*
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (° C)	1.8 (° C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	*By*	*To Obtain*
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces	28.35	grams
pounds (lb)	0.4536	kilograms
pounds	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (° F)	0.5556 (° F - 32)	Celsius degrees

CONTENTS

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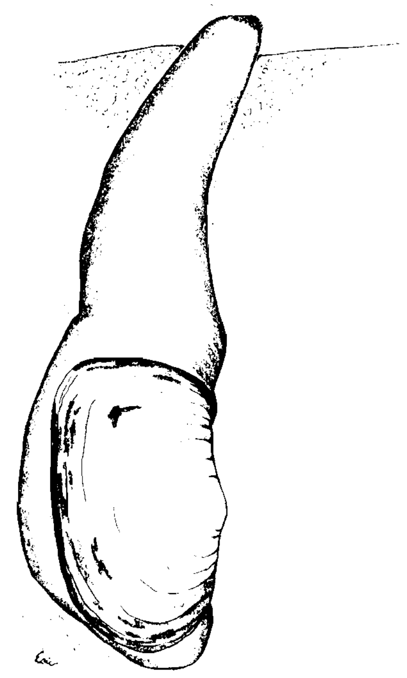

Figure 1. Pacific geoduck clam (figure courtesy of Eric Hurlbert, Washington Department of Fisheries).

PACIFIC GEODUCK CLAM

NOMENCLATURE/TAXONOMY/RANGE

Scientific name......*Panopea abrupta* (Conrad 1849)
Preferred common name...Pacific geoduck clam (Figure 1)

Class .... Bivalvia (Pelecypoda)
Order .... Myoida
Superfamily .... Hiatellacea
Family.. Hiatellidae

Geographical Range: Lower intertidal and subtidal to depths of over 110 m along the west coast of North America from Alaska to Baja California, and in Japan (Andersen 1971; Bernard 1983; Goodwin and Pease 1987); very abundant in Puget Sound, Washington and British Columbia (Figure 2), where subtidal stocks support important commercial fisheries (Goodwin and Pease 1987).

MORPHOLOGY/IDENTIFICATION AIDS

The geoduck clam is one of the largest burrowing clams in the world, attaining a shell length of at least 212 mm and a live weight (including shell) of 3.25 kg (Goodwin and Pease 1987). It gapes so widely (except at the hinge)

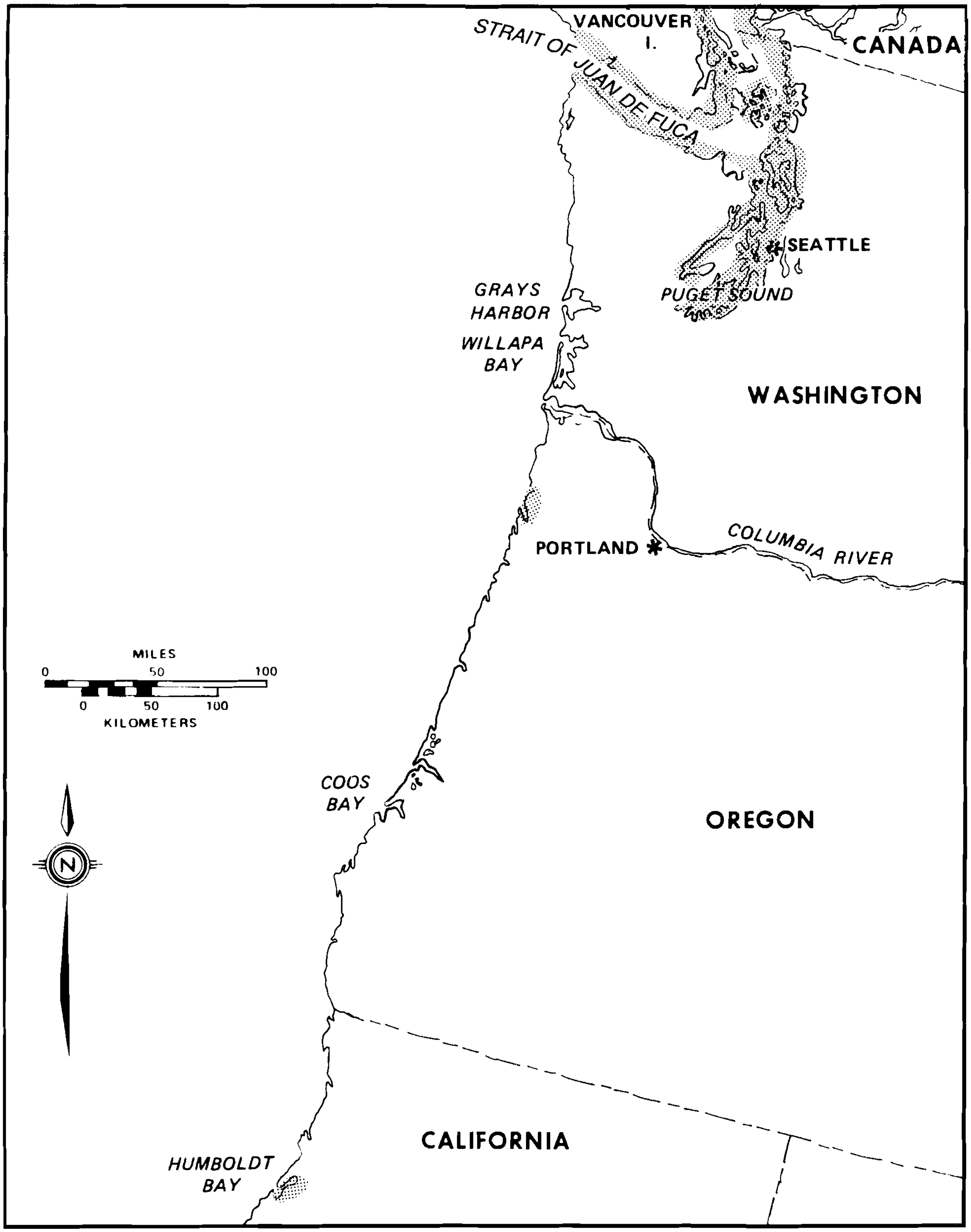

Figure 2. Distribution of the geoduck clam in the Pacific Northwest.

that the long, fused siphons and large mantle cannot be completely withdrawn into the shell. In buried adults the extremely long, contractile siphon may extend 1 m to reach the surface of the seabed. Siphonal openings are not ringed with tentacles except in early post-larval stages. The tips of the siphons lack the cutaneous plates found in the horse clams *Tresus* sp.

Small juveniles have a large, well-developed foot, which becomes proportionally smaller as the clam grows. The foot of an adult is so small that the clam, if placed on its side, is not capable of righting itself and digging into the substrate. The fused mantle is large and fleshy and has only a small slit for the pedal gape.

The shell of an adult clam is quadrate and has a thin, light brown periostracum. Shell sculpture and thickness vary from fine and thin to rugose and thick (Goodwin and Pease 1987). Fyfe (1984) demonstrated that geoduck clam shell is so highly variable in shape that it is difficult to quantify by the traditional measurements of height, length, width, and thickness.

The hinge has one large cardinal tooth in each valve. The tooth on the left valve is always largest. The pallial sinus mark on the shell is very broad and the anterior and posterior adductors are similar in size.

REASON FOR INCLUSION IN SERIES

Geoduck clams dominate the biomass of benthic infaunal communities in many parts of Puget Sound (Goodwin 1978; Goodwin and Pease 1987) and support the most valuable commercial clam fishery along the Pacific Coast of North America. From 1975 to 1987 the annual catch from Puget Sound has remained between 1,100 and 3,900 t (2.4-8.6 million lb) and landings in British Columbia have recently exceeded 5,000 t/yr (Goodwin and Pease 1987; Harbo and Jamieson 1987). The Washington State Department of Fisheries is currently exploring the feasibility of enhancing the commercial fishery by planting hatchery-reared geoduck clam seed into fished-out beds.

Domestic and industrial pollution in Puget Sound, which has increased with the expanding human population of the region, has led to restrictions on geoduck clam harvest in portions of the Sound. Marine construction projects such as piers, jetties, marinas, and pipelines displace increasing amounts of geoduck clam habitat every year; aquaculture projects are also rapidly expanding and competing for space in geoduck clam habitat. Because geoduck clams are sedentary, suspension feeders that are very long-lived, they are particularly susceptible to the effects of pollution and habitat loss.

LIFE HISTORY

The geoduck clam passes through the seven life-history stages common to most pelecypods (Table 1). Growth rate, thus age at any life history stage, is extremely variable and depends on environmental conditions and general health of the animal.

Spawning

Andersen (1971) found size at sexual maturity of geoduck clams to be variable. The smallest sexually mature clam in his sample (n=365) was 45 mm long (all lengths refer to shell length). Of the clams sampled, 50% were mature at 75 mm and an age that Andersen estimated to be 3 years. Goodwin and Shaul (1984) found growth rates in Puget Sound to vary geographically, but indicated that geoduck clams may reach a length of 75 mm in 2-8 years. The sexes are separate; males generally mature at a smaller size and earlier age than females (Andersen 1971). Sloan and Robinson (1984) in British Columbia found ripe gonads in geoduck clams as old as 107 years.

Geoduck clams follow a simple annual reproductive cycle. Gametogenesis begins in September and clams spawn from March to July (Andersen 1971; Goodwin 1976; Sloan and Robinson 1984). Males become sexually mature at younger ages than females; sperm can be found in the gonads of some males during any month of the year.

Table 1. The life stages and characteristics of the geoduck clam (sizes from Goodwin 1976 and ages from K. Cooper, currently with Coast Oyster Company, Quilcene, Washington; pers. comm.).

Stage	Size	Age, size, and characteristics
Fertilized egg	80 μm	Spherical
Trochophore	80-100 μm	<24 hr at 14 °C, top-shaped
Prodissoconch I (veliger)	110-165 μm	Straight-hinged shell
Prodissoconch II (veliger)	165-400 μm	Umbones on shell. (The two veliger stages last between the ages of 2-16 days; the larvae have shells and swim with the velum.)
Dissoconch (postlarval stage)	400-1,500 μm	16-35 days at 16 °C shell length spines on shell, attaches to substrate particles with bysuss threads, but does not dig into substrate
Juvenile	1.5-7.5 mm shell length	36 day to 2 years; no spines on shell actively digs; not sexually mature
Adult	75-200+ mm shell length	2-146 years; does not actively dig, sexually mature

The sex ratio of clams older than 10 years is 50:50. Males can be distinguished from females only by a microscopic examination of the gonads. No hermaphrodites have been found.

Geoduck clams have been successfully spawned in the laboratory (Goodwin 1976; Goodwin et al. 1979) and are spawned annually in the geoduck clam hatchery at the Point Whitney Shellfish Laboratory (Shaul, unpubl.). Spawning is triggered primarily by an increase in water temperature and the addition of cultured phytoplankton to the spawning tank. Laboratory spawning has occurred at water temperatures of 8.5-16.0 °C (mostly 12-14 °C). Spawning has occurred as early as January 10 and as late as July 5 (Goodwin et al. 1979). Females have huge ovaries that contain many millions of eggs; however, they are dribble spawners, normally releasing only 1 to 2 million eggs (or less) during each spawning event. The largest release observed from a single female during one spawning episode was 20 million eggs.

In the hatchery, spawning is triggered by holding the brood stock at 9-12 °C, and then increasing the water temperature slightly while adding algal cells to the influent water. A male normally spawns first which then triggers spawning in other males and females. Usually relatively few females release eggs during a spawning event. Individuals can be induced to spawn as many as three or four times during one season. Shaul (unpubl.) noted that geoduck clams from areas where water temperatures are relatively high in summer, such as south Puget Sound, spawn earlier in the season than those from cold water areas such as the Strait of Juan de Fuca. Eggs and sperm are released into the water, where fertilization occurs. Fertilized eggs are spheres about 80 μm in diameter, which are slightly negatively bouyant in sea water of 14 °C and 29 ppt of salinity. Very weak water currents will keep the eggs suspended.

Larvae

Depending on a number of factors such as water temperatures, health of the brood, and presence of chemical cues, the larval stage in laboratory and hatchery-reared geoduck clams has ranged from 16 to 47 days. The minimum of 16 days has been observed in the laboratory at temperatures of 16 °C (C. Bradley, Point Whitney Shellfish Laboratory; pers. comm). The maximum of 47 days was reported from early laboratory studies by Goodwin et al. (1979) at water temperatures of 14 °C. The larval period was shortened to 30 days at 17.6 °C. Bacterial contamination and overcrowding may have artificially delayed larval growth and metamorphosis in the early laboratory studies. Larval mortalities were extremely high, indicating problems with culture practices. The length of the larval period in nature has not been studied.

The fertilized egg undergoes cell division and develops into a top-shaped trochophore larva that has rows of short, hair-like cilia for swimming. This stage of the life history of geoduck clams has not been reported in the literature. Goodwin et al. (1979) described larval development from the straight-hinge through early post-larval stages. Within 48 hours, the larvae form a straight-hinged shell and a ciliated swimming organ called the velum. This stage is known as the straight-hinged larva or prodissoconch I, and the shell is about 110 µm long. When length reaches 165 µm, rounded elevations called umbones appear at the hinge on each shell and the larvae enter the prodissoconch II stage of development. This is the last free-swimming stage in the clam's life history.

Postlarvae

Geoduck clams pass through a distinctive post-larval stage called the dissoconch for 2-4 weeks. At a shell length of 350-400 µm, the animal loses its velum and associated swimming ability, develops spines on the growing edge of the shell, and starts to crawl with its newly developed foot. This transformation to the dissoconch is called metamorphosis and is a critical phase in the clam's life, marking a change of life-style from a planktonic existence in the water column to an increasingly sedentary style on the seabed. Metamorphosis may be delayed when the animals are stressed or critical environmental cues are lacking.

Cooper and Pease (unpubl.) observed that chemicals from the tubes of several polychaete worm species trigger metamorphosis of competent geoduck clam larvae (larvae capable of metamorphosis). These tubes commonly occur in habitats where adult geoduck clams are abundant. Cooper and Pease (unpubl.) suggested that the larvae are capable of selecting certain habitats by metamorphosing in response to chemical cues from those habitats.

Postlarvae are capable of actively crawling along the surface of the seabed using the well-developed ciliated foot (Goodwin et al. 1979). They are also capable of attaching themselves to the substrate with byssal threads produced by an organ in the foot (Shaul, unpubl.). On a sand substrate, the postlarva inserts its foot into the sand and burrows down less than one shell length (Goodwin and Pease, pers. obs.). (They apparently do not burrow deeper because the siphons are not developed at this stage.)

During the process of burrowing, byssal threads are attached to a number of sand grains, forming a sand anchor. After the byssal attachment, the larvae often return to the seabed surface, remaining attached to the sand anchor. In strong water currents, postlarvae often detach from the sand anchor and form several long byssal threads that greatly increase drag, thus forming a parachute that carries the postlarvae down current (Shaul, unpubl.). Thus, postlarvae can remain stationary, crawl short distances, or travel long distances with their byssal parachutes.

Juvenile Clams

When the shell length is 1.5-2.0 mm, the siphons have developed and the clams start to burrow into the substrate, remaining buried with only the tips of the siphons exposed. At this point the clams begin to take on the general morphology of adults but are considered juveniles until sexually mature at an average length of 75 mm. Small juveniles, less than 8 mm long, are unlike adults in having a shell that is less sharply quadrate; also they can almost completely withdraw into the shell, actively dig, and are still capable of producing byssal threads. Juveniles up to 5 mm long may use the byssal parachute for movement, but not as effectively as it is used by smaller postlarvae. Juveniles longer than 5 mm probably do not move to another location, but simply bury themselves deeper into the substrate as they grow.

Digging speed is inversely related to shell length. Hatchery-reared juveniles placed in partly sand-filled beakers with seawater right themselves and dig completely into the substrate. Juveniles averaging 5 mm long take about 8 min to bury themselves, whereas 10 mm animals require 30 min. Burial depth is directly related to shell length and the length of the siphon (Goodwin et al. 1985).

Juveniles 8-20 mm long are called seed clams. At this size, they are taken from the hatchery and planted in the natural environment. Plantings have been done to determine optimum clam size, planting density, and habitat. Survival of planted seed has varied from 0% to 40% and was less than 10% in prime, unprotected habitat (no exclusion cages or mesh covering substrate). Predation by fish, starfish, crabs, and snails is believed to be responsible for most of the seed mortalities.

Adult Clams

Upon reaching maximum adult size, geoduck clams become poor diggers and are completely sedentary. They contribute substantially to the biomass of benthic communities in which they occur. Average abundance in Puget Sound in sand and mud bottoms at water depths of 6-18 m is 1.7 clams/m^2. The average whole wet weight is 872 g. Biomass in these areas averages 1,483 g/m and ranges up to 19,651 g/m (Goodwin and Pease 1987).

COMMERCIAL AND SPORT FISHERIES

The geoduck clam is a valuable sport and commercial species in Puget Sound. Most of the sport catch is dug on intertidal beaches, but a small portion (800 clams in 1982) is hand-dug subtidally by sport divers (Bargmann 1984). Geoduck clams taken for sport must be dug with hand tools. The daily legal limit is three per person. The total sport catch is low compared with the commercial landings.

The commercial fishery in Puget Sound is co-managed by the Washington Department of Fisheries and Washington Department of Natural Resources (Bowhay 1985). These agencies lease subtidal geoduck clam tracts to commercial divers who take the clams one at a time, using a water jet to loosen the clams from the substrate. A significant portion of the catch is frozen and exported to Japan, but there is a growing domestic market for the whole, live clams. Large, light-colored geoduck clams (good quality) are in high demand in the market compared to small, dark ones. Quality is inversely related to the age of the clam and the water depth at which the clam was growing (Goodwin and Pease 1987).

The total standing stock of subtidal geoduck clams in major beds in Puget Sound was estimated to be 126,984 t before commercial fishing began in 1970 (Washington Department of Fisheries and Washington Department of Natural Resources 1985). Because many of these beds were polluted, not economically or physically accessible, or were in conflict with other water uses, only an estimated 74,829 t were actually harvestable. The maximum sustained yield was estimated to be 2% of the harvestable stocks/yr (Shaul and Goodwin, unpubl.) or 1,497 t/yr. Washington Department