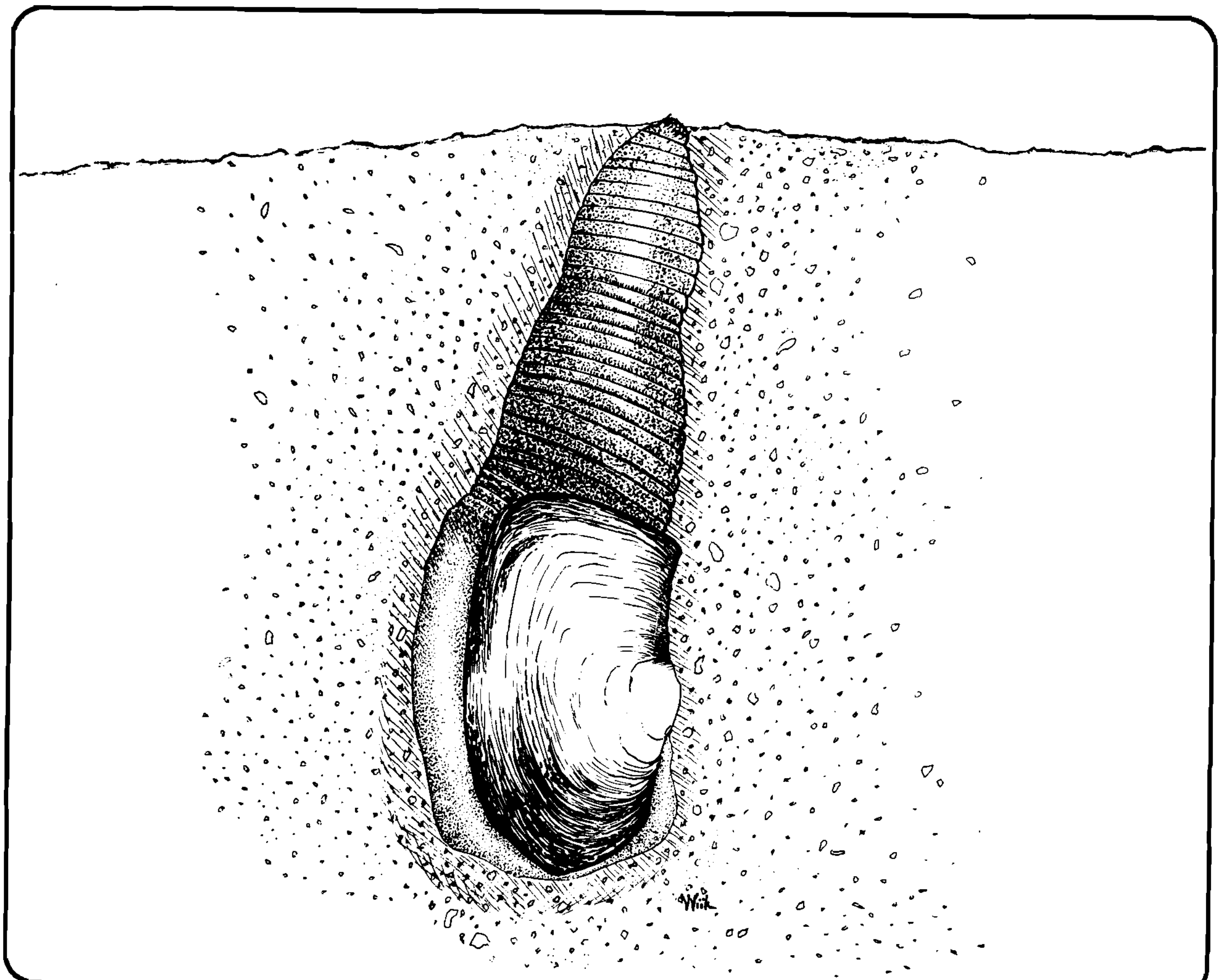
Biological Report 82(11.120)
December 1989

TR EL-82-4

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

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

Biological Report 82(11.120)
TR EL-82-4
December 1989

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

PACIFIC GEODUCK CLAM

by

C. Lynn Goodwin
and
Bruce Pease
Point Whitney Shellfish Laboratory
Washington Department of Fisheries
Brinnon, WA 98320

Project Officer
David Moran
National Wetlands Research Center
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Performed for
U.S. Army Corps of Engineers
Coastal Ecology Group
Waterways Experiment Station
Vicksburg, MS 39180

and

U.S. Department of the Interior
Fish and Wildlife Service
Research and Development
National Wetlands Research Center
Washington, DC 20240

This series should be referenced as follows:

U.S. Fish and wildlife Service. 1983-19__. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. U.S. Fish Wildl. Serv. Biol. Rep. 82(11). U.S. Army Corps of Engineers, TR EL-82-4.

This profile should be referenced as follows:

Goodwin, C.L., and B. Pease. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)--Pacific geoduck clam. U.S. Fish. Wildl. Serv. Biol. Rep. 82(11.120). U.S. Army Corps of Engineers, TR EL-82-4. 14 pp.

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.

Information Transfer Specialist
U.S. Fish and Wildlife Service
National Wetlands Research Center
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458

or

U.S. Army Engineer Waterways Experiment Station
Attention: WESER-C
Post Office Box 631
Vicksburg, MS 39180

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

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

ACKNOWLEDGMENTS

The authors would like to thank Bobbe Hardie, Washington State Department of Fisheries, for typing and editing early drafts and Dr. Ken Chew of the University of Washington and Rick Harbo of the Canada Department of Fisheries and Oceans, Nanaimo, BC, for their technical reviews.

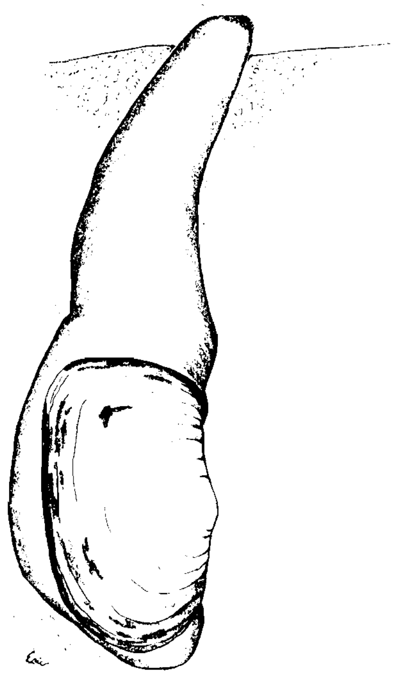


Figure 1. Pacific geoduck clam (figure courtesy of Eric Hurlbert, Washington Department of Fisheries).

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)

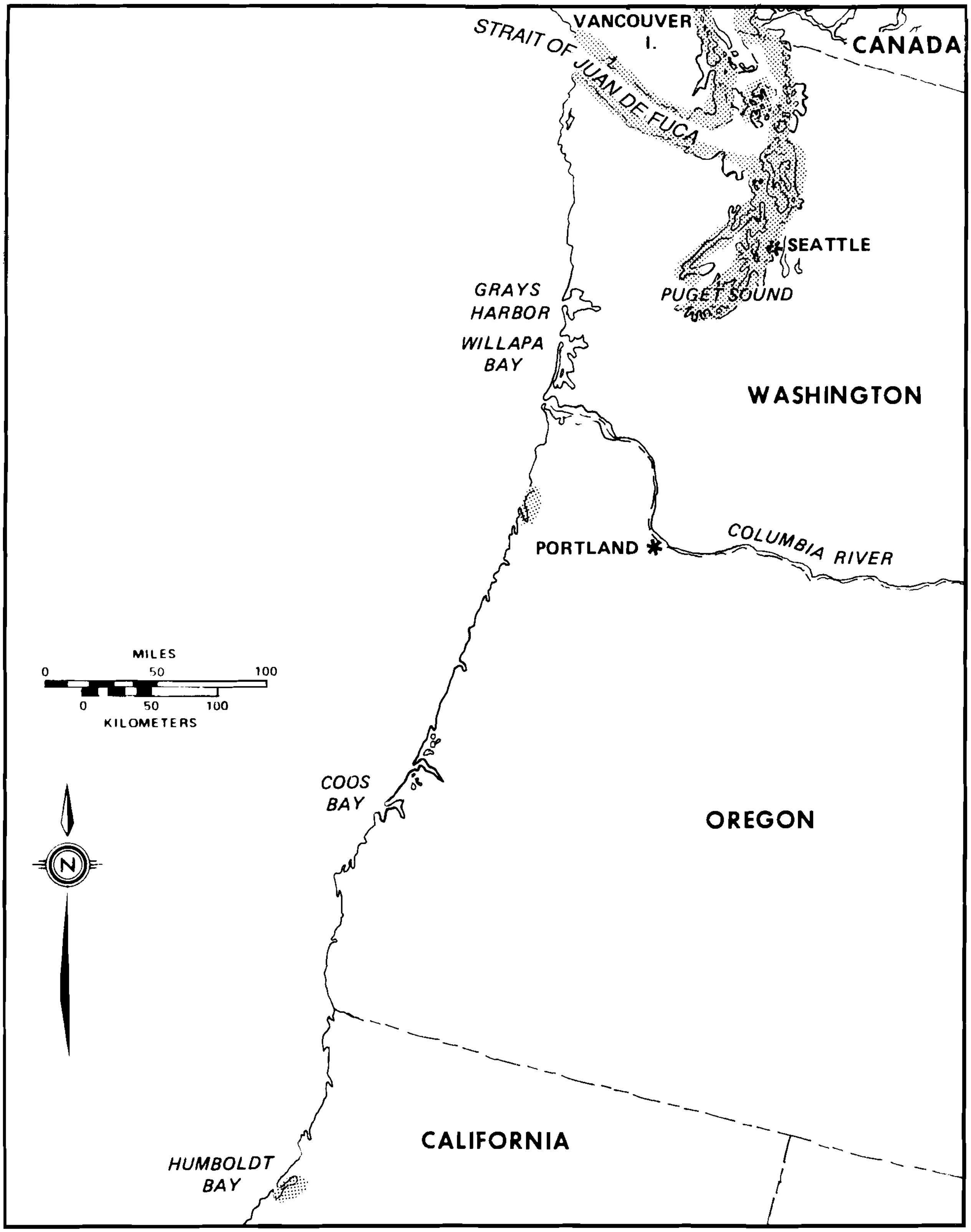


Figure 2. Distribution of the geoduck clam in the Pacific Northwest.

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 of Fisheries and Washington Department of Natural Resources have set the optimum sustained at 3% of the harvestable stock/yr or 2,245 t, which is higher than the 1,607 t average reported from the fishermen since the fishery started in 1970 (Table 2). The Washington Departments of Fisheries and Natural Resources are engaged in a program to reseed the clam beds with hatchery reared seed as the beds are fished out. The goal of the project is to be able to plant about 30 million seed in 160-200 ha/yr. The ability to produce the juvenile clams has been proven; however, it is still unclear whether or not enough clams survive after planting to economically justify the project.

Table 2. Puget Sound commercial geoduck clam landings (whole wet weight, Goodwin and Pease 1987; Dick Hegen, Washington Department of Natural Resources; pers. comm.).

Year	Metric Tons
1970	37
1971	277
1972	234
1973	210
1974	364
1975	1,076
1976	2,434
1977	3,922
1978	3,216
1979	2,371
1980	1,774
1981	1,946
1982	2,405
1983	1,598
1984	2,005
1985	1,864
1986	1,180
1987	2,017
18-yr average	1,607

If the seeding program fails and no new beds of clams are discovered in the future, the optimum sustained yield may eventually have to be reduced slightly.

Since 1979 the annual catch has been limited to the optimum sustained yield by regulating the numbers and sizes of the geoduck clam tracts that are leased each year (limited entry). Washington Department of Fisheries conducts extensive stock surveys on all tracts before they are leased to ensure that the optimum sustained yield is available to the fishermen each year. The tracts are sold by an auction process which generates enough income to fund the cost of the geoduck clam hatchery located at Point Whitney.

POPULATION DYNAMICS

Despite the high fecundity of geoduck clams, the recruitment of juveniles into the population is very low (Goodwin and Shaul 1984). As in most bivalves, mortality during the planktonic and early settlement phases is extremely high, decreasing as the clams pass through each life stage. The annual mortality rate of adults is very low: reported rates are 0.01-0.04 (Breen and Shields 1983), 0.02-0.05 (Shaul and Goodwin, unpubl.), and 0.00-0.02 (Harbo et al. 1983). Survival of a juvenile or adult is directly related to the depth that the clam digs into the substrate. Clams are more susceptible to predators near the surface of the seabed (Sloan and Robinson 1983). Once the clam buries itself deeper than 60 cm, it is beyond the reach of virtually all predators except man. Juvenile and adult clams can be accurately aged from acetate peels of the hinge plate (Shaul and Goodwin 1982). Goodwin and Shaul (1984), who studied the age frequency distribution of geoduck clams at 14 sites in Puget Sound, reported that the average age ranged from 28-57 years. Clams older than 100 years were common, and the age of the oldest live clam collected was 131 years. Harbo et al. (1983) and Sloan and Robinson (1984) found similar age distributions in British Columbia and a maximum age of 146 years. From a study of empty geoduck clam shells in Puget Sound, Goodwin and Shaul (1984) determined that mortality rate in each age group was proportional to the number of clams in that age group. The oldest empty shell was from a clam that died at the age of 141 years.

Goodwin and Shaul (1984) also studied the recruitment of juvenile clams in Puget Sound. They defined juvenile clams as those less than 5 years old. Recruitment rates were found to be highly variable from area to area and year to year but were generally low (0-2.5/m^2). The average density of these young clams was 0.78/m^2 in unfished areas and 0.54/m^2 in fished areas. The results indicated that fishing had an adverse effect on recruitment. Other adverse environmental effects are believed to be minimal (Goodwin 1978). In some locations juveniles were clumped around adults, indicating that larvae selectively settle near adults, postlarvae seek adults or survive at higher rates near adults. Clumping of juveniles near adults has also been observed in British Columbia (Fyfe 1984). Canadian studies (Breen and Shields 1983; Harbo et al. 1983) indicated that recruitment rates are also low in British Columbia. Goodwin and Shaul (1984) concluded after several experiments that commercial harvest adversely affected recruitment, but the mechanism of the effect was not determined.

Geoduck clams are abundant in the shallow subtidal mud and sand zones of Puget Sound. The average density based on 8,589 transects (41.8 m each) was 1.7/m and ranged from 0-22.5 clams/m (Goodwin and Pease 1987). Reported densities from British Columbia were 0.2-14.7/m (Breen and Shields 1983) and 0-13/m, with an average of 4.9/m (Fyfe 1984). As many as 36 clams/m have been found on the central coast of British Columbia (Harbo et al. 1986). In Puget Sound the density was inversely related to latitude and directly related to water depth (Goodwin and Pease 1987). Density was highest in substrates of mud-sand or sand compared to mud or pea gravel or gravel substrates. Geoduck clams were contagiously distributed: the average number of clams per clump was 109 and the average number of clumps per 41.8 m transect was 0.64 (1.53 clumps/100 m). Density was directly related to water depth down to 20 m, whereas geoduck clam size was inversely related to water depth.

GROWTH CHARACTERISTICS

Growth in length and weight is rapid during the first few years of life and then nearly ceases. In most populations the clams reach a size near their final size after 10 years of life (Andersen 1971; Goodwin 1976; Breen and Shields 1983; Harbo et al. 1983). In fast-growing areas, the clams average an increase in shell length of 30 mm per year during the first 3 or 4 years of life. The greatest rate of growth by individual clams was 60 mm per year in clams that were 1-3 years old (Goodwin 1976). In more recent experiments conducted in an area of fast growth in south Puget Sound, hatchery seed planted in October 1986 (mean length 10.9 mm) and recovered in June 1987, increased an average of 3.4 mm/month in length. The fastest growing clam grew 5.7 mm per month (Washington Department of Fisheries, unpubl. data). At this rate the clam would have increased in length by 68.6 mm in 1 year. Geoduck clams at this location can reach the acceptable commercial size of 680 g (whole wet weight) in 4-5 years. Growth rates vary greatly among locations in Puget Sound and British Columbia (Goodwin 1976; Breen and Shields 1983; Harbo et al. 1983).

Growth slows during winter, but does not stop completely (Shaul and Goodwin 1982). Geoduck clams become less active in winter and spend considerable time with their siphons retracted (Goodwin 1977).

Geoduck clam length and weight, and probably growth rates, are closely related to current speed, sediment type, and water depth in Puget Sound (Goodwin and Pease 1987). Size is related directly to current speed and inversely to water depth. The largest clams are found in substrates of mud and sand or sand.

ECOLOGICAL ROLE

Food and Feeding Habits

Studies of the food habits of geoduck clam larvae, juveniles, and adults have not been published; however, some information is available from casual observations of gut contents of adults and from hatchery operations at the Point Whitney Shellfish Laboratory. Geoduck clam larvae, juveniles, and adults, like these stages in other clam species, feed by filtering food particles from seawater with their gills. Microscopic examination of wet smears of gut contents from adults taken from Puget Sound have shown only phytoplankton (flagellates and diatoms). Geoduck clams live in water as deep as 110 m, which is well below the photic zone. Clams below this zone probably feed on live phytoplankton carried by wind-driven or tidal currents or dead plankton and bacteria called marine snow (Strickland 1983), which settles from the photic zone. Geoduck larvae at the Point Whitney hatchery were fed cultured phytoplankton. *Isochrisis* sp. (Tahitian) and *Chaetocerous calcitrans* were fed to young larvae and later *Chaetocerous gracilis* was added. Cell concentrations were kept between 5,000 and 10,000/ml. When the postlarvae were moved out of the hatchery into the juvenile "grow-out" system, algae from a fertilized seawater pond were used for food. The water was filtered with 150 μm screens before it was added to the raceways. The dominant algae in the filtered water were diatoms of both single cell and chain forming species.

King (1985) demonstrated that postlarval geoduck clams may feed on substrate deposits by a pedal-palp method. Larvae, after losing the velar feeding apparatus and before the adult ctenidial apparatus develops, can feed by protracting the foot into the sediment, then withdrawing it along with adherent deposit material. Food is brought near the mouth during pedal retraction when the foot brushes against the labial palps. How important this method is to geoduck clams in nature is unknown.

Predators

Predation on geoduck clams is probably similar to that on other clams or invertebrates that release millions of eggs into the water. Mortality rates are high at first, slow during the juvenile stage, and become very low when the clams reach adult size. Planktonic larvae are probably eaten by fish, other plankton, or suspension-feeding invertebrates. After metamorphosis and assuming the benthic life style, the young postlarvae face a new host of predators, including epibenthic fish (soles, flounders), worms, snails, starfish, and crabs. Geoduck clams in the juvenile stage have thin, fragile shells that do not fully enclose and protect the soft body parts from predators. Young geoduck clams cannot leap as cockles (*Clinocardium nuttallii*) do to avoid predators (Sloan and Robinson 1983). They have adopted instead a strategy of growing very long siphons and gradually digging into the substrate as the siphons grow and permit deeper penetration. Fast-growing clams can reach a depth refuge of 60 cm or more in 2 years.

In a recent Washington Department of Fisheries experiment in an area of fast geoduck clam growth in Puget Sound, 3-month-old hatchery clams were planted in a mud and sand substrate without hard materials that would prevent penetration by the young clams. They were planted in October and recovered in July of the following year. The recovered clams averaged 36.6 mm in shell length (range 28-51 mm) and were buried in the substrate an average of 33.6 cm (range 23-46 cm). Burial depth was the distance from the seabed surface to the anterior edge of their shells (the edge which is near the foot and faces downward).

Hatchery-reared seed clams, when planted into geoduck clam beds, are spread from the water surface and must fall through the water column, land on the seabed, and quickly dig in before being eaten by predators. Animals observed feeding on the exposed seed include the sunflower star (*Pycnopodia helianthoides*), lean basket-whelk (*Nassarius mendicus*), coonstripe shrimp (*Pandalus danae*), red rock crab (*Cancer productus*), and graceful crab (*C. gracilis*), starry flounder (*Platichthys stellatus*), English sole (*Parophrys vetulus*), rock sole (*Lepidopsetta bilineata*), sand sole (*Psettichthys melanostictus*), and pile perch (*Rhacochilus vacca*). These animals, with the exceptions of pile perch and shrimp (*Pandalus danae*), probably prey on juvenile geoduck clams that are buried in the substrate also. Dead shells of juvenile geoduck clams have been recovered with holes through the umbones which are typical bore holes of the moon snails *Polinices lewisii* and *Natica* sp. (Washington Department of Fisheries, unpubl. data).

Adult geoduck clams have few natural enemies if they are buried in the substrate 60 cm or more; however, the starfishes *Pisaster brevispinus* and *Pycnopodia helianthoides* can dig up and eat geoduck clams that are unable to penetrate the substrate to the normal depth for adults (Sloan and Robinson 1983). According to diving fishermen of British Columbia, sea otters (*Enhydra lutris*) may excavate and eat adult geoduck clams. Geoduck clams can also suffer from siphon grazing, which does not necessarily result in the death of the clam. Andersen (1971) reported that the tips of geoduck clam siphons have been found in the guts of spiny dogfish *Squalus acanthia* and the cabezon *Scorpaenichthys marmoratus*. Fishermen have found the siphon tips in the guts of halibut (*Hippoglossus stenolepis*). Divers of the Washington Department of Fisheries have observed geoduck clams in many locations throughout Puget Sound with obvious bites or portions taken from the tips of the siphons. Siphon grazing has been observed in other west coast species (Gallucci and Rawson 1979; Peterson and Quammen 1982).

ENVIRONMENTAL REQUIREMENTS

Salinity and Temperature

The only published data on salinity and temperature requirements are from Goodwin (1973). In this study, newly fertilized eggs were allowed to develop to the straight-hinge stage in various combinations of salinity and temperature. For 70% or more of the embryos to develop into normal straight-hinge larvae the salinities had to remain between 27.5 and 32.5 ppt and the temperatures between 6 and 16 °C.

Like many bivalves, the older life stages of geoduck clams can tolerate a wider range of salinity and temperatures. Larvae beyond the straight-hinge stage are routinely grown at the Point Whitney hatchery at water temperatures up to 17 °C. Juveniles do well in water of 18 °C and can survive short periods of exposure °C water. Adults in the lower intertidal and shallow subtidal zones of Quilcene and Dabob Bays (Puget Sound) are exposed to water temperatures of 21-22 °C, sometimes for several days, during July and August in warm years.

Substrate

Geoduck clams live in substrates of soft mud, sand, and pea gravel or gravel substrates or mixtures of these materials. As mentioned earlier, they grow larger in mud and sand or sand than in mud or pea gravel and gravel. Density is mud and sand or sand and lowest in mud. The quality of the meat (light color of meat=high quality) is weakly correlated with substrate particle size: the highest quality clams from coarse substrates (Goodwin and Pease 1987).

Substrate can affect the shape and color of the shells. Organically rich and therefore poorly oxygenated substrates stain the shells of the clam, making them gray or black instead of the white or cream color typical of well-oxygenated substrates. Geoduck clams growing in substrates with large gravel rocks or shells often have misshapen shells due to their being wedged between the large hard objects.

Pollution

Little work has been done on determining the accumulation of pesticides, heavy metals, or other toxic substances in geoduck clams. However, significant portions of the total stocks of clams in Puget Sound cannot now be commercially fished because of domestic pollution. Most of the shoreline along the eastern side of Puget Sound cannot be certified for the commercial use of filter feeders such as geoduck clams. Other areas near towns and rural developments with effluents from sewage treatment plants are also non-certifiable. More geoduck clam beds will probably be lost in the future because of the popularity of home ownership along the shorelines of Puget Sound and the increase of general human population occurring in the Puget Sound basin. Paralytic shellfish poisoning has not been a significant problem in the commercial fisheries of Washington or British Columbia. Geoduck clams have been tested extensively for this problem. Paralytic shellfish poisoning may be a deterrent to the exploitation of geoduck clams in Alaska.

REFERENCES

Andersen, A.M., Jr. 1971. Spawning, growth and spatial distribution of the geoduck clam, *Panope generosa* (Gould) in Hood Canal, Washington. Ph.D. Thesis. University of Washington, Seattle. 133 pp.

Bargmann, G.G. 1984. Recreational diving in the state of Washington and the associated harvest of food fish and shellfish. Wash. Dep. Fish. Tech. Rep. No. 82. 66 pp.

Bernard, F.R. 1983. Catalogue of the living bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. No. 61. 102 pp.

Bowhay, C. 1985. A comparison of fishery management approaches: license limitation vs. individual harvest quotas: case example--the geoduck fishery. M.S. Thesis. University of Washington, Seattle. 88 pp.

Breen, P.A., and T.L. Shields. 1983. Age and size structure in five populations of geoduc clams (*Panope generosa*) in British Columbia. Can. Tech. Rep. Fish Aquat. Sci. No. 1169. 62 pp.

Cooper, K. and B. Pease. Induction of settlement and metamorphosis of the geoduck clam, *Panope abrupta* (Conrad) by polychaete tubes with implications for recruitment and adult distribution patterns. Washington Department of Fisheries. Unpubl. MS.

Fyfe, D.A. 1984. The effect of conspecific association on growth and dispersion of the geoduck clam, *Panope generosa*. M.S. Thesis. Simon Frazer University. Vancouver, B.C. 110 pp.

Gallucci, V.F., and C.B. Rawson. 1979. The population dynamics and management modeling of harvested bivalves in Garrison Bay, Washington. University of Washington Library, Seattle, Washington.

Goodwin, C.L. 1973. Effects of salinity and temperature on embryos of the geoduck clam (*Panope generosa*). Proc. Natl. Shellfish. Assoc. 63:93-95.

Goodwin, C.L. 1976. Observations of spawnings and growth of subtidal geoducks (*Panope generosa*, Gould). Proc. Nat. Shellfish. Assoc. 65:49-58.

Goodwin, C.L. 1977. The effects of season on visual and photographic assessment of subtidal geoduck clam (*Panope generosa*, Gould) populations. Veliger 20:155-158.

Goodwin, C.L. 1978. Some effects of subtidal geoduck (*Panope generosa*) harvest on a small experimental plot in Puget Sound, Washington. Wash. Dep. Fish. Prog. Rep. No. 66. 21 pp.

Goodwin, C.L., and B. Pease. 1987. The distribution of geoduck (*Panope abrupta*) size, density and quality in relation to habitat characteristics such as geographic area, water depth, sediment type, and associated flora and fauna in Puget Sound Washington. Wash. Dep. Fish. Tech. Rep. No. 102. 44 pp.

Goodwin, C.L., and W. Shaul. 1984. Age, recruitment and growth of the geoduck clam (*Panope generosa*, Gould) in Puget Sound Washington. Wash. Dep. Fish. Prog. Rep. No. 215. 30 pp.

Goodwin, C.L., W. Shaul, and C. Budd. 1979. Larval development of the geoduck clam (*Panope generosa*, Gould). Proc. Natl. Shellfish. Assoc. 69:73-76.

Goodwin, C.L., B. Pease, K. Cooper, and J. Bronson. 1985. Observations on rearing, seeding, and ecology of juvenile geoducks (Panope abrupta). Nat. Shellfish. Assoc. (Pacific Coast Section) (abstr.)

Harbo, R.M., and G.S. Jamieson. 1987. Status of invertebrate fisheries off the Pacific Coast of Canada (1985/1986). Can. Tech. Rep. Fish. Aquat. Sci. No. 1576. 158 pp.

Harbo, R.M., B. E. Adkins, P. A. Breen, and K. L. Hobbs. 1983. Age and size in market samples of geoduck clams (*Panope generosa*). Can. Manuscr. Rep. Fish. Aquat. Sci. No. 1714. 77 pp.

Harbo, R.M., C.M. Hand, and B.E. Adkins. 1986. The commercial geoduck clam fishery in British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 1873. 59 pp.

Jamison, D., R. Heggen, and J. Lukes. 1984. Underwater video in a regional benthos survey. Proc. Pacific Congress on Marine Technology. Marine Technology Society, Honolulu, Hawaii.

King, J. J. 1985. Feeding in post-larval geoducks. Natl. Shellfish. Assoc. (Pacific Coast Section) (abstr.)

Petersen, C.H., and M. Quammen. 1982. Siphon nipping: its importance to small fishes and its impact on growth of the bivalve Protothaca staminea (Conrad). J. Exp. Mar. Biol. Ecol. 63:249-258.

Shaul, W. Methods for culturing algae and rearing bivalve larvae and juveniles at the Point Whitney Shellfish Laboratory 1976-1981. Washington Department of Fisheries. Unpubl. MS.

Shaul, W., and C.L. Goodwin. 1982. Geoduck (*Panope generosa*: Bivalvia) age as determined by internal growth lines in the shell. Can. J. Fish. Aquat. Sci. 39:632-636.

Shaul, W., and C.L. Goodwin. A yield model for the Puget Sound commercial geoduck fishery. Washington Department of Fisheries. Unpubl. MS.

Sloan, N.A., and S.M.C. Robinson. 1983. Winter feeding by asteroids in a subtidal sand bed in British Columbia. Ophelia 22 (2):125-140.

Sloan, N.A., and S.M.C. Robinson. 1984. Age and gonad development in the geoduck clam *Panope abrupta* (Conrad) from southern British Columbia, Canada. J. Shellfish Res. 4 (2):131-137.

Strickland, R.M. 1983. The fertile fjord. Washington Sea Grant Publication University of Washington, Seattle. 145 pp.

Washington Department of Fisheries and Washington Department of Natural Resources. 1985. The commercial geoduck fishery: management plan and environmental impact statement. 139 pp.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(11.120)*	2.	3. Recipient's Accession No.

4. Title and Subtitle
Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)--Geoduck Clam

5. Report Date
December 1989

6.

7. Author(s)
C. Lynn Goodwin and Bruce Pease

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Point Whitney Shellfish Laboratory
Washington State Department of Fisheries
Brinnon, WA 98320

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U.S. Department of the Interior
Fish and Wildlife Service
Research and Development
National Wetlands Research Center
Washington, DC 20240

U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180

13. Type of Report & Period Covered

14.

15. Supplementary Notes
U.S. Army Corps of Engineers Report No. TR EL-82-4

16. Abstract (Limit: 200 words)

The geoduck clam (*Panope abrupta* Conrad) is one of the largest burrowing clams in the world and ranges along the west coast of North American from Alaska to Baja California and along coastal Japan. It lives at depths extending from the lower intertidal zone to 110 m and is very abundant in Puget Sound, Washington, and British Columbia, where it supports important commercial fisheries. Geoduck clams are commercially fished by divers, who wash them from the substrate with hand-operated water jets. Significant portions of the catch are exported to Japan. Geoduck clams are long-lived, reaching ages of at least 146 years. Growth is rapid, but recruitment rates are low. Because of their high value, large size, and rapid early growth but low recruitment rates, they are being artificially stocked in Washington waters.

17. Document Analysis a. Descriptors

Taxonomy	Spawning cycle	Predators
Range	Fisheries	Environmental requirements
Morphology	Population dynamics	Pollution
Life stages	Growth rate	Food habits

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release Unlimited	Unlcassified	14
	20. Security Class (This Page)	22. Price
	Unclassified	

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

TAKE PRIDE *in America*

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
National Wetlands Research Center
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458