WASHU-H-82-001 C2

TECHNICAL REPORT

A GUIDE TO MANILA CLAM AQUACULTURE IN PUGET SOUND

Gregory J. Anderson
Mark B. Miller
Kenneth K. Chew

A GUIDE TO MANILA CLAM AQUACULTURE IN PUGET SOUND

Gregory J. Anderson
Mark B. Miller
Kenneth K. Chew

Washington Sea Grant Program
College of Ocean and Fishery Sciences
University of Washington HG-30
Seattle, Washington

Acknowledgments

The authors wish to thank Charles D. Magoon, of the Washington Department of Natural Resources, Lynn Goodwin, of the Washington Department of Fisheries, and Chris R. Jones, formerly with Washington Department of Fisheries, and Barry Wenger-DuVaux, for advice, assistance, and support which was valuable in completing this research. We are indebted to the following beach owners for use of their tidelands: Thomas Beveridge, Carl H. Johnson, Bill Nelson, James Penfield, and Bill Webb of Webb Camp Sea Farms. For other study sites, we thank personnel at the National Marine Fisheries Service Laboratory on Clam Bay and Leonard Benston and other personnel of Kopachuck State Park. Our deepest gratitude is owed to the numerous students, Department of Natural Resources and Department of Fisheries employees, and others who performed strenuous work in the field and tedious work in the laboratory. We appreciatively acknowledge Ryan Instrument Company for use of its temperature recording equipment, Chet Belknap of Pacific Mariculture, Inc. for his helpfulness in supplying clam seed, and Nick Budnick of Consolidated Net and Twine Company for supplying plastic nettings and useful suggestions. Pete Becker, James Penfield, Dick Steéle, Justin Taylor, and Bill Webb are credited with providing funding for certain portions of these studies. Finally, the authors wish to thank James Bray, Neil Bourne, Lynn Goodwin, Charles D. Magoon, Terry Nosho, Justin Taylor, and others for reading the manuscript and providing many useful criticisms which have helped to improve it.

About the Authors

Gregory J. Anderson received a Master of Science in Fisheries, with a specialty in shellfish aquaculture, July 1982, from the University of Washington. Mark B. Miller received a Ph.D. in Fisheries, with a specialty in shellfish aquaculture and management, March 1982, University of Washington. Kenneth K. Chew is Professor of Fisheries and Chairman, Division of Aquaculture and Invertebrate Fisheries, School of Fisheries, College of Ocean and Fisheries Sciences, University of Washington.

Key Words

1. Clams, Manila 2. Clams, planting methods 3. Clams, survival factors 4. Aquaculture

Support for publication of this report was provided in part by grant number NA81AA-D-00030, project A/PC-5, from the National Oceanic and Atmospheric Administration to the Washington Sea Grant Program.

WSG 82-4
$3.50 out of print

Washington Sea Grant Program
College of Ocean and Fishery Sciences
University of Washington HG-30
Seattle, Washington 98195

July 1982

Contents

Preface

In a previous publication (WSG 78-2), based largely on research conducted in Puget Sound by the School of Fisheries, the Manila clam was proposed as a candidate for use in marine aquaculture and guidelines for planting hatchery-spawned clams were outlined. This report updates the initial publication with recent findings and addresses questions frequently asked of the authors by commercial clam growers and owners of small beach properties. The commercial clam growers of the State of Washington, the Washington Department of Fisheries and the Washington Department of Natural Resources cooperated with the School of Fisheries in certain aspects of this work, providing considerable assistance in studies conducted at various locations in Puget Sound. Field study sites and facilities used in this research were furnished by the Washington Department of Parks and Recreation, the Washington Department of Natural Resources, the National Marine Fisheries Service of the United States Department of Commerce, and private beach owners.

Origin, Fisheries, and Attributes Of the Manila Clam

Even though the Manila clam is not endemic to Northwest waters--having been introduced via shipments of Pacific oyster seed from Japan in the 1930s and 1940s (Quayle 1938, 1941, 1964)--its selection for use in aquaculture is well founded. Except for the geoduck, it is the most important commercial clam in Washington. Reported Manila clam landings--clams harvested entirely by manual digging from intertidal areas--have averaged over 850,000 pounds annually during the past 10 years (Washington Department of Fisheries data). Supply is short of demand and the market could probably support twice the present production (Chris Jones, personal communication). According to Glude (1974), the market for clam products in the United States, and particularly in the Pacific Northwest, is increasing each year. The Manila clam is also very popular with sportsmen in Washington. However, on most public beaches it is not abundant due to excessive harvesting and damage to juveniles (Al Scholz, personal communication). Thus, a means to enhance Washington's Manila clam resource would be beneficial.

The Manila clam also has several attributes which make it an excellent species for intertidal aquaculture. It usually survives and grows well at a higher tide level than other utilized clam species in Puget Sound and thus may be less subject to competition for food and space. It also occurs at a relatively shallow depth within the substrate which makes it easy to dig; but because of this it may also be more vulnerable than other commercial species to extreme temperatures and predation. Finally, it bears up well under harvesting and handling, and has an adequate shelf life.

The Manila is the only clam species produced regularly by Pacific Coast shellfish hatcheries. Most of the seed produced has been exported as food for cultured shrimp (Chet Belknap, personal communication). In any case, consistent large-scale production attests to the Manila's adaptability to the hatchery environment. Characteristics rendering it suitable for hatchery rearing are that it can be spawned easily from spring to fall, has a short planktonic larval period of about 3 weeks,

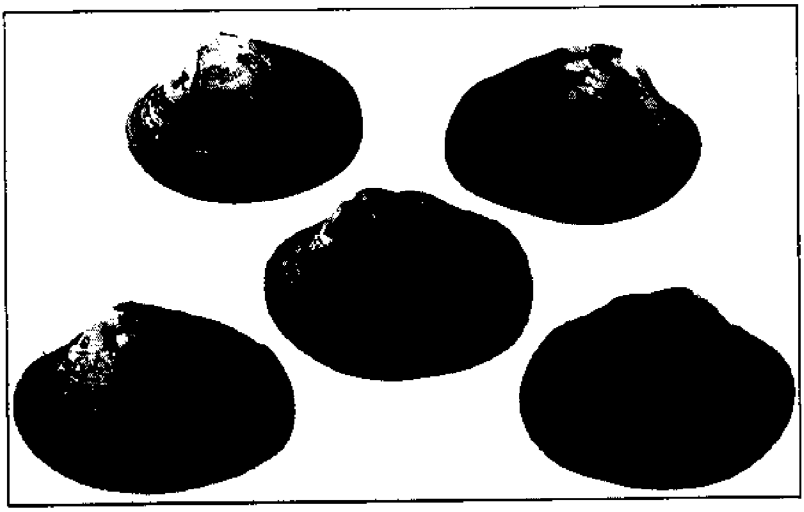


Figure 1
Manila clams
Tapes japonica

and is apparently not as susceptible to disease or stress problems which beset larvae of other clam species in hatchery culture. Another desirable feature is that growth is relatively fast; Manilas are often harvestable at 2 to 3 years of age.

Small seed of the Manila, or Japanese littleneck clam, *Tapes* or *Venerupis japonica* (Figure 1) produced in commercial hatcheries, has been planted and raised on various Puget Sound beaches by School of Fisheries researchers since 1972. This has been done to determine the potential of planting seed to supplement declining intertidal clam stocks and for use in clam mariculture. This report is intended as a reference and guide to the culture of the Manila clam. It deals primarily with recovery and growth of planted clams, planting and culturing procedures, and the practicality and economic feasibility of providing large-scale protection for planted clams. While most applicable to the Pacific Northwest, the information presented may also be useful in other areas and with other species of clams.

A principal advantage in using hatchery seed, as opposed to collection of natural seed, is consistency of availability. Supplies of natural Manila seed vary from year to year in Puget Sound and since the most productive beaches are under lease or in private ownership, collection of natural seed for beach stocking may not be feasible. Considerable time and effort may also be required to collect large numbers of natural seed. Another advantage of hatchery seed is uniformity of size. This simplifies management by allowing production of very uniform crops on a regular basis.

The cost of hatchery-reared clam seed, however, poses constraints on enhancement ventures. A fairly high return in terms of survival or recovery of clams at harvest is necessary to realize a profit for a commercial grower or to provide justification for recreational clam population enhancement by management agencies. However, achieving a profit margin is probably not an important consideration for private beach owners interested in small-scale clam culture for personal use.

The profitability of culturing Manila clams is very sensitive to the cost of the seed because the clam is rather small (15-25/lb) when marketed. Thus, more spat are needed to produce a ton of clams than would be required to produce a ton of the much larger Pacific oyster (Walne *in* Lucas 1976). The maintenance of high densities of planted clams for commercial production (probably greater than 256-340/yd^2 or 300-400/m^2) requires virtually without exception that the clams be protected from hazards found in their environment. After several years of experimentation, the most practical and least expensive method found for protecting seed clams was to cover planted beaches with a lightweight DuPont Vexar™ plastic netting called "Car Cover." This appears to be a suitable means for raising planted Manila clams on a large scale.

Factors Influencing Survival and Growth In Aquaculture

Experimental intertidal plantings of Manila clams have been conducted and monitored by the School of Fisheries during the past 7 years at eight Puget Sound locations (Figure 2) (*see* also Miller 1982). Several preliminary short-term School of Fisheries planting studies were also conducted at other sites--Burley Lagoon in Carr Inlet, Kilisut Harbor on Marrowstone Island, Totten Inlet, and Point Whitney on Hood Canal (Jones 1974). Most plantings were performed in the spring, although several were carried out in the fall to judge the influence of planting time on subsequent recoveries. At each location, except Clam Bay, recovery and growth were compared for groups of clams planted with and without protection. Protective devices affixed to the beach within planted areas included small wire-screen cages, short fences of screening material, and layers of different types of plastic netting. The more recent studies dealt exclusively with the latter type of protection, and in two cases-- Wescott Bay and Filucy Bay--large 300 to 360 yd^2 (250 to 300 m^2) areas of planted beach were covered by plastic netting. These studies were conducted to demonstrate the feasibility of using plastic netting to protect planted clams on a pilot or semi-commercial scale.

In a number of studies, recovery and growth of planted clams were analyzed with respect to tide level planted, beach sediment type, beach slope, substrate, temperature, salinity, seed size, and planting density. In most instances, clam seed planted were relatively small (1/8 to 1/6 inch or 3 to 4 mm in length), being of the size most readily available from commercial hatcheries. Some larger seed were also planted. Efforts were also made to document and to some degree quantify dispersal--displacement and transport--of seed clams during the first several months after planting. Finally, to evaluate the impact of predation on Manila clams, gut content analysis was performed on suspected clam predators collected by hand at low tide and by means of beach seine sampling at Kopachuck State Park and Marrowstone Island. Field and laboratory observations also contributed knowledge concerning predation.

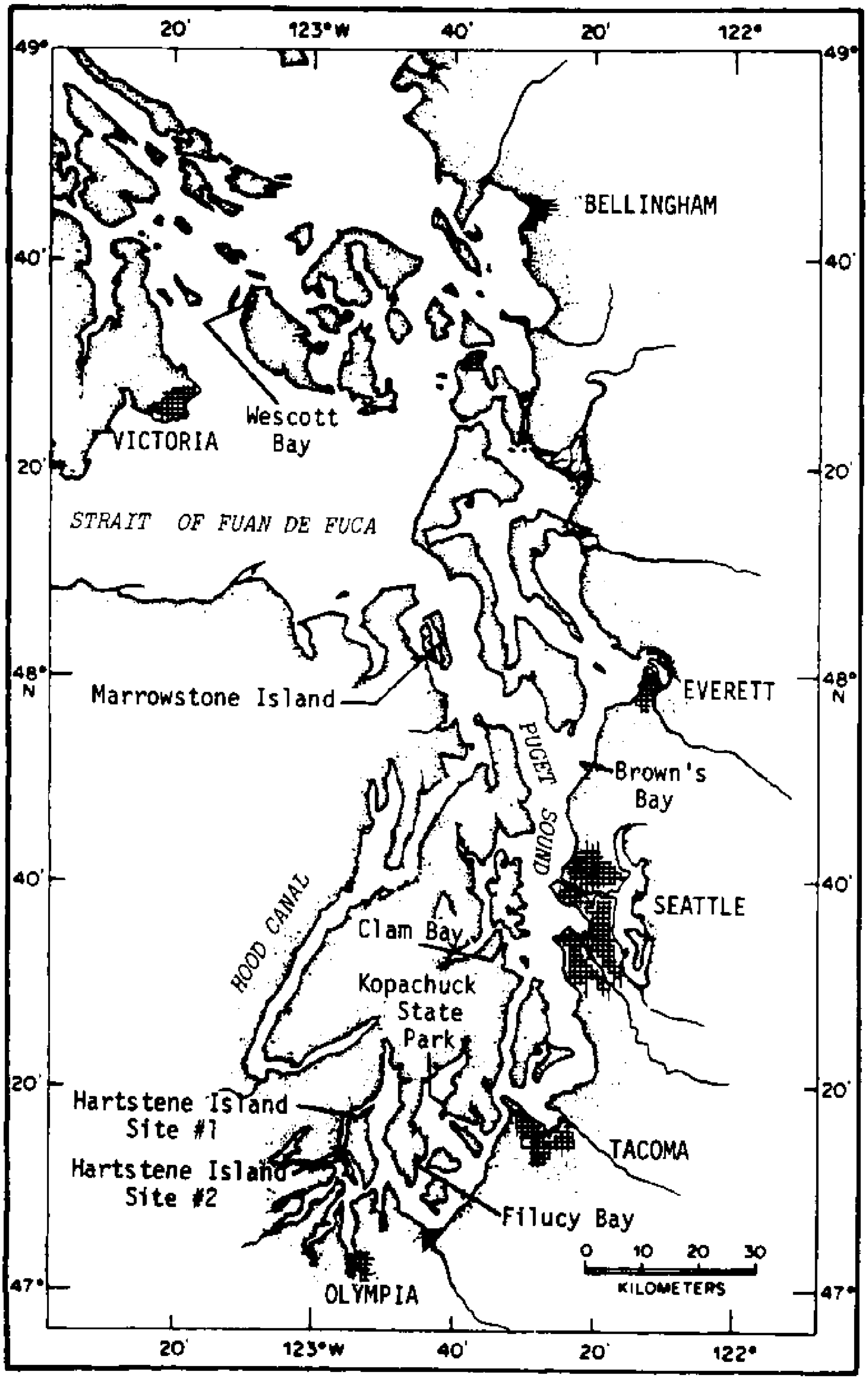


Figure 2. Map of Puget Sound region showing study locations.

Geographic Location

Manila clam stocks of Puget Sound are most abundant in the various bays and inlets of the south. It was in this area, where most oyster culture takes place, that the Manila clam was accidentally introduced with imported Japanese oyster seed earlier this century. Since the Manila clam remains concentrated in south Sound while occurring only sparsely elsewhere, factors such as sediment conditions and wave exposure apparently prevent large-scale colonization of other areas. This suggests that south Puget Sound may be a superior location for Manila clam aquaculture.

By comparing results of planting studies conducted throughout Puget Sound, it was determined that Manila clams could be cultured in many areas (although artificial protection was usually required and, in one instance, it was necessary to modify the natural substrate). Overall, however, clam growth is very dependent upon planting location (Table 1). The highest growth rates are attained in the lowest reaches of Puget Sound. Since minimum size for commercial harvest of the Manila clam is about 1 1/2 inches or slightly less (about 35 to 38 mm), the majority of clams planted in south Sound on Hartstene Island were harvestable 18 months after a springtime planting (the end of the second growing season). By the end of the third growing season, all clams had reached harvestable size.

Table 1. Typical shell length attained by small (1/8 to 1/4 inch or 3 to 5 mm) planted Manila clams at Puget Sound study sites after each of several growing seasons.

Study site	Growing Season				
	1	2	3	4	5
Clam Bay	9/16 in (14mm)	1 in (26mm)	1 3/8 in (34mm)		
Filucy Bay	11/16 in (18mm)	1 1/8 in (28mm)			
Hartstene Island #1	11/16 in (18mm)	1 1/2 in (38mm)	1 7/8 in (47mm)	2 in (51mm)	2 1/16 in (53mm)
Hartstene Island #2	1 in (25mm)	1 5/8 in (41mm)			
Kopachuck State Park	3/4 in (19mm)	1 1/4 in (32mm)			
Marrowstone Island	1/2 in (12mm)	7/8 in (23mm)	1 3/16 in (30mm)		
Wescott Bay	11/16 in (18mm)	1 1/8 in (29mm)			

Favorable water temperature and phytoplankton productivity of south Sound may be related to the superior growth observed there. Typical summer water temperature of Miyagi Prefecture, Japan, the origin of Puget Sound Manila stock, is about 69.8°F (21°C) (Kasahara and Ito 1953). Of the study locations under consideration, maximum summer water temperature in the Hartstene Island vicinity (65.1°F or 18.4°C) most nearly approaches that value (Washington Marine Atlas 1974).

According to Winter et al. (1975), annual phytoplankton production is greater in the central basin of Puget Sound (465 g-C/m^2/yr) than in south Puget Sound (270-290 g-C/m^2/yr) based on measurements from a limited number of stations. However, in the central basin, this algal growth occurs in a series of intense blooms beginning in late April or May and continuing through the summer, while in south Sound, phytoplankton production is fairly uniform from March through September. Thus, although total phytoplankton productivity in south Puget Sound may be lower, the consistent availability of such a food supply may be cause for enhanced growth.

Growth rate is an important consideration when selecting a site for commercial production of clams. Faster growth results in a higher and more rapid investment return with less risk of loss. South Puget Sound appears to be the most desirable location from this standpoint. However, other areas also may be suitable for commercial culture and certainly would be acceptable for personal use culture.

Recent outbreaks of PSP (paralytic shellfish poison), which have occurred in the central and northern parts of the Sound, may pose problems for clam culture. Clams themselves are not harmed by ingesting the toxic red tide microorganisms (*Gonyaulax catenella*, a dinoflagellate phytoplankter). However, during an episode, harvesting must be prohibited until levels of toxin concentrated in clam tissue again become safe for human consumption. The maximum legal level for shellfish harvest is 80 micrograms toxin per 100 grams of wet meats. Updated information concerning PSP may be obtained by dialing the toll-free Washington State "red tide hotline" number, 1-800-562-5632.

Planting Season

Spring (April or May) appears to be the optimal time for planting seed. Comparative studies conducted at Kopachuck State Park and Marrowstone Island indicated that clams planted in fall do not subsequently outperform clams planted the following spring. "Hardening" or overwintering clam seed on the beach before growth commences in the spring, as is commonly done with oyster seed, is not advantageous. Further, if planted in the fall, many seed may be lost to storms, low temperatures, and possibly to predators before even starting to grow. A spring planting affords clam seed the greatest opportunity to reach a larger size--which may constitute a refuge from some predators and wave scour--while being exposed to the fewest environmental hazards. However, some hazards are always present and can never be avoided by planting at a particular time.

Protection

Recoveries of Manila clams (planting size 1/8 to 1/6 inch or 3 to 4 mm) protected by 1/4 inch (6 mm) or 1/2 inch (13 mm) mesh plastic netting are usually significantly higher than recoveries of unprotected clams (Table 2) except if beach sediment is unsuitable (e.g., Marrowstone Island) or exposure to wave activity is great (e.g., Brown's

Bay). Wire-screen cages used to protect clams are also effective for significantly enhancing recoveries. However, due to expense, limited lifespan, and small size, cages are not practical for use in clam aquaculture. Although not investigated in great detail, short fences (approximately 6 inches high) constructed around planted areas to protect clams provide no benefits.

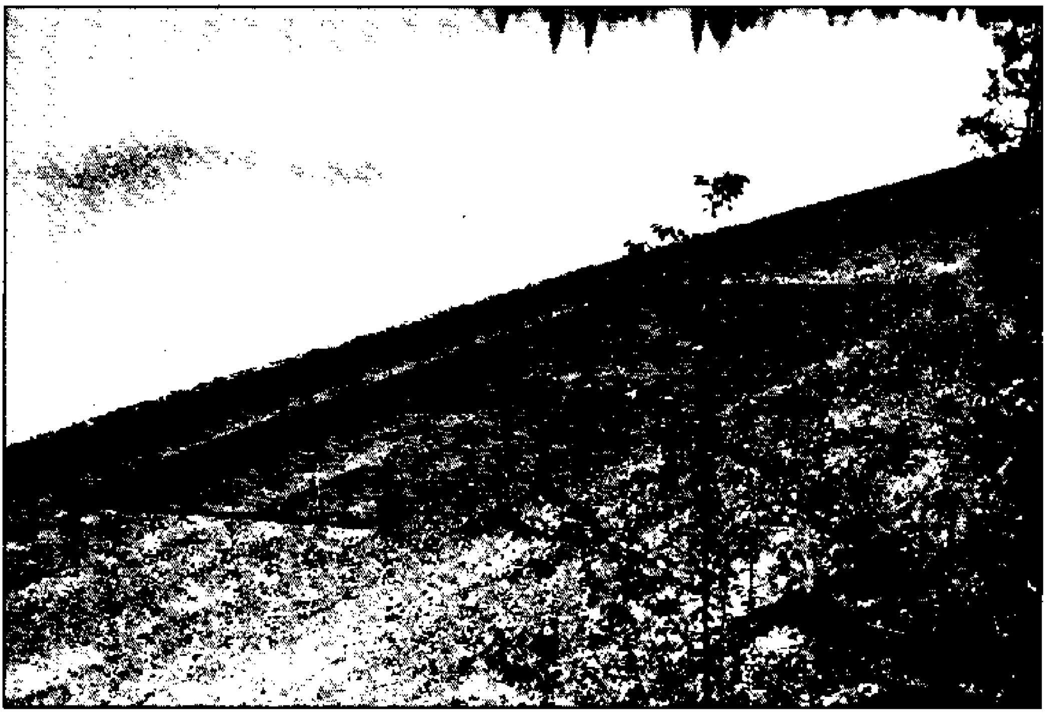
Covering small planted clams with screen of moderately small mesh size is important for attaining a high return. Recoveries of clams protected by materials with mesh size 1 inch (25 mm) or greater are comparable to those of unprotected clams. Conversely, mesh size of protective netting should be no less than 1/4 inch (6 mm) because smaller sizes tend to trap fine sediment and become clogged and are also more easily plugged by algal growth. Since some fouling is likely even with 1/4 inch (6 mm) materials, 1/2 inch (13 mm) mesh netting seems to be the most practical choice.

Of the types of DuPont Vexar™ plastic netting tested (different brands, which should also be suitable, were not compared), the one found most suitable for clam culture was a lightweight, 1/2-inch (13-mm)

Table 2. Typical percentage recoveries of small planted Manila clams from protected and unprotected plots at Puget Sound sites after each of several growing seasons.

Study site	Treatment	Growing season 1	2	3
Brown's Bay	unprotected	0	-	-
	protected	0	-	-
Clam Bay	unprotected	41	23	19
	protected	Not tested		
Filucy Bay	unprotected	2	1	-
	protected	60	57	-
Hartstene Island #1	unprotected	10	2	-
	protected	66	42	35
Hartstene Island #2	unprotected	0	0	-
	protected	60	45	-
Kopachuck State Park	unprotected	14	6	-
	protected	62	-	-
Marrowstone Island	unprotected	8	4	2
	protected	8	5	-
	modified substrate	48	-	-
Wescott Bay	unprotected	13	10	-
	protected	33	30	-

Figure 3 Culture plot protected by Vexar™ "Car Cover" netting.



mesh netting called "Car Cover" (Figure 3). This netting, even though used in double layers to insure durability, is much less expensive and far easier to handle than single layers of heavier materials. "Car Cover" and heavier netting of similar mesh size have similar protective qualities, provided that plots are properly maintained. Also, growth of clams covered by plastic netting is not diminished, except when severe fouling occurs.

Although recoveries of planted clams can be greatly enhanced when protected by plastic netting, plots must be maintained to prevent invasion by clam predators. Predatory fish and crabs will rapidly gain entry once the netting is damaged. Even though covered by netting, small clams may still be washed away by waves or currents. Thus, care must be taken in selecting a planting site and netting of appropriate mesh size. Growing small hatchery seed to a larger size in some type of containment system prior to planting should also be considered. Large seed for planting can sometimes be obtained from hatcheries, but generally at a price too high for culture to be profitable.

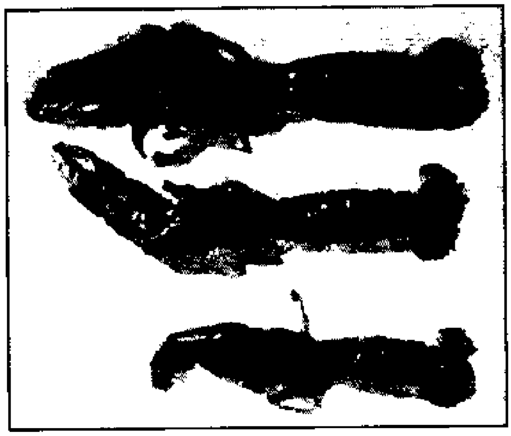
Tide Level

Manila clams usually occur from about +3 to +6 feet (+1 to +2 meters) above mean lower low water (MLLW), depending upon the tidal range of a given location. Local sediment conditions and other factors will also influence the tidal elevation inhabited by the clams. Manilas were planted and grown from +1 to +7 feet (+0.3 to +2.3 meters) above MLLW in the Puget Sound studies, but usually did poorly at the extremes of this range.

Use of plastic netting to protect planted clams may permit culture to take place over a wider tidal range than would otherwise be feasible. However, physiological and ecological limitations are imposed by tidal height--even though beach sediment and other variables appear

Figure 4 The moon snail, *Polinices lewisi*, and remains of its prey.

Figure 5 Ghost shrimp, *Callianasa* spp.



suitable over a very broad range. Although growth of the Manila clam is often uniform over a fairly wide tidal range, an upper limit usually exists at about +6 or +7 feet (+2 meters) above MLLW where growth rate declines considerably. Often, when observed on a low tide, beach sediment appears very dry above this level.

The lower range of the planted area may be restricted by unsuitable habitat (silt, hard clay, etc.), or the presence of various predators. Since removal of predators such as the moon snail, *Polinices lewisi* (Figure 4), is very difficult, the best way to minimize predation is to plant clams at a tide level above the zone where moon snails are active (i.e., plant no lower than +2 to +4 feet--or +0.6 to +1.3 meters--above MLLW, depending upon the beach).

To choose the most appropriate planting zone on a given beach, however, some trial and error may be necessary. Presence of natural Manila clams on a beach may aid in finding an area to plant. (Methods for determining tide level are outlined in Appendix A).

Sediment Type

An ideal substrate for Manila clams consists of gravel (of which much is less than one inch or 25 mm in diameter), sand, a small amount (4-5%) of mud, and shell. Such a substrate is inherently stable--a factor even more important than precise sediment composition--owing to cohesive or "glue-like" properties of the mud (silt or clay). Beaches of this type are usually found in relatively protected bays or inlets. The best recoveries of unprotected planted clams in Puget Sound (15 to 30% after 2 or 3 years at certain tide levels) were from such beaches as Kopachuck State Park and Clam Bay.

However, when plastic netting is secured to the substrate surface to cover planted clams, beaches which would not otherwise be suitable may be turned into productive clam beds. Such beaches are located on Hartstene Island and Filucy Bay, and, as reported by Glock and Chew (1979), on the west side of Squaxin Island. Beaches at these locations are primarily composed of a rather uncohesive mixture of sand and fine or "pea" gravel. Ghost and mud shrimp, *Callianasa* spp. (Figure 5) and *Upogebia pugettensis*, are abundant in such beaches and their burrowing and feeding activities apparently contribute to sediment instability. Beaches of this type, which are usually unproductive in nature, are

Figure 6
Native littleneck clams, *Protothaca staminea*

very common--particularly in south Puget Sound--and represent potential culture sites.

Unsuitable beaches, however, are also common. Tightly packed large cobble and "hardpan," which are very difficult to till, prevent burrowing by Manila clams. Beds of loose gravel or "clean" sand may be so unstable that currents and waves can cause substantial sediment shifting even when covered by plastic netting. Very soft sediments, particularly "soupy" mud or mud-sand combinations, are very poor habitats.

A 2- to 3-inch thick surface layer of mud situated below the +4 foot (+1.3 m) tide level on the study beach at Marrowstone Island was determined to be responsible for poor recovery and growth of planted Manila clams at that site--even though a thriving natural population of the closely related native little neck clam, *Protothaca staminea* (Figure 6), was present. The Manila clam may have difficulty maintaining position and keeping its filter-feeding apparatus unclogged in such sediments (Kurashige 1942; Loosanoff 1961; Bardach et al. 1972). However, Manilas were raised with success at Marrowstone Island when planted in plots to which gravel was added. Thus, in certain cases, modification of the natural substrate may be the only means to grow clams on a beach. However, this procedure is probably only practical for very limited-scale culture.

Beach Slope

Beach slope or gradient does not appear to be strongly associated with recovery or growth of planted clams. Other overriding factors, particularly beach sediment type and exposure to wave or current action, seem to be much more important. When Manila clams are planted without protection, recoveries tend to decline faster on steeper beaches (slope = 10 to 1 or greater) than on more gradually sloping beaches (slope = 20 to 1 or less). However, steep beaches in Puget Sound are often composed of relatively uncohesive sand-fine gravel sediment, while more gently sloping beaches commonly consist of a more compact mix of larger gravel, sand, mud, and shell. More severe erosive forces seem to be at work on steeper beaches. In any case, when planted clams are protected by plastic netting, any influence of beach slope is reduced significantly.

Water and Substrate Temperature

Puget Sound water temperatures seem to be appropriate for Manila clams since the clams occur throughout Puget Sound. However, maximum summer temperatures (65.1°F or 18.4°C) of Puget Sound are usually lower than the 73.4° to 75.2°F (23° to 24°C) reported by Bardach et al. (1972) to produce the best growth in Manila Clams. Thus, the warmer waters of south Sound are probably most suitable.

Although fluctuations of water temperature in Puget Sound are not great enough to harm Manila clams, extreme substrate temperatures--which occur at night during winter and in afternoon during summer--are potentially lethal. Substrate temperatures were monitored for several years at Kopachuck State Park and Marrowstone Island by means of continuously recording Ryan thermographs placed beneath the sediment surface in planted areas. However, little evidence of temperature-related mortalities was found. Further, it has been demonstrated that certain hard-shell clams can tolerate subfreezing temperatures for extended periods. Williams (1970) proved that the east coast "quahog" can tolerate exposure to 21°F (-6°C) for at least 24 hr; the Manila clam may be equally resilient. In any case, little can be done to circumvent adverse effects of extreme temperatures except perhaps to avoid planting excessively high in the intertidal zone.

Salinity

Salinity apparently has no negative impact on Manila clams planted in Puget Sound. Where monitoring has been conducted readings are well within the known tolerance limits of the Manila clam. Historical records (Washington Marine Atlas 1974) also attest to the suitability of Puget Sound salinity for the Manila clam.

Monthly salinity measurements taken at Kopachuck State Park and Marrowstone Island respectively averaged 30.3 ppt (28.8 to 31.5 ppt) and 31.5 ppt (29.3 to 31.7 ppt). Bardach et al. (1972) reported that the optimum salinity range for Manila clam growth is 24 to 32 ppt. According to Higgens (1969), Manila clams can tolerate salinities at least as high as 35 ppt and as low as 13.5 ppt for periods of 40 days or more.

Seed and Size at Planting

Unless covered by protective netting, use of large seed clams (at least two or three times the usual 1/8 to 1/16 inch, or 3 to 4 mm length usually available from hatcheries) does not necessarily result in better recoveries. In unprotected plantings conducted at Hartstene and Marrowstone Islands, Kopachuck State Park, and Filucy Bay, subsequent recoveries of large seed clams were not significantly higher than those attained with smaller seed.

However, there appears to be an advantage in planting large seed beneath plastic netting, especially when they are too large to be scoured through netting mesh by wave action. Thus, in certain locations, use of large seed may be essential in attaining an acceptable recovery of clams from netting plots. To illustrate the significance of size, results of Hartstene Island studies in which three size groups of seed were planted with and without protection are presented in Table 3.

Table 3. Recovery of three size groups of Manila clams planted at Hartstene Island with and without plastic netting.

	Seed size planted	Recovery after 6 months
Unprotected groups	1/8 to 1/6 inch (3 to 4 mm)	11.4%
	3/8 to 1/2 inch (10 to 12 mm)	1.0%
	13/16 inch (21 mm)	2.5%
Protected groups	1/8 to 1/6 inch (3 to 4 mm)	49.2%
	3/8 to 1/2 inch (10 to 12 mm)	46.0%
	13/16 inch (21 mm)	85.9%

Stocking Density

Clam seed were planted at a variety of densities, ranging from about 19 seed/ft^2 (200 seed/m^2) to 158/ft^2 (1700 seed/m^2), in various studies conducted in Puget Sound. When planted clams were protected with netting it was demonstrated that a higher planting density results in a relatively higher return of harvestable clams--provided that external forces, such as wave scour, are not too great. Percentage recovery is nearly always inversely proportional to planting density (i.e., higher planting densities yield lower survival) when no protection is provided. Therefore, when raising clams without protection, very few seed should be planted per unit area (e.g., 200/m^2).

Planting densities of clams covered by plactic netting may vary depending upon the purpose of the culture operation, but probably should not be much higher than 93 seed/ft^2 (1000 seed/m^2) with small (1/8 inch or 3 mm) seed and only 56-65/ft^2 (600-700/m^2) when large (10 mm) seed are used. This is important when recovery is high, since competition for food and space may retard growth of clams. However, some trial and error might be necessary at a given location when determining commercial planting densities and when planting large seed clams.

Movement (Dispersal)

Movement (dispersal or displacement) of small Manila clams in the first few weeks or months after planting is a common occurrence. Dispersal has been confirmed when tagged (stained or painted) planted clams were found in samples taken outside but close to experimental planted areas. Unprotected clams commonly became concentrated in nearby cages or netting plots. Wave and/or current activity was apparently responsible for dispersal, based on observations and experiments designed to detect movement direction.

Considerable dispersal occurs at sites which differ significantly in sediment type, current speed, and exposure to wind-driven waves. In particular instances, such as at Brown's Bay, waves may scour all clams from unprotected and protected planted areas shortly after planting. In less exposed areas, more subtle forces are apparently still sufficient to displace clam seed. However, scour from boat wakes may be of considerable importance in seemingly sheltered areas, especially at the critical time just after planting.

While current action at a site is relatively constant from year to year, wave activity may vary considerably. Therefore, it may be difficult to achieve consistent results even with use of netting to circumvent potential losses. It may be possible to erect a baffle system to reduce wave impact (see Kraeuter and Castagna 1977), however, such devices may accelerate siltation and pose a hazard to navigation. Use of smaller-mesh (1/4 inch or 6 mm mesh) netting during the first few weeks or months after planting may help in preventing seed washout, providing that sediment fouling is not greatly increased. However, selection of the best possible location and the use of advanced-size seed clams appear to be the best hedges against dispersal-related losses.

Conversely, high numbers of small, wild Manila clams may be concentrated within netting plots, as was determined in experiments at Kopachuck State Park. In those studies, washout of planted clams was not more than about 20 to 40% of the numbers planted. Further, survival of recently settled Manila clam spat may be greatly improved by covering the beach with plastic netting. Thus, in some instances, natural seed dispersal may be beneficial. Although not documented, netting-covered areas may also encourage settlement of clam larvae by causing small eddies just above the beach surface, perhaps creating a more desirable environment for the larvae.

Predation

Manila clams may fall prey to a wide variety of predators, whose activity and relative importance vary depending on location and season. Although at times predation may actually be observed, it is most often detected by means of indirect evidence (i.e., damaged empty shells). While a covering of plastic netting effectively protects planted clams from most predators, certain problems may still occur. Since several predators consume large-sized clams, protective netting must be maintained from planting until harvest time.

Perhaps the predator most difficult to control is the moon snail, *Polinices lewisi* (Figure. 4). Since this gastropod is usually hidden within the beach sediment, removal of all snails is not practical. Although erection of a netting barrier (sunk 12 inches into the substrate and projecting above for several inches) may prevent snails from moving into a planted area, the simplest means of avoidance is by situating the culture plots at a tide level (above +2 to +4 ft above MLLW depending on the beach) where moon snails are not active.

The moon snail usually destroys clams by drilling a countersunk hole in the "umbonal" or beak region of the clam's shell. Through this opening the snail inserts its proboscis (feeding organ) to consume the soft tissues. Most intertidal moon snail predation is performed by individuals from 1 to 4 inches (25 to 100 mm) in shell diameter on relatively large clams. However, moon snails as small as 1/4 inch (6 mm) may prey upon Manila clams as small as 1/8 inch (3 mm), as observed on Hartstene Island.

Certain crabs may be very serious predators of the Manila clam. The most important species appears to be the red rock or black-clawed crab, *Cancer productus* (Figure 7). A close, but slightly smaller relative, the graceful crab, *C. gracilis* (Figure 8), is apparently a less serious threat. Little evidence of clam predation has been detected on examination of crab stomach contents, at least in part because crabs effectively separate shell from consumed tissue. However, broken and chipped empty Manila shells commonly observed intertidally are suggestive of crab predation.

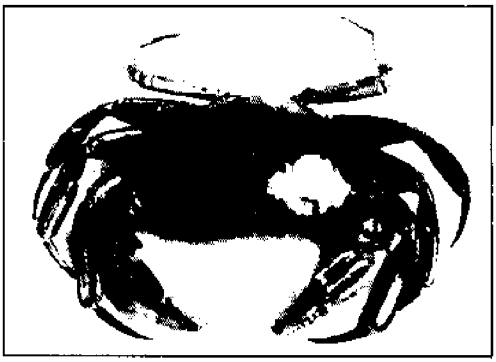
Figure 7 (Left)
Red rock crab, *Cancer productus*

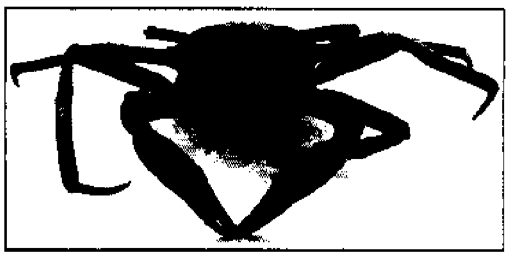
Figure 8 (Middle left)
Graceful crab, *Cancer gracilis*

Figure 9 (Top right)
Dungeness crab, *Cancer magister*

Figure 10 (Bottom left)
Shore crabs, *Hemigrapsus spp.*

Figure 11 (Bottom right)
Kelp crab, *Pugettia producta*





On several occasions many red rock crabs (carapace width of about 2 3/8 to 5 inches or 60 to 125 mm) and a few graceful crabs (carapace width of 2 to 4 inches or about 50 to 100 mm) were found beneath experimental netting plots along with many broken 1 to 2 inch (25 to 50 mm) clam shells. Crabs had entered the netting plots through loose seams or damaged sections. In one experimental plot decline in recovery from $48/ft^2$ ($500/m^2$) to $14/ft^2$ ($150/m^2$) was apparently related to crab predation over a short period. Laboratory tests have confirmed field observations of crab predation as both crab species opened and consumed Manila clams. Based on these observations the red rock crab alone is probably responsible for predation on clams larger than about 1 1/4 inches (30 mm).

Although not encountered at the study beaches, the Dungeness crab, *Cancer magister* (Figure 9), common in the more central and northern areas of Puget Sound, may be a potential predator of the Manila clam. Literature reports indicate that bivalves are among its preferred food items (Gotshall 1977). Small purple and green shore crabs, *Hemigrapsus nudis* and *H. oregonensis* (Figure 10), have been found to consume Manila seed clams in the laboratory (Bourne and Lee 1973), but such predation was not confirmed in Puget Sound. Finally, a common kelp crab, *Pugettia producta* (Figure 11), was suspected of predation on Manila clams on Vashon Island, based on observations by John Landahl (personal communication).

Unprotected Manila clams may be eaten by particular bottom fish. Rock sole (*Lepidopsetta bilineata*), English sole (*Parophrys vetulus*), starry flounder (*Platichthys stellatus*), and pile perch (*Rhachochilis vacca*), which are shown in Figures 12 through 15, all prey upon small Manila clams as demonstrated by studies conducted at Kopachuck State Park. At Marrowstone Island, where sampling was also conducted, Manila clams were not found in the stomachs of any fish, although native littleneck clams were on occasion eaten by pile perch and starry flounder. A summary of Kopachuck fish predation is provided in Table 4.

Table 4. Fish predation at Kopachuck State Park. Low tide samples taken at monthly intervals, June 1976 to December 1977. High tide samples taken during June 1976, and at monthly intervals, June to September 1977.

	Rock sole	English sole	Starry flounder	Pile perch
SAMPLES TAKEN AT LOW TIDE				
Number of fish examined	460	110	58	36
Number which had eaten	443	105	54	34
Percentage which had eaten Manila clams	11.7	10.5	31.5	23.5
Average number Manilas/fish	0.26	0.37	3.94	0.38
SAMPLES TAKEN AT HIGH TIDE				
Number of fish examined	80	16	6	53
Number which had eaten	77	13	6	42
Percentage which had eaten Manila clams	25.3	7.7	40.0	63.4
Average number Manilas/fish	0.80	0.08	6.60	2.73
Overall size range of clams consumed	1/16-11/16" (1-17mm)	1/16-1/2" (1-12mm)	1/8-1/2" (3-13mm)	3/10-13/16" (5-20mm)

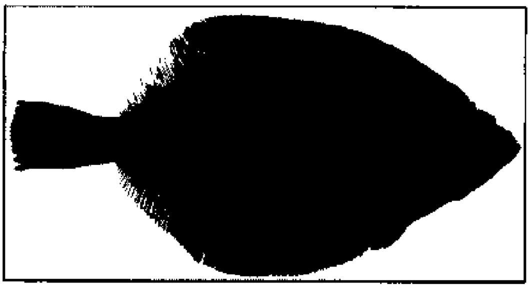


Figure 12 Rock sole,
Lepidopsetta bilineata

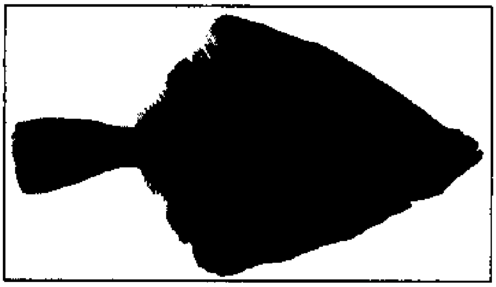


Figure 14 Starry flounder,
Platichthys stellatus

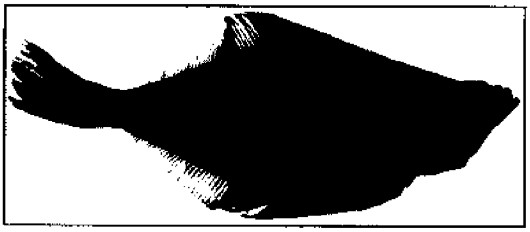


Figure 13 English sole,
Parophrys vetulus

Figure 15 Pile perch,
Rhachochilis vacca

Most predation on Manila clams was done by adult, or at least relatively large fish. Size ranges (shell lengths) of clams eaten by each fish species at Kopachuck were relatively small ($\leq$ 3/4 inch or 20 mm) suggesting that large size may constitute a refuge from fish predation. In many areas planted clams may grow large enough to escape this type of predation by the end of their first growing season.

Three species of duck, the white-winged scoter (*Melanitta delgandi*), surf scoter (*M. perspicillata*), and American scoter (*Oidemia americana*),--shown in Figure 16--which winter in high numbers in inland marine waters of Washington, can be very destructive to unprotected Manila clams. After feeding on clams, numerous small pits or depressions may be seen in the substrate. Although not observed to prey upon planted clams at any of the study sites, a small amount of scoter, or other bird predation, may have occurred.

An investigation by Glude (1964) conducted in Dabob Bay, located in Washington's Hood Canal, demonstrated that each species of scoter consumed Manila clams, with predation by the white-winged and surf scoters being most significant. An apparent decline in number of small Manila clams from about 1/5 to 3/4 inch (5 to 19 mm) in length was detected on a Dabob clam flat during November to March when the ducks fed on them. Although Glude reported that few clams over 1 inch (25 mm) were eaten in Dabob Bay, Neil Bourne (personal communication) found that white-winged scoters can ingest clams up to 2 inches (50 mm) in length. In Japan, scoters are considered to be the most important predators of Manila clams (Bardach et al. 1972), where up to 52 clams from about 2/5 to 4/5 inch (10 to 20 mm) per bird were consumed daily for 150 consecutive days (Cahn 1951).

Four species of starfish, the sun star (*Pycnopodia helianthoides*), mottled star (*Evasterias troschellii*), pink star (*Pisaster brevispinus*), and ochre star (*P. ochraceus*)--shown in Figures 17 through 20--were occasionally found intertidally on various study beaches. According to Quayle and Bourne (1972), only the sun star and mottled star are serious clam predators. However, nearly all starfish observed occurred at tide levels below planted areas and therefore probably did little harm to planted clams.

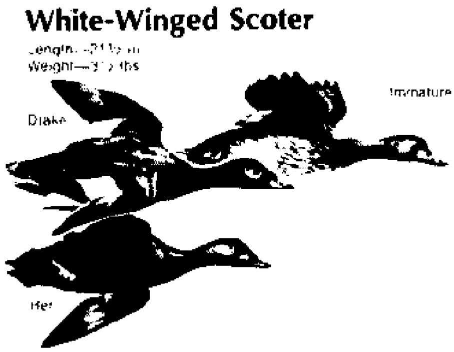
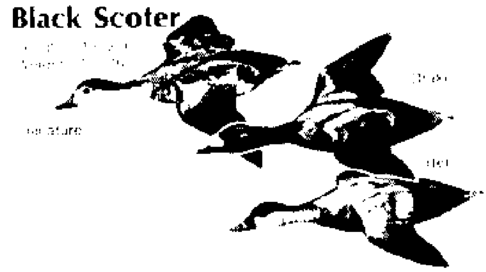


Figure 16 Scoter ducks. From *Ducks at a Distance: A Waterfowl Identification Guide*, by Bob Hines, U.S. Fish and Wildlife Service, U.S. Department of Interior. 1978.



In certain instances (e.g., Filucy Bay), the mantle cavity of Manila clams may be inhabited by commensal "pea crabs" (Figure 21). Pea crabs, which are more common in other clam species, do not harm their hosts or affect edibility of clams. However, for aesthetic reasons, clams containing such crabs may not be marketable and are therefore undesirable in commercial culture. Although found infrequently, at particular areas the crabs may occur in abundance.

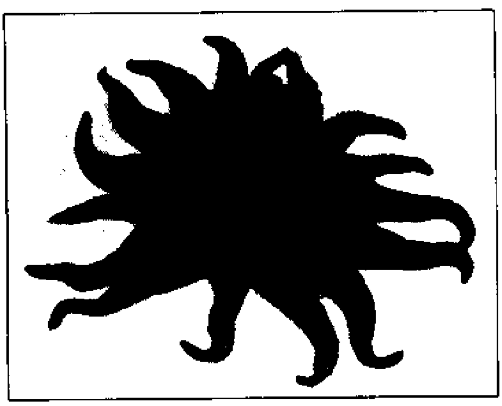


Figure 17
The sun star,
Pycnopodia helianthoides

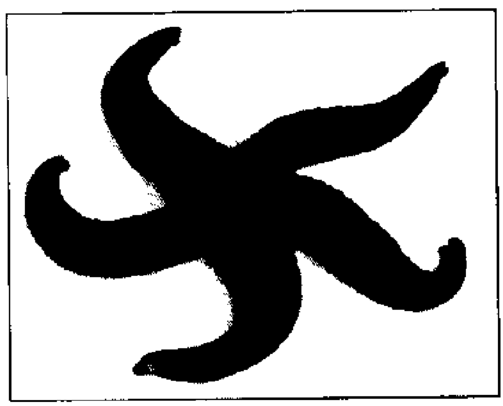


Figure 18
Mottled star,
Evasterias troschellii

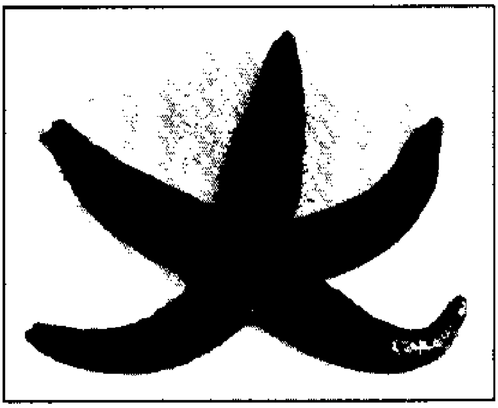


Figure 19
Pink star,
Pisaster brevispinus

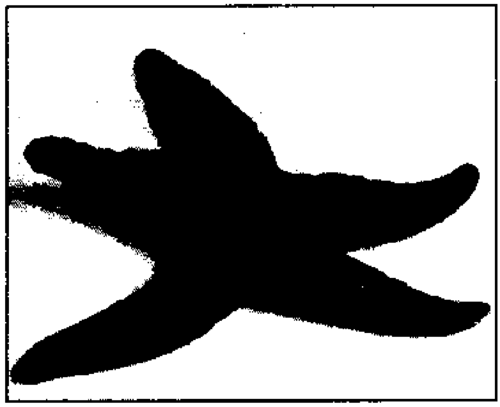


Figure 20
Ochre star,
Pisaster ochraceus

Figure 21
Pea crabs,
Pinnotheridae

Methods for Planting and Grow-out

Obtaining Permits and Governmental Approval

To engage in clam farming or other aquaculture, approval of several governmental agencies is needed. Certain agencies require that permits and licenses be obtained. For some environmental permits, detailed drawings of proposed culture plots (and any other shoreline or floating structures to be built) are required with the permit application. Therefore, detailed plans should be made well in advance of planting. Further, various regulations and guidelines must be followed after approval is obtained.

Regulatory agencies and processes include: Department of Social and Health Services (DSHS) and local health authorities--concerned with the safe consumption of shellfish; monitors pollution and paralytic shellfish poison, certifies commercial shellfish growing areas.

Department of Fisheries (WDF)--manages and safeguards Washington's marine shellfish resources; approves potential shellfish projects on a case-by-case basis; issues clam or oyster farm licenses and hatchery licenses.

Department of Natural Resources (DNR)--manages all beds of navigable waters and most state-owned tidelands; leases DNR-managed aquatic lands for aquaculture.

Local governments--have primary authority over shoreline developments; control shoreline development by a permit system.

State Environmental Policy Act (SEPA)--requires an environmental impact statement (EIS) before a government decision is made on a major project which significantly and adversely affects the environment; SEPA guidelines help to determine when an EIS is required.

Army Corps of Engineers--regulates work in all navigable waters; supplies permits for project affecting the course, location, condition, or capacity of navigable waters.

A better understanding of the regulatory process is provided in Chapter 7 of a recent Washington Department of Natural Resources publication entitled "Introduction to Shellfish Aquaculture in the Puget Sound Region" (Magoon and Vining 1981). This reference manual may be obtained for $5.00 by writing:

Department of Natural Resources
Division of Land Management
Public Land Building
Olympia, Washington 98504
Telephone (206) 753-5324

Additional information regarding aquaculture and environmental permits may be found in a booklet entitled "Operating a Business in Washington State: Volume III, Resource Protection Requirements." This booklet is published by the Department of Ecology (DOE) and may be obtained for free at any DOE office, or by writing:

Department of Ecology
Mail Stop PV-11
Olympia, Washington 98504
Telephone (206) 753-2800

Culture Plot Design and Construction

When a suitable location for a clam farm has been obtained, the site should be evaluated to determine the appropriate number, size, and orientation of culture plots to be constructed. (Tools and materials needed for construction of culture plots are listed in Appendix B).

The primary factors affecting plot design are tidal range, beach slope, and total area a harvest crew can work on an average low tide. Unequal, semi-diurnal tides (i.e., two high and two low tides on each daily cycle) occur in the Pacific Northwest. In Puget Sound, maximum tide range is approximately 23 ft (6.9 m) near Olympia, Washington, but decreases to approximately 16 ft (4.8 m) at Neah Bay, Washington (Magoon and Vining 1981). Thus, a wider tidal range in south Puget Sound is usable for culture plots than in northern areas.

Beach slope also limits the zone of usable intertidal areas as measured perpendicular to the water line. On a steep beach, the distance between two tide levels is less than on a gently sloped beach. Therefore, on a very steep beach, plots are best oriented with the longest dimension parallel to the shoreline. This allows all clams to be planted at a tide level where growth is optimal. On a gently sloping beach, plot orientation is less dependent upon slope.

The time required to harvest a culture plot--including excavation, removal, and possible replacement of netting--during a single low tide should ultimately determine plot size. Plot sizes of 100 to 150 square yards (or square meters) may be most easily managed on clean, firm substrates such as sand-gravel beaches. On muddy beaches and in areas of heavy fouling, smaller plots (100 square yards or less) will be most practical for culture work.

While actual construction of a culture plot is the same for any size, use of large plots will require that pieces of netting be joined together due to the limited widths of commercially produced netting ("Car Cover" comes in 12-ft-wide rolls). Netting can be taken to the culture site, rolled out, and cut to length. The pieces are then sewn together as necessary to make one large net. Alternately, entire nets may be prefabricated before transport to the beach. The netting may be purchased from suppliers as listed in Appendix C.

Once netting has been prepared, a trench should be excavated around the perimeter of the plot. The netting is laid out and positioned on the plot. Extra netting on all sides should fall into the trench. The netting is then anchored by stretching it tightly and pounding stakes through the netting along the base of the trench every 10 to 20 ft (3 to 6 m). Next, excess netting is folded into the trench and buried completely with sediment, filling the trench to beach level. The plot is now ready for seeding. (Note: If seed clams over 1/4 inch or 6 mm in length are used, the plot should be seeded before the netting is put in place.)

Acquisition, Care, and Handling of Clam Seeds

Before clam seed can be imported to Washington, the importer (the clam grower) must obtain a Shellfish Importation Permit from the Washington Department of Fisheries. This procedure applies only to import of non-exotic species which already inhabit waters of this state. The permit is free and may be requested by letter addressed to:

Director
Point Whitney Shellfish Laboratory
Washington Department of Fisheries
600 Point Whitney Road
Brinnon, Washington 98320
Telephone (206) 754-1498 or (206) 796-4601

Required information in the permit application includes:

1. name and address of importer,
2. name and address of clam seed producer,
3. amount of seed being imported,
4. when and where seed will be planted,
5. intended use of seed.

If clam seed are not planted on the day of their arrival from the hatchery, a holding facility is needed. They require cool, aerated seawater to remain alive. Two types of systems can be used:

1. Static System

Clams are placed in a large, clean container of fresh sea water. Water should be changed daily if kept cool and aerated, twice daily or more if not. Water is best kept in the range of 46° to 77°F (8° to 25°C). This method is adequate for less than 4 to 5 days, but not recommended when seed clams must be held beyond this period.

2. Seawater Holding

It is best to hold the seed clams until planting by placing them in lantern nets (see Appendix C for supplier), fine mesh bags, or any similar device suspended in sea water from a dock or float. This method is advantageous in that it allows clams to acclimate to ambient sea water conditions.

Seed clams 1/8 to 3/16 inch (3 to 4 mm) in length may be obtained from several Pacific Coast hatcheries (see Appendix C for suppliers).

They typically sell in lots of 1000 clams at prices of $4.00 to $6.00 per thousand. Some hatcheries offer lower unit prices for very large orders (i.e., over 1 million seed). Most hatcheries request that seed be ordered at least 3 months before delivery.

Hatchery clam seed is certified against disease and packed in styrofoam containers for shipping. Orders are shipped via air freight and normally arrive within 24 to 36 hr. They should be picked up promptly and placed back in cool sea water to minimize stress from extended periods out of the water.

Planting Seed Clams

When planting small seed clams ($\leq$ 1/8 to 3/16 inch or 3 to 4 mm) netting plots should be prepared in advance. Advance preparation of plots allows time for substrate to resettle and thereby provide a better environment for the clams.

In commercial culture schemes, several large plots might be planted over a short period. To spread seed evenly throughout each plot, small batches, or subunits, of seed should be planted in each plot rather than seeding an entire plot from one batch. This is done by dividing each plot into subunit areas, e.g., marked off by stakes, or string, and planting equal subunits of seed in each).

The number of clams in a planting subunit is chosen so that a desired density (number of clams per square foot, etc.) will result. In experimental plantings, relatively small subunit areas of 10 square yards (or meters) or less were used.

Since counting out a large number of seed clams is impractical, the number of clams for the subunits must be estimated. Estimates can be made on a number per volume basis, although a system based on the number of seed at a given weight is probably more practical, especially when dealing with large numbers of small clams. Before using either method, clam seed should be thoroughly mixed together to insure even size distributions between batches.

Clams should be divided into planting subunits at least several hours before planting. While clams are being transported to the planting site they must be kept cool and moist. Clam seed may be planted by scattering them as evenly as possible through each subunit area. Adding a small amount of water to each batch of seed as they are planted may facilitate separation of individuals.

Planting should be done on an incoming tide, starting at the lowest beach level and proceeding upward, ahead of the rising water. This prevents exposure of clams to the drying effects of the sun. If shells of the seed clams dry, surface tension at the air-water interface can cause them to float and be carried way. To prevent this, on warm, calm days, sea water should be splashed or sprayed over newly planted clams until the tide covers them. On windy days, when waves higher than about six inches occur, planting should proceed cautiously and possibly be postponed. Wave action can wash clams from planting areas before they have had a chance to burrow. However, if currents are not too great, clams may be planted even when the site is covered by a foot or more of water which allows planting in the presence of small waves.

Up to 3000 ft^2 (280 m^2) have been planted during one low tide by two persons, using methods described above, but other methods may be equally suitable for large-scale plantings. When covered by calm water, healthy seed clams are capable of digging into the substrate within minutes, so there is no need to bury them. (A time schedule for planting seed is provided in Appendix D).

Use of Netting to Improve Productivity of Natural Clam Beds

In experimental plantings at a variety of locations, densities of wild Manila clams often increased beneath net-covered areas. Since most of these clams had not recently settled--having shell lengths of 1/8 to 1/4 inch (3 to 6 mm)--it appears they were concentrated beneath the netting after being scoured by waves from the beach and washed into the netting plot. Also, netting placed on beaches where natural settlements of Manila clams occur will significantly increase survival of the spat. In Puget Sound, Manila clams may spawn in early summer and again in late summer (Williams 1978). Therefore, to take advantage of natural settlements, netting should be put out in late fall. This way, the present year's spat will be protected as well as any new settlements in the following year.

Culture Plot Maintenance and Fouling

Well-maintained culture plots will easily last 3 years although during this period netting damage may occur which will require repairs. Since failure to adequately maintain plots may result in loss of clams, routine inspection is important.

Commonly observed damage in experimental planting studies included separation of seams and tears caused by drift logs or debris. Open seams or tears may simply be stitched together, but in some cases, pieces of netting may be needed to patch holes.

Biological fouling may present some problems at certain locations during spring and summer. Two potentially serious fouling organisms are the common bay or blue mussel, *Mytilus edulis*, and barnacles, *Balanus* spp.). Both organisms will settle on netting and, when attached in great number, greatly add to the weight of a section of netting, clog the mesh, and compete with clams for food. Mussels are difficult to remove because they attach firmly with tough byssus threads. If the problem is severe, fouling organisms may be removed manually, with the aid of a brush or other tool.

Algae sometimes form mats under netting plots and occasionally thick piles of drift algae may cover netting plots at low tide. Unless severe enough to create anaerobic conditions, such algae may actually be beneficial by insulating clams from high air temperatures. Microalgae or diatoms may form a brown, hair-like web on the netting surface but cause no harm. However, if any algal fouling occurs on a netting surface prior to planting, it should be removed with a push-broom.

Crop Management and Standing Crop Estimation

When Manila clams reach minimum market size (about 1 1/2 inch or 35 to 38 mm) they may be harvested for sale. It may, however, be more profitable to delay harvest for up to an additional year because Manila clams gain significant weight during this period. As shown in Table 5, the weight of planted clams may more than double between the ends of the second and third growing seasons. Weight gains beyond the third season in this example would not warrant further postponement of harvest.

Total grow-out time, however, will vary substantially between locations. Although some growth data for certain parts of Puget Sound has been provided (Table 1), it may be useful for growers to monitor growth at their particular location for at least one full crop cycle. Such monitoring will also allow standing crop to be estimated.

Table 5. Weight increase between growing seasons for Manila clams planted at Hartstene Island study site #1.

Growing season completed	Second	Third	Fourth	Fifth
Average no. clams per kg	92	43	30	24
Average no. clams per lb	42	19	14	11
Average shell length	1.5 in. or 36.6mm	1.8 in. or 45.8mm	2.0 in. or 50.8mm	2.1 in. or 53.5mm

Growth rate after planting is estimated by periodically collecting clams from representative culture plots and determining their average shell length or live-weight or both. For convenience, a conversion table for converting shell length to live-weight is provided in Appendix E.

A rough estimate of standing crop (i.e., the total weight or number of clams in a given culture plot) is obtained by taking several uniformly-sized core samples of sediment from each plot and determining the average number of clams per core. Then, the number of clams per core may be extrapolated to estimate the total number of clams in the plot. Similarly, weight of clams per core may be used to estimate biomass in each plot. (Specifications for construction of sieves, which are useful for processing core samples, are provided in Appendix F and standard, scientific procedures for taking samples are outlined in Appendix G.)

Harvesting Methods

A wide range of technology exists for harvesting clams. Harvesting gear may be categorized as: 1) hand-held implements such as tongs, clam forks, rakes, and shovels; 2) dredges pulled by hand or boat; and 3) hydraulic-escalator dredges. In Washington, hydraulic-escalator dredges are regulated under a permit system and are used to harvest both subtidal and intertidal stocks of clams. However, most intertidal harvest is done by hand. Hand tools most commonly used in Washington are longed-tined clam forks and short-tined hand rakes.

The Manila clam, a shallow intertidal burrower, is easily harvested by hand if the substrate is not too coarse or compacted. Once harvested, clams are submerged in floating trays called "sink floats" where they cleanse themselves of sand. The following day or later, the clams are packed and sold to a fish buyer. Some buyers will pick up clams directly from the grower which substantially reduces transportation costs.

Record Keeping

Management of clam farm activites will be improved if well-organized records of all farm activities are maintained (see Shang 1981). Up-to-date and accurate records will provide a broad base for farm management decisions and may be invaluable in the event of legal proceedings which require a grower to show proof of loss. Record keeping may therefore serve as important insurance.

Certain records of production and sales are required by the Washington Department of Fisheries (WDF). Daily sales of clams must be reported on a Shellfish Receiving Ticket each day and be reported on a monthly basis using a Hardshell Clam Production Report form. Clam farms or leases using mechanical harvestors report catches on a Clam Harvest Log. Copies of these forms may be obtained by writing:

Washington State Department of Fisheries
Room 115, General Administration Bldg.
Olympia, Washington 98504
Telephone (206) 234-6749

Economic Prospects of Manila Clam Aquaculture in Washington State

Commercial clam aquaculture is relatively new in the United States and very little information is available concerning the economics of clam farming. Pilot-scale studies of Manila clam aquaculture in Puget Sound have provided some basic information pertaining to prospects for its successful implementation in Washington State.

Table 6 lists capital investments made in 1979 to establish large culture plots at Filucy Bay and Wescott Bay. Higher labor costs for plot construction at Wescott Bay were related to poor substrate conditions; trench excavation was hindered by patches of hard-packed clay. Other costs were the same for both locations and varied directly in relation to plot size. The average cost of each plot was approximately \$4.46 to \$4.65 yd^2 (\$5.33 to \$5.56 m^2). Present costs for the same plots would be higher when adjusted for inflation. Certain expenses, such as taxes, insurance, professional fees, mortgages, and major building costs, could not be estimated from these studies.

Harvest costs, which include crew wages (no benefits), lease royalties, processing, and harvest equipment are listed in Table 7. Since many fish buyers in Washington purchase clams directly at the harvest site, it is assumed that transportation costs to the grower are minimal. Annual equipment costs, which vary depending on the size of the operation, were estimated to be approximately 3% of the total harvest cost (or \$0.02/kg harvested). Hence, a difference is seen between Filucy Bay and Wescott Bay in equipment costs.

Expected net profits from these two culture plots were calculated as the difference between total cost and wholesale value of the clams (Table 8). The average wholesale price for littleneck clams in 1980 was used because price tends to fluctuate seasonally in Washington. According to the figures shown, the plot at Wescott Bay would be unprofitable to harvest at the time when clams were of minimum market size, whereas clams harvested at Filucy Bay would return a net profit of approximately \$0.30 on each dollar invested. However, profits from each

Table 6. Estimated total capital investment in 1979 for the 10 X 30m (Filucy Bay) and 10 X 25m (Wescott Bay) plots.

Item	Cost	
	Filucy Bay	Wescott Bay
Clam seed[a] ($4.00/1000 seed)	$1218.56	$1015.46
Vexar™ car cover netting[b]	$ 156.86	$ 131.56
Wooden stakes, twine, nails, etc.	$ 17.46	$ 14.64
Labor ($4.50/man-hour)		
1. net fabrication	$ 123.19	$ 123.19
2. plot construction	$ 38.25	$ 63.00
Seed preparation and planting	$ 24.55	$ 20.45
Plot maintenance[c]	$ 22.50	$ 22.50
Total	$1601.37	$1390.80
Average cost/m^2	$ 5.33/m^2	$ 5.56/m^2

[a]Planting density = 1000 seed/m^2; includes shipping charge.

[b]Calculated for two layers of netting at $0.23/$m^2$/layer.

[c]Estimated 5 hours maintenance time per plot for 3 yrs. Wage rate = $4.50/hour.

Table 7. Estimated harvest costs for culture plots at Filucy Bay and Wescott Bay. (1980 values)

	Filucy Bay	Wescott Bay
Live biomass to be harvested	1952.965 kg	823.290 kg
Harvest crew wages ($0.53/kg)[a]	$1035.07	$436.34
Equipment[b] ($0.02/kg)	$ 39.06	$ 16.47
State lease royalty ($0.07/kg)	$ 136.71	$ 57.63
Total harvest cost	$1210.84	$510.44

[a]Includes wages paid for on-site processing and washing.

[b]Estimated cost to replace or repair harvest equipment.

Table 8. Estimated total cost and expected profit for culture plots at Filucy Bay and Wescott Bay.

Costs	Filucy Bay	Wescott Bay
Capital investments[a]	$1601.37	$1390.80
Harvest cost	$1210.84	$ 510.44
Total	$2812.21	$1901.24
Expected Profit		
Wholesale value of clams harvested[b]	$3652.04	$1539.55
Net profit after total costs	+ $ 839.83	- $ 361.69
Monetary return of each dollar invested	+ $ 0.30	- $ 0.23

[a]Calculated in 1979 dollars.

[b]Average annual wholesale price approximately $1.87/kg in 1980.

location could be greatly improved by extending the grow-out period for another year.

Profits can also be increased at locations where wild clams will contribute to the total harvest. Wild clams return greater profits than planted clams since they have only a harvest cost associated with them. For example, approximately 1400 lb (635 kg) of wild Manila clams will be harvested from the 10 x 30 m plot at Filucy Bay. After deducting harvest costs, these wild clams will contribute an additional $793.54 in profits.

Although a complete economic analysis of Manila clam aquaculture was not possible in these studies, the results suggest that commercial clam aquaculture may be economically feasible at the present time. At best, however, only marginal profits should be expected under normal conditions with good management practices. The greatest opportunity for success in Manila clam aquaculture appears to lie with the clam growers and oystermen who have already made the major capital investments necessary to initiate large-scale Manila clam aquaculture.

Conclusions

Manila clam aquaculture is biologically and at least marginally economically feasible in Puget Sound. The practicality of using plastic netting to protect intertidally planted clams has been demonstrated. Success of commercial clam aquaculture, however, will still depend upon adequate culture site evaluation, sound crop management practices, good business management, and patience in dealing with regulatory constraints. Certain risks must also be accepted, such as unfavorable changes in production costs or wholesale clam prices, episodes of pollution, or PSP outbreaks which may temporarily close beaches for clam harvesting.

It is hoped that this publication will provide worthwhile information about the potential for clam aquaculture in Puget Sound. More importantly, it is the authors' wish that this report will serve as a general guide to those with an active interest in commercial Manila clam aquaculture. Most certainly, the information will be very useful to noncommercial holders of private beaches who contemplate the purchase of clam seed for planting.

References and Selected Bibliography

References

Anonymous. 1974. Washington Marine Atlas. Wash. Dep. Natural Resources. Vol. 2, South Inland Waters.

Anonymous. 1978. Ducks at a distance - a waterfowl identification guide. Department of the Interior, U.S. Fish and Wildlife Service. U.S. Government Printing Office, Washington, D.C.

Bardach, J.E., J.H. Rhyther, and W.P. McLarney. 1972. Aquaculture - the farming and husbandry of freshwater and marine organisms. John Wiley and Sons, Inc., New York. 868 pp.

Bourne, N., and J. Lee. 1973. Predation on juvenile bivalves by the shore crab, *Hemigrapsus oregonensis* and *H. nudis* (abstract). Proc. Nat'l. Shellfish. Assoc. 64:10.

Cahn, A.R. 1951. Clam culture in Japan. U.S. Fish Wildl. Serv., Fish Leafl. No. 399:33-52.

Glock, J.W., and K.K. Chew. 1979. Growth, recovery, and movement of Manila clams, *Venerupis japonica* (Deshayes) at Squaxin Island, Washington. Proc. Nat'l. Shellfish. Assoc. 69:15-20.

Glude, J.B. 1964. The effect of scoter duck predation on a clam population in Dabob Bay, Washington. Proc. Nat'l. Shellfish. Assoc. 55:73-86.

Glude, J.B. 1974. Recent developments in shellfish culture on the U.S. Pacific Coast. *In*: Proc. of the First U.S. - Japan Meeting on Aquaculture at Tokyo, Japan. NOAA Tech. Rep., NMFS Circ. 338. 113 pp.

Gotshall, D.W. 1977. Stomach contents of Northern California Dungeness crabs, *Cancer magister*. Calif. Fish Game 63(1):43-51.

Higgins, J.H. 1969. Some aspects of the ecology of a bivalve mollusk in Kaneohe Bay, Oahu, Hawaii. M.S. Thesis, Univ. Hawaii, Honolulu. 47 pp.

Jones, C.R. 1974. Initial mortality and growth of hatchery-reared Manila clams, *Venerupis japonica*, planted in Puget Sound, Washington beaches. M.S. Thesis, Univ. Washington, Seattle. 90 pp.

Kasahara, H., and H. Ito. 1953. Ecology of mackerals (in Japanese, English summary). Fish Sci. No. 7 Fish. Agency, Japan.

Kraeuter, J.N., and M. Castagna. 1977. An analysis of gravel pens, crab traps, and current baffles as protection for juvenile hard clams, *Mercenaria mercenaria*. Proc. World Mariculture Soc. 8:581-592.

Kurashige, H. 1942. Kaisui chu no fuyudo ni taisuvu Tyosen san Asari no Teikosei (Resisting ability of *Paphia phillipinarus* produced in Korea against mud-granule suspension in sea water). Suisan Gakkaiho (Proc. Sci. Fish. Assoc.) 4(1):23-35.

Loosanoff, V.L. 1961. Effects of turbidity on some larval and adult bivalves. Proc. Gulf and Carib. Fish. Inst. 14th. Annual Session. Nov.:80-95.

Lucas, A. 1976. Aspects of the rearing and cultivation of *Venerupis*. Shellfish Assoc. Great Britain. Seventh Shellfish Conference: 32-36.

Magoon, C., and R. Vining. 1981. Introduction to shellfish aquaculture. Washington Dep. Natural Resources. 68 pp.
Miller, M.B. 1982. Recovery and growth of hatchery-produced juvenile Manila clams, *Venerupis japonica* (DeShayes), planted on several beaches in Puget Sound. Ph.D. dissertation, Univ. Washington, Seattle. 250 pp.
Miller, M.B., K.K. Chew, C.R. Jones, L. Goodwin, and C. Magoon. 1978. Manila clam seeding as an approach to clam population enhancement. Washington Sea Grant, Publ. No. WSG 78-2. 18 pp.
Quayle, D.B. 1938. *Paphia bifurcata*, a new molluscan species from Ladysmith Harbor, B.C. J. Fish. Res. Bd. Canada 4:53-54.
Quayle, D.B. 1941. The Japanese "little neck" clam accidentally introduced into British Columbia waters. Prog. Reps. Fish. Res. Bd. Pac. Coast Station, No. 48, June:17-18.
Quayle, D.B. 1964. Distribution of introduced marine mollusca in British Columbia waters. J. Fish. Res. Bd. Canada 21:1155-1181.
Quayle, D.B., and N. Bourne. 1972. The clam fisheries of British Columbia. Fish. Res. Bd. Canada, Bull. No. 179, 70 pp.
Shang, Y.C. 1981. Aquaculture Economics: Basic Concepts and Methods of Analysis. Westview Press, Boulder, CO, 153 pp.
Williams, J.G. 1978. The influences of adults on the settlement, growth, and survival of spat in the commercially important clam, *Tapes japonica* Deshayes. Ph.D. dissertation, Univ. of Washington, Seattle. 60 pp.
Williams, R.J. 1970. Freezing tolerance in *Mytilus edulis*. Comp. Biochem. Physiol. 35:145-161.
Winter, D.F., K. Banse, and G.C. Anderson. 1975. The dynamics of phytoplankton blooms in Puget Sound, a fjord in the northwestern United States. Mar. Biol. 29:139-176.

Selected Bibliography

Anonymous. 1947. Tidal current charts, Puget Sound, northern part. U.S. Coast and Geodetic Survey. Ser. No. 696.
Anonymous. 1948. Tidal current charts, Puget Sound, southern part. U.S. Coast and Geodetic Survey. Ser. No. 713.
Bernard, F.R. 1967. Studies on the biology of the Natacid clam drill *Polinices lewisi* (Gould) (Gastropoda, Prosobranchiata). Fish. Res. Bd. Canada Tech. Rep. No. 42. 41 pp.
Castagna, M. and J.N. Kraeuter. 1981. Manual for growing the hard clam *Mercenaria*. Spec. Rep. Appl. Mar. Sci. and Ocean Eng., No. 249, Virginia Inst. Mar. Sci., Gloucester Point, VA 23062. 110 pp.
Carefoot, T. 1977. Pacific seashores: A guide to intertidal ecology. Univ. Washington Press, Seattle. 208 pp.
Cottam, C. 1939. Food habits of North American diving ducks. U.S. Dep. Agric. Tech. Bull. 643, 139 pp.
Glock, J.W., and K.K. Chew. 1978. Growth, recovery, and movement of Manila clams, *Venerupis japonica*, planted under protective devices and on open beaches at Squaxin Island, Washington. Final Rep., Coll. Fish., Univ. Washington. 69 pp.
Glude, J.B. 1978. The clams (genera *Mercenaria, Saxidomus, Protothaca Tapes, Mya, Panopea,* and *Spisula*) - A literature review and analysis of the use of thermal effluent in the culture of clams. Unpubl. Manuscript. Aquaculture consultant, 2703 W. McGraw, Seattle, WA.

Greene, G.T., and D.S. Becker. 1977. Winterkill of hard clams in great South Bay, N.Y. 1976-1977. Mar. Sci. Res. Center, St. Univ. N.Y., Spec. Rep. No. 9, Reference 77-5. 23 pp.
Hart, J.L. 1973. *Pacific fishes of Canada*. Fish. Res. Bd. Canada. 180. 740 pp.
Holland, D.A., and K.K. Chew. 1973. Reproductive cycle of the Manila clam (*Venerupis japonica*), from Hood Canal, Washington. Proc. Nat'l. Shellfish. Assoc. 64:53-58.
Ikematsu, W. 1957. Ecological studies on the clam, *Tapes japonica* (Reeve) II. On the setting season and the growth in the early young stage. Bull. Jap. Soc. Sci. Fish. 22(12):736-741.
Korringa, P. 1976. Farming marine organisms low in the food chain, developments in aquaculture and fisheries science. Vol. 1, Elsevier Sci. Publ. Co., Amsterdam, 264 pp.
Kozloff, E.N. 1974. Keys to the marine invertebrates of Puget Sound, the San Juan Archipelago, and adjacent regions. Univ. Washington Press, Seattle. 226 pp.
Landless, P.J., and A. Edwards. 1976. Economic ways of assessing hydrography for fish farms. Aquaculture 8(1):29-43.
Lucas, A. 1976. Aspects of the rearing and cultivation of *Venerupis*. Unpubl. manuscript: Seventh Shellfish Conference, May 18-19, 1976. Shellfish Assoc., Great Britain.
Lucas, A. 1977. Culture of the Manila clam (*Venerupis semidecussata* Reeve) from hatchery-reared spat. Third meeting of the I.C.E.S. Working Group on Mariculture, Brest, France. May 10-13, 1977. Actes de Colloques du C.N.E.X.O., No. 4:317-330.
Lucas, A. 1980. Croissance de jeunes Parlourdes (*Venerupis semidecussata*) en nurserie et en mer en fonction des conditions d'elevage. In: Mecanismes et controle de la production biologique marine - Systems clos artificiels, ecosystemes littoraux. Publ. Sci. Tech. C.N.E.X.O.: Actes de Colloques, No. 7:85-104.
Lukas, G., and T.F. Gaumer. 1974. Clam-abalone stock supplementation feasibility study. Annual Rep., July 1, 1973 to June 30, 1974. Fish. Comm. Oregon. 20 pp.
Lutz, R.A., and L.S. Incze. 1979. The impact of toxic dinoflagellate blooms on the North American shellfish industry. Pages 476-483 In: Taylor and Seliger, eds. Toxic Dinoflagellate Blooms. Elsevier-North Holland, Inc.
MacKenzie, C.L., Jr. 1979. Management for increasing clam abundance. Mar. Fish. Rev., October 1979:10-21.
Mann, R. 1979. The effect of temperature on growth, physiology, and gametogenesis in the Manila clam *Tapes philippinarum* (Adam and Reeve 1850). J. exp. mar. Biol. Ecol. 38:122-133.
Mathiessen, G.C. 1960. Intertidal zonation in populations of *Mya arenaria*. Limnol. Oceanogr. 5:381-388.
Miliekovsky, S.A. 1974. On predation of pelagic larvae and early juveniles of marine bottom invertebrates by adult benthic invertebrates and their passing alive through their predators. Mar. Biol. 26:303-311.
Norris, L., K.K Chew, and A.C. Duxbury. 1973. Shellfish and the Red Tide. Washington Sea Grant Publ. No. WSG-AS73-2. 2 pp.
Nosho, T.Y. and K.K. Chew. 1972. The setting and growth of the Manila clam, *Venerupis japonica* (Deshayes), in Hood Canal, Washington. Proc. Nat'l. Shellfish. Assoc. 62:50-58.
Ohba, S. 1956. Effects of population density on mortality and growth in an experimental culture of a bivalve, *Venerupis semidecussata*. Biol. J. Okayama Univ. 2(4):169-173.

Ohba, S. 1959. Ecological studies in the natural population of a clam, *Tapes japonica*, with special reference to seasonal variations in the size and structure of the population and to individual growth. Biol. J. Okayama Univ. 5(1/2):13-42.

Partridge, J.K. 1977. Annotated bibliographies of the genus *Tapes* (Bivalvia; Veneridae). Part I - *Tapes decussatus* (L.); Part II - *Tapes semidecussatus* Reeve. Proc. Royal Irish Acad., Section B., Vol. 77(1):1-63.

Quayle, D.B. 19 . The relation of digging frequency to productivity of the butter-clam, *Saxidomus giganteus* Deshayes. J. Fish. Res. Bd. Canada 8(5):369-373.

Rhoads, D.C., and R.A. Lutz (eds.). 1980. Skeletal Growth of Aquatic Organisms. Plenum Publ. Corporation, New York, 750 pp.

Ricketts, E.F., and J. Calvin. 1968. Between Pacific Tides, 4th ed. Revised by J.W. Hedgepath. Stanford Univ. Press, Stanford, CA. 614 pp.

Ritchie, T.P. (ed.). 1977. A comprehensive review of the commercial clam industries in the United States. U.S. Dep. Commerce. DEL-SG-26-76. 106 pp.

Smith, O.R. 1955. Movements of small soft-shell clams, (*Mya arenaria*). U.S. Fish Wildl. Serv., Spec. Sci. Rep., Fish. No. 159.

Smith, R.I., and J.T. Carlton (eds.). 1975. Light's Manual: Intertidal Invertebrates of the Central California Coast. 3rd ed. Univ. California Press, Berkeley, CA. 716 pp.

Stanley, S.M. 1970. Relation of shell form to life habits of the Bivalvia (Mollusca). The Geological Society of America, Inc., Boulder, CO. Memoir 125, 296 pp.

Walne, P.R. 1974. Culture of bivalve Molluscs. Fishing News (Books) Ltd. Surrey, England. 173 pp.

Walne, P.R. 1976. Experiments on the culture in the sea of the butterfish, *Venerupis decussata* L. Aquaculture 8(4):371-381.

Williams, J.G. 1980. The influences of adults on the settlement of spat of the clam, *Tapes japonica*. J. Mar. Res. 38(4):729-741.

Wood, L., and W.J. Hargis, Jr. 1971. Transport of bivalve larvae in a tidal estuary. Pages 29-44 *in* D.J. Crisp, ed. Fourth European Marine Biology Symposium. Cambridge Univ. Press.

Appendix A
Tide Level Determination

Tidal height for planting Manila clams (about +3 to +6 feet above MLLW) can be determined by the following methods.

a. By leveling from one of the many U.S. Coast and Geodetic Survey tidal bench marks distributed throughout Puget Sound. (Call Seattle 206-442-7657 for their location.)
b. By using a tide calendar or tide table to determine the tide level at a particular time for your location. (Call Seattle 206-442-7657 for daily tidal corrections.)
c. By leveling from the uppermost limit of barnacles, if present on the upper beach. Barnacles will survive in central Puget Sound to approximately the 10-11 ft tide level. The upper barnacle level is about 2 ft higher in south Puget Sound and about 2 ft lower in the Port Townsend area.

Appendix B
Required Supplies and Materials

General

rubber boots
rubber gloves
rain gear
water-proof notebook
pencils
knife
tide chart
clipboard
calculator
thermometer
permits, etc.

Surveying

tide chart with correction table
benchmark map
handheld eye level or surveyors level
sighting pole or stadia rod
30 x 2 x 1 inch cedar stakes

Sampling

core sampler
sampling quadrat
trowels
screens (smallest mesh = 1/4 inch or 6 mm)
screen stand
buckets
labels (water-proof)
plastic bags
rubber bands
stakes (temporary markers)
shovels
meterstick
vernier calipers or ruler

Maintenance

plastic netting
twine or netting ties
stakes
nails
sledge hammer
shovels
push broom

Nighttime Work

lanterns (at least 2)
lantern fuel and funnel
extra lantern parts
lantern stands (i.e., tripod with hanger)
matches
flashlights

Netting plot construction

plastic netting
twine/cord
net sewing needles (no. 5/4)
plastic netting ties
tape measure
30 x 2 x 1 inch cedar stakes
nails
16 oz. hammer
sledge hammer

Planting

containers for clams (i.e., small plastic tubs with lids)
ice chest
ice
scales/balance
graduated cylinders
buckets
tape measure
stakes (temporary markers)

Harvesting

clam forks
shovels
buckets
porous bags (e.g., onion sacks)
float (or other method for sand depuration of clams
nighttime work gear (for winter harvest)

Appendix C
Suppliers of Clam Seed And Other Aquaculture Materials

Shellfish Hatcheries

Pacific Mariculture, Inc.
P.O. Box 336
Moss Landing, CA 95039
Phone (408) 633-3548
Attn: Chet Belknap

Pigeon Point Shellfish Hatchery
921 Pigeon Point Road
Pescadero, CA 94060
Phone (415) 879-0391

Coast Oyster Company
Hatchery Division
P.O. Box 635
Ocean Park, WA 98640
Phone (206) 665-4075

Plastic Netting

Consolidated Net and Twine Co., Inc.
Box. 5223, University Station
Seattle, WA 98105
Phone (206) 784-5100

Attn: Nick Budnick

Conwed Corporation
1105-16th Street S.W.
Puyallup, WA 98371
Phone (206) 848-5880

Lantern Nets

Culture Fisheries, West Coast Representative
Webb Camp Sea Farms, Inc.
4071 Westcott Drive
Friday Harbor, WA 98250
Phone (206) 378-2489
Attn: Bill Webb

Miscellaneous Materials

Most other materials mentioned in this manual can be purchased at any hardware store or fishermen's supply. See also Magoon and Vining (1981) for their list of suppliers.

Appendix D
Time Schedule for Planting Seed

1. At least 18 months before planting seed for commercial purposes, obtain suitable tideland and initiate the permit process if necessary.

2. Approximately 5 months before planting (September-December):

   a. determine amount of seed and number of plots to be planted
   b. design plots
   c. order seed and other materials, allowing at least 5 months advance notice on seed order
   d. obtain seed importers permit from WDF

3. One week or less before planting:

   a. prefabricate nets and build culture plots
   b. prepare holding facility for seed clams
   c. check on seed order to insure delivery

4. Three to 5 days prior to planting:

   a. check weather forecasts for planting day
   b. take delivery of seed shipment
   c. check plots for last minute modifications if necessary

5. On the day before planting:

   a. portion out seed for planting subunits
   b. mark out planting subareas on culture plots
   c. perform a planting "dry run" on incoming tide
   d. clean from plots any attached algae or diatoms

6. Plant seed.

7. Three to 5 months after planting, sample the culture plots to determine growth and standing crop.

Appendix E
Length vs. Live-Weight Approximations For Manila Clams Cultured in Puget Sound

Length (mm)	Weight (g)[b]	Length (mm)	Weight (g)	No. clams/pound (clams $\geq$ 33 mm)
9	0.13	33	7.57	60
10	0.18	34	8.31	55
11	0.25	35	9.09	50
12	0.33	36	9.92	46
13	0.42	37	10.80	42
14	0.53	38	11.74	39
15	0.65	39	12.73	36
16	0.80	40	13.77	33
17	0.96	41	14.87	31
18	1.15	42	16.02	28
19	1.36	43	17.24	26
20	1.59	44	18.52	25
21	1.86	45	19.86	23
22	2.14	46	21.26	21
23	2.46	47	22.74	20
24	2.81	48	24.27	19
25	3.19	49	25.88	18
26	3.61	50	27.56	16
27	4.05	51	29.31	15
28	4.54	52	31.14	15
29	5.06	53	33.04	14
30	5.63	54	35.01	13
31	6.23	55	37.07	12
32	6.88	56	39.21	12

[a]Live-weight values were calculated using the regression:

i. ln(live-weight) = 3.11 x ln(length) - 8.85 and then doing an e transformation,

or,

ii. live-weight = $(1.433 \times 10^{-4}) \times (\text{length})^{3.11}$

[b]These values are accurate to 0.1 g. Two decimal places are given to allow for rounding.

Appendix F
Construction of Sieves

I. Sieves (enough for two)

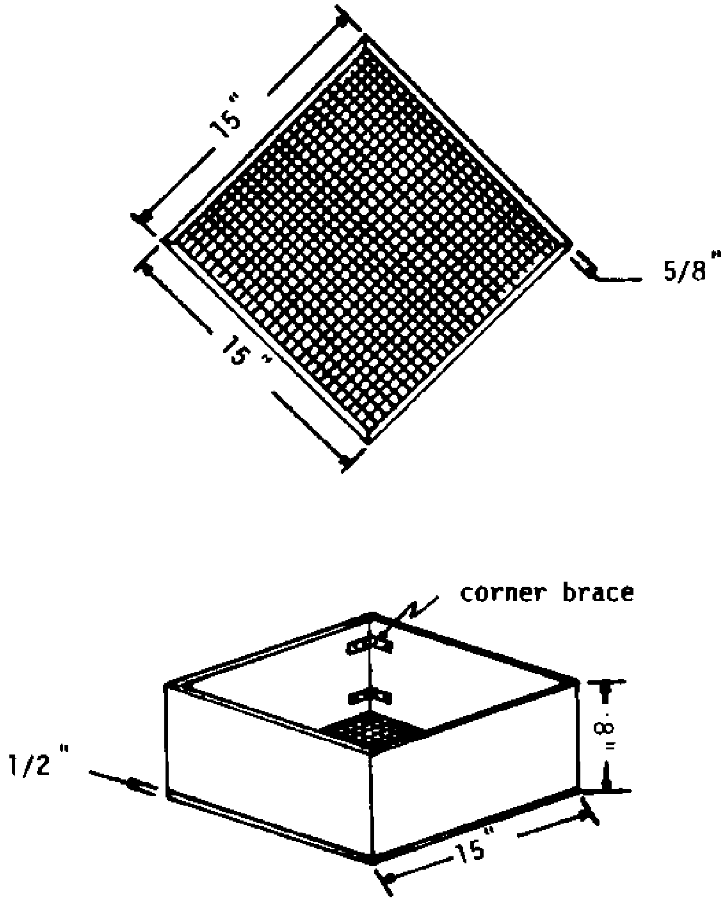
8 - 1" x 8" x 15" fir plank
8 - 1/2" x 1" x 15" fir strips
16 - corner braces with screws
1 - 24" x 48" pc 1/2" mesh hardware cloth, trim to 15" x 15"
1 - 24" x 48" pc 1/4" mesh hardware cloth, trim to 15" x 15"
Assorted nails, galvanized

In addition to corner bracing, the sides should also be nailed together. The hardware cloth should be attached to the wood frame using staples or horseshoe tacks and then secured with the wood strips. Longevity of the sieves may be increased by treating with a good preservative.

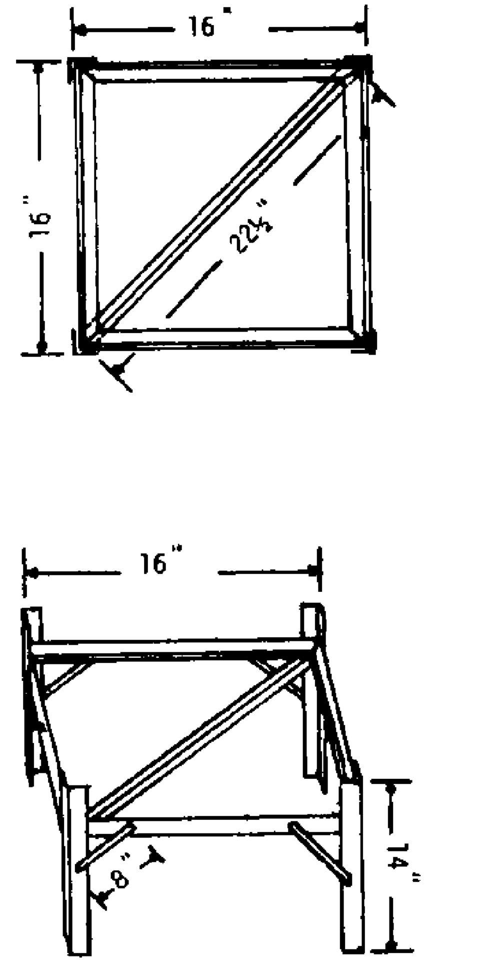
II. Sieve Stand

4 - 14" angle iron
4 - 16" angle iron
1 - 22 1/2" angle iron
8 - 1" x 8" flat iron

A sieve stand of this design will be most sturdy if welded rather than bolted together. Note also that the center piece of angle iron (22 1/2" piece) should be concave upwards, thus giving two points of contact at each end.



a. Sieve design



b. sieve stand design

Appendix G
Sampling Procedures and Estimation Of Standing Crop

G.1. Standard Sampling Procedures

1. Random Sampling Method

In random sampling, it is assumed that planted clams are not distributed evenly within each plot. Therefore, sampling is conducted to allow an equal opportunity to sample every clam. In this way, unbiased and accurate estimates of growth and density can be made. Briefly, a random sample is obtained in the following way:

a. Choose a standard sampling unit such as a hollow cylinder, 4 to 6 inches (10 to 15 cm) in diameter and about 10 inches (25 cm) long (a 2-lb size coffee can is suitable).
b. Determine the number of sample units to be taken in each plot. Eight cores of the size given above per 500 ft^2 (47 m^2) of area will yield adequate information.
c. On graph paper, draw a diagram of the plots to be sampled, allowing each grid to equal 1 ft^2 (0.1 m^2). Each row and column should then be numbered in sequence beginning with zero (proceeding top to bottom for rows, left to right for columns) so that each grid can be identified by unique row and column coordinates.
d. The locations at which core samples are taken, which correspond to the graph paper grids, are selected by using a random number table. (A random number table and directions for its use are provided in Appendix G.3.)

2. Systematic Sampling Method

Systematic sampling is simpler and somewhat faster to perform than random sampling, but will yield accurate estimates only when clams are distributed uniformly within each culture plot. Therefore, clam seed must be planted very evenly and the area under culture not exposed to appreciable wave and current activity. Sytematic sampling may be performed as follows:

a. Select a standard sample unit and determine the number of samples to be taken as described for random sampling.
b. Establish horizontal sample lines or transects through the plot parallel to the water's edge. One transect for each foot of elevation within the plot - with at least 2 transects per plot - is usually suitable. Positions of transects are chosen along the vertical plot dimension using the random number table in the same manner as described above.
c. Beginning at a randomly selected point, core samples are taken at equal intervals over the length of the transect. For each transect, the first yard (or meter) should be divided by inches numbering from 00 to 35 (or 00 to 99 if using meters). Using the random number table, select a number which falls in this range as the location of the initial core sample. Subsequent core positions on the transect are located at equal intervals so that at least 8 cores are taken per 500 ft^2 of plot. For example, if the first

core is to be taken at inch 27 and a 1-yd interval is chosen, the end of the tape measure is placed at inch 27 and subsequent core locations are marked at yard 1, yard 2, yard 3, etc., until the plot is crossed. If three transects are established for sampling a plot of 2000 ft^2, about 11 samples per transect should be taken.

3. Stratification in Sampling

A culture plot may often be situated on a steeply sloped beach with a vertical change of $\geq$2 ft ($\geq$0.60 m) within the plot, or its substrate may consist of patches of two or more distinct sediment types. When such conditions exist, a more precise estimate of production can be obtained by dividing, or stratifying, the area to be sampled by tide height and/or sediment type.

For example, if a plot is situated between +2 ft and +5 ft (+0.6 m to +1.7 m) above MLLW, it may be divided into equal sized subareas which approximate the +2 to +3 ft, +3 to +4 ft, and +4 to +5 ft tide levels. Each sub-area (or stratum) should then be treated separately and can be sampled randomly or systematically with an equal number of sample units taken in each. If equal-sized strata cannot be selected, as may be the case when stratifying by sediment type, the number of sample units taken in each should be roughly proportional to the area of each stratum.

4. Sampling Technique and Standing Crop Calculation

When sample locations have been selected, they should be marked on the plot diagrams and sample identification tags prepared. Sample tags should be made of waterproof paper of surveyor's tape and written with indelible ink or pencil, and indicate plot number, sample position, and date.

To obtain samples, the sampling device (core, etc.) should be centered over each sample position and pushed into the substrate approximately 5 inches. Manila clams tend to burrow deeper in pea gravel than in large cobble or mud. The core is removed with aid of a garden trowel and sediment from each sample placed with its tag in a separate plastic bag.

Each sample should be washed through a set of sieves to partially separate clams from sediment. Sieve mesh sizes of 1/2 and 1/4 inch (13 and 6 mm) are usually suitable. As considerable time is required to sort clams from material small enough to pass through a 1/4 inch sieve, allow seed clams to grow for 3 to 4 months prior to sampling to eliminate the need for a smaller mesh sieve. Clams may be measured at once after screening or kept for later analysis by refrigeration or freezing.

Shell length of clams from each sample should be measured using either Vernier calipers or a ruler. Live-weight of each clam may also be taken using an appropriate balance or refer to Appendix H for approximations. The following data should be recorded for each sample unit: plot identification number, date collected, plot stratum and transect numbers, coordinates of sample unit within plot or location on transect, sample unit area (i.e., area sampled by each core), and total number of clams by species. The following data should be recorded for each clam (commercial species) within the sample unit: species, shell length, and live-weight. Using this data, standing crop may be calculated as shown in Appendix G.2.

G.2. Calculation of Standing Crop

Standing crop = (average clam weight)(density of clams)(number of sample units in plot)

1. Average clam weight (lb or kg) $= \frac{\text{total weight of clams sampled}}{\text{total number of clams sampled}}$
2. Density of clams (number/sample unit) $= \frac{\text{total number of clams sampled}}{\text{number sample units taken}}$
3. Total number of sample units in plot $= \frac{\text{total area of plot}}{\text{sample unit area}}$

When stratified sampling is used, standing crop for each stratum or subarea should be calculated and then summed for the entire plot to yield total standing crop.

Example of standing crop calculation:

sampling method used = random sample; unit = 2 lb size coffee can

total weight of clams sampled = 13.406 lb or 6.081 kg
total number of clams sampled = 429
number of sample units taken = 40
total area of plot = 200 yd^2 or 168 m^2
sample unit area = 0.0154 yd^2 or 0.0125 m^2

$$\text{Standing crop} = \left(\frac{13.406\ \text{lb}}{429\ \text{clams}}\right)\left(\frac{429\ \text{clams}}{40\ \text{units}}\right)\left(\frac{200\ \text{yd}^2}{0.0154\ \text{yd}^2}\right)$$

= 4352.6 lb or 1970.5 kg
= 21.7 lb/yd^2 or 11.7 kg/m^2

Total number of clams in culture = 139,425
= 697 $clams/yd^2$ or 808/m^2

G.3. Random Number Table

To use the random number table, an arbitrary starting point is selected within the table. From this starting point, write down pairs of consecutively selected numbers which fall within the range of plot diagram coordinates. For example, if on the plot diagram, rows are numbered 00 to 10 and columns 00 to 50, only two digits from each group of three in the table need be used. Thus, 204 may be read as 20 or 04 depending on which two are chosen. The same two (first or last) should be selected from each number group, moving through the table as if reading a book or reading down each column. Only numbers falling in the range of the rows and column may be chosen, those outside should be discarded. For example, if the second two digits were chosen from each group, selections in the random number table locating five sample positions might look as follows:

204 817 931 610 828 088 001 198 721 320
509 001 457 900 542 390 637 012 319 991

From these selections, sample units would be taken at the following coordinate positions:

Row	Column
04	17
10	28
01	21
09	01
00	42

The five coordinate pairs selected would now be marked on the plot diagram. In the event duplicate pairs are selected, the second is discarded and a new pair is selected, continuing in the table from where the last selection was made. When the end of the table is encountered during selection, simply go back to the beginning of the table (or a new starting point) and continue on. After the initial sampling, care must be taken to avoid sampling the same core positions in later samples.

Random number table.

Numbers should be read proceeding from left to right, top to bottom. At the end of the table, return to the beginning and continue selections.

580	950	786	297	453	6	275	305	689	182	132	831	582	98	276
629	83	990	979	693	934	217	130	862	818	540	18	314	765	941
289	584	903	886	496	396	871	931	595	209	888	464	628	446	457
234	763	591	443	495	921	210	832	152	846	677	926	361	252	281
378	93	312	665	650	510	183	386	116	851	710	722	641	15	71
953	422	387	604	847	76	576	908	572	121	784	589	278	452	233
623	804	137	516	633	740	702	507	748	562	308	485	875	800	42
897	854	856	688	501	201	184	297	858	121	218	812	953	535	577
730	362	644	505	887	384	764	880	129	74	764	916	764	506	521
852	957	918	751	321	803	911	836	350	800	458	542	867	342	294
700	47	189	66	85	739	529	491	186	372	36	185	919	694	623
945	955	595	523	336	237	589	627	414	445	670	190	602	522	605
269	850	147	504	305	378	180	263	815	103	981	3	292	51	218
524	104	536	590	747	45	66	75	409	441	795	404	759	412	438
119	557	611	654	727	200	937	349	90	992	278	447	679	187	154
795	954	123	421	23	677	34	273	581	164	597	205	808	339	348
68	60	205	137	819	256	316	257	53	60	635	827	307	692	522
912	778	318	450	587	323	415	567	41	80	526	653	650	948	608
942	906	626	728	331	873	392	209	583	421	850	331	297	565	341
336	939	518	624	379	554	258	283	198	474	983	522	32	326	441
304	635	810	77	519	300	366	808	138	502	268	154	265	137	479
883	324	75	564	302	753	871	911	160	323	493	765	701	294	731
247	997	185	955	298	950	134	856	898	487	72	952	969	42	869
727	39	402	999	322	345	951	4	303	998	27	489	180	757	993
576	473	670	352	604	49	383	157	694	535	997	516	950	546	460
540	166	444	80	832	748	972	665	803	81	482	919	902	950	959
38	259	269	756	221	478	620	62	549	797	26	568	149	696	450
737	508	40	256	248	18	191	265	624	491	939	507	405	972	310
757	378	299	535	619	844	341	295	447	498	687	192	224	520	953
749	997	692	217	273	960	948	902	104	494	256	523	99	491	347
980	18	225	805	677	709	234	600	994	758	682	372	9	469	202
729	587	602	213	495	883	32	185	126	9	179	688	353	371	429
670	153	389	368	969	360	625	255	496	18	641	23	688	815	975
966	136	954	33	269	27	301	366	227	870	777	703	465	608	487
741	53	748	740	120	188	571	794	289	157	353	458	683	694	114
130	242	477	797	228	472	297	414	447	976	271	189	642	555	979
860	352	638	479	23	792	212	282	900	324	399	213	512	583	968
140	551	305	626	311	774	893	48	796	773	510	876	786	182	249
737	323	376	251	586	825	813	666	201	500	52	422	686	661	19
3	559	899	336	975	75	193	591	876	389	48	958	324	0	645
795	655	670	373	37	37	863	881	757	498	287	383	954	556	805
132	225	618	774	155	487	839	665	980	713	133	900	690	932	944
490	338	296	894	951	43	430	504	752	995	20	512	252	386	593
884	775	932	151	660	489	294	791	530	607	218	436	314	822	480
79	574	641	669	32	125	535	130	751	235	804	784	388	532	155
486	890	900	941	647	236	460	507	541	23	940	270	517	682	628

continue on next page...

Random number table (continued),

53	636	144	432	368	775	726	486	186	246	851	905	122	683	240
700	787	555	218	38	441	86	481	885	392	671	308	991	223	758
667	910	735	758	821	584	189	484	966	644	198	808	412	27	660
311	431	392	887	326	553	221	201	545	983	502	568	799	625	872
287	129	477	889	611	325	978	721	719	986	232	69	374	127	277
163	530	672	48	341	134	925	277	371	435	396	852	441	685	251
453	716	606	989	572	665	139	772	521	892	681	850	254	969	275
562	911	583	338	183	65	962	899	989	607	869	665	16	534	952
252	510	551	737	737	557	884	383	386	143	906	192	438	353	773
983	738	758	7	375	522	527	891	883	760	558	678	965	259	30
508	678	531	241	887	819	747	433	561	113	669	322	284	400	32
147	687	531	649	959	230	9	713	338	800	669	785	347	260	146
482	896	384	619	702	396	703	556	333	945	593	936	950	848	289
573	746	251	594	894	993	400	106	360	115	715	259	767	588	595
117	457	57	805	387	808	290	394	720	753	956	326	84	226	159
299	469	591	176	367	725	983	166	779	46	177	889	556	145	633
134	492	3	770	258	918	239	686	858	381	487	365	988	715	116
140	852	259	353	657	824	537	262	820	544	887	514	8	566	730
850	80	329	185	307	10	498	927	417	182	968	568	867	906	877
992	547	313	215	868	155	746	200	111	51	716	336	830	336	576
462	74	280	818	359	355	331	336	447	949	818	492	406	646	667
300	328	435	707	749	398	937	172	13	449	56	706	156	684	539
147	613	125	212	741	203	804	425	211	272	662	741	804	569	668
282	404	189	497	211	981	924	789	655	677	152	481	586	104	388
37	750	981	142	780	213	719	187	517	199	481	789	730	248	641
307	774	689	218	693	205	691	281	85	22	867	649	705	632	126
264	707	794	269	2	215	803	66	550	469	265	285	271	346	931
476	330	434	34	278	921	624	160	593	413	754	754	929	0	326
826	599	628	453	204	824	374	104	206	995	979	853	138	942	158
880	409	700	824	107	838	385	186	155	206	958	328	440	209	146
694	2	258	43	722	708	543	91	278	942	133	588	618	809	724
355	639	751	871	990	642	211	707	78	881	936	576	946	276	543
479	785	304	221	602	557	214	690	539	784	25	822	380	767	251
232	47	699	267	638	788	73	870	356	364	42	540	671	168	471
834	476	603	664	206	97	717	573	359	858	87	831	431	346	927
580	137	411	273	762	407	391	123	517	549	586	767	542	975	142
834	650	838	978	402	326	413	447	881	458	840	723	203	624	165
627	481	821	64	195	185	159	645	831	564	254	464	780	461	462
29	688	686	97	198	633	80	786	53	820	541	447	990	345	268
351	368	745	44	477	393	367	412	115	837	513	286	414	311	770
190	426	472	140	414	27	609	598	602	853	285	483	570	894	418
557	517	403	353	659	487	12	957	218	439	34	789	431	212	504
845	146	780	996	36	204	627	205	149	524	820	39	55	353	47
842	9	870	812	862	467	564	147	465	857	328	370	437	592	681
806	905	933	780	289	944	584	301	199	710	768	693	379	39	494
893	551	37	334	100	664	61	81	710	437	386	143	540	463	490
586	80	369	699	698	38	414	608	435	859	642	537	667	343	383
792	959	946	968	970	431	681	531	231	728	671	468	600	393	155
831	96	968	732	861	828	459	712	172	323	813	57	485	19	574
210	824	121	709	539	817	646	993	693	383	219	379	62	694	794
179	311	503	579	46	553	228	576	751	636	843	930	447	24	676
881	398	264	783	945	226	629	90	383	936	893	520	288	862	720
866	935	420	575	258	938	123	746	252	382	267	22	182	363	310
491	995	324	789	652	392	80	175	881	608	57	361	637	674	944