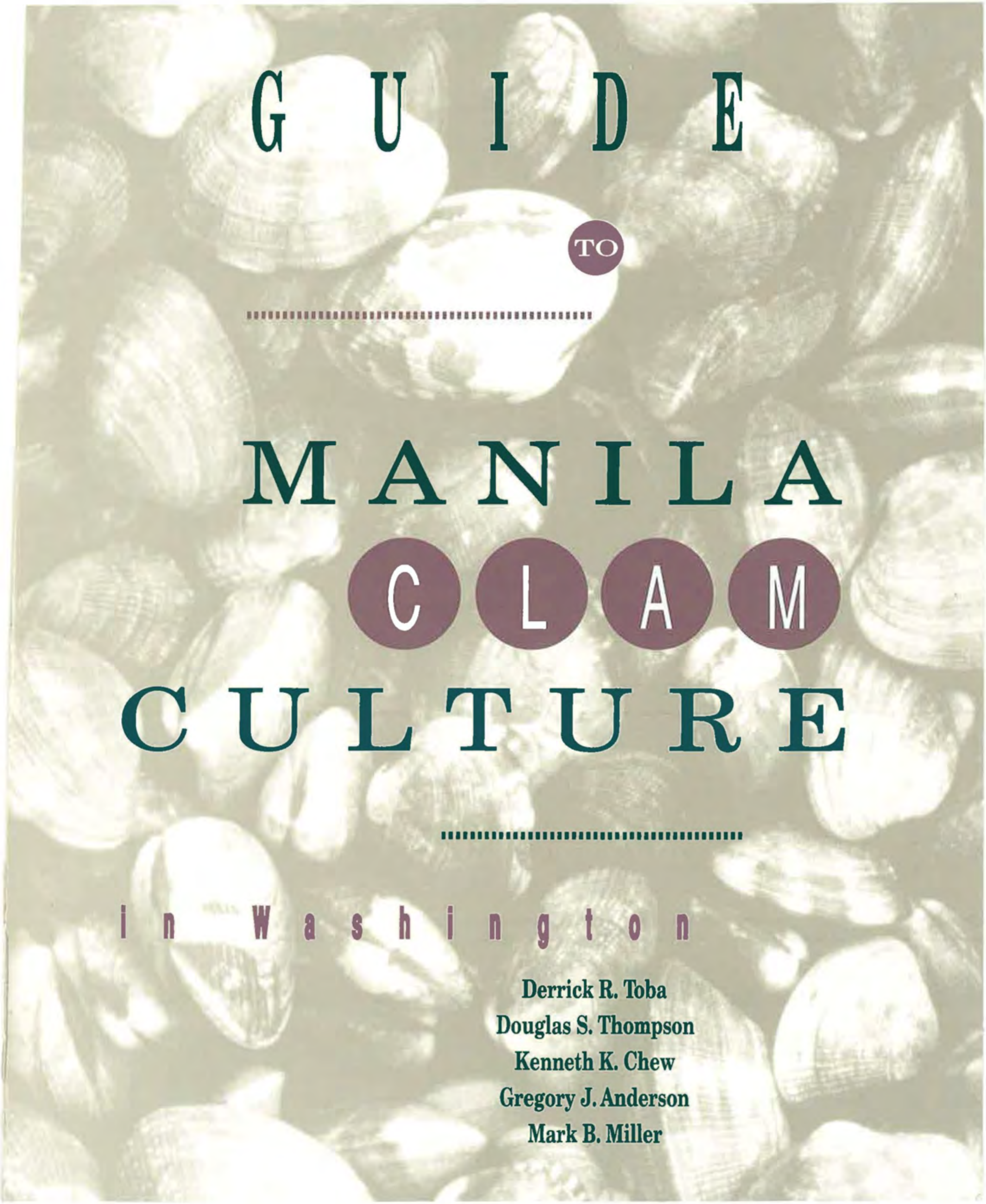

GUIDE TO MANILA CLAM CULTURE in Washington

Derrick R. Toba
Douglas S. Thompson
Kenneth K. Chew
Gregory J. Anderson
Mark B. Miller

Guide to Manila Clam Culture in Washington

Guide to Manila Clam Culture in Washington

Derrick R. Toba
Douglas S. Thompson
Kenneth K. Chew
Gregory J. Anderson
Mark B. Miller

Washington Sea Grant Program
University of Washington

The work from which this guide was derived is the result of an appropriation from the Washington state legislature for shellfish studies conducted by the Washington Sea Grant Program (project R/SH-2). Additional support was provided by a grant (No. NA89AA-D-SG022) from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, to the Washington Sea Grant Program (projects R/A-16 and A/PC-5).

First published in 1992 by Washington Sea Grant Program, University of Washington.

Library of Congress Cataloging-in-Publication Data

Toba, Derrick R., 1965–
Guide to Manila clam culture in Washington / Derrick R. Toba, Douglas S. Thompson, Kenneth K. Chew ; with contributions by Gregory J. Anderson, Mark B. Miller
p. cm.
Includes bibliographical references.
ISBN 0-934539-16-2 : $10.00
1. Clam fisheries—Washington (State) 2. Manila clam—Washington (State) I. Thompson, Douglas S., 1948– II. Chew, Kenneth K. III. Title.
SH373.2.U5T63 1992
639'.44'09797—dc20

92-14055
CIP

Contents

Preface

This guide is the third Washington Sea Grant publication to focus on the farming of Manila clams in Puget Sound. In 1978, Mark Miller, Kenneth Chew, Chris Jones, Lynn Goodwin, and Doug Magoon, the authors of *Manila Clam Seeding as an Approach to Clam Population Enhancement* (WSG 78-2), proposed the Manila clam as a candidate for aquaculture and listed guidelines for planting hatchery-produced clam seed.

Four years later, Gregory Anderson, Mark Miller, and Kenneth Chew updated the original publication. In *A Guide to Manila Clam Aquaculture in Puget Sound* (WSG 82-4), they presented the results of studies on the use of predator netting and addressed questions that were asked frequently by those interested in growing Manila clams.

Guide to Manila Clam Culture in Washington follows in that tradition: it updates the information that appeared in the earlier Sea Grant publications and adds recent information on culture techniques of Manila clams. It includes work done by the University of Washington, the Washington Department of Fisheries, and members of the industry . Their cooperation made this report possible.

Acknowledgments

The authors would like to thank the Washington Sea Grant Program, the Washington Department of Fisheries, and the University of Washington School of Fisheries for funding this project. We would also like to thank the advisors to this project—Dr. Neil Bourne, Richard Burge, and Al Scholz.

We are grateful to our many reviewers for their helpful comments: Hal Beattie, Washington Department of Fisheries; Dale Bonar and Kenneth Brooks, Pacific Rim Mariculture; Michael Castagna, Virginia Institute of Marine Science; Bill Dewey, Rock Point Oyster Company; Jim Donaldson, Coast Oyster Company; Sandy Downing, University of Washington; Duane Fagergren, Calm Cove Oyster Company; Lynn Goodwin, Washington Department of Fisheries; Christine Hodgson, North Island Aquaculture Resource Center; John Kraeuter, Rutgers University; Ted Kuiper, Kuiper Mariculture, Inc.; Bob Malouf, Oregon Sea Grant; Mary McCallum, Washington Department of Health; Harry Miller, University of Victoria; Dick Poole, Sound Sea Farms; Dan Quayle, Fisheries Research Board of Canada; Don Rogers, Olympia Clams, Inc.; John Spence, British Columbia Aquaculture Research and Development Council; Mary Lou Taylor, Washington Department of Health; Paul Taylor, Taylor United, Inc.

Our thanks to Taylor United, Olympia Clams, Inc., Dahman Shellfish Company, and WDF Point Whitney Shellfish Laboratory for contributing photographs or allowing us to photograph their facilities. Sandra Noel drew the illustrations of clam predators and the internal structure of the Manila clam. Special thanks to Alma Johnson, Sea Grant editor, and Vicki Loe, Sea Grant graphic designer.

1. Introduction

The Manila or Japanese littleneck clam, *Venerupis japonica* (Deshayes), was accidentally introduced into Puget Sound during the 1930s and 1940s with shipments of Pacific oyster seed from Japan (Chew 1989; Quayle 1938, 1988). Since its introduction, the clam has become established throughout the Puget Sound region (Figure 1); many small clam farms now harvest Manila clams on the beaches of the sound, as well as in Hood Canal, Sequim Bay, Discovery Bay, Willapa Bay, and Grays Harbor. It is the area's most important steamer clam both in aquaculture and in recreational fisheries. The Washington Department of Fisheries has estimated that 3.4 million pounds of Manila clams were harvested commercially in Washington in 1990. Even if present production were doubled it would not meet current market needs (W. Taylor, Taylor United, Inc., personal communication).

The culture of Manila clams helps to meet increasing market demands by supplementing supply of wild stocks. Culture includes the planting, cultivation, and harvest of natural or hatchery-produced clam seed for personal use or for sale. Seeding clam beds ensures that there is a consistent supply, without the low abundances in some year classes that commonly occur with natural production. Manila clam seed can be purchased from hatcheries, a practice that provides a more consistent, reliable supply of seed than natural recruitment does. Cultivation increases yield and shortens the time between harvests.

The Manila clam is well suited to culture. It grows rapidly and so can be harvested within two or three years of planting. Because it grows at a higher tidal level than native hardshell clam species and burrows to a shallow depth within the substrate, it is easier to harvest. Its marketability is enhanced by the relatively long shelf life of 7–10 days.

This guide covers Manila clam production from hatchery to harvest (Figure 2). We begin with a description of the biology of the Manila clam and the environmental factors that affect Manila clam production, because we consider such information to be essential to a successful culture operation. The hatchery section covers broodstock conditioning, spawning, and larval rearing to setting size, at which point they can be shipped to growers for remote setting. Algae

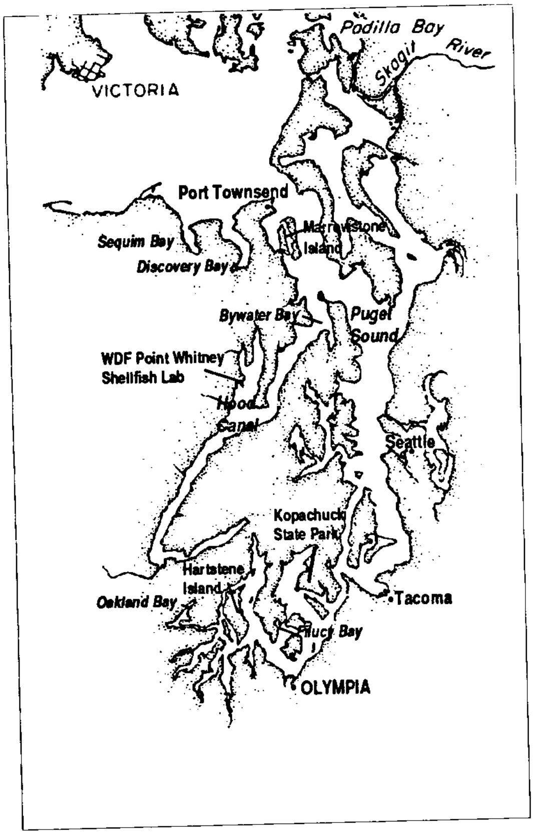

Figure 1. Puget Sound region.

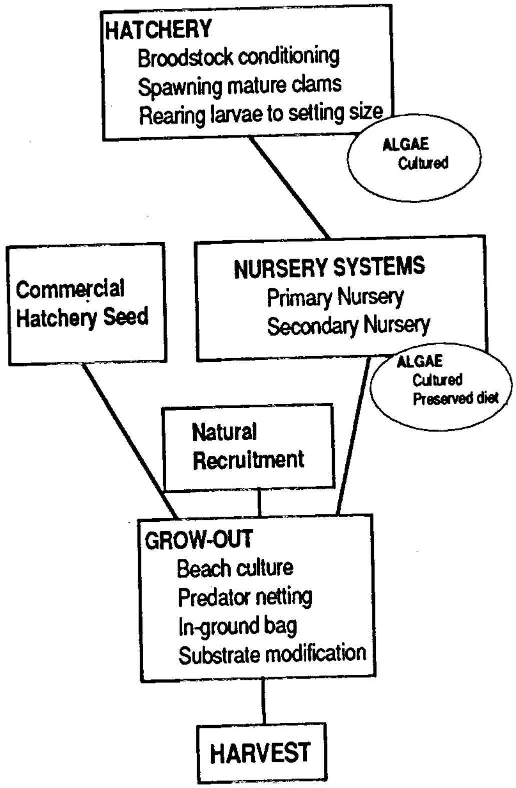

Figure 2. Processes involved in Manila clam production.

culture is discussed for growers who wish to grow their own algae for remote setting and nursery culture of juveniles. The nursery section covers primary nurseries, for rearing clams to 1 mm length, and secondary nurseries, for growing small clams to planting size. The grower can also obtain seed at a size ready for planting directly from the hatchery to supplement natural recruitment.

Beach culture, predator exclusion netting, and in-ground bags are described, as are ways to increase natural recruitment by substrate modification and structures. Finally, we cover briefly some of the "paper" aspects of Manila clam culture, including record keeping, permits, and costs.

The information in this guide is tailored to the Pacific Northwest, but it may be useful in other geographic locations and for other species of clams. Conversely, growers in this region may also be interested to read about methods used in others countries. We direct their attention to recent manuals that focus on clam culture in Italy (Alessandra 1990), France (deValence and Peyre 1989), and the United Kingdom (Spencer et al. 1991).

The aquaculture industry uses metric and English units of measure interchangeably. Readers encountering one expression of measure where they wish the other can refer to the conversion table given in Appendix A.

2. Biology

The manila clam, also called the Japanese littleneck clam, belongs to the family Veneridae. It appears in the literature under a variety of names including *Tapes semidecussata*, *T. japonica*, *T. philippinarum*, *Venerupis semidecussata*, *V. philippinarum*, *V. japonica*, *Paphia philippinarus*, *P. bifurcata*, and *Ruditapes philippinarum*.

Anatomy

The Manila clam has an elongate shell with oval valves, well-defined radiating ribs, and less prominent concentric ridges (Figure 3). The radiating ribs can be heavy and conspicuous at the posterior end. External shell color varies greatly; most are off-white or buff with patterns of wavy brown or black bands and blotches on their sides. The clam can attain a shell length of up to 3 inches (Fitch 1953; Quayle 1964). The interior of the shell is smooth and normally tinged with purple.

Figure 3. Manila clam, Venerupis japonica.

The age of the Manila clam can be seen on the shell in the form of rings, called checks, which develop in the winter, when growth slows due to low water temperatures, less available food, and slower metabolism. Checks can also be caused by environmental or biological stress, for example, by the disturbance of a big storm or from spawning.

The internal structure of the Manila clam is shown in Figure 4. The mantle completely surrounds the soft body parts and secretes the shell. At the posterior end, the mantle is fused to the siphons. The lower, incurrent siphon and the upper, excurrent siphon channel water into and out of the mantle cavity. The most visible feature within the mantle cavity is a hatchet-shaped foot, located between a pair of gills. Two pairs of small labial palps are located at the anterior end of the foot and mark the entrance to the mouth. The foot can be extended outside the shell to dig and to move the animal. The gills are used for respiration and feeding. As water is brought over and through the gills, small hairlike structures called cilia filter the food and transfer it forward to the labial palps. The palps are small flaps of tissue that sort the filtered food particles that enter the mouth. The visceral mass located above the gills contains the digestive diverticula, gonads, heart, and kidney. Adductor muscles located at either end of the animal close the shell and keep it shut. The physical structure of the hinge keeps the valves apart when not being opposed by the adductor muscles.

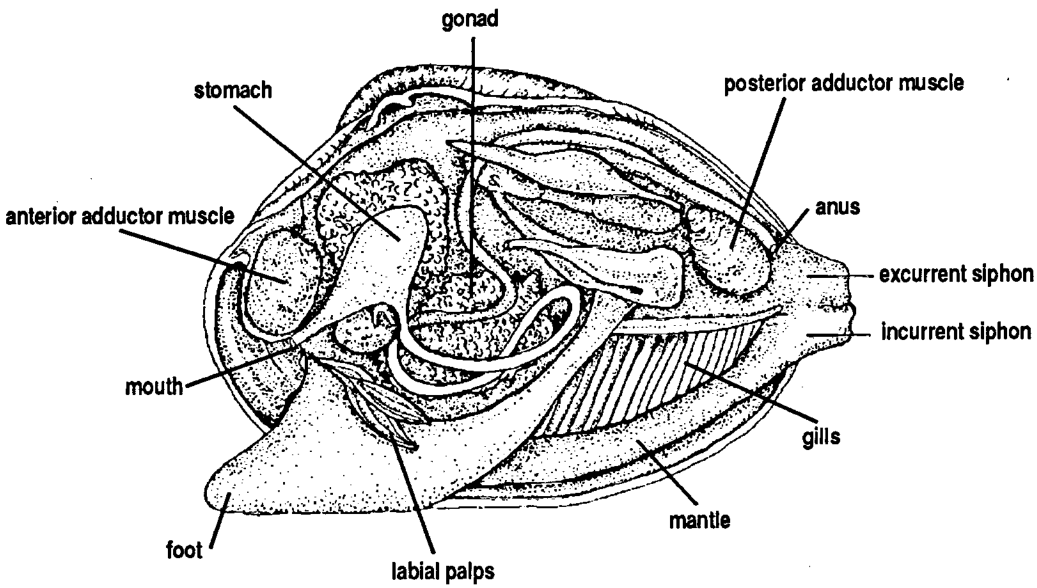

Figure 4. Internal structure of the Manila clam.

Sexual Maturity and Spawning

Manila clams have been shown to initiate gonadal development at 5–10 mm (1/4–3/8 inch) shell length and reach sexual maturity at a shell length as short as 15 mm (5/8 inch) (Holland and Chew 1974). It was also noted that some clams started to spawn at 21 mm (3/4 inch) shell length. Clams of this size would be approximately two years old and in their second growing season.

Spawning occurs when males and females release sperm and eggs into the water column. The spawning season for Manila clams extends from May to September in Puget Sound and from June to July in Hood Canal (Nosho and Chew 1972). According to Holland and Chew (1974), females spawn once during the summer, with no apparent second maturation of gametes. Males, on the other hand, release a large portion of their gametes and quickly redevelop to maturity during the same season. The marketability of Manila clams is not affected by its spawning condition, as is often the case with oysters.

Larval Development

Larval development from egg to metamorphosis takes from two to four weeks (Cahn 1951, citing Miyazaki 1934); the exact duration depends on temperature and food (Yoshida 1935; Cahn 1951; Ohba 1959; Quayle and Bourne 1972). The larvae swim and feed in the water column with an organ called the velum. At this stage they are called veliger larvae. Larvae settle when they reach 165–235 μm (microns) shell length (Williams 1978; Ohba 1959; Yoshida 1935).

Metamorphosis and Settlement

When the larvae are ready to settle, they actively search the substrate with their foot for a place to attach. Larvae attach to a pebble or piece of shell with a byssal thread secreted from the foot. This holds the juvenile clams to the substrate while they go through metamorphosis. During metamorphosis, they lose the velum and the gills form rapidly. Williams (1980) reported that settlement occurs throughout summer and fall in southern Puget Sound. As the clam grows, it burrows into the substrate and no longer needs to be anchored.

Growth

Many studies have been made on the growth rates of Manila clams in British Columbia and Washington (Nosho and Chew 1972; Quayle and Bourne 1972; Jones 1974; Miller et al. 1978; Glock and Chew 1979; Anderson 1982; Bourne 1982; Miller 1982). There is ample evidence that growth is dependent on food availability and temperature, factors that vary from location to location (Williams 1980).

Clam growth rates for various beaches in Puget Sound are shown in Table 1. Highest growth rates were attained in the southernmost reaches of Puget Sound, where water temperatures are relatively high and the food supply is constant. Most of the clams planted in southern Puget Sound reach minimum marketable size (38 mm, or about 1 1/2 inches) by the end of the second growing season, or 18 months after a springtime planting.

Table 1. *Average shell length attained by planted Manila clams at Puget Sound study sites after each of several growing seasons. Shell length at spring planting was 3–5 mm (1/8–1/4 inch). (Modified from Anderson et al. 1982)*

Study Site	Growing Season 1	2	3	4	5
NORTH PUGET SOUND					
Westcott Bay	18 mm	29 mm	—	—	—
CENTRAL PUGET SOUND					
Clam Bay	14 mm	26 mm	34 mm	—	—
Filucy Bay	18 mm	28 mm	—	—	—
Marrowstone Island	12 mm	23 mm	30 mm	—	—
SOUTH PUGET SOUND					
Kopachuck State Park	19 mm	32 mm	—	—	—
Hartstene Island #1	18 mm	38 mm	47 mm	51 mm	53 mm
Hartstene Island #2	25 mm	41 mm	—	—	—

3. Factors Influencing Production

When selecting a site for commercial production of Manila clams, growers should be aware of the environmental factors that influence clam survival and growth. These factors include such physical characteristics as tidal level, substrate type, wave exposure, temperature, and salinity. Biological factors that influence clam production are food availability, movement and dispersal, predation, competition, pests, and disease. Pollution and paralytic shellfish poisoning are factors that affect the harvestability of clams.

PHYSICAL FACTORS

Tidal Level

The amount of air, competition, and predation that Manila clams are exposed to is directly related to the tidal level at which they occur. Natural Manila clams are most abundant at 3–6 feet above mean lower low water (MLLW). Below that range, they are vulnerable to various predators and may have to compete for space with other species of hardshell clams. Above it, they are exposed to the air too long and their growth rate declines considerably.

To choose the most appropriate planting zone on a given beach, some trial and error may be necessary. The presence of natural Manila clams on a beach may aid in finding a suitable area. Methods for determining tide level are outlined in Appendix B.

Substrate

According to some researchers (Cahn 1951; Higurashi 1934; Icho and Oshima 1938), the best bottom sediment for growing Manila clams contains 50%–80% sand. Jones (1974), however, reported high survival of clams planted on beaches with primarily a shell substrate or a combination of gravel and sand.

In our opinion, the ideal substrate is a stable, loosely packed substrate consisting of gravel, sand, mud, and shell (Miller 1982). Stability is important because Manila clams cannot live in a constantly changing sediment (Kurashige 1942). Suitable beaches are usually found in relatively protected bays or inlets.

Beaches of tightly packed cobble, hardpan, and soft mud are totally unsuitable for clam culture. Packed cobble and hardpan prevent the clams from burrowing. In soft mud, Manila clams have difficulty maintaining their position and keeping their gills clean (Kurashige 1942; Loosanoff 1961; Bardach et al. 1972).

If a site does not naturally have the necessary substrate to support Manila clams, the grower may choose to provide it. A later section of this guide describes ways to modify the substrate.

Wave Exposure

The degree of wave exposure affects stability and substrate composition of a beach. Clam seed will not survive on beaches exposed to a high degree of wave action. The fine sediment that holds gravel and sand together washes away, leaving a loose deposit of gravel and sand. As the beaches shift, clam seed are buried, washed away, or crushed.

Sheltered beaches retain silt and other fine sediment, resulting in a more compact mix of larger gravel, sand, mud, and shell. These beaches, being more stable, have shown higher production of clams. A later section of this guide discusses structures to enhance clam settling.

Temperature

Optimal water temperature for the Manila clam is 73°–75° F (Bardach et al. 1972), but the cooler waters of Puget Sound have not prevented the species from becoming widespread. Seasonal water temperature fluctuations in Puget Sound are within the tolerance limits for Manila clams. Summer water temperatures in central Puget Sound seldom rise above 62° F. The average summer water temperatures for southern Puget Sound and Hood Canal are 70° and 71° F, respectively (Washington Department of Natural Resources 1974). Warmer water and good phytoplankton productivity may explain why Manila clams grow bigger and more abundantly in southern Puget Sound than in other areas.

Hard winter freezes can be lethal to Manila clams if the freezes are coupled with low tides. Such mortalities normally are not apparent until late winter or early spring (W. Taylor, Taylor United Inc., personal communication; Bower et al. 1986). Adverse effects of extreme temperatures can be minimized by not planting at high tidal levels.

Salinity

The optimum salinity range for Manila clam growth is 24–32 ppt (parts per thousand) (Bardach et al. 1972), but they can tolerate salinities as high as 35 ppt and as low as 13.5 ppt for periods of at least 40 days (Higgens 1969). Salinity monitoring and historical records show that the salinity of Puget Sound is within the reported tolerance range for Manila clams (Washington Department of Natural Resources 1974). However, areas near the mouths of rivers or streams may have salinities that are too low for Manila clams.

BIOLOGICAL FACTORS

Food Availability

Manila clams feed on phytoplankton. Because the central basin of Puget Sound produces more phytoplankton annually than the southern reaches (Winter et al. 1975), one might expect that Manila clams would grow better in the central basin. However, the opposite is true: Manila clams grow faster and bigger in the south.

The reason for this apparent anomaly may lie in the patterns of phytoplankton growth, which are different in the two areas. In the central basin, phytoplankton increase in a series of intense blooms that begin in late April or May and continue through the summer. In south Puget Sound, phytoplankton production is fairly uniform from March through September. It appears, then, that Manila clams grow better when a moderate food supply is consistently available over long periods than when a lot of food is available sporadically for shorter periods.

Movement and Dispersal

Clams do not always stay where you put them. Experiments with marked clams found the clams close to but outside their planting areas (Miller 1982), an indication that wave or current activity causes dispersal. Even in seemingly sheltered areas, waves and scour from boat wakes can move newly planted clam seed. Clams may also redistribute themselves in response to high planting densities, but no experiments have been conducted to test this possibility.

The movement or dispersal from the planting area can greatly reduce the expected harvest. It may be possible to erect a damping system to reduce wave impact (Kraeuter and Castagna 1977). The best approach is to select areas away from high currents and boating activity.

Predation

Manila clams attract a wide variety of predators. Some of them, such as scoter ducks, are easy to spot, but often the broken, chipped, or empty shells are the only evidence that predators are at work.

Moon Snails—The moon snail, *Polinices lewisii* (Figure 5), drills a countersunk hole in the clam shell and inserts its proboscis to consume the soft

Figure 5. Moon snail, Polinices lewisii, *shell and egg case.*

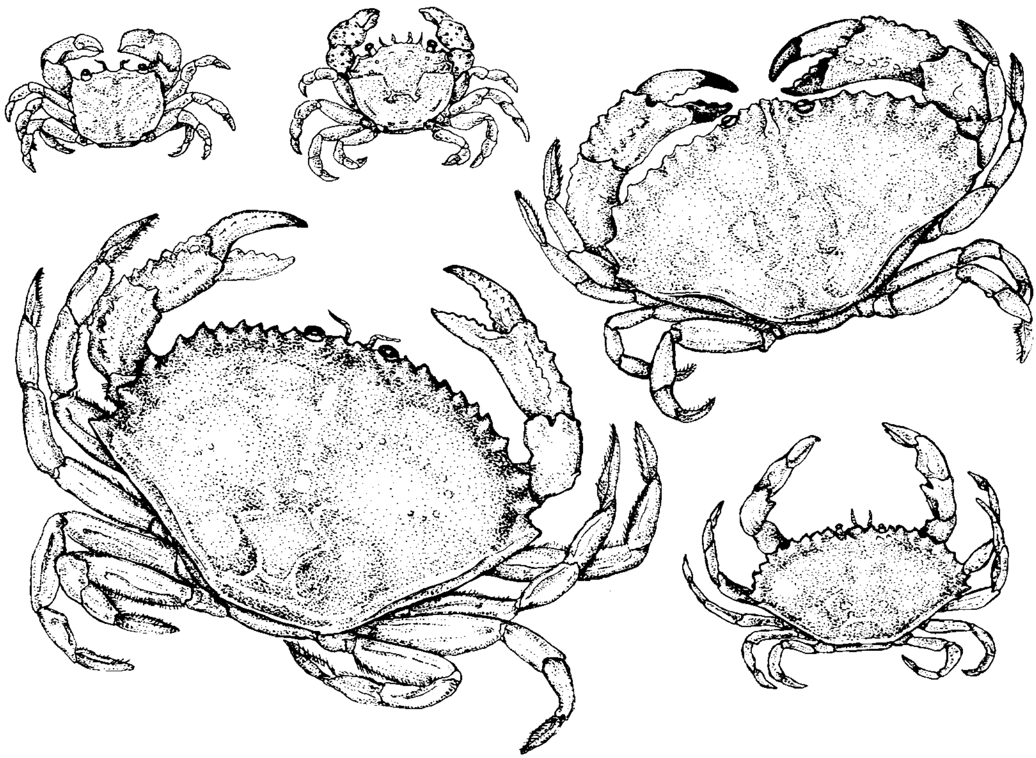

Figure 6. Crab predators of the Manila clam: (clockwise, from upper left) *purple shore crab* (Hemigrapsus nudis); *green shore crab* (H. oregonensis); *red rock crab* (Cancer productus); *graceful crab* (C. gracilis); *Dungeness crab* (C. magister).

tissues. The size of clam on which a moon snail preys depends on the shell size of both predator and prey. Rogers and Rogers (1989) found that moon snails cannot bore into a Manila clam shell larger than the maximum diameter of its own shell, which may be between 1 and 4 inches.

Moon snails are often subtidal, with a large population adjacent to the intertidal zone, so removing them from intertidal areas has little impact on the total population (D. Rogers, Olympia Clams, Inc., personal communication). Since the early life stage of this snail is planktonic, removal of adults and egg collars does not permanently eliminate moon snails.

Growing the clams in mesh bags offers a considerable degree of protection from moon snails, and this culture method is described later in the guide. Installing a netting barrier (sunk 1 foot into the substrate and projecting above for several inches) may prevent snails from moving into a planted area. However, the simplest way to avoid heavy moon snail predation is to plant clams at a tide level (2–4 feet above MLLW) where the snails are not present or active.

Crabs—Crab species are serious predators of Manila clams (Figure 6) (Miller 1982). The red rock or black-clawed crab *(Cancer productus)* appears to be the most significant crustacean predator, but the graceful crab *(C. gracilis)* is also a serious threat. In laboratory tests, both crab species opened and consumed Manila clams (Miller 1982).

The Dungeness crab *(Cancer magister),* common in the central and northern areas of Puget Sound, may be a predator on the Manila clam (Gotshall 1977). Small purple and green shore crabs *(Hemigrapsus nudis* and *H. oregonensis)* preyed upon Manila clam seed in the laboratory (Bourne and Lee 1973), but such predation has not been observed in the field. Observations suggest that the common kelp crab *(Pugettia producta)* may also be a predator .

Fish—Manila clams are eaten by several species of fish including the rock sole *(Lepidopsetta bilineata),* English sole *(Parophrys vetulus),* starry flounder *(Platichthys stellatus),* and pile perch (*Rhachochilis vacca*) (Figure 7). Clams eaten by fish tend to be smaller than 20 mm. In many areas, planted clams may grow large enough to escape fish predation by the end of their first growing season.

Birds—Among the bird predators, gulls and crows feed on Manila clams at or near the substrate surface, but more significant than these in the destruction of natural beds are three duck species that winter in the inland marine waters of Washington: white-winged scoter *(Melanitta fusca delgandi),* surf scoter *(M. perspicillata),* and black scoter *(M. nigra americana)* (Figure 8) (Bourne 1984).

Numerous small pits and depressions in the substrate indicate that ducks have been feeding on clams. All three species of scoter consume Manila clams, with predation by white-winged and surf scoters being the heaviest (Glude 1964). Scoters feed most heavily from November to March, and they appear to feed

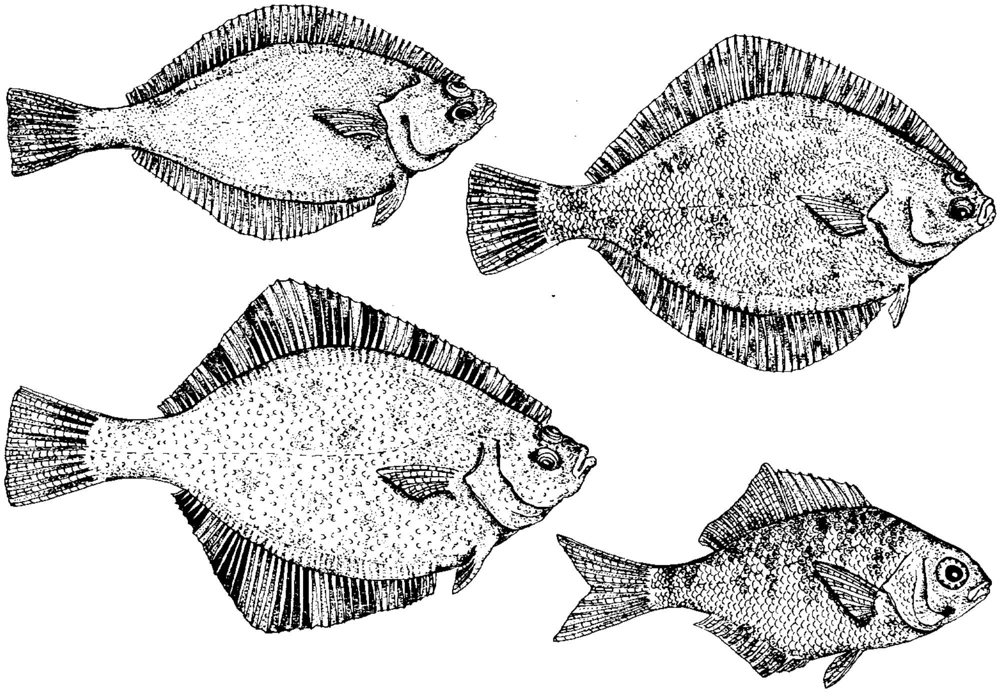

Figure 7. Fish predators of juvenile Manila clams: (clockwise, from upper left) *English sole* (Parophrys vetulus); *rock sole* (Lepidopsetta bilineata); *pile perch* (Rhachochilis vacca); *starry flounder* (Platichthys stellatus).

mainly on small clams, decreasing the Manila clam population in the 1/4–3/4 inch range. Few clams longer than 1 inch were taken (Glude 1964), although white-winged scoters have been known to ingest clams up to 2 inches long (Neil Bourne, Pacific Biological Station, personal communication). Scoters are considered to be the main predators of Manila clams in Japan (Bardach et al. 1972), where they were seen to consume as many as 52 small clams (<1 inch) per bird per day for 150 consecutive days (Cahn 1951).

Starfish—Four species of seastars—sun star *(Pycnopodia helianthoides),* mottled star *(Evasterias troschellii),* pink star *(Pisaster brevispinus),* and ochre star *(P. ochraceus)*—are occasionally found on Puget Sound beaches. According to Quayle and Bourne (1972), only the sun star and mottled star are serious clam predators. Since most starfish occur at tidal levels below productive areas, they probably do little harm to Manila clams.

Competition

Mussels, native littleneck clams, macoma clams, and barnacles are all found at the same tidal levels as Manila clams, or at overlapping tidal levels. In areas of low productivity, they may compete with Manila clams for food and space. Manila clams may also compete with each other in high densities. Effects

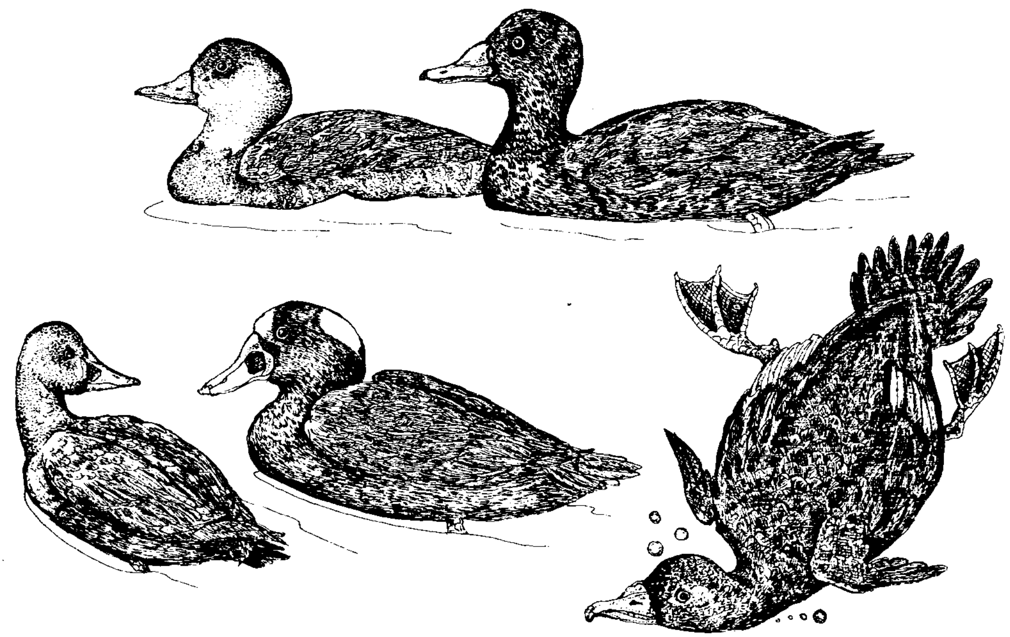

Figure 8. Major duck predators of the Manila clam: top, *black scoter* (Melanitta nigra americana); left, *surf scoter* (M. perspicillata); right, *white-winged scoter* (M. fusca delgandi).

of competition include decreased growth and lower survival. In many cases, such effects are hard to quantify because there is no direct evidence that can be measured in natural beds.

Pests

In certain locations, the mantle cavity of Manila clams may be inhabited by commensal pea crabs *(Pinnixa* sp). Because they live within the mantle cavity, they do not significantly harm their hosts or affect the edibility of clams. Mantle irritation does occur, but not enough to kill the host.

The sand dollar, *Dendraster excentricus*, can occur in high numbers on certain beaches. Their burrowing activity loosens substrate and undermines clams.

Ghost shrimp *(Callianasa* spp.) and mud shrimp *(Upogebia pugettensis)* are abundant in sand and fine sediment beaches. They compete with clams for space, and their burrowing activities contribute to the sediment instability that causes poor survival of small clams. These shrimp can also change a gravel-sand beach to an unstable sand-mud beach by bringing up fine sediment to the surface when they burrow.

Diseases

No major diseases have seriously affected Manila clams in Puget Sound. Hinge ligament disease, commonly found in other bivalve juveniles, has been found in hatchery-produced Manila clam seed (Elston 1990). Good hatchery management, however, can eliminate most hatchery-related disease problems.

There have been several isolated cases in which conditions were right to cause a single outbreak of a disease. In 1971, for example, an unknown sporozoan parasite was found in the digestive tract of more than 50% of the clams at Misery Point on Hood Canal (Holland 1972). Infection was light in most of the clams; however, heavily infected specimens failed to develop mature sexual organs. This parasite has not been a problem since the 1971 occurrence. Most of the diseases found in Manila clams have occurred only one or twice, when conditions were favorable. This does not rule out the possibility that this or any other disease can become a problem in the future.

It is important that the grower know the characteristics of the Manila clam in order to spot something out of the ordinary. For example, if clams are lying on the surface of the substrate rather than buried in it, it may indicate that something is irritating the clam. Unusual internal blotches on the mantle cavity may indicate a disease or parasite of some form.

Not all diseases or parasites have a negative impact on the survival of clams. Many disease organisms are killed when the clam is cooked, and others cannot be transferred to humans. Questions regarding diseased or dying clams can be directed to WDF Point Whitney Shellfish Lab or the University of Washington.

POLLUTION

Bivalves can filter bacteria and viruses present in the water column. Because clams are capable of pumping and filtering a large quantity of water, they can quickly concentrate microorganisms to levels harmful to humans. Contaminated shellfish may transmit enteric diseases such as hepatitis A, cholera, and typhoid fever to humans (Morse et al. 1986). Temperatures used to steam open soft-shelled clams *(Mya arenaria)* are inadequate to kill some species of viruses and render them harmless to humans (Morse et al. 1986). Shellfish should not be harvested from areas of high concentrations of viral and bacterial organisms, even if they are cooked prior to eating.

Two types of pollution sources have been identified by the Washington Department of Ecology (Saunders 1984). *Point* source pollutants come from pipes or other discharges that transport waste water to the bay. Because they enter a body of water at fixed locations, they can be measured. *Nonpoint* source pollutants are washed from the ground surface into streams and bays or enter through groundwater transport. Nonpoint pollution from unknown locations is often hard to detect and measure; it may come from farms, failing septic systems, urban storm water runoff, seal populations, or marinas.

The Office of Shellfish Programs (OSP) of the Washington State Department of Health (DOH) is responsible for monitoring and certifying areas for bivalve harvest. DOH certification is based primarily on the results of water column sampling, hydrological analysis, and shore sanitary surveys. The extent of bacterial pollution is measured by the concentration of fecal coliform bacteria, *Escherischia coli*. This bacterium is associated with the digestive system of humans and other warm-blooded mammals, and its presence indicates the potential for human viral and bacterial pathogens.

All shellfish harvesting locations must be approved by the DOH. Four types of sanitary classications have been established (U.S. Department of Health and Human Services 1986):

> **Approved**—Fecal material, pathogenic organisms, poisonous, and deleterious substances are not present in the area in harmful concentrations. Shellfish can be harvested from the area at any time.
> **Conditionally Approved**—Growing areas are subject to intermittent microbiological pollution. Harvest is conditional to predictable seasonal or weather-related events, such as sewage overflows resulting from winter storms. The period of closure varies and is based on local conditions.
> **Restricted**—Fecal coliform levels in restricted waters are such that shellfish can be grown in these waters but must be moved to an approved site where, over a period of time, they purge themselves of fecal coliform bacteria as a natural consequence of the feeding process.
> **Prohibited**—No commercial harvest of shellfish is permitted because of excessive concentrations of fecal material, pathogenic organisms, and poisonous or deleterious substances. Relaying for purposes of natural cleansing is not allowed.

Beaches are monitored each year to check on their condition. The classifications can be upgraded or downgraded depending on the results of these annual checks.

Of the commercial growing areas that were classified in Washington in 1989, 63% of the total acreage was classified as Approved, 20% as Conditionally Approved, 5% as Restricted, and 12% as Prohibited (see Table 2). Most of the Willapa Bay growing area was classified as Approved, while most of Grays Harbor was Conditionally Approved. In Puget Sound, 25% of the growing area was classified as either Restricted or Prohibited, and 28% of Grays Harbor was Prohibited. Clearly, a significant part of potentially commercial tidelands in

Table 2. For 1989, classification of Washington state commercial shellfish growing areas, in acres, rounded to nearest 5. (From Taylor 1989)

Area	Approved	Conditionally Approved	Restricted	Prohibited	TOTAL
Puget Sound	55,905	1,535	10,480	8,840	76,760
Grays Harbor	0	43,085	0	16,760	59,845
Willapa Bay	87,400	0	0	2,550	89,950
TOTAL	143,305	44,620	10,480	28,150	226,555

Washington cannot be used.

Between 1950 and 1970, most closures because of bacterial contamination were due to point sources of contamination, primarily sewage treatment plants. Since 1981, fifteen commercial growing areas totaling 16,113 acres in Washington have been reclassified downward by DOH due to bacterial contamination (Washington Department of Health 1990). Most of the recent closures were due to pollution from nonpoint sources. Shellfish farmers and the general public should be concerned by the increase in the rate of such closures. Any new area should be carefully examined for trends in pollution before the shellfish farmer commits any effort to grow-out. Fecal contamination, of course, is less of a problem at a hatchery or nursery.

Shellfish can be transferred from moderately polluted growing areas to unpolluted bodies of water and kept in clean holding sites until their contaminating microorganisms have been reduced to safe levels. This method of decontamination, called *relaying*, is regulated closely by the DOH to ensure that the eventual product is safe for human consumption. After holding shellfish for a specified period, new tests are run to determine if they are safe for harvest. During 1990 in Washington, there were five active relays and seven relay applications pending (Washington Department of Health 1990).

PARALYTIC SHELLFISH POISONING (PSP)

Paralytic shellfish poisoning (PSP) is an illness not of shellfish but of shellfish consumers. It is caused by eating filter-feeding bivalves that have fed on various microscopic dinoflagellates. In Washington, the chief cause of PSP is *Alexandrium catanella* (formerly known as *Gonyaulax catanella* and *Protogonyaulax catanella*). Under certain climatic and oceanographic conditions, *A. catanella* replicates rapidly to produce planktonic blooms on which the shellfish feed. The neurotoxin produced by this dinoflagellate, while not harmful to shellfish, is absorbed and accumulated within their bodies. It can cause severe illness and, in high concentrations, even death to humans and other warm-blooded animals.

The Washington Department of Health's Office of Shellfish Programs is responsible for monitoring and setting closures for commercial harvesting due to PSP. Some level of testing is conducted on all commercial shellfish growing areas throughout the year. The shellfish industry participates in testing by submitting samples from their harvest areas as required by the OSP certification program. If there are several growers in an area, only one grower may be required to submit samples, or two or more growers may alternate sampling. In most cases, results are reported within 48 hours. If the toxin level exceeds 80 μg (micrograms) of toxin per 100 grams of shellfish meat, a closure is mandated. Harvesting is allowed after two consecutive samples, taken at least a week apart, have toxin levels below 80 μg. Other factors considered in PSP closures are test results from nearby areas, species of shellfish tested, rates of toxification or detoxification, weather conditions, and time of year.

The economic impact of PSP is twofold. First, delays caused by closures affect harvesting and marketing schedules. Second, the announcement of PSP warning depresses shellfish sales, and sales may continue to suffer for several weeks or months, even after the warning is lifted.

Information is available through the PSP Program Coordinator at the Office of Shellfish Programs in Olympia (206-753-5964), or call the PSP Hotline (1-800-562-5632). The PSP Hotline provides information only on recreational beach closures, but it can give commercial growers an indication of which areas are affected.

4. Hatchery Seed Production

Many Manila clam growers use hatchery-produced clam seed to supplement inconsistent natural recruitment. This section gives the grower general information about the hatchery production of Manila clam seed. Growers wishing to gain a more detailed understanding of bivalve hatchery procedures may refer to Loosanoff and Davis (1963), Price and Mauer (1969), Breese and Malouf (1975), Dupuy et al. (1977), Castagna and Kraeuter (1981), Manzi and Castagna (1989), and Utting and Spencer (1991).

Growers wishing to set up their own remote setting and nursery system will find the discussion on algal culture, setting, and nursery systems helpful. Additional information on remote setting and nursery systems is found in Nosho and Chew (1991).

ALGAL CULTURE

Hatchery production of larval and juvenile bivalves requires a consistent, reliable supply of high-quality food in the form of algae. This section provides a brief overview of algae—their growth patterns, culture vessels, and requirements for nutrients, light, temperature, and salinity. Those wishing more specific information concerning the daily maintenance and growth of algae cultures can find it in Guillard (1975) and Bourne et al. (1989).

Species and Growth Patterns

Algae suitable for feeding Manila clam larvae are unicellular diatoms, *Chaetocerous calcitrans* (CC), *C. muelleri* (Chagra), and *Thalassiosira pseudonana* (3H), and a flagellate, *Isochrysis* aff. *galbana* (Tahitian variety, T-Iso). These algae increase by cell division.

When algae are introduced into large seawater containers infused with a fresh growth medium, they pass through three phases of growth: a lag phase, an exponential phase, and a stationary phase. The lag phase lasts for only a few hours as the algal cells absorb nutrients from the growth medium. The exponential phase of rapid cell division then begins, and cultures grow to their maximum cell densities. At this stage, algal cells are healthiest; cultures in this phase are fed to clam larvae and juveniles or are used to start new cultures. In the stationary phase, the culture stops growing and dies due to low light penetration and low nutrient levels.

Batch and Semicontinuous Culture

Algae are grown in both batch and semicontinuous cultures in a variety of containers. In batch culture (Figure 9), the entire culture is harvested as it enters the late exponential phase. Batch cultures are grown in transparent fiberglass columns or in open-top fiberglass tanks. In semicontinuous culture, only a portion of the culture is harvested, then the tank is refilled with sterile, nutrient-enriched seawater. Semicontinuous cultures are grown in sterile plastic bags that remain closed to airborne contamination (Figure 10). They can be

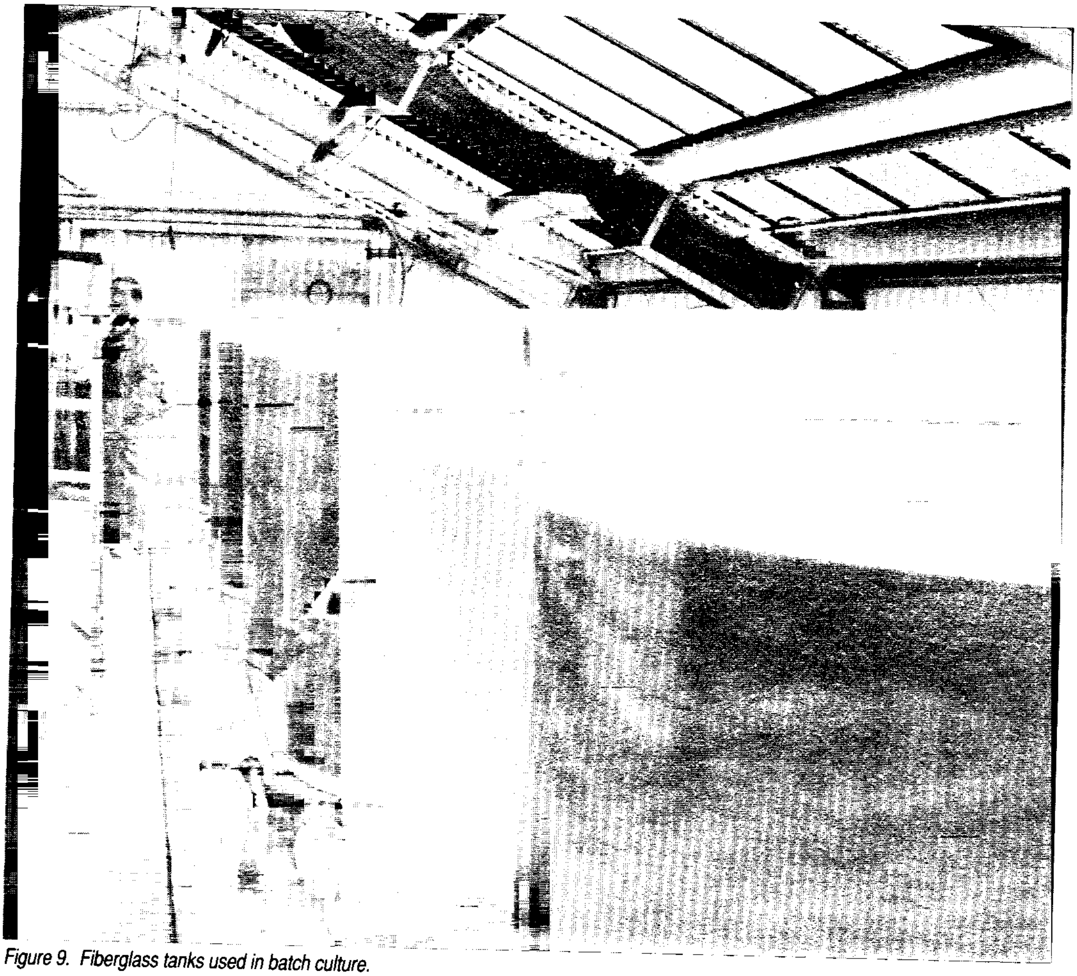

Figure 9. Fiberglass tanks used in batch culture.

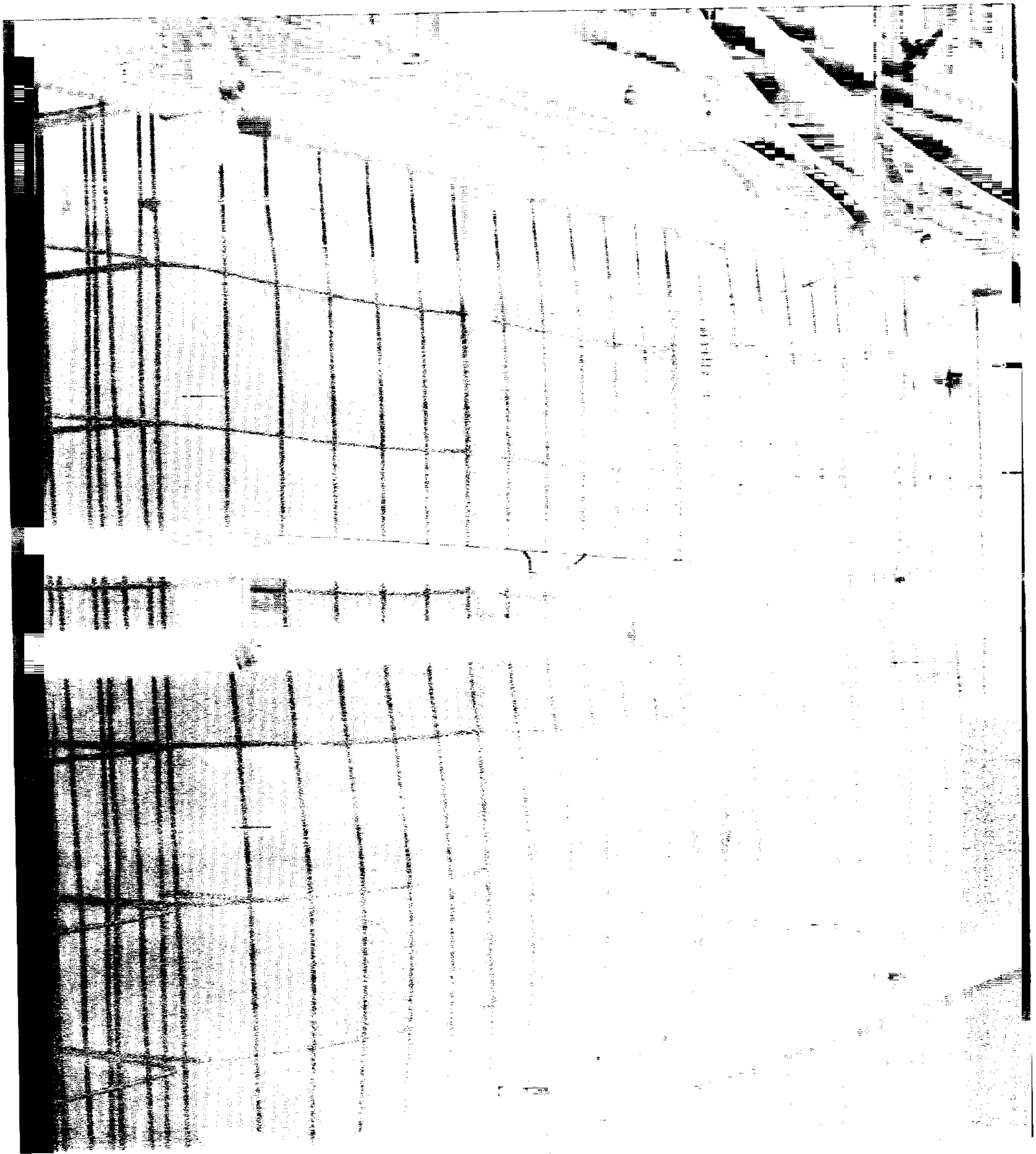

Figure 10. Plastic bags, 150-gallon capacity, used in semicontinuous culture.

maintained for as long as two months if they are kept free of bacteria (H. Beattie, WDF, personal communication).

Stock Cultures

Stock cultures of the algal species are maintained under sterile conditions in 500–1,000 mL flasks and are used for starting new cultures in small 1-gallon flasks or 5-gallon carboys (Figure 11). The flasks or carboys in turn are used to

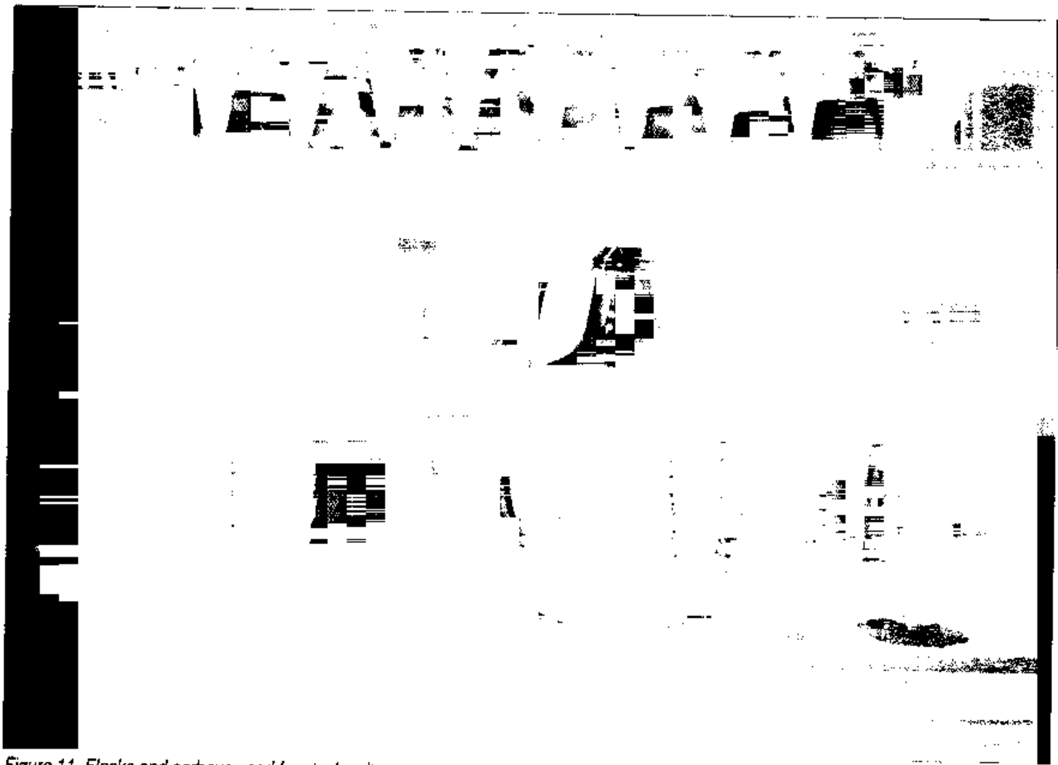

Figure 11. Flasks and carboys used for stock cultures.

start a new chain of transfers to larger containers: intermediate 150-gallon plastic bags and fiberglass columns, and large 1,000–6,500 gallon fiberglass tanks. To achieve maximum algal growth at each stage in the chain of transfers, stock cultures must remain clean and be kept at the exponential growth stage.

Starting and Maintaining Algal Cultures

To start an algal culture, seawater is filtered (<10 µm screen) to remove debris that would interfere with light penetration. The seawater is then sterilized to kill any bacteria or naturally occurring microalgae that would contaminate the culture.

The seawater is next inoculated with nutrients—nitrate, phosphate, silicate, vitamins, trace metals—and then with a stock culture of algae. Standard fluorescent bulbs (60 watt), high-intensity metal halide lamps (500–1,000 watt), and natural sunlight are used for lighting. Artificial lighting supports the most consistent algal growth.

Compressed air, bubbled into the culture, keeps algal cells suspended and moving continually past the light source. As the culture grows, it uses up natural carbon in the seawater. If left alone, the pH (alkalinity) of the culture would increase to levels that are toxic to algae. To prevent this, carbon dioxide (CO_2) is added with the compressed air, so that the algae remain in an optimum pH range (7.8–8.4) for growth.

The best temperature for algal growth is between 65° and 72° F. Below 65° F, the cultures grow too slowly; above 72° F, the diatoms may die. Most algal species cultured in hatcheries can adapt to a moderate range of salinities. The species listed in this section grow best at salinities between 18 and 28 ppt.

Algal Paste and Dried Algae

Several hatcheries centrifuge algal cultures to produce a concentrated algal paste that can be shipped to growers for feeding newly set clams. Commercially produced dried algal diets (*Tetraselmis* spp.) have also been used singly and as a food supplement with algae diets. At least one commercial hatchery uses dried algae as an ingredient with algal paste to make a concentrated slurry that can be diluted and fed to juvenile clams. It can be stored under refrigeration for up to a year and still retain its nutritive qualities (J. Donaldson, Coast Oyster Co., personal communication). The main benefit of dried algae or algal paste is that farmers can buy it rather than spend time and money to construct their own algae system. A listing of suppliers for stock algae cultures and dried algae is included in Appendix C.

Natural Algae

Natural algae can also be cultured and used as food. In this process, seawater is filtered to remove large particles (>20 µm), but the seawater is not sterilized; instead, nutrients are added to promote growth of the natural microalgae. The method is particularly useful for growers who intend to buy clam larvae and raise their own seed. However, because the culture is not sterilized, it is possible for bacteria or inappropriate species of algae to multiply rapidly and contaminate the culture. For this reason, natural microalgae should be grown in batch cultures and not in semicontinuous cultures.

BROODSTOCK CONDITIONING

The gonadal development of adult clams can be controlled by manipulating the temperature of their ambient water. By exercising such control, hatcheries can condition their broodstock to spawn synchronously on a year-round basis.

For conditioning, the broodstock of adult clams are selected from wild populations and placed in hatchery conditioning tanks. The time required to condition clams for spawning depends on their natural gonadal development cycle. In late spring or early summer, clams are already preparing naturally for spawning and so less time is required to condition them in the hatchery. In fall or winter, clams have usually spawned already and are in the process of rebuilding glycogen (energy) reserves for the following year. Thus, conditioning takes longer because the process of gonadal development has just begun.

The best temperature for conditioning Manila clams is between 64° and 75° F. Clams will ripen in about 8 weeks at 75° F, but they may spawn too soon if held long at this temperature. At 64° F, it may take 12–15 weeks to condition clams (Mann 1979), but the chance of a too early spawning is greatly reduced. Puget Sound salinities (15–30 ppt) are adequate for conditioning Manila clams (H. Beattie, WDF, personal communication.)

Broodstock are fed a variety of algal diets, usually 3H or Chagra. The daily ration is the quantity of food that can easily be consumed by the broodstock within 24 hours. Because food is also a stimulant for spawning, the ration is gradually reduced or eliminated as broodstock ripen to prevent premature spawning.

During conditioning, the stage of gonadal development is checked periodically by sacrificing clams and examining a small sample of the gonad under a compound microscope. Gonadal material will flow easily from an incision made in the gonad of a sexually mature clam. Mature eggs are rounded (65–70 μm in diameter), with a well-defined membrane, and mature sperm (1–2 μm) are highly motile. Broodstock are spawned within two or three weeks of being conditioned to ensure the highest viability of gametes and good survival of developing larvae.

BROODSTOCK SPAWNING AND LARVAL DEVELOPMENT

The standard method for spawning Manila clams is a sequence of air exposure, thermal stimulation, and exposure to gonadal products or excess food. For spawning, clams are removed from the conditioning tanks and allowed to air dry for a period of 1–2 hours. They are moved to a shallow trough with 74°–75° F seawater. An algal suspension is added to initiate feeding. Once the clams are actively feeding with their siphons fully extended, the temperature of the water is raised to 85° F . The water temperature is alternately lowered to 72° F and raised back to 85° F until spawning is initiated. If spawning does not occur, one or two animals are sacrificed and their gonadal products are added to the water to stimulate spawning. As spawning begins, male and female clams are placed in separate containers. After spawning, the eggs are pooled and fertilized at a ratio of ten sperm to one egg. Then after 10–15 minutes, the fertilized eggs are rinsed free of excess sperm on a 25 μm screen and transferred to rearing tanks for embryonic development at a density of 5–10 eggs per milliliter.

At 68°–75° F, 70% of the embryos will develop to the swimming veliger stage within 18–24 hours after fertilization. After embryos are able to swim, they are siphoned onto screens, rinsed in fresh seawater, and counted. The larvae are then returned to the rearing tank at a density of 2 per milliliter of seawater. Water changes continue every 3–4 days throughout the larval period. During each water change, the larvae are separated into size classes by sieving through a series of screens (Figure 12). The smallest, slowest-growing larvae are discarded; the larger larvae are counted and returned to the rearing tanks. As the larvae grow, the rearing density is reduced gradually to 1 larva per milliliter seawater at setting.

The optimum water temperature for rearing Manila clam larvae is 68°–75° F. Within this temperature range, larvae will metamorphose within 2 or 3 weeks of fertilization.

The diet for larvae changes during their development. Small larvae (< 120 µm shell length) are fed a mixture of CC and T-Iso ranging from 10,000 to 20,000 algal cells/larva/day. Larvae greater than 120 µm are gradually switched to a mixed diet of 3H and Chagra. By the time larvae reach setting size, they may be fed as much as 100,000 algal cells/larva/day. Calculating the ratio as cells per larva takes into account larval density.

SETTING

Manila clam larvae metamorphose and set over a wide size range (170–240 µm in shell length) because setting is independent of shell length (Loosanoff

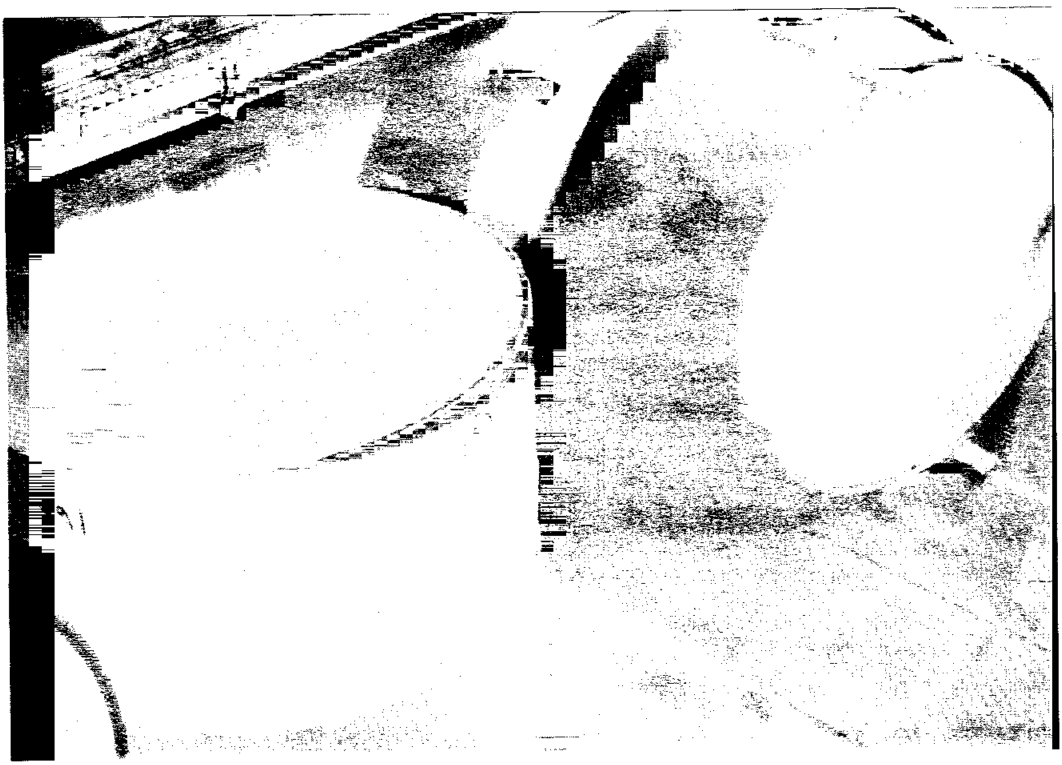

Figure 12. Larval sorting screens.

et al. 1966). Increased crawling behavior in 50% or more of the larvae is a good indicator that metamorphosis is about to occur. When this activity is observed, the larvae are drained from the rearing tanks and the largest larvae are separated by sieving through a 140 μm screen. Larvae retained on the screen are then placed into a setting system. Other larvae are returned to the rearing tanks for further growth and are checked daily for crawling behavior.

Clam larvae set best at temperatures of 67°–78° F. During summer, therefore, larvae can usually be set at ambient water temperatures. After setting, the water temperature is held between 72° and 75° F because this temperature range yields the fastest growth for juvenile clams (Bardach et al. 1972).

Larvae can be set in recirculating or in flow-through systems. A common recirculating system consists of two 36 x 24 x 4 inch wood frames, each with a 140 μm mesh screen glued to the bottom. These screens are floated in a 500-gallon fiberglass tank to which larvae and cultured algae are added. Water is circulated by an airlift to the top of each screen. Larvae are set at a density of about 2 million larvae per screen. With this system, the tank water and food are replenished daily until the larvae complete metamorphosis. The advantage of recirculating systems is that they can be used during cooler months of the year to conserve heating costs.

In flow-through systems, the setting density can be much higher. As

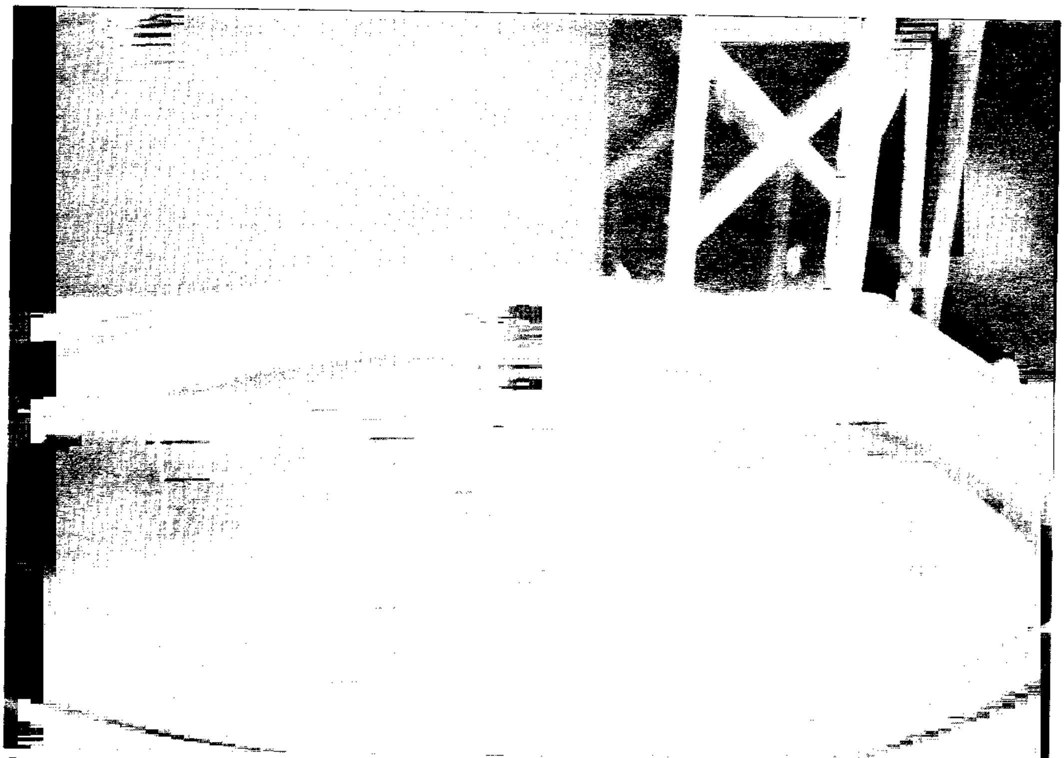

Figure 13. Downwelling setting system with larvae and ground oyster shell.

many as 5 million larvae can be set on a circular fiberglass frame screen 36 inches in diameter and 6 inches deep (Figure 13). Water is added to the top of the screens to create a downward water flow of about 1.5 gallons per minute. Five million larvae will cover the surface of the screen in a single layer.

Larvae can be set with or without a substrate. Substrate creates more surface area for larvae to attach to, but it is not necessary; clams will attach just as easily to the screen or sides of the setting container. The most common substrate, because of its availability, is ground oyster shell, screened to a slightly larger size than the larvae (300 µm). Some hatchery managers believe the calcium carbonate in the oyster shell stimulates clam settlement, but this opinion has not been tested. Fine sand may also be an appropriate substrate for setting. Once the larvae reach 500 µm in shell length, juveniles can be screened from the unused substrate, counted, cleaned, and transferred to larger mesh screens for nursery grow-out. Survival rates for larvae through metamorphosis generally range between 25% and 50%.

Like oysters, clam larvae can be shipped to other locations for setting. The larvae are bundled in mesh screen, wrapped in paper towels, and moistened with seawater. They are shipped in insulated boxes with gel packs to keep the temperature at 40°–50° F. Upon arrival, the larvae are placed in a setting system. Clam larvae set more slowly than oyster larvae, and buyers can expect some larvae to crawl and swim for 2–3 days before they metamorphose.

During setting, larvae are fed cultured algae or algal paste unless local waters are rich in natural phytoplankton. Large diatoms such as 3H or Chagra usually are used as food for setting larvae. As discussed above, centrifuged algae, dried algae, and mixed algal slurries can be used as a food supplement with cultured algae.

5. Nursery Systems

Clam nurseries are used for growing newly set seed to an appropriate size for planting. Nurseries located on naturally productive bays are most efficient. Nurseries are designed to operate with both flow-through and recirculating water systems. Bay water is pumped into a header tank or reservoir, and this water is pumped or gravity-fed into the nursery. From the nursery, recirculating water systems pump the water back into the header tank. A certain portion or all of the header tank is replenished on a regular basis. In a flow-through system, water from the nursery flows back into the bay. The effluent from nurseries consists of uneaten algal cells and feces. Because this material disperses easily, no discharge permit is required.

Nurseries can utilize natural phytoplankton production by operating flow-through seawater systems. During fall and winter, clam growth declines as water temperature and phytoplankton availability decrease. Flow-through ambient seawater systems are usually adequate for simply overwintering seed. However, clams wintering in such systems do not grow, and sometimes they require extra food to survive. Survival is excellent with supplemental food, but growth is sporadic. If seed growth is desired, cultured phytoplankton and heated seawater must be used. Recirculating seawater systems are most economical when using heated seawater and cultured food. Many nurseries use a combination of flow-through and recirculating systems throughout the year.

The nursery phase of clam culture can be divided into two stages. In the primary stage, newly set seed are raised in land-based downwell tanks to about 1 mm in shell length. In the secondary stage, 1 mm seed are grown to a size of 6–8 mm shell length in preparation for grow-out. Land-based upwells, intertidal trays, floating upwells, and rafts are used at this stage.

PRIMARY STAGE NURSERY

The systems used for setting can also be used as primary nurseries. After setting, the water flow remains unchanged, entering the screen from above and flowing through the seed and out the bottom. The best density for seed growth and survival is a single layer of seed spread over the surface of the screen. Recirculating systems do require more labor, as tanks need to be drained and cleaned every two days to prevent a buildup of high bacteria concentrations. As the seed grow, they are sieved through 180, 230, 300, 500, and 750 µm mesh screens. Slower-growing clams are routinely thinned out and discarded to make room for the larger, faster-growing clams. Growing clams are transferred to larger-mesh screens to facilitate circulation of food and water. Washing screens daily with fresh seawater keeps the screens clean of feces and uneaten algae. Floating rafts, circular tanks, and raceways can also serve as primary nursery systems and are discussed below.

Juveniles should be held on downwellers until they reach 1 mm shell length. The gills of small clams (<1 mm shell length) are not completely developed and therefore are unable to filter food efficiently in an upwell system (Reid 1990). In downwellers, food accumulates on the surface of the screen, where small clams can scrape it off with their foot (pedal-palp feeding).

SECONDARY STAGE NURSERY

Upwellers, floating upwellers, and intertidal trays as well as floating rafts, circular tanks, and raceways are used as secondary nursery systems for clams larger than 1 mm in length.

In upwell systems, water flows up through the seed held on the screen (Figure 14). Seed can be held at high densities in upwells, up to several layers deep. The water flow should be strong enough to slightly suspend the bed of seed. Food is filtered from the water as it passes through the seed. As the clams grow, they may need to be redistributed so that crowding does not hinder growth. Manzi and Castagna (1989) discuss the mechanics of upwell systems and how flow rates and stocking densities relate to seed production.

The floating upwell system (FLUPSY) is the preferred method for secondary stage culture (Figure 15). With this system, individual upwell units are connected to a center drain or trough. Water is removed from the drain by an airlift pump or by propellers and is passively replaced through the bottom of the upweller. In a FLUPSY, the individual upwell units are large, approximately 3 foot square and 3 feet deep, and capable of supporting a seed mass up to 1 foot deep.

The benefits of a FLUPSY include low maintenance and utilization of natural phytoplankton blooms. Also, it can be used to overwinter seed safely; because the seed is floating, predation and freezing are not concerns. However, it needs to be close to a source of electrical power to drive the pump, and it requires a higher capital cost than other secondary stage nursery systems.

The intertidal tray method involves holding clam seed in stacked Nestier,

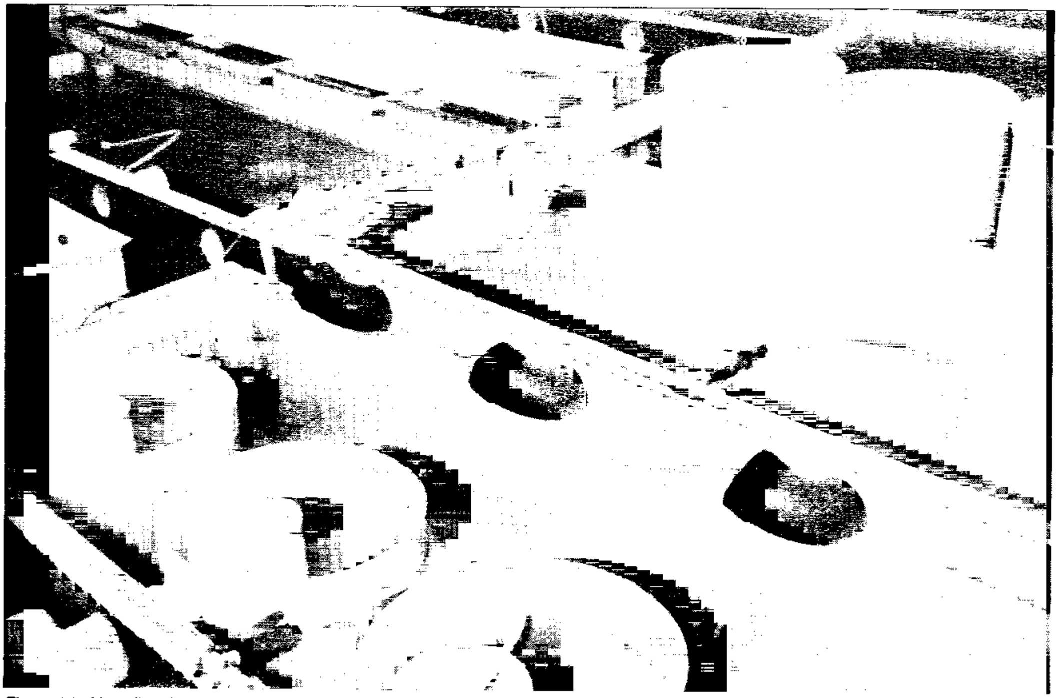

Figure 14. Upwellers in a trough.

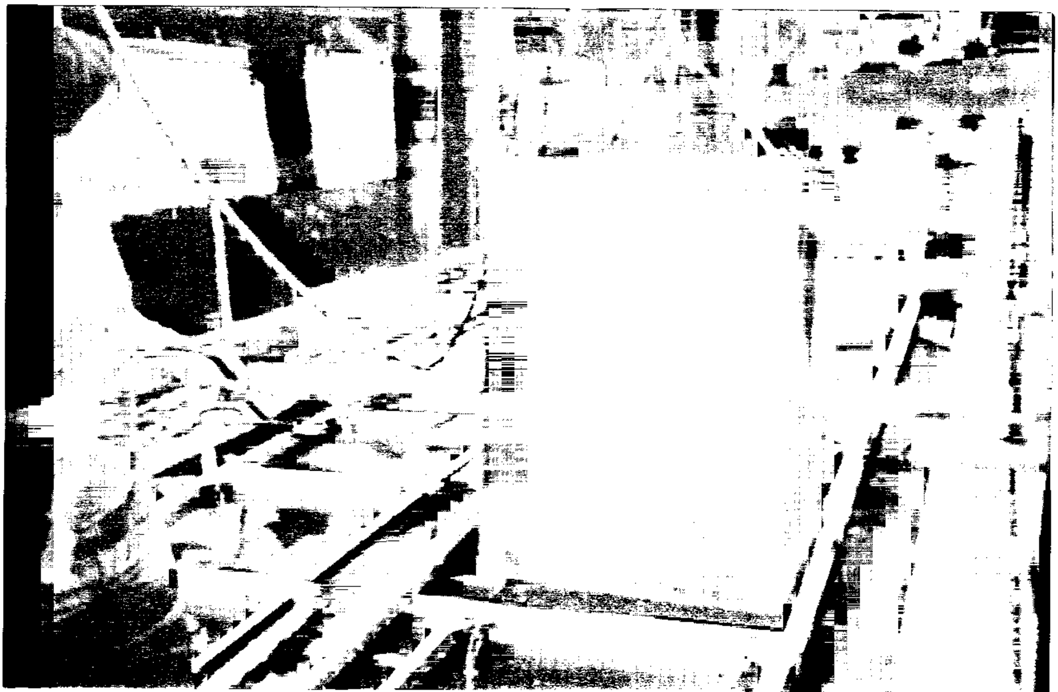

Figure 15. Floating upwell system (FLUPSY), showing one chamber being removed.

or Mexican, trays which are placed on the beach (Figure 16). The trays are approximately 2 x 2 feet and are held together in stacks of six or seven by polypropylene straps that are easy to fasten and unfasten. Various methods are used to secure the stacks of trays to the beach. Because the trays have large (1/4 inch) holes for water circulation, fine mesh window screen or mosquito netting is glued to the bottom of each tray to hold the seed. As clams grow, they are transferred to trays with larger mesh to increase the circulation of water between trays and limit the amount of accumulating detritus. The trays are checked periodically to remove any crab predators that have settled in the trays and to thin out clams if they appear to be overcrowded. A volume of 1 quart of seed per tray is the usual stocking density. The bottom tray is left empty and serves to support the other trays above the sediment.

Seed should not be held in Nestier trays through the winter because they would be vulnerable to freezing. The trays can be moved to the lower intertidal area to limit the effects of freezing. A better system for overwintering Nestier trays is to secure them in sink floats where clams will not be exposed to freezing temperatures. Clams can be held on trays until they reach a shell length of 15 mm; after that, they must be transferred to the beach or their shells become deformed.

Open-ended rafts, which hold a 1-inch layer of sediment on a plywood

Figure 16. Stacks of Nestier trays on a beach.

bottom, combine both primary and secondary nursery systems. Clam larvae can be added to the rafts for setting (W. Taylor, Taylor United Inc., personal communication). The ends of the raft are initially covered with 140 μm mesh screen, which allows water exchange but retains larvae. Two weeks after setting, the screens are removed. Seed grow through the summer and winter over in the rafts, and are planted the following spring. Seed survival is highest if larvae are set into this system during spring and summer, when phytoplankton production is high and water temperatures are warmest (Taylor 1990).

Land-based tanks and raceways can also be used as primary and secondary nurseries. A thin layer (2–4 inches) of sand is spread over the tank bottom and interstitial water flow is provided by PVC pipes positioned beneath the sand substrate. Water entering from the top of the tank provides a horizontal flow. Larvae can be added at setting, or the tanks can be used to overwinter the 4–6 mm seed.

6. Acquisition and Care of Clam Seed

The "hobby" grower who does not wish to remote set clam larvae or maintain a nursery system can obtain seed from hatcheries, of which several exist on the Pacific Coast (see Appendix C for suppliers). To ensure that they can meet the demand, most hatcheries request that seed be ordered at least three months before delivery. Hatchery clam seed are packed for shipping in plastic bags and placed in Styrofoam containers with ice packs. Orders are shipped via air freight or express mail and usually arrive within 24–36 hours.

When they arrive at the site, the clam seed should have no foul or rotten "fishy" odors. The seed mass should be moist but not wet. There should be no standing water in the package; stagnant water, which contains no oxygen, can cause bacteria to proliferate. Temperature inside the package should be cool, between 40° and 46° F. If the clam seed are healthy, they will extend their siphons and begin probing and crawling with their feet within fifteen minutes of being placed in seawater.

Clam seed should be planted or placed in holding facilities as soon as they arrive. They can be kept for several days in fine mesh bags, lantern nets, or similar containers suspended in seawater from a dock, or they can be held in trays placed in sink floats (see Appendix C for supplier). Any of the secondary nursery systems described in the nursery section can also be used to hold seed.

Planting takes forethought. Spring (April or May) is the best time for planting Manila clam seed, because rising water temperatures and food levels provide the most favorable conditions for growth and survival. Comparative studies indicate that clams planted in the fall do not have a head start on clams planted the following spring (Miller 1982), because clams do not grow in the winter. Furthermore, if planted in the fall, seed may be lost to winter storms, low substrate temperatures, and an extra six months of predation.

Appendix D puts the culture steps into a time frame. It describes a schedule for growing clams with predator netting, but much of the advance planning is common to in-ground bag culture as well.

(For where to plant, see "Factors Influencing Production.")

7. Beach Culture

The clam grower who has a naturally productive beach simply harvests wild adult clams and leaves undersized clams on the open beach to continue growing through the next year. Harvesting loosens the substrate, thins out the crop, and improves growth of the remaining clams. On less productive beaches, growers can supplement the natural recruitment by planting hatchery-produced seed. This is, in fact, the commonest form of Manila clam culture in Washington.

With open beach culture (that is, culture on a natural beach, without protective netting or bags), there will undoubtedly be losses due to predation. As basic maintenance, the grower should remove any predators found on the plot.

SEED SIZE AND PLANTING DENSITY

The size and planting density of clam seed influence the growth and survival of the seed. Low planting densities may improve clam survival by reducing competition for food and space; therefore, the grower should plant seed at a fairly low density of 30–60 per square foot (Table 3).

Because of the high cost of clam seed, a grower may wish to know more exactly how much seed to plant per unit area to get the best yield. The answer will depend on the amount of natural recruitment, phytoplankton production,

Table 3. *Survival rates of 3–4 mm Manila clam seed at different planting densities at Burley Lagoon. (From Jones 1974)*

Planting Densities (clams per square foot)	% Survival
30	27
60	12
120	9
200	6

and predation on a given beach, as well as the competition for space and food resources.

Small 15 x 15 ft plots can be used to determine the survival and growth of clam seed. Appropriate planting densities to test are 20, 40, 60, and 80 seed per square foot. To obtain accurate results, at least three plots should be planted at each density, and a set of unplanted plots should be maintained as a control to compare natural recruitment with the tested densities of planted clams. Planting should take place in the spring, with sampling every six months to record survival and growth.

Large seed generally have higher survival rates than smaller seed (Chew 1975; Miller et al. 1978; Anderson et al. 1982). The exact relationship between planting density, seed size, and survival has yet to be defined.

SEEDING THE PLOTS

While clams are being transported to the planting site they must be kept cool and moist. Clam seed are normally planted by scattering them by hand over the plot. The clams should be distributed as evenly as possible. The best way to ensure even distribution is to divide the batch of seed into equal units, one for each plot. This should be done several hours before planting, always keeping the seed moist and cool.

To further improve planting uniformity, each plot may be divided into subunits (marked off by stakes or string) and the seed for that plot divided into an equal number of subunits. The number of clams in a planting subunit is chosen to achieve a desired density (number of clams per square foot, etc.).

How to Estimate Number of Seed Per Plot

Counting out a large number of seed clams is impractical, so you must estimate the number of clams per subunit. A system based on the number of seed at a given weight is the most practical, although estimates can be made on a number per volume basis. Before using either method, clam seed should be thoroughly mixed to ensure even size distributions between batches.

To begin, count the seed that equal 1 gram weight (or that displace 1 milliliter of water). Do this several times to get an average number of clams per gram (or milliliter). Next, weigh the entire batch (or measure the volume of displaced water). Then, figure the total number of clams based on the number per gram (or per milliliter).

Plant by the Tide

Planting should be done on an incoming tide. Start at the lowest beach level and proceed upward, ahead of the rising water. This protects clams from the drying effects of the sun.

It is important to keep the clams wet. If the shells dry, surface tension at the air-water interface can cause the clams to float and be carried off the plot. If there is any danger of this happening, splash or spray seawater over the newly planted clams until the tide covers them.

Up to 3,000 square feet can be planted during one low tide by two persons, using methods described above.

Take Precautions on Windy Days

On windy days, it is best to plant cautiously or to postpone planting until the wind dies down. Waves higher than about 6 inches can wash clams from planting areas before they have a chance to dig in. If currents and waves are not too great, clams may be planted when the site is covered by 6–24 inches of water. When covered by calm water, healthy seed clams are capable of digging into the substrate within minutes.

ESTIMATING YOUR CROP

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

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. (Standard scientific procedures for taking samples are outlined in Appendix G.)

HARVESTING A NATURAL BEACH

When Manila clams reach minimum market size (>1.5 inches, or 38 mm) they may be harvested. Because the Manila clam is a shallow burrower, it is easily harvested by hand if the substrate is not too coarse or compacted. Manila clam harvesting gear generally consists of handheld implements such as tongs, clam forks, rakes, and shovels. Tongs and clam forks are used best with loose, wet gravel of small size. The distance between the tines is large enough to allow gravel to pass through, but small enough to retain harvestable clams. Clam rakes and shovels are most effective for removing clams from more compacted gravel-mud substrate. Dredges and mechanical harvesters are no longer used in Puget Sound.

Once harvested, clams are submerged in floating rafts called "sink floats" where they cleanse themselves of sand. The following day or later, the clams are packed and sold.

8. Predator Netting

If predators prove to be a problem at a Manila clam site, growers can cover the plots with predator-exclusion netting (Figure 17). Netting does not work for all predators—moon snails, for example, can burrow beneath the net—but studies comparing survival of protected and unprotected clam seed have shown the beneficial effects of using netting to exclude crab, fish, and birds (Miller 1982; Anderson 1982). Table 4 compares the percent recovery of unprotected 3–4 mm Manila clam seed with clam seed protected by 1/4–1/2 inch mesh netting. Clearly, protected seed fare better.

Moon snail predation can be countered by growing the clams inside mesh bags partially buried in the substrate; see "Planting with In-Ground Bags."

What Kind of Netting?

The netting that studies have found to be most suitable for use on beaches is a light-weight, 1/2 inch mesh material called Car Cover. Heavier net of the same mesh works as well as Car Cover, but it is harder to handle and much more expensive. Netting with a mesh size of less than 1/4 inch tends to trap fine sediment and become clogged; mesh sizes greater than 1 inch do not keep out many predators. Netting may be purchsed from suppliers listed in Appendix C.

The grower should note that small clams, even when covered by netting, may still be washed away by waves or currents. Thus, care must be taken in selecting a planting site and appropriate netting. If 3–4 mm seed are planted, 1/4 inch mesh netting should be used. For larger (6–8 mm) seed, a 1/2 inch mesh is recommended.

Because the netting comes in rolls 12 feet wide, large plots require that pieces of netting be joined together and then transported to the beach before low tide. Nylon thread or 6-inch plastic Tylon ties work well for joining pieces of net or for attaching lead line, which anchors the net. Nylon thread does not rot in seawater, but it will decompose when exposed to anaerobic conditions. Plastic ties last a long time and are easy to use.

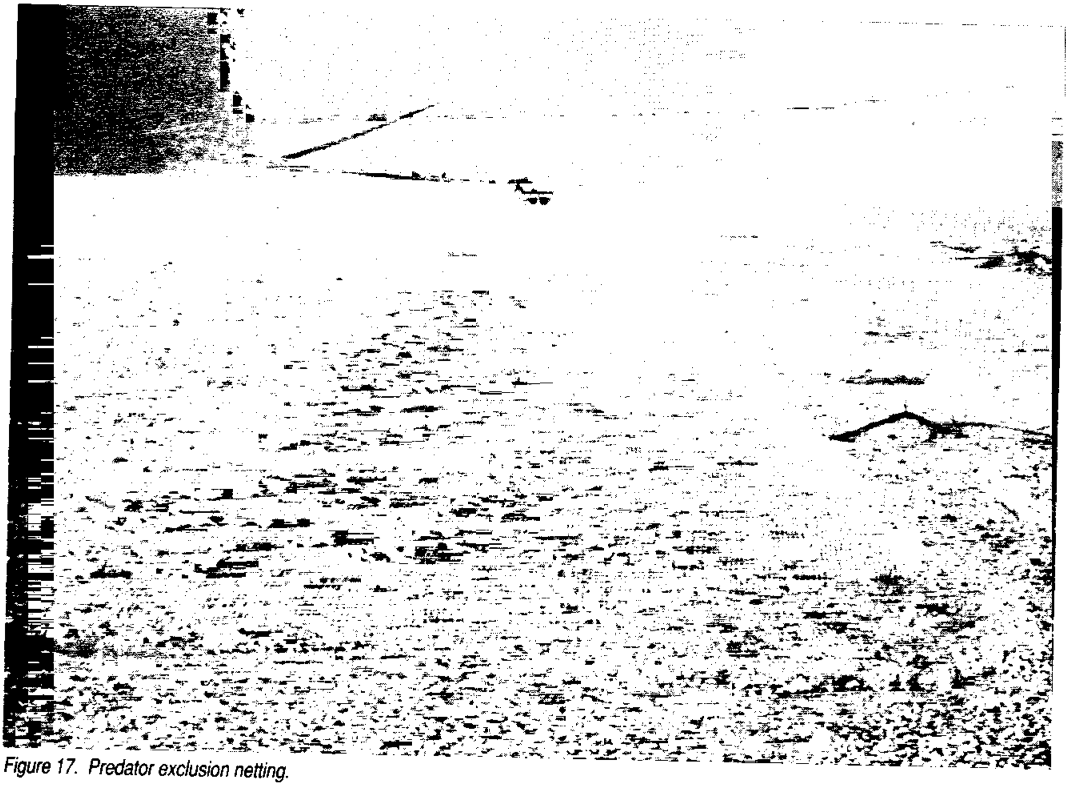

Figure 17. Predator exclusion netting.

Table 4. Average percent survival of 3–4 mm Manila clams from protected and unprotected plots at Puget Sound sites after each of several growing seasons. Protected plots were covered with 1/4–1/2 inch mesh netting. (Modified from Anderson et al. 1982)

Study Site	Treatment	Percent Survival Rate (growing season) 1	2	3
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	—
Westcott Bay	unprotected	13	10	—
	protected	33	30	—

Anchoring the Netting

The netting must be anchored over the site. There are two ways to do this. The first one takes more work but works better:

1. Once the netting is ready, dig a trench around the edge of the plot. At this point if you are using clam seed that are larger than the mesh size, distribute them over the plot. Next, lay out the netting and position it on the plot. Fold the excess netting into the trench and cover it completely with the trench tailings, filling the trench to beach level. If you are using small clam seed, now is the time to distribute them over the netted plot.

2. An alternate method for anchoring netting is to sew 8-ounce lead line around the edges of the net to hold it down. Then pin down the lead line over the plot every 10–20 feet with 18-inch-long rebar sections bent to form a U or a J. This method is easier than digging a trench; but because the edges of the net are not buried, it will not exclude the crabs or burrowing predators such as the moon snail.

PLANTING SEED CLAMS ON A NETTED PLOT

The counting and planting of Manila clam seed on plots with predator netting is similar to that described in the beach culture section.

When planting small clam seed (less than the netting mesh size), the netting is secured on the plot prior to seeding because the anchoring of the netting may disturb the plot. The seed can be planted the following day to allow the plot to settle. The seed are planted by hand, starting at the lowest portion of the beach and working up the beach as the tide comes in. The clams pass through the netting and dig into the substrate within several minutes.

If the seed is larger than the mesh size, the seed is planted before laying the net. Clam seed should be planted as the tide is receding. This allows them to settle into the substrate before the tide goes out. This also allows time for securing the net before the tide comes back in. Large seed can also be planted a day before laying the net. However, they are exposed to predators until the net is placed.

MAINTAINING A NETTED PLOT

Culture plots will easily last three years if they are well maintained, but net damage is common; seams separate, and debris or drift logs tear holes in the fabric. Predators gain entry to the plot quickly once the netting is damaged. Miller (1982) noted that on plots in which crabs entered through loose seams or damaged sections, clam numbers declined from 50 to 15 per square foot over a three-month period. Routine inspection and continual maintenance, therefore, are important to avoid losses. Open seams or tears may simply be stitched together, but pieces of netting may be needed to patch big holes.

Fouling

Biological fouling may cause problems at certain locations during spring and summer. The native bay or blue mussel (*Mytilus trossulus*, formerly *M. edulis*) and barnacles (*Balanus* spp.), for example, will settle on netting. If large numbers of them attach, they add greatly to the weight of a section of netting. They may also clog the mesh and compete for food, which can result in poor clam growth and survival. If the problem is severe, fouling organisms must be removed manually, with a brush or other tool. Mussels are difficult to remove because they attach firmly with tough byssus threads.

Macroalgae (such as *Ulva* sp.) sometimes form mats under netting plots and occasionally cover netting plots in thick piles at low tide. Unless the accumulation is 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, hairy web on the netting surface, but this is harmless.

HARVESTING A NETTED PLOT

Harvesting is done by hand using forks, rakes or shovels, as described for beach culture. Prior to harvesting, the net must be removed or rolled back. If the entire plot is not harvested before the tide comes in, the netting must be reanchored.

EVALUATING A SITE FOR NETTED CULTURE

When a promising location has been found (see "Factors Influencing Production"), you should determine the appropriate number, size, and orientation of culture plots. (See Appendix E for the tools and materials you will need for construction.) The primary factors that determine plot design are tidal range, beach slope, and area a harvest crew can work on an average low tide. Plot sizes of 100–150 square yards can be managed easily on clean, firm substrates such as sand and gravel beaches. However, on muddy beaches or in areas of heavy fouling, smaller plots (less than 100 square yards) would be more practical for culture work.

Beach slope limits the zone of usable tideland as measured perpendicularly to the water line. On a steep beach, it is best to orient plots with the longer dimension parallel to the shoreline. This places the planted clams at a tide level where growth is optimal. On a gently sloping beach, plot orientation is less dependent upon slope.

9. Planting with In-Ground Bags

On beaches where moon snails are serious predators, clam seed can be protected by enclosing them in mesh bags and partially burying the bags in the substrate. With in-ground bag culture, the grower can raise Manila clams at the lower tidal levels, where other predator avoidance methods are ineffective. In-ground bag culture is not cheap, but it may be cost effective when used in conjunction with netted plots at the higher tidal levels, thus extending the culture to a broad tidal range.

Clam seed 7–10 mm in length are used in bag culture. Because of the high cost of large hatchery-produced seed, growers can obtain smaller seed (3–4 mm) and grow them in a secondary nursery system to reach that size before they are bagged.

PLANNING A PLOT FOR BAG CULTURE

In-ground culture bags are made of 1/4 inch plastic mesh, a mesh size that allows for good water flow through the bag but prevents large moon snails from entering. Moon snails that are small enough to pass through the mesh are too small to eat the clam seed.

The grower can fabricate the bags or purchase them already made. Common bag size is 32 x 18 x 4 inches, which is based on the dimensions of a roll of mesh netting. This heavy mesh comes in a 48-inch width, which is cut to form a rectangle 48 x 40 inches. The netting is folded to form a bag with two open ends. The edges can be closed with Tylon ties or sewn with nylon thread.

Bags are placed in shallow excavations on the beach and secured with metal rods or rebar pins until the bags are silted firmly in place. Once the bags have filled with enough sediment, the pins are removed.

Care must be taken to avoid placing bags in depressions that are too deep or in areas of heavy siltation. If sediment covers the entire bag, access to food and seawater will be reduced. On the other hand, if bags are not deep enough or are set in areas of shifting substrate, the bags will become uncovered and wash away. Bags should protrude approximately 1 inch above the beach surface.

In the usual procedure, row culture, bags are placed about 2 feet apart in rows that parallel the beach (Figure 18). Spacing between rows depends on the amount of area needed to access the bags during harvesting; a spacing of about 3 feet is usually sufficient. The bags are secured with rebar pins, which are removed when enough silt has been deposited to hold down the bags. In a more efficient method of row culture, bags can be placed end to end forming rows parallel to the beach. Two or three feet between these rows is sufficient space to access the bags. This method allows more bags on the beach, producing more clams per acre. It is the method used in the cost comparison tables of the Economics section.

Bags in Mats

As an alternative to row culture, bags can be placed together in groups, called mats, with no space between adjacent bags (Figure 19). Mats of bags are anchored to the substrate by laying metal bars across the bags.

Mat culture has met with only limited success. Survival of clams is about the same in mats as in rows, but clams in the bags at the outer edges of the mat grow faster than clams in the middle bags.

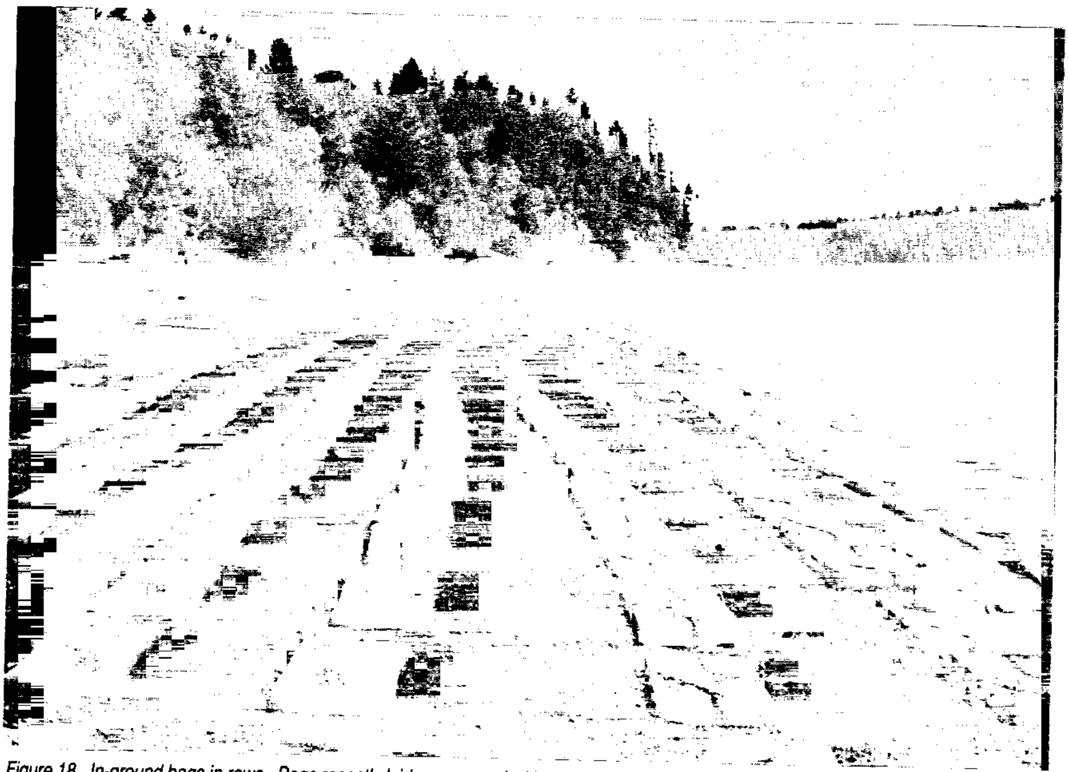

Figure 18. In-ground bags in rows. Bags recently laid are secured with metal bags; established bags are silted in place.

Figure 19. In-ground bags placed in mats and held down with a metal bar.

PLANTING DENSITY IN BAGS

The optimal planting density is approximately 500–700 clams per bag (D. Rogers, unpublished). This density range had the best combination of growth and survival after 17 months of grow-out (Table 5). Growth was found to be inversely proportional to the number of seed planted, while survival was high in all bags regardless of density.

MAINTAINING A BAG CULTURE PLOT

Fouling can become a problem on the inside or outside of a bag if the bag is not completely filled with sediment. Exterior fouling organisms can be scraped off, while interior fouling organisms can be removed at harvest. When emptied, bags can be easily cleaned for reuse.

On several beaches of southern Puget Sound, large numbers of sand dollars (*Dendraster excentricus*) live in the lower intertidal zone. Their burrowing activity may prevent bags from successfully settling into place. If sand dollars prove to be a problem, it may be possible to dig a depression, rake away the sand dollars, and reset the bag.

Table 5. Survival of seed clams planted at different densities in in-ground bags after 17 months of grow-out. (From D. Rogers, unpublished)

Clams per bag	Average survived	Percent survival	Averge total weight (grams)	Average weight per clam (grams)
300	153	51	2,000	13.1
500	326	65	3,750	11.5
700	520	74	6,000	11.5
800	481	60	4,525	9.4
900	652	72	6,250	9.6
1,000	700	70	6,000	8.6
1,500	1,183	79	8,000	6.8

HARVESTING BAGGED CLAMS

In-ground bag harvesting is done by hand at low tide. It is a laborious, time-consuming process. A shovel can be used to lift one edge of a bag just enough to break the suction. Each bag, which weighs around 55 pounds (combined weight of clams and sediment), is loosened from the depression by working one end of the bag and then the other. Upon removal, bags are placed on the beach just above their holes and a new bag with clam seed is placed into the depression and secured with rebar pins or (if mat culture is practiced) with metal rods. The incoming tide cleans the harvested bags and washes the released sediment down to fill the newly planted bags.

The cleaned bags are emptied and the clams sorted, either directly on the beach or in a processing plant. Areas with a natural set of Manila clams will yield undersized clams in the bag at harvest; clams under 38 mm (1.5 inches) should be replanted. Other bivalves and fouling organisms are discarded. Market-size clams are placed in a sink float for several days to purge themselves of sediment and are then sent to market.

Easier methods to harvest the bags could be developed. Possibilities include harvesting from a boat during high tide, or using a winch. This could significantly reduce labor costs of harvesting and increase the profits.

IS BAG CULTURE FEASIBLE FOR YOU?

In-ground bag culture is an expensive and labor-intensive way to grow clams. It is worth the grower's while to consider other methods first —predator netting, for example. To determine whether in-ground bag culture is practical for a given beach, a grower should make a preliminary evaluation before committing time, money, and effort to a full-scale operation.

Different areas have varying amounts of primary productivity and may not support the number of clams recommended in Table 5. If too many clams are placed in each bag, overcrowding can result in slow growth or stunted clams. Bags should be filled with concentrations of 400, 600, and 800 seed clams per bag to test for the optimal density at a given site. At yearly intervals until the clams reach a harvestable size, the bags are dug out and the clams are measured and counted, and then returned to the bags and replanted. This will determine the planting density that achieves the best growth and survival for a particular site.

10. Substrate Modification

A beach that attracts and retains a population of wild Manila clams is a boon to the grower, who will not have to buy (or will not have to buy as many) expensive clam seed. If the beach lacks the natural features to accomplish this, the grower may find it advantageous to make changes that encourage natural recruitment. At some locations, for example, the use of predator netting might help to increase the density of wild Manila clams by slowing the water currents and creating eddies that concentrate larvae and allow them to settle.

On a larger scale, the character of the beach can be altered to increase the amount of clam habitat, providing areas to grow clams that were not previously available. One of these enhancements is substrate modification.

Substrate modification involves placing gravel or a combination of gravel and crushed oyster shell onto a mud or mud-sand beach to provide a substrate that approaches the "ideal" substrate mentioned earlier: a stable, loosely packed substrate consisting of gravel, sand, mud, and shell. Gravel stabilizes the substrate and creates interstitial space for newly settled clams; it also protects clams from predators (Belding 1930; Castagna and Kraeuter 1977; Kraeuter and Castagna 1977; Flagg and Malouf 1988). Crushed oyster shell is mixed with the gravel to keep plots from compacting and to provide calcium carbonate, which may improve natural recruitment (Taylor 1988, 1990).

Because substrate modification alters existing habitat and may have an impact on the environment (see Newman and Cook 1988; Thompson 1990), permits from WDF, the county planning department, and the U.S. Army Corps of Engineers are required before starting. The permit process evaluates potential impacts to all fauna and flora. Eelgrass communities and documented spawning areas for herring are of particular concern. If such sites can be avoided at the outset, the clam grower can prevent long delays and denial of requests for permits.

EVALUATING A SITE FOR MODIFICATION

When considering a site for substrate modification, the grower must take several factors into account.

Existing substrate—The best substrate for modification is composed of a shallow (ankle deep) surface layer of soft mud or mud-sand over a firm layer of sediment. On this type of surface the added material bonds and mixes with the soft surface layer while it is supported by the firm layer of sediment beneath. On softer (knee deep) substrates, the added material sinks, requiring too much material to create a stable layer.

Recruitment potential—The potential for recruitment to the site under consideration can be gauged by checking adjacent beaches. If Manila clams are found, chances are good that larvae will be transported to the new site.

Tidal height—The tide level of the site should be determined to ensure that it is within the appropriate range for Manila clam growth and survival.

Microalgae—Beaches with concentrations of macroalgae greater than one or two layers thick should not be used. When covered by a layer of shell and gravel, the algae will die and the decomposition will make the plot unsuitable for juvenile clam recruitment and survival.

Slope—Beaches with slope gradients greater than 1%–2% should not be used for substrate modification due to the high probability of material displacement. A 2% slope gradient is equivalent to a 2-foot change in height over a distance of 100 feet.

Sedimentation—Highly sedimented sites should be avoided because they would require annual layering of materials, which is not economical. Beaches below areas of heavy upland runoff or adjacent to seasonal creeks might be buried or eroded and should be avoided. Areas of high wave exposure are also not suitable, because gravel and shell would be washed off the plot.

Experimenting with Substrate Modification

Growers who want to experiment with substrate modification should construct test plots to look at natural recruitment, growth, and survival in relation to substrate composition and layer depth. Plots that are 15 feet square will provide reliable projections of future commercial production. Tests to perform are 100% gravel and 75:25 and 50:50 mixtures of gravel and crushed oyster shell at layer thicknesses of 2, 4, and 6 inches. Each of these tests should be replicated three times at similar tide levels to gain the best degree of statistical interpretation for the results. As with any test, there should be a set of unmodified (control) plots with which to compare the modified plots. The plots should be monitored for one or two years.

WHAT MATERIAL SHOULD YOU USE?

The best type of gravel to use for substrate modification is 1/4–3/4 inch in diameter with rounded edges and a nonuniform shape (Newman and Cooke 1988; Thompson 1990). Gravel of this size provides the proper amount of interstitial space to retain the fine sediments that juvenile clams need. Angular (sharp sided), flat gravel tends to compact, eliminating any interstitial space; and larger, cobble-size gravel has too much interstitial space to retain fine sediments.

Crushed oyster shell is obtained mainly from oyster growers. It is more expensive than gravel and, since old shell is used as cultch to set oyster larvae, is available only if the growers have a surplus. Before spreading, the shell should be crushed to a diameter of 1/3–1/2 inch using a rock crusher. This size shell spreads easily and is incorporated quickly into the substrate.

APPLYING THE SUBSTRATE

Several methods have been used for spreading substrate materials. All the methods discussed here spread material from barges that can be floated over the site at high tide. This method is preferred because it keeps the beach clear of heavy equipment whose weight would kill benthic organisms and compact the substrate.

To position a barge over the plot at high tide, the corners and sides of the plot are marked with fir or cedar saplings cut to 15–20 ft lengths. Placing these markers 20–25 ft apart divides the plot into subsections and helps to orient the barge to specific locations on the plot. When the barge is in position, it is pushed or pulled along as the material is spread.

Commercial growers prefer to spray gravel from a small barge or power scow (Figure 20) using a high-pressure fire hose (Taylor 1988). This method is particularly useful for spreading thin, even layers of gravel. Because the equipment used with this technique cannot carry more than 100 square yards of material, it may take several tides to cover one acre of ground. For spreading larger quantities of material, up to 6,000 square yards, multiple fire hoses can be used to spray material from a single large-capacity barge (Marwitz and Bryan 1990).

The WDF has developed an automated hopper for spreading gravel and shell (Figure 21). The hopper is 25 ft wide and holds approximately 30 square yards. It is mounted at the front end of the barge and filled by a front-end loader. By adjusting the speed and the bottom opening of the hopper, a precise depth of material can be applied to the substrate as the barge is pushed over the plot. The width of the bottom opening of the hopper is controlled hydraulically. With this technique, approximately 80 square yards of material can be spread over

Figure 20. Gravel spread with high-pressure hoses from a barge.

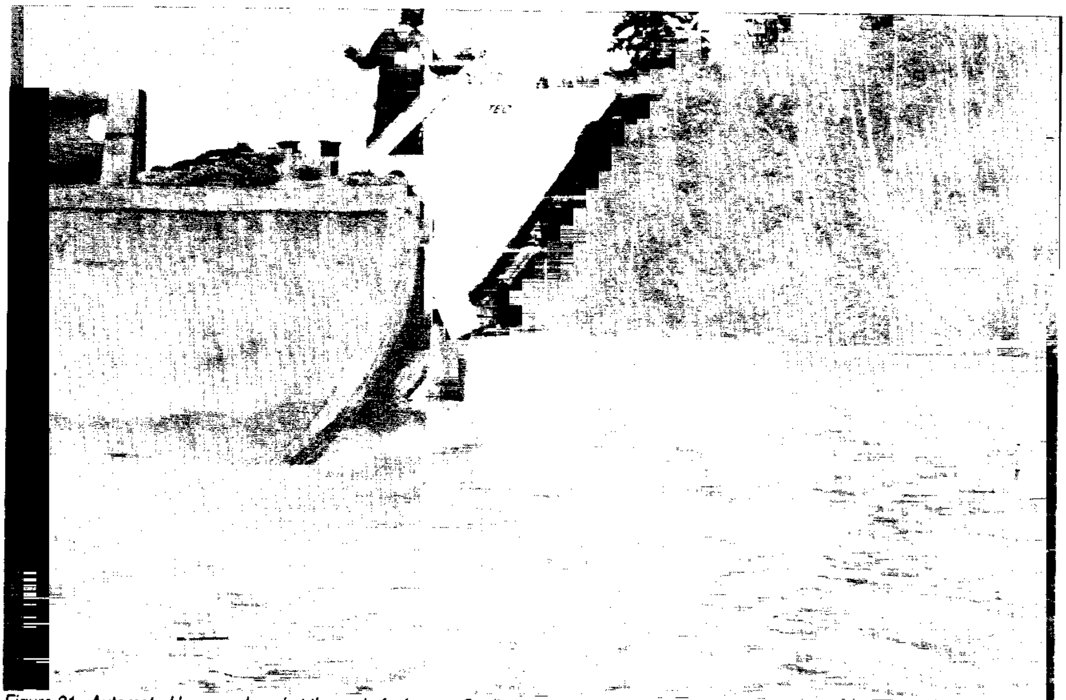

Figure 21. Automated hopper placed at the end of a barge. Saplings are used as plot markers.

three acres in three days. A centrifugal spreader, similar to those mounted on dump trucks for spreading gravel, may be equally effective for spreading gravel and shell.

The WDF has also tried spreading substrate material from a barge by using a dump bucket on a large crane, dropping the material from the bucket as it swings over the plots (Figure 22). This method is fast—it can spread up to 500 square yards of material in less than two days—but it produces a substrate that is too thick in some places, too thin in others; and for this reason it cannot be recommended for laying down a substrate.

There is another reason not to use a dump bucket. When applying a mixture of gravel and crushed oyster shell, the grower should make sure that the two materials remain mixed. This is not possible when the mixture is dropped from a dump bucket. Instead, the heavier gravel settles to the bottom first and the lighter shell follows, covering the surface of the plot. When this happens, the beneficial effect of using oyster shell is lost. The shell behaves like angular, flat gravel; it compacts and eliminates interstitial space. Unable to dig into such a substrate, the juvenile clams are more vulnerable to predation and freezing.

A dump bucket was used by WDF to construct test plots at Oakland Bay in 1989, and it is the probable cause for the poor survival of juvenile clams on the mixed gravel/crushed oyster shell substrate.

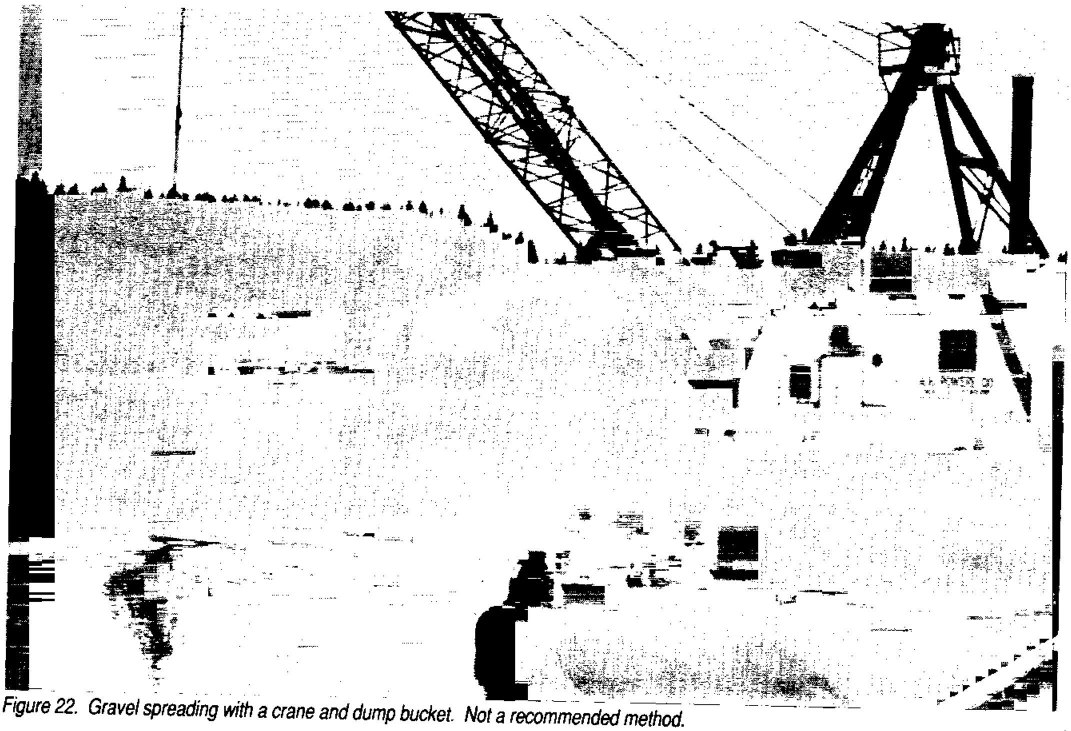

Figure 22. Gravel spreading with a crane and dump bucket. Not a recommended method.

How Much Is Enough?

On soft mud beaches a material depth of 4 inches or more is necessary to provide substrate stability for clams as they grow and a firm base for the grower to walk on. Commercial growers have found that adding thin layers of material, about 1–2 inches per year, minimizes die-off of existing clams and other benthic (bottom living) organisms. With limited die-off, the substrate and interstitial water stay fresh and clean for optimal clam setting and growth, resulting in the earliest possible clam production.

A major disadvantage of applying multiple thin layers of material is the expense of moving equipment and material to and from the site. Therefore, a grower who wants to develop a plot should determine how to achieve a good substrate with the fewest possible layers—"good" in this case meaning thick enough to provide an adequate base for the clams but thin enough to allow the benthic organisms to survive. This can be determined with test plots.

Maintaining the Substrate

If a plot whose substrate has been modified were abandoned, silt and sediment would eventually cover it and it would return to its original unproductive state. However, routine harvesting by hand digging should adequately turn over the substrate and keep it free of excessive sedimentation. In areas of heavy deposition, additional layers of shell and gravel may be needed to keep the plot productive.

MANAGING AND HARVEST ON A MODIFIED SUBSTRATE

Crop management techniques for gravel plots are essentially the same as those employed on a natural beach. Standing crop is estimated as described in Appendix G.

If natural recruitment is still not satisfactory after modifying the substrate, clam seed and predator netting can be used to increase production. The method for planting and spreading clam seed is presented in the section on predator netting.

11. Structural Enhancement

Many beaches in Puget Sound have good clam substrate but lack substantial populations of Manila clams. Currents or temperature barriers may prevent Manila clam larvae from reaching such beaches; and if they do get there, exposure to waves and currents may prevent them from settling.

Current and wave energy can be reduced by constructing permanent or temporary structures that allow clam larvae suspended in the water column to concentrate and settle out near or behind the structures. In constructing permanent structures, permits need to be obtained from WDF, county planning departments, and the U.S. Army Corps of Engineers.

PERMANENT STRUCTURES

In Japan, permanent breakwaters made of concrete have been used to develop clam grounds (Mottet 1981). Large breakwater blocks were set in long, single rows, perpendicular to the shore. They create eddies that encourage settlement of larvae.

A gravel berm was constructed in the Port Townsend Ship Canal by the WDF and the U.S. Army Corps of Engineers in 1974. Approximately 15,000 cubic yards of dredged gravel was placed on the adjacent beach between the –2 ft and the 0 ft tidal level. The berm functions to reduce wave action and slows currents, thereby increasing the level of natural recruitment to the beach behind it. Natural recruitment and annual production of hardshell clams on this beach were insignificant before the gravel was deposited, but annual production is now about 9,500 pounds.

In south Puget Sound, concrete and wooden oyster dikes originally used to culture the native oyster, *Ostrea lurida*, have also increased natural recruitment of Manila clam seed. Concentrations of clam seed have been found in gravel areas shoreward of dikes and in silt accumulated along the sides of dikes (W. Taylor, Taylor United Inc., personal communication). In many areas that once supported the Olympia oyster industry, the dikes have been converted to growing Manila clams.

TEMPORARY STRUCTURES

Japanese experiments tested cupped, circular, and parallel configurations of sand bags (Figure 23) for their effectiveness in increasing recruitment and survival of Manila clam seed (Tsutsumi et al. 1981). The circular placement significantly outperformed the other two configurations in increasing the recruitment and survival of Manila clam seed.

In Japan, large concentrations of seed have been found routinely in areas where the seaweed nori (*Porphyra* spp). has been cultured using the "hibi" technique (Mottet 1981). With this technique, wave and current energy is reduced by bamboo poles that are stuck vertically in the substrate at a density of 1–3 poles per square meter.

Commercial clam growers in south Puget Sound have reported that Manila clam seed are often found attached to driftwood branches and other woody debris. In 1989, WDF biologists found concentrations of Manila clam seed on driftwood branches in concentrations as high as 170 clams per square foot.

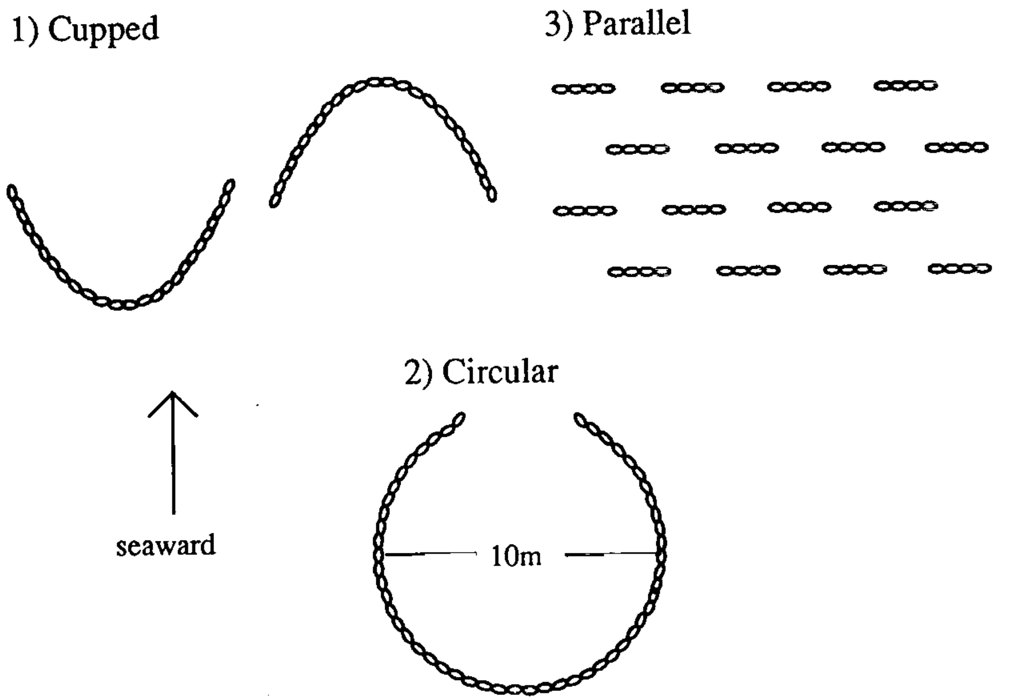

Figure 23. Configurations of sand bags used to increase natural recruitment of Manila clam seed in Japan. Sandbags are in two layers. (From Tsutsumi et al. 1981.)

12. Record Keeping

Well-organized records should be maintained for all aspects of an aquaculture project. Record-keeping makes "hobby" farming more meaningful, and for a commercial venture it is a requirement. Up-to-date and accurate records provide a broad base for farm management decisions and may be invaluable in the event of legal proceedings that require a grower to show proof of loss (Shang 1981).

Certain records of production and sales are required by the WDF. Sales of clams must be reported daily on a Shellfish Receiving Ticket and on a monthly basis in a Hardshell Clam Production Report.

13. Permit Requirements

To engage in clam farming or other types of aquaculture, the farmer must obtain approval and permits from several governmental agencies. Certain permit applications require detailed drawings of proposed culture plots (and any other shoreline or floating structures to be built), and so it is important to plan carefully and well in advance of planting. Regulations and guidelines must be followed after approval is obtained. Regulating agencies and processes include the following:

- *Washington Department of Health* (DOH) and local health authorities are concerned with the safe consumption of shellfish. They monitor pollution and paralytic shellfish poison and certify commercial shellfish growing areas. Beach certification for bacterial and viral contaminants must be obtained before planting seed.
- *Washington 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; approves movement of seed from one location to another within the state; and approves importation of nonnative species. Growers must register as aquatic farmers. A Hydraulic Project Approval (HPA) permit is required for any beach alteration.
- *Washington Department of Natural Resources* (DNR) leases DNR-managed aquatic lands for aquaculture. A lease is required for farming on public lands.
- *County Planning Department* has primary authority over shoreline development, which it controls by a permit system. A county representative should be consulted on each project to learn about permit requirements.
- *State Environmental Policy Act* (SEPA) requires an environmental impact statement (EIS) before a government decision is made on any major project that alters the substrate and has the potential for negative environmental impacts. SEPA guidelines help to determine when an EIS is required.

• *U.S. Army Corps of Engineers* regulates work in all navigable waters and supplies permits for projects affecting the course, location, condition, or capacity of navigable waters.

For More Information

A better understanding of the regulatory process is provided in a Washington Department of Natural Resources publication, Introduction *to Shellfish Aquaculture in the Puget Sound Region* (Magoon and Vining 1981). This reference manual may be obtained for $5.00 plus tax by phoning (206-753-5324 or 753-5338) or by writing to:

Department of Natural Resources
Division of Land Management
Public Land Building
Olympia, Washington 98504

Additional information regarding aquaculture and environmental permits may be found in a booklet entitled "Commonly Required Environmental Permits for Washington State," published by the Department of Ecology (DOE). It may be obtained free at any DOE office by phoning (206-753-2800) or by writing to:

Department of Ecology
Mail Stop PV-11
Olympia, Washington 98504

14. Economic Aspects

Few economic analyses have been completed on Manila clam culture, and so it is easy to mention those that do exist: cost analyses of predator exclusion netting by Anderson et al. (1982) and Roland and Gubbels (1990); an estimate of construction costs for predator exclusion netting and substrate modification by Taylor (1988); and a detailed review of hardshell clam culture and procedures for economic forecasting by Adams et al. (1991).

To assist growers in selecting the most cost-effective method for grow-out, we compare, in Tables 6, 7, 8, and 9, five-year forecasts of income and cost of growing clams using beach culture, predator netting, in-ground bags, and substrate modification. The seeding density and survival rates used in the tables are solely for illustrative purposes. Before starting up, the prospective grower needs to generate his/her own income forecast statement with planting densities and survival rates based on preliminary site evaluations.

The assumptions used to develop the income forecast statements are as follows:

1. Costs are based on the development of one acre of private ground. No lease fees will apply.
2. The ground is located in an area that has been approved for harvest by the Washington Department of Health (DOH). No relaying of harvested stock is necessary.
3. Natural recruitment is insignificant, and so the ground will need to be seeded. Seed costs for 6–8 mm clam seed are based on a price of $7.00 per 1,000.
4. Seeding density for beach culture, predator netting and with substrate modification is 60 clams per square foot. For in-ground bag culture, the seeding density is 600 clams per bag.
5. Seed is harvested 24–30 months after planting. Clams are harvested when they reach 38 mm (1.5 inches) shell length and weigh approximately 25 clams/pound.
6. A survival rate of 50% is assumed for seed through three years, with culture methods of predator exclusion netting, in-ground bags, and

Table 6. Five-year income forecast for beach culture of Manila clams on one acre of ground.

Year	One	Two	Three	Four	Five
CAPITAL INVESTMENT					
Boat, trailer, motor	8,500				
Sink float (materials and labor)	1,500				
Truck	14,000				
Miscellaneous	1,000				
TOTAL CAPITAL LOAN	25,000				
OPERATING COSTS					
Bank charges	500	500	500	500	500
Repayment loan[1]	4,300	9,460	15,480	15,480	15,480
Professional fees[2]	1,000	500	500	500	500
Insurance	1,000	1,000	1,000	1,000	1,000
Clam seed[3]	18,300	18,300	18,300	18,300	18,300
Harvest cost[4]	0	0	7,840	7,840	7,840
Depreciation[5]	2,500	2,500	2,500	2,500	2,500
Miscellaneous	500	500	500	500	500
TOTAL OPERATING COSTS	28,100	32,760	46,620	46,620	46,620
INCOME (clam sales)[6]	0	0	54,890	54,890	54,890
PROFIT (income less operating costs)	(28,100)	(32,760)	8,270	8,270	8,270
OPERATING LOAN	28,100	32,760	0	0	0
25% PROFIT TAX (RESERVE)	0	0	–2,070	–2,070	–2,070
BALANCE FORWARD	0	0	6,200	12,400	18,600

1 Interest on capital loan calculated into first year operating budget. Subsequent years include both capital and operating budget loans. Interest rate is 12%, amortized over 120 months.

2 Professional fees include legal and accounting fees to develop a business proposal plus annual bookkeeping fees.

3 Cost of clam seed is based on price of $7/1,000 seed. A planting density of 60 seed/ft^2 requires 2,613,600 seed.

4 Harvest cost ($0.30/lb) includes $0.25 for digging and $0.05 for handling and maintenance of sink float. 25% survival of planted seed = 653,400 clams at 25 clams /lb = 26,140 lbs. @ $0.30 = $7,840.

5 Depreciation calculated at 10% of capital expense ($25,000 x 0.10 = $2,500).

6 Clams sales based on 25% survival of planted seed x 25 clams/lb x wholesale price of $2.10/lb.

Table 7. Five-year income forecast for Manila clam culture using predator exclusion netting on one acre of ground.

Year	One	Two	Three	Four	Five
CAPITAL INVESTMENT					
Boat, trailer, motor	8,500				
Sink float (materials and labor)	1,500				
Truck	14,000				
Miscellaneous	1,000				
TOTAL CAPITAL LOAN	25,000				
OPERATING COSTS					
Bank charges	500	500	500	500	500
Repayment loan[1]	4,300	11,520	18,780	18,780	18,780
Professional fees[2]	1,000	500	500	500	500
Insurance	1,000	1,000	1,000	1,000	1,000
Clam seed[3]	18,300	18,300	18,300	18,300	18,300
Netting[4]	4,070	0	0	4,070	0
Plot maintenance[5]	2,500	2,500	2,500	2,500	2,500
Harvest cost[6]	0	0	15,680	15,680	15,680
Depreciation[7]	2,500	2,500	2,500	2,500	2,500
Miscellaneous	500	500	500	500	500
TOTAL OPERATING COST	34,670	37,320	60,260	64,330	60,260
INCOME (clam sales)[8]	0	0	109,770	109,770	109,770
PROFIT (income less operating costs)	(34,670)	(37,320)	49,510	45,440	49,510
OPERATING LOAN	34,670	37,320	0	0	0
25% PROFIT TAX (RESERVE)	0	0	–12,380	–11,360	–12,380
BALANCE FORWARD	0	0	37,130	71,210	108,340

1 Interest on capital loan calculated into first year operating budget. Subsequent years include both capital and operating budget loans. Interest rate is 12%, amortized over 120 months.

2 Fees include legal and accounting fees to develop a business proposal plus annual bookkeeping fees.

3 Cost is based on price of $7/1,000 seed. A planting density of 60 seed/ft^2 requires 2,613,600 seed.

4 One 12' x 100' section of "Car Cover" netting at $0.76/linear foot costs $76. Lead line (224') attached to the perimeter of the net costs $20, and materials (stakes and nylon string) cost about $4. Labor at $6/hour (2 man hours/net) is about $12. Total cost for one section equals $112. Total netting cost for one acre is $4,065 (36 sections are required to cover one acre).

5 Includes annual net maintenance cost and management expenses for growth and standing crop estimation.

6 Harvest cost ($0.30/lb) includes $0.25 for digging and $0.05 for handling and maintenance of sink float. 50% survival of planted seed = 1,306,800 clams, divided by 25 clams/lb = 52,270 lbs @ $0.30 = $15,680.

7 Depreciation calculated at 10% of capital expense ($25,000 x 0.10 = $2,500).

8 Clams sales based on 50% survival of planted seed x 25 clams/lb x wholesale price of $2.10/lb.

Table 8. Five-year income forecast for Manila clam culture using in-ground bags on one acre of ground.

Year	One	Two	Three	Four	Five
CAPITAL INVESTMENT					
Boat, trailer, motor	8,500				
Sink float (matrials and labor)	1,500				
Truck	14,000				
Miscellaneous	1,000				
TOTAL CAPITAL LOAN	25,000				
OPERATING COSTS					
Bank charges	500	500	500	500	500
Repayment loan[1]	4,300	12,380	15,850	15,850	15,850
Professional fees[2]	1,000	500	500	500	500
Insurance	1,000	1,000	1,000	1,000	1,000
Clam seed[3]	18,270	0	18,270	0	18,270
Bags[4]	15,440	0	0	0	15,440
Plot construction[5]	2,180	0	2,180	0	2,180
Plot maintenance[6]	1,090	1,090	1,090	1,090	1,090
Harvest cost[7]	0	0	4,790	0	4,790
Depreciation[8]	2,500	2,500	2,500	2,500	2,500
Miscellaneous	500	500	500	500	500
TOTAL OPERATING COST	46,780	18,470	47,180	21,940	62,620
INCOME (clam sales)[9]	0	0	109,620	0	109,620
PROFIT (income less operating costs)	(46,780)	(18,470)	62,440	(21,940)	47,000
OPERATING LOAN	46,780	18,470	0	0	0
25% PROFIT TAX (RESERVE)	0	0	–15,610	0	–11,750
BALANCE FORWARD	0	0	46,830	24,890	60,140

1 Interest on capital loan calculated into first year operating budget. Subsequent years include both capital and operating budget loans. Interest rate is 12%. Loan is amortized over 120 months.

2 Fees include legal and accounting fees to develop a business proposal plus annual bookkeeping fees.

3 Cost is figured at $7/1,000 seed. Planting density of 600 seed/bag x 4,350 bags = 2,610,000 seed.

4 Based on cost of $3.55/bag for 1/4 inch mesh bags and 4,350 bags/acre (bags are placed end to end in rows parallel to beach with 2' between rows in an area 435' x 100'.

5 Plot construction based on assumed cost of $0.50/bag for seeding, plot excavation, and rebar placement.

6 Plot maintenance based on assumed cost of $0.25/bag to remove fouling organisms and reposition bag.

7 Harvest cost based on assumed labor cost of $0.50/bag for clam sorting ($0.50 x 4,350 bags = $2,175) plus handling to sink float and market at $0.05/lb ($0.05 x 52,200 lb = $2,610).

8 Depreciation calculated at 10% capital expense ($25,000 x 10% = $2,500).

9 Clams sales based on 50% survival of planted seed x 25 clams/lb x wholesale price of $2.10/lb.

Table 9. Five-year income forecast for Manila clam culture using substrate modification on one acre of ground. Plot developed over three years with annual 2-inch layers of material.

Year	One	Two	Three	Four	Five
CAPITAL INVESTMENT					
Boat, trailer, motor	8,500				
Sink float (materials and labor)	1,500				
Truck	14,000				
Miscellaneous	1,000				
TOTAL CAPITAL LOAN	25,000				
OPERATING COSTS					
Bank charges	500	500	500	500	500
Repayment loan[1]	4,300	11,590	19,340	19,340	19,340
Professional fees[2]	1,000	500	500	500	500
Insurance	1,000	1,000	1,000	1,000	1,000
Plot construction[3]	8,840	8,840	8,840	0	0
Clam seed[4]	18,300	18,300	18,300	18,300	18,300
Netting[5]	4,070	0	0	4,070	0
Plot maintenance[6]	2,500	2,500	2,500	2,500	2,500
Harvest cost[7]	0	0	15,680	15,680	15,680
Depreciation[8]	2,500	2,500	2,500	2,500	2,500
Miscellaneous	500	500	500	500	500
TOTAL OPERATING COST	43,510	46,230	69,660	64,890	60,820
INCOME (clam sales)[9]	0	0	109,770	109,770	109,770
PROFIT (income less operating costs)	(43,510)	(46,230)	40,110	44,880	48,950
OPERATING LOAN	43,510	46,230	0	0	0
25% PROFIT TAX (RESERVE)	0	0	–10,030	–11,220	–12,240
BALANCE FORWARD	0	0	30,080	63,740	100,450

1 Interest on capital loan calculated into first year operating budget. Subsequent years include both capital and operating budget loans. Interest rate is 12%, amortized over 120 months.
2 Fees include legal and accounting fees to develop business proposal plus annual bookkeeping fees.
3 Based on gravel at $8/yd^2, barge leasing and gravel spreading at $26/yd^2. Total cost = $34/yd^2. Quantity of material needed to cover one acre with 1 inch of material is 130 yd^3. One-inch layer costs $4,420. Two-inch layer costs $8,840. Plot developed with multiple layers, 2 inches each year for first three years. Total cost equals $8,840 x 3 = $26,520.
4 Cost is based on price of $7/1,000 seed. Planting density of 60 seed/ft^2 requires 2,613,600 seed.
5 One 12' x 100' section of "Car Cover" netting at $0.76/linear foot costs $76. Lead line (224') attached to the perimeter of the net costs $20 and materials (stakes and nylon string) cost about $4. Labor at $6/hour (2 man hours/net) is about $12. Total cost for one section equals $112. Total netting cost for one acre is $4,065 (36 sections required to cover one acre).
6 Includes annual maintenance for repair and removal of net before each material layer, and management expenses for growth and standing crop estimation.
7 Harvest cost includes $0.25/lb for digging, plus handling and maintenance of sink float at $0.05/lb for total harvest cost of $0.30/lb.
8 Depreciation calculated at 10% capital expense ($25,000 x 10% = $2,500).
9 Clams sales based on 50% survival of planted seed x 25 clams/lb x wholesale price of $2.10/lb.

substrate modification. A survival rate of 25% is assumed for beach culture without using predator exclusion netting.

7. It is assumed that the owner/operator is using clam culture as an investment opportunity; any return to the investor will be from profits, which will be reinvested in the business. No salary will be drawn from the annual expenses.

8. Cash for capital and operation expense is assumed to be financed at a 1991 interest rate of 12% for commercial loans amortized over 10 years.

9. A rate of 25% is used to calculate taxes for years in which the net profit is greater than zero.

With each culture system, clam seed is the largest part of expenses. All methods show positive cash flow beginning with the third-year harvest. The return on investment, however, can vary considerably (Table 10).

The best return per dollar invested is with the use of predator netting (22.4% per year), followed by substrate modification (17.4%) and in-ground bags (13.4%). Beach culture alone, without protecting the seed, returns only 4.4% and is not recommended.

The profitability of each of these culture methods can be affected by factors beyond the control of the owner/operator. Market conditions and decreases in the wholesale price can make a marginally profitable operation unprofitable. Increasing costs of seed, labor, and equipment can also affect the profit margin. Winter storms and freezing temperatures may destroy stocks, resulting in catastrophic losses with a complete loss of investment. Careful site evaluation and testing of the proposed method should always precede any culture operation. This will help the grower to select the best culture method and to identify the risks.

Table 10. *Cost and return comparisons for clam culture using predator netting, in-ground bags, and substrate modification for five years.*

	Beach Culture	Predator Netting	In-Ground Bags	Substrate Modification
START-UP COSTS				
Operating	$60,860	$71,990	$65,250	$89,740
Capital	25,000	25,000	25,000	25,000
TOTAL	$85,860	$96,990	$90,250	$114,740
FIFTH-YEAR CASH BALANCE	$18,600	$108,340	$60,140	$100,450
RETURN ON INVESTMENT (cash balance/start-up costs)	0.22	1.12	0.67	0.88
PERCENT RETURN ON INVESTMENT PER YEAR	4.4	22.4	13.4	17.6

15. Conclusion

Manila clam culture is biologically and economically feasible in Puget Sound, thanks in part to recently developed hatchery technology and to the use of predator exclusion netting and in-ground bags. Growers who wish to enhance the natural recruitment of Manila clams to their beaches can make the beaches attractive to clams by adding gravel to modify the natural substrate.

It is not a can't-miss venture. A successful operation depends on adequate site evaluation, sound crop management, and good business practices. Even then, certain risks must be accepted, such as unfavorable changes in production costs or wholesale clam prices and episodes of pollution or PSP outbreaks that may temporarily delay harvesting or marketing.

Literature Cited

Adams, C., J. C. Cato et al., eds. 1991. *Investing in commercial clam culture: a comprehensive guide to the South Atlantic states.* Florida Sea Grant Program Report 104, 128 pp.

Alessandra, G. 1990. Tapes philippinarum: *Biologia e sperimentazione.* Ente Sviluppo Agricolo Veneto, Italy. 299 pp.

Anderson, G. J. 1982. Intertidal culture of the Manila clam, *Tapes philippinarum,* using large netting enclosures in Puget Sound, Washington. M.S. thesis, University of Washington, Seattle, 99 pp.

Anderson, G. J., M. B. Miller, and K. K. Chew. 1982. *A guide to Manila clam aquaculture in Puget Sound.* Washington Sea Grant Technical Report WSG 82-4, 45 pp.

Bardach, J. E., J. H. Ryther, and W. P. McLarney. 1972. *Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms.* John Wiley and Sons, Inc., New York. 868 pp.

Belding, D. L. 1930. *The soft-shelled clam fishery in Massachusetts.* Massachusetts Department of Conservation, Division of Fish and Game, Marine Fisheries Series 1. 65 pp.

Bourne, N., and J. Lee. 1973. Predation on juvenile bivalves by the shore crab, *Hemigrapsus oregonensis* and *H. nudis. Proceedings of the National Shellfish Association* 64:10.

Bourne, N. 1982. Distribution, reproduction, and growth of Manila clam, *Tapes philippinarum* (Adams and Reeves), in British Columbia. *Journal of Shellfish Research* 2:47–54.

Bourne, N. 1984. *Clam predation by scoter ducks in the Strait of Georgia, British Columbia, Canada.* Canadian Technical Report on Fisheries and Aquatic Sciences 1331. 20 pp.

Bourne, N., C. A. Hodgson, and J. N. C. Whyte. 1989. *A manual for scallop culture in British Columbia.* Canadian Technical Report of Fisheries and Aquatic Sciences 1694. 215 pp.

Bower, S. M. 1989. Unidentified protozoan parasite associated with disease in bivalves from British Columbia. *Journal of Shellfish Research* 8(1):318.

Bower, S. M.., R. Harbo, B. Adkins, and N. Bourne. 1986. *Investigations of Manila clam* (Tapes philippinarum) *mortalities during the spring of 1985 in the Strait of Georgia, with a detailed study of the problem of the Savary Island, British Columbia.* Canadian Technical Report of Fisheries and Aquatic Sciences 1444.

Breese, W. P. and R. E. Malouf. 1975. *Hatchery manual for the Pacific oyster.* Oregon State University Sea Grant College Program Publication ORESU-H-75-002, 22 pp.

Cahn, A. R. 1951. *Clam culture in Japan.* U.S. Fish and Wildlife Service, Fish Disease Leaflet 399, 103 pp.

Castagna, M., and J. N. Kraeuter. 1977. *Mercenaria* culture using stone aggregate for predator protection. *Proceedings of the National Shellfish Association* 67: 1–6.

Castagna, M., and J. N. Kraeuter. 1981. *Manual for growing the hard clam* Mercenaria. Virginia Institute of Marine Sciences (Gloucester Point, Va.), Special Report in Applied Marine Sciences and Ocean Engineering 249, 110 pp.

Chew, K. K. 1989. Manila clam biology and fishery development in western North America. In *Clam Mariculture in North America,* ed. J. J. Manzi and M. Castagna (Elsevier, Amsterdam), pp. 243–261.

deValence, P., and R. Peyre. 1989. Clam culture. In *Aquaculture,* ed. G. Barnabe (Ellis Horwood, N.Y.), vol. 1, pp. 388–415.

Dupuy, J. L., N. T. Windsor, and C. E. Sutton. 1977. *Manual for design and operation of an oyster seed hatchery.* Virginia Institute of Marine Science Special Report in Applied Marine Science and Ocean Engineering 142, 74 pp.

Elston, R. A. 1990. *Mollusc Diseases: Guide for the Shellfish Farmer.* Washington Sea Grant, Seattle. 73 pp.

Fitch, J. E. 1953. *Common marine bivalves of California.* California Department of Fish and Game, Fisheries Bulletin 90, 102 pp.

Flagg, P. J., and R. E. Malouf. 1983. Experimental plantings of the juveniles of the hard clam *Mercenaria mercenaria* (Linne) in the waters of Long Island, New York. *British Columbia Journal of Shellfish Research* 3:19–27

Glock, J. W., and K. K. Chew. 1979. Growth, recovery and movement of Manila clams, *Venerupis japonica* (Deshayes) at Squaxin Island, Washington. *Proceedings of the National Shellfish Association* 69:15–20.

Glude, J. B. 1964. The effect of scoter duck predation on a clam population in Dabob Bay, Washington. *Proceedings of the National Shellfish Association* 55:73–86.

Gotshall, D. W. 1977. Stomach contents of Northern California Dungeness crabs, *Cancer magister. California Fish and Game* 63:43–51.

Guillard, R. L. 1975. Culture of phytoplankton for feeding marine invertebrates. In *Culture of Marine Invertebrates,* ed. P. B. Smith and P. E. Chaney (Plenum Press, N.Y.), pp. 29–60.

Higgens, T. H. 1969. Some aspects of the ecology of a bivalve mollusk in Kaneohe Bay, Oahu, Hawaii. M.S. thesis, University of Hawaii, Honolulu, 47 pp.

Higurashi, T. 1934. *Textbook of Aquaculture.* (In Japanese.) Yokendo Book Company. 431 pp. (Cited in Cahn, 1951.)

Holland, D. A. 1972. Various aspects of the reproductive cycle of the Manila clam *(Venerupis japonica).* M.S. thesis, University of Washington, Seattle, 61 pp.

Holland, D. A., and K. K. Chew. 1974. Reproductive cycle of the Manila clam (*Venerupis japonica)* from Hood Canal, Washington. *Proceedings of the National Shellfish Association* 64:53–58.

Icho, S., and Y. Oshima. 1938. *Textbook of Clam Culture.* (In Japanese.) Sugiyama Book Co. 289 pp. (Cited in Cahn, 1951.)

Ikematsu, W., and J. Wakita. 1955. Studies on the scattering sands in clam bed aimed at propagation of Vene*rupis semidecussata* (Reeve). I. The changes in granular composition of clam bed. (In Japanese, English summary.) *Ariake-kai Kenkyu Hokoku* 2:9–29.

Ikematsu, W., and J. Wakita. 1957. Studies on the scattering sands in clam bed, for aimed-at propagation of *Tapes japonica* (Reeve). II. On the effects of scattering sands, based on an estimation by the amount of setting clam seeds. (In Japanese, English summary.) *Ariake-kai Kenkyu Hokoku* 4:1–12.

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

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. Proceedings of the World Mariculture Society* 8:581–592.

Kurashige, H. 1942. Resisting ability of *Paphia philippinarum* produced in Korea against mud-granule suspension in seawater. (In Japanese.) *Suisan Gakkaiho* (Proceedings, Scientific Fisheries Association) 4:23–35.

Loosanoff, V. L. 1961. Effects of turbidity on some larval and adult bivalves. *Proceedings of the Gulf and Caribbean Fisheries Institute* 14:80–95.

Loosanoff, V. L., and H. C. Davis. 1963. Rearing of bivalve mollusks. *Advances in Marine Biology* 1:1–136.

Loosanoff, V. L., H. C. Davis, and P. E. Chaney. 1966. Dimensions and shapes of larvae of some marine bivalve mollusks. *Malacologia* 4:351–435.

Magoon, C., and R. Vining. 1981. Introduction to shellfish aquaculture. Report, Washington Department of Natural Resources, 68 pp.

Mann, R. 1979. The effects of temperature on growth, physiology, and gametogenesis in the Manila clam, *Tapes philippinarum* Adams and Reeve 1850. *British Columbia Journal of Experimental Marine Biology and Ecology* 38:121–133.

Marwitz, S. R., and C. E. Bryan. 1990. *Rehabilitation of public oyster reefs damaged by a natural disaster in San Antonio Bay.* Texas Parks and Wildlife Department, Management Data Series, no. 32, 10 pp.

Manzi, J. J., and M. Castagna, eds. 1989. *Clam Mariculture in North America.* Developments in Aquaculture and Fishery Science, vol. 19 (Elsevier, Amsterdam), 461 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. thesis, University of 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 Publication WSG 78-2, 18 pp.

Miyazaki, I. 1934. On the development of *Paphia philippinarum.* (In Japanese.) *Suisan Gakkaiho* (Proceedings of the Scientific Fisheries Association) 6. (Cited in Cahn 1951.)

Morse, D. L., J. J. Guzewich, J. P. Harahan, R. Stricof, M. Shayegani, R. Deibel, J. C. Grabau, N. Nowak, J. E. Herrman, G. Cukor, and N. R. Blacklow. 1986. Widespread outbreaks of clam- and oyster-associated gastroenteritis. *New England Journal of Medicine* 314:678–681.

Mottet, M. G. 1980. *Research problems concerning the culture of clam spat and seed.* Washington Department of Fisheries, Technical Report 63, 106 pp.

Mottet, M. G. 1981. *Enhancement of the marine environment for fisheries and aquaculture in Japan.* Washington Department of Fisheries, Technical Report 69, 96 pp.

Newman, J. R., and W. A. Cooke. 1988. Final impact statement for the enhancement of hardshell clam production by beach graveling. Report, Washington Department of Fisheries, 63 pp.

Nosho, T. Y., and K. K. Chew. 1972. The setting and growth of the Manila clam, *Venerupis japonica* (Deshayes) in Hood Canal, Washington. *Proceedings of the National Shellfish Association* 62:50–58.

Nosho, T. Y., and K. K. Chew. 1991. *Remote setting and nursery culture for shellfish growers.* Washington Sea Grant Publication WSG-WO 91-02, 68 pp.

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 population and individual growth. *Biological Journal of Okayama University* 5:13–42.

Price, K. S., Jr., and D. L. Maurer, eds. 1971. *Proceedings of the Conference on Artificial Propagation of Commercially Valuable Shellfish — Oysters.* University of Delaware, College of Marine Studies, Newark.

Quayle, D. B. 1938. *Paphia bifurcata*, a new molluscan species from Ladysmith Harbor, B.C. *Journal of the Fisheries Research Board of Canada* 4:53–54.

Quayle, D. B. 1941. The Japanese "little neck" clam accidentally introduced into British Columbia waters. *Progress Reports of the Fisheries Research Board Pacific Coast Station* 48:17–18.

Quayle, D. B. 1964. Distribution of introduced marine mollusca in British Columbia waters. B.C. *Journal of the Fisheries Research Board of Canada* 21:1155–1181.

Quayle, D. B. 1988. *Pacific oyster culture in British Columbia.* Canadian Bulletin of Fisheries and Aquatic Sciences 218, 241 pp.

Quayle, D. B., and N. Bourne. 1972. *The clam fisheries in British Columbia.* Fisheries Research Board of Canada, Report 179, 70 pp.

Reid, R. 1990. Nursery systems and juvenile clam feeding behavior. Proceedings of the 1990 Manila Clam Culture Workshop. *Aquaculture Industry Development Reports* 90-9:39–42.

Rogers, B. B., and D. A. Rogers. 1989. Can a small moon snail, *Polinices lewisii*, eat a large clam, *Tapes japonica*? *Northwest Environmental Journal* 5:177–179.

Roland, W. G., and P. M. Gubbels. 1990. Estimated costs and returns for a clam growout enterprise that supplements an existing oyster farm. Report, Province of British Columbia Ministry of Agriculture and Fisheries, 11 pp.

Saunders, R. S. 1984. *Shellfish protection strategy.* Washington Department of Ecology, WDOE 84-2.

Shang, Y. C. 1981. *Aquaculture Economics: Basic Concepts and Methods of Analysis.* Westview Press, Boulder, Colo. 153 pp.

Spencer, B. E., D. B. Edwards, and P. F. Millican. 1991. *Cultivation of Manila clams.* U.K. MAFF Directorate of Fisheries Research (Lowestoft), Laboratory Leaflet 65, 29 pp.

Taylor, M. M. 1989. Controlled purification: a policy option in the management of Washington state commercial shellfish resources. M.S. thesis, University of Washington, Seattle.

Taylor, P. 1988. Washington State clam farmer's experience. In *British Columbia Manila Clam Culture Workshop*, ed. T. A. Broady, W. E. Clayton, and W. G. Muad (Aquaculture and Commercial Fisheries Branch, B.C. Ministry of Agriculture and Fisheries), pp. 180–185.

Taylor, P. 1990. Hatchery and nursery culture of the Manila clam. In *Proceedings of the 1990 Manila Clam Culture Workshop,* Aquaculture Industry Development Report 90-9, pp. 29–31.

Thompson, D. 1990. Substrate enhancement of clam beaches in Washington. In *Proceedings of the 1990 Manila Clam Culture Workshop,* Aquaculture Industry Development Report 90-9, pp. 59–64.

Tsutsumi, Y., H. Kawabe, and K. Tominaga. 1981. Investigations into what contributes to the development of nursery areas of the asari clam *(Venerupis japonica).* (In Japanese.) Kumamoto Prefectural Nori Laboratory, 1980 Report of the Cooperative Aid Project for Designated Research, 23 pp. (Cited in Mottet 1981.)

U.S. Department of Health and Human Services. 1986. *National Shellfish Sanitation Program Manual of Operations.* Part 1. *Sanitation of Shellfish Growing Areas.* US DHHS, Food and Drug Administration, Washington, D.C.

Utting, S. D., and B. E. Spencer. 1991. *The hatchery culture of bivalve mollusc larvae and juveniles.* U.K. MAFF Directorate of Fisheries Research (Lowestoft), Laboratory Leaflet 68, 31 pp.

Washington Department of Health. 1990. *Third Annual Inventory of Commercial and Recreational Shellfish Areas in Puget Sound.*

Washington Department of Natural Resources. 1974. *Washington State Marine Atlas,* vol. 2: *South Inland Waters.*

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. thesis, University of Washington, Seattle, 60 pp.

Williams, J. G. 1980. Growth and survival in newly settled spat of the Manila clam, *Tapes japonica. Fishery Bulletin* (U.S.) 77:891–900.

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. *Marine Biology* 29:139–176.

Yoshida, H. 1935. On the full-grown veliger and early young-shell stages of *Venerupis philippinarum* (Adams and Reeve). *The Venus* (Kyoto) 5:264–273. (In Japanese, with English summary.)

APPENDIX A
CONVERSIONS FOR WEIGHTS and MEASURES

LINEAR MEASURE

1 inch	=	2.54 centimeters	=	25.4 millimeters
12 inches	=	1 foot	=	0.3048 meter
3 feet	=	1 yard	=	0.9144 meter
10 millimeters	=	1 centimeter	=	0.3937 inch
1 meter	=	39.37 inches	=	3.28 feet

SQUARE MEASURE

144 square inches	=	1 square foot	=	929.03 square centimeters
27 cubic feet	=	1 cubic yard	=	0.8361 square meter
4840 square yards	=	1 acre	=	0.4047 hectare
10 square millimeters	=	1 square centimeter	=	0.15499 square inch
1 square meter	=	1549.9 square inches	=	1.196 square yards
1 hectare	=	2.471 acres		

LIQUID MEASURE

1 pint	=	28.875 cubic inches	=	0.4732 liter
2 pints	=	1 quart	=	0.9464 liter
4 quarts	=	1 gallon	=	3.7854 liters
1 centiliter	=	0.338 fluid ounces		
1 liter	=	1.0567 liquid quarts		

WEIGHTS

1 ounce	=	28.35 grams		
16 ounces	=	1 pound	=	453.56 grams
100 pounds	=	45.36 kilograms		
1 gram	=	0.03527 ounces		
1000 grams	=	1 kilogram	=	2.2046 pounds

TEMPERATURE

Degrees Fahrenheit (F°)	=	(9/5C°) + 32
Degrees Celsius (C°)	=	5/9 (F° – 32)

APPENDIX B
TIDE LEVEL DETERMINATION

Unequal, semidiurnal tides (two high and two low tides on each daily cycle) occur in the Pacific Northwest. In Puget Sound, maximum tidal range is approximately 7 m (23 ft) near Olympia, Washington, but decreases to approximately 5 m (16 ft) at Neah Bay, Washington (Magoon and Vining 1981). Thus, a wider tidal range is usable for culture plots in south Puget Sound than in more northern areas.

Tidal height for planting Manila clams (about 3–6 ft 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 (206)442-7657 in Seattle for their locations.

b. By using a tide calendar or tide table to determine the tide level at a particular time for your location. Call (206) 442-7657 in Seattle for more information.

c. By leveling from the uppermost limit of barnacles, if present on the upper beach. Barnacles will survive in central Puget Sound to approximately +10 to +11 foot tide level. The upper barnacle level is about 2 feet higher in south Puget Sound and about 2 feet lower in north Puget Sound.

The 0-foot tide level in the Washington is the mean of the lower low water level, while the 0-foot tide level in British Columbia and other countries is the lowest low water level. A 0-foot tide level in Canada is rarely seen.

APPENDIX C
SUPPLIERS OF CLAM SEED AND OTHER AQUACULTURE MATERIALS

MANILA CLAM SEED

Canadian Benthic Ltd.
Box 97
Bamfield, BC V0R 1B0
Attn: Geoff Lindsey
(604) 728-3274

Coast Oyster Company
P.O. Box 327
Quilcene, WA 98376
Attn: Jim Donaldson
(206) 765-3345

Dahman Shellfish Company
SE 393 Dahman Road
Shelton, WA 98584
Attn: Don Dahman
(206) 426-9880

Innovative Aquaculture Products, Ltd.
Skerry Bay
Lasqueti Island, BC V0R 2J0
CANADA
(604) 248-8615 (messages)

Kuiper Mariculture, Inc.
3025 Plunkett Road
Bayside, CA 95524
Attn: Ted Kuiper
(707) 822-9057

Sound Sea Farms, Inc.
P.O. Box 100
Lummi Island, WA 98262
Attn: Dick Poole
(206) 647-6261

Westcott Bay Sea Farms, Inc.
4071 Westcott Drive
Friday Harbor, WA 98250
Attn: Doree Webb
(206) 378-2489

Whiskey Creek Oyster Farm
2905 Bayshore Road
Tillamook, OR 97141
Attn: Lee Hanson
(503) 842-8365

MANILA CLAM STARTER KITS

Madrona Shellfish Ltd.
Box 3056
Parksville, BC V0R 2S0
CANADA
Attn: David Mitchell, R.P.Bio.
(604) 248-6609

Olympia Clams, Inc.
6331 Murray Court N.W.
Olympia, WA 98502
Attn: Don Rogers
(206) 866-7417

Pacific Rim Mariculture
644 Old Eaglemount Road
Port Townsend, WA 98368
Attn: Dale Bonar
(206) 732-4464

ALGAL PASTE/DRIED ALGAE

Coast Oyster Company
P.O. Box 327
Quilcene, WA 98376
Attn: Jim Donaldson
(206) 765-3345

Innovative Aquaculture Products, Inc.
Skerry Bay
Lasqueti Island, BC V0R 2J0
CANADA
(604) 248-8615 (messages)

MATERIALS

ADP Enterprises Inc.
3621 B Street
Philadelphia, PA 19134
(800) 621-0275
Plastic netting, clam bags

Conweb Corporation
1105 16th Street SW
Puyallup, WA 98371
Phone: (206) 848-5880
Plastic netting

Eglund Marine
280 Wilson Street
Westport, WA 98595
Attn: Barney Tole
(206) 268-9311
Longlines

Internet, Inc.
Plastic Netting Fabrications & Sales
2730 Nevada Avenue North
Minneapolis, MN 55427
Phone: 1-800-328-8456
Plastic netting

Norplex, Inc.
7048 South 190th Street
Kent, WA 98032
Attn: Ralph Schley
Phone: (206) 251-6050
Clam grow-out bags, plastic netting, colored nets

Seattle Marine & Fishing Supply
P.O. Box 99098
2121 W. Commodore Way
Seattle, WA 98199
(206) 285-5010
Rope, floats, boots, raingear

Shoalwater Bay Oyster Co.
P.O. Box 51212
Seattle, WA 98115
Attn: Randy Shuman
(206) 523-2702
Nestier / Mexican trays, grow-out trays

Westcott Bay Sea Farms, Inc.
4071 Westcott Drive
Friday Harbor, WA 98250
Attn: Doree Webb
(206) 378-2489
Lantern and pearl nets, buoys

MISCELLANEOUS MATERIALS

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

APPENDIX D
TIME SCHEDULE FOR PLANTING SEED

The schedule below outlines the steps to be taken if you are planting seed with predator netting. In-ground bag culture and substrate modification require some other, or additional, steps.

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:
   a. Determine amount of seed and number of plots to be planted.
   b. Design plots.
   c. Order seed and other materials, allowing at least 3 months advance notice on seed order.
   d. Obtain seed importer's permit from WDF if needed.

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 ensure delivery.

4. Three to five days prior to planting:
   a. Check weather forecasts for planting day.
   b. Take delivery of seed shipment.
   c. Check plots for any last minute modifications.

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 five months after planting, sample the culture plots to determine growth and standing crop. Maintain plots for damage and fouling.

APPENDIX E
REQUIRED SUPPLIES AND MATERIALS

General
rubber boots
rubber gloves
rain gear
waterproof notebook
pencils
knife
tide chart
clipboard
calculator
thermometer
permits, etc.

Surveying
tide chart with correction table
benchmark map
hand-held eye level or surveyor's level
sighting pole or stadia rod
30 x 2 x 1 inch cedar stakes

Sampling
core sampler
sampling quadrant
trowels
screens (smallest mesh 1/4 inch, 6 mm)
screen stand
buckets
waterproof labels
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

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

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

In-Ground Bag Plot Construction
shovel
preconstructed bags
rebar pins
ties
tape measure

Planting
containers for clams (e.g., 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 bags)
float (or other method for sand depuration)
nighttime work gear (for winter harvest)

APPENDIX F
LENGTH VERSUS LIVE WEIGHT APPROXIMATIONS FOR MANILA CLAMS

Live-weight values are 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 = $(1.433 \times 10^{-4}) \times (\text{length})^{3.11}$

Length[a] (mm)	Weight[b] (g)	Length (mm)	Weight	No. Clams/Pound (g)(clams ≥ 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. 25.4 mm = 1 inch

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

APPENDIX G
SAMPLING PROCEDURES AND ESTIMATION OF STANDING CROP

STANDARD SAMPLING PROCEDURES

1. Random Sampling Method

Random sampling is necessary because planted clams are not distributed evenly within each plot. Therefore, sampling is conducted to allow 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, 4–6 inches (10–15 cm) in diameter and about 10 inches (25 cm) long (a 2-pound coffee can is perfect).

b. Determine the number of sample units to be taken in each plot. Eight cores of the size given above per 500 ft^2 (50 m^2) of area will yield sufficient 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 from top to bottom for rows, from left to right for columns) so that each grid can be identified by unique row and column coordinates.

d. Use a random number table to select the locations at which to take core samples, which correspond to the graph paper grids. (A random number table and direction for its use is provided below.)

2. Systematic Sampling Method

Systematic sampling is simple and somewhat faster to perform than random sampling, but it will yield accurate estimates only when clams are distributed fairly 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. Systematic 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 described above.

c. Beginning at a randomly selected point, take core samples at equal intervals over the length of the transect. For each transect, the first yard should be divided by inches numbering from 00 to 35. 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 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 2,000 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 ≥2 feet (0.6 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 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 subarea (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 on waterproof paper of surveyor's tape and written with indelible ink or pencil, and indicate plot number, sample position and date.

To obtain samples, center the sampling device (such as a 2 lb coffee can) over each sample position and push it into the substrate approximately 5 inches. Manila clams tend to burrow deeper in pea gravel than in large cobble or mud. Remove the core with a garden trowel and place the sediment from each sample, with its tag, into a separate plastic bag.

Wash each sample 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 3–4 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 measures using either Vernier calipers or a ruler. Live weight of each clam may also be taken using an appropriate balance. 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 (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 these data, standing crop may be calculated as stated in Appendix F.

CALCULATION OF STANDING CROP

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

1. Average weight (lb or kg) = total weight of clams sampled/total number of clams sampled.
2. Density of clams = total number of clams sampled/number sample units taken.
3. Total number of sample units in plot = total area of plot/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	=	random sampling; unit, 2 lb coffee can
Total weight of clams sampled	=	13.406 lb (6.081 kg)
Total number of clams sampled	=	429
Number of sample units taken	=	40
Total area of plot	=	200 yd^2 (168 m^2)
Sample unit area	=	0.0154 yd^2 (0.0125 m^2)

Standing crop = Avg. clam weight x density of clams x number of sample units

$$\frac{13.406 \text{ lb}}{429 \text{ clams}} \times \frac{429 \text{ clams}}{40 \text{ units}} \times \frac{200 \text{ yd}^2}{0.0154 \text{ yd}^2}$$

= 4,352.6 lb (1,970.5 kg)
= 21.7 lb/yd^2 (11.7 kg/m^2)

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

RANDOM NUMBER TABLE

To use the random number table, select an arbitrary starting point within the table. From this point, write down the pairs of consecutively selected numbers that fall within the range of plot diagram coordinates. For example, if the rows on the plot diagram are numbered from 00 to 10 and the columns from 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 and 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 columns 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:

2<u>04</u>	8<u>17</u>	931	6<u>10</u>	8<u>28</u>	088	0<u>01</u>	198	7<u>21</u>	320
5<u>09</u>	0<u>01</u>	457	9<u>00</u>	5<u>42</u>	390	637	012	319	991

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

<u>row</u>	<u>column</u>
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, discard the second and select a new pair, continuing in the table from where the last selection was made. When you get to the end of the table during selection, simply go back to the beginning of the table (or a new starting point) and continue. After the initial sampling, take care to avoid sampling the same core positions in later samples.

Random Number Table

Numbers should be read 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	382	132	831	582	98	276
620	83	990	979	593	934	212	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	667	926	361	252	281
348	93	312	665	650	510	183	386	116	851	710	722	641	15	71
953	442	387	604	897	76	576	908	572	424	784	589	278	452	233
623	804	197	516	633	740	702	507	748	562	308	485	875	800	42
897	854	854	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
952	957	918	751	321	803	911	836	350	800	458	542	867	342	294
700	47	189	66	85	739	529	491	106	372	36	185	919	694	623
945	955	596	523	336	237	589	627	414	445	670	190	602	522	602
269	850	147	504	305	378	180	263	815	301	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	361
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	397	516	950	546	460
540	166	444	80	832	748	972	665	803	81	482	919	902	950	959
38	269	269	756	211	478	620	62	549	797	26	568	149	696	450
737	508	40	266	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	693	317	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	388	368	968	360	625	255	496	18	641	23	688	815	975
966	136	956	33	269	27	301	366	227	870	777	703	465	608	487
741	53	748	740	120	188	571	794	289	157	353	458	483	694	114
130	242	477	797	228	472	297	414	447	976	271	188	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	616	774	155	487	839	665	980	713	133	900	690	932	944
490	338	286	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
686	890	900	941	647	236	460	507	541	23	940	270	517	682	628
53	636	144	432	368	775	726	486	186	246	851	905	122	483	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	646	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	879	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	522	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	387	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	980	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
149	850	259	352	657	824	537	262	820	544	807	514	8	556	730
852	80	329	185	307	10	498	927	417	182	968	568	867	906	877
992	547	313	215	868	165	746	200	111	51	716	336	830	336	576
462	74	290	818	359	365	331	336	447	949	818	492	406	646	667
300	328	435	707	749	398	937	172	13	448	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	724	689	218	693	205	691	281	85	22	867	649	705	632	126
264	707	794	269	2	215	803	66	550	469	265	286	271	346	931
676	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	852	138	942	158
880	409	700	824	107	838	385	186	155	206	958	328	440	209	146
494	2	258	43	722	708	543	91	270	942	133	588	610	809	724
555	639	751	871	990	642	211	707	78	881	936	576	946	276	543
679	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	631	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
265	146	780	996	36	204	627	205	149	524	820	39	55	353	47
362	9	870	812	862	467	564	147	465	857	328	370	437	592	481
806	905	933	780	289	944	584	301	199	710	768	693	379	39	494
893	9	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
631	96	968	732	861	828	459	712	172	323	813	57	485	19	574
210	824	121	706	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
481	898	264	783	945	226	629	90	383	936	593	520	288	862	720
566	935	420	575	258	438	123	746	252	382	267	22	182	363	310
491	995	326	789	652	392	80	175	801	608	57	361	637	674	994

IN THE FIFTY YEARS since its accidental introduction into Puget Sound, the Manila clam has established itself so firmly in the region that it is now the area's major steamer clam. Both commercial and recreational clam growers prize the Manila clam for its adaptability to culture, ease of harvest, and long shelf life. And shellfish consumers can't seem to get enough—if present production were doubled, it would not meet current demand.

This guide covers clam production from hatchery to harvest. It includes instructions for growing Manila clams under predator-exclusion netting and in buried bags, and explains how to modify the beach to encourage clam seed to settle. Clam growers, whatever the size of their operation, should find it a useful guide.

About the Authors

DERRICK TOBA is pursuing an advanced degree in the School of Fisheries at the University of Washington.

DOUGLAS THOMPSON is a fisheries biologist at the Washington Department of Fisheries shellfish laboratory located at Point Whitney.

KENNETH CHEW is Professor of Fisheries at the University of Washington and director of the administrative office of the Western Regional Aquaculture Center.

GREGORY ANDERSON AND MARK MILLER wrote the original Washington Sea Grant publication upon which this guide is based when they were students of Professor Chew.

ISBN 0-934539-16-2
WSG 92-01

$10.00