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The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe

Volume 2, Pacific Coast and Supplemental Topics

Edited by

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U.S. Department of Commerce

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On the cover
An early etching of oysters of varying ages attached to a block of wood, circa 1880's, courtesy of W. L. Hobart.

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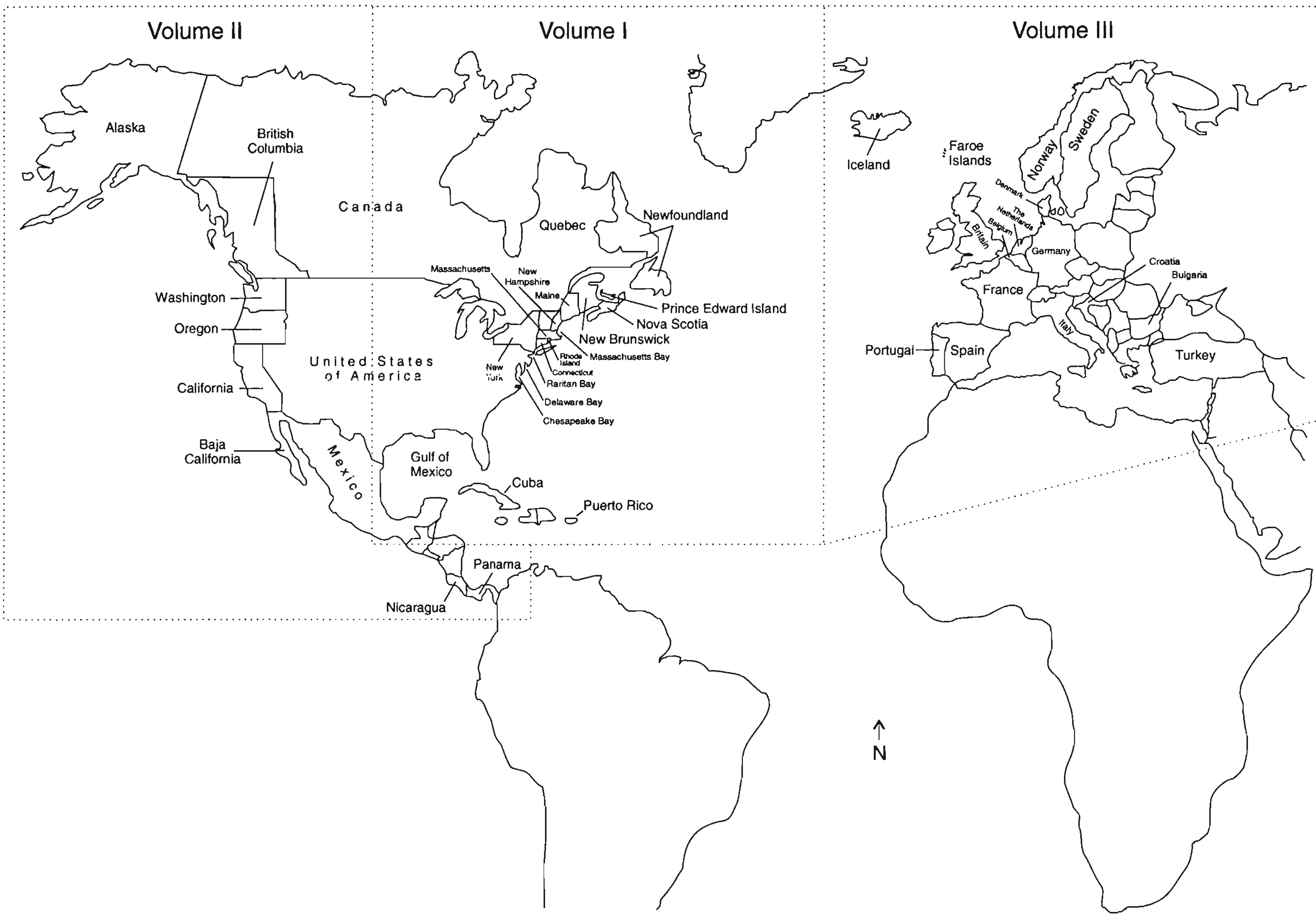
CONTENTS

The molluscan fisheries areas of North and Central America and Europe featured in each volume



The Molluscan Fisheries of Mexico

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ABSTRACT

Over 100 molluscan species are landed in Mexico. About 30% are harvested on the Pacific coast and 70% on the Atlantic coast. Clams, scallops, and squid predominate on the Pacific coast (abalone, limpets, and mussels are landed there exclusively). Conchs and oysters predominate on the Atlantic coast. In 1988, some 95,000 metric tons (t) of mollusks were landed, with a value of $33 million. Mollusks were used extensively in prehispanic Mexico as food, tools, and jewelry. Their use as food and jewelry continues. Except in the States of Baja California and Baja California Sur, where abalone, clams, and scallops provide fishermen with year-round employment, mollusk fishing is done part time. On both the Pacific and Atlantic coasts, many fishermen are nomads, harvesting mollusks wherever they find abundant stocks. Upon finding such beds, they build camps, begin harvesting, and continue until the mollusks become so scarce that it no longer pays to continue. They then look for productive beds in other areas and rebuild their camps. Fishermen harvest abalones, mussels, scallops, and clams by free-diving and using scuba and hooka. Landings of clams and cockles have been growing, and 22,000 t were landed in 1988. Fishermen harvest intertidal clams by hand at wading depths, finding them with their feet. In waters up to 5 m, they harvest them by free-diving. In deeper water, they use scuba and hooka. Many species of gastropods have commercial importance on both coasts. All species with a large detachable muscle are sold as scallops. On the Pacific coast, hatchery culture of oysters prevails. Oyster culture in Atlantic coast lagoons began in the 1950's, when beds were enhanced by spreading shells as cultch for spat.

Introduction

In 1990, fisheries production in Mexico (Fig. 1) was 1,461,105 metric tons (t) with a total value of 3,131,103 million pesos (US$1,043.7 million). Mollusks contributed only 98,771 t of the total (6.76%), with a value of $45.09 million (4.32% of the total), but they are of great importance to fishermen as a primary or alternative source of income. Fisheries statistics group more than 100 species landed in the country into 11 categories: Abalone, conchs, and limpet (gastropods); clams, mussels, oysters, cockles, scallops, and pen shells (pelecypods); octopus and squids (cephalopods); and shells.

About 30% of mollusk landings are from the Pacific coast and 70% from the Atlantic coast, but the Pacific coast leads in value (Fig. 2, 3). Abalone, limpets, and mussels are landed exclusively on the Pacific coast, while clams, scallops, pen shells, and squid predominate there. Conchs, oysters, and octopus predominate on the Atlantic coast. Oysters, clams, and octopus lead in production (Fig. 4), while oysters, octopus, and abalone lead in value (Fig. 5).

Historical Uses of Mollusks

Mollusks were used extensively in prehispanic Mexico. Their use as food is shown by the presence of many shell middens along the Pacific and Atlantic coasts (Sheng and Gifford, 1952; Lorenzo, 1955; Fieldman, 1969; Foster 1975; Reigadas et al., 1984). They were also used as tools and jewelry (Suarez, 1977; Suarez, 1988; Luna, 1986). That mollusks were carried inland is evident from offerings in the main temple of Tenochtitlan (Prehispanic Mexico City). Later, they were used by Indians in New Spain as food, ornaments, and medicine (Ancona and Del Campo, 1953; Del Campo, 1984). The manufacture of handcrafts and jewelry from mollusks continues to the present time.

Current Fishing Practices

Many fishermen are nomads, harvesting mollusks along the coast wherever they find them sufficiently abundant. Fishermen build temporary camps and then harvest mollusks until they become so scarce that it no longer pays. The practice prevails along most of the Pacific coast and for marine species on the Atlantic coast. Table 1 lists the number of fishing permits by group and state, and the numbers of boats and fishermen that might be engaged in the shellfisheries. The number of permits issued by each state is much smaller than the number of boats and fishermen that actively harvest mollusks. Except in the States of Baja California and Baja California Sur, where abalone, clams, and scallops provide fishermen with year-round employment, mollusk fishing is done only part time, even where harvesting cooperatives have been formed.

Fishermen harvest clams, abalones, mussels, and scallops by free-diving and by using scuba and hookah. They usually overexploit the stocks, except on the west coast of Baja California. There, zones have been assigned to cooperatives, the members of which demand that biologists assess their stocks.

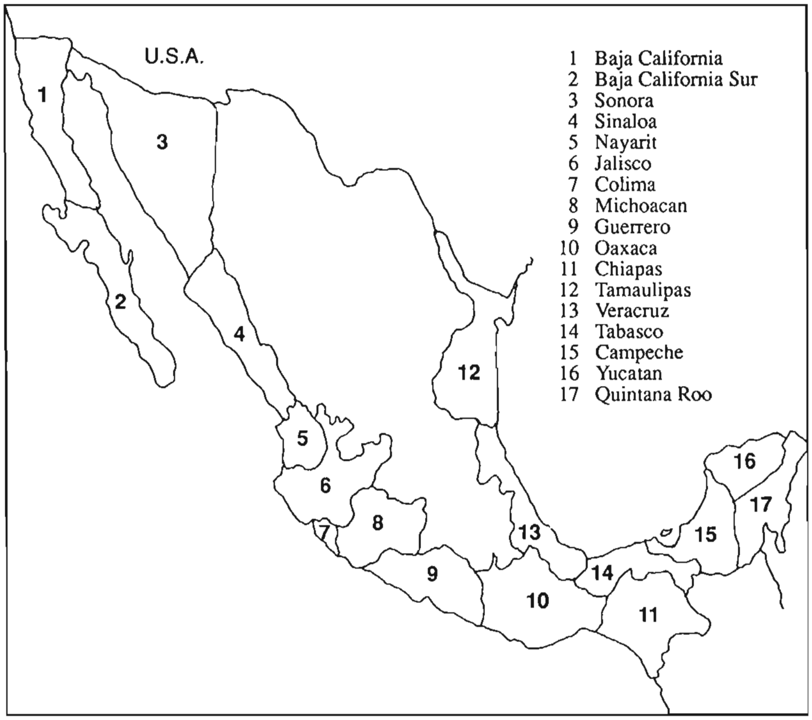

Figure 1
The coastal states of Mexico.

Abalone Fishery

The abalone, *Haliotis* sp., fishery is limited to the Pacific coast of Baja California. Five of the eight abalone species that inhabit the northeast Pacific coast share this habitat (Table 2). They live on rocky bottoms from the intertidal zone to 30 m, and are associated with beds of giant kelp, *Macrocystis* sp., and other algae, including

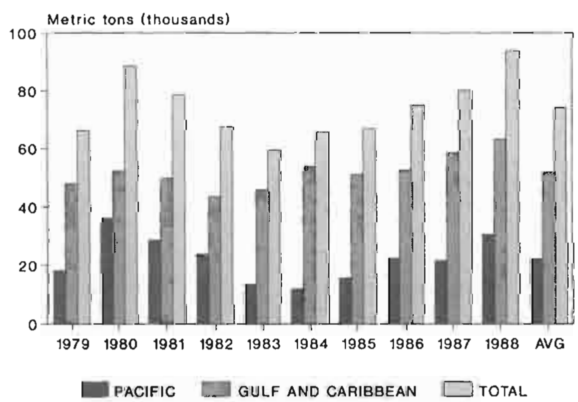

Figure 2
Mollusk landings from the Pacific and Atlantic coasts of Mexico, 1979–88.

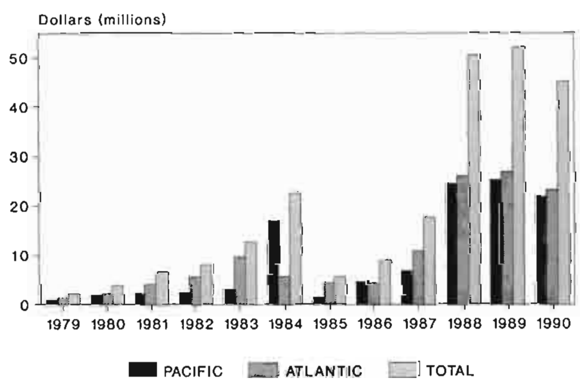

Figure 3
Value of mollusk landings from the Pacific and Atlantic coasts of Mexico, 1979–90.

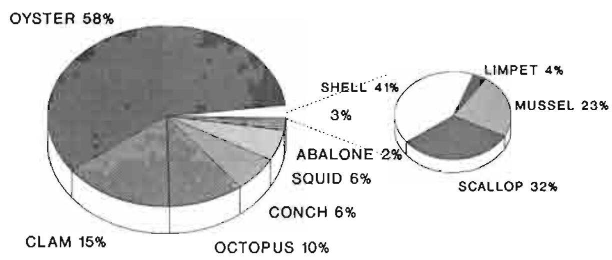

Figure 4
Percent of volume landed by groups of Mexican molluscan fisheries.

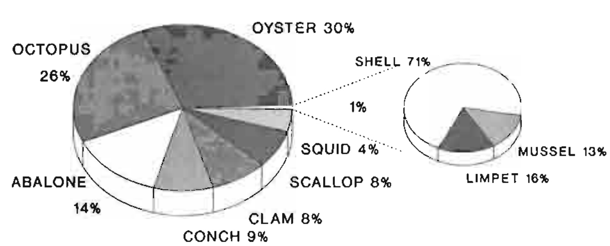

Figure 5
Percent of value landed by groups of Mexican molluscan fisheries.

Pelvetia sp., *Eisenia* sp., *Egregia* sp., and *Gigartina* sp. (Ortiz and Leon, 1988). Abalone compete for space and food with sea urchins, *Strongylocentrotus* sp. (Palleiro et al., 1988), turbo shells, *Astraea* sp. and *Turbo* sp., and the giant keyhole limpet, *Megathura crenulata.* When fishermen remove abalone, its space is occupied by competitors (Baqueiro et al., 1980; Gusman, 1989).

Fishery History

Evidence from middens and other archaeological sites show that Indians used abalone as food, tools, and jewelry long before the Spanish arrived (Reigadas et al., 1984). The Indians collected them from intertidal pools using sharp stones, and pounded the meat to soften it for eating.

The commercial fishery began when Chinese immigrants came to the United States. In 1880, they paid $60/boat for fishing rights along the coasts of Baja California and fishermen used hand rakes from small boats to gather abalones. At the turn of the century, when the Chinese were expelled from California, a syndicate at Ensenada, Baja California, acquired all the boats there and established the first Mexican abalone fleet. Shortly afterward, some Japanese fishermen introduced free diving as a method to gather abalones. They used barrels as floating devices to support themselves when at the surface. The Japanese controlled the fishery until the beginning of World War II.

Figure 6
Hard hat diver descending to harvest abalone. Photograph by Erik Baqueiro C.

In 1930, hard hat divers began fishing for abalone (Fig. 6), each collecting an average of 1,500 kg of abalone/day. In 1937, the first fishing area with rights for local fishermen was established, and in 1950 the first cannery was built at Ensenada. Eventually, fishermen replaced hard-hat gear with scuba, and recently have replaced scuba with hookah gear. Hard-hat diving ended in 1980.

Present Status of the Fishery

In 1972, the government set aside abalones, pismo clams, oysters, lobsters, and shrimp for fishing only by cooperatives, thus limiting access to them by private individuals. With the assistance of the Federal government, 34 cooperatives with 180 boats now actively fish along the coast of Baja California. The catches are processed in 12 local canneries (Fig. 7). A total of 30,000 people are employed as fishermen and cannery workers and in associated jobs.

The boats used for harvesting abalone are 4.9–6.7 m (16–22 feet) long and are powered by 40–55 hp outboard motors. The crew of each boat consists of a diver, an oarsman who follows the diver, and a lifeline man who tends the air hose and lifeline and takes up the catch. Each diver is overweighted, wears boots, and has a net bag kept open with a ring that hangs from his weight belt (Fig. 8). The diver collects abalones using a scraper and then places them in the bag. When the bag is loaded, the diver releases his weight belt and the lineman hauls the belt and bag to the surface. The diver can then ascend freely.

As with other mollusks, abalone production has varied annually. It increased sharply in the late 1940's and reached 5,993 t in 1950. It fell to 1,220 t in 1952, but then increased slowly to 3,461 t in 1956. Production was nearly stable in the 1960's at about 3,000 t. It began to decline in the mid-1970's and was only about 1,000 t in

Table 1
Permits, equipments, fishermen, cooperatives, and aquaculture enterprises in mollusk fisheries of Mexico for the year 1990.

					Equipment		Aquaculture	
	Permits	Boats[1]	Cooperatives	Fishermen	Scuba	Hookah	Cooperative	Private
Pacific coast								
Baja California	126	2,245	14	3,093	1,335	20	1	3
Baja California Sur	99	1,955	40	2,399	571	23	5	1
Sonora	284	2,738	51	5,165	47	15	13	8
Sinaloa	290	7,627	124	7,325	102	0	76	4
Nayarit	42	1,877	14	2,022	0	3	2	0
Jalisco	72	2,383	25	1,585	19	5	2	0
Colima	45	877	13	1,186	2	86	0	0
Michoacan	42	3,110	18	1,653	0	15	0	0
Guerrero	51	3,920	38	2,115	73	37	4	1
Oaxaca	95	2,531	36	2,802	3	30	2	0
Chiapas	79	4,599	33	3,534	4	25	4	0
Total	1,225	33,862	406	32,879	2,156	259	109	17
Gulf and Caribbean								
Tamaulipas	147	5,004	37	2,732	0	0	1	0
Veracruz	133	14,600	59	8,634	6	13	2	10
Tabasco	29	5,420	34	1,988	0	1	0	4
Campeche	222	2,529	37	2,809	0	0	1	2
Yucatan	54	1,580	17	1,771	178	35	1	0
Quintana Roo	39	811	13	567	175	98	0	0
Total	624	29,944	197	18,501	359	147	5	16

Number of permits by groups.

	Abalone	Clams	Squid	Conch	Oyster	M. Cockle	Octopus	Total
Total	34	267	423	223	561	19	322	1,849
Pacific	34	210	379	109	381	19	92	1,225
Atlantic	0	57	44	114	180	0	230	624
Private	140	165	143	1	14	250	713	
Social	34	119	234	67	560	5	64	1,083
Government	8	24	13	8	53			

[1] Total number of boats registered for coastal fisheries.

Table 2
Commercial abalone of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Haliotis cracherodii	R, Sl, Ow	C	11	$4/kg	Baja Calif. and Baja Calif. Sur
H. corrugata	R, Sl, Ow	C	20	$4/kg	Baja Calif. and Baja Calif. Sur
H. fulgens	R, Sl, Ow	C	63	$4/kg	Baja Calif. and Baja Calif. Sur
H. rufescens	R, Sl, Ow	I	1	$4/kg	Baja Calif. and Baja Calif. Sur
H. sorenseni	R, Sl, Ow	I	5	$4/kg	Baja Calif. and Baja Calif. Sur

[1] Habitat: R=rock substrate, Sl=sublitoral level, Ow=open waters location.
[2] Exploitation: C=commercial, I=incidental.

1981, but has been increasing slowly since then, reaching nearly 2,000 t in 1988.

Abalone prices paid to fishermen increased sharply until 1981 when they were nearly $70/kg. When the peso was devaluated, prices fell sharply, and abalones sold for only $2.25/kg in 1983. Later, prices rose to about $4.95/kg in 1988.

Management and Regulations

One or two management directives have been applied in the abalone fishery. From 1940 to 1972, the fishing season was closed from January 15 to March 15. From 1972 to 1982, it was closed from 1 July to 31 August. In 1982, the seasons were changed again. Based on growth studies of different populations, closed seasons were fixed locally, so that the species now has a different minimum size in each area (Table 3).

Abalone Culture

Studies showed abalones were being overfished (Polanco et al., 1988). The decline of production in the 1970's motivated the Federal government to construct an abalone hatchery at Tortugas Bay on the west coast of Baja California. Production of juveniles 2.5 cm long began in 1985. The intent was to restock areas where natural recruitment was poor. Since then, due to technical and management problems, only a few thousand abalones have been released each year.

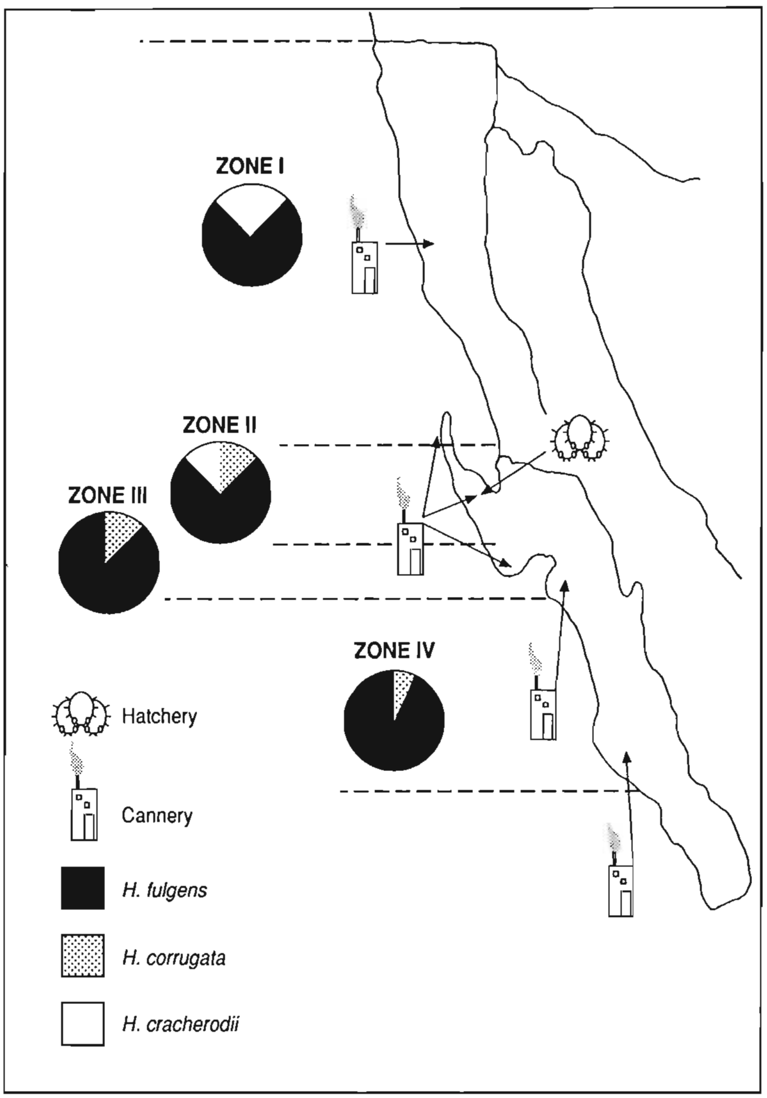

Figure 7
Baja California, showing location of abalone hatchery, canneries, and relative abundance of main species of abalone (*Haliotis* sp.).

Conch Fishery

Conchs have had commercial importance recently in several states, as other species have become scarcer (Fig. 9). From 1979 to 1988, landings ranged from 325 t to about 810 t (weight without shell). Landed value was about $400,000 in 1984, but rose sharply after 1986 to about $5.3 million in 1988.

In Baja California Sur, which leads the nation in conch production, catches are monospecific: species differ with location. On the northern part of the Pacific coast, the catch is directed toward the rockpile turban, *Astrea turbanica*, and wavy turban, *A. undosa*, while on the southern portion of that coast, it is directed towards the Pacific crown conch, *Melongena patula*. In the Gulf of California, the target species are *Muricanthus nigritus* and the pick-mouthed murex, *Hexaplex erythrostomus*, both fished with baited traps. Other species landed include the giant eastern Pacific conch, *Strombus galeatus*, eastern Pacific fight conch, *S. gracilior*, and granulated conch, *S. granulatus*, all of which are fished by divers. The Pacific conch occurs around protected islands, whereas the fighting conch and granulated conch occur in bays along the coast (Table 4).

Landings in the State of Chiapas are second in importance on the Pacific coast, and sixth in Mexico. They are comprised of *Purpura pansa*, found on rocky shores, and several species of *Murex*, which are harvested with baited traps.

On the Atlantic coast, landings records of queen conchs, *Strombus gigas*, began in the

Figure 8
Hookah diver collecting abalone. Photograph by Erik Baqueiro C.

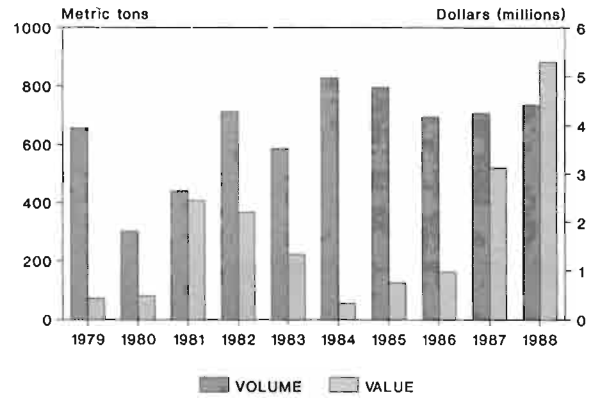

Figure 9
Annual conch production from Mexico, 1979–88.

Table 3
Minimum size and closed season for the five species of abalone on the four fishing zones. (Shell length in mm.)

Zone	Yellow	Blue	Red	Black	White
I	140	150	165	120	140
II	135	145	165	120	135
III	130	140		120	130
IV	110	120		120	110

Closed season	
I	1 July–30 Nov.
II	1 Aug–31 Dec.
III	1 Aug–31 Dec.
IV	1 Sept.–31 Jan.

1950's when the towns of Cosumel and Isla Mujeres, in the State of Quintana Roo, were opened to tourism. In the 1970's, exports began to the United States, which soon became the main market, leaving only a small portion for domestic consumption and tourists. Queen conch landings reached a peak of 350 t in 1976 when there were about 325 fishermen whose annual catch was about 1 t each. In 1978, the catch fell to 200 kg/fisherman and has since fallen even further, while the number of fishermen increased to 850 by 1983 (Polanco et al., 1988; Quijano, 1988).

In 1984, only 26% of the conch production in Quintana Roo was comprised of queen conchs. The milk conch, *S. costatus*, comprised 70% of the catch, and the West Indian shank, *Xancus angulatus*, and knobbed whelk, *Busycon carica*, comprised most of the remainder (De la Torre, 1984).

On the Gulf of Mexico coast, landings are multispecific, with *Busycon* sp. dominating in Tamaulipas, Veracruz, and Tabasco, while the milk conch dominates in Campeche and Yucatan. Production in Yucatan has fallen to such an extent that in 1989 the government banned conch fishing. In Campeche, the maximum sustainable yield of conchs is 750 t a year, an amount that has been reached since 1984 (Baqueiro et al., 1991).

Aquaculture Development and Prospects

Efforts have been made to culture the queen conch, which has a planktonic larval period of 18–26 days. A laboratory was outfitted to produce juveniles for restocking depleted beds in Quintana Roo (Baqueiro, 1991). From 1984 to 1987, the laboratory reared and liberated 25 thousand juveniles whose length was about 25 mm. However, in 1987, hurricane Gilbert damaged the laboratory and the rearing ended.

Limpet Fishery

Fishermen land two species of limpets. One is the keyhole limpet, which is attached to rocks in beds of giant kelp in Baja California Sur. Fishermen sell it as a substitute for abalone. The other limpet is the top shell, *Ancistromesus mexicanus*, which occurs on rocky shores with heavy seas, from the states of Sonora to Oaxaca.

Catches of keyhole limpets are listed in landings statistics as "others" or with the rockpile turban, as both are canned. Most limpets taken at Sonora are also canned. Limpets from other states are consumed fresh

Table 4
Commercial conchs and limpets of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Conchs					
Astraea turbanica	R, Sl, Ow	C	90	\$3/kg	Baja Calif. and Baja Calif. Sur
A. undosa	R, Sl, Ow	C	10	\$3/kg	Baja Calif. and Baja Calif. Sur
Busycon carica	S, Md, R	C		\$4/kg	Tamaulipas to Quintana Roo
B. canaliculatum	S	I		\$4/kg	Tamaulipas to Quintana Roo
B. candelabrum	Sl	I		\$4/kg	Tamaulipas to Quintana Roo
B. coarctatum	S1	I		\$4/kg	Tamaulipas to Quintana Roo
B. contrarium	S1	C		\$4/kg	Tamaulipas to Quintana Roo
B. perversum	S1	C		\$4/kg	Tamaulipas to Quintana Roo
B. spiratum	"	I		\$4/kg	Tamaulipas to Quintana Roo
Cassis madagascariensis	"	C		\$4/kg	Yucatan and Quintana Roo
C. tuberosa	"	C		\$4/kg	Yucatan and Quintana Roo
Charonia variegata	"	C		\$4/kg	Tamaulipas to Quintana Roo
Fasciolaria princeps	S, Md, R, Sl	C	20	\$4/kg	Baja Calif. to Oaxaca
F. tulipa	"	C		\$4/kg	Tamaulipas to Quintana Roo
F. lilium	"	C		\$4/kg	Tamaulipas to Quintana Roo
Hexaplex erythrostomus	S, Md, R, Sl	C	40	\$4/kg	Baja Calif. to Oaxaca
Melongena corona	"	C		\$4/kg	Tamaulipas to Quintana Roo
M. melongena	Md, M, I-Sl	C		\$4/kg	Tamaulipas to Quintana Roo
M. patula	S, M, Sl	C	60	\$3/kg	Baja Calif. and Baja Calif. Sur
Muricanthus nigritus	S, Md, R, Sl	C	60	\$4/kg	Baja Calif. to Oaxaca
Pleuroploca gigantea	"	C		\$4/kg	Tamaulipas to Quintana Roo
Pomasea patula	Md, Mp, Fw	C		\$4/kg	Veracruz
Strombus alatus	"	I		\$4/kg	Tamaulipas to Quintana Roo
S. costatus	"	C,O		\$4/kg	Yucatan to Quintana Roo
S. galeatus	S, Md, Sl	C	80	\$4/kg	Baja Calif. to Oaxaca
S. gallus	"	I		\$4/kg	Tamaulipas to Quintana Roo
S. gigas	S, Md, Sl	C,O		\$4/kg	Yucatan to Quintana Roo
S. gracilior	S, Md, Sl	C,P	60	\$4/kg	Baja Calif. to Oaxaca
S. granulatus	S, Md, Sl	C,P	40	\$4/kg	Baja Calif. to Oaxaca
S. peruvianus	S, Md, Sl	I		\$4/kg	Baja Calif. to Oaxaca
S. pugilis	"	C,P		\$4/kg	Tamaulipas to Quintana Roo
S. raninus	"	I		\$4/kg	Tamaulipas to Quintana Roo
Xancus angulata	"	C		\$4/kg	Tamaulipas to Quintana Roo
Limpets					
Ancistromesus mexicanus	R, Sl, Ow	C,O	100	\$4/kg	Nayarit to Guerrero
Megathura crenulata	R, Sl, Ow	C	100	\$4/kg	Baja Calif. and Baja Calif. Sur

[1] Habitat: substratum: S=sand, Md=mud, R=rock, Mp=macrophyt, M=mangrove; level: I=intertidal, Sl= sublitoral; location: Ow=open waters, Fw=fresh water.
[2] Exploitation: C=commercial, O=overexploited, P=potential, I=incidental; Pr=protected.

and are available locally or in markets in the cities of Ixtapa and Acapulco.

From 1979 to 1988, landings of limpets have ranged from 180 t in 1982 to only 1 t in 1988. Their landed value increased from \$2,000 in 1979 to \$37,500 in 1986.

Management and Regulations

The taking of conchs and limpets is open to all fishermen, except in Quintana Roo where permits are issued only to cooperatives.

Clam and Cockle Fisheries

Fishermen harvest clams and cockles intensively in only a few states. The largest quantities are landed in the States of Baja California Sur, Baja California, and Sinaloa on the Pacific coast; and Campeche on the Atlantic coast (Fig. 10). This group includes clams of several families, with species of the family veneridae being the most important, and cockles of the genus *Anadara* (Table 5). Clams and cockles constitute 15% of the quantity and 8% of the value of all mollusks landed.

On the Pacific coast, fishermen harvest the red clam, *Megapitaria aurantiaca*, and black clam, *M. squalida*, from Baja California to Chiapas; the two comprise as much as 70% of clam production. They are usually harvested with *Dosinia ponderosa*. Though the three have different sediment preferences, sometimes they occur in the same general areas (Baqueiro, 1979). The mangrove cockle, *Anadara tuberculosa*, inhabits mud between roots of the red mangrove, *Rhizophora mangle*, in mesohaline areas. The cockle is harvested extensively from Baja California Sur to Chiapas.

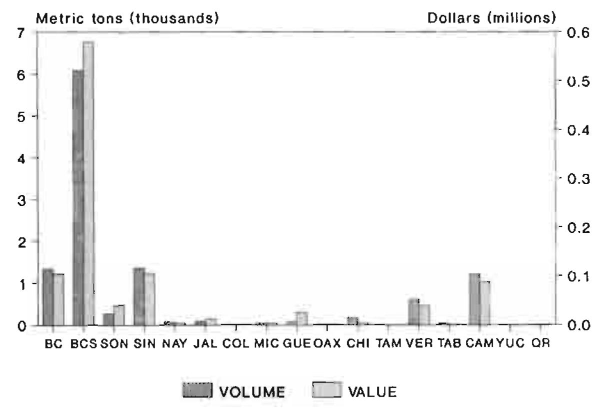

Figure 10
Mean annual clam landings in coastal states of Mexico.

On the Atlantic coast, the principal clam produced is the Atlantic rangia, which occurs in muddy bottoms in low salinity estuaries from Chesapeake Bay to Campeche. Clams that fishermen harvest occasionally from sandy bays and open high salinity waters are the gaudy sanguine, *Asaphis deflorata;* tiger lucine, *Codakia orbicularis;* southern quahog, *Mercenaria campechensis*; and the cross-barred venus, *Chione cancellata.*

Fishermen harvest intertidal clams and cockles by hand at low tide. At wading depths, fishermen feel for the clams with their feet and collect them. In deeper water, up to about 5 m, fishermen harvest them by free-diving using fins and mask. In yet deeper water, they

Table 5
Commercial clams and cockles of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Clams					
Asaphis deflorata	Mp, S, Md	C,O		$2/kg	Veracruz to Quintana Roo
Chione californiensis	S, I-Sl, Pw	C	20	$4/kg	Baja Calif. to Sonora
C. cancelata	"	C,P		$2/kg	Tamaulipas to Yucatan
C. gnidea	S, Sl	C,P	60	1¢/each	Baja Calif. to Chiapas
C. subrugosa	S, Sl	C,P	40	1¢/each	Baja Calif. to Chiapas
C. undatella	S, I-Sl, Pw	C	80	$4/kg	Baja Calif. to Sonora
Codakia orvicularis	"	C,P		$2/kg	Veracruz to Quintana Roo
Dosinia ponderosa	S, Sl	P		10¢/each	Baja Calif. to Chiapas
Glycymeris gigantea	S, Sl	P		1¢/each	Baja Calif. to Chiapas
Laevicardium elatum	S, Sl	P		1¢/each	Baja Calif. to Chiapas
Megapitaria aurantiaca	S, Sl	C	60	10¢/each	Baja Calif. to Chiapas
M. squalida	S, Sl	C	40	10¢/each	Baja Calif. to Chiapas
Mercenaria campechensis	Mp, S	C,P		$2/kg	Tamaulipas to Yucatan
Peryglypta multicostata	S, Sl	P		1¢/each	Baja Calif. to Chiapas
Polimesoda carolineana	"	C,P		$2/kg	Tamaulipas to Campeche
Rangia cuneata	Md, Cl	C		$2/kg	Tamaulipas to Campeche
R. flexuosa	"	P		$2/kg	Tamaulipas to Campeche
Tivela byronensis	S, Sl	P		1¢/each	Baja Calif. to Chiapas
T. stultorum	S, I-Sl, Ow	C	100	$2/kg	Baja Calif. and Baja Calif. Sur
Trachycardium sp.	S, Sl	P		1¢/each	Baja Calif. to Chiapas
Ventricolaria isocardia	S, Sl	P		1¢/each	Baja Calif. to Chiapas
Cockles					
Anadara grandis	S, Sl	I		1¢/each	Baja Calif. to Chiapas
A. multicostata	S, Sl	I		1¢/each	Baja Calif. to Chiapas
A. tuberculosa	M, Md, I	C	100	1¢/each	Baja Calif. to Chiapas

[1] Habitat: substratum: S=sand, Md=mud, Mp=macrophyt, M=mangrove; level: I=intertidal, Sl= sublitoral; location: Cl=coastal lagoons, Pw=protected waters, Ow=open waters.
[2] Exploitation: C=commercial, O=overexploited, P=potential, I=incidental.

use scuba and hookah. To locate the clams, the divers use a hand tool which they punch into the bottom. This forces nearby clams to issue a jet of water and sand. The divers see the jets and dig out the clams, then put them in net bags. When the bag is filled, the lineman hauls it to the surface with a line. In contrast to diving for abalone, clam divers use fins and are not heavily weighted (Fig. 11).

Landings and value of clams and cockles have been growing. From 1979 to 1981 fishermen landed about 8,000 t annually, but by 1988 they landed about 22,000 t. Annual landings fluctuate as beds become overfished.

Mussel Fishery

Fishermen harvest mussels on the Pacific and Atlantic coasts, but statistics are collected only on the Pacific coast (Table 6). On the Atlantic coast, they are included with clams in the few areas where they are harvested.

Figure 11
Scuba diver probing for clams. Photograph by Erik Baqueiro C.

Production on the Pacific coast is from Baja California and Baja California Sur where blue mussels, *Mytilus edulis*, and California mussels, *M. californianus*, grow. Fishermen also harvest a small quantity of *Mytella strigata* from coastal lagoons in the state of Guerrero (Table 6). From 1979 to 1988, mussel production fluctuated widely from about 850 t in 1981 to 190 t in 1984, while their value has been increasing from about $2,000 in 1985 to nearly $50,000 in 1988. Most mussels from the Baja California States are shipped fresh to the United States, and a small portion is also canned locally. Those from Guerrero and the Atlantic coast are eaten locally and some are occasionally shipped to Mexico City.

Scallop and Pen Shell Fisheries

All mollusks harvested only for their adductor muscle are considered as scallops (Table 7). At one time, pen shells, *Pinna* sp. and *Atrina* sp., from the Pacific coast were the only species of the group. But as they became scarce and U.S. demand for scallops increased, all species with a large detachable muscle have been sold as "Callo de almeja."

In recent years, the mother of pearl oyster, *Pinctada mazatlanica*, and the western wing oyster, *Pteria sterna*, have been harvested for their muscles, even though they have been under protection for over 20 years. The pen shells *Pinna rugosa* and *Atrina rigida* are still harvested along the coasts of the Pacific and Gulf of California. Next in importance to pen shells are the rock scallops *Spondillus calcifer* and *S. princeps* and, finally, *Pecten bogdesii* and *Argopecten circularis*. In the Gulf of California states of Sonora, Sinaloa, and the Californias, where scallops are in a great demand, additional species have been harvested (Fig. 12, 13, 14). Production

Table 6
Commercial mussels of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Choromytlus paliopunctatus	R, I, Ow	P		$4/kg	Sonora to Chiapas
Geukensia demissa	Md, I	P		$4/kg	Camp. and Yucatan
Modiolus capax	R, Sl, Ow	P		$4/kg	Sonora to Chiapas
Mytella strigata	Md. I. Cl	C	100	$4/kg	Sonora to Chiapas
Mytilus californianus	R, I-Sl, Ow	C	80	$2/kg	Baja Calif.
M. edulis	R, I-Sl, Pw	C	20	$2/kg	Baja Calif.

[1] Habitat: substratum: Md=mud, R=rock; level: I=intertidal, Sl= sublitoral; location: Cl=coastal lagoons, Ow=open waters.
[2] Exploitation: C=commercial, P=potential.

Table 7
Commercial pen shell and scallops of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Pen shell					
Atrina rigida	S, Sl, Ow	C		$4/kg	Campeche and Yucatan
A. maura	S, Sl, Ow	C,O	50	$4/kg	Baja Calif. to Sinaloa
Pinna rugosa	S, Sl, Ow	C,O	50	$4/kg	Baja Calif. to Sinaloa
Scallops					
Argopecten circularis	Md, Mp,I-Sl	C	100	$4/kg	Baja Calif. Sur
Lyropecten subnudosus	S, Sl, Ow	I		$4/kg	Baja Calif. Sur
Pecten vogdesi	S, Sl, Ow	C,O		$4/kg	Baja Calif. Sur
Spondylus calcifer	R, Sl, Ow	O	80	$4/kg	Baja Calif. Sur
S. princeps	R, Sl, Ow	O	20	$4/kg	Baja Calif. Sur
Pearl oysters					
Pinctada mazatlanica	R, Sl, Ow	Pr		$4/kg	Baja Calif. to Oaxaca
Pteria sterna	R, Sl, Ow	Pr		$4/kg	Baja Calif. to Oaxaca

[1] Habitat: substratum: S=sand, Md=mud, R=rock, Mp=macrophyt; level: I=intertidal, Sl= sublitoral; location: Ow=open waters.
[2] Exploitation: C=commercial, O=overexploited, I=incidental, Pr=protected.

Figure 12
Lifeline man unloading a bag of scallops. Photograph by Erik Baqueiro C.

increased from only about 1 t in 1981 to nearly 2,000 t in 1986, then was about 500 t in 1987, and 900 t in 1988.

Aquaculture Development and Prospects

Bivalve culture in Mexico dates from the beginning of this century when the pearl oyster, *Pinctada mazatlanica*, was cultured at Baja California Sur from 1904 to 1919 (Baqueiro and Castagna, 1988). Oyster larvae were collected from the plankton, and juveniles were placed on the bottom for growth and natural pearl formation. The oysters were grown for their nacre and pearls, while the meat was eaten by the workers and their families. Since the begining of this century, fishermen have harvested pearl oysters by diving in shallow water (Fig. 15).

In the 1970's, the Federal government created an office of aquaculture. Except for some previous efforts to develop oyster culture, this marked the first time that attention was paid to resources with aquaculture potential.

A laboratory was constructed at La Paz, Baja California Sur, to develop bivalve culture methods, and another laboratory was built for producing spat of the Pacific bay scallop, *Argopecten circularis.* In 1985 a laboratory in Kino Bay, Sonora, spawned and grew larvae of the pen shell, *Pinna rugosa,* using the methods of Felix et al. (1978) and Arizpe and Felix (1980). Using the methods of Loosanoff and Davis (1963), workers condition adult bivalves for spawning and rearing their larvae. They grow the juveniles in fenced pens.

Oyster Fishery

Mexico now has six oyster species of commercial importance (Table 8). *Crassostrea palmula, C. corteziensis,* and *C. iridescens* are native to the Pacific coast, and the mangrove oyster, *C. rhizophorae,* and the eastern oyster, *C. virginica,* are native to the Atlantic coast. The sixth species, the Pacific oyster, *C. gigas,* has been introduced to the north Pacific states for culture. *C. iridescens* grows on rocky coasts exposed to heavy wave action, *C. corteziensis* grows on mangrove roots and other hard surfaces in coastal lagoons with freshwater runoff, and *C. palmula* grows on exposed intertidal rocks and man-

Figure 13
Workers shucking scallops. Photograph by Erik Baqueiro C.

groves that have little influence from freshwater. The eastern oyster inhabits mesohaline waters and grows mainly on shells and other hard objects in coastal lagoons and intertidal canals. It forms beds where there is little siltation. The mangrove oyster grows on mangrove roots in high salinity zones on the coast of the Yucatan peninsula.

Fishery History

Mexicans have eaten oysters since prehispanic times. Middens of oyster shells are present in many places along the Pacific coast from Baja California to Chiapas, but are scarce along the Atlantic coast from Tamaulipas to Campeche (Sheng and Gifford, 1952; Lorenzo, 1955; Fieldman, 1969; Foster 1975; Reigadas, et al., 1984). They are also common in inland middens. Considered a food for kings, they were brought fresh to Moctezuma at Tenochtitlan (Del Campo, 1984).

Oyster fishery data comprise the oldest fishery records in Mexico. From 1940 to 1953, national annual production averaged 7,277 t, of which 23% were sold as raw shucked meat. From 1952 to 1963, national production averaged over 15,000 t (Ramirez and Sevilla, 1965). From 1979 to 1988, production ranged from 37,000 t to 58,000 t, while value ranged from $0.5 million to about $11 million.

Fishing methods have not changed since early times. Fishermen gather them at low tide using a sharp tool. Where the oysters lie in subtidal beds, the fishermen harvest them by hand (Fig. 16) or with tongs, from small boats powered with outboard motors. They can use large open boats to take the catch to port (Fig. 17).

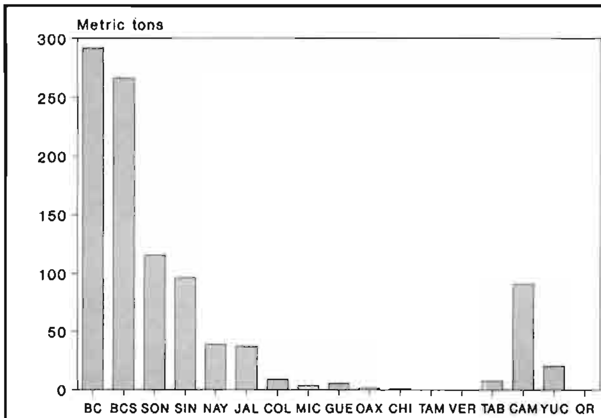

Figure 14
Mean annual scallop and pen shell landings in coastal states of Mexico.

Present Status of the Fishery

Fishermen harvest oysters in every coastal state, but most are produced by Tamaulipas, Veracruz, Tabasco, and Campeche—the four states bordering the Gulf of

Mexico (Fig. 18). Oysters were one of five mollusks reserved for cooperative fishermen until 1992, when the government passed the new fishery law. Of the 88,015 fishing cooperatives in Mexico, 561 had permits to gather them.

Management

The only management regulations for oysters involve two species. Fishermen cannot harvest eastern oysters from May 15 to July 30, or *C. iridescens*, from July 15 to November 15. The minimum length for both is 8 cm. Other species are managed locally, but this has resulted in mismanagement and depletion of stocks.

Aquaculture Prospects

On the Pacific coast, hatchery culture prevails. Four laboratories produce spat of Pacific oysters for commercial culture. Though their combined production

Figure 15
Divers harvesting mother of pearl oysters. Photograph by Gaston Bives.

Table 8
Commercial oysters of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Crassostrea corteziensis	M, I, Cl	C	100	$1/bushel	Sonora to Chiapas
C. gigas	I, Cl	C	100	10¢/each	Baja Calif. to Sinaloa
C. iridescens	R, I-Sl. Ow	C	80	$1/bushel	Baja Calif. Sur to Oaxaca
C. palmula	R, M, I, Ow	I		$1/bushel	Sonora to Chiapas
C. rhizophorae	M, I, Pw	I		$1/bushel	Campeche to Quintana Roo
C. virginica	R, Sh, I, Cl	C		$1/bushel	Tamaulipas to Campeche
Ostrea fisheri	R, I-Sl, Ow	C	20	$1/bushel	Baja Calif. Sur to Oaxaca

[1] Habitat: substratum: R=rock, M=mangrove, Sh = shell; level: I=intertidal, Sl= sublitoral; location: Cl=coastal lagoons, Pw=protected waters, Ow=open waters.
[2] Exploitation: C=commercial, I=incidental.

has reached 42.5 million spat per year, many cooperatives have to import spat from U.S. hatcheries. Cultchless Pacific oysters are grown on rafts and long lines from Baja California to Sinaloa. Culture of this oyster has also been introduced in Guerrero and further south.

Another hatchery, in the town of San Blas, Nayarit, produces *C. corteziensis* spat to compliment natural sets (Alanis, 1982). *C. corteziensis* is grown in trays or on the bottom in States from Colima to Chiapas. The seed comes from hatcheries or is collected naturally on oyster shells.

Figure 16
Fisherman gathering oysters from a subtidal bank. Photograph by Erik Baqueiro C.

Figure 17
Boatload of oysters on its way to a landing port. Photograph by Erik Baqueiro C.

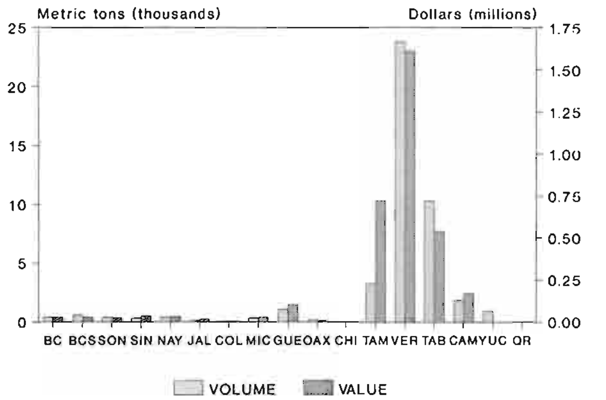

Figure 18
Mean annual oyster landings in coastal states of Mexico.

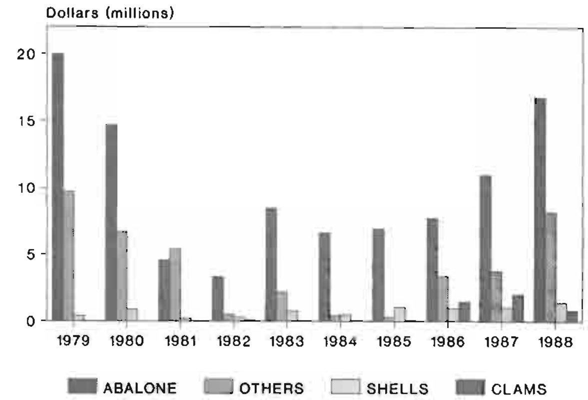

Figure 20
Value of mollusk exports in Mexico, 1979–88.

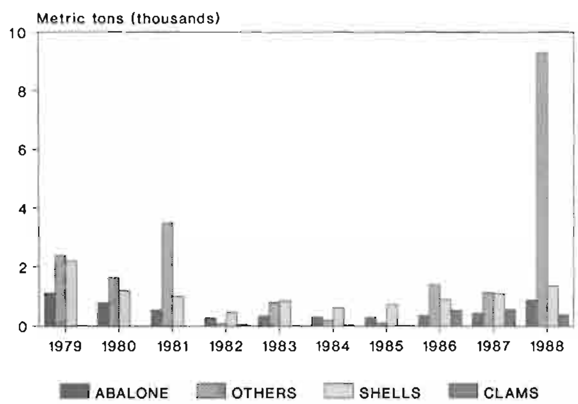

Figure 19
Volume of mollusk exports in Mexico, 1979–88.

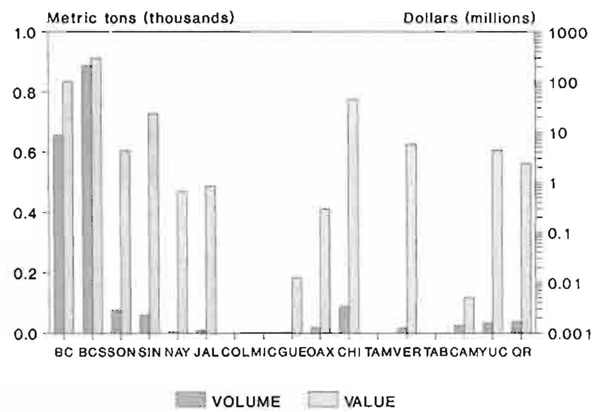

Figure 21
Mean annual shell landings in coastal states of Mexico.

Oyster culture in Atlantic coast lagoons began in the late 1950's and early 1960's, when beds were enhanced by spreading shells as cultch for oyster larvae. Such enhancement is responsible for about 10% of oyster production from Tamaulipas and Campeche, 20% from Veracruz, and 90% from Tabasco (Polanco et al., 1988; Garcia and Mendoza, 1988). In addition, some intensive culture was begun using the Japanese method of string culture. This method was abandoned in the late 1960's, but was recently begun again with success.

Shells

Shells are an important part of mollusk fisheries. The main shell producers are Baja California and Baja California Sur (Fig. 19). Annual landings in Mexico average about 100,000 t valued at $100,000. They contribute substantially to the export trade (Fig. 20, 21).

Squid and Octopus Fisheries

Fishermen catch squid in all coastal states, but there is an established fishery only in the north Pacific states (Table 9). At Baja California, Sonora, and Sinaloa, a fleet of multipurpose ships, equipped with electric blocks, employ lines and jiggers and light attractors to catch squid at night. In all other states, squid are an incidental catch of shrimp trawlers. Catches from the Pacific coast consist of the giant squid, "*Dosidiscus gigas*," which has cyclic fluctuations of abundance. Production from the Atlantic coast consists mainly of *Loligo paelei* (Fig. 22).

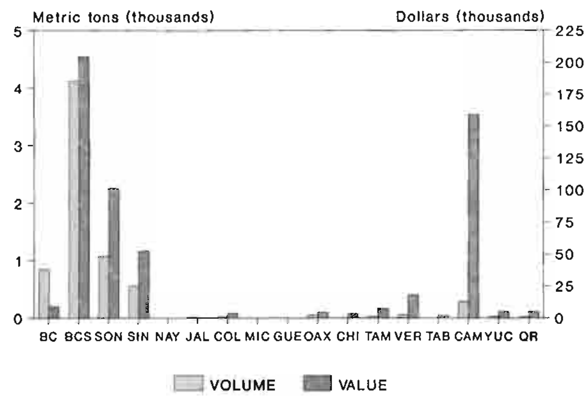

Figure 22
Mean annual squid landings in coastal states of Mexico.

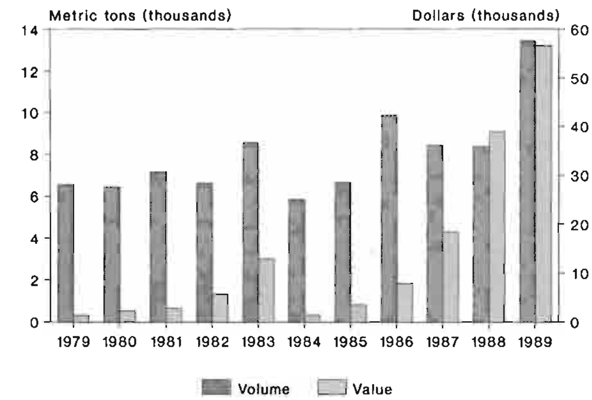

Figure 23
Annual octopus landings in Mexico, 1979–89.

Table 9
Commercial octopus and squid of Mexico.

Species	Habitat[1]	Exploitation[2]	Percent of production	Price	Area of exploitation
Octopus					
Octopus bimaculatus	R, Sl	C,I	80	$2/kg	Baja Calif. to Chiapas
O. digueti	R, Sl	C,I	20	$2/kg	Baja Calif. to Chiapas
O. maya	R, Sl, Ow	C	90	$2/kg	Tamaulipas to Yucatan
O. vulgaris and	Pw	C	10	$2/kg	Tamaulipas to Yucatan
Squids					
Dosidiscus gigas	Ow	C		$3/kg	Baja Calif. to Chiapas
Loligo pealei Pelagic	"	C,I		$3/kg	Tamaulipas to Yucatan

[1] Habitat: substratum: R=rock; level: Sl= sublitoral; location: Pw=protected waters, Ow=open waters.
[2] Exploitation: C=commercial, I=incidental.

The octopus fishery is well developed only in Campeche and Yucatan, with a minimum contribution from the Pacific coast states. *Octopus vulgaris* is the main species landed from Tamaulipas to Tabasco, while *Octopus maya* is the main species from Campeche and Yucatan. Though production has been stable, averaging about 6,000 t annually (Fig. 23), prices have risen sharply since 1984.

Fishery History

The earliest record of octopus catches dates from only 1949, when fishermen landed 50 tons. In 1960 they landed 307 t, and by 1969, 2,038 t. Landings declined sharply, however, in 1970 to 1,108 t.

In most states, fishermen capture octopi by diving or by using a hook during low tides. But in Yucatan and Campeche, where intensive fisheries exist, diving and use of hooks are prohibited. The catches there are made from outboard motor boats that drift while trawling six to eight baited lines. The bait is half a crab or a live crab. When the octopus attaches to the crab, the fisherman pulls it aboard.

Uses of Mollusks

In Mexico, clams and cockles are usually eaten raw on the half-shell, or in cocktails or salads. Sometimes the red clams, *M. aurantiaca;* and the black clam, *M. squalida,* are shucked, chopped, prepared with other ingredients, and broiled in their shells. The Atlantic rangia, cross-barred Venus, and other small clams are used for soups and cooked dishes with rice or spaghetti.

Oysters are eaten in cocktails or on the half-shell. In addition, a tiny quantity (0.1% of landings) is smoked and canned in Tamaulipas and Tabasco.

Shells for export are mainly the mother of pearl or nacre for cosmetics, clam shell for buttons, and abalone shell for jewelry. In Mexico, shells are used as poultry feed, building material, handcrafts, jewelry, and souvenirs (Fig. 24, 25).

Figure 24
Handcrafts made from mollusk shells. Photograph by Erik Baqueiro C.

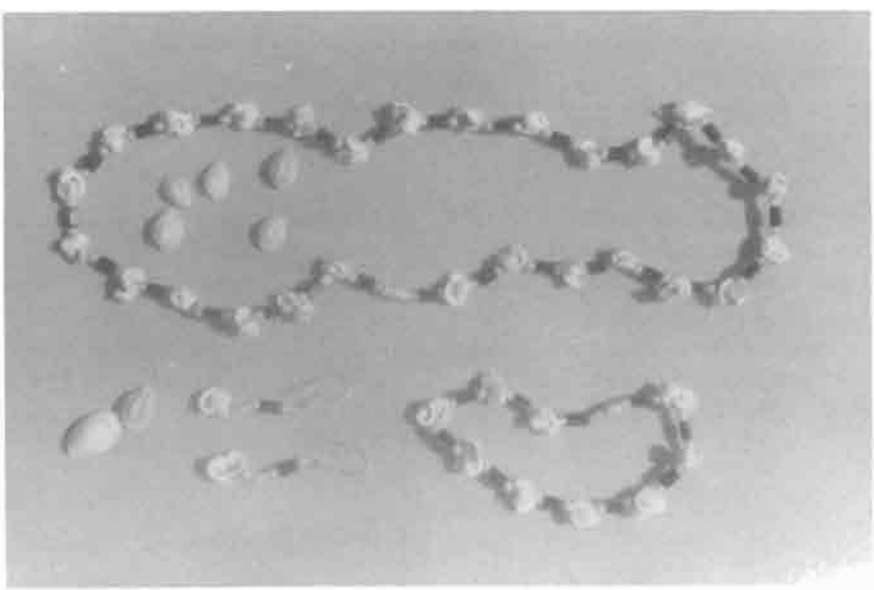

Figure 25
Jewelry made from mollusk shells. Photograph by Erik Baqueiro C.

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Molluscan Fisheries of Nicaragua

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Managua, Nicaragua

ABSTRACT

Mollusks are harvested on both coasts of Nicaragua. On the Atlantic coast, the species harvested are marshclams, *Polymesoda* sp.; coquina clams, *Donax denticulata* and *D. striata*; Caribbean oysters, *Crassostrea rhizophorae*; and some gastropods. Market demand is weak and most mollusks are eaten by the harvesters and their families. On the Pacific coast, the black ark clam, *Anadara tuberulosa*, is the most important mollusk harvested, and it is sold whole and in cocktails in nearly every town and city in the west. Other species include beanclams, *D. dentifer*; chitons, *Chiton stokesi*; and conchs, *Strombus galeatus*. On both coasts, nearly all harvesting is by hand; no rakes or dredges are used. The primary vessel used is the dugout canoe, which is propelled by paddles, sail, or outboard motor.

Introduction

Nicaragua lies at about the mid-way point of Central America (Fig. 1), with Honduras, El Salvador, Guatemala, and Belize to the north, and Costa Rica and Panama to the south. It is the poorest of these underdeveloped countries, with an annual per capita income of $425 (Anonymous, 1995). The eastern half of Nicaragua has about 10% of the country's population of 4 million people (Anonymous, 1995); the western half has the rest. Mollusks are harvested on both the Atlantic (Caribbean Sea) and Pacific coasts. On the Atlantic coast, subsistence fishing predominates, while on the Pacific coast, commercial sales are more extensive.

The presence of shell middens on the Atlantic coast suggests that mollusks have been harvested for a great many years. Among them are marshclams, *Polymesoda* sp.; coquina clams, *Donax denticulata* and *D. striata*; Caribbean oysters, *Crassostrea rhizophorae*[1]; and the gastropods *Strombus gigas*, *Melongena corona*, and *M. melongena*.

Species harvested on the Pacific coast include black ark clams, *Anadara tuberculosa*; beanclams, *D. dentifer*; chitons, *Chiton stokesi*; and giant eastern Pacific conchs, *S. galeatus*. Black ark clams are by far the most important, since they are sold in central markets and along streets, and black clam cocktails are sold in most restaurants and many food stands in the western part of the country.

Nearly all mollusks are harvested by hand; no rakes or dredges are used. The most common type of boat used is the dugout canoe, which averages about 4.5 m long. Scuba divers harvest most of the gastropods on both coasts. No species now are cultivated, though oyster farming was tried without success. Mollusks are rarely exported, owing to low production, uncertified beds, and a lack of production and transportation facilities.

Nothing heretofore has been published about Nicaragua's mollusk fisheries, and no government sta-

[1] This species may actually be *Crassostrea virginica*. Its classification remains unsettled.

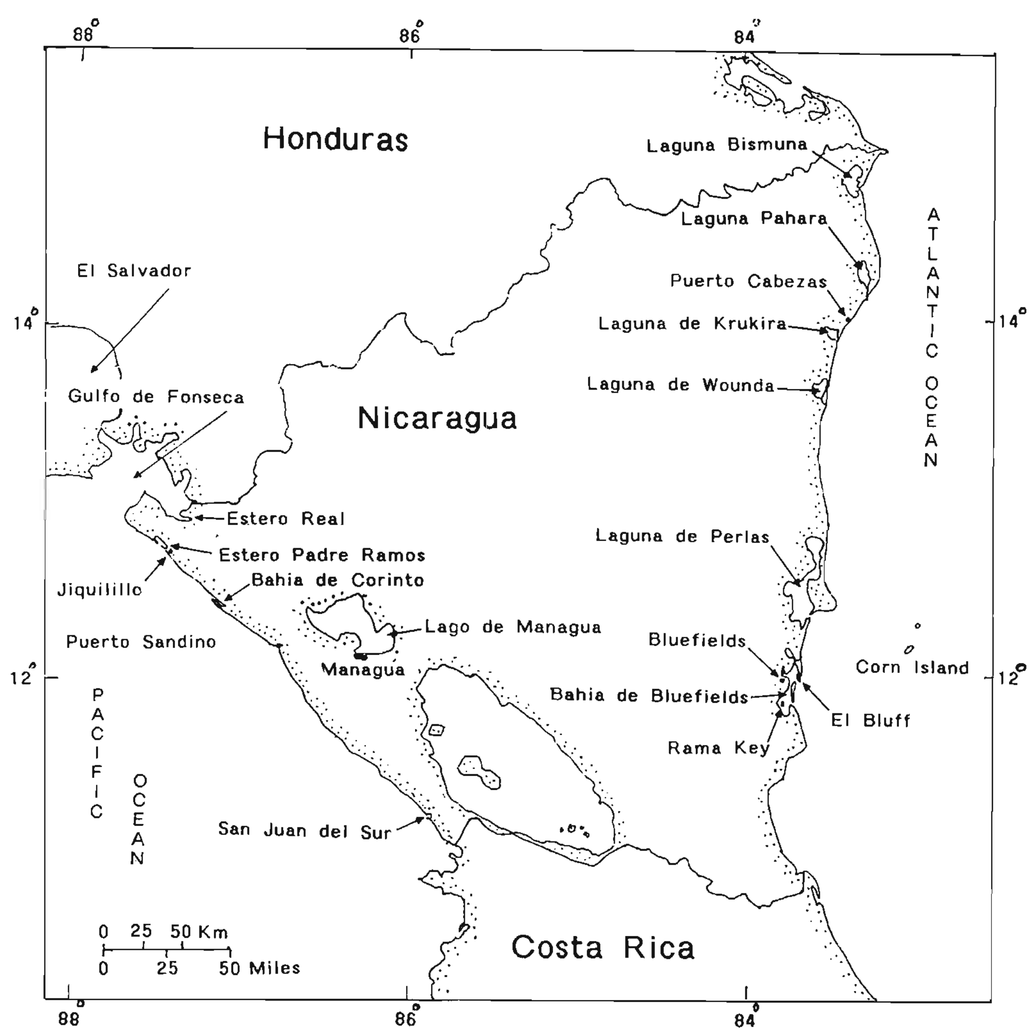

Figure 1
Mollusk fisheries are active on the Atlantic (Caribbean Sea) and Pacific coasts of Nicaragua.

tistics on total annual mollusk landings have ever been collected. In addition, no previous formal surveys of the mollusk fisheries were made, little biological study has been made of any mollusks, and local people have little knowledge of fishing practices elsewhere.

Habitats

The Atlantic coastline, about 460 km long, is indented with six shallow, muddy estuaries, the largest of which are Laguna de Perlas and Bahia de Bluefields. The coast is otherwise fairly straight and smooth. Many rivers flow eastward across Nicaragua's broad eastern lowlands, termed the Costa de Miskitos, into the estuaries and ocean. The tidal range is 0.75 to 0.9 m. Mangroves, *Rhizophora* sp., are present in the estuaries, but are much less extensive than in the smaller Pacific coast estuaries and mixed with other large plants. The estuaries contain large quantities of marshclams (30–40 mm long). In the surf zone along the Atlantic coast, coquina clams, *D. denticulata* (25 mm long) and *D. striata* (25–40 mm long), are abundant. Oysters are abundant only in Bahia de Bluefields.

The Pacific coast, about 300 km long, is straight and mostly smooth, and similar in appearance to the Atlantic coast. Several small muddy estuaries, mostly lined with mangrove swamps (Fig. 2), indent the northern coast. The tidal range is from 1.8 to 3.4 m. Black ark clams occur only in the mangrove swamps and are found in mud bottoms among roots and under the leaf cover of the trees. The clams grow to a length of about 65 mm. Loud pops can be heard every minute or so in the swamps, which probably are the sounds of snapping shrimp.

Figure 2
The edge of a mangrove swamp in Estero Padre Ramos, with dugout canoe tied to a tree: black ark clams are present in the mud. The canoe was used by three harvesters. Photograph by C. L. MacKenzie, Jr.

Beanclams occur near the sediment surface in sandy, intertidal, sheltered zones of the same estuaries inhabited by black ark clams, and they grow to a length of about 38 mm.

No mollusk harvesting takes place along the Pacific coast from Puerto Sandino to San Juan del Sur. Sheltered by land on three sides, but exposed on the east, the port of San Juan del Sur is bounded by rocks and rock cliffs along both sides of its wide entrance. It has a gradually sloping sand beach about a kilometer long on its west side, with restaurants lining it. The port has one large dock on its south side, just beyond the beach. Chitons are present on the large rocks and rock faces at the base of the steep cliffs that line the entrance to the port. Chitons range to at least 130 mm long. They usually occupy shady areas under ledges during the day, crawling around at night to feed. At night, during low tides, many are exposed in the intertidal zone. Giant eastern Pacific conchs are found on ocean bottoms beyond the port and in the Gulfo de Fonseca to the north.

Shell Middens

Shell middens left by ancient peoples are present on the Atlantic coast. The senior author examined two of them at Punta de Masaya on the west shore of Bahia de Bluefields, about 2 km south of the city of Bluefields and about 50 m inland from shore. Each is roughly an acre in area and about 25 cm deep. Their shells consist of marshclams, with some brown crown conchs, *M. melongena*, scattered among them. In 2 hours of digging, a crew of three local men found one clay artifact of early origin. They said that other middens in the vicinity have many clay artifacts of native origin, but of unknown age. Various other middens along the coast contain shells of oysters, cockles, coquinas, and gastropods (Ramirez Arthurs[2]).

Atlantic Coast Fisheries

Clams, oysters, and gastropods are harvested year-round. The government sets no harvest regulations, nor does it provide sanitary controls over marketing, or require a harvesting or marketing license.

Bivalves

Marshclams—Marshclams (called "cockles" locally) are harvested in all but one estuary along the coast, includ-

[2] Ramirez Arthurs, S. 1995. Fisherman advisor, Bluefields. Personal commun.

ing Laguna Bismuna, Laguna Pahara, Laguna de Wounda, Laguna de Perlas, and Bahia de Bluefields. The exception is Laguna de Krukira. It contains marshclams, but is polluted, so no one can safely eat them (Ramirez Arthurs[2]). Marshclams usually are abundant, more so in sand than in mud bottoms, and most are 20–50 mm under the surface (Burga[3]). They also are common in oyster beds (McCrae[4]).

Native Nicaraguans, from Laguna Bismuna to Laguna de Perlas, regularly harvest marshclams. Families eat the clams as often as 15 days a month year-round (Ramirez Arthurs[2]; Rigby[5]). The harvesters, mostly women and children, paddle or sail in dugout canoes to the clam beds, which are 60–90 cm deep at low tide. Stepping out onto the bottom, they simply feel for the clams with their fingers and put them in buckets or sacks. Each typically harvests about four 4-gallon buckets of marshclams in 3 hours (Wilson Hudson[6]). In contrast, individuals harvest them only once every 1–2 weeks in Bahia de Bluefields where they eat oysters daily instead (Wilson Hudson[6]).

To prepare marshclams for the table, housewives first boil them in a small amount of water until the meats fall out to be collected for use in various recipes. They sometimes are placed in a bowl of water before being boiled, so they will pump out the sand from their mantle cavities (Rigby[5]). When sold for human consumption, the clam meats are cooked and placed in plastic bags that hold a little more than a pint. But the market for them is limited and sales are minute (Ramirez Arthurs[2]; Rigby[5]). The clams also are used as fish bait (Vogel[7]).

Coquina Clams—Along nearly the entire Atlantic coast, people in small, scattered villages harvest coquina clams (called "ahis" and "coquinas" locally). Most often women and children, but sometimes men, wade into 30–60 cm of water in the gentle surf zone at low tide and harvest them with shovels (Ramirez Arthurs[2]); or, if only a small quantity is needed, they simply stir the sand with their hands and gather them (Howard[8]). They use shovels to scoop the sand and clams into mesh sacks or mesh baskets, then rinse them to flush out the sand. A good catch with a shovel is 3–5 sacks of coquinas in 30 minutes of harvesting. The best harvests are made after an easterly storm (Ramirez Arthurs[2]).

Fishermen take the coquinas home, usually to boil whole with vegetables in a pot. The meats rise, while the shells and any sand remain at the bottom of the pot, and the liquid, clam meats, and vegetables are dipped off to be eaten. Cooks often dump the shells and sand out the windows of their homes (Petuch[9]). A typical family eats coquinas about 10 days a month (Ramirez Arthurs[2]).

Oysters—Oystering is concentrated in Bahia de Bluefields. Oysters also occur in estuaries to the north, such as Laguna Bismuna, Laguna de Pahara, and Laguna de Perlas, but are scarcer in these locations and are not harvested to any extent (Ramirez Arthurs[2]). In Bahia de Bluefields, oysters have been harvested from several beds for a great many years, shells have never been returned, and yet supplies have remained adequate. Natural setting and growth of oysters so far appears to at least equal the harvesting losses.

No one has studied the oysters, but Elick Burga[3], a local fisherman-farmer, believes stingrays (family Dasyatidae) eat some, but that boring gastropods do not. The harvested oysters are 50–75 mm long and are in clumps; barnacles, undersized oysters, and a few ribbed mussels are attached to them. Oysters also occur on hard surfaces along shorelines of the bay.

Oysters are harvested in beds 60–90 cm deep at low tide. The principal harvesters are native Nicaraguans, mostly women and teenage girls, from Rama Key (Fig. 3). They travel to the oyster beds, about 2 km from Rama Key and 8 km south of Bluefields, in dugout canoes (1–3 people in each). The canoes are paddled or sailed, the sails consisting of a sheet of cloth or black plastic. Wearing rubber boots, commonly about 30 cm high, or rubber sandals, the harvesters stand in the beds and pick up the oysters with one hand, while holding onto their canoes with the other. Some wear gloves, while others go bare-handed. In any one day, 10–15 canoes with 23–35 people are harvesting oysters (Fig. 4). Each person gets 2–3 bushels of oysters in typically 3 hours of harvesting. The total daily harvest from the bay is about 70–75 bushels. While the females are harvesting mollusks to eat at home, the adult males go after fish, shrimp, turtles, lobsters, and gastropods to sell.

The harvesters return home with their oysters, put them on the kitchen floor, and, with the help of other female family members, shuck a sufficient quantity of meats to last a day or two (Fig. 5), leaving the rest for later use. Women also cook the oysters (Fig. 6) and toss the shells onto large piles near their homes (Fig. 7). Oysters, eaten every day, are the main source of animal

[3] Burga, E. 1995. Fisherman-farmer, Masaya Point, Bahia de Bluefields. Personal commun.

[4] McCrae, R. 1995. Rama Key, Bahia de Bluefields. Personal commun.

[5] Rigby, R. 1995. Biologist, Haulover, Pearl Lagoon. Personal commun.

[6] Wilson Hudson, D. 1995. Boat repairman, Bluefields. Personal commun.

[7] Vogel, J. 1995. President, Oceanic, Oceanus De Nicaragua, S.A., Reparto San Juan, Managua. Personal commun.

[8] Howard, J. 1995. Pearl Lagoon. Personal commun.

[9] Petuch, E. 1995. Florida Atlantic University, Boca Raton, FL. Personal commun.

Figure 3
Some homes of native Nicaraguans on Rama Key, where people are dependent on oyster harvests for daily food. Photograph by C. L. MacKenzie, Jr.

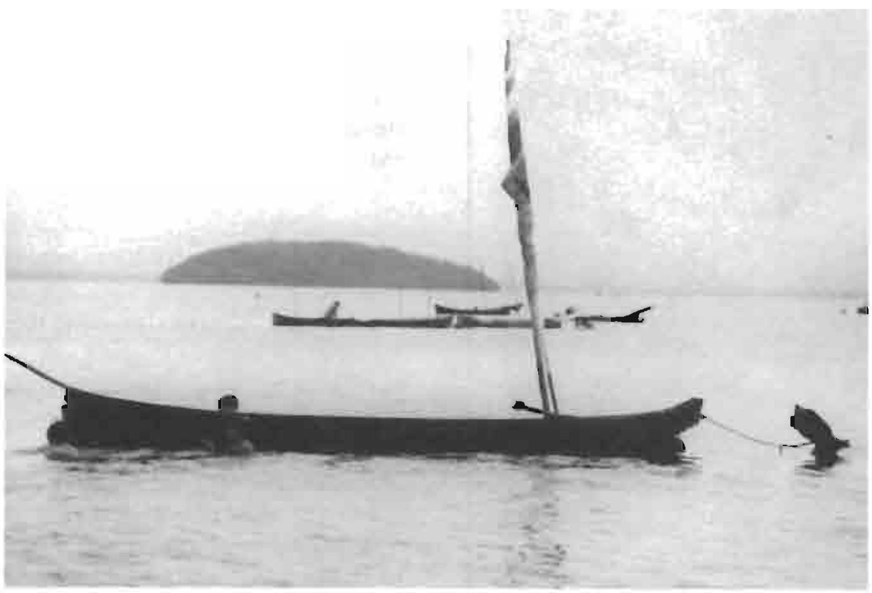

Figure 4
Group of Rama Key dugout canoes with people harvesting oysters on a bed in Bahia de Bluefields. Photograph by C. L. MacKenzie, Jr.

protein here. They are considered a good food and do not cost anything, as is true for marshclams and coquinas wherever they are harvested (Ramirez Arthurs[2]).

Some oyster meats are sold, but the market is very small. The meats are put in plastic bags or plastic bottles, both of which hold a little more than a pint, or in gallon

Figure 5
A native woman shucks oysters in her home on Rama Key. Photograph by C. L. MacKenzie, Jr.

Figure 6
A native woman shows her preparation of oyster soup. Ingredients include oysters, flour, onions, coconut milk, water, and black pepper. Photograph by C. L. MacKenzie, Jr.

plastic bottles. The containers of meats are then put in buckets and, with no delay, are taken by canoe to Bluefields, which has a population of about 50,000 (Atily C.[10]). Each family's children peddle the uniced oysters to hotels, door-to-door along the streets of Bluefields, and at the local airport to passengers from Managua, the capital (Fig. 8) (Chang[11]). The oysters sell for US$0.65/bag and US$6.45/gallon. Oyster sales are highest in November and December (McCrae[4]), but otherwise are slow. Meats not sold are discarded before they spoil. Oysters are never sold in the shell.

At least one man in Bluefields goes oystering on Sundays. He puts his harvests of 2–3 bushels of oysters under his house and opens them on orders. He usually sells 1.0–1.5 gallons of oyster meats a week and spreads the shells to fill low marshy areas near his house.

Many locals believe the bay water and oysters near Bluefields are contaminated, because untreated sewage is discharged into the bay (Briceno[12]). No studies of water quality are available, however, and no established sanitary controls are practiced when oysters are opened in fishermen's homes.

A Japanese national once attempted to develop oyster culture in the Laguna de Perlas, but a freshwater flood killed the oysters and the project was abandoned (Martinez Casco[13]).

Gastropods

A gastropod fishery exists along the Atlantic coast of Nicaragua as an adjunct to the spiny lobster, *Panulirus argus*, harvest by scuba divers. The gastropods are gathered in quantity with the lobsters only when a market exists for them. The harvesting proceeds along most of the coast from near shore to a distance of about 65 km offshore.

On any weekday throughout the year, from 800 to 1,000 divers are working. They operate from three types of boats: 1) industrial boats from 18 to 55 m long, 2) sailboats, and 3) artisanal boats. The industrial boats, which land at the ports of Puerto Cabesa, Corn Island,

[10] Atily C., M. A. 1995. Delegado De Gobernacion (RAAS), Bluefields. Personal commun.

[11] Chang, R. 1995. University of Maryland Field Station, Laguna de Xiloa, Managua.

[12] Briceno, M. 1995. Fisherman, G-18, Managua. Personal commun.

[13] Martinez Casco, S. 1995. Director, Centro De Investigacion De Recursos Hidrobiologicos, Managua. Personal commun.

Figure 7
Piles of oyster shells outside homes on Rama Key. Photograph by C. L. MacKenzie, Jr.

and El Bluff, can carry as many as 20 dories each. Each dory carries a diver and a tender. The tender follows with the dory as the diver harvests. The dories go out from industrial boats each morning in different directions, and crews harvest all day at depths from 3.5 to 15 m, the shallowest being near various keys scattered along the coast, particularly in the north. The industrial boats remain at sea for 12 days at a time. They ice the lobster and freeze the gastropod catches (Ramirez Arthurs[2]).

Sail boats (12–14 m long), artisanal boats (dugout canoes 3.7–9.0 m long), and fiberglass boats about 7.6 m long (called "pongas" locally) leave from various ports (Ramirez Arthurs[2]; Cassells[14]), including Bluefields (Wilson Hudson[6]). The pongas sometimes tow 2–3 dugout canoes, each with a diver and tender (Wilson Hudson[6]), and harvest in the same waters as the industrial boats (Ramirez Arthurs[2]).

The gastropods harvested include queen conchs, *S. gigas*; high-spired crown conchs, *M. corona*; and brown crown conchs, *M. melongena*. Conchs (called "weelks" locally) also are taken around numerous keys at wading depths (Ramirez Arthurs[2]). The gastropods are kept mostly for home use, but sometimes a few are sold locally (Chang[11]).

Figure 8
Children offer bags of oyster meats for sale at the Bluefields airport. Photograph by C. L. MacKenzie, Jr.

Pacific Coast Fisheries

As is true on the Atlantic coast, mollusks are harvested year-round. The Federal government has only recently

[14] Cassells M., R. 1995. Consejo Regional Automonio Atlantico, Sur, Bluefields. Personal commun.

regulated the Pacific coast mollusk fishery. The exceptions are a recent regulation (that is somewhat ignored) prohibiting fishing for black ark clams from 15 August to 30 September, to give the clams some time to reproduce and grow (Camacho Bonilla[15]), and a 45 mm minimum length rule for the clams, passed in 1995.

Bivalves

Black Ark Clams—The most important estuaries for black ark clams (called "conchas negras" locally) are Estero Real, Estero Padre Ramos, Bahia de Corinto (Puerto de Esparta and Puerto el Baruito), and Puerto Sandino, though the clams also occur in a few smaller estuaries in this region. The fishermen (called "concheros" locally) who harvest the clams are usually males and range in age from 8-year-old boys to the elderly. On any day, about 30 fishermen harvest the clams in Estero Real, 60 in Estero Padre Ramos (Fig. 9), 30 in Bahia de Corinto, 10 in Puerto Sandino, and perhaps 30 in all the smaller estuaries combined, for a total of about 160.[16]

The fishermen live in tiny villages or isolated homes along the estuaries. The houses have roofs of thatch or corrugated, galvanized metal sheets, and walls of thatch or wood. Roads to the villages are unpaved, and motor vehicles have difficulty traversing them during rainy periods.

[15] Camacho Bonilla, M. G. 1995. Departamento de Fauna Silvestre, Ecologo R.R.N.N., Managua. Personal commun.

[16] Personal communication with various native fishermen.

At low tide, fishermen paddle to the mangrove swamps in dugout canoes, though some go in 7.6-m fiberglass boats with 15–25 hp engines. They tie their boats to mangrove trees, walk into the swamps over the roots in their bare feet, then bend down and feel with their fingers for the clams in the mud between the roots (Fig. 10). The clams seem to be most abundant in small pools of water interspersed in pockets over the mud; no other clam species are harvested in the swamps.[16] Fishermen sometimes camp for up to 4 days near good harvesting sites that are some distance from their homes (Torrente[17]).

Catches range from 10 to 40 dozen clams/person/tide, and fishermen retain them in cloth sacks (Fig. 11). Most harvested clams range from 45 to 65 mm long. Some fishermen have ignored the 15 August–30 September closure and continue harvesting, while others switch temporarily to seining shrimp larvae to sell to local shrimp farms.[16]

When fishermen return home, they usually set aside a dozen clams for themselves, bag the rest, and then walk them to a dealer (Fig. 12) or a main market to sell them. Many harvest clams one day and sell them the next. In 1995, the fishermen were paid from US$0.26–0.39/dozen for the clams, the largest clams bringing the highest prices.[16] An average price of US$0.325/dozen would bring the fishermen US$8.13 for a day's harvest of 25 dozen. Trucks deliver the clams to markets in towns and cities.

[17] Torrente, L. 1995. Fisherman, Puerto Sandino. Personal commun.

Figure 9
Villagers in Jiquilillo, all but the youngest of whom harvest black ark clams. Photograph by C. L. MacKenzie, Jr.

The peak demand period for black ark clams is during holidays, especially Easter, but they are eaten year-round. Whole clams are sold in central markets and along streets, where customers pay US$0.65–0.77/dozen for them. In restaurants and roadside stands, the clams are served as black clam cocktails, or "coctel de conchas negras" (Fig. 13). The clams can be opened by being held in a person's hand and forcing a knife between the shells, or using a "mechanical" knife (Fig. 14). Each clam has a large amount of shell liquor which is dark brown, nearly black. The orange meat and liquor are served together with added lime juice as a cocktail in a cup or on the half-shell. Either 6 or 12 clams comprise a serving,[16] the smaller one selling for about US$1.95. A hotel restaurant in Managua sells a cocktail with 12 clams and chopped onions for US$4.50.

Beanclams—Fishermen harvest beanclams (called "Almejas" locally) at low tide by stirring the sand with their hands to bring the clams to the surface, and then picking them up and putting them in sacks. Fishermen's families commonly eat all the beanclams harvested. They usually boil the clams and mix the meats with scrambled eggs;[16] the meats also are consumed with milk (Montealegre[18]).

Some beanclams are sold, and they can be found in several fish markets in Managua. The markets pay dealers US$0.65/pound, and sell them for US$1.30/pound; a pound has from 20 to 25 whole clams. Markets sometimes cook the clams and sell the meats in a frozen 0.25-pound package for US$1.56. Managua residents often eat beanclams in paellas (Martinez Casco[13]). The demand for beanclams is small, as is the fishery.

Figure 10
A woman harvests black ark clams between the roots of mangrove trees in Estero Padre Ramos. On the same day, her husband gill-netted fish. Photograph by C. L. MacKenzie, Jr.

Giant Ark Clams—Giant ark clams, *A. grandis*, often are found by fishermen in the Gulfo de Fonseca in the north and off the coast of San Juan del Sur in the south. Called locally "Casco de burro" or, literally, hoof of the mule, they are as long as 15 cm when harvested. Fishermen sell the meats and shells, which are used as ash trays, separately.[16]

Oysters—Small numbers of oysters occur in places such as the Gulfo de Fonseca and around San Juan del Sur, but not in sufficient quantity to have much commercial value. A number of years ago, a second Japanese national attempted to introduce the Pacific oyster, *Crassostrea gigas*, to the Gulfo de Fonseca, but the planted oysters did not reproduce and they died (Martinez Casco[13]).

Gastropods

Chitons—From 30 to 50 fishermen in San Juan del Sur go after chitons (called "cucarachas" locally) during low tides, mostly at night. They walk from their homes to the harvesting sites, where they use a flashlight to see the chitons and a knife to pry them off the rocks (Fig. 15). The harvested chitons, which range from 38 to 130 mm long, are retained in small sacks.[16]

Upon returning to their homes, the fishermen use the knife to shuck the meats, putting them in a dish and discarding the shells. In a night, each fisherman gets 15–20 pounds of meat, whereas in the daytime he gets much less. A fisherman harvests about 85 pounds of meat (about 2,000 chitons) a week. Most of the meat is sold to dealers who take it to towns and cities but sometimes also to local restaurants for resale. Fishermen are paid US$1.56–$1.95/pound for the meat.[16]

[18] Montealegre G., O. 1995. Hotel Consiguina, Chinandega. Personal commun.

Figure 11
A woman and her two daughters, taking a break from harvesting black ark clams in Estero Padre Ramos, hold their clams in a sack. Photograph by C. L. MacKenzie, Jr.

Figure 12
A dealer in Jiquilillo counts the black ark clams she has purchased from harvesters. Photograph by C. L. MacKenzie, Jr.

Giant Eastern Pacific Conchs—In the Gulfo de Fonseca, lobster fishermen often find giant eastern Pacific conchs (called "cambuste" locally and pronounced "cambutay") in their gear. They eat the conchs, which grow to a length of about 20 cm, themselves. Fishermen used to harvest the conchs by snorkel diving along the south shore of the Gulf and sell them to dealers across the bay in El Salvador. The conchs have since become scarcer, and this practice has been abandoned.[16]

Fishermen in San Juan del Sur scuba dive for conchs commercially on grounds as far as 800 m offshore. Crews of four divers each work from 7.6 m fiberglass

Figure 13
Ice chests with black ark clam cocktails in a roadside stand. The sign on the left, "vuelve a la vida," roughly translates to "restore vigor"; the one on the right advertises clam and shrimp cocktails. A cocktail with six clam meats sells for 15 cordobas = US$1.93. Photograph by C. L. MacKenzie, Jr.

Figure 14
Before being opened, black ark clams must be scrubbed of mud. The knife and block are used to open the clams. Photograph by C. L. MacKenzie, Jr.

boats propelled by outboard motors. Two of the divers descend and gather conchs, while the others remain in the boat. Each crew gets 200–300 conchs every 2 days working from 7 a.m. to 3 p.m. Some crews bring in the conchs whole, while others bring in only the meat so they will have less volume to handle.[16]

Snorkel divers from San Juan del Sur also go after conchs. A diver can get as many as 30 conchs/day if the water is clear over a concentration of conchs. Each snorkel diver gets about 300 pounds of conch meat/month to sell to restaurants along the coast, where it is served in cocktails and serviche.[16]

Figure 15
A mollusk harvester in San Juan del Sur holds a knife used to pry chitons from rocks. Other types of common knives also are used. Photograph by C. L. MacKenzie, Jr.

Shell Uses

The shells of mollusks harvested for food are used to a small extent, but most are discarded. Some jewelry is made in Puerto Cabesa and Bluefields using mollusks, such as the West Indian topsnail, *Citarium pica* (Fig. 16) (Atily C.[10]; Gutierrez[19]; Ramirez Arthurs[2]). Elsewhere, people who harvest variously colored coquina clams sometimes string the shells for necklaces or paste them onto paper in various designs, for ornaments (Howard[8]). On Corn Island, queen conch shells are used to decorate porches (Chang[11]; Hooker[20]). Marshclam shells sometimes are used to decorate the surfaces of cement walkways (Fig. 17) (Howard[8]) and to fill in low areas (Ramirez Arthurs[2]). Oyster shells often are used to make roads, fill in low areas (McCrae[4]; Rigby[5]), and make cement (McCray de Ramacy[21]). Some shells of freshwater clams have been taken from Lago de Managua; chicken farmers use them for hardening egg shells (Camacho Bonilla[15]).

The Future

Interest in developing Nicaraguan mollusk fisheries contrasts sharply on the two coasts. On the Atlantic coast, local leaders (McCrea[4]; Ramirez Arthurs[2]; Rigby[5]; Vogel[7]) regularly discuss possible ways to preserve natural resources and to enhance fishermen's incomes by commercializing production of estuarine mollusks. Commercial clam and oyster harvesting would have to be carefully controlled, because it could deplete the food supply of the locals. Besides, uncontaminated waters would have to be identified for harvesting, and sanitary processing and handling would have to be assured.

No one knows the size of marshclam stocks, and no one has estimated how many could be taken without depleting them. A company based in Managua has plans to process the clams on the Atlantic coast (Vogel[7]), but to obtain a sufficient supply, it might have to encourage harvesters to use rakes or dredges.

Increasing oyster production would require much effort. Oyster supplies in Bahia de Bluefields could be increased by spreading shells beyond the borders of existing beds; this has never been done. The harvesting waters would have to be tested and certified, as would waters where marshclams were harvested for commerce. A shucking plant with a cold room to hold oyster meats also might be constructed. Transporting the meats in the warm climate to distant markets under refrigeration would be difficult and expensive: Quantities would likely be small, refrigerated transport now is unavailable, and, though it is a port for airplanes and boats, Bluefields does not have any roads leading from it. The meats might be canned as an alternative to refrigerating meats. After this, markets would have to be found.

Market testing has been underway. During October 1995, the Rama Key natives shipped 50 gallons of oyster meats to Jamaica as a trial to develop a market demand there. A market exists for oysters in Costa Rica, but transporting them there is difficult (McCrae[4]).

In contrast, interest in enhancing mollusk fisheries on the Pacific coast is nil. The likely expansion of

[19] Gutierrez, P. P. 1995. Tienda Y Taller de Artesania, Bluefields. Personal commun.

[20] Hooker, O. 1995. Cook, South Atlantic Hotel 2, Bluefields. Personal commun.

[21] McCrae de Ramacy, F. 1995. Fisherman, Rama Key, Bahia de Bluefields. Personal commun.

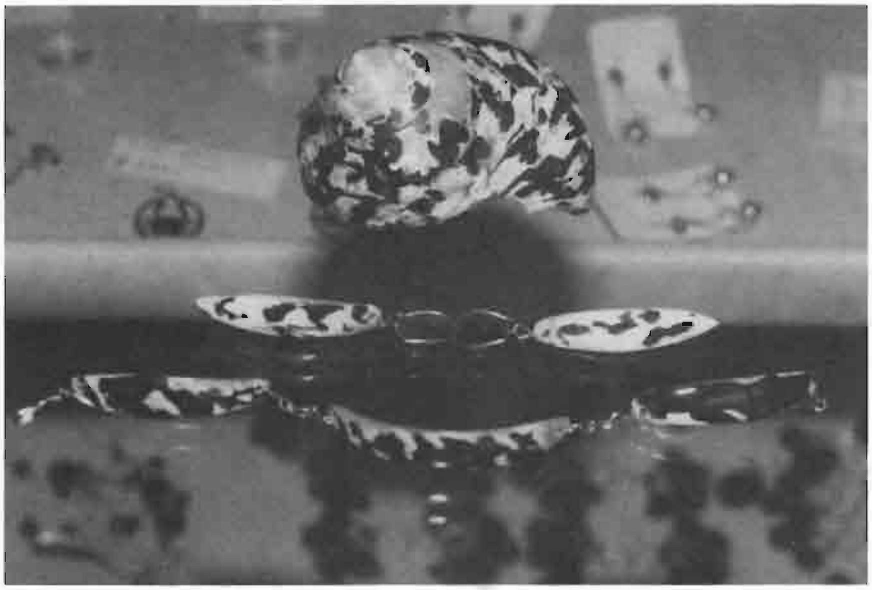

Figure 16
Earrings and a bracelet made from West Indian topshell, *Cittarium pica* (top), are displayed in a shop in Bluefields.

shrimp farming is a threat to the black ark clam fishery. New shrimp farms would remove some existing mangrove swamps along shores and eliminate the clam habitat.

Traditional Nicaraguan Mollusk Recipes

The principal daily foods of most Nicaraguans are rice and beans. On the Atlantic coast, they also eat plant roots, plantain, fish, mollusks, shrimp, turtle, red meat, chicken, and fruits. In the west, many people subsist almost entirely on rice and beans, with plant roots and plantains included (Levie, 1985). When they can afford animal protein, they eat red meat (Cook[22]). Fish and other seafood, except for black ark clams, rarely are eaten in inland towns and cities. Adult males along the Pacific coast consider clams, such as beanclams and black ark clams, to be aphrodisiacs.

Atlantic Coast

A stew of Jamaican origin, called "rundown," frequently is made. It contains plantains, plant roots, coconut milk, and fish or clams (marshclams) (Hooker[20]).

[22] Cook, H. L. 1995. Aquaculture Services, Inc., Apartado 137, Chinandega. Personal commun.

Serviche is made with raw shellfish meat (usually cut into little pieces, if from a conch) or fish with lime juice, tomato, onions, salt, and black pepper. It is left to marinate for about 2 hours. If left for an extended period, the citrus juice breaks down the meat too much (Hooker[20]).

Oyster soup at Rama Key is made with oysters, sliced bananas, Irish potatoes, tomatoes, coconut juice, water, and pepper (McCrae[4]).

Western Nicaragua

The locals prepare black ark clams in various ways: 1) on the half-shell, 2) chopped up raw with lemon juice and such other condiments as tomatoes and onions, and served in a cup (black clam cocktail), 3) clam meat and rice, and 4) clam patties (clams mixed with corn or wheat flour and eggs and then cooked).[16]

When a housewife purchases black ark clams, she washes the mud off the shells, opens them, chops the meat, and adds bell pepper, chili pepper, onion, tomato, and lemon juice to the meat and shell liquor. This is eaten as a side dish.[16]

Beanclams can be prepared by boiling the meats with rice in the same water, continuously until little water is left. The result is extra flavorful rice. The beanclams also are used in paella, soup, and cocktails.[16]

Giant eastern Pacific conchs usually are boiled, their meat is chopped up, and then mixed with rice.[16]

Figure 17
Marshclam shells decorate a walkway at Rama Key. Photograph by C. L. MacKenzie, Jr.

Acknowledgments

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History, Present Condition, and Future of the Molluscan Fisheries of Panama

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ABSTRACT

In Panama, the Pacific calico scallop, *Argopecten ventricosus*; mangrove oyster, *Crassostrea rhizophorae*; edible oyster, *Ostrea iridescens*; littleneck clam, *Protothaca asperrina*; grand ark clam, *Anadara grandis*; and queen conch, *Strombus gigas*, have been harvested for food, and the pearl oyster, *Pinctada mazatlanica*, mainly for pearls. Most scallop meats and pearls have been exported, while the other species are eaten locally. The calico scallop occurs only in the Gulf of Panama, and in the 1960's, about 300 metric tons (t) were landed annually. During 1981–84, landings were 1.5–26 t, but they increased to 41 t in 1985 and to 2,050 t in the first half of 1986. Fishermen harvested the scallops with shrimp boats 13 m long, and small boats 5 m long. Since then, the scallops have become scarce. Shells of the grand ark clam once were used by Indians to make knives. The mangrove oyster and queen conch are harvested on the Caribbean side of the Isthmus of Panama. The pearl oyster was harvested at least as early as the 16th century, when the Spanish began to collect pearls. Between 1900 and 1940, earnings from pearl oysters were high. Annual exports were 700 t (2 million oysters) annually. During the 1940's, the oysters became scarce, apparently from overfishing.

Introduction

The shellfisheries of Panama (Fig. 1) have utilized the Pacific calico scallop, *Argopecten ventricosus*; mangrove oyster, *Crassostrea rhizophorae*; edible oyster, *Ostrea iridescens*; littleneck clam, *Protothaca asperrima*; grand ark clam, *Anadara grandis*; and queen conch, *Strombus gigas*, for food, and the pearl oyster, *Pinctada mazatlanica*, mainly for pearls. The scallop meats and pearl oysters have usually been exported, while the other species are eaten locally.

Habitat

The Pacific side of the Isthmus of Panama is 1,780 km (1,100 miles) long, but most shellfishing takes place in the Gulf of Panama (Fig. 2). All fisheries there are influenced by oceanographic conditions that vary seasonally. During the dry season (January–March), a distinct upwelling of deep water brings cold (about 20°C), nutrient-rich water into the Gulf which stimulates an increase in phytoplankton (Glynn, 1972). The upwelling does not occur during the wet season (April–December), when the seawater reaches about 30°C and the phytoplankton density is low. The seasonal changes affect the life cycles of many marine organisms, including molluscan shellfish, squid, shrimp, and anchovies.

Pacific Calico Scallop Fishery

The Pacific calico scallop (Fig. 3) is the most abundant pectinid in the Panamic province of the Pacific Ocean (Keen, 1971). It ranges from Cedros Island in Baja California to Puerto Paita in Peru, in depths of 1–135 m. In Panama, it occurs only in the Gulf of Panama on mud-sand bottoms that have large amounts of scallop shells. The scallop has a life span of 2 years and has a maximum shell height of 6.0 cm (2.3 inches). In 1986, scallop beds were found in the Gulf near San Miguel (Rey) Island, Tortola Island, Tortolita Island, Veracruz Beach, Farallon Beach, and in Parita Bay (Arosemena and Martínez, 1986).

The scallops are subjected to predation and are parasitized. Scuba divers have observed portunid crabs, gastropods, octopuses (Fig. 4), starfish, and rays preying on juvenile and adult scallops. In 1977, Iverson (1978) found a heavy infestation of a larval stage of a digenetic

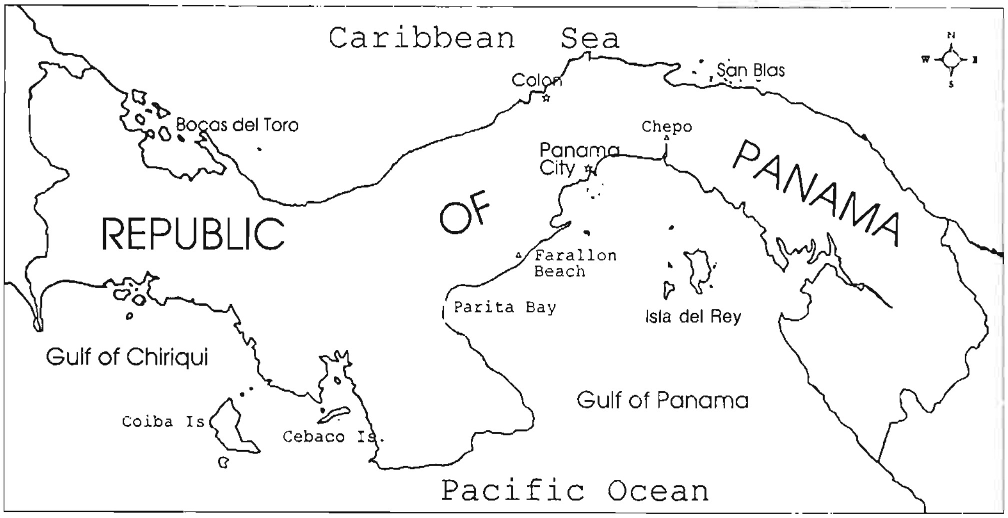

Figure 1
The Republic of Panama, including important areas mentioned in text.

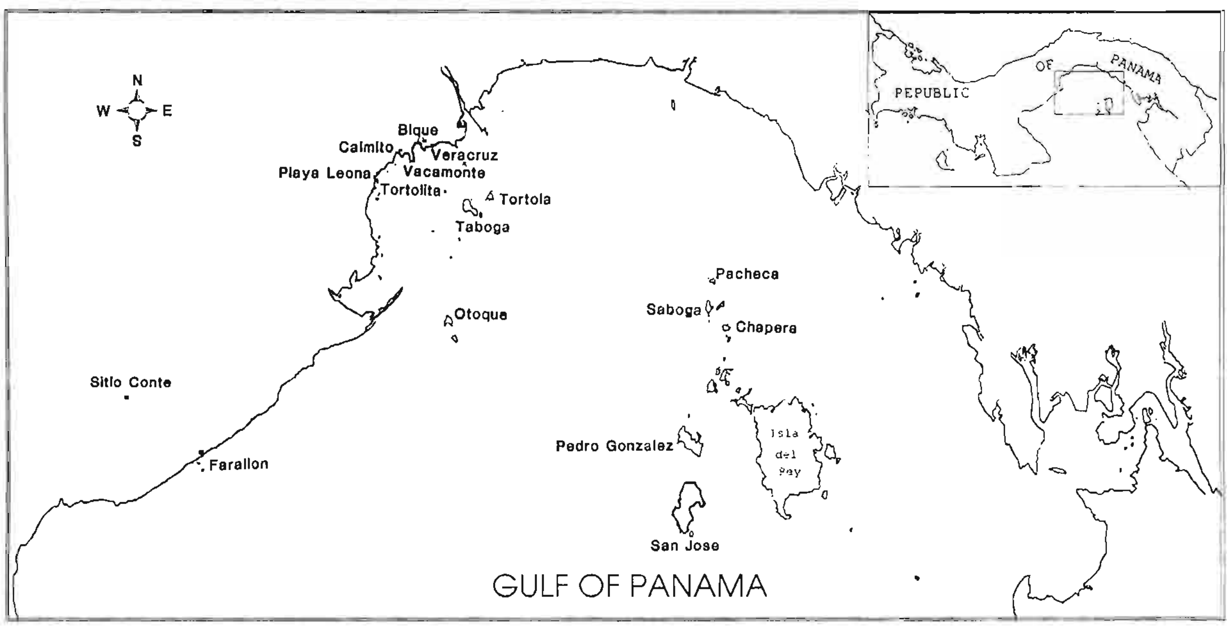

Figure 2
The Gulf of Panama, with important areas mentioned in text.

trematode and a minor infestation of a cestode in the scallops' adductor muscle. The parasites are not harmful to humans.

Fishery History

The Panamanian Government's first official scalloping statistics in the 1960's showed that several boats harvested about 300 metric tons (t) of scallops annually (Arosemena and Martínez, 1986). Statistics were not gathered again until 1975, when the Dirección de Recursos Marinos (a branch of the Secretary of Commerce in charge of administration of marine resources) reported that 6.9 t of scallop meats (adductor muscles) worth $5,696 were exported. In 1976, exports of scallop meats totalled 143 t worth $351,026, but no scallops were available for harvest in 1977. The scallop fishery resumed in 1982 when 26 t of meats were harvested, but in 1983 and 1984 meat exports fell to 3.9 t and 1.5 t, respectively (USDOC, 1979).

The scallop fishery expanded dramatically in 1985 and 1986. Scallops were harvested from Veracruz Beach to

Figure 3
The Pacific calico scallop, *Argopecten ventricosus.*

Farallon Beach, at depths from 3 to 20 m. In 1985, scallop meat exports reached 41 t, and during the first 6 months of 1986 scallop exports were 2,050 t, worth $10 million (Anonymous, 1987). Fishermen harvested the scallops using shrimp boats about 13 m (42 feet) long (Fig. 5), and small boats 5 m (16 feet) long (Fig. 6, 7). In 1986, 20 shrimp boats had licenses for scallop fishing. They used large nets (Fig. 8), whereas the small boats used dredges pulled by hand. The small boats, with crews of three and powered by outboard motors of 25 or 40 hp, could each harvest about half a bushel of scallops in 20 minutes of dredging or about 20 bushels a day. A catch of 20 bushels yielded about 136 kg of meats. Puerto Caimito was a major landing port for the small scallop boats (Fig. 2), having about 300 of them (Arosemena and Martínez, 1986). About 400 people (fishermen, divers, shuckers, middlemen, drivers, and assistants) worked in the scallop fishery.

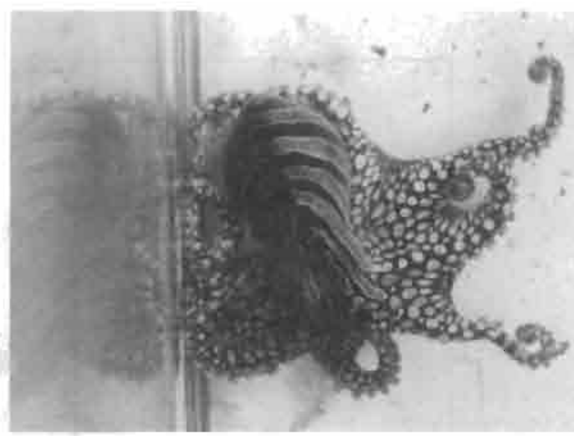

Figure 4
The octopus, *Octopus chierchae.*

Fishery Conflict

The shrimp boats and small boats sometimes had conflicts, and the crews of the small boats claimed that the shrimp vessels were depleting the scallop beds. To resolve the conflict, the Dirección de Recursos Marinos ruled that shrimp vessels were excluded from scallop fishing within 4.5 km (3 miles) of the coast.

Processing

In 1985–86, the shrimp vessels brought whole scallops to Puerto Vacamonte to sell to large companies, whose workers shucked them in processing plants. The small-boat fishermen brought the scallops ashore to beaches or ports, where crews of shuckers ("peladores") removed the adductor muscles and packed them in plastic bags that held 3.5 kg. Another group, the middlemen, sold the meats to exporting companies (freighters) for $6.30/kg. The fishery provided nearly 35,000 jobs (Anonymous, 1987). The income distribution among different workers was 70% for fishermen, 17.5% for shuckers, and 12.5% to middle men (Gaceta Financiera, 1986). Most scallop meat was sold to the United States; air shipments from Panama docks to U.S. retail outlets took less than 48 hours.

Figure 5
Panama shrimp boat, about 13 m (42 feet) long.

Current Condition of the Fishery

The Gulf of Panama's scallop fishery has totally collapsed, and fishermen have switched to catching fish and shrimp. The collapse is attributed to several causes: 1) The short life span of the scallop, 2) predation, 3) overfishing, 4) interannual oceanographic variations in El Niño which adversely affected recruitment, and 5) deterioration of the environment caused by pollutants (Villalaz, 1992).

According to Villalaz (1992), the large scallop production in 1985 and 1986 resulted from good oceanographic conditions, a large settlement of scallop seed, and a low density of predators. However, in 1985 the predators increased rapidly and, after 1986, killed most of the scallops.

The Future

The scallop fishery will again reach 1985–86 production when 1) A strong upwelling brings a water temperature of 20°C and a high density of plankton, 2) scallop larvae set in large numbers, 3) predators are scarce. If a high density of scallops is reached again, the Dirección de Recursos Marinos and the U.S. National Marine Fisheries Service suggest three areas of action: Quality control, marketing, and monitoring of the fisheries. Quality control must include good storage and

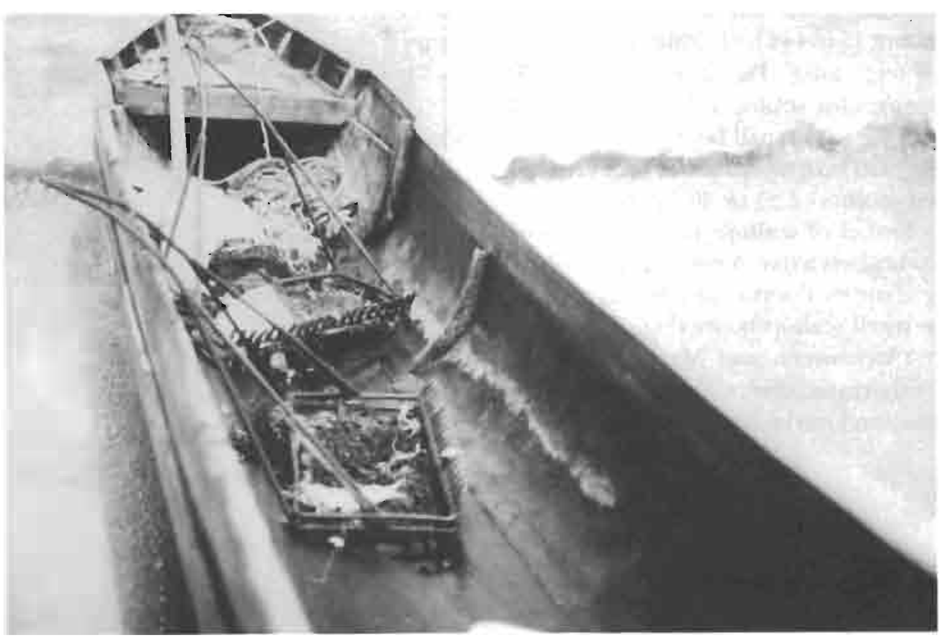

Figure 6
A small boat, about 5 m (16 feet) long, used for dredging scallops.

sanitary conditions on boats and good sanitary conditions in processing plants. Marketing should include sales in Europe and new techniques for cooking scallops such as frying them. Monitoring of the scallop fishery must include: 1) Collection of oceanographic and fisheries data, 2) an ecological study of natural beds and the scallop's reproductive cycle, 3) establishment of fishing licenses for boats and types of nets, and 4) creation of a temporal ban in specific areas either by weight or shell height, according to the scallop reproductive stage. The Centro de Ciencias del Mar y Limnología at the University of Panama has been inves-

Figure 7
A small scallop boat, used with a crew of three and powered by an outboat motor of 25–40 hp.

Figure 8
Doors and part of net on shrimp boat used for harvesting scallops.

tigating possible aquaculture techniques which can provide scallop seed for depleted beds.

Mangrove Oyster Fishery

The mangrove oyster, *Crassostrea rhizophorae*, grows intertidally on the roots of the mangrove tree, *Rhizophora mangle*, on the Caribbean side of the Isthmus of Panama. It is routinely harvested and eaten locally. The Panamanian Government tried culturing the species in Archipiélago of Bocas del Toro between 1979 and 1980 using methods developed in Cuba (MCI, 1980). It was found that oysters could be grown there, but it was too expensive to transport them to markets afterward and the program did not develop.

Other Edible Oysters

Other edible oysters, which include mainly *Ostrea iridescens* and, to a lesser extent, *O. columbiensis*, have shells with a rugose texture outside and that are white with purple spots inside. They are harvested on rocky bottoms, especially in intertidal zones and set gregariously in beds.

Littleneck Clam Fishery

The littleneck clam, *Protothaca asperrima*, ranges from the Gulf of California to Peru. Its rugose shell has a maximum height of 37 mm (1.5 inches). It inhabits muddy-sandy beaches such as Playa Bique (Arraiján), Playa Leona (Chorrera), and Chepo, and is harvested in all three areas. Fishermen also harvest another clam, *Chione subrugosa*, but its numbers are small, compared with *P. asperrima*. Clams are harvested daily for sale to local markets and restaurants.

Grand Ark Fishery

The grand ark clam, *Anadara grandis*, occurs in mangrove areas in the Gulf of Panama. Before Europeans arrived in the Americas, Indians used its shells as knives, as described by Lothrop (1937) after an archeological study at Sitio Conte, Cocle. Today, this clam is exported to other countries of Central America, where is consumed in "seviche."

Queen Conch Fishery

The queen conch, *Strombus gigas*, occurs on the Caribbean side of Panama. The San Blas Indians harvest and eat conchs in Bocas del Toro, Colón, and the Archipelago of San Blas. Recent overfishing has caused a large stock decline (Uribe, 1988).

Local Preparation of Edible Mollusks

In Panama, people eat scallops and oysters in a traditional dish called "seviche": Raw scallop adductor muscles or raw oysters are soaked in lemon juice and onions for 24 hours and then eaten. Scallops are also cooked in rice, pastas, and soups, or fried with butter. The littleneck clam is served in several dishes, often with rice and pastas.

Pearl Oyster Fishery

The pearl oyster, *Pinctada mazatlanica*, has a heavy brown-to-gray shell and a maximum shell height of 10–12 cm (4–4.75 inches) (Fig. 9). It ranges along the Pacific coast from Baja California to Peru (Keen, 1971). In Panama, this oyster occurs in the Gulfs of Chiriquí and Panama on rocky bottoms, where it attaches by a byssus. It is not gregarious (Galtsoff, 1950).

The earliest fisheries for pearl oysters were reported in the 16th century, when the Spanish, including Vasco Nuñez de Balboa, collected pearls in the Gulf of Panama. Before the arrival of Europeans, Indians commonly harvested oysters by diving. They ate the meat, but did not use the pearls. The Spanish harvested the oysters from small row boats and sail boats called "bergantins." A small boat could be built from a single tree and carry as many as eight people (Camargo, 1983). At first the Spanish employed Indians to dive for pearl oysters, but disease and poor food reduced their numbers. By the end of the 16th century, African divers had replaced the Indians, as they had more resistance to tropical diseases.

Spain's monarchy levied several taxes on products brought from the New World, including pearls. Pearls from Panama were sold in Santo Domingo (Dominican Republic), and the European cities of Seville, Venice, Amberes, Nuremberg, Hamburg, and Lisbon (Camargo, 1983). During the 17th century, prices for pearls declined when some countries began to produce imitation glass "pearls." During the 18th century, the Spanish continued extracting pearls from oysters and they employed 400 divers and 230 boats for the work in Panama.

In 1812, an estimated 500 persons harvested oysters, receiving a total income of 35,000 pesos. Panama declared its independence from Spain in 1821 and immediately joined Colombia. The oyster fisheries continued, but in 1855, the industry declined when many divers left oystering and went to work building the

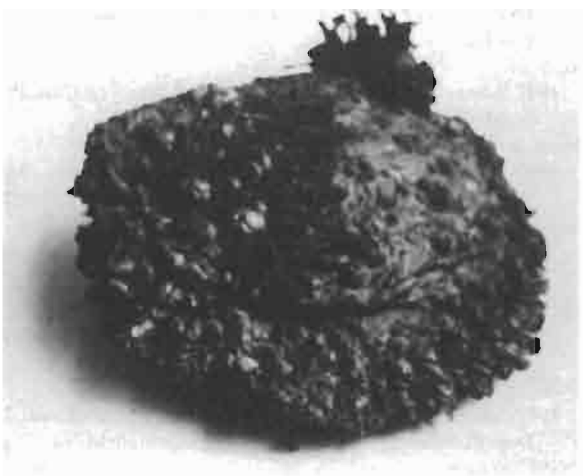

Figure 9
The pearl oyster, *Pinctada mazatlanica.*

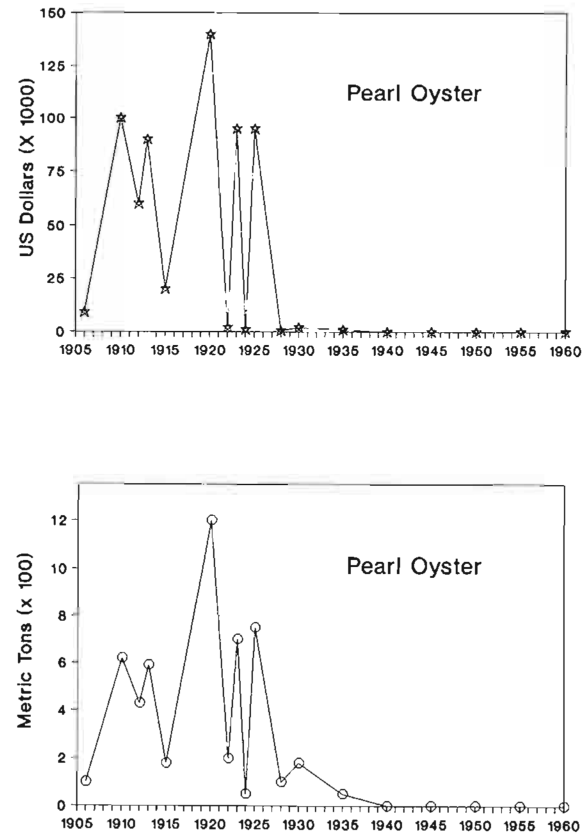

Figure 10
Total income and weight per year of the pearl oyster, *Pinctada mazatlanica,* in Panama, 1906–60. Data (to 1948) from Galtsoff (1950) and annual bulletins published by the Department of Statistics of the Republic of Panama.

Trans-Isthmian Railroad. When that construction ended, oyster harvesting was resumed. Soon thereafter, overfishing in the Gulf of Panama prompted a shift to harvest them in the Gulf of Chiriqui.

In 1903, Panama peacefully separated from Colombia. The oyster harvests continued, and from 1900 to 1940, earnings from the pearl oysters were high, with exports declining only during World War II.

The first fishery regulations were issued by Panama President Belisario Porras in 1913, at which time four main companies and many small groups were harvesting oysters. The largest company owned two large 100 t vessels. Each of these large vessels had an auxiliary fleet of 10 small boats about 10.5 m (35 feet) long, with crews of 10, including the crew, divers, and inspectors. Divers were paid $1.25 for each quintal (100 pounds) of oysters harvested, and some harvested as much as 7 quintals a day. The fisheries were active year-round, and oysters were harvested around several islands in the Gulfs of Chiriqui and Panama, including Cébaco, Coiba, Taboga, Otoque, Pacheca, Saboga, Chapera, Pedro González, and San Miguel (Rey) (Fig. 1, 2).

During the 1940's, pearl exports began to decline (Fig. 10). Although the causes were never documented, some people claimed the Japanese poisoned the beds, while others blamed overfishing. Paul S. Galtsoff, who studied the oyster beds in 1950, did not believe poisoning caused the decline because it would have affected many species, not just oysters. He also ruled out diseases and parasites, though he found that *Nematopsis* and *Bucephalus* were present; and he ruled out deterioration of the bottom, because the divers who collected the oysters did not damage the bottom.

When the Panamanian Government showed him data indicating that annual oyster exports had been 700 t (2,000,000 oysters with an average of 350 g each) since 1925, Galtsoff (1950) concluded that overfishing was the main reason the oyster industry failed. To restore the fishery, he recommended that further fishing be banned and oyster research be started. Similar overfishing of oysters had been reported in the 16th century, and it forced the cessation of oyster fishing for many years.

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Mussel Fishery and Culture in Baja California, Mexico: History, Present Status, and Future

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ABSTRACT

The native mussel, *Mytilus californianus*, has been gathered for human consumption for centuries. Middens as old as 8,890 years have shells comprised of mussels, abalone, limpets, and snails. Fishermen have harvested *M. californianus* from rocky shores, using simple tools. Landings reached a peak between 1968 and 1981, when average annual production was 430 metric tons. Most mussels were processed in canneries. Two mussel species, *Mytilus californianus* and the exotic *M. galloprovincialis*, now have good potential to be cultured in Baja California. The first attempts to culture both species were made in the 1970's. A company now is culturing *M. galloprovincialis*, using longlines 200 m long. Seed is collected on rope collectors, then attached to ropes at a rate of 2 kg/m, and hung on longlines. The seed is thinned after 1–2 months and is harvested for market at a length of 6–7 cm, at 7–8 months. The culture has been fairly successful, but will require further development because of the exposed condition of the bays in Baja California. A recovery of *M. californianus* beds, an appropriate technology for *M. galloprovincialis* (using specific machinery), and the possibility of using *M. capax* in the Gulf of California suggest a promising future for the mussel fishery.

Introduction

The State of Baja California is located on the peninsula of the same name in northwestern Mexico. It borders California on the north and the State of Baja California Sur (parallel 28°) on the south (Hernandez, 1975; INEGI, 1987) (Fig. 1). Abundant natural beds of bivalve mollusks, including mussels, occur along its 1,129 km coast, which represents 11.6% of Mexico's total coastline (Bassols, 1961; Ruiz, 1978). Two species of mussels, *Mytilus californianus* and *M. galloprovincialis*, have good economic potential (Garcia and Reguero, 1987).

M. californianus has been gathered for human consumption in Baja California for centuries (Linik, 1977; Tellez, 1987). The fishery for this mussel now continues on a small scale for local markets. The first attempts to culture both mussel species were made at the end of the 1970's to found a new industry and conserve the natural *M. californianus* beds which were heavily exploited for sales to the cannery industry from 1967 to 1981. One private company is culturing *M. galloprovincialis* using submerged longlines, with good results, and another company is preparing to culture them. This paper describes the history of the fishery and culture of *M. californianus* and *M. galloprovincialis* and offers recommendations for the future.

Habitat

M. californianus, locally named "choro," is found in dense aggregations along the Pacific coast of Baja California from the U.S. border to Bahia Magdalena in the south. It primarily inhabits the middle and low intertidal areas of exposed rocky shores, but is found to depths of 12 m (Fitch, 1953; Berry, 1954; Bernaldez, 1987). In the area of abundant mussel beds between Jatay and El Rosario, the water temperature ranges from 13°C to 17°C, the salinity is around 33.5‰ (Salas and Garcia, 1987; Fernandez and Aldeco, 1981), and

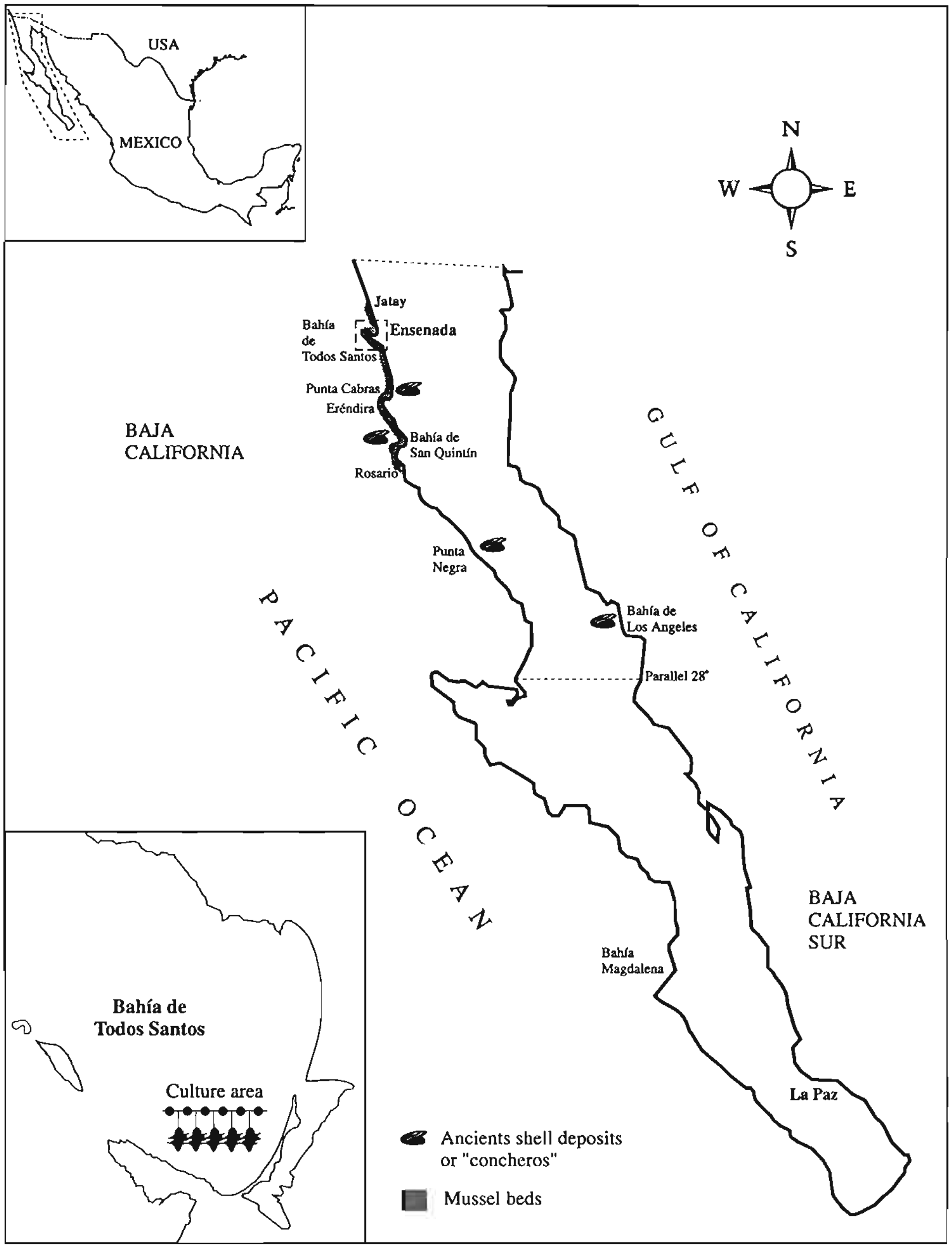

Figure 1
Baja California, Mex., showing locations mentioned in the text. The mussel fishery area is from Jatay to El Rosario, and the mussel culture area is in Bahia de Todos Santos.

the tidal range averages 2.0 m (Gutierrez and Gonzalez, 1989). Upwellings of cold Pacific water, rich in nutrients throughout the year and with a maximum intensity during spring and summer (Roden, 1971; Amador, 1975; Torres, 1982), support good growth of organisms (Dawson, 1951).

M. galloprovincialis apparently was introduced accidentally to southern California from Europe many years ago (McDonald and Koehn, 1988). Beds of this mussel are not abundant, but aggregations occur on submerged structures like cliffs, boulders, etc., and on exposed rocky shores, but mainly in pools in association with *M. californianus*.

Characteristics

M. californianus has a good survival rate combined with good growth, and its thick shell offers resistance to predators and allows for mechanical cleaning. It is in marketable condition during the entire year because it lacks a pronounced seasonal spawning cycle, instead spawning at low intensity throughout the year. This mussel is not particularly tolerant of siltation and low salinity. Thus, it does not survive well where they occur. In culture tests, it has settled in only sparse numbers on artificial collectors (Yamada and Dunham, 1989).

Figure 2
Conchero (shell midden) in a cave of Las Rosas, Ensenada, B.C.

Associates and Predators

Several species are associated with the *M. californianus* beds on the exposed rocky shores. The most common are the leaf barnacle, *Pollicipes polymerus*; balanus, *Megabalanus californicus*; keyhole limpet, *Fissurella volcano*; ribbed limpet, *Collisela digitalis*; polychaete worms, such as *Phragmatopoma californica*; emarginate dogwinkle, *Nucella emarginata*; circled rock snail, *Ocenebra circumtexta*; and isopods, *Cirolana harfordi* and *Idotea* (*Pentidotea*) *montereyensis*. Species of *Gelidium*, *Egregia*, *Corallina*, and *Gigartina* are common algae (Chi and Garcia, 1983; Dittman and Robles, 1991). *M. galloprovincialis* often occurs with *M. californianus*, but its abundance in exposed rocky shores is limited because it has a relatively weak attachment and slow growth in exposed habitats (Ricketts et al., 1968; Harger, 1970; and Haderlie and Abbott, 1980).

The most important predators are the neogastropod, *Acanthina lugubris*, and the starfish, *Pisaster ochraceus* (Suchanek, 1978; Salas and Oliva, 1983). Snails (*Roperia poulsoni*, *Nucella emarginata*, and *Ceratostoma nuttalli*), intertidal crabs, and shore birds also prey upon small *M. californianus* (Haderlie and Abbott, 1980). The commensal crab, *Fabia subquadrata*, is found living within the mantle cavity of mussels (Haderlie and Abbott, 1980; Chi and Garcia, 1983; Salas and Oliva, 1983). Trematodes (possibly *Proctoeces*) and the protozoan *Haplosporidium* also have been found in *M. californianus* (Chi et al., 1981). Studies have not been made of the associates of *M. galloprovincialis* under culture conditions in Baja California.

History of the Fishery

People have eaten mussels and other intertidal mollusks in coastal areas since antiquity (Mateus, 1985, 1986; Tellez, 1987). Local shell deposits (middens) are called "concheros" (DEMARSA, 1965; Tellez, 1987). The earliest one found, 8,890 years old, was discovered in a cave near Punta Negra, in the north of the peninsula (Linik, 1977). Other concheros were found on the peninsula at Bahia de los Angeles (6,100 years old), Punta Cabras (6,400 years old), and Bahia de San Quintin (6,165 years old) (Leon-Portilla, 1983). Concheros occur on both coasts of Baja California, near permanent freshwater sources, such as in Bahia de los Angeles (Aschmann, 1959), and in mountain caves of the peninsula (Tellez, 1987) (Fig. 2, 3).

M. californianus is the most common species in the concheros, comprising up to 90% of the shells present. This correlates with the presence of dense populations of the species on rocky shores where they are easily collected (Tellez, 1987).

The good condition of the mussel shells, the marks on them, and the presence of lithic tools such as scrapers and razors observed in several concheros, show something of the techniques used to collect and eat bivalves (Tellez, 1987). An example of the shells and tools is found in conchero Las Rosas, belonging to the community denominated "Cumiai" in Ensenada, with an estimated age of 4,000 years[1].

When the Spanish arrived in Baja California, they named the natives "Californios" (Fig. 4), but those living near the shore were specifically named "Playanos." The latter had developed rafts, nets, and harpoons to catch fish, mollusks, and turtles (Leon-Portilla, 1983).

Mussels, abalone, clams, oysters, and other shellfish were important foods of the Playanos, who used fire to open the shells and boil the meats. They ate most of the

[1] Ensenada History Museum, Av. Riviera y Blvd. Lazaro Cardenas, 22800, Ensenada, B.C., Mexico.

Figure 3
Shells of mussels, abalone, and limpets from the Conchero Las Rosas, Ensenada, B.C.

mollusks at the shore. For transport to distant places, the meats were removed from their shells, preserved by drying, and strung together (Barco, 1973; Espinoza, 1992).

Unlike in Spain, where oysters, clams, and mussels were consumed by the elite (Gondar, 1983; Ferreira, 1988), few records indicate that Spanish priests at the early missions ate mollusks. One report in the Dominic Mission in Santo Tomas, north of the peninsula, noted in 1800 that the shellfish was important for the nutrition of the local people (Moreno et al., 1987).

Natives probably have always eaten mollusks. During exploration of the peninsula and establishment of clerical missions, one priest recruited native guides and porters to help him explore the area. When food occasionally was scarce, the natives, expert in the knowledge and use of local food resources, went ashore to collect various shellfish including mollusks to eat and continue the exploration. This is documented in the diary of the priest Fernando Consag from the Jesus Company in 1751 (Ortega and Baltasar, 1944).

Several elderly people interviewed in Ensenada stated mussels have always been eaten in the area. They remember that, during the weekends, they opened and boiled mussels in saltwater in handy buckets or in casseroles at the shore, providing them with a delicious food (Guerrero[2]). This practice still takes place.

The recent history of the *M. californianus* fishery began to be officially recorded by the Delegacion Federal de Pesca from Ensenada in 1962. Fishermen harvest mussels from accessible beds between Jatay and El Rosario and sell them to local markets and the canneries. Mussels occasionally are also used as bait for fishing.

The fishery reached its peak between 1968 and 1981, when average production was around 430 t (15,800 bushels) per year (Fig. 5). Production was irregular because there was little or no management. Whenever fishermen found a new mussel bed, they harvested all of it. Periodic increases in production resulted from finding new beds. Most of the production went to canneries, which then sold it in Ensenada, Tijuana, Mexicali, San Luis Rio Colorado, and Mexico City. The names[3] of some canneries handling mussels were Pesquera Peninsular (now defunct), Conservas del Pacifico, Empacadora Marco Antonio, Empacadora Mar (which supported part of the production of the governmental company), and Productos Pesqueros Mexicanos (which sold the product under the trademark "mejillones la Coruna"). Another trademark was "Marco Antonio" (Bernaldez[4]).

In the 1970's, overexploitation of accessible beds exhausted the mussel populations. The supply to the canneries consequently was reduced, and fishermen sought other products with higher market value, such as abalone, lobster, tuna, and sea urchins. Harvesting and processing small quantities of mussels for the canneries was unattractive.

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[2] Guerrero, T. Fisherman (chorero), Ejido Erendire, B.C., Mexico. Personal commun.

[3] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[4] Bernaldez, A. Founder of Empacadora Marco Antonio (cannery factory), Rayon #357, Ensenada, B.C., Mexico. Personal commun.

Figure 4
A Californio, an ancient inhabitant of Baja California. French illustration of J. Gaildrau; picture from Leon-Portilla (1987).

The reduced harvests allowed the mussel beds to recover, and, in 1991, a new attempt was made to exploit mussels for a canning factory named Playa Mar located in La Paz. However, the excessive cost and problems associated with transporting mussels from Ensenada 800 miles to La Paz, made this operation unprofitable. Natural mussel beds currently are fairly abundant, and fishermen harvest them for local markets and occasionally for the canneries.

Harvesting Methods

The fishermen, or "choreros," who harvest *M. californianus* gather them during low tides on accessible rocky shores. The simple tools used to pull off mussel clusters include a pipe with a piece of spring welded on the top, called a "barra" (Fig. 6), a pike called a "talacho" (Fig. 7), an iron beam called a "pata de chivo," and protective gloves (Santiago and Rojas, 1982; Bernaldez, 1987).

During the period of greatest mussel production, 1967–81, a group of 40–50 choreros harvested about 10 t (365 bushels) of mussels per day for the canneries. Cannery personnel collected the mussels at the shore or purchased them from the choreros who delivered them (Bernaldez[4]). After depleting the stocks during those years, the choreros then exploited previously overlooked species such as marine algae (*Macrocystis pyrifera, Gelidium robustum*) to be used for extracting alginate and agar, starfish and anemones for biology laboratories, and barnacles, *Pollicipes polymerus*, to be sold in Spain (Bernaldez, 1987; Bernaldez[5]).

Choreros sort the mussels by size on the shore, putting the market sizes in sacks and the small mussels back on their beds (Fig. 8). After that, they transport the mussels to the cooking site. Mussels about 8 cm long are preferred by the canneries, while larger mussels are destined for the fresh market. The mussels are cleaned, the byssus and digestive glands (only when mussels are large) are pulled out, and the meat is boiled. After that, the meats are cooled, put in packages of 15 kg each, and sent on trucks to the canning factories or fresh markets. Mussels may be harvested throughout the year, but the main season is during autumn and winter when the mussels have their best condition index and major low tides occur (Guerrero[2]).

Mussel Culture

Various semiprotected bays and zones occur along the Baja California coast where mussel culture is possible. According to Baylon (1987), the potential surface area for mussel culture in the northwest Pacific coast of Baja California is about 8,000 ha, with a potential production of 80,000 t per year. The most important culture area is Bahia de Todos Santos which is approximately 18 km long and 14 km wide and has a surface area of 230 km^2. Its bottom is sandy and it is partially separated from the ocean by two small islands which delineate two channels to the ocean. The depth of the culture area is between 10 and 20 m (Garcia, 1987; Garcia and Garcia, 1987).

Culture History and Research

In 1978 the Direccion General de Tecnologia Pesquera of the Secretaria de Pesca, and, in 1979, the Instituto de Investigaciones Oceanologicas of the Universidad Autonoma de Baja California, and Industrias Pesqueras

[5] Bernaldez, A. J. General director of Empacadora Marco Antonio (cannery factory), Rayon #357, Ensenada, B.C., Mexico. Personal commun.

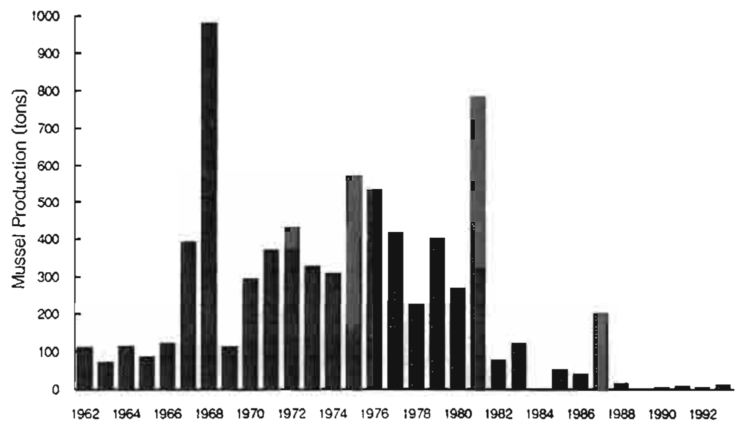

Figure 5
Mussel production (in metric tons), 1962–93.

Figure 6
Fisherman (chorero) using a "barra," a special type of shovel to remove clusters of *Mytilus californianus* from a natural bed.

Paraestatales del Noroeste began projects to establish mussel culture and to protect natural mussel beds in Baja California. Knowledge relating to the use of and the biology and management of *M. californianus* was obtained. Mateus (1978) studied the feasibility of including mussel meal in chicken diets; Santiago and Rojas (1982), Chi and Garcia (1983), and Hoyos (1988) determined spawning periods; Olguin (1983) studied the fluctuations of mussel larvae in the plankton; Orozco (1982), Salas and Oliva (1983), Chi and Garcia (1983), and Monje (1983) determined the settlement periods on established mussel beds and artificial collectors; Lagos (1982) and Carpizo (1983) studied conditioning of mussels in laboratory; and Chi and Garcia (1983) and Salas and Oliva (1983) determined the incidence of the parasite crab *Fabia subquadrata*. Establishing annual limits on mussel harvesting and leaving patches of mussels in beds to favor population recovery was recommended.

During the studies of *M. californianus*, *M. galloprovincialis* settled on artificial collectors, permitting their

Figure 7
A pike, called "talacho," occasionally used by choreros to pull out clusters of mussels.

collection and study (Orozco, 1982; Monje, 1983). Culture experiments were conducted to compare the characteristics of the two species. Trials were made with floating rafts using Spanish technology (Orozco, 1982; Cancino, 1985; Garcia, 1987; Garcia and Garcia, 1987; Lizarraga, 1987) and with longlines (Gonzalez and Guerrero, 1987)(Table 1). The first results were encouraging, and in 1985 some investigators who participated in the experiments from the Instituto de Investigaciones Oceanologias received financial support from the National Fishery Bank (BANPESCA) to found the first private mussel culture company using floating rafts. The company was called Martesano, S. A. In 1987 the first cooperative (social company), called the "Cooperative Society Bahia Falsa," for mussel culture using longlines was constituted, and in 1987 the groups had a regional meeting with the Trust National Capital for Fishing Development agency (FONDEPESCA), educational institutions, and fishing authorities (Secretaria de Pesca) to stimulate the growth of mussel culture in Baja California. Several mussel production limitations were identified:

1) The procurement of *M. californianus* seed on artificial collectors is limited because the seed does not remain attached to them. While *M. galloprovincialis* remains on artificial collectors, settlement is irregular, beds of seed are scarce, and beds where seed can be obtained in quantity are unknown;

2) Protected areas to practice culture are limited and thus adequate culture technology in semiexposed conditions needs to be developed;

3) The various culture steps require mechanization;

4) *M. californianus* is not known and accepted in the international market; and

5) Market demand needs to be enhanced by promotion to attract further investments to the culture operations and canneries.

The efforts of cooperatives and private companies have focused on the culture of *M. galloprovincialis*. However, the seed supply remained small, and, in 1988, the worst storm in about 100 years hit the area and destroyed all the rafts of the private company (Rangel, 1990). In addition, organizational problems beset the cooperative Bahia Falsa. Culture activities consequently ceased in 1988 and mussel production was low in the following years (Fig. 5). The members of the Martesano Company returned to their academic activities in the Instituto Investigaciones Oceanologicas and switched their research efforts to producing *M. galloprovincialis* seed in the laboratory (Alvarado, 1989; Anguiano, 1989; Gonzalez, 1992; Velazco, 1994).

In 1991 a new private company, Acuacultura Oceanica, began culturing *M. galloprovincialis* using subsurface longlines in Bahia de Todos Santos, a semiexposed area. Its results have been promising and represent an important effort to develop mussel culture. Another mussel culture company also is beginning operations.

Culture Methods

The first mussel culture company, Martesano, raised *M. galloprovincialis* using floating rafts with two wooden floats covered with fiberglass and with sharpened foward ends. The floats supported a wooden framework, 10×10 m, from which 375 culture ropes, each 10 m long, were suspended. The raft was anchored with an iron chain and a 5 t concrete anchor. The seed was obtained from artificial collectors which had been placed in the area during the winter. The production capacity of the company was 200 t (7,300 bushels). About 20 permanent employees and 40–50 temporary employees (during collecting time) were working for the company (Garcia and Garcia, 1987; Rangel, 1990).

The cooperative, Bahia Falsa, used 20 m longlines supported by 5 buoys and anchored with 80 kg concrete

Figure 8
Sacks with mussels ready to be carried from shore to boiling areas in Erendira, B.C.

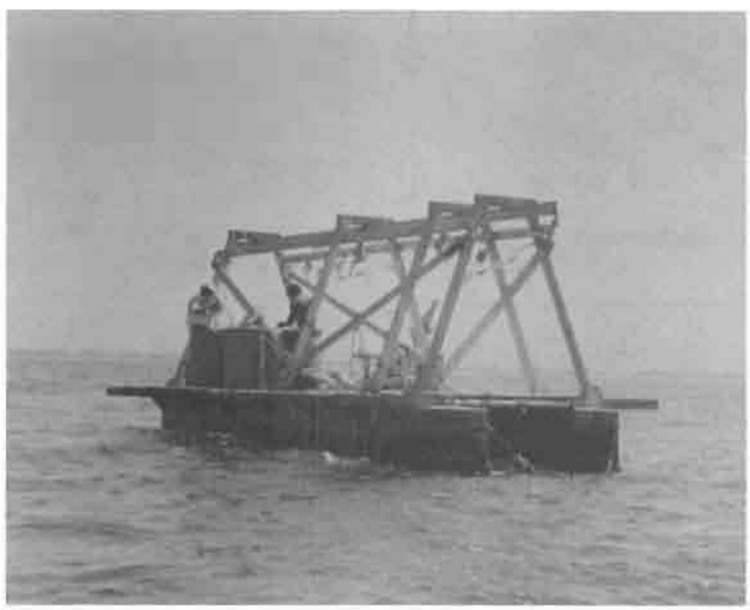

Figure 9
Small raft used to support different maintenance operations of mussel culture in longlines in Punta Banda, B.C.

anchors, and obtained seed from artificial collectors. The cooperative's production capacity was 50 t (1,835 bushels) (Baylon, 1987; Gonzalez and Guerrero, 1987).

The culture of *M. galloprovincialis* currently is carried out by a private company, Acuacultura Oceanica, which uses submerged longlines suspended from 200 l plastic floating barrels and are anchored with 0.8 or 1.2 t concrete anchors. Longlines, 200 m long, are placed in lines parallel to the shore. The main line is placed at a 5 m depth from which culture ropes, 7 m long, are suspended. The company uses a 7.6-m boat, scuba divers, and a small raft of 6×4 m to maintain the longlines (Fig. 9).

Table 1
Trials of Baja California mussel culture.

Institution or company	System	Locality	Year	Observations/species
Direcction General de Tecnologia Pesquera	Floating rafts	El Sauzal	1978	Experimental
Delegacion Federal de Pesca	Longline Tomas	Bocana de Santo	1979	Experimental
Industrias Pesqueras Paraestatales	Floating rafts Longline	Bahia de Todos Santos	1980–82	Experimental *M. galloprovincialis* *M. californianus*
Productos Pesqueros Mexicanos	Floating rafts	Bahia de Todos Santos	1985	Commercial Raft destroyed by deficient design
IIO[1]	Longline	Erendira	1980–82	Experimental *M. galloprovincialis* *M. californianus*
IIO[1]	Floating rafts	Bahia de Todos Santos	1982–83	Experimental *M. californianus*
MARTESANOS	Floating rafts	Bahia de Todos Santos	1985–88	Commercial In 1988 rafts were destroyed by storm *M. galloprovincialis*
Sociedad Cooperativa Bahia Falsa	Longline	Isla de San Martin	1987	Commercial *M. galloprovincialis*
Acuacultura Oceanica	Longline	Bahia de Todos Santos	1991 to date	Commercial In operation *M. galloprovincialis*

[1] Instituto de Investigaciones Oceanologicas.

The culture follows the usual sequence of steps when using longlines and floating rafts.

Collecting and Handling Seed

Mussel seed is obtained from artificial collectors that consist of a polyethylene rope of 1 cm diameter and 7 m long which is placed inside a thin polyethylene net (Fig. 10) and suspended from surface longlines. Larval settlement occurs during autumn and winter on longlines in locations where there are no other culture ropes. By May and June, the seed has grown to a size of about 3 cm, and is taken to the harbor where it is removed from the collectors and attached to polyethylene growing ropes of 2 cm diameter.

Workers attach the seed by enveloping it with a polyethylene or cotton mesh in a process called "encalcetinar" (put in socks). They attach about 2 kg of seed per meter of rope. As in the Spanish system (Caceres-Martinez and Figueras, 1997), at every 40–50 cm of rope, the workers insert pieces of PVC tubing, 20–25 cm long and 2 cm in diameter, between strands of the ropes, to prevent clumps of mussels from sliding down the ropes. The following day, scuba divers attach the seeded lines to the longlines. The nylon mesh remains during the growing season, while cotton mesh disintegrates soon after the mussels have attached to the culture rope with their byssus.

Thinning Seed

While growing, the mussels compete with each other for space and food and some clusters fall off the ropes during rough weather. After the mussels have grown for 1–2 months and have reached a size of about 5 cm, scuba divers remove the ropes (Fig. 11). Workers then take them to the harbor and thin them by removing the mussels from one rope and reattaching them to two or three ropes. This operation may be repeated again depending on growth of the mussels. In placing the

Figure 10
A mussel seed collector made of polyethylene rope in Punta Banda, B.C.

Figure 11
A rope with *Mytilus galloprovincialis* about 5 cm long for distribution in two or three new ropes in Punta Banda, B.C.

seed on ropes, seed of different sizes is kept together to maintain a uniform distribution of sizes during growth and for the market.

Growing and Harvesting

Mussel growth is rapid and is comparable with that in the most productive mussel culture areas of the world, such as Spain and New Zealand (Salas and Garcia, 1987). The first harvesting can take place when the mussels attain a size of 6–7 cm, 7–8 months (November–December) after the seed has been placed on the ropes. If the market demands larger sizes, the mussels may be left for another 4–5 months. As in the previous steps, the ropes are taken out by hand, the mussels are taken to the harbor, and they then are transported by truck to markets.

Marketing

For the local fresh market, the meat of *M. californianus* is taken from the shells at the shore and is boiled, then transported, and sold. Freshly boiled meat sells for N$10/kg (N$8 = US$1). It also is sold in the shell, in which case the price is N$5/g (Fig. 12). There are no markets for fresh mussels outside of Ensenada due to a lack of adequate transportation routes, refrigerated trucks, and demand.

The *M. californianus* destined for canning arrived uncooked in the shell at the canneries, where they were cleaned, the byssus removed, and then boiled. Their meats were prepared in brine or marinated in cans holding 115 or 454 g. The product finally was sterilized and packed. Most production was sent to markets in Mexico City (Bernaldez[5]). In 1987, the production capacity of canning factories in Ensenada was 150 t (5,500 bushels) of mussels per day and the estimated annual national demand was 6,000 t (220,000 bushels) (Baylon, 1987). In contrast, cultured *M. galloprovincialis* is sold in the shell to seafood restaurants in Mexico City and other places in the country. Currently mussels are also sold to the U.S. market.

Figure 12
Fresh mussels in an Ensenada, B.C., fish market.

Fishery Regulations

During the period of maximum mussel production, choreros had to have special permission from the Delegacion Federal de Pesca from Ensenada to harvest mussels, and the choreros and canneries had to report the quantities of mussels to fishing authorities and pay a tax of N$2.0 per kg of harvested mussels (Bernaldez[4]). The Delegacion Federal de Pesca in Ensenada currently gives the social organization in "Ejidos" (delimited land, including their coast, that belongs to farmers and fishermen of the area) permission to exploit marine resources in their area, including mollusks. This situation favored the recovery of accessible mussel beds and, in fact, any exploitation of them is in accordance with the members of the Ejido whose members are called "ejidatarios." In general, they permit the free harvests of controlled quantities of mussels for local consumption and the fresh market and, when necessary, the canneries. However, there is no systematic and regulated harvest to increase the supply to the canning factories.

The Delegacion Federal de Pesca in Ensenada has established a written form, called a "ventanilla unica," which must be completed to carry out any aquacultural project including mussel culture. Mussel farmers have to present a technical description of their project, which includes the environmental impact of the culture. The project is analyzed by technicians from the ministry, and, if adequate, the project is approved and authorized for implementation in Federal zones.

The water in the bay is periodically analyzed by technicians of the National Program of Bivalve Mollusks who certify its quality and verify whether mussels require depuration (Velarde, 1987). Red tides occur, but heretofore they have not caused problems. Toxicity by DSP (diarrhetic shellfish poison) or PSP (paralytic shellfish poison) have not been reported in the area, but this is an aspect that requires attention.

The Future

The exceptional development of the mussel industry in Europe provides promise for the mussel industry in Baja California. Baylon (1987) estimated that the potential demand for mussels will be about 37,000 t (1.4 million bushels) per year, but some limitations of the mussel fishery and culture are related to marketing. In markets, *M. californianus* is considered inferior to *M. galloprovincialis*. *M. galloprovincialis* tastes better than *M. californianus* and does not contain sand in its shell cavity or organisms on its shells as *M. californianus* frequently does. In addition, the shelf life of *M. galloprovincialis* is reportedly longer (Guevara[6]). *M. galloprovincialis* farmers emphasize these points when selling their mussels.

However, the qualities of *M. californianus* have been understated. The problem of sand in *M. californianus* may be easily resolved by placing the mussels in a current of clean seawater for about 12 h. The problem of organisms attached to the shell could be resolved by cleaning the shell with brushes. The taste difference and shell problem disappear when mussels are canned. This argument is used by canneries to offer the same price for both species. The result is an undervaluation of *M. galloprovincialis* which causes culturing them to be less cost-effective than harvesting *M. californianus*. The negative comparisons between *M. californianus* and *M. galloprovincialis* with respect to their sales could be changed to positive values by differentiating the quali-

[6] Guevara, S. General director of Acuacultura Oceanica, S. de R.L.M.I. Lote 4, Manzana 8, Parque Industrial Fondeport, El Sauzal, Baja California, Mexico. Personal commun.

ties of each species and giving each a distinctive place in the market, emphasizing the high quality of fresh and canned mussels.

The fishery for *M. californianus* must be carried out to allow harvesting while conserving the natural beds. This can be done by establishing annual harvest limits and seasons, leaving patches in beds, and establishing temporary reserves (Chi and Garcia, 1983; Salas and Oliva, 1983; Paine, 1989; Caceres-Martinez et al., 1994).

Resource managers initially believed that *M. californianus* had low culture potential, but potential seed sources exist in abundant *M. californianus* beds. Studies need to be made concerning the reasons for limited sets of this species on artificial collectors to assist in further development of a culture system.

The culture experiences with *M. galloprovincialis* have been relatively successful but will require further development because of the semiexposed conditions of the bays in Baja California. Irregular sets of seed on artificial collectors of the first company to attempt mussel culture suggested that seed production in a laboratory could be useful. The Instituto de Investigaciones Oceanologicas has developed successful methods to produce mussel seed in the laboratory. However, during the last five years, natural mussel settlement has been successful and therefore, laboratory seed production has not been necessary. Academic researchers and companies need to continue to develop methods for collecting natural seed and search for natural populations of *M. galloprovincialis* seed. Appropriate insurance services that protect the industry need to be developed, and some steps in mussel culture need to be mechanized.

More scientific findings need to be made available to mussel farmers. The scientific studies that have been conducted at local academic institutions have been reported mostly in bachelor of science theses, and the relevant information has been circulated only within the institutions or at national or academic meetings. This situation is especially limiting in Baja California where an aquaculture tradition is lacking and where fishermen have little training. The fishermen have been harvesting marine resources without an attitude of culture, i.e. seeding and growing, throughout the years. It is difficult for them to change their work patterns to culture activities which require additional effort, investment, and training for a species without an immediate economic return such as is obtained from harvesting abalones, lobsters, and tuna. In critical situations or with the arrival of poorly educated people in the region searching for work, alternative employment has been found in easier work such as sales of used merchandise coming from the U.S. border region.

The fat horse mussel, *Modiolus capax*, has some economical potential in the Gulf of California (Buckle and Farfan, 1987; Garcia and Reguero, 1987). However, the existence of valuable scallops (*Argopecten circularis, Pecten vodguesi*), shrimp (*Penaeus vannamei, P. stylirostris*), and lobsters (*Panulirus inflatus, P. gracilis*) in the Gulf of California, and the presence of *M. californianus* and *M. galloprovincialis* on the northwest coast of Baja California has resulted in a low interest in this mussel for fishery or culture purposes. The recovery of *M. californianus* beds, an appropriate *M. galloprovincialis* culture technology perhaps using specialized machinery, and the possibilities of exploiting other mussel species such as *M. capax* suggest a promising future for the mussel industry in Baja California. Future mussel development efforts should include contributions from politicians, educational institutions, fishing authorities, canneries, the choreros, and mussel farmers. It should take into account both *M. californianus* and *M. galloprovincialis*, and both harvesting wild stocks and culture.

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The Shellfish Industry of California—Past, Present, and Future

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ABSTRACT

The shellfisheries of California are relatively small because there are only a few bays and estuaries suitable for producing mollusks, and no offshore scallop or clam grounds. In the past, there were fisheries for the native oyster, *Ostreola conchaphila*; eastern oyster, *Crassostrea virginica*; pismo clam, *Tivela stultorum*; and California mussel, *M. californianus*. The completion of the transcontinental railroad in 1869 made it possible to ship *C. virginica* to San Francisco for immediate sale or for planting in San Francisco Bay. The highest production from planted oysters was 335,000 bushels in 1899. By 1920 the bay had become polluted and the shipments ended. The most important shellfish in commercial landings now is the Pacific oyster, *Crassostrea gigas*; California produces about 16% of these oysters landed on the west coast of North America. Next are abalones, *Haliotis* spp., and the blue mussel, *Mytilus galloprovincialis*, in relatively small quantities. Farms culture the oysters and most of the mussels, while divers harvest nearly all the abalones from wild populations. The 1950's and 1960's were the peak years for abalone fishing, when about 1,000 commercial divers harvested them, but now only about 15 divers harvest them. There now are substantial sport fisheries, mainly for the pismo clam, Pacific littleneck, *Protothaca staminea*, and abalones, and to a lesser extent for other clams, mussels, and the giant rock scallop, *Crassadoma gigantea*.

Introduction

The molluscan shellfisheries of California are relatively small because its 5,520 km (3,427 mile) tideline coast has only a few small bays or estuaries suitable for producing shellfish, with the only exception being San Francisco Bay (Fig. 1). Offshore scallop and clam grounds do not exist. The most important shellfish in commercial landings is the Pacific oyster, *Crassostrea gigas*. Next are the abalones, *Haliotis* spp., and then, in relatively small quantities, the bay mussel, *Mytilus trossulus* and *M. galloprovincialis*. Farms culture the oysters and most of the mussels, while divers harvest nearly all the abalones from wild populations. In the past, other commercial mollusks were the native or Olympia oyster, *Ostreola conchaphila*; eastern oyster, *Crassostrea virginica*; pismo clam, *Tivela stultorum*; and California mussel, *M. californianus*. A substantial sportfishery exists for the pismo clam; Pacific littleneck, *Protothaca staminea*; and abalones, and to a lesser extent for other clams, mussels, and the giant rock scallop, *Crassadoma gigantea*.

The Habitat

The most important shellfishing bays in California have been San Francisco Bay, Humboldt Bay, Tomales Bay, Drakes Estero, Elkhorn Slough, and Morro Bay. Coastal upwelling keeps their water temperatures between 10° and 18°C; temperatures rarely attain 20°C and are too cool for eastern oysters and Pacific oysters to spawn (Barrett, 1963).

The predators of eastern oyster seed in San Francisco Bay included the northern oyster drill, *Urosalpinx cinerea*, and bat ray, *Myliobatis californica*. Predators of the Pacific oyster include the bat ray; red rock crab, *Cancer productus*; Japanese drill, *Tritonalia japonica*; and several species of starfish. Sea otters, *Enhydra lutris*, have preyed heavily on abalone populations in northern California, and abalone and pismo clam populations in central California (Fig. 2). Other abalone predators include the California sheepshead, *Pimelometopon pulchrum*; several other fishes; and octopi. Predators of pismo clams also include gulls, sharks, and rays; the

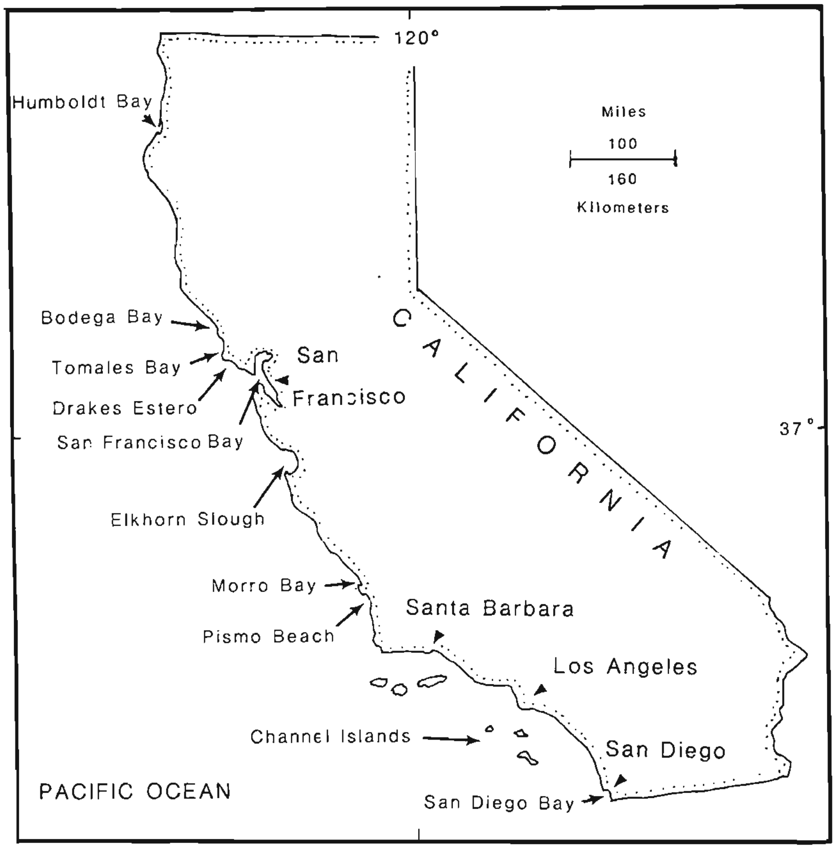

Figure 1
The State of California.

California corbina, *Menticirrhus undulatus*; the moon snail, *Polinices* spp.; and cancer crabs (Anonymous, 1971).

Olympia Oyster Fishery

The native Olympia oyster ranges from Sitka, Alaska, to Cape San Lucas, Baja California, and is most abundant in estuaries, small rivers, and streams (Korringa, 1976). It forms oyster reefs in subtidal zones bordered by mud flats at high elevations, and by eelgrass, *Zostera marina*, beds at low elevations (Couch and Hassler, 1989). Its larvae attach to any firm surface, such as oyster shells and the undersides of rocks high in intertidal zones (Fitch, 1953). Olympia oysters thrive at salinities above 25‰ and tolerate occasional short exposures to lower salinities (Korringa, 1976) but are sensitive to extreme high or low temperatures (Matthiessen, 1970).

The shell middens of Native Americans date from 3,000 to 4,000 years ago and show early utilization of Olympia oysters in San Francisco Bay (Fig. 3) They were also an important food of other coastal tribes (Barrett, 1963). The middens show a sudden change in numbers of oysters; native oyster shells were abundant in the basal layers of a few larger mounds but were

Figure 2
Sea otter off the California coast. From Anonymous (1971).

scarce in the upper layers of the same mounds. Siltation was thought to be one cause for the fluctuations in abundance.

In the 1840's California had a small fishery for the native Olympia oysters which served San Francisco (Conte and Dupuy, 1982). Beginning in the 1850's, the oysters were imported from Puget Sound, Wash., because local demand exceeded supply. They were transported by sailing vessels in 100-pound sacks or in baskets weighing 32 pounds. As many as 32,000 baskets/year were shipped to San Francisco Bay, where workers placed them on tidal beds so the oysters would remain in good condition until needed (Ingersoll, 1881; Anonymous, 1984).

In the early decades of the 1900's, commercial harvests reduced the numbers of Olympia oysters in Elkhorn Slough and in Humboldt, Tomales, and Newport Bays. In the 1930's, oystermen attempted to increase populations in Humboldt Bay, but they failed, and the natural beds became ever more depleted.

A 1930 survey of California coastal waters revealed limited potential for increasing Olympia oyster culture areas. San Francisco and San Diego Bays were somewhat polluted, and Tomales Bay was infested with oyster drills and slippersnails, *Crepidula* spp. The areas rated "good" were Elkhorn Slough, Drakes Estero, and Humboldt Bay.

The industry attempted to expand Olympia oyster culture in Humboldt Bay by constructing diked beds and relying on brood stock from natural beds to provide larvae for the cultch that was spread. Workers spread cultch near the beds during setting seasons to collect enough seed so they would not be dependent on the natural beds. Meanwhile, the natural beds declined in productivity as setting ranged from insubstantial to good, and only small numbers of Olympia oysters were available for marketing.

In November 1937, the California Fish and Game Commission finally allowed eastern oysters to be imported to Humboldt Bay; and the imports continued until the early 1940's. Meanwhile, the Olympia oyster industry continued to dwindle.

Limited financial resources and a lack of experience in raising oysters were two causes for failure. But also, the Olympia oyster did not lend itself to commercial development: Spat collection was poor, growth from spat to market size took 5 years, and the meats were small. The only time oysters were fat was during the winter, which limited the market season.

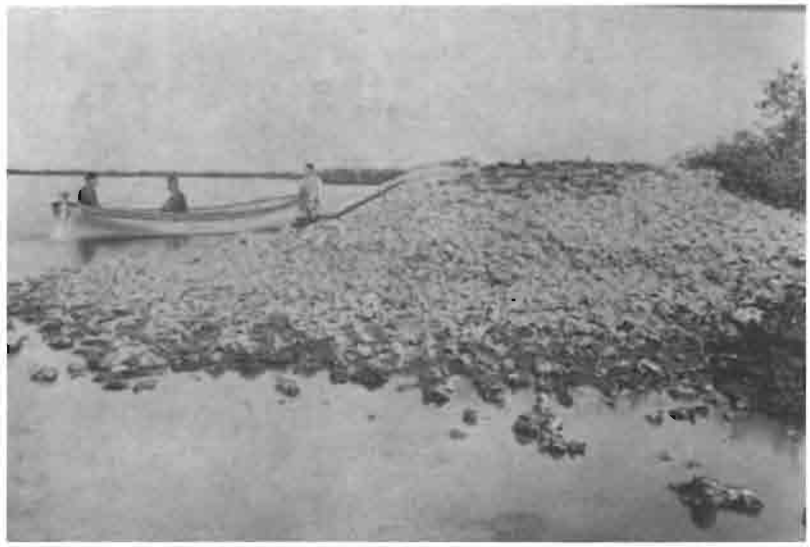

Figure 3
Oyster shell midden left by Yaqui Indians. From Townsend (1893).

Eastern Oyster Fishery

The completion of the transcontinental Central Pacific Railroad in 1869 made it possible to ship eastern oysters from New York City to San Francisco. The first experimental plantings in California were made in about 1870, on the eastern side of San Francisco Bay. Though the oysters grew rapidly and their flavor and meat yield were good, it was not until 1875 that San Francisco dealers brought in large quantities, ordering market-sized oysters for immediate sale and seed oysters for planting. As travel time was about 18 days, about one-fourth of the seed died during the trips. The oyster beds were near the shores throughout much of the bay, but mainly in its southwestern end (Fig. 4). The seed remained on the beds for 2–4 years before being sold (Ingersoll, 1881).

This seed came from bays around New York City, principally Newark and Raritan Bays, and from the Hudson and Raritan Rivers. Between 1887 and 1900, dealers shipped from 69 to 262 (124 avg.) carloads (90 barrels [270 bushels]/carload)/year—roughly an average of 33,480 bushels/year—to San Francisco Bay for planting (Barrett, 1963).

Growers installed fences of close-set stakes about 3.5 meters (12 feet) long, driven a little more than 1 meter (about 4 feet) into the bottom around the beds, to keep out bat rays (Fig. 5). Since bat rays remained in the bay from spring until late fall, they would have destroyed many oysters otherwise (Townsend, 1893). The seed grew year-round and attained a market size 12 months earlier in the bay than on the U.S. east coast (Conti and

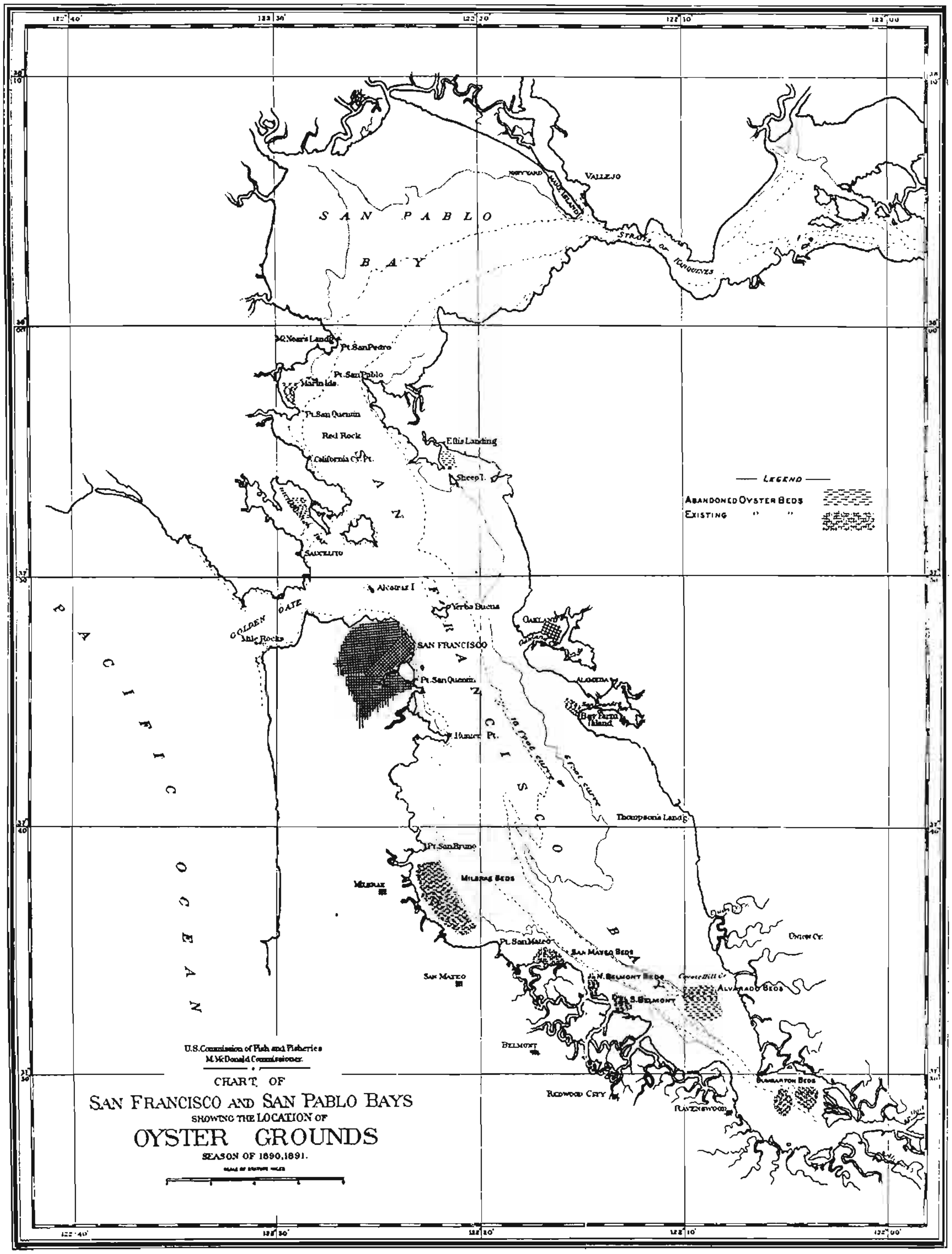

Figure 4

Areas in San Francisco Bay where eastern oysters were grown. From Townsend (1893).

Dupuy, 1982). The demand for eastern oysters soon eclipsed that for Olympia oysters from Washington.

About 100 men were usually employed in the oyster industry in San Francisco Bay, but the number was larger at times. The types of boats used were schooners, sloops, scows, floats, and rowboats. The scows were used for tonging (Fig. 6), while growers used the floats—large barges with bottom planks separated to admit water—to keep culled and cleaned oysters in good condition before marketing them (Fig. 7). Sloops carried

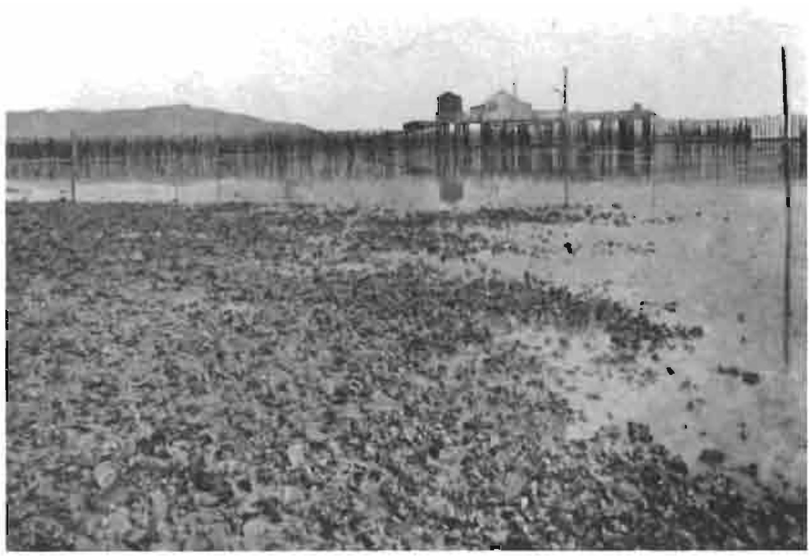

Figure 5
Bed of eastern oysters growing in San Francisco Bay with a stake fence to protect beds from bat rays. From Townsend (1893).

Figure 6
Tonging oysters in San Francisco Bay. From Townsend (1893).

oysters between harvest areas and to market. When the tide was out, all the boats were left high and dry on tidelands, and workmen wearing rubber boots levelled or otherwise improved the surface for oyster bedding (Townsend, 1893).

Between 1888 and 1900, the eastern oyster accounted for 80% of total California oyster production. Around 1890, they sold for $4.00/box of 200, or about twice their selling price on the U.S. east coast (Townsend, 1893). The highest production was 2,520,000 pounds of meats (about 335,000 bushels), in 1899. Production ranged from 819,000 to 910,000 pounds of meats (109,000–121,000 bushels) from 1888 to 1891, and from 376,000 to 1,020,000 pounds (50,000–136,000 bushels) from 1904 to 1915 (Barrett, 1963). Between 1875 and 1900, trial plantings of eastern oysters also were made in Humboldt and Tomales Bays, but they were later discontinued (Conte and Dupuy, 1982).

In the early 1900's, deteriorating water quality in San Francisco Bay caused oyster production to decline. In

Figure 7
Culling oysters in scows with floats between them. From Townsend (1893).

1908, about 100 carloads of eastern oysters were still being imported, but imports declined soon after, as oyster growing began to die out in the bay. By 1910 the large-scale transfer of east coast seed oysters to California had ended. Full-grown east coast oysters continued to be imported, and many were bedded in San Francisco and Tomales Bays until sold; San Francisco Bay was abandoned for oyster culture in 1939 and California landings of the eastern oyster ended in about 1960 (Barrett, 1963).

Pacific Oyster Fishery

Introductions of Pacific oysters to the west coast of North America from Japan and by coastal transplants have spread this species from northern British Columbia to Morro Bay, Calif. (Pauley et al., 1988), and it has been recently introduced to southeastern Alaska. Because the Pacific oyster fails to reproduce in California, due to low water temperatures, the industry is entirely dependent on imported seed.

The first experimental planting of Pacific oysters in California was made in Tomales Bay in 1928. At that time, the Department of Fish and Game did not allow Pacific oysters in Humboldt Bay (Barrett, 1963). The following year they were planted in Elkhorn Slough; and, in 1932, small quantities were introduced in Drakes Estero, Bodega Lagoon, Morro Bay, Mugu Lagoon, Anaheim Creek, and Newport Bay. They were first planted in San Francisco Bay in 1932–33.

When the purchase of oyster seed from Japan became formalized in 1939, the Pacific Coast Oyster Growers and Dealers Association purchased the entire amount, with Japanese producers usually shipping the seed to California between February and March. California growers harvested small quantities from San Francisco Bay, until World War II interrupted the Japanese imports. San Francisco Bay is no longer suitable for oyster culture because of contamination by many types of pollutants, including organic chemicals (Crosby, 1988).

When the growers introduced large quantities of Pacific oysters to several bays during the 1950's, farming expanded rapidly. In the 1960's and early 1970's, oysters in a few California bays suffered severe mortalities. Losses were highest in Humboldt Bay, affecting oysters in their second summer, and from 1961 through 1964, losses ranged from 34% to 56% (Glude, 1975). Studies between 1966 and 1972 to determine mortality causes in Humboldt Bay were unsuccessful, but investigators believed the cause might have been the bacterium *Vibrio* sp. A decreasing trend in oyster mortalities was observed during 1972 and 1973, and noticeable mortalities, other than those caused by predators, have not occurred since.

Currently, two bays, Humboldt and Drakes Estero, supply over 80% of California's oyster production. The state has two large companies and 15–20 much smaller ones producing oysters in Humboldt, Tomales, and Morro Bays, and in Drakes Estero.

The Coast Oyster Company[1] in Humboldt Bay produces 48% of the state total; it employs about 120 field hands and shuckers and about 8 management person-

[1] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

nel. Bottom culture is the primary method. Workers spread shells with attached spat on the bottom, allow them to grow for 2 or 3 years to a length of about 10 cm (4 inches), and harvest them by suction dredge.

The Johnson Oyster Company of Drakes Estero produces 41% of the state's oysters, employing 92 field hands and shuckers and 8 management personnel. The primary culture system used is offbottom rack culture. Workers string spatted shells on lines, the shells being spaced by a tube. Next they hang the lines over rails of racks set in the bay (Fig. 8). In selected shallow areas of the bay, they also practice stake culture: Three spatted shells separated by spacers are threaded by a stake that is driven into the bottom. Small California growers produce the remaining 11% of oysters and employ a total of about 60 people.

From 1980 to 1989, the state's total annual oyster production was fairly stable at 949,000–1,457,800 pounds of meats (Table 1). Production is limited by available habitat and markets.

Figure 8
Harvesting a string of Pacific oysters belonging to Johnson Oyster Company in Drakes Estero, circa 1975. Photograph by author.

Oyster Hatcheries

In recent years, there have been major changes in seed sources. Seed imports from Japan were later supplemented by occasional imports from Washington, where natural sets had occurred. Unfortunately, natural sets in Washington were erratic and undependable, so west coast oyster companies built several hatcheries to supply their own seed. Now, almost all Pacific oysters grown in California come from Washington hatcheries. One of the largest, owned by the Coast Oyster Company, on Hood Canal, Wash., supplies all the seed for grounds it leases in Humboldt Bay. Initially, its workers shipped the seed to Humboldt Bay on oyster shells similar to the method used by the Japanese.

A procedure known as remote setting followed. The Washington hatchery shipped millions of eyed larvae to Humboldt Bay. Workers poured them into large cement tanks filled with water and bags of oyster shells. The larvae set within 3 days, and then workers suspended the shells from rafts until the oysters grew large enough to plant on the bottom. The Coast Oyster Company has since abandoned this method and is now shipping spat-laden shells from its hatchery. The industry now grows mostly *C. gigas* (Fig. 9), the smaller Kumamoto variety of *C. gigas*, and an insubstantial quantity of the European flat oyster, *Ostrea edulis*.

California hatcheries, unlike the one mentioned above, were constructed to supply a special product known as cultchless oysters, produced by removing the seed from cultch shortly after setting. With cultchless oysters, growers could transfer millions of seed to growout sites, in small containers such as fine-mesh bags. In addition, because the cultchless oysters were singles when they attained market size, they were much less expensive to cull than oysters in clusters and were ideal for the half-shell trade.

California once had two large hatcheries, one at Pigeon Point and the other at Moss Landing, producing cultchless seed. As the seed was minute and extremely vulnerable to predators (especially crabs), it had to be grown in cages and then in trays for awhile. But this type of culture was too expensive, and the market for cultchless oysters diminished. California hatchery operators had considered producing a variety of oysters, including *C. gigas*, *C. virginica*, *C. rivularis*, and *O. edulis* (Conte and Dupuy, 1982), but both hatcheries have since gone out of business, and California no longer has an oyster hatchery.

In the past, the quality of Pacific oysters for summer eating was poor because they had large gonads. As the California waters are too cool for oysters to spawn, the gonads are retained. In recent years, the industry has been growing sterile triploid Pacific oysters, that are without gonads. These provide a high quality product

Table 1
Weight and value of landings of Pacific oysters from California ports, 1980–89.

Year	Humboldt Bay	Tomales Bay	Drakes Bay	Morro Bay	Santa Barbara	San Diego	Totals
Weight in thousands of pounds of meats							
1980	492.2	73.7	360.0	69.7	0.0	0.0	995.6
1981	480.9	61.9	357.4	49.6	0.0	0.0	949.8
1982	492.2	73.7	360.0	69.7	0.0	0.0	995.6
1983	584.2	21.6	440.1	0.0	0.0	0.0	1,045.9
1984	576.0	61.7	598.1	17.5	0.0	0.0	1,253.3
1985	482.7	23.7	700.1	2.0	0.1	0.0	1,208.6
1986	615.1	34.4	473.0	0.0	7.3	0.0	1,129.8
1987	442.5	60.2	634.9	0.0	0.0	0.0	1,137.6
1988	445.6	112.7	593.1	5.9	0.0	4.7	1,162.0
1989	682.5	185.0	550.0	38.8	1.5	0.0	1,457.8
Value in thousands of dollars							
1980	521.7	189.0	704.5	76.5	0.0	0.0	1,491.7
1981	625.0	175.7	701.6	55.8	0.0	0.0	1,558.1
1982	521.7	189.0	704.5	76.5	0.0	0.0	1,491.7
1983	937.4	56.1	706.3	0.0	0.0	0.0	1,699.8
1984	1,339.6	143.5	1,390.9	40.8	0.0	0.0	2,914.8
1985	1,221.3	60.1	1,771.2	5.2	0.4	0.0	3,058.2
1986	1,473.4	179.3	1,196.9	0.0	12.9	0.0	2,862.5
1987	1,060.0	313.8	1,606.3	0.0	0.0	0.0	2,980.1
1988	1,313.7	379.3	1,408.6	17.2	0.0	11.0	3,129.8
1989	1,968.2	622.4	1,306.1	112.7	0.0	0.0	4,009.4

during the summer and will likely become a major production item.

Oysters and Pollution

Many oyster-growing grounds in California are classified as "conditional," as they are subject to closures when E-coli counts are high. Areas around Humboldt Bay are grazed by cattle, and during heavy rains cattle wastes wash into the bay, raising E-coli counts. Public health officials consider E-coli produced by humans and cows as similar, and they often close the bay after extended rains.

In 1979, the Humboldt Bay oyster industry lost 34 harvesting days after heavy rains. Oysters are also not harvested from the bay during January, because bacteria counts are too high. The industry is interested in depurating oysters to avoid such closures (Conti and Dupuy, 1982), but although the depuration cost has been estimated at only three-fourths of a cent/oyster, no company has yet adopted this procedure.

Figure 9
Oyster racks belonging to Eureka Oyster Farms in Humboldt Bay, in 1970's. Photograph by author.

Marketing Oysters

Oysters are sold either in the shell or as meats in 8- or 10-ounce jars (Fig. 10). In 1988, the landed price for shellstock was $25–35/100 oysters. Jarred oysters are sold in many parts of the United States.

Figure 10
Washing and packing meats of Pacific oysters, circa 1992. Photograph by author.

Abalone Fishery

The principal abalone species now harvested is the red abalone, *Haliotis rufescens,* which ranges from Sunset Bay, Oreg., to Turtle Bay, Baja California. It occurs around the Farallon Islands off San Francisco, and around the Channel Islands off Santa Barbara, Los Angeles, and San Diego (Cox, 1962). It prefers open ocean salinities, has a thermal optimum of between 14° and 18°C (Leighton, 1974), and is always attached to rocks.

In northern California, the red abalone occurs from the lower intertidal zone to a depth of about 6 m (20 feet). In southern California, it occurs subtidally to a depth of 40 m (130 feet) (Leighton, 1968), but is most common from 10.5 to 21 m (35–70 feet). Red abalone up to 20 mm (3/4-inch) long commonly live under clean boulders with veneers of inarticulate coralline algae, while those 20–80 mm (3/4–3 inches) long often live in crevices. Seams, cutbacks, and ledges in rock faces with abundant algae are also optimal habitats. In northern California, abalone longer than 75 mm (3 inches) live in crevices, under large boulders, and on exposed bedrock, where sea otters are scarce. Smaller red abalone are cryptic.

Growth rates of red abalones are relatively slow. In northern California, where only sportfishing is allowed, it takes them 11.8 years to attain 7 inches (175 mm)—the minimum length at which fishermen can legally take them. In southern California, it takes them 15 years to attain the legal minimum length of 7 3/4 inches (197 mm) required for both commercial and sportfishing (Tegner et al., 1992).

Native Americans gathered abalone for both food and jewelry, and the shells are common in middens on coastal California islands and in Native American graves.

Commercial fishing began in the early 1850's, when the Chinese harvested them from skiffs, using long, hooked poles (Haaker et al., 1986). A thriving industry developed and, by 1879, commercial landings of whole abalones totaled 4.1 million pounds. As a conservation measure, California authorities banned inshore commercial harvests, and the Chinese were eliminated from the fishery. They were replaced by Japanese "sake barrel" divers who worked in deeper waters by holding their breath. Japanese hard-hat divers eventually replaced them, harvesting from yet deeper waters. Their crews consisted of a diver with a helmet, a boat operator, and a line tender (Cox, 1962). Diving usually began in early morning and continued until late afternoon, unless winds ended the operations earlier. They dominated the fishery until World War II. Caucasian hard-hat divers continued the fishery after the war (Anonymous, 1971).

In the late 1950's, new diving methods were introduced. Divers used hookah gear and wore light-weight rubber suits and swim fins. They fished from high-speed vessels termed Radon Craft that could withstand rough seas. Using them, divers were able to harvest from the remaining virgin abalone stocks around the Farallon and Channel Islands (Tegner et al., 1992). Those areas now constitute the principal abalone harvesting grounds.

The 1950's and 1960's were the peak years for abalone fishing, when about 1,000 commercial divers were harvesting a daily catch that varied from 10 to 30 dozen abalones/diver. Since then, the numbers of abalones and divers have declined and, in recent years, the state has licensed 120 abalone divers. Several years ago, nearly all divers (>95%) harvested every good weather day, but currently, only about 15 divers harvest abalones daily. The others, also licensed to harvest red sea urchins, *Strongylocentrotus franciscanus,* harvest them instead. The ages of the divers ranges into the late 40's and 50's.

Commercial divers work from boats 9 m (30 feet) long with 2.7–3.7 m (9–12 feet) beams. The length of hoses that divers use with their hookah gear is 170 m

(600 feet). In addition to their rubber suits, divers wear gloves and knee pads to protect themselves from barnacles and rocks. Most boats have one diver and one lineman, but some have two divers. Divers usually work in depths of 7.5–24 m (25–80 feet), but may range to depths of 6–55 m (20–180 feet). The water where they harvest has a usual visibility of 9–12 m (30–40 feet), to a maximum of 30 m (100 feet), and temperatures of about 12°C in winter to 22°C in summer.

Divers remain underwater harvesting for 4–8 hours a day. They observe many undersized abalone as they search for legal ones (7¾ inches long for red abalone and 6 inches for other species), which they hold in a bag. The daily catch, about 3 dozen abalone/diver, has been stable for about the past 10 years. They used to put abalones on the boat decks with wet sacks over them, but because markets now want them alive, the divers keep them in containers in the water beside their boats. When the divers and tenders go out to islands and remain there harvesting all week, they sleep on the boats at night.

In 1993 divers were paid an average of $260/dozen abalone, with the highest price being $350/dozen.

State-wide landings averaged over 1.8 million pounds (whole weight)/year with a high of 3.5 million pounds in 1935 and a low of 90,000 pounds in 1942 (Tegner et al., 1992). Catches began declining in south-central California in the late 1960's. In 1990, total landings of red abalone were about 169,000 pounds (meat weight). California landings for all abalones (black, *H. cracherodii*; green, *H. fulgens*; red, *H. rufescens*; pink, *H. corrugata*; white, *H. sorenseni*; threaded, *H. assimilis*; pinto, *H. kamtschatkana*; and flat, *H. walallensis*) declined from nearly 2 million pounds of meats in 1968 to about 233,000 pounds in 1990. The declines were caused by a substantial commercial effort, heavier predation by increasing numbers of sea otters, more pollution-caused area closures, and competition with a growing sportfishery (Haaker et al., 1986).

In northern California, the catch is restricted to "free" sport divers (using mask and snorkel), and the season is split into two parts—April through June and August through November. In central California, scuba gear can be used (Fig. 11), and the season lasts for 10 months. The daily possession limit in California is four red abalone, with a minimum shell size of 7 inches (175 mm). Abalone can be taken only by tools similar to a tire iron, and each fisherman must have in his possession an accurate fixed-caliber measuring gauge.

In northern and central California, the number of shore pickers and sport divers increased more than fourfold, and the sport catch from Marin, Sonoma, and Mendocino counties in northern California increased twofold between 1965 and 1980 (Ault, 1985).

In southern California, the number of abalone sport divers increased fourfold and their catch twofold, from 1965 to the early 1980's (Ault, 1985). The number of party boats designed for scuba diving has also increased. The boats now have sufficient range to take sport divers to all offshore islands in southern California. Considerable friction exists between commercial and sport divers.

Tegner et al. (1992) suggest the sport and commercial fisheries may end if the sea otter's range is not contained. They advocate 1) immediate reduction in the sport harvest through a reduced bag limit, or seasonal closure coupled with continuing monitoring, or both; 2) further reduction of commercial effort and establishment of mechanisms to prevent illegal harvests on the north coast; and 3) research to refine models for stock management and to understand the ecological changes taking place in abalone habitat, caused by the sea urchin fishery on the north coast. Enhancement of wild populations with hatchery stocks has been considered, but this is a slow process.

Figure 11
Sport scuba diver gathering abalones at Catalina Island, circa 1960's. From Anonymous (1971).

Management

Besides imposing a minimum size for abalones, the state is now trying to reduce the number of licensed abalone divers from 120 to 80, and licensed sea urchin divers from 600 to 400. Any divers who wish to leave either fishery can sell their licenses to new entrants. In 1993, the selling price was $10,000. To reduce the number of divers, the state has ruled that an entrant has to purchase two licenses from retiring license holders.

Figure 12
Newly-designed rectangular cage used to grow abalone from 39 mm to market size, Crescent City, California (Abalone International, Inc.), circa 1992. Photograph by Chris Van Hook.

Mariculture

Because abalone stocks have diminished since the 1960's, and the market for them is strong and will probably increase, some abalone farms have recently been developed. Sixteen abalone culturists were once registered (Ebert, 1992), but only three farms are engaged in full-scale production. Hatcheries produce mostly red abalone (95%), with some green and pink abalones, and they market them at lengths of 50–65 mm (2–2.5 inches). Abalones are grown to 8–10 mm in tanks, then are transferred to larger tanks or raceways. After 20–28 months, the kelp-fed abalones are 50–65 mm long and are ready to sell (McMullen and Thompson, 1989; Shaw, 1991) (Fig. 12). In 1989, 315,000 of the 50–65 mm abalones were marketed alive, and in 1992 the largest farm produced 120,000 pounds (whole weight). Farms sell them primarily to markets in Tokyo and Hong Kong and secondarily to upscale restaurants on the U.S. west and east coasts. The farms are just beginning to develop a market for fillets of the small abalones.

Pismo Clam Fishery

The pismo clam is rare-to-common along the Pacific coast from Monterey Bay, Calif., to Bahia Magdalena, Baja California. It occurs from the low intertidal zone, to a depth of 10–25 m (33–82 feet) (Fitch, 1953), burrowing to depths of 52–156 mm (2–6 inches) in sandy substrates (Armstrong, 1965). The most productive areas have extensive upwelling of cool oceanic water that brings nutrients essential for phytoplankton blooms (Coe and Fitch, 1950).

Authorities ruled that, as of 1986, clams must be at least 5.0 inches (125 mm) long in Monterey County and north, and 4.5 inches (114 mm) long in San Luis Obispo County and south, before they can be harvested. On most beaches, pismo clams attain the legal minimum in 5–9 years, while at Pismo Beach, they do so between ages 7 and 8 (Collins[2]).

Pismo clams have been gathered and used over the past 2,000 years, as shown by their shells in coastal middens. Native Americans ate the meats and used the shells as ornaments or as household aids for digging or scraping (Anonymous, 1971).

In the early 1900's, some fishermen harvested them commercially, using horse teams to pull plows in areas from Pismo Beach to Imperial Beach. The clams were loaded in wagons and fed to hogs and chickens (Anonymous, 1971).

During 1916–47, commercial diggers harvested a total of 6.25 million pounds of pismo clams (whole weight) (Fitch, 1954). This represents 78,000 bushels, assuming a weight of 80 pounds/bushel. The most productive year, 1918, yielded about 60,000 pounds (8,000 bushels), but then landings declined sharply (Table 2). To protect the resource, state authorities have prohibited commercial digging since 1947.

[2] Collins, R. 1993. Aquaculture specialist, Calif. Department of Fish Game, Sacramento. Personal commun.

Sportfishermen gather pismo clams in several ways, but the most common digging tool is a six-tined potato fork (Fig. 13). The digger puts the clams in a sack attached at the waist. In deeper water, fishermen gather them by towing long-handled rakes from skiffs; when a clam is struck, a diver gathers it. In another method, a skin diver wears a face mask and lies on a paddle board. When he sees a clam siphon, he digs out the clam with a short digging bar. Wading fishermen can locate clams by moving their feet back and forth, and they also find them by looking for hydroid colonies, which often grow on the edges of the clam shells. California authorities reduced the daily state limit from 200 clams in 1911 to 10 clams in 1985.

In the 1960's, on a single weekend at Pismo Beach, an estimated 150,000 diggers were observed, and over 75,000 pounds of clams (whole weight) (940 bushels) were harvested. In a 10-week period, diggers gathered 4 million pounds (50,000 bushels) from a 4-mile stretch of beach (Anonymous, 1971).

Since 1986, sea otter predation has substantially reduced pismo clam numbers. The current number of diggers can only be estimated, but in any one day, perhaps 1,000 people are digging in the entire state, with 300–400 at Pismo Beach alone (Fig. 14) (Collins[2]).

Table 2

Annual commercial landings of pismo clams in round weight (in thousands of pounds).

Year	Calif. landings	Shipments[1]	Total
1916	220.6		220.6
1917	502.1		502.1
1918	665.7		665.7
1919	417.5		417.5
1920	299.0		299.0
1921	219.5		219.5
1922	193.5		193.5
1923	237.9		237.9
1924	293.1		293.1
1925	323.2		323.2
1926	274.3		274.3
1927	133.0		133.0
1928	125.8		125.8
1929	109.7		109.7
1930	108.9		108.9
1931	104.7		104.7
1932	110.3		110.3
1933	106.2		106.2
1934	140.7		104.7
1935	181.9	14.2	196.1
1936	209.8		209.8
1937	224.0		224.0
1938	214.6		214.6
1939	192.7		192.7
1940	167.5		167.5
1941	168.8	86.7	255.5
1942	93.6	727.8	821.4
1943	45.9	4,526.1	4,572.0
1944	34.5	11,719.8	11,754.3
1945	26.1	53,414.2	53,440.3
1946	69.2	11,408.5	11,477.7
1947	60.6	1,279.7	1,340.3

[1] From south of the international boundary. Cleaned weights reported on fish receipts have been multiplied by 8 to supply round weights given here (Bureau of Marine Fisheries, 1949).

Pacific Littleneck Clam Fishery

The Pacific littleneck clam ranges from Alaska's Aleutian Islands to Cape Lucas, Baja California. In California, they are common at Malibu Point and San Mateo Point, south of San Clemente, but less so at other points of central and northern California. They also occur in Bodega and Tomales Bays. Littlenecks grow in coarse,

Figure 13

Sport digger at Pismo Beach checking the size of a pismo clam in a measure attached to his fork to determine whether it is legal to keep, circa 1993. Photograph by Sandra Owen, California Dep. Fish Game.

Figure 14
Sport diggers at Pismo Beach harvesting pismo clams, circa 1993. Photograph by Sandra Owen, California Dept. Fish Game.

sandy mud of bays, sloughs, and estuaries (Fitch, 1953). On the open coast, they occur in nearly all areas where rocky points or reefs consist of small cobbles over coarse sand (Anonymous, 1971), and they often occur on small beaches that exist in pockets on rocky shorelines, or in small patches of larger beaches (Fraser and Smith, 1928). The best beaches for littleneck clams have coarse sand or fine gravel mixed with mud, stones, or shells. Apparently, they do poorly in fine sand.

Littlenecks are most abundant in the lower part of intertidal zones, and subtidally to depths of 3 m (Glude, 1978). Their maximum burrowing depth is about 15 cm. In most areas, the clams attain the legal length of 1.5 inches (38 mm) in 2 years (Anonymous, 1971).

Fishermen dug littlenecks commercially before World War II, but now nearly all beds have been overharvested, and only sport clamming is allowed. San Francisco Bay is the only large area with enough littlenecks to support a commercial fishery (Ritchie, 1977), but the clams are polluted and none are harvested.

Sportfishermen harvest littlenecks in intertidal areas at low tide, with hand rakes or shovels (Anonymous, 1971). Authorities limit the catch to 50 clams/person/day, which yields about 1.5 pounds of edible meat.

A major problem of the clam sportfishery is the discharge of sewage and animal wastes into estuaries and nearshore marine waters (Ritchie, 1977). Although authorities have issued a coastwide warning citing the dangers of paralytic shellfish poison (PSP) in coastal bivalves from 1 May to 31 October, the poison has not been a problem with littlenecks.

No one cultures Pacific littlenecks in California. Ritchie (1977) concluded that clam farming should be permitted in California in those areas where no other endemic clam species are present. Such culture would involve some form of beach rehabilitation, the planting of hatchery produced seed, or both. Since residents in many areas might object to using public lands for private benefit, the potential for littleneck clam culture in California is low.

Other Clam Fisheries

California's clam stocks have never been large (Bureau of Marine Fisheries, 1949), although before World War II, a small commercial clam fishery did exist. Besides the pismo clam and Pacific littleneck, the following clams once appeared in commercial catches: Pacific razor, *Siliqua patula*; softshell, *Mya arenaria*; California venus, *Chione* sp.; fat gaper, *Tresus capax*; Pacific gaper, *T. nuttalli*; Washington clam, *Saxidomas nuttalli*; butter clam, *S. giganteus*; California jackknife clam, *Tagelus californianus*; and gourd beanclam, *Donax gouldii* (Ritchie, 1977; Schink et al., 1983). Commercial fisheries for these clams, always small through the 1950's (Schink et al., 1983), are now negligible. Pollution, commercial overharvesting, economics, and increasing harvests by sport diggers are causes for the decline.

San Francisco Bay, while polluted, is probably the only area in California with enough clams to support a commercial fishery. Dense populations of the introduced Japanese littleneck (locally termed "Manila clam"), *Tapes philippinarum*, and softshells occur in its lower intertidal zones and some subtidal areas, as well, and in the 1970's the state enacted legislation permitting a commercial fishery for them. A private corporation, which owns part of the bay's subtidal lands, and an aquaculture firm have shown interest in pursuing this possibility. Because the bay is polluted, the clams would have to be depurated before being sold for human consumption.

Little potential exists for commercial clam harvesting. While culture is possible, the stringent state regulations and economic factors may be too great to overcome. Though Schink et al. (1983) felt that in many areas residents would object to use of public land for private benefit or profit, they advanced two positive arguments for culture operations, namely that intertidal and subtidal lands could be leased from the state, and that procedures were available to obtain leases for land-based culture, similar to those to obtain oyster leases. Farming could be limited to areas where native clams did not exist.

Two companies have attempted to culture clams in Humboldt Bay. The Coast Oyster Company grew Japanese littlenecks in cages in intertidal zones on its leased areas. The clams attained market size and were sold, but fouling of cages, crab predation, and labor costs forced the company to quit. The other company, Kuiper Mariculture, Inc., is currently producing over 70 million seed of Japanese littlenecks/year in floating net cages. This is only a nursery operation. The company sells seed littlenecks, oysters, and mussels to U.S. and European growers.

Recreational clam fishing is substantial, but is restricted to bays free of pollution, such as Humboldt, Bodega, and Tomales, and to Humboldt and Del Norte county beaches with Pacific razor clams. California manages its sport clam fisheries by placing catch limits on all important species and setting size limits for the pismo clam, Pacific littleneck, soft clam, and California venus. Authorities close seasons to conserve the pismo and Pacific razor clams.

The major problem facing the sport clam fishery is pollution. In the past, harbor dredging and marina development have harmed clamming areas, but both have now been curtailed (Schink et al., 1983).

The California State Department of Health evaluates oyster-growing areas for the certification required under the National Shellfish Sanitation Program, but usually does not declare areas safe or unsafe for recreational clam harvests. If an area such as San Francisco Bay is grossly polluted, county health departments establish a permanent quarantine. In other areas, county health departments post notices on unsafe beaches. Some localized areas are closed to shellfish harvests because of industrial pollution. For example, the northern quahog, *Mercenaria mercenaria*, was introduced into Colorado Lagoon near the City of Long Beach, a few miles south of Los Angeles, and a reproducing stock was established (Crane et al., 1975), but harvesting is restricted because the lagoon is polluted by lead (Schink et al., 1983).

Another problem for the recreational clam fishery is overharvesting. The number of clam diggers is increasing and the resource is limited.

Mussel Fishery

The California mussel, which grows to a length of 25 cm, occurs in massive beds on surf-exposed rocks and wharf pilings on the outer coast, and subtidally to depths of 24 m from Alaska's Aleutian Islands to southern Baja California. The bay mussel, which grows to a length of 10 cm, is common in bays and sheltered areas, often in clusters attached to wharf pilings, in low intertidal zones, and subtidally to 40 m, from the Arctic Ocean to Isla Cedros, Baja California (Morris et al., 1980). The California mussel differs from the bay mussel in having up to 12 broad radial ribs; the exterior of the bay mussel is unmarked by ribs.

The California mussel has a much narrower geographic distribution and is adapted to fewer habitats than the bay mussel. The bay mussel prefers quieter water, lives lower in intertidal zones, and is a common fouling organism on buoys and floats and in seawater piping systems on ships and in seaside laboratories. On the California coast, it sometimes grows on coastal rocks and wharf pilings, but only in mixed populations with the California mussel. Small individuals can withstand wave impact about as well as the California mussel, but larger ones cannot, owing to a weaker attachment (Morris et al., 1980).

McDonald and Koehn (1988) reported that the bay mussel in California is not *Mytilus edulis* as found in the Atlantic Ocean. Mussels in southern California are similar to *M. galloprovincialis* from the Mediterranean Sea, which may have been introduced to southern California. Mussels in Oregon and Alaska are similar to *M. trossulus* from the Baltic Sea and parts of eastern Canada. In central and northern California, *M. trossulus* occurs with *M. galloprovincialis* and their hybrids. In Humboldt Bay, there are two distinct types of blue mussels, one oval and deep cupped and the other wedge shaped and flatter. Possibly one is *M. trossulus* while the other is a hybrid of *M. galloprovincialis* and *M. trossulus* (Richards and Trevelyan, 1992).

Both the California and bay mussels were once landed commercially in California. Over 69,000 pounds (1,200 bushels) were landed in 1927, but most areas have since been closed by the California State Board of Health, because mussels can carry PSP. After 1927, production for human consumption declined sharply, but between 1963 and 1976, from 47,336 to 111,799 pounds (785 to 1,900 bushels) were landed, mostly to sell as fish bait (Table 3). No mussels can now be sold for human consumption from 1 May to 31 October, because PSP may be present.

Mussel culture is emerging as a new industry in California, to meet a growing market demand. In Tomales Bay, four mussel farming companies each employ 5–10 workers. To collect natural sets, workers hang ropes from longlines supported by floats and they put the seed in plastic net socks hung from the longlines (Shaw and Hassler, 1988).

A somewhat similar method is used by Carlsbad Aquafarms in Aqua Hedionda Lagoon (originally carved out as a water source for the San Diego Gas & Electric Co.) near Carlsbad, Calif., 20 miles north of San Diego. The company's three employees fill 8-foot long mesh socks with mussels of all sizes and hang them from anchored lines in the lagoon. Empty 2-gallon plastic jugs keep the lines floating. When most mussels attain market size, workers take the socks ashore and put them in sorting machines that separate the commercial-sized mussels from the smaller ones. Mussels ready for market are depurated in a series of 10 fiberglass tanks that receive a constant flow of water for 48 hours. The tanks can hold up to 4,000 pounds (about 65 bushels) of mussels. One problem with this growout system is that the small mussel seed move around almost like snails, fall off the socks, and are lost (Glenn, 1988). In the past 5 years, the company has been growing *M. galloprovincialis*, purchasing the seed from Kuiper Mariculture, Inc., in Humboldt Bay.

Another company, Ecomar, the largest mussel producer in the state, gathers mussels from the legs of oil drilling platforms in the Santa Barbara channels. The company harvests wild bay mussels from the legs and also plants seed Mediterranean mussels on them. It sends a broodstock of Mediterranean mussels to a hatchery in Oregon, which spawns and obtains seed from them, and sells it to Kuiper Mariculture, Inc., which grows it to a length of several mm and then sells it to Ecomar. Its workers put the seed in socks and wrap them around the platform legs. When the mussels attain maturity, divers scrape them and any wild mussels off the legs, using suction hoses to convey them to the surface. A crew of eight can harvest 3,500 pounds (about 60 bushels) of mussels a day. Workers ashore clean, package, and ship the mussels fresh to markets (Shaw and Hassler, 1988). The company usually has two full-time divers and two workers who pack mussels for sale, but at peak harvest times it has employed four divers and six packers.

In 1989, the mussel farms landed 162,958 pounds (2,700 bushels) of mussels having a value of $153,463 (Table 4). Total state production was 1,370,000 pounds (23,000 bushels) (Conte, 1990).

A limited sport fishery for mussels now exists during the open season, from 1 November to 31 April. People usually remove the mussels from rocks and pilings by hand; authorities allow a daily harvest of 25 pounds/person.

Table 3

Annual landings in pounds of mussels in California. A bushel of mussels weighs about 60 pounds.

Year	Landings	Year	Landings
1916[1]	53,799	1936	750
1917	69,042	1937	1,490
1918	49,154	1938	150
1919	35,095	1939	1,800
1920	33,112	1940	100
1921	9,196	1942	50
1922	43,872	1946	639
1923	60,026	1947	530
1924	49,223	1963[2]	105,118[3]
1925	25,942	1964	67,827[3]
1926	14,614	1965	69,403[3]
1927	29,631	1966	102,644[3]
1928	1,610	1967	95,110[3]
1929	1,028	1968	91,472[3]
1930	325	1969	101,668[3]
1931	1,800	1972[4]	111,799[3]
1932	230	1974[5]	81,642[3]
1933	465	1975[6]	53,691[3]
1935	10	1976[7]	47,336[8]

[1] Years 1916–47 from Bureau of Marine Fisheries (1949).
[2] Years 1963–69 from Frey (1971).
[3] Used for bait.
[4] Pinkas (1974).
[5] McAllister (1976).
[6] Pinkas (1977).
[7] Oliphant (1979).
[8] 2,357 pounds for human consumption; rest for bait.

Table 4

Weight (pounds) and value (dollars) of mussels landed from mariculture. A bushel of mussels weighs about 60 pounds.

Year	Tomales Bay		Santa Barbara		San Diego		Total	
	Weight	Value	Weight	Value	Weight	Value	Weight	Value
1986	28,398	22,718	306,219	244,975	0	0	334,617	267,693
1987	22,823	23,736	263,866	274,421	0	0	286,689	298,157
1988	26,802	33,504	41,957	37,437	83,000	90,000	151,759	160,941
1989	19,431	24,290	143,527	129,173	0	0	162,958	153,463

Source: Rob Collins, Aquaculture Specialist, Calif. Dep. Fish Game, Sacramento. Personal commun.

Giant Rock Scallop Fishery

The giant rock scallop ranges from the Queen Charlotte Islands, British Columbia, to Punta Abreojos, Baja California (Morris et al., 1980). In California, it is common in rock crevices along exposed outer coasts, on pilings, underneath floats, and from the low intertidal zone, to depths of 50 m.

As juveniles, rock scallops resemble ordinary scallops in shape and in their ability to swim by clapping their valves together. At rest, juveniles usually attach temporarily to hard substrates by byssal threads (Morris et al., 1980), but when slightly over 25 mm in diameter, they attach permanently to substrates (Fitch, 1953).

Rock scallops are not fished commercially in California, but a mariculturist in Drakes Estero cultures them as a secondary crop. He collects juvenile scallops off his harvested oysters, and then grows them to market size in pens supported off the bottom (Leighton, 1991).

State regulations limit the catch for sportfishermen to 10 scallops/day, with no size limit. In northern California, rock scallops usually are found near shore in shallow water, where abalone fishermen take them at low tide. In southern California, sport divers usually harvest them along breakwaters and in rocky areas of the outer coast (Fitch, 1953). In Humboldt Bay, divers collect them off bridge pilings (Malachowski, 1987).

The rock scallop has excellent potential for being cultured. Techniques have been developed to collect natural sets, and hatchery methods have been developed to produce the seed. Juveniles have been grown to adulthood in cages or attached to panels or sheets of asbestos construction board, concrete, and plastic (Leighton and Phleger, 1977). Adults are sometimes marketed at $1.00 each. As it takes about 9 adductor muscles, averaging about 1.75 ounces (50 g) each to make a pound, scallop meat is valued at about $9.00/pound (Leighton, 1991).

Shellfish Preparation

In California, Pacific oysters are usually eaten on the half-shell or barbecued and eaten with barbecue sauce. Few are eaten in stews, as is common on the U.S. east coast. In restaurants, abalone meat is sliced into 1/4-inch steaks, which are pounded with a hammer to tenderize them, dipped in egg batter and crumbs, and fried. Small cultured abalones are shucked, then the meat is tenderized, covered with a mixture of flour and eggs, sauteed for 10 seconds in butter or oil, placed back in the shells, and served (Shaw, 1991). Abalone shells are used in jewelry and as inlays in musical instruments. Pismo clams are eaten raw, fried, or in chowders. Mussels are steamed in water or wine. Sport divers who bring scallops home usually poach or fry them.

The Future

California produces about 16% of the oysters landed on the west coast of North America, a consistent percentage since 1977. Although the demand for west coast oysters has been good because oyster production in Chesapeake and Delaware Bays has been low, California production will probably not increase in the near future, since the present growing areas are near maximum carrying capacity, and no additional space is available.

Areas where oysters are grown should be maintained and protected. As the state's population grows and more people move into coastal zones, the potential for more domestic pollution, loss of marshlands, and more harbor development increases. The spread of pollution threatens the entire shellfish industry. California has experienced extensive urban growth in this century, and 85% of its potentially productive shellfish waters have been closed by pollution. Shellfishing areas are also being closed due to red tide for longer periods. It is hoped that the threats can be controlled, and a viable oyster industry can be maintained in the future.

The mussel fishery has begun to obtain some of its seed from a hatchery. However, it will likely remain small.

The California shellfisheries will probably remain fairly stable, as expansion does not look promising. Possibly, a few more small shellfish farms like the abalone farms might develop, but suitable space with clean water is becoming harder to find. As competing groups seek to use such space, shellfish farming permits will always be difficult to obtain. Although unfavorable publicity related to such problems as PSP and domoic acid in shellfish may make it more difficult to market shellfish products in California, people will continue to desire them if assured they are safe to eat.

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Molluscan Fisheries in Oregon: Past, Present, and Future

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ABSTRACT

In Oregon, a number of small rivers enter the Pacific Ocean and form estuaries that are habitats for most of the mollusks harvested or cultured. The native (Olympia) oyster, *Ostreola conchaphila*, once was harvested by Native Americans and later by European settlers into the 1800's. The Pacific oyster, *Crassostrea gigas*, was introduced in 1934. Growers use a variety of methods for culturing oysters. They usually spread seed on the bottoms of estuaries, but in soft bottoms they use horizontal lines, sticks, or trays, or lines hung from rafts. They harvest the oysters by dredging, hand gathering, or hoisting the trays or lines. Production was highest at 924,800 gallons of meats in 1940, but from 1954 to 1990 it ranged between 21,000 and 68,000 gallons. A hatchery established at Netarts Bay in 1979 annually produces several billion eyed larvae of oysters; Manila clams, *Tapes philippinarum*; and bay mussels, *Mytilus trossulus*, for growers from Alaska to Mexico. Commercial and sport fishermen harvest several species of clams. Cockles, *Clinocardium nuttalli*, account for half of the clam landings, followed by butter clams, *Saxidomus gigantea*; littleneck clams, *Protothaca staminea*; and gaper clams, *Tresus capax*. Some razor clams, *Siliqua patula*, also are harvested. Recreational clam digging is becoming more important, with between 300 and 900 people digging them a day. Some 40,000 pounds of sea mussels, *M. californianus*, are landed each year, and *M. trossulus* is cultured in small quantities. Boats began harvesting weathervane scallops, *Patinopecten caurinus*, in 1981, using New Bedford, Mass., scallop dredges and modified shrimp nets, and the stock lasted until 1990. The best year was 1981, when 16.8 million pounds of meats were landed.

Introduction

Mollusks produced in Oregon have included oysters, clams, mussels, scallops, squid, and octopi. Located on the U.S. west coast, Oregon is bordered by the State of Washington to the north and the State of California to the south. Oregon has about 300 miles of Pacific Ocean coastline, which varies from steep cliffs and rocky shores to sandy beaches. The Columbia River, with its large estuary, forms a natural border between Washington and Oregon (Fig. 1). A number of smaller coastal rivers meet the Pacific Ocean and form small estuaries that are important habitats for the majority of mollusks gathered or cultured in Oregon.

Oysters

Oregon's native oyster, *Ostreola conchaphila*, commonly called the Olympia, California, shoalwater, rock, or Yaquina Bay oyster, once ranged from southeast Alaska to Baja California, in estuaries, bays, and sounds (Fitch, 1953). Shells found in Native American kitchen middens show that they were an important food for coastal tribes (Barret, 1963).

According to old and unpublished letters and newspaper articles from the Oregon Historical Society collection in Portland, white settlers led by Captain Collins discovered native oysters in Yaquina Bay, Oregon, in 1852. Bancroft (1888), in his history of Oregon, stated: "On the 28th of January the schooner 'Juliet', Captain Collins was driven ashore near Yaquina Bay, the crew and passengers being compelled to remain upon the stormy coast until by aid of an Indian messenger horses could be brought from the Willamette to transport them to that more hospitable region. While Collins was detained which was until the latter part of March he occupied a portion of his time exploring Yaquina bay . . . ."

On 6 April, 1852, the *Oregon Statesman* newspaper reported: "Capt. Collins, of the schooner Juliet, who

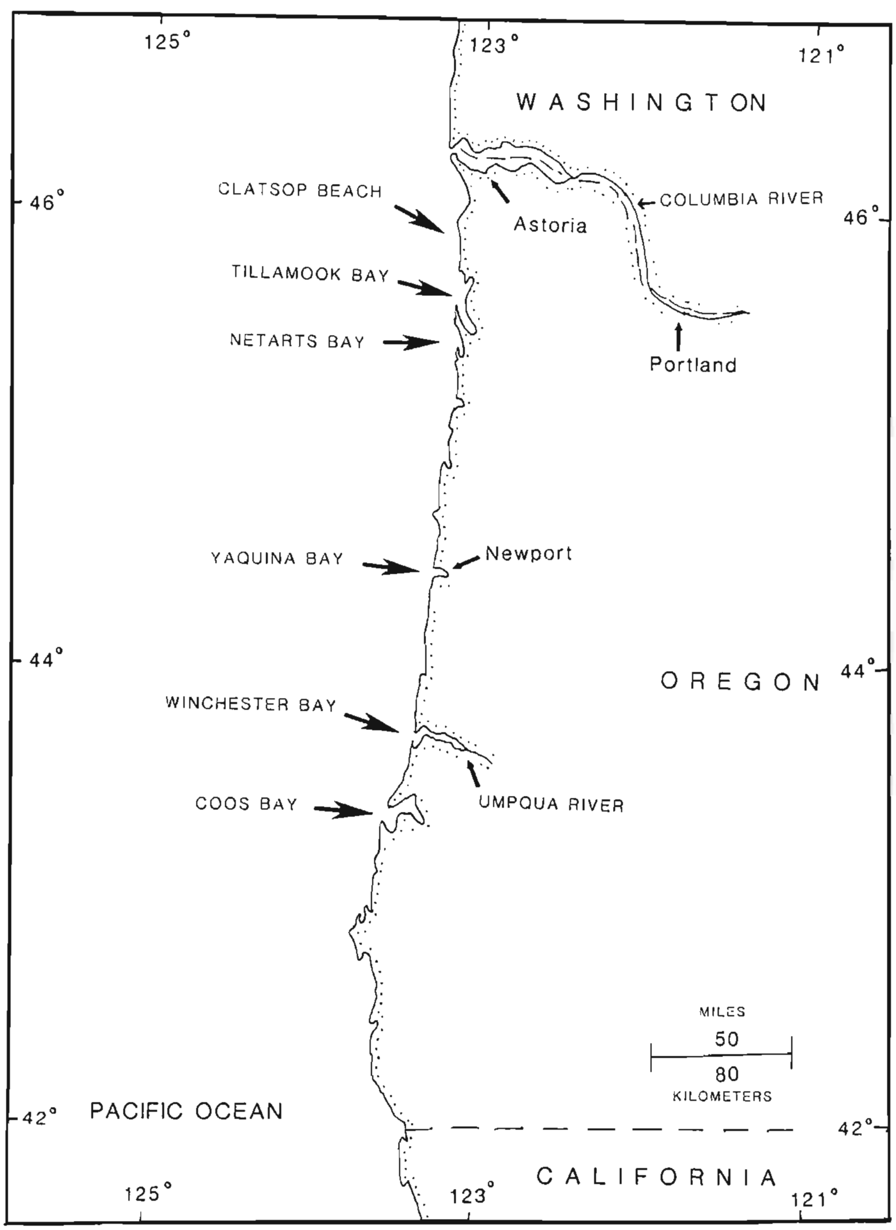

Figure 1
The Oregon coastline.

visited Yaquina Bay during his captivity, informs us that he found there a fine river, navigable for vessels drawing six or eight feet of water a distance of twenty miles. But from the appearance he deemed the inlet to be a bad one. He says that the river abounds with oysters, clams, and fish of all kinds. The land around is level and highly productive. The timber has been nearly all destroyed by fire. None of the land in the vicinity is claimed yet."

By 1854 oysters were being harvested in commercial quantities in Yaquina Bay. By 1864 the harvesting was organized, and shiploads of oysters were being sent to California, where the market for them was good. Fishermen in boats harvested them with tongs, the same method used on the U.S. east coast, and by hand (Fig. 2, 3). Several schooners, operated by a Captain Winant, shipped oysters from Yaquina Bay to San Francisco (Bancroft, 1888) (Fig. 4). The *Oregonian* newspaper stated on 1 October, 1864: "A handsome little town is just beginning on Yaquina Bay. The principal trade now is in oysters with the San Francisco market."

In 1868 several oystermen in the area organized an association to regulate oystering (Washburn, 1900). The first indication of oyster depletion in Yaquina Bay was from a statement in the *Oregonian* dated March 3, 1882:

Figure 2
Fishermen tonging native oysters in Yaquina Bay, late 1800's. Source: Oregon Historical Society.

Figure 3
Fishermen harvesting native oysters from an intertidal flat in Yaquina Bay, turn of the century. Source: Oregon Historical Society.

Figure 4
Native oysters being transported from Yaquina Bay, turn of the century. Source: Oregon Historical Society.

"The business of oystering was carried on some years ago until the native oyster beds were exhausted. A few years rest, however, allowed the growth of a new crop. The Yaquina oyster is about double the size of the Puget Sound oyster."

Toward the end of the century, oyster harvesting was no longer as profitable as it had been. In 1899, U.S. Commissioner George M. Bowers reported that Yaquina Bay had the only oyster grounds in Oregon, and total production was 591 sacks weighing 100 pounds each, valued at $1,625.00. Oystermen, who by then were well organized, imported the eastern oyster, *Crassostrea virginica*, from the U.S. east coast. They were taken first to California by railroad in wooden sugar barrels. According to data on file at the Oregon Historical Society, 25 barrels of eastern oysters were planted in Yaquina Bay on 7 November, 1896, about 7.5 miles inland from the ocean. Two varieties were planted—long, slender oysters from eastern rivers; and oval, fan-shaped, ribbed oysters from Prince's Bay (in Raritan Bay), New York. Some *C. virginica* were spawned artificially in 1897 and 1898. The larvae were released in the Bay but did not survive.

Fishermen transferred some eastern oysters 9 miles (14.5 km.) upriver, hoping the warmer water and lower salinity would induce some recruitment. During the spawning season, they built a shallow-water float, and the sun warmed the water in it up to 20°C. The oysters spawned, but few larvae survived and set. The Prince's Bay variety grew well and were excellent oysters, but no natural recruitment occurred, so spat had to be imported every year from the east coast (Washburn, 1900).

The Oregon oyster industry supported few people from the turn of the century to the introduction of the Pacific oyster, *Crassostrea gigas*, from Japan. The areas in Yaquina Bay producing native oysters were surveyed by a Mr. Wygant in 1908; 38.8 acres were private oyster beds, and 102 acres were natural oyster grounds (Fig. 5). Beginning in 1919, commercial quantities of Pacific oysters were shipped to the west coast. They were first introduced in Washington, and it was not until 1934 that they were introduced in Oregon (Steele, 1964). A test planting of 65 cases was successful, and over the years the number of cases planted increased (Fig. 6). By 1960, a total of 94,951 cases of oyster seed had been planted in Oregon (Steele, 1964).

In the relatively cool waters of Oregon, with temperatures ranging from 8 to 14°C, Pacific oysters do not reproduce naturally. In 1968 the first pilot oyster hatchery for artificial spawning and larval rearing was con-

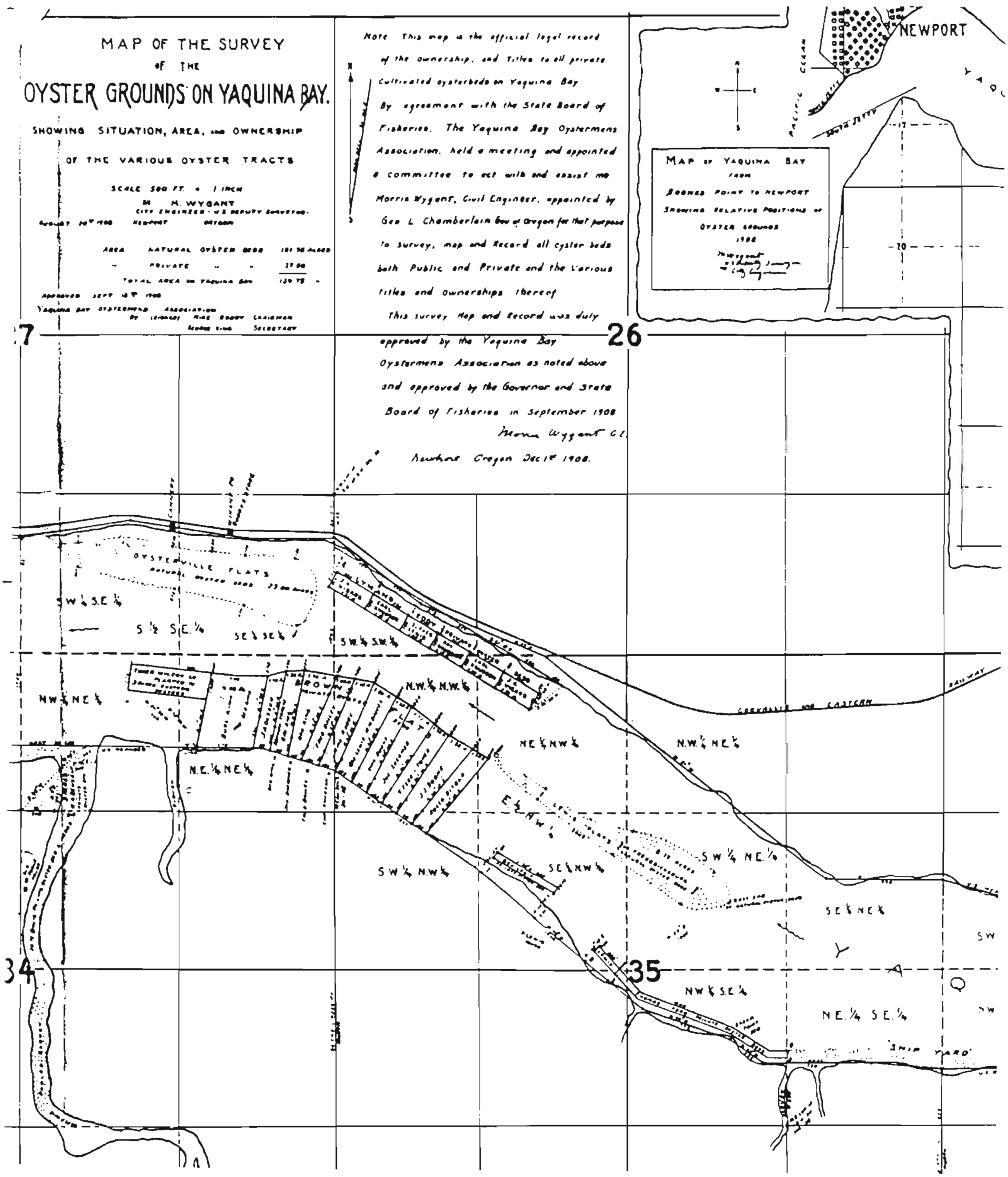

Figure 5
Oyster grounds in Yaquina Bay, according to Mr. Wygant's survey, 1908. Source: Oregon Historical Society.

Figure 6
Pacific oysters growing on a tidal flat in Yaquina Bay, 1935. Source: Oregon Historical Society.

structed at Oregon State University's Hatfield Marine Science Center, Yaquina Bay. Once the hatchery techniques for conditioning oysters for spawning, rearing larvae, and remote setting were established, growers no longer had to depend on the costly importation of spat from Japan (Breese and Malouf, 1975; Breese, 1979).

An oyster hatchery[1] constructed by Lee Hansen has operated at Netarts Bay, Oreg., since 1979 (Fig. 1). The hatchery, which has been enlarged over the years, currently supplies eyed larvae to oyster growers from Canada to Mexico. It produces several billion eyed larvae annually, including several species of oysters, Manila clams (Japanese littlenecks), *Tapes philippinarum*; and bay mussels, *Mytilus trossulus* (formerly *Mytilus edulis*). It operates from March to October and is staffed by two full-time and one part-time employee. The eyed larvae are sold in lots of one million and cost $100/million larvae. The eyed larvae are shipped to oyster growers, and each grower has his own setting tanks where the eyed larvae set on cultch and metamorphose.

Growers use a variety of culture methods, depending on the type of ground at the oyster farm. Usually, they spread seed on the bottom of the estuary, but in soft-bottom areas they use horizontal lines, stick culture, or elevated culture such as trays or lines hung from rafts. They harvest oysters by dredging, hand gathering, or hoisting the trays or lines.

Fresh oysters are sold locally in the shell or shucked, and if shipped, they are packed into jars or other containers. Oysters are also frozen or smoked. Prices vary from $2.50 to $3.50/dozen in the shell, depending on size and type. The price for a gallon of shucked oyster meat is $24–30. Oregon production hit its peak in 1940,

[1] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1
Total oyster meat production and estimated value at the fisherman's level, 1928–90 (ODFW Annual Reports).

	Oyster meats			Oyster meats	
Year	Gallons	$ Value	Year	Gallons	$ Value
1928	432		1960	60,000	546,000
1929	9,000		1961	39,000	355,000
1930	8,177		1962	61,000	555,000
1931	5,993		1963	43,000	396,000
1932	2,476		1964	32,000	294,000
1933	29,750		1965	29,412	271,000
1934	32,300		1966	41,716	382,000
1935	18,800	131,600	1967	71,625	380,000
1936	36,800	257,600	1968	58,034	453,000
1937	97,100	679,700	1969	66,146	451,000
1938	203,800	1,528,500	1970	35,064	274,000
1939	215,300	1,614,800	1971	34,863	319,000
1940	924,800	6,936,000	1972	21,965	351,000
1941	560,800	4,206,000	1973	24,759	379,000
1942	137,500	1,031,300	1974	29,191	526,000
1943	114,970	862,300	1975	26,642	425,000
1944	509,900	3,824,300	1976	20,768	370,000
1945	575,500	4,316,300	1977	29,217	424,000
1946	130,200	976,500	1978	30,146	451,000
1947	78,800	551,600	1979	27,756	460,000
1948	12,000	90,000	1980	29,398	527,000
1949	64,000	512,000	1981	33,730	607,000
1950	135,000	1,080,000	1982	37,085	675,000
1951	95,000	836,000	1983	30,892	575,000
1952	97,000	854,000	1984	48,030	917,000
1953	82,000	723,000	1985	37,434	723,000
1954	51,000	439,000	1986	37,554	736,000
1955	62,000	558,000	1987	40,706	810,000
1956	68,000	612,000	1988	38,449	777,000
1957	50,000	450,000	1989	39,985	890,000
1958	61,000	549,000	1990	25,293	584,000
1959	74,000	666,000			

at 924,800 gallons, but from 1954 through 1990 production has ranged from about 22,000 gallons selling for $351,000, to 74,000 gallons selling for $666,000 (Table 1).

All oyster-growing areas are leased from the state. According to the Oregon Department of Agriculture's annual report, a total of 3,568.63 acres were being used for oyster production at the end of 1991. Most were in Tillamook Bay, with 2,521.84 acres, followed by Yaquina Bay, with 390.86 acres, Coos Bay, with 240.04 acres, Netarts Bay, with 224.89 acres, and the Umpqua River, with 191.00 acres. The state collected a total of $7,895.82 in user fees from the leases in 1991. The Tillamook Bay acres are farmed by five oyster companies, the Coos Bay grounds by three companies, and Netarts Bay, Yaquina Bay, and the Umpqua River by two companies each. The most commonly cultured oyster is the Pacific oyster, but small quantities of eastern; Kumamoto, *Crassotrea sikamea*; European flat, *Ostrea edulis*; and Suminoe, *C. ariakensis*, oysters are also produced for an annual total of 16,970 gallons of oyster meats in 1991.

Records kept by the Port of Alsea, and articles in the *Waldport Record* newspaper, described oyster farming in Alsea Bay from 1948 through 1951. According to a 14 April 1948 *Waldport Record* article, 300 boxes of oyster seed from Japan were planted on mud flats in Alsea Bay. One month later, the newspaper reported that the young oysters were doing well. The Bay City Oyster Company, holder of the Alsea Bay oyster grounds lease, planted more seed and hoped to obtain harvestable oysters in 2–3 years. Logging up the Alsea River, however, exposed soil, and subsequent heavy rains caused silt to flow into Alsea Bay, thus damaging the promising oyster growing area. According to a 13 December 1951 *Lincoln County Times* article, the company surrendered the lease because silting had killed the oysters.

Some oyster-growing areas have problems with burrowing ghost shrimp, *Callianassa californiensis*, and blue mud shrimp, *Upogebia pugellensis*. Their burrowing activity stirs up mud and the oysters become silted over. To kill the shrimp, some growers have sprayed Sevin on oyster grounds during low tides. However, since 1984, its use on Oregon oyster grounds has been forbidden. Small oysters are also preyed upon by rock crabs, *Cancer productus*, and some waterfowl (scaups and scoters). With the introduction of Pacific oysters, a flatworm, *Pseudostylochus ostreophagus*; a copepod, *Mytilicola orientalis* or "red worm"; and an oyster drill, *Tritonalia japonica*, were also introduced and have become pests (Sindermann, 1974). The Atlantic slippersnail, *Crepidula fornicata*, a fouling organism, was introduced with oyster shipments from the U.S. east coast at the end of the last century. Various sponges, barnacles, mussels, and macroalgae also foul the oysters.

As the human population has increased, parts of estuaries have become polluted with industrial wastes, especially pulp mill effluents and raw sewage (Gunn and Saxby, 1982). Dairy farming at Tillamook Bay has caused high coliform counts in oyster-growing areas because of runoff from surrounding land, especially during the rainy season. Since 1952, the Oregon Department of Health has had a coliform monitoring program in place. When coliform counts exceed 70/100 ml, the estuary is closed to all commercial shellfish harvesting until the count falls below that level.

The Department of Health also monitors toxic algal blooms in areas where shellfish might become toxic. When a bloom reaches a certain count, the Department issues warnings to inform the public of the health risk involved in eating contaminated shellfish. Long-term closures can be costly for affected oyster farmers.

Clams

Commercial and sport fishermen harvest several species of bay clams. The largest are gaper clams, *Tresus capax*, that grow in muddy bottoms in subtidal and intertidal areas of most Oregon bays. Most gaper clams are harvested from Coos Bay. Mechanical harvesting has not been allowed in Oregon since 1985, so commercial fishermen use diving equipment. Sport fishermen harvest with shovels during low tides; the state bag limit is 12 gaper clams/day (Fig. 7).

Butter clams, *Saxidomus gigantea*; and littleneck clams, *Protothaca staminea*, grow in areas of fine sand or mud mixed with rocks. The bag limit set by the Oregon Department of Fish and Wildlife (ODFW) for both is 20/day for sport clammers. Cockles, *Clinocardium nuttallii*, occur close to the surface of the mud and are harvested by raking. The bag limit is also 20/day. The same bag limit applies to bend nose clams, *Macoma nasuta*, but they are harvested in smaller quantities than other types of clams. The softshell clam, *Mya arenaria*, originally from the U.S. east coast, occurs in dense numbers in muddy bottoms in the upper areas of bays. Although the bag limit is 36/day, this species is underutilized in Oregon, even by sport clammers. Nevertheless, they account for more than one-third of all clams harvested recreationally.

Gapers bring fishermen about $1.00/pound, while the other types of clams bring only $0.40–0.50/pound. Commercial landings of bay clams from 1941 to 1990 fluctuated from 306,000 pounds in 1945 to 16,315 pounds in 1974; the number of diggers ranged from 202 in 1948 to 7 in 1976 (Table 2). Cockles usually account for half the clam landings, followed by littlenecks, gapers, butters, and others.

Over the years, the number of recreational clam diggers has increased. During good low tides, from 300 to 900 clammers flock onto the mud flats to dig their bag limit. Bag limits have been cut and size requirements removed to minimize waste. According to estimates by the ODFW, the average catch/digger is from 9.2 to 18.8 clams/trip (Gaumer and McCrae, 1990).

The ODFW monitors commercial and recreational harvests closely and conducts stock surveys to regulate the harvest when necessary. They have also undertaken a long-term stock enhancement program. Laboratory-produced and imported adult Manila clams have been introduced to several Oregon estuaries over the last 15 years. Their survival, growth, and natural recruitment have been documented in annual reports prepared by the Department.

Razor clams, *Siliqua patula*, occur on open sandy beaches along the Pacific coast. Their shells have been found in kitchen middens of Native Americans (McConnell[2]). The razor clam industry in Oregon was started

[2] McConnell, S. J. 1972. Proposed study of the spawning and larval rearing of the Pacific razor clam (*Siliqua patula*). Unpubl. Proposal to Wash. Dep. Fish., Olympia.

Figure 7
Sport fishermen digging clams at Seaside, Oregon, 1910. Source: Oregon Historical Society.

by P. F. Halfarty in 1894 (Nickerson, 1975), when fresh clams were marketed locally and canned for storage or shipping. Canning operations later spread to Alaska (Weymouth et al., 1925). The largest and most persistent populations of razor clams occur on the northern beaches, such as Clatsop Beach, just south of the Columbia River (Fig. 1). Clam diggers crowd the sandy beaches during minus tides to look for the shallow depressions left in the sand when clams retract their siphons. Fishermen dig them individually using special narrow-bladed shovels or tubular suction devices. Sport fishermen are allowed 24 razor clams/day. Commercial clam diggers use diving equipment and are not dependent on low tides. Landings of razor clams were reported as early as 1899, when 980,000 pounds were harvested (Bowers, 1902). Fresh clams were sold locally for one cent/pound and were also canned and shipped as far as Chicago.

Razor clams are considered a delicacy. Commercial fishermen are paid about $3.00/pound for them and they are sold fresh and frozen for $7.00 to $14.00/pound in retail markets. Annual landings have varied widely, ranging from 970,899 pounds in 1956, when 253 licenses were issued, to only 100 pounds in 1983, when 9 licenses were issued (Table 3).

The razor clam population in Oregon has declined as the number of sport clam diggers has increased (Table 4). Some losses were also caused by gill disease in 1984 and 1985 (Elston et al., 1986). In November 1991, all Oregon beaches were closed to razor clam

Table 2

Commercial bay clam harvest in pounds, estimated value in dollars at the fisherman's level, number of diggers, and permits from 1928 to 1990 (ODFW Annual Reports).

Year	Harvest	No. of diggers	Permits issued	$ Value	Year	Harvest	No. of diggers	Permits issued	$ Value
1928	110,000[1]			3,300	1960	76,000			15,200
1929	57,000[1]			1,710	1961	68,000			14,280
1930	163,000[1]			4,890	1962	109,000			23,980
1931	143,000[1]			4,290	1963	71,000			16,330
1932	132,000[1]			3,950	1964	61,000			15,250
1933	128,000[1]			3,840	1965	48,000			12,480
1934	224,000[1]			11,200	1966	40,000			12,000
1935	469,000[1]			23,450	1967	27,605			8,282
1936	448,000[1]			22,400	1968	27,866			8,360
1937	472,000[1]			23,600	1969	20,860	41		6,258
1938	664,000[1]			33,200	1970	25,884	40		7,765
1939	608,000[1]			36,480	1971	28,526	50		8,558
1940	659,000[1]			39,540	1972	61,505	37		18,452
1941	214,000	131		10,700	1973	17,156	19		5,148
1942	121,000	59		6,050	1974	16,315	23		5,058
1943	178,000	77		8,900	1975	26,550	19		8,231
1944	204,000	110		10,200	1976	88,054	7		27,297
1945	306,000	115		15,300	1977	85,733	29		26,577
1946	265,000	90		13,250	1978	216,962	15		69,428
1947	178,000	106		8,900	1979	94,912	19		30,372
1948	122,000	202		9,760	1980	81,467	36		27,034
1949	135,000			10,800	1981	81,138	30		28,765
1950	149,000			11,920	1982	134,090	46		53,076
1951	155,000			13,950	1983	136,185	41		68,530
1952	149,000			13,410	1984	120,567	30		73,962
1953	135,000			12,150	1985	99,254	44	65	63,865
1954	134,000			12,060	1986	82,609	36	65	48,718
1955	113,000			12,430	1987	46,283	34	121	24,939
1956	124,000			14,880	1988	44,696	28	136	23,578
1957	96,000			14,400	1989	60,482	24	111	33,341
1958	77,000			11,550	1990	72,756	38	92	44,952
1959	65,000			12,350					

[1] Bay and razor clam harvest combined, 1928–40.

Table 3

Landings, number of licenses issued, and estimated values at the fisherman's level for commercial razor clams, 1941–90 (ODFW Annual Reports).

	Razor clams				Razor clams		
Year	Pounds	Licenses	$ Value	Year	Pounds	Licenses	$ Value
1941	123,934	238	18,590	1966	82,852	217	24,856
1942	13,353	192	2,003	1967	120,432	297	38,539
1943	15,697	57	2,355	1968	92,462	340	29,588
1944	57,787	197	8,668	1969	25,142	185	8,799
1945	81,794	242	13,087	1970	14,806	79	5,183
1946	151,477	719	30,296	1971	30,135	134	13,561
1947	166,355	558	33,271	1972	12,550	76	5,020
1948	206,835	505	45,504	1973	16,030	111	6,733
1949	200,486	681	44,107	1974	8,553	58	3,678
1950	335,091	790	77,071	1975	41,412	146	24,019
1951	255,631	574	58,795	1976	118,016	391	76,711
1952	319,165	613	73,408	1977	45,781	269	38,914
1953	264,278	592	63,427	1978	41,455	253	49,746
1954	156,215	430	37,492	1979	36,228	236	47,097
1955	180,818	295	43,397	1980	20,291	145	26,630
1956	970,899	253	233,016	1981	22,516	91	34,967
1957	67,157	193	16,789	1982	26,528	209	42,807
1958	82,140	221	20,535	1983	100	9	189
1959	48,401	118	12,100	1984	5,803	34	10,417
1960	340,126	98	85,032	1985	58,253	340	114,989
1961	17,845	58	4,462	1986	2,906	51	6,058
1962	24,221	79	6,055	1987	29,197	173	64,172
1963	200,822	77	56,230	1988	33,910	178	86,831
1964	35,300	125	9,884	1989	32,177	228	87,963
1965	79.767	213	23,930	1990	13,474	151	39,487

digging because the clams contained domoic acid. Domoic acid concentrations are monitored by the Oregon State Health Division, which reopens the beaches when the domoic acid has dropped to a safe level.

Paralytic shellfish poisoning is also a concern to bivalve consumers and problems with razor clams have been reported (Browning, 1980). The Oregon Department of Health has monitored coastal areas since 1952.

Razor clams appear to be a good species for culture. They grow relatively fast, have a high price and stable market, and laboratory spawning and rearing has been successful.

Mussels

California mussels, *Mytilus californianus*, of all ages form dense beds on wave-exposed rocky cliffs along the open coast. Sea mussels have traditionally been harvested for bait, but since 1975, wild populations have been harvested commercially in designated areas on the Oregon coast, for human consumption. Landings have increased from 800 pounds in 1975 to the 40,000 pounds currently landed each year (Yamada and Dunham, 1989). The bag limit for sport fishermen is 72 mussels/day.

Oregon's only commercial California mussel farm operates at Winchester Bay. Workers collect juveniles from wild populations, wrap them onto ropes with gauze, and hang the ropes from subtidal long lines. Growth there is twice that of mussels in intertidal wild populations (Yamada and Dunham, 1989).

Bay mussels, *Mytilus trossulus* and *M. galloprovincialis*, are collected and cultured in small quantities. Cultured and wild-harvested mussels are sold fresh to restaurants and specialty markets for $1.50/pound. Between 1978 and 1989, annual mussel landings ranged from 818 to 68,821 pounds (Table 5).

California mussels dominate available space when competing with barnacles and sea anemones. The mussels can exclude barnacles by covering them completely (Paine, 1974). Sea stars and crabs prey on California mussels, while sea birds and sea otters prey on both California and bay mussels. Since bay mussels are easier to crush, they are more vulnerable than California mussels. Mussel beds can become overgrown by sponges and other epifauna, which causes a decrease in their tissue weight (Paine, 1976).

Table 4
Effort data and annual harvest for commercial and sport razor clam fisheries in Oregon, 1955–90 (ODFW Annual Reports).

	Commercial fishery		Sport fishery				
Year	No. of diggers	No. of clams	No. of diggers	Clams per trip	No. of clams	Wastage	Total
1955	295	904,000	56,000	22	1,212,000	295,000	2,411,000
1956	253	490,000	60,000	18	1,061,000	295,000	1,846,000
1957	193	336,000	77,000	21	1,646,000	416,000	2,398,000
1958	221	386,000	89,000	19	1,679,000	218,000	2,283,000
1959	118	179,000	54,000	12	646,000	124,000	949,000
1960	93	154,000	48,000	12	596,000	46,000	796,000
1961	58	80,000	51,000	11	583,000	70,000	733,000
1962	79	102,000	56,000	16	892,000	105,000	1,099,000
1963	77	107,000	55,000	13	713,000	70,000	890,000
1964	125	125,000	71,000	16	7,098,000	264,000	1,487,000
1965	213	399,000	76,000	15	1,134,000	186,000	1,719,000
1966	217	282,000	78,000	14	1,052,000	434,000	1,768,000
1967	297	494,000	74,000	20	1,472,000	195,000	2,161,000
1968	340	361,000	64,000	13	831,000	162,000	1,354,000
1969	185	111,000	59,000	14	851,000	155,000	1,117,000
1970	79	61,000	56,000	13	751,000	125,000	901,000
1971	134	123,000	77,000	13	968,000	213,000	1,304,000
1972	76	49,000	69,000	9	636,000	139,000	824,000
1973	111	89,000	76,000	10	725,000	159,000	973,000
1974	58	32,000	44,000		347,000	5,000	384,000
1975	146	171,000	75,000	10	785,000	157,000	1,113,000
1976	391	717,000	119,000	12	1,431,000	63,000	2,211,000
1977	269	143,000	51,000	10	499,000	33,000	675,000
1978	253	205,000	72,000	12	849,000	137,000	1,191,000
1979	236	180,000	90,000	11	958,000	63,000	1,201,000
1980	145	116,000	70,000	11	747,000	143,000	1,006,000
1981	91	128,000	30,000	6	187,000	49,000	364,000
1982	209	165,000	84,000	9	758,000	123,000	1,046,000
1983	9	1,000	32,000	3	105,000	12,000	118,000
1984	34	37,000	23,000	15	341,000	15,000	393,000
1985	340	303,000	94,000	10	984,000	147,000	1,434,000
1986	51	18,000	46,000	5	260,000	33,000	311,000
1987	173	236,000	68,000	15	1,010,000	83,000	1,329,000
1988	178	161,000	84,000	11	1,016,000	168,000	1,345,000
1989	228	195,000	97,000	11	1,082,000	136,000	1,413,000
1990	151	75,000	55,000	12	579,000	61,000	715,000

Mussels can accumulate toxic heavy metals and hydrocarbons in their tissues (Roberts, 1976) and can also ingest algae that makes them toxic to humans.

A great potential exists for increasing mussel production in nonpolluted areas. They are relatively fast-growing, and the market demand for them is good.

Scallops

Incidental harvesting of weathervane scallops, *Patinopecten caurinus,* has been common along the Pacific coast for years. In 1981, two east coast vessels searched for scallops off the Oregon coast. Investigations conducted by the crew of the R/V *John N. Cobb* led to the discovery of beds with commercial quantities of scallops off Coos Bay. Sea scallop vessels came from the east coast to harvest them. They had crews of 12 people and spent 10–12 days dredging scallops. Crew members shucked the scallops at sea, stored the meats in cotton bags (40 pounds/bag), and placed them on ice. Most local boats had to be converted for scallop fishing. Scallops were harvested with New Bedford-type dredges, as well as several modified ones. Shrimp nets were also

Table 5
Landings and estimated values at the fisherman's level for mussels in Oreon, 1972–90 (ODFW Annual Reports).

	Mussel landings	
Year	Pounds	$ Value
1972	588	177
1973	0	0
1974	0	0
1975	728	291
1976	666	266
1977	312	125
1978	818	327
1979	19,068	7,627
1980	60,629	22,289
1981	17,866	15,642
1982	18,372	24,911
1983	30,752	17,171
1984	40,054	34,773
1985	40,168	30,161
1986	39,872	34,043
1987	52,310	27,432
1988	53,220	20,819
1989	68,821	22,965
1990	54,394	17,273

commonly used. Large vessels over 24 m (80 feet) long comprised 20% of the fleet, but landed 75% of the catch. Boats landing scallop meats received more for their scallops than those landing whole scallops. Initially, the processors at Coos Bay refused to buy the scallops, because little market existed for them. They were shipped to Los Angeles, Calif., where they sold well, before local fishermen and processors became interested in them. During the fourth week of the fishery, 15 vessels landed scallops; by the ninth week, 60 boats landed 7,500,000 pounds of meats; by the end of the year, a total of 118 boats had landed scallops. Finally, depressed prices and lower scallop densities forced most vessels to return to their traditional fisheries, and by 1990, the scallop fishery was no longer profitable. The best year for landings was 1981, when 16,853,845 pounds of meats were landed with a value of $4,671,448. Production then fell steadily and only 1,805 pounds of meats worth $767 were landed in 1990 (Table 6). Information about the scallop fishery was obtained from ODFW's yearly shellfish investigations and progress reports.

Squid

The squid, *Loligo opalescens*, fishery in Oregon is intermittent, prospering during years when warm currents sweep northward to the Oregon coast (Table 6). Most squid are sold for bait.

Table 6
Permits, landings, and estimated value at the fisherman's level for scallops and squid in Oregon, 1978–90 (ODFW Annual Reports).

	Scallops			Squid	
Year	Permits	Pounds	$ Value	Pounds	$ Value
1978	0	0	0		
1979	0	3,434		0	0
1980	0	0	0	0	0
1981	196	16,853,845	4,671,448	225	45
1982	164	1,487,941	247,292	113,138	9,117
1983	144	2,648.965	778,781	297,410	79,901
1984	134	3,329,234	1,017,784	946,725	199,941
1985	113	819,030	327,922	1,751,773	318,577
1986	101	105,523	47,588	26,371	2,684
1987	103	13.590	6.406	29	3
1988	104	29,226	12,017	5	1
1989	105	220	0	96,025	7,683
1990	100	1,805	767	0	0

Vessels use lampara nets, purse seines, and shrimp trawls to catch squid. Experimental gear permits were issued in 1984 to allow trawlers to fish for squid. The ODFW issued 26 nearshore permits for fishing with trawl gear inside of 50 fathoms (91 m) in each of four designated areas of the coast. The permits were valid for a 3-week period. Three additional permits were issued for midwater trawling for the entire coast, outside of 50 fathoms. The vessels did not land squid from deep waters. A trip limit of 20,000 pounds/day was set for all vessels. More than 40 vessels expressed an interest in the fishery, but only 13 vessels landed squid (Annual Progress Reports. ODFW Marine Region). Fishermen sell squid for about $0.10/pound, $600 to $700/ton for squid weighing not over 10/pound, and $240 to $300/ton when the mantle quality is poor and the count per pound is high.

Octopi

Catches of octopus, *Polypus* spp., are incidental. Octopi are caught in crab pots, by groundfish and shrimp trawls, and by hook and line. Most of the octopus catch is sold fresh or frozen to specialty markets or for bait. Fishermen earn less than $1/pound for octopus. Annual landings have ranged as high as 46,903 pounds in 1988 (Table 7).

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Table 7
Landings and estimated values at the fisherman's level for octopus in Oregon, 1932–90 (ODFW Annual Reports).

	Octopus landings	
Year	Pounds	$ Value
1932	33	
1941	345	
1943	264	
1944	249	
1945	169	
1946	160	
1947	206	
1948	379	
1972	2,886	1,039
1973	11,095	3,994
1974	0	0
1975	7,244	2,898
1976	14,538	6,106
1977	4,049	1,741
1978	16,122	6,933
1979	24,187	10,643
1980	14,013	6,180
1981	14,082	6,254
1982	18,597	8,354
1983	16,780	7,065
1984	12,970	5,924
1985	7,682	4,151
1986	9,540	5,861
1987	18,771	14,199
1988	46,903	31,282
1989	15,318	8,625
1990	17,022	11,532

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The Fisheries for Olympia Oysters, *Ostreola conchaphila*; Pacific Oysters, *Crassostrea gigas*; and Pacific Razor Clams, *Siliqua patula*, in the State of Washington

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ABSTRACT

Shellfisheries in the State of Washington include harvests of the Olympia oyster, *Ostreola conchaphila*; the Pacific oyster, *Crassostrea gigas*; and the Pacific razor clam, *Siliqua patula*. The oysters occur in Puget Sound, Grays Harbor, and Willapa Bay, while the razor clam occurs on surf-pounded ocean beaches. Other species harvested have included the native littleneck, *Protothaca staminea*; butter clam, *Saxidomus nuttalli*; geoduck, *Panope generosa*; cockle, *Clinocardium nuttalli*; horse clams, *Tresus nuttalli* and *T. capax*; Manila clam, *Tapes philippinarum*; mussel, *Mytilus trossulus*; and softshell clam, *Mya arenaria*. Before 1900, production of Olympia oysters was from natural beds and reefs, but afterward most were farmed in diked grounds. Peak production was 14,500 sacks in 1910; it has since declined and production is currently small. Pacific oyster culture began in the early 1900's when seed was imported from Japan. Seed imports reached a peak of nearly 72,000 cases in 1935 but declined afterward. In recent years, Pacific oyster seed has been produced in local hatcheries. Most commercial oyster culture is practiced on bottoms between 3.5 feet above and 1.5 feet below mean low water. In the beginning, harvesting was accomplished by hand, but as larger areas were planted, towed and self-powered dredges were used along with hand harvesting. Washington is the leading producer of Pacific oysters in North America, i.e., more than one million gallons/year since 1987. The state once had a commercial fishery for razor clams and the meats were canned. The commercial harvest decreased steadily from 7.6 million clams in 1946 to 600,000 in 1967. By 1968, the true commercial clam fishery had ended as commercial digging was prohibited except in small areas. The recreational fishery peaked at almost 15 million clams and 960,000 digger trips. Numerous challenges complicate future management of the species.

Introduction

Shellfisheries in the State of Washington include harvests of the native or Olympia oyster, *Ostreola conchaphila*; Pacific oyster, *Crassostrea gigas*; and the Pacific razor clam, *Siliqua patula*. However, after the Pacific oyster became established in the 1920's and 1930's and the Willapa Bay production of Olympia oysters declined, Olympia oysters have comprised only a small part of oyster production. The oysters occur in Puget Sound, Grays Harbor, and Willapa Bay, while the razor clam occurs on ocean beaches (Fig. 1, 2). Less important species harvested have included the native littleneck, *Protothaca staminea*; butter clam, *Saxidomus nuttalli*; geoduck, *Panope generosa*; cockle, *Clinocardium nuttalli*; horse clams, *Tresus nuttalli* and *T. capax*; Manila clam, *Tapes philippinarum*; mussel, *Mytilus trossulus*; and softshell clam, *Mya arenaria*.

The bottoms of the bays consist of gravel-sand or mud, and the Pacific coastal substrate consists of firm sand. Water salinities in the oyster-growing areas range from 15–30‰, while water temperatures in them range from 5°C in winter to 23°C in summer; those on the coast range from 8–15°C. In Puget Sound, maximum tidal ranges are at least 6 m (20 feet). In the coastal bays they are about 4 m (13 feet), and on the Pacific coast they are about 3.35 m (11 feet).

Olympia Oyster Fishery

Olympia oysters (Fig. 3) once were found in beds or reefs throughout Puget Sound, Willapa Bay, and Grays Harbor. They grew best where salinities averaged 25‰ and where they were protected from extremes of heat and cold. They could not withstand prolonged periods of low salinity. The best habitats were natural tidepools, shallow channels, and some deep channels where predators were scarce. The best bottom types were fine gravel, shell, or firm mud. Fauna associated with Olympia oysters were those common to sheltered low intertidal zones and in tide pools such as mussels, native littlenecks, thin-shelled littleneck, *P. tenerrima*; Manila clams, butter clams, cockles, horse clams, and *Macoma nasuta*. Other associated species are Pandalid and Crangon shrimp, the mud shrimp, *Upogebia* sp.; grapsoid and cancroid crabs, annelid worms, barnacles, nudibranchs, tunicates, bryozoans, and fishes such as cottids, gobies, and blennies.

Native Americans ate Olympia oysters wherever they found concentrations of them. Oyster shells have been found in middens throughout Puget Sound and coastal bays near places where *O. conchaphila* probably grew in the past. The largest concentrations in Puget Sound occurred in its southern bays. In early times, Indians traded seafood products including dried fish and clams (but probably not oysters) to inland tribes. Non-Indian settlers gathered oysters for food and for sale (Steele, 1957; Taylor[1]).

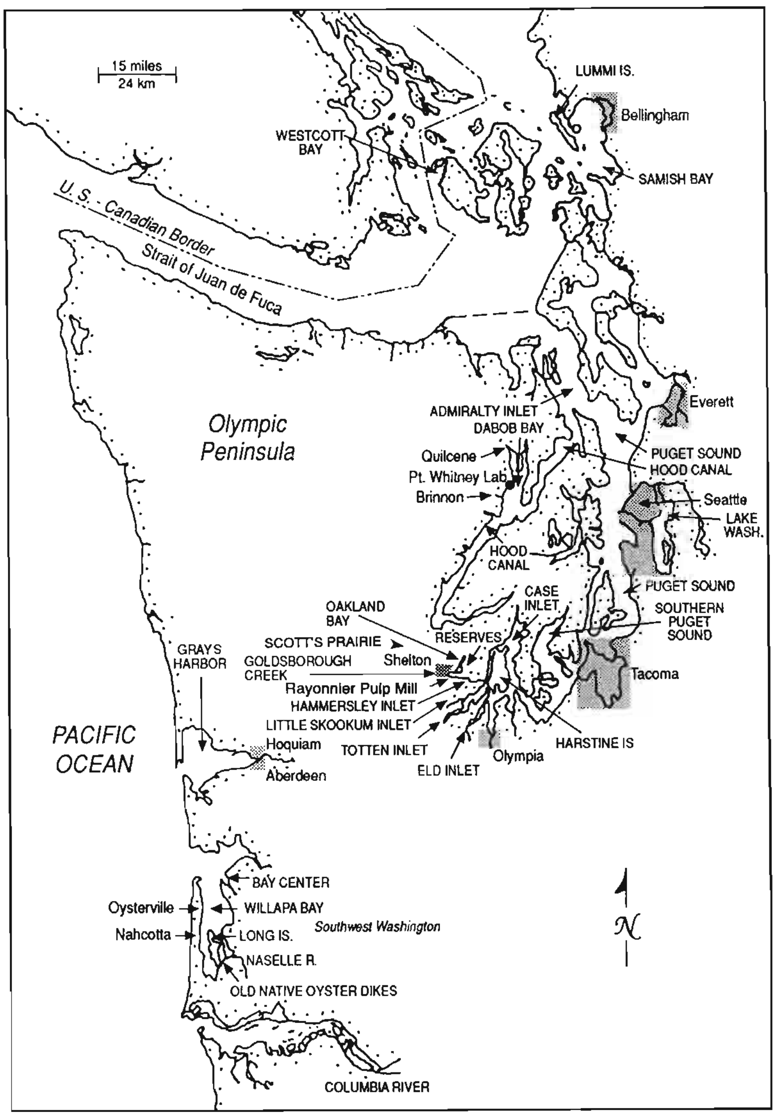

Figure 1
The coastline of Washington.

Willapa Bay Fishery

In the 1850's the Willapa Bay oyster stocks were sold to buyers on sailing ships, who carried them to the large San Francisco market (Swan, 1857). Stocks in northern California and Oregon bays had been quickly depleted, but the Willapa Bay stocks were extensive enough to sustain a much larger fishery. Puget Sound stocks did not share in this trade due to spoilage problems resulting from longer voyages. Willapa Bay oysters were gathered from potholes, low intertidal ground, and shallow sloughs found throughout the bay. Grays Harbor stocks apparently were not large enough to sustain extensive harvesting. At first, Indians gathered the oysters and sold them to non-Indian entrepreneurs, but as trade increased rapidly more white men came to gather oysters to sell to the sailing ships. Harvested oysters were moved to shallow beds for culling and sacking before the arrival of a ship. Once loaded, the sailing ships headed for San Francisco as fast as possible.

[1] Taylor, J. 1992. President, Taylor United Inc., S.E. 130 Lynch Road, Shelton, Wash. Personal commun.

Throughout the fishery's heyday, which lasted from the late 1850's into the 1870's, the fishermen took all the oysters they could gather with little conservation or enhancement (Espy, 1977). By the end of the 1870's, the beds were depleted, and the fishery had virtually collapsed. An 1895 U.S. Fish Commission report concerning transplantation of eastern oysters, *Crassostrea virginica*, mentions the Willapa Bay Olympia oyster fishery, and contains a map of the bay showing natural and cultivated (transplanted) beds of the Olympia oyster (Fig. 4). Over 2,000 acres of transplanted beds were shown in the vicinity of Tokeland, Bruceport, Bay Center, and Oysterville. The natural beds occupied low ground from the Willapa River mouth to the south end of Long Island. In 1895 about 350 persons produced $66,000 worth of oysters (Townsend, 1895).

Some effort was made to actually cultivate Olympia oysters in the early 1900's, because several abandoned and silted oyster dikes south of Long Island have been found; no information has been verified about how and when the dikes were constructed. Small numbers of Olympia oysters in some sloughs and potholes and on shell reefs are still present in the southern end of the bay. After the collapse of the Olympia oyster fishery, oystermen began to import railcar loads of eastern oysters from the U.S. Atlantic coast for planting. For a time, the industry revived, but, by the 1920's, an unexplained mass mortality of the eastern oysters caused the industry to fail.

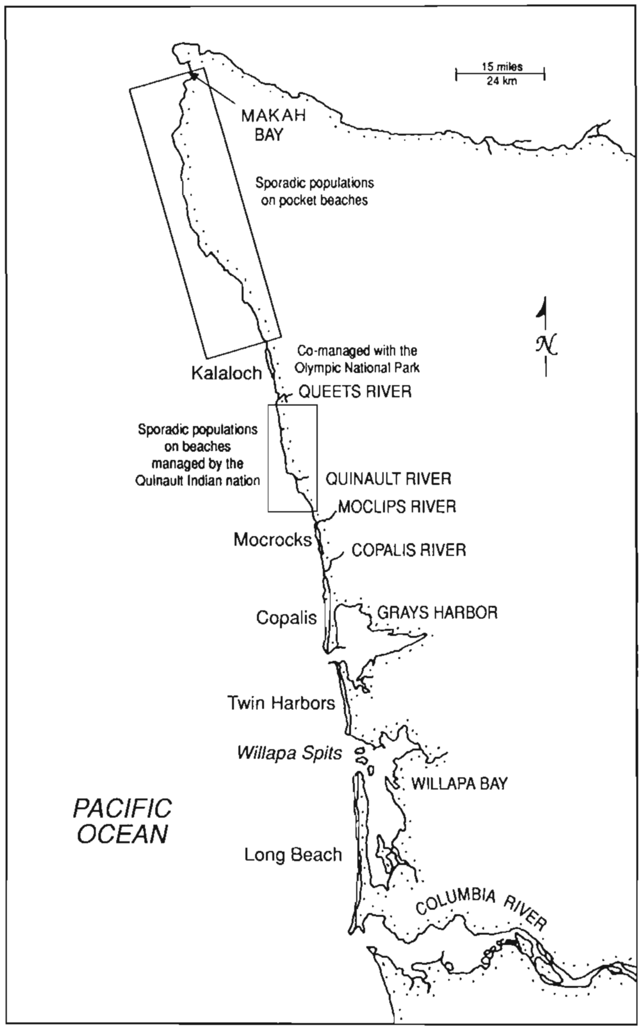

Figure 2
The outer coast of Washington, where razor clams occur.

Puget Sound Fishery

The Puget Sound fishery for the Olympia oyster had a slower beginning. Before the advent of rail service, markets were mostly local. The pioneers bought Olympia oysters from the Indians and harvested them for family use as well. At first, the small oysters were gathered by hand, put into baskets or tubs, and brought ashore for use or sale. It was a free fishery, as oysters were gathered wherever found. Some beds were fished by squatters and others by Indians who lived along the shore.

Before statehood in 1889, all titles of tidelands and beds of navigable water were vested in the Federal Government. Upon gaining statehood, however, titles passed to the State of Washington. In March 1895 the state legislature passed the Callow Act which authorized the sale of natural oyster beds to individuals who occupied and cultivated beds before that date (Taylor[1]). Indians occupying land along the shore beside the natural beds claimed title to them at that time. Purchasers would maintain title only so long as they continued to cultivate shellfish. The Bush Act was also passed in March 1895 which gave any person the right to purchase oyster land whether or not they had previously used it for oystering. However, the Bush Act deeds still specified the state could reclaim the land if it was used for any purpose other than growing shellfish. In 1927 a provision was added to the law that allowed for purchase of the reversionary right. Many tideland owners did get full title, but there are still Bush Act lands for which the reversionary rights have never been acquired.

Indians as well as non-Indians purchased Bush Act lands and developed productive oyster farms. One of the first persons to realize the potential of expanding the acreage by diking ground to create artificial tidepools was J. Y. Waldrip (Steele, 1957). Others soon followed. They found that productive beds could be greatly expanded by installing wooden and later concrete dike walls at successive levels above the low ground. They levelled the ground behind the walls so as to retain 10–15 cm (4–6 inches) of water over the oysters. At first, they did it by hand, shoveling bottom material onto

Figure 3
Three clusters of Olympia oysters ranging from juveniles, seed, and adults.

scows or floats and unloading it to fill the hollows. Since excavation had to be done at low tide, the work took months to complete.

As workers gained experience, they used mechanical dragline buckets to excavate and self-dumping scows to unload the fill material. Sometimes, the original mud was too soft to support the heavier fill material and so tarpaper, boards, or plywood skins were used as flooring under the fill to stabilize the bottom and to prevent burrowing shrimp from digging holes under the dike walls and allowing the water to drain. The cost of diking even in the 1930's has been reported as high as $5,000 per acre, which seems high except that the yield from those beds at the peak of the industry easily justified the cost.

Steele (1957) listed names of more than 60 growers who were in the oyster business about 85 years ago when diking was getting underway. About this time, the name Olympia was chosen for the Olympia oyster to stimulate market demand and sales. Some growers hired Indians and later Japanese to build dikes, harvest, cull, and sack the oysters for market. After the internment years of World War II, some old country and American born Japanese came back to work for the companies or to build beds of their own. Oyster dikes varied in size with the slope of the beach. Broad flats near the heads of the bays contained dikes of 10–15 acres, but on steeper beaches dikes varied from about 1 to 5 acres, and they were built on several terraced levels (Fig. 5). Records of the total area of original diked ground do not exist, but it amounted to more than 1,000 acres.

Seeding the Beds

The normal reseeding practice was to take advantage of natural sets that attached to live oysters or shells already in the dike. Growers found that upper-level dikes caught and grew seed best. Reseeding was adequate in Oakland Bay, and in most of Totten and Little Skookum Inlets. Parts of Totten and Eld Inlets were less dependable as were other bays and inlets. Growers there had to obtain seed from locations where good setting was consistent. In fact, as dikes were being completed, some oystermen went to the State Oyster Reserve in Oakland Bay, harvested oysters, poled their top floats down Hammersley Inlet, and over to their beds on Totten Inlet (about 40 km or 25 miles). In the years that followed, the state sold thousands of bushels of Olympia oysters to oyster growers for replanting their beds.

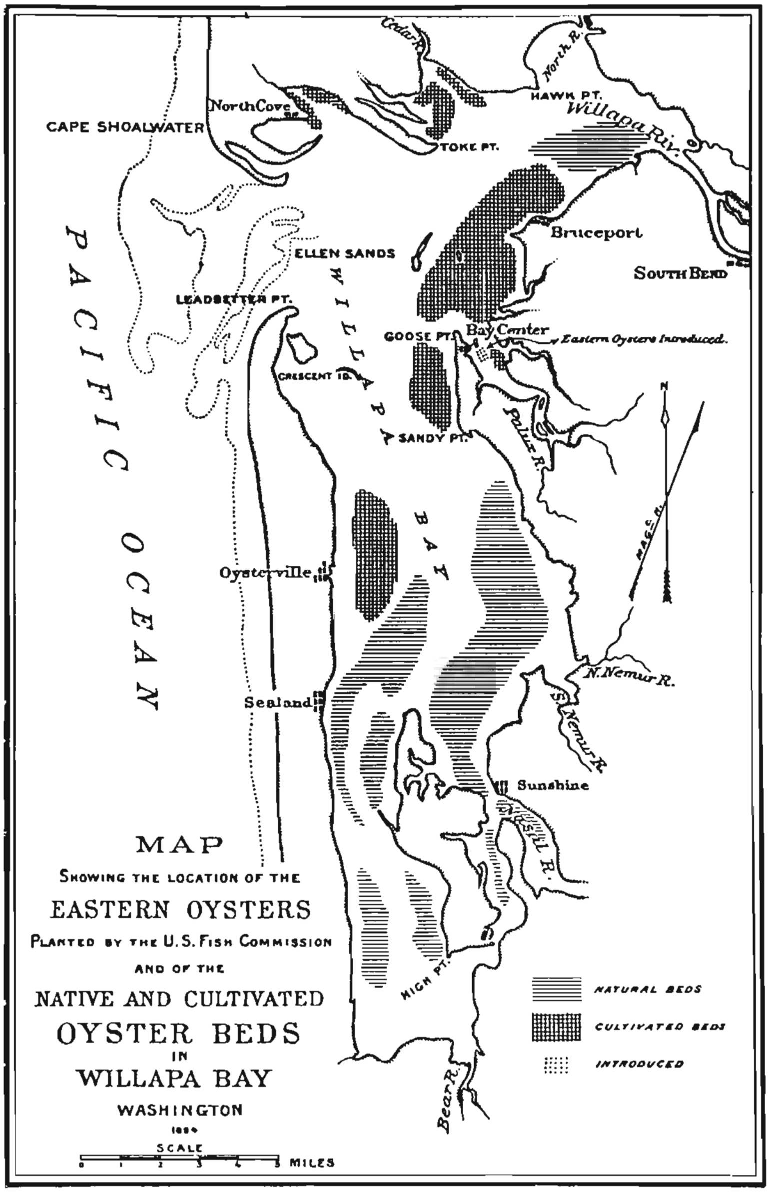

Figure 4
Willapa Bay showing oyster growing areas.

The state built dikes to increase the supply of seed and sold oysters until the 1930's when the Oakland Bay Reserves failed to get a set.

As adequate oyster setting continued in Totten Inlet during the 1940's, growers with oysters in other bays brought cultch to Totten and floated it in bins during June and July, and returned the seed to their own beds after setting had finished. In Case Inlet, local growers used concrete-coated wooden lath frames as cultch (Nelson, 1990). In other bays, they used cemented egg crate fillers along with shell to catch and grow seed. These types of artificial cultch were used by Olympia oyster growers until the early 1960's when oyster survival and growth had reached a low ebb in formerly productive bays.

Growing the Oysters

Olympia oysters ready for market had a shell diameter of 25–40 mm (1–1.5 inches). It took about 2,000 oyster meats to fill 1 gallon. On most beds, growth to maturity took 4 or 5 years. During the growth period, the crop was usually culled two or three times. Oyster workers with the close-tined forks lifted all oysters from a portion of the beds onto scows or top floats and towed the

Figure 5
Oyster dikes in Mud Bay, Eld Inlet, showing market-sized oysters growing on top of leveled and gravelled tidelands, 1910. Photograph by Brenner Oyster Company.

load to the company's nearby culling house (Fig. 6). The workers removed the market- sized oysters, separated clusters, stockpiled dead shell for cultch, and dumped pests, including predators and debris, on shore. They stockpiled the market oysters in sink floats for later sacking and shipment to restaurants or processing plants, and rebedded the smaller oysters and seed in the area from which they had been removed. If the small oysters were mostly seed, however, they rebedded on previously cleaned and diked ground. If any beds contained juveniles as well as seed, the crop was taken up and culled again. A healthy rapidly growing bed required culling at least every second year and sometimes more often.

The smaller farms were usually family-sized operations, and one or two persons were hired on a part-time basis. The small size of oysters and limited acreage of farms tended to discourage the development of mechanical handling methods. In later years, one or two larger companies used power-driven portable conveyor belts to move the harvested oysters onto the deck of the scow. No dredge or mechanical vacuuming system was found to be practical or economically feasible.

Production and Marketing

Statistics of the Willapa Bay Olympia oyster production are not available, while records of the early Puget Sound Olympia oyster fishery have been more readily available. Production was first reported in numbers of sacks, because in Puget Sound, after culling, market-size oysters were sacked and carried by a boat to processing plants in Olympia. Oysters were also shipped to restaurants or to out-of-state wholesalers in the sack and opened at the retail outlets. Later, as new processing plants were built in Olympia, more oysters were opened and shucked, refrigerated in glass jars and sent to the markets in that form, saving the cost of shipping sacked oysters as well as the cost of an oyster shucker at the retail outlet. Besides, the small shells for cultch that was always in short supply were retained (Taylor[1]).

Steele (1957) reports that early production may have been more than 50,000 sacks (100,000 bushels) annually. Before 1900 the oysters were principally from natural beds and reefs, which eventually became depleted. With diking of tidelands and conversion to an aquaculture system, annual yields increased. Production in 1910 was reported as 14,500 sacks. Some fluctuation occurred, but by 1925 yield had increased to over 20,000 sacks, after which it declined below 10,000 sacks in 1933, and rose to 12,000 sacks in 1936. After 1936, statistics were collected by the Washington Department of Fisheries (WDF) and production was reported in gallons. For comparison, fat oysters yielded 2–2.5 gallons/2-bushel sack, and each gallon contained about 2,000 oyster meats. By 1943 production had declined below 20,000 gallons, and in 1953 below 14,000 gallons except for 1949 when it was over 23,000 gallons. In 1954, 8,000 gallons were produced, and in 1957, 2,100 gallons. From 1961 to 1970, production fluctuated between 3,500 and 6,000 gallons. In 1979 less than 1,000 gallons was reported. From 1981 to 1985 annual production was only 3,000 gallons, and, in the next 5 years, average annual production was just under 1,000 gallons.

The prices for Olympia oysters underwent sharp increases from the early days when a bushel of oysters sold for $0.25 (Steele, 1957). By the 1950's, oysters were around $25/gallon. In the 1970's, the price was around $125/gallon if one could get them, and, in the early 1990's, prices were more than $200/gallon. Even with such high prices, growers report there is little profit for a company in growing Olympia oysters (Taylor[1]).

Figure 6
Oscar Zandel, bed foreman for Brenner Oyster Company for 30 years, holding a handful of market-sized Olympia oysters and a standard Olympia oyster fork. Photograph by Earl Brenner.

Fishery Decline

The decline of the Willapa Bay Olympia oyster fishery was due to depletion of the vast natural beds and lack of success in establishing a culture system. In Puget Sound, harvest and depletion of natural beds also occurred, but with the development of progressive diking and cultural techniques, production increased until 1926 (Steele, 1957). In 1927 a sulfite pulp mill began operating in Shelton and discharging untreated sulphite waste liquor (SWL) into Oakland Bay. Private and state beds were adversely affected immediately. Oyster setting ended and adult oysters died. Between the start-up and closure of the mill in 1945, due to wartime conditions, disposal of SWL underwent several changes. A major change occurred when the liquor was pumped to Goose Lake west of Shelton and later to settling ponds on nearby Scott's Prairie. Unfortunately, the groundwater became saturated, and the SWL leached back to the bay via Goldsborough Creek (McKernan et al., 1949).

As illustrated by the brief summary of production statistics, the first major decline in Olympia oyster production coincided with the discharge of pulp mill waste directly into Oakland Bay. Between 1931 and 1962, three major investigations were undertaken to try to ascertain causes for the oyster losses. The first, by the U.S. Bureau of Fisheries, began in 1931 with A. E. Hopkins conducting the research under the direction of Paul S. Galtsoff. With the help of H. C. McMillin, they studied various aspects of Olympia oyster biology and culture and the effects of pulp mill operations. They examined effects of temperature extremes, predation from Japanese oyster drills, and reproduction, as well as possible effects of pulp mill wastes. They concluded that the most likely cause of the decline was the presence of high concentrations of pulp mill waste in Oakland Bay, and that even in lower concentrations it could be affecting survival in other bays of southern Puget Sound (Hopkins et al., 1931).

A second major study was undertaken by the WDF in 1943. Donald L. McKernan headed this group, which intensified studies of temperature extremes, pests and predators, competition with Pacific oysters, oyster reproduction, water transport and circulation out of Oakland Bay, and also included a laboratory dilution study to test the effect of low concentrations of SWL on adult oysters.

Their drift-bottle studies showed that polluted water from Oakland Bay could reach adjacent bays in a few days. The dilution study showed a harmful effect from SWL concentrations as low as 64 ppm. They concluded that, although natural factors such as predation had an adverse effect on oysters, the most probable factor causing the oyster losses was pulp mill waste (McKernan et al., 1949).

During World War II, the pulp mill closed, but it reopened in 1945. Before the reopening, the mill officials said the waste liquor was to be evaporated and the residue burned. This was done, and the mill management claimed that over 90% was burned. However, in the winter of 1956–57, a severe mortality of Olympia oysters occurred again. This time, there was the belief that the mill had substantially increased its production so that the burners were not eliminating as much waste as originally claimed.

The WDF investigated further the possible causes for the severe losses of oysters. C. E. Woelke[2] conducted extensive field work to document the condition of the oyster stocks and to collect samples for disease analyses. Woelke later developed the Pacific oyster larvae bioassay technique for assessing toxicity of sea water. R. E. Westley (1957) undertook extensive water sampling to ascertain whether or not SWL could be detected in waters of southern Puget Sound, and Clifford Barnes of the University of Washington provided much help in working out local water circulation patterns. An elaborate dilution study was set up at the Pt. Whitney Laboratory to determine, if possible, the lower limits of SWL concentrations that might affect adult Olympias.

Before full-scale studies were well underway, the sulfite pulp mill closed permanently. However, a few water samples taken beforehand contained low concentrations of SWL in the outer part of Totten Inlet (Westley, 1957). The oyster growers again sued the pulp mill, but the suit was thrown out of court by Federal Judge George Boldt. The results of this latest group of studies demonstrated that water from Oakland Bay could eventually circulate throughout southern Puget Sound. The concentrations of SWL detected in the bays near the commercial oyster beds were not as high as the 8 ppm indicated by the laboratory dilution study to be deleterious to oysters. No disease, temperature extreme, or predation was found to have a major effect on the Olympia oyster stocks. Siltation and the presence of large plantings of Pacific oysters, which might have contributed to the problem, could not be demonstrated.

Within 2 years after the pulp mill closed, water quality improved, oyster growth and survival improved, and good oyster setting occurred again except in Oakland Bay. In the meantime, most of the growers had planted Pacific oysters for economic survival, although Olympia oyster culture was still carried on by a few growers. With the severe decline in production and lack of product, markets for Olympias became much reduced.

Prognosis for Future

High labor costs along with inflated costs of supplies and services, continued predation from oyster drills and flatworms, the high price for the products, and limited market availability seem to preclude any large-scale revival of the Olympia oyster industry. There are specialty growers with good diked ground who will continue to culture them while using hand labor, but no grower is likely to rely on Olympia oysters alone as growers did in the past. Probably only two companies and two individuals are currently culturing Olympia oysters on a small scale. Also an early 1990's report indicated that the Squaxin Indian tribe had received grant funds to develop oyster dikes on the reservation (Taylor[1]).

Most productive oyster grounds will also grow Manila clams successfully. The market for those clams as steamers is good. Furthermore, Manila clam seed can now be purchased from shellfish hatcheries. Possibly, a small, well-run farm may be able to grow Olympia and European flat oysters, *Ostrea edulis*; clams, and mussels, and provide a good income for one family. The grower might then concentrate only on culturing, and market his crops through a larger grower or local processor.

All shellfish growers in Washington face potential decertification of beds if domestic pollution spreads. However, there is wide public recognition that shellfish beds need protection, and perhaps even willingness of all parties to attempt correction of the problems.

Pacific Oyster Fishery

Pacific oysters grow well in most waters of Puget Sound and the two coastal bays, Willapa Bay and Grays Harbor, except where they have prolonged exposure to salinities lower than 15‰ and summer temperatures below

[2] Woelke, C. E. 1956. Adult Olympia oyster mortalities, 1929–1956. Wash. State Dep. Fish., Olympia Oyster Problems 2., 2 p. (proc.).

12°C. They thrive on a variety of bottom types and conditions of exposure to wind and waves and do well suspended in the water. Most commercial bottom culture is practiced between 1 m (3.5 feet) above and 0.5 m (1.5 feet) below mean lower low water (0 tide level), although in some parts of Willapa Bay and Grays Harbor they may be grown as deeply as 7.6 m (25 feet) below extreme low tide. They are marketed at lengths of 10–15 cm.

Broad tideflats are best for bottom culture, but soft mud and shifting sand cause burial and smothering. Where bottoms are soft, the oysters must be suspended off bottom or the bottom must be hardened. Beds of rock or coarse gravel are usually less satisfactory since oysters must be attached to substrate or kept in large clusters. Fauna associated with these oyster beds include crabs, Olympia oysters, barnacles, snails, hard and softshell clams, starfish, shrimp, ghost or mud shrimp, annelid worms, nudibranchs, tunicates, bryozoans, cottids, gobies, and blennies.

Origins of the Pacific Oyster Industry

People in Washington's oyster business began to look for other species to meet market demand as stocks of Olympia oysters declined. P. S. Galtsoff (1930) authored a report to the U.S. Bureau of Fisheries in 1929, which documented the early negotiations in 1899 between the Bureau and Tokyo Imperial University. Japanese scientists suggested that Pacific oysters from northern Japan might be well adapted for growing on the Pacific coast of the United States, and during the early 1900's several shipments of oysters were planted in Puget Sound (Hori[3]). These were apparently market-sized oysters for the half-shell trade. Some did survive the sea voyage, but no steady trade was developed.

In April 1919 a shipment of 400 cases of adult oysters from Miyagi Prefecture was planted in Samish Bay (Steele, 1964). The adult oysters all died, but spat, attached to the shells of the large oysters, survived and grew. This led the grower to believe that since these spat survived the voyage across the Pacific this was the way to ship oysters. Subsequent experiments were conducted quietly by Japanese nationals (probably S. Miyagi and J. E. Tsukimoto), and a successful farm was established in Samish Bay.

In 1921 E. N. Steele and J. Barnes of Olympia, growers of Olympia oysters, inspected the beds with J. E. Tsukimoto and observed good survival and rapid growth of the Miyagi Prefecture oysters. Also, in 1921, the Washington State Legislature passed an anti-alien law which prevented ownership of land by noncitizens. Thus, Japanese were prohibited from owning oyster land. E. N. Steele and J. Barnes became interested in growing Japanese oysters and, after negotiations, purchased the oyster crop and 600 acres of tidelands. Tsukimoto then returned to Japan and entered the seed business.

As word of successful survival of Japanese seed spread, other growers of Olympia and American oysters placed orders with Japanese producers. Due to the general antipathy for anything from Japan, the name Pacific oyster was adopted for better market acceptance. Nowadays, the source area names such as Miyagi, Kumamoto, and Hiroshima are accepted with no especially negative connotation.

Within a few years of the advent of seed shipments, regular production of seed oysters was established, and the best early spring shipment procedure was worked out. An extensive seed production system was established in the Sendai Bay area of Miyagi Prefecture about 320 km (200 miles) north of Tokyo. People in villages in the Matsushima Island area and along the Ojika Peninsula, southeast of Ishinomaki, were pioneers in export seed production.

Production Methods

In Japan, oyster shells were strung on 2 m (6.6 foot) wires and suspended from beach racks, floating rafts, or longlines in summer just before the anticipated larval settlement (Fig. 7). As soon as the setting season ended, strings were overwintered on horizontal racks high in the intertidal zone to slow growth and to harden the seed oysters. Packing sites were set up in each village, and, usually in February, strings were removed from hardening racks and brought to the site by small sampans. Wires were cut and shells were put in wash baskets. Seaweed and other small debris was then washed from the loose shells. Clean shells went to selection tables where individual mother shells were examined and sorted to determine whether debris, young Japanese oyster drills, *Ocenebra inornatum*; drill egg cases, or other snails might be present, or whether there was any other evidence that the seed might be contaminated. At the same time, shells were graded to assure adequate quantities of live spat less than 15 mm (0.6 inches) in diameter and then placed in 2½-bushel wooden seed oyster cases or half-sized cases. It was ruled that each standard case of unbroken seed had to contain at least 12,000 spat and 16,000 spat for broken seed. Some buyers preferred broken seed. Thus, whole shells were fractured into 2–3 pieces before filling the cases.

The filled cases were placed on holding racks just below high tide to await transfer by lighter boat to the seed ship. After the war, predator control was exercised

[3] Hori, J. 1947. History of transplantation of Japanese oysters to the United States. Tokyo Imperial Fish. Coll., Tokyo, Jpn. Unpubl. Manuscr.

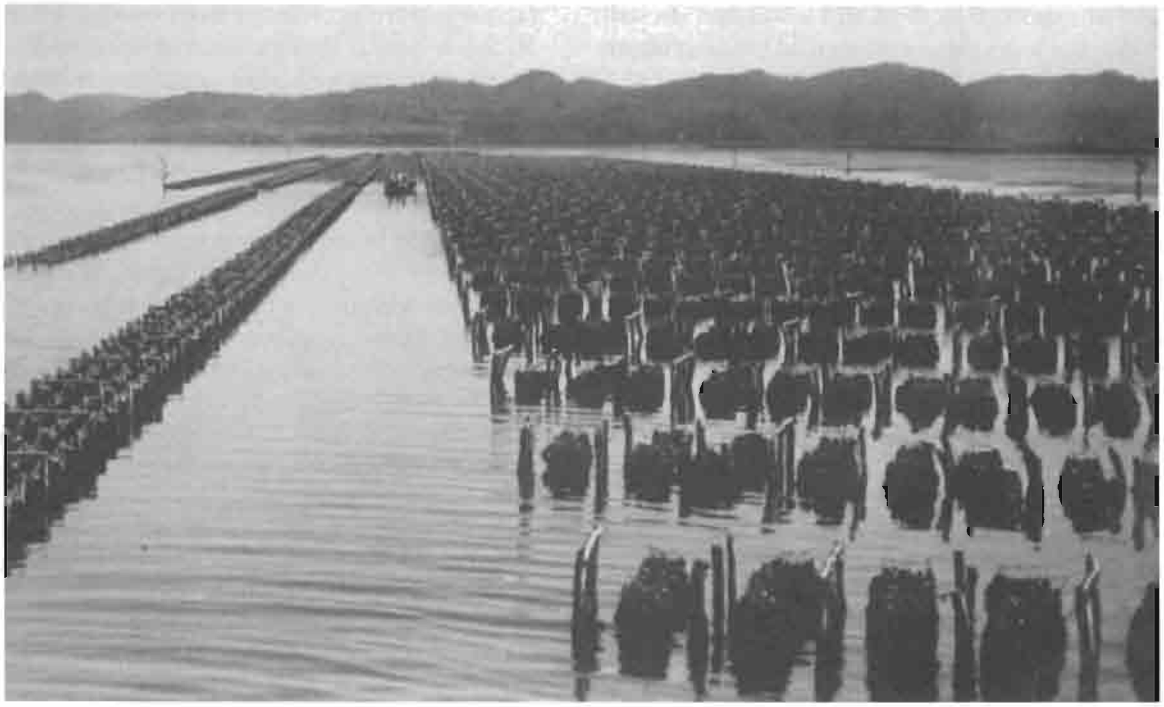

Figure 7
Pacific oyster cultch on catching racks in Mongoku Ura at Watanoha, Miyagi Prefecture, Japan, 1934. Photograph by J. Emy Tsukimoto.

at all levels by responsible growers keeping shell strings from coming in contact with the bottom on catching and hardening racks. Inspection was done by buyers' representatives and inspectors of the U.S. and Japanese governments to certify the seed as acceptable for export. Ships were contracted for by the buyers' organization to load seed in Sendai Bay next to the port of Shiogama or small bays of the Ojika Peninsula. Cases were loaded as deck cargo, covered with straw matting, lashed down, and transported across the Pacific to Washington ports in 9–12 days, arriving in March and April (Fig. 8). Individual growers collected the cases they had contracted for and transported them to their planting beds. Seed imports began slowly, reached a peak of nearly 72,000 cases in 1935, and then declined. The imports ceased during World War II, but began again in 1947 and continued each year except 1978 until 1979. They then ceased because of a high price, $46.40/case, and the Japanese domestic oyster growers took the entire supply (Table 1).

Domestic Seed

During the warm summer of 1936, *C. gigas* spawned and set in large numbers in Hood Canal, southern Puget Sound, and Willapa Bay. The resulting adults provided a large brood stock and were an important source of market oysters to sustain the industry during World War II. Other warm years followed in 1942, 1946, and 1958, as well as in some later years, and excellent setting occurred in the same areas. Growers made special efforts to provide cultch on their beds to obtain domestic seed. The resulting stocks continued to supply the markets after World War II until the 1947 Japanese seed plantings grew to market size. Growers also continued to purchase accumulated stocks on private and state-owned tidelands and State Oyster Reserves. Thereafter, many growers cultched every year as an economical supplement to Japanese seed.

In 1942 the WDF assigned biologists to study spawning and setting of *C. gigas* in Hood Canal and Willapa Bay. In a timely manner, they kept growers informed about the time and intensity of spawning and setting (Lindsay et al., 1959). Every summer thereafter, two WDF Shellfish Laboratories have continued to provide Hood Canal and Willapa Bay oyster set prediction services to the industry.

Techniques for collection of natural-set oyster seed has been similar to that done by the Japanese, except that shells are also suspended in plastic mesh bags or are spread loosely on the tidelands. No special selec-

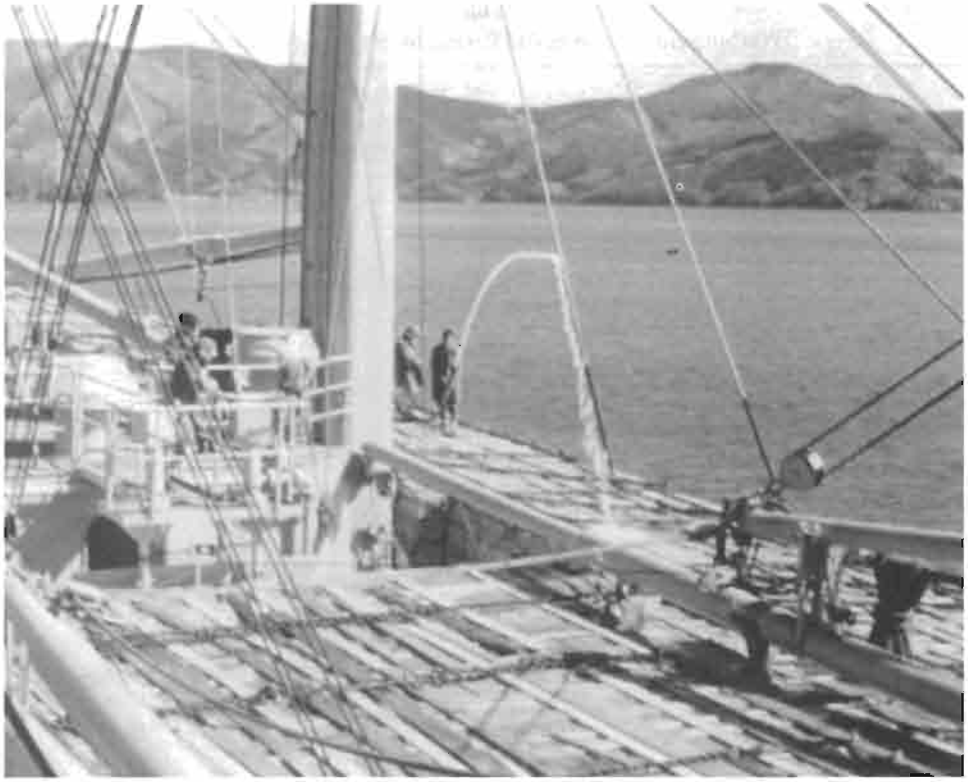

Figure 8
Deckload of oyster seed being wet-down with seawater before departure from Momono Ura, Sendai Bay, Miyagi Prefecture, Japan, enroute to Washington State. Photograph by C. E. Lindsay.

tion or pest control measures are taken with domestic seed except to prohibit transfers of infested seed to clean areas.

Growing Oysters

The private beds upon which oysters were and are grown in Washington vary in quality. The best growing ground will produce market-sized oysters in $2^1/_2$ years, medium good ground in $3^1/_2$ years, and the poorest ground in 5 years or more (Fig. 9). Fatness also varies greatly. The best fattening grounds are limited in extent, and, in modern practice, they are used mostly to fatten adult oysters which are taken from growing beds where they may have been cultured for 1–3 years.

Some farmers use their safest ground for holding seed. They may hold it for 6 months through the summer after planting or for as long as 12–16 months. Where a farmer's ground is limited all growing may be done on a single piece of ground. Better utilization of a given piece of ground may be to go back to techniques developed by the Japanese several hundred years ago. This usually involves longline or stake culture above the substrate. A newer technique is to place seed in polyethylene mesh bags fastened to racks off bottom or in bags on firm bottom (Fig. 10). The oysters may be removed from the bag and marketed as they reach half-shell size, or they may be spread on tidelands for further growth for 1–2 years before opening. Where oysters are cultured intertidally, the farmer observes the response of the oysters to a particular location and where possible modifies cultural techniques to improve survival, growth, and fatness.

Harvesting

In the beginning, many growing and harvesting activities were accomplished by hand, either by the individual farmer or by large bed crews. Oysters were picked into bushel baskets and put in skiffs, small scows, or floats and much later into 10 to 20-bushel tubs. Wheelbarrows to carry oysters were also used on firm beds. As larger areas were planted and deeper ground was used, towed and self-powered dredges were brought in from

Table 1
Washington's commercial Pacific oyster seed production.

Standard cases of seed imported from Japan: Year	Standard cases of seed imported from Japan: Amt.	Dollars/case Japanese oyster seed	Equivalent cases of oyster seed produced in N. Hood Canal
1924	400		
1925	840		
1926	1,403		
1927	4,050		
1928	1,367		
1929	1,500		
1930	2,750		
1931	?		
1932	34,741		
1933	64,550		
1935	71,787		
1936	42,953		
1937	29,350		
1938	14,705		
1939	14,747		
1940	13,493		
1941	10,432		
1942	0		
1943	0		
1944	0		
1945	0		
1946	0		
1947	40,502	5.86	
1948	27,369		
1949	41,026		
1950	36,861		
1951	36,668		
1952	68,975	7.98	
1953	63,815		
1954	64,679		
1955	46,680		
1956	74,059	8.05	1,000
1957	48,863	8.67	0
1958	47,862	10.28	2,000
1959	48,984		2,500
1960	36,304	9.95	3,500
1961	27,479	9.88	3,700
1962	32,799	10.83	5,200
1963	42,392	11.00	2,700
1964	30,535		0
1965	27,283		6,900
1966	14,922	17.00	9,200
1967	34,229		15,900
1968	28,085	17.00	6,200
1969	33,600	16.50	3,000
1970	22,213	19.40	5,000
1971	25,486	20.50	32,900
1972	7,321	25.50	33,400
1973	8,346	29.00	34,200
1974	12,406	29.28	46,700
1975	7,866	28.64	0
1976	15,820	32.50	0
1977	30,399	32.90	50,000
1978	0		45,000
1979	4,900	46.40	29,000
1980	0		
1981	0		40,150
1982			6,160

the Atlantic coast or built locally (Fig. 11). On firm ground, farm tractors were used on beds accessible from the uplands. As operations grew larger and labor costs increased, larger companies had to adapt or develop mechanical equipment for increased efficiency. Depending on the type of ground and type of product cultured, however, hand harvest is still used where appropriate, even by the largest companies.

Once harvested for processing, the oysters are brought to a shore plant where they are opened by hand using knives adapted to the characteristics of the Pacific oyster shell. Other than steam, no mechanical method of shucking has yet been developed. In the past, one person operated small shucking plants and large plants had as many as 40 openers. At present, few one-person plants operate, but even the largest plants use only enough openers to fill their day-to-day market demand.

Marketing

In the early days, oysters were mostly opened fresh and retailed in small paper containers or shipped in bulk to wholesalers or directly to restaurants. As sanitary laws were adopted, oysters were packed in glass and refrigerated (Steele, 1964). Larger quantities were sealed in gallon and half-gallon cans, refrigerated, and used in the institutional trade. In some instances, oysters were shipped in bulk to wholesalers in 10-gallon milk cans for repacking. During World War II, large orders were sold to the military services. After the war, recipes were developed for oyster stew, and large volumes were produced and marketed. In addition, small quantities were smoked and canned. With Federal approval of imports from Japan and Korea, however, canned oysters were imported at prices that undercut local processors. In recent years, small and medium

Figure 9
Clusters of 2-year-old oysters being separated by bed crew at Tokeland, Willapa Bay, 1948. Photograph by C. E. Lindsay.

Figure 10
Rack and bag oyster culture in northern Willapa Bay. Photograph by R. Shuman.

Figure 11
The self-powered oyster dredge, *Pacific*, with load of transplant oysters for rebedding on fattening ground in Willapa Bay. Photograph by C. E. Lindsay.

Pacific oysters have found acceptance in the retail and restaurant trade. Extra small oysters are used for cocktails, while small and medium oysters are opened as half-shells, both to be eaten raw. Large oysters are barbecued in the shell.

Between 1937 and 1993, Washington commercial oyster production ranged from 458,000–1,553,000 gallons. Production since 1986 has averaged over 930,000 gallons. About 51% were produced in Willapa Harbor, 36% in Puget Sound, and 13% in Grays Harbor.

The Industry

The numbers of individuals or firms engaged in growing Pacific oysters before World War II is not well known as no licensing system was in effect. Steele (1964) reports that 13 companies formed the Pacific Coast Oyster Growers Association in 1930. Since then, membership rose and fell as companies were formed, were bought out, or went out of business. Probably, the largest number of firms operated during World War II. Afterward, larger companies acquired the assets of smaller companies and individuals.

About 1951, the state required that oyster farms have licenses, and anyone could buy a license regardless of acreage owned or leased. In 1991 the number of commercial licenses totalled 253 (Zinicola[4]). However, most oysters were produced by less than 20% of the growers. Production statistics by company are not available.

[4] Zinicola, T. 1992. Statistician, Data Manage. Div., Wash. Dep. Fish., 115 General Admin. Bldg., Olympia. Personal commun.

Predator Control

Modern oyster farmers control predation by culturing around the predators wherever possible. If this is not possible, then direct elimination must be used. One of the most serious predators is the Japanese oyster drill, which was introduced with oysters from Japan during the early imports. It first appeared in Samish Bay and later in other bays. Most of the rest of the infestations were the result of transfers of infested oysters or equipment from previously infested locations. Spread of drills is by physical transport as the drill does not have pelagic larvae. The most serious predation is on seed and thin-shelled oysters.

In 1945 regulations were adopted to prohibit transfer of drills among oyster plantings. A permit system was developed and operated by the WDF for transfers within and from outside the state and continues to the present. In 1947 inspection of Japanese seed was begun and continued until seed oyster imports ceased in 1979. Methods for drill control in Japan have already been described. For many years, the drill quarantine in Washington was successful, but gradually, through carelessness or deliberate violation, additional beds became infested. Even so, many beds remain uninfested. Considerable research has been directed toward eradication of drills, but no feasible method has been found.

Other predators include several species of cancroid crabs capable of breaking open seed and adult oysters. The red crab, *Cancer productus*, probably causes the most damage, while the Dungeness crab, *Cancer magister*, is less aggressive but a substantial predator in Samish Bay on oysters with thin shells.

Starfish remain serious predators of seed and adult oysters in some areas of Puget Sound and Hood Canal. If not controlled, they can wipe out entire oyster crops. They are not a serious problem in the coastal bays as their abundance is low. In bays where they are abundant, the only feasible control method is by hand picking as beds are being worked. Growers have found that with steady removal, starfish damage can be kept to a minimum. Currently, the only permissible control method is by picking or trapping.

Additional pests are the ghost shrimp, *Callianassa californianus*, and mud shrimp, *Upogebia pugettensis*. Both make burrows which riddle the substrate so that oysters smother. The most effective control is to apply carbaryl (Sevin[5]), an insecticide, to discrete infested areas before planting them with oysters. For more than 25 years, the WDF has carefully controlled and limited applications of carbaryl. Many beds have been rehabilitated in Willapa Bay and Grays Harbor without substantial damage to the Dungeness crab population. Nevertheless, the use of carbaryl is controversial and could be banned at any time.

[5] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Pollution Problems

Sanitary control of oyster production came into effect nationwide in about 1925 following an outbreak of typhoid fever from eating raw oysters produced on the U.S. Atlantic coast. In Washington, all tidelands near cities had long been decertified for direct opening. Oyster culture on these lands was terminated since much productive ground was available in certifiable areas. This situation generally prevailed until the 1960's when residential and commercial development along the shores began to increase. The Washington State Health Department found it necessary to decertify those places where sanitary surveys and water sampling detected pollution from human and animal sources, seasonally or permanently. The agency did not have the authority, however, to require correction of the problem at its source.

In areas where growing oysters were affected by pollution, the state allowed growers to relay them to clean areas in limited instances. However, relaying as a routine depuration method has been discouraged. Thus far, shoreside depuration plants have not been approved. During the past 10 years, increased surveys have identified several previously clean areas where nonpoint source pollution has occurred from failed septic systems, livestock pastures, and concentrations of harbor seals. As a result, additional areas have been decertified.

State legislation resulting from the 1992 sessions of the legislature has provided funding to assist the counties in correcting some of the pollution sources. Implementation of the 1991 State Growth Management Act may also result in local ordinances designed to prevent further degradation of water quality.

Another source of pollution believed to affect oyster growth and survival has been effluent from pulp mills in Bellingham, Anacortes, Everett, and Hoquiam. There is no question but that effluent discharged into bays is toxic (Woelke, 1972). However, proving that mill waste detrimentally affected oyster beds several km (miles) away from a discharge has been impossible. Federal and state action has required mills to reduce effluent discharges. Mills in two of the places mentioned have closed. Oyster growth and fatness on some of the affected beds seems to have improved, but the cause and effect relationship has not been established.

Pollution resulting from residential development in the Puget Sound basin also may have negative effects on water quality, and effort is being directed toward reducing uncontrolled storm water runoff, effects of logging, industrial waste discharge generally, and use of pesticides and fertilizers. Oysters and other filter feeders are finally recognized as indicators of water quality, and their continued cultivation may provide impetus for avoiding further water quality degradation as well as helping to reverse the trend.

In some bays, mass mortality of oysters has occurred occasionally, mostly among 2-year-olds. After 5 years of research, the WDF failed to identify disease or pollution as a direct cause. The conclusions were that lack of spawning in warm years at the heads of some highly productive bays contributed to the mortality.

Oyster Hatcheries

Oyster hatcheries in Washington have a history nearly as long as Pacific oysters have been imported. Professor Trevor Kincaid, University of Washington, Seattle, recognized early on that summer water temperatures in Washington were too cold for *C. gigas* to reproduce. In 1925 he attempted to spawn *C. gigas* adults artificially, grow larvae to setting size, and obtain a set at Samish Bay (Steele, 1957). That effort failed, and 2 years later, with the help of some oyster growers, Kincaid built ponds near Naselle on Willapa Bay, again without success. During the 1950's, Kincaid and others had a large covered concrete pond at Nahcotta on Willapa Bay. A roof served to keep out the frequent rains and to control solar radiation much as with an agricultural greenhouse. For several years efforts were made to achieve commercial setting of *C. gigas*, but these too were unsuccessful.

Nevertheless, the desire to develop regular domestic seed supplies remained strong, and during the 1960's several efforts by oyster growers were tried, using information developed by V. L. Loosanoff and H. C. Davis of the Milford Laboratory of the Bureau of Commercial Fisheries (Loosanoff and Davis, 1963). A small hatchery was operated for several years by the Engman Oyster Co., but it closed eventually due to lack of a suitable permanent site. However, one of Engman's former employees, Lee Hanson, moved to Netarts Bay, Oreg., and has operated a hatchery there since 1979 to produce setting-sized larvae which were then shipped to growers who placed the larvae in tanks with cultch in warm seawater (Robinson, 1997). This technique resulted in successful commercial setting by many people who bought larvae from him and from others who got into the business. Lee Hanson's operation continues, but in the meantime the Coast Oyster Co. set up hatcheries at Nahcotta and later at Quilcene in 1978 (Fig. 12). The Quilcene hatchery succeeded and has since expanded substantially. Biologists working at the Coast Co. hatchery developed a viable system to produce seed consistently for planting and culture. Much research went into the eventual success through growing suitable food for larvae and learning effective handling techniques. Coast uses 90% of its hatchery production to seed its own beds and sells the rest (Donaldson[6]). Another shellfish hatchery has been built by Taylor United Oyster Co. on Dabob Bay. This hatchery began producing oyster and clam seed in 1990.

Other smaller hatcheries are being operated by Dahman Oyster Co. at Totten Inlet, R. Wilson at Bay Center, R. Poole at Lummi Island, Westcott Bay Oyster Co. on San Juan Island, and the WDF on Hood Canal.

The capacities of shellfish hatcheries range from several million, to 5 billion, and to as high as 20 billion setting-size larvae per year. As the larvae are set on different kinds and sizes of material, such as whole shell, crushed shell, and plastic tubes, it is difficult if not impossible to compare the quantities of hatchery-produced seed with case equivalents of Japanese seed. However, a goal that seems to be reachable is to produce all the seed the industry needs and not have to depend on natural reproduction which is often variable among years.

The apparent success of modern shellfish hatcheries has resulted from exchange of information between university, government, and private researchers worldwide. Even in Japan, much hatchery research has been conducted with the objective of stabilizing supplies of oyster seed. Natural variations of weather and hydrography result in variations in seed supply of natural stocks even with native species in their native areas. An interesting development in late 1992 was the receipt of orders in Washington for Pacific oyster seed from buyers in Japan. The orders were the result of a spatting failure in Miyagi Prefecture, the location of the original U.S. seed source. The first report to reach one of the authors (Lindsay) was from the Lummi Island shellfish hatchery (Poole[7]). Later it was learned that several other Washington hatcheries and private collectors of natural catch seed had also received orders for shipment in early 1993. Occasional spatting failures in Japan had occurred in the past as well but the increased domestic demand for seed apparently caused Japan growers to seek an outside source. If the seed from the U.S. Pacific Northwest survives and grow well, future orders can be anticipated. Successful aquaculture requires a dependable seed supply, and it would appear that economics may now be favorable for further hatchery development.

[6] Donaldson, J. 1992. Manager, shellfish hatchery, Coast Seafood Inc., Quilcene, Wash. Personal commun.

[7] Poole, R. 1992. Owner, Sound Sea Farms, Lummi Is., Wash. Personal commun.

Figure 12
Interior of Coast Seafood Co. shellfish hatchery at Quilcene, showing algae culture tanks. Photograph by Coast Seafood Co.

Future Problems

Washington oyster farmers have been successful because, with the advent of statehood, tidelands were transferred from Federal ownership to the new state. Several laws passed by early state legislatures allowed private individuals to purchase and own tidelands. Ownership rights made certain that oyster farmers could prohibit trespass and protect their crops from unauthorized removal. Owners were then able to plan cultural activities and be assured that their investments could not be arbitrarily taken away from them. The entire system of culture has been built on the basis of these ownership rights and which are generally recognized by the state's citizens. Oysters have also been legally identified as personal property. In recent years, there have been attempts to abridge ownership rights on tidelands, but so far they are intact, subject to state laws and local ordinances which may affect some aspects of culture or use of tidelands and beds in navigable waters. Nevertheless, the state's Shoreline Management Act defines aquaculture as a primary use of aquatic areas.

When oyster farmers expand beyond the tidelands and seek to lease subtidal bottoms, upland owners and others have an opportunity to intervene in the leasing process. Some objections or proposed limitations to the use of the leases may be considered legitimate where matters of aesthetics or navigation are concerned. Some objections are nevertheless unreasonable since objectors do not own the bed land. At times, different elements of the management agencies themselves object to some aspects of culture, contending that young salmon or tideland inhabitants are impacted. As a result, the oyster farmers may have to accept environmental requirements imposed by management agencies, but once granted the farmer is free to operate within the imposed limitations for the term of his lease or permit.

The future of the Pacific oyster industry in Washington seems fairly bright. If the pollution threat is brought under control, if oyster economics remain competitive, and if markets continue to expand, then oyster farmers will be willing to continue to invest time and money to help the industry grow.

Pacific Razor Clam Fishery

The Pacific razor clam inhabits surf-pounded beaches on the Pacific coast from the Aleutian Islands in Alaska to northern California (McMillin, 1924). In Washington, razor clams occur on four major beach areas from the Columbia River to the Moclips River (Fig. 2), on the Quinault Indian Reservation north of Moclips, and on various scattered, remote beaches on the northern coast including beaches at Kalaloch. The clams inhabit the intertidal surf zone from about the +1 m (+3-foot) level to extreme low water and in some subtidal areas. This zone has a high oxygen concentration. Subtidally, divers have found large amounts of wood-chip detritus which greatly depletes the oxygen needed by this species. Another species of razor clam, *Siliqua sloati*, is located subtidally (Hertlein, 1961). Larger numbers of *S. patula* occur subtidally in Alaska than further south because the water is colder and has more dissolved oxygen.

Because the surf zone environment is dynamic, few animals survive there. The only mollusks present besides razor clams are scattered tellins and mussels on nearby rocks. However, amphipods and isopods abound along with various species of annelids. Sand dollars in large numbers, Dungeness crabs, various species of flatfishes, and the red-tailed surf perch, *Amphistichus rhodoterus*, occur just seaward of the surf zone. The Dungeness crabs, flatfishes, and surf perch are predators of razor clams, as are gulls and ravens which prey mostly on their juveniles (Lassuy and Simons, 1989).

Human use of razor clams dates from before the Caucasian settlements as the Indians used them for food and later for trading with the settlers. Evidence of their use had been found in middens (McConnell[8]). The commercial razor clam industry began in Oregon in 1894 when P. F. Halfarty first developed a method for canning the clams using glass jars. He later substituted tin cans for the jars. In 1902 he moved the operation to Grays Harbor, Wash. (Schaefer, 1939). Soon, other companies began canning operations there, and the commercial fishery expanded very rapidly. The razor clams were harvested by specialized hand-shovels, the same method used currently (Fig. 13).

The rapid expansion of the unregulated fishery led to a decline in the number of razor clams, however, and in 1902 the Fish Commissioner reported, "Our long wide, sandy seabeaches are the home of the much prized razor clam, once so abundant but now fast decreasing in numbers on account of overfishing and lack of protection" (Lassuy and Simons, 1989). In 1905 the first regulation was passed which set dates for the commercial season, but the commercial fishery continued to increase. In that year, 8 million pounds of clams were

[8] McConnell, S. J. 1972. Proposed study of the spawning and larval rearing of the Pacific razor clam (*Siliqua patula*). Unpubl. proposal to Wash. Dep. Fish., Olympia.

Figure 13
A sport digger with his shovel and catch of razor clams; other diggers are in background. Photograph by D. Simons.

harvested and processed into 3.2 million 1-pound cans (Schink et al., 1983). At this time, sport digging began taking an additional quantity of clams, and in 1917, separate seasons were established for commercial and recreational clam digging. People became more aware that the numbers of clams were declining, as individual catches and total harvests declined noticeably. Finally, in 1929 the state adopted the first substantial restriction on sport digging by setting a daily limit of 36 clams for each digger. In addition, a minimum length limit of 3½ inches (9 cm) was established for the commercial and recreational fisheries. The length limit was in effect for 13 years before it was determined that it was ineffective and had actually contributed to more clams being wasted by discarding undersized clams.

The commercial fishery remained unchanged until 1942 when annual quotas were established. They were adopted to help reduce the harvest from the combined commercial and sport fisheries. The quota system had limited success and contributed to a growing feud between commercial and sport fishermen. Each blamed the other for the decline of the razor clams. Both had strong enough support to convince the WDF to adopt stricter regulations to preserve the clams.

From 1946 through 1967, quotas became steadily smaller or people were allowed to dig in smaller areas. The commercial harvest decreased steadily from 7.6 million clams in 1946 to 600,000 in 1967 (Table 2) (Tegelberg and Magoon, 1969). By 1968, the true commercial clam fishery had ended as all commercial digging in Willapa Bay ceased; however, a separate commercial fishery continued on the Quinault Indian Reservation (Table 3). The fishery on the "Willapa Spits" as they are called, remained small with landings of 7,000–25,000 pounds each year. The clams from those sand bars were used mostly for crab bait as they were usually small and in poor condition. In sum, the demise of the commercial industry on Washington beaches was a combination of: 1) The establishment of a quota system, 2) a large increase in the sport fishery, 3) a decline in recruitment of year classes of clams, 4) the introduction of less expensive clams from the U.S. east coast to local markets, weakening the market for razor clams, 5) widespread illegal sales of sport-dug clams or bootlegging, and 6) increased use of razor clams for Dungeness crab bait (Schink et al., 1983).

In the late 1970's, the number of people buying a $5 commercial clam license increased suddenly. The in-

Table 2

Yearly combined razor clam fishery including sport digging intensity, sport catch, commercial catch, and total catch, 1946–67.[1]

	Thousands of sport diggers						Catch (million clams)		
Year	Long Beach	Twin Harbors	Copalis	Mocrocks	Kalaloch	Total	Sport	Commer.	Total
1946	134	28	46			208	7.4	7.6	15.0
1947	167	35	59			261	9.4	7.1	16.5
1948	79	39	69			187	5.2	6.8	12.0
1949	84	62	87			233	5.5	4.0	9.5
1950	86	63	88			237	4.6	1.4	6.0
1951	161	110	151			422	10.0	2.8	12.8
1952	154	90	122			366	8.1	2.6	10.7
1953	163	144	161			468	11.8	2.8	14.6
1954	186	171	165			522	12.5	2.3	14.8
1955	158	151	165			474	11.3	2.5	13.8
1956	150	154	155			459	10.1	1.7	11.8
1957	172	186	188			546	11.6	2.1	13.7
1958	174	247	263			684	14.9	3.0	17.9
1959	197	162	166	14	7	546	9.8	2.3	12.1
1960	149	128	205	17	11	510	6.8	0.9	7.7
1961	157	100	278	26	14	575	8.2	1.2	9.4
1962	183	172	272	45	11	683	11.2	0.7	11.9
1963	192	213	293	52	15	765	13.1	1.0	14.1
1964	120	208	261	41	13	643	10.8	0.0[2]	10.8
1965	127	154	252	50	—	583	9.2	0.6	9.8
1966	185	159	288	50	—	682	11.5	1.0	12.5
1967	215	173	275	86	—	749	11.5	0.6	12.1

[1] Note: 36-clam limit 1946 and 1947; 24-clam limit 1948 through 1959, except 18 in 1950; 18-clam limit 1960 through 1967.
[2] Season closed after 2 days owing to a petroleum spillage.

crease was related to a depressed local economy, and it was also a means for sport diggers to bypass the existing sport limit of 15 clams. Many of the true commercial diggers urged the WDF to request that the legislature adopt an increased license fee of $50 to discourage the "sport-comm" digger. It worked. The number of licenses decreased from a high of 1,700 in 1982 to about 350 currently. During this time, the commercial fishery on the Indian reservation actually increased. Most of the clams were exported to Japan. But clams on the reservation, similar to others, were over-harvested and the fishery began to collapse in the early 1980's. Overharvesting, combined with apparent failures in spawning or recruitment and a clam disease, has not allowed the reservation clam fishery to recover until recently.

Table 3
Razor clam production by the Quinault Indian Tribe, 1970–82.

Year	Pounds landed[1]	Year	Pounds landed[1]
1970	750,000	1976	294,952
1971	678,838	1977	373,142
1972	379,086	1978	890,161
1973	179,818	1979	645,389
1974	201,139	1980	373,581
1975	135,033	1981	84,030
1976	294,952	1982–91[2]	

[1] One pound = about 4.2 clams.
[2] Fishery closed; it opened in 1992 but landings data are not available.

Meanwhile, the recreational fishery on state beaches became so huge (Fig. 14) that more clams were landed by sport diggers than by combined commercial and sport diggers in the mid-1940's. After the first sport limit was set in 1929, there followed a succession of decreased limits and seasons to conserve the clam population in spite of increasing numbers of diggers. The major limit changes of the sport fishery were: 1929, 36 clams allowed; 1948, 24 clams; 1960, 18 clams; 1973 to present, 15 clams.

The WDF found it difficult, however, to manage the clam fishery properly because the number of users was large and vocal and the fishery was extremely visible. Public meetings to discuss regulation recommendations turned unruly with angry clam diggers demanding their "rights." For over 40 years, motel/trailer park operators and chambers of commerce banded together to form powerful lobbies, which influenced the setting of regulations. Meanwhile, most biologists who worked with razor clams recommended more conservative regulations than were adopted. The annual harvest peaked at almost 13 million clams and over 950,000 digger trips in 1977 (Table 4) (Ayres and Simons, 1991). Besides the actual harvest, additional millions of clams were lost as people broke them while digging and discarded them and small ones as well (Fig. 15). In response, the

Figure 14
Razor clam sport diggers. Photograph by D. Simons.

WDF issued warnings to clam diggers that continual high wastage would lead to early closures. The warnings were mostly ignored and seasons had to be shortened.

This resulted in a tremendous upheaval, however, in the tourist industry that had relied on the clam digging. People who had reservations for motels cancelled them, and as the closures were often made without much notice, people were hesitant to make reservations for the following year. The impact to the local economy was severe, as many of the businesses depended heavily on tourists digging razor clams. The pattern of abuse and declines of the razor clam resource, caused in part by recruitment failures and restrictive closures, became serious in the late 1970's and early 1980's. Seasons were open only 4–5 months. But while this saved many clams that would have been wasted, it did not lead to recovery of the resource.

Beginning in 1983, the razor clam resource was severely damaged by a new disease now known as NIX or Nuclear Inclusion Unknown (Elston, 1986). After a 5-month closure of the digging season, biologists surveying the razor clam resource found the clams substantially scarcer than they ever had been. Further investigation revealed that almost 25 million razor clams of all sizes, representing over 90% of the razor clams in Washington, were missing and most likely had died. The Battelle Marine Laboratory in Sequim found that a previously unknown gill parasite was infecting the razor clams. This bacteria-like organism infected the epithelial cells of the gills and prevented the clams from respiring (Lassuy and Simons, 1989).

The WDF responded by closing the entire fishery for 2 years to allow for some recovery. Fortunately, a good spawning and recruitment from surviving clams did provide enough clams to allow some digging in the fall of 1985. This became a turning point for the management of razor clams in Washington. Where previously the capacity of the WDF to manage the resource properly was often compromised by lobbying of user groups, new management plans were put into place that reduced the seasons to as short as 17 days and the harvest to only 2.5 million clams. For the most part, the plans were supported by the clam diggers who hoped it would bring the clam resource back to historic quantities. Unfortunately, the clams continue to be infected with NIX, and an increased mortality rate has kept the popu-

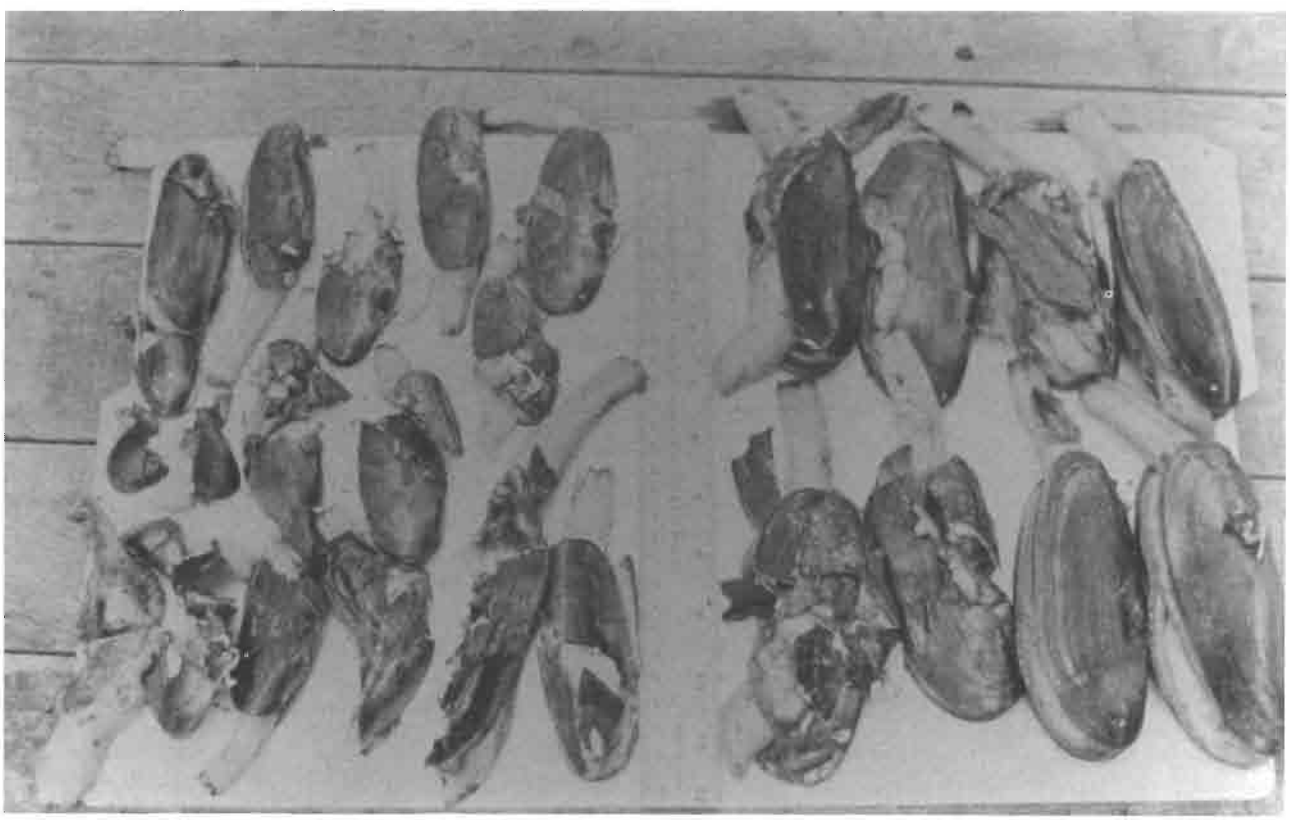

Figure 15
Sport diggers break and leave to die many razor clams while harvesting them. Photograph by D. Simons.

Table 4
Seasonal summary of razor clam sport digging on the ocean beaches, 1949–91.[1]

	Long Beach			Twin Harbors			Copalis			Mocrocks[2]			Totals[3]	
Year	Effort	CPUE	Wastage	Effort	CPUE	Wastage	Effort	CPUE	Wastage	Effort	CPUE	Wastage	Effort	Harvest
1949	84,000		28.2%	62,000		15.2%	87,000						233,000	5,466,000
1950	86,000			63,000			88,000						237,000	4,571,000
1951	161,000		11.5%	110,000		9.9%	151,000		12.7%				422,000	10,004,000
1952	154,000		12.8%	90,000		10.0%	122,000		13.3%				366,000	8,123,000
1953	163,000		5.5%	144,000		4.5%	161,000		8.7%				468,000	11,768,000
1954	186,000		6.5%	171,000		4.3%	165,000		4.4%				522,000	12,447,000
1955	158,000	20.4	8.1%	151,000	20.8	6.6%	165,000	22.9	8.0%				474,000	11,315,000
1956	150,000	17.8	7.8%	154,000	20.0	6.5%	155,000	22.7	3.0%				459,000	10,119,000
1957	172,000	17.3	9.6%	186,000	17.7	9.1%	188,000	20.8	7.7%				546,000	11,625,000
1958	174,000	19.9	9.0%	247,000	19.7	3.5%	263,000	20.3	5.7%				684,000	14,946,000
1959	197,000	20.6	6.1%	162,000	12.2	3.0%	166,000	16.3	4.9%	14,000	17.0		539,000	9,765,000
1960	149,000	12.6	5.0%	128,000	6.7	2.0%	205,000	15.9	5.0%	17,000	13.9		499,000	6,656,000
1961	157,000	13.5	5.3%	100,000	11.3	11.0%	278,000	14.0	2.6%	26,000	15.0		561,000	8,054,000
1962	183,000	14.3	8.2%	172,000	15.7	4.9%	272,000	15.2	5.7%	45,000	16.4		672,000	10,886,000
1963	192,000	13.6	19.7%	213,000	14.7	14.9%	293,000	14.0	12.1%	52,000	14.8	6.3%	750,000	13,044,000
1964	120,000	13.7	17.8%	208,000	14.1	13.5%	261,000	14.7	6.5%	41,000	16.2	8.0%	630,000	10,712,000
1965	127,000	15.1	4.0%	154,000	14.2	4.6%	252,000	13.6	7.9%	50,000	15.3	2.7%	583,000	9,201,000
1966	185,000	14.2	14.9%	159,000	12.0	12.1%	288,000	14.2	13.5%	50,000	16.4	4.0%	682,000	11,554,000
1967	215,000	16.3	9.1%	173,000	13.0	4.1%	275,000	11.8	6.9%	86,000	14.5	4.8%	749,000	11,478,000
1968	159,000	12.4	18.7%	120,000	8.8	9.2%	240,000	12.8	8.6%	115,000	15.5	8.0%	634,000	9,420,000
1969	104,000	10.7	19.2%	100,000	11.1	10.4%	248,000	13.4	8.8%	103,000	15.1	6.5%	555,000	8,358,000
1970	120,000	9.9	9.4%	87,000	8.8	5.9%	274,000	9.2	4.4%	142,000	11.8	6.1%	623,000	6,795,000
1971	154,000	12.9	7.6%	104,000	9.4	3.1%	213,000	8.9	2.4%	145,000	11.6	1.0%	616,000	6,966,000
1972	87,000	8.2	12.2%	58,000	6.2	6.1%	130,000	7.8	10.1%	88,000	10.9	12.9%	363,000	3,495,000
1973	106,000	9.3	2.5%	67,000	11.5	4.9%	257,000	14.0	5.8%	105,000	13.6	9.4%	535,000	7,487,000
1974	99,000	8.1	5.1%	92,000	11.5	3.5%	321,000	12.1	3.7%	93,000	2.2	2.2%	605,000	7,505,000
1975	107,000	9.7	2.9%	101,000	11.9	4.8%	332,000	13.2	3.7%	171,000	14.5	4.4%	711,000	9,746,000
1976	142,000	9.4	2.5%	106,000	12.5	1.8%	354,000	11.5	3.0%	205,000	13.9	2.5%	807,000	11,652,000
1977	175,000	9.0	9.1%	160,000	10.0	8.4%	353,000	12.7	6.5%	262,000	14.8	1.0%	950,000	12,600,000
1978	115,000	11.3	13.0%	101,000	9.3	7.0%	177,000	11.5	9.5%	275,000	12.8	5.9%	668,000	8,787,000
1979	231,000	11.3	2.0%	158,000	10.5	3.1%	306,000	13.6	5.7%	272,000	13.7	4.0%	967,000	13,025,000
1980	149,000	6.8	3.4%	94,000	9.2	6.7%	274,000	12.7	4.0%	185,000	12.8	5.5%	702,000	8,304,000
1981	73,000	9.7	6.0%	97,000	9.0	3.6%	298,000	7.2	8.0%	81,000	5.5	4.7%	549,000	4,549,000
1982	126,000	10.5	1.9%	79,000	9.2	5.4%	281,000	11.9	5.6%	135,000	13.5	8.3%	621,000	7,823,000
1983	106,000	9.6	4.2%	52,000	10.9	7.8%	203,000	11.3	10.7%	112,000	12.5	8.2%	473,000	6,026,000
1984	0			0			0			0			0	0
1985	0			0			0			0			0	0
1986s	61,000	11.4	0.0%	54,000	11.5	0.0%	113,000	11.3	0.0%	44,000	13.1	0.0%	272,000	3,169,000
1986f	1,000	4.3	4.7%	1,000	7.8	9.0%	3,000	13.3	11.0%	1,000	13.6	10.0%	6,000	75,000
1987s	43,000	12.0	6.6%	22,000	9.6	6.2%	89,000	10.8	9.8%	36,000	6.5	6.5%	190,000	2,477,000
1988s	79,000	13.1	5.0%	27,000	10.8	4.0%	106,000	9.9	1.0%	39,000	12.2	0.0%	251,000	2,754,000
1988f	23,000	13.3	0.0%	20,000	12.1	0.0%	0			0			43,000	550,000
1989s	79,000	11.7	2.9%	32,000	11.4	8.3%	57,000	12.4	9.1%	27,000	13.7	4.4%	195,000	2,524,000
1989f	26,000	12.4	0.0%	13,000	12.2	0.0%	16,000	13.0	0.0%	0			55,000	700,000
1990s	64,000	10.2	11.7%	24,000	10.9	4.0%	82,000	14.2	4.8%	34,000	14.8	2.5%	204,000	2,580,000
1990f	0			0			25,000	13.7	0.0%	7,000	14.2	0.0%	32,000	440,000
1991s	115,000	11.6	5.6%	0			93,000	8.8	2.2%	66,000	13.4	1.2%	274,000	3,233,000
1991f	22,000	13.3	0.0%	0			0			0			22,000	299,000
Total	5,579,000	12.0	8.4%	4,616,000	11.5	6.6%	8,680,000	13.0	6.5%	3,124,000	12.8	5.0%	21,999,000	343,073,000

[1] Seasonal summary from fall of previous year through spring of year listed; annual summaries beginning in 1987.
[2] Area between Copalis River and Moclips River.
[3] Includes wastage.

lations from increasing as expected. For example, on Twin Harbors Beach, a major management area, lack of recruitment for 3 years coupled with continued digging and losses from NIX has left this area with its lowest clam population since population estimates were begun. The WDF hopes that an extended closure of this area will allow this population to recover.

In the late 1970's, it was recognized that the razor clam fishery needed additional help. In 1979, the state legislature provided for a razor clamming recreational license. This provided funding for additional enforcement, enhancement, and public education (Schink et al., 1983). Initially, clam enforcement efforts were doubled, but those were reduced in the subsequent years as personnel were reassigned to other areas. In addition, a twofold enhancement program was also initiated. The first part involved rearing juvenile razor clams in a hatchery located at the WDF Nahcotta Laboratory on Willapa Bay. For 7 years, hatchery personnel attempted to develop methods to raise millions of clams to augment the declining populations. But over that period it produced only 1.8 million clams for transplant. Poor water quality, mortalities of clams, and funding cuts led to the closure of the hatchery in 1987 (Creekman[9]).

The second part of the enhancement program involved transplants of juvenile razor clams from a subtidal area to intertidal beaches. The clams were dredged from the subtidal area offshore from the razor clam beaches with a hydraulic airlift suction device operated from a boat. It could dredge clams in 4.5–15 m (15–50 feet) of water (Rickard and Newman[10]). In 1985, over 100 million razor clams, from 3–6 mm (⅛–¼ inches) long, were transplanted to poor production beaches on Long Beach and Twin Harbors, and in 1988, over 30 million clams were transplanted (Rickard et al.[11]).

It became important to know how much of a contribution the transplants made to existing clam stocks. This was nearly impossible to determine, however, as the clams, being small, were both difficult to mark and to monitor their survival. As a result, and because funds were cut, the transplant program was discontinued in 1992.

The only remaining program originally funded by the license is the public education program. It specifically targets razor clam diggers and attempts to teach them a conservation ethic to help balance effort with a declining resource. It appears to be successful in making people more aware of the necessity to conserve this valuable resource.

The razor clam resource is subject to pollution, but much less so than some other shellfish-producing areas in the United States. Petroleum spills, with refined petroleum products, have been the most serious source of pollution. In 1964, a barge containing aviation gas grounded on the coast near Moclips, Wash., leaking thousands of gallons of fuel and killing over 200,000 razor clams (Tegelberg, 1967). Other spills, mostly of bunker-C type oil, have resulted in limited impacts on clams while killing many large and small birds.

In November 1991, a new problem surfaced when a rare, but naturally occurring marine toxin, domoic acid, infected the razor clam populations in Washington and Oregon. While it does not harm the clams, humans who consume shellfish contaminated with domoic acid develop symptoms such as vomiting, cramps, diarrhea, dizziness, permanent loss of short-term memory, and in severe cases, death. A total of 23 people soon suffered symptoms of domoic acid poisoning after eating razor clams.

In fall 1991, the Washington State Department of Health had to close the razor clam fishery owing to domoic acid concentrations. Testing through spring 1992 showed continued high concentrations of domoic acid in razor clams along the entire coast of Washington. As a result, all recreational and commercial harvesting was prohibited until concentrations dropped to below 20 ppm, i.e., the acceptable safe concentration listed by the U.S. Food and Drug Administration. In fall 1992, domoic acid concentrations rose again on beaches south of Grays Harbor, causing a digging closure there.

An additional problem occurred in the fall of 1992, with concentrations of paralytic shellfish poisoning (PSP) that were higher than any found before in razor clam tissue. Concentrations were high on all beaches from August through September, but finally fell to acceptable quantities on the beaches north of Grays Harbor to allow for some harvesting. The combination of two marine toxins in the razor clams created much anxiety and uncertainty for the clam diggers. As a result, digging effort was less than expected.

The future of Washington's razor clam resource remains clouded because clam abundances are low and digging effort can be high. Even though studies are currently being conducted on NIX and domoic acid, important questions about the resource will probably remain unanswered for many years, especially if funding cuts continue to reduce research. In the future, the managing agency must have full control to regulate the razor clam resource for the safety of the public and the

[9] Creekman, L. 1987. Razor clam hatchery in Washington State. Wash. Dep. Fish., Draft Rep.

[10] Rickard, N. A., and R. A. Newman. 1986. Development of technology for harvesting and transplanting subtidal juvenile Pacific razor clams, *Siliqua patula* Dixon, along the coast of Washington State. Abstr. presented at Natl. Shellfish. Assoc. Annu. Meet., Seattle, Wash.

[11] Rickard, N. A., M. Peoples, and D. Simons. 1992. The history and development of the subtidal transplant project. Wash. Dep. Fish., Montesano. Unpubl. tech. rep.

resource. In the next 10 years, we anticipate limited harvests as efforts continue to cope with disease, toxin, and management issues.

Clam, Mussel, and Scallop Fisheries

Commercial fisheries for clams (other than razor clams) exist in Puget Sound, Strait of Juan de Fuca, and the coastal bays. Before the accidental introduction of Manila clams sometime before 1940, the fisheries were primarily for the native littleneck and butter clam. The geoduck was commercially dug intertidally before the 1930's, but fear of overdigging caused the legislature to prohibit commercial harvests in 1931. In 1969, after diver surveys demonstrated that abundant subtidal stocks were present, the legislature authorized commercial harvests of geoducks lying below low tide only. Lesser numbers of cockles and horse clams supplied a limited market for bait and food.

The Manila clam did not become commercially important until after World War II. However, by the 1970's the commercial demand for Manila clams as steamers increased substantially, while demand for native littlenecks slowed. Demand for butter clams, cockles, and horse clams, formerly used for canning, virtually ceased due to competition from clam imports from the Atlantic coast. The excellent market for Manila clams has resulted in the development of sources of hatchery seed to expand culture of the species.

Mussel culture is being carried on in Puget Sound but is somewhat limited due to undependable natural reseeding, adult mortality, and high production costs. Experiments to produce hatchery seed from various species of mussels are being conducted by commercial hatcheries.

Three species of scallops are commercially harvested in Washington. Natural stocks have been too small to sustain extensive trawling. A small-scale diver harvest exists where scallop beds are sufficiently dense, as well as incidental catches while shrimp trawling and small-scale scallop trawling.

The fishery for subtidal geoduck stocks increased substantially following the 1967 passage of laws authorizing commercial diver harvest from Puget Sound bedlands leased from the state. This closely regulated fishery continues and its yield is largely based on stock assessments designed to limit the harvest to the rate of replacement through natural setting, artificial seeding, and growth.

The softshell clam commercial fishery expanded briefly during the decade of the 1970's, but as a result of limited stocks, harvest cost, and severe sociological problems, the dredge fishery died and has not resumed. Limited harvests by hand digging occurs.

Shellfish Preparation

In Washington, most Pacific oysters are marketed fresh. Fresh oyster meats are fried, made into stew by the user, wine broiled, sauteed, baked in casseroles or as oysters Rockefeller, and incorporated in poultry dressing. A small percentage are sold in the shell, with the small ones served as cocktails, the mediums as half-shells, and the large are barbecued.

In the past when still abundant, Olympia oysters were used as cocktails, fried, or made into stew. The small numbers currently available are used as cocktails or tiny half-shells.

In restaurants or homes, razor clams are most frequently prepared by frying. Some may be minced and used in chowder by recreational diggers.

The geoduck siphon and breast (mantle) are cut into steaks and fried, minced and fried as patties, or made into chowder. People of Asian heritage and a few Caucasians eat tender parts raw. The visceral mass, when used, is blanched and minced in chowder.

Manila and native littleneck clams are usually steamed in the shell and with the meats frequently dipped in melted butter. Recreational diggers may also put them in chowder.

Large butter clams are usually minced for chowder and a few are split open and fried with the shell attached. Small ones are usually steamed along with the other steamers.

Mussels are steamed in the shell and eaten with sauces or melted butter.

Small eastern softshells, *M. arenaria*, are steamed and large ones are usually fried. Only limited numbers are harvested commercially. Recreational diggers take them from beds where abundant, but the fishery is very small.

A small commercial scallop harvest occurs and the muscles supply a gourmet half-shell market. Recreational divers usually fry the whole meats.

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Molluscan Fisheries of British Columbia

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ABSTRACT

Mollusks have long been important to Native Americans, being used for food, decoration, and money. They also were important to early settlers. Commercial fisheries for mollusks are relatively small, but they form an important part of the heritage and economic viability of many coastal communities. In addition to the commercial fisheries that began in the late 1800's, mollusks provide important recreational fisheries. The only gastropod harvested commercially is the northern abalone, *Haliotis kamtschatkana*. In 1990, 97.5% of mollusks landed were comprised of bivalves. Three species of oysters have been harvested: Olympia, *Ostrea conchaphila*; eastern, *Crassostrea virginica*; and Pacific, *C. gigas*. Four species of clams comprise nearly all the intertidal clam landings: Razor, *Siliqua patula*; butter, *Saxidomus giganteus*; littleneck, *Protothaca stamina*; and Manila, *Tapes philippinarum*. A recent development is a fishery for subtidal clam stocks, primarily geoducks, *Panope abrupta*, but also for two species of horse clams, *Tresus capax* and *T. nuttallii*. There is considerable interest in clam culture. Four species of scallops have been or are harvested commercially: Weathervane, *Patinopecten caurinus*; rock, *Crassoderma gigantea*; and pink, *Chlamys rubida* and *C. hastata*. Landings of mussels, *Mytilus edulis* and *C. californianus*, have been minor. In recent years, mollusk landings have been increasing as markets have expanded. In 1990, the total landed weight of mollusks in commercial fisheries was 11,258 metric tons. The future of these fisheries appears promising.

Introduction

Mollusks have long been important to the native people of British Columbia (Clark, 1963; Quayle and Bourne, 1972; Schink et al., 1983). Based on evidence in many middens along the British Columbia coast, species used were mainly the same as those used in present fisheries. Mollusks were important also to the early settlers and frequently provided a major food source during winter months.

Commercial molluscan fisheries were established before the turn of the 20th century. These molluscan fisheries are relatively small when compared to total fisheries landings in British Columbia, but they form an important part of the heritage and economic viability of many communities along the coast. Besides commercial fisheries, mollusks are an important resource in native food and recreational fisheries (Bourne et al., 1987).

Molluscan fisheries have changed greatly since their inception, and landings have fluctuated widely owing to both biological and socioeconomic factors. Erratic recruitment, local depletion of some stocks, and the widespread occurrence of PSP (paralytic shellfish poisoning) have all contributed to inconsistent landings, but socioeconomic factors probably have been the major factor (i.e., lack of markets, transportation problems, harvesting and processing economics, and frequently, the availability of more attractive employment elsewhere).

In the last 10–15 years, however, the situation has begun to change. Transportation facilities have improved and other more lucrative fields of employment no longer exist. A major reason for the change is that shellfish are now widely accepted as delicacies in the North American diet. Their increasing popularity is creating a stronger market for them. In addition, mollusks are now being harvested to a greater extent in the valuable recreational fishery. There is little data on the extent of this fishery, but now that people have more free time, these landings are increasing (Bourne et al., 1987). These factors have led to increased interest by scientists, managers, and the general public in molluscan resources and the need for better management practices to insure their optimum use.

British Columbia Molluscan Fisheries

The coastal waters of British Columbia have a rich molluscan fauna. Bernard (1970) estimated there were over 500 species along the coast which included representatives from the five classes in the phylum mollusca: 29 polyplacophora, 283 gastropoda, 180 bivalvia, 5 scaphopoda, and 21 cephalopoda. Molluscan resources from three of these classes support valuable commercial fisheries (Quayle and Bourne, 1972; Ketchen et al., 1983; Jamieson and Francis, 1986; Quayle, 1988). In 1990 molluscan resources comprised 55.7% of total landed weight of all invertebrate fisheries in British Columbia and 49.3% of the landed value (Table 1). Less than 30 of the 500 species of mollusks on the British Columbia coast are utilized in commercial fisheries, and probably the same number are used in recreational and native food fisheries. In 1990, total landed weight of mollusks in commercial fisheries in British Columbia was 11,258 t (metric tons) with a value of about C$21.4 million (Tables 2, 3).

Commercial fisheries for mollusks in British Columbia began in the late 19th century. Landings of butter clams, *Saxidomus giganteus*, were reported in 1882, and landings of native or Olympia oysters, *Ostrea conchaphila*, were made in 1884 (Thompson, 1913, 1914; Quayle and Bourne, 1972; Quayle, 1988). Since then landings have varied greatly, and molluscan fisheries are currently enjoying a period of increased landings and market value.

Table 1
Landings from commercial fisheries for invertebrates in British Columbia, 1988–90. Landings in metric tons (t, whole weight) and value in thousands of dollars (Can.). Data from annual statistics, Department of Fisheries and Oceans.

	1988		1989		1990	
Resource	Weight	Value	Weight	Value	Weight	Value
Echinoderms	3,378.3	2,081.7	3,870.5	3,105.3	4,311.5	3,726.9
Crustaceans	4,267.2	13,303.4	3,885.5	13,325.6	4,655.0	18,282.0
Mollusks	12,895.5	22,160.9	11,567.9	24,379.2	11,258.0	21,432.0
Total	20,541.0	37,546.0	19,323.9	40,810.1	20,224.5	43,440.9

Table 2
Landings of molluscan shellfish (t, whole weight) in British Columbia commercial fisheries, 1982–90.

	Landings (t)								
Species	1982	1983	1984	1985	1986	1987	1988	1989	1990
Intertidal clams									
Razor	68	31	101	90	142	142	155	117	114
Butter	103	77	131	252	159	69	83	92	93
Littleneck	241	325	295	192	285	373	288	429	462
Manila	597	1,049	1,677	1,914	1,894	3,608	3,839	2,729	1,452
Mixed	155	280	409	478	369	87	27	159	148
Subtotal	1,164	1,762	2,613	2,926	2,849	4,279	4,392	3,526	2,269
Geoduck	3,135	2,636	3,483	5,370	5,006	5,734	4,553	3,964	3.991
Horse clams	321	21	7	6	96	355	328	243	127
Oysters	2,366	2,977	3,542	3,420	2,394	3,751	3,667	3,672	4,518
Scallops	8	11	18	53	68	66	57	66	69
Mussels		Tr[1]			2	1	3	Tr	Tr
Abalone	54	56	58	42	52	49	48	49	50
Octopus		37	25	34	53	130	205	169	185
Squid		Tr	14	111	79	132	1	35	49
Grand total	7,048	7,500	9,760	11,962	10,599	14,497	13,254	11,724	11,258

[1] Tr=trace

In the following sections, the history, present status, and future of these fisheries are discussed. Only mollusks in the classes cephalopoda, gastropoda, and bivalvia are considered. Tusk shells, class scaphopoda, were used by natives for decoration and money but are no longer harvested (Clark, 1963). Amphineurans, particularly the gumboot chiton, *Cryptochiton stelleri*, are used occasionally in native and recreational fisheries but don't enter commercial fisheries.

Physiography of Coastal British Columbia

Some knowledge of the geography of British Columbia is necessary to understand the nature and problems of its molluscan fisheries. British Columbia has a long coastline that is heavily indented with many islands and inlets, giving a total coastline of about 27,000 km (Thomson, 1981) (Fig. 1). There is much protected water between the many islands and the mainland, between the islands, and in numerous sheltered bays and inlets. Waters along the coast are temperate and open throughout the year; ice formation is rarely a problem except under local conditions. The waters are productive and relatively free of pollution outside a few areas in the southern part of the Province. The rugged coastline makes local oceanographic conditions complex and there can be significant variations in oceanographic conditions within a distance of 5 km.

Intertidal areas are limited, owing to the steep mountainous coastline, and the continental shelf area is also limited. Much of the coast drops precipitously to great depths within a short distance of shore. Most intertidal beaches are small, steep-sloped and very rocky. Much of the exposed outer coast is also rocky and there are few sandy beaches. Harbo[1] estimated that in the south coast district (from the northern tip of Vancouver Island to the U.S. border) about 800 beaches are used in commercial, recreational or native food bivalve fisheries. Total area of these beaches is about 8,100 ha (hectares) but the actual clam-bearing parts of these beaches is probably about 40–50% of the total area.

The mountainous nature of the coast makes communications difficult and often expensive. There are few roads, and travel must frequently be by boat or air. Most of the Province's population of 3,000,000 live in the southwestern corner and this is also the major local market.

One further important factor in molluscan fisheries, particularly for bivalves, is the occurrence of paralytic shellfish poisoning (PSP) (Quayle, 1969). The entire north coast area (from the northern tip of Vancouver Island to the Alaska border) has been closed to the harvest of bivalves since 1963 because of chronic low levels of PSP and there are periodic seasonal closures in other locations along the coast. A monitoring system is in place to ensure only good quality shellfish reach consumers but outbreaks of PSP can cause serious problems in supplying a consistent product to the market.

[1] Harbo, R. M. 1990. Department of Fisheries and Oceans, 3225 Stephenson Point Road, Nanaimo, B.C. Canada. V9T 1K3. Personal commun.

Table 3
Landed value of molluscan shellfish (C$1,000) in British Columbia commercial fisheries, 1982–90.

	Landed value (C$1,000)								
Species	1982	1983	1984	1985	1986	1987	1988	1989	1990
Intertidal clams									
Razor	55	24	123	95	127	126	137	124	129
Butter	36	33	55	138	75	40	40	44	46
Littleneck	263	329	311	202	327	474	357	580	703
Manila	611	1,043	1,813	2,278	2,762	6,003	7,023	5,919	3,748
Mixed	169	293	455	575	510	132	36	196	217
Subtotal	1,134	1,722	2,757	3,288	3,801	6,775	7,593	6,863	4,843
Geoduck	2,814	1,818	2,937	4,777	4,294	6,184	9,762	12,570	10,580
Horse clams	235	12	5	6	63	309	300	109	136
Oysters	1,229	1,554	2,000	2,600	2,354	3,851	3,572	2,800	3,545
Scallops	17	45	56	139	212	244	285	275	316
Mussels		1			3	2	4		
Abalone	457	464	530	442	734	973	1,076	1,170	1,347
Octopus		80	56	82	136	381	629	543	611
Squid		17		183	123	132	1	47	54
Grand total	5,886	5,713	8,341	11,517	11,720	18,851	23,222	24,377	21,432

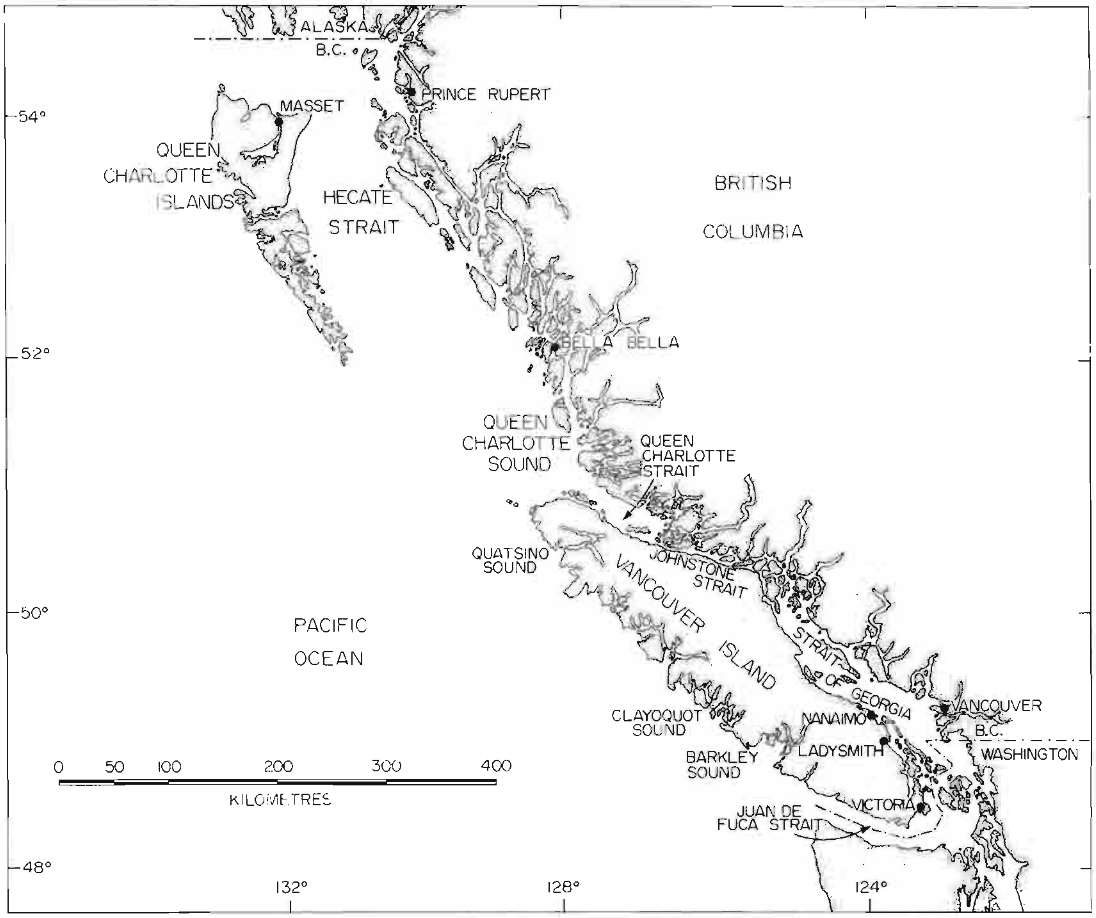

Figure 1
Coastal British Columbia.

Cephalopoda

The class cephalopoda includes octopus and squid, and there are minor fisheries for both in British Columbia (Tables 2, 3).

Octopus

Three species of octopus occur in British Columbia, but only the giant Pacific octopus, *Octopus dofleini*, is harvested commercially (Jamieson and Francis, 1986). This species occurs commonly throughout British Columbia waters, although there are no population estimates. Growth is rapid and animals over 25 kg have been recorded (Hartwick, 1973; Hartwick et al., 1981). For many years most of the catch was taken incidentally in shrimp and groundfish fisheries, and landings were small at about 50 t (Table 2). Attempts were made to harvest octopus commercially with traps similar to those used in Japan (Mottet, 1975), but they were not successful. In the past few years there has been a directed dive fishery for octopus, mostly in the Strait of Georgia and landings have been around 150 t with a value of about $0.5 million (Tables 2, 3).

The octopus resource in British Columbia is probably underutilized, and the fishery could be expanded. Future expansion will depend on the extent of the resource, the economics of harvesting, and markets.

Squid

Squid probably form a substantial part of the biomass in the northeast Pacific (Jefferts, 1986). Four species have been exploited commercially in British Columbia: opal, *Loligo opalescens*; nail, *Onychoteuthis borealijaponica*; red, *Berryteuthis magister*; and flying, *Ommastrephes bartrami*, but to date landings have been minor.

Most of the fishery has been for opal squid, and landings have been mainly from by-catches in groundfish and shrimp trawling operations. The species is common in British Columbia waters, although large concentrations rarely occur. There have been directed small seine fisheries for this species, but since a 1982 peak in annual landings of 132 t, catches have been small (Table 2).

Minor attempts have been made to harvest nail and red squid in experimental fisheries. There was an experimental joint fishing venture with the Japanese for flying squid using floating drift nets. However, there were serious problems with the by-catch, and the fishery has now been forbidden within Canadian territorial waters (Jamieson and Heritage, 1988).

Large squid stocks undoubtedly exist in British Columbia waters. The problem in developing a sizeable commercial fishery is the lack of biological knowledge, an extended breeding season, and erratic occurrence of spawning concentrations. Since it is impossible to predict when and where schools will occur it makes the fishery unprofitable (Bernard, 1980).

Gastropoda

Most species of mollusks in British Columbia are gastropods and about 300 species have been identified (Bernard, 1970). However, only one species, the northern abalone, *Haliotis kamtschatkana*, is harvested commercially. Occasional attempts have been made to harvest such other gastropods as *Astrea gibberosa, Tegula* sp., and *Fusitriton oregonensis*, in small experimental fisheries, but they have not been successful.

Northern abalone occur throughout coastal British Columbia in exposed or semi-exposed habitats, although distribution is patchy (Sloan and Breen, 1988). They occur from the lowest part of the intertidal zone to subtidal depths of 100 m, although most of the adult population is found at depths <10 m. Growth is slow, and it requires 6–10 years for abalone to attain the legal commercial size of 100 mm shell length.

Abalone were harvested by native people in British Columbia, as seen from evidence in middens. They were used both for food and decoration. Artisanal commercial fisheries developed in the early 1900's, and reference is made to canning abalone in some parts of the northern area in the early part of the 20th century (Quayle, 1962). Production from those fisheries was low.

The advent of scuba and hookah gear changed the abalone fishery. Landings from 1951 to 1971 fluctuated widely but were generally low, under 50 t (Sloan and Breen, 1988). This was probably due to lack of established markets and to socioeconomic factors. In the 1970's the fishery expanded rapidly, and peak landings of over 400 t were made in 1977 and 1978 (Fig. 2). Landings were from the entire outer coast, but since the early 1970's most of the commercial catch was from the north coast district. The large increase in landings was due primarily to extremely strong markets, mostly

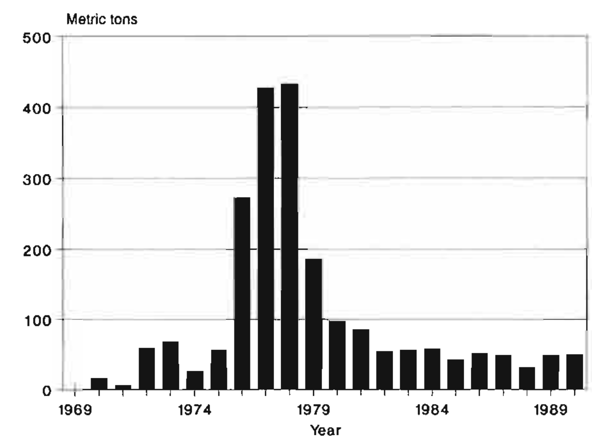

Figure 2
Landings, in metric tons (whole weight) of northern abalone in British Columbia commercial fisheries, 1969–90.

Japanese. Quota management and effort (boat) restrictions were introduced and annual landings declined to around 50 t annually. Landings remained at that level until 1991 when the fishery (both commercial and recreational) was closed because of conservation measures.

In 1979 the fishery was restricted to 26 vessels and the quota equally divided among the boats (Sloan and Breen, 1988). Each boat employed 2–4 divers and the quota was generally harvested in 25–30 diver days per vessel.

Strong interest continues in abalone fishing in British Columbia owing to demand. At present, the market price is about $30.00 per kg (whole weight), but the future of the fishery is uncertain. Abalone are slow growing and recruitment appears to be erratic; hence, populations will probably require a lengthy period to attain levels observed in the early 1970's. Whether populations can recruit to support commercial fishing, even at reduced levels, is unknown.

Because wild populations of abalone are limited, there is great interest in abalone culture using technology developed in Japan and California (Mottet, 1978; Uki, 1984; Hooker and Morse, 1985; Hahn, 1989). One commercial culture operation existed in British Columbia for most of the 1980's (Calderwood, 1985). Techniques were adapted to breed adults, raise and set larvae in a hatchery, rear juveniles in a nursery, and grow out juveniles to adult size. A major problem was slow growth rate; however, markets for small "cocktail size" abalone exist. These abalone are about 5 cm in shell length and could be produced within 2–3 years. A second and devastating problem was disease. A protozoan parasite that may be widely distributed in the natural environment was found in juveniles in the hatchery (Bower

1987a, b). Although it did not appear to affect adults, it was lethal to almost all juveniles (animals <6 months old).

The future of the abalone industry in British Columbia is uncertain. Undoubtedly, build-up of natural stocks to commercial levels of abundance will be slow. Establishment of a culture or enhancement industry will depend on continued research to improve culture technology to produce faster growth and higher survival of abalone in either the culture or natural environment.

Bivalvia

Almost 200 species of bivalves occur in British Columbia waters (Bernard, 1970, 1983) but less than 20 have been used in commercial fisheries. Bivalves comprise the major portion of mollusk landings in British Columbia. In 1990, 97.5% of the landed weight and 90.6% of the landed value of molluscan shellfish in commercial fisheries were bivalves (Tables 2, 3). For convenience in this paper, bivalves are divided into four groups: oysters, clams (intertidal and subtidal), mussels, and scallops.

Oysters

The oyster industry is a culture operation, and oysters have been cultured for a longer period in British Columbia than any other organism. Pseudo culture was carried out early in the 20th century, but the oyster industry is considered to have begun in 1925 with the first importation of seed (juveniles) from Japan (Quayle, 1988).

Three species of oysters have been harvested in the British Columbia industry: Olympia or native, *Ostrea conchaphila*; eastern, *Crassostrea virginica*; and Pacific, *C. gigas* (Quayle, 1988). At present there is minor experimental culture of the European flat oyster, *O. edulis*, but commercial landings have been miniscule.

Native oysters occur throughout British Columbia in scattered locations low in the intertidal zone or in lagoons. Commercial landings of this species began before the turn of the century and continued to about 1930 (Quayle, 1988). Native oysters were never actually cultured in British Columbia, as in the State of Washington, and the fishery was for wild stock. The fishery was small, and annual landings probably never exceeded 300 t. The fishery ended in about 1930 because of overfishing and a very severe cold winter which caused extensive mortalities. For reasons that are unknown, stocks have never returned to previous levels of abundance. Growth of native oysters is slow, requiring about 4 years to attain commercial size, and mortalities are high unless they are grown submerged in water. Although market price is high, slow growth, high mortalities, small size, and high labor costs preclude commercial culture of this species in British Columbia. Native oysters are used to a limited extent in the recreational fishery.

Eastern oysters were first imported into British Columbia about 1895 and put out in several areas in southern British Columbia (Bourne, 1979; Quayle, 1988). They did poorly except in one area, Boundary Bay, south of Vancouver. In 1900, annual importations of eastern oysters began into Boundary Bay. At first seed was imported and grown to commercial size, but mortalities were high and the industry then began bringing in boxcar loads of 3- to 4-year-old oysters and holding them for 1 or 2 years. They were imported from several locations along the Canadian and U.S. east coasts and used mainly for the half-shell trade on ocean liners travelling to the Orient. The trade stopped in about 1940 and no further introductions were made since then. Widespread breeding of this species did not occur in Boundary Bay, but sufficient breeding has occurred to maintain a small relict population (Bourne, 1979).

The Pacific oyster is the only species used commercially at the present time in British Columbia (Quayle, 1988). It was first introduced from Japan into Ladysmith Harbour and Fanny Bay in 1912. Low-level introductions continued after 1913. In 1925, the first substantial introduction of oysters, both adults and juveniles, was made into British Columbia and this marked the beginning of the industry. Pacific oysters spread rapidly throughout the southern part of the Province as a result of general breedings in 1942 and 1958 and are now one of the dominant intertidal organisms in many areas there. Culture methods for Pacific oysters in British Columbia have been well described (Quayle, 1988).

In British Columbia, virtually all intertidal and subtidal areas are owned by the Provincial government and open to the public; they are referred to as "Crown Land." To obtain sole rights to an intertidal area for oyster culture, it is necessary to lease it from the Provincial Government. This is done through the Lands Branch of the Ministry of Lands, Parks, and Housing.

Intertidal bottom culture is the primary method of culture in British Columbia. Seed (juveniles) is obtained and either spread directly on growing areas or held on seed ground which has firm substrate and is high in the intertidal area. After the seed is held for a year to harden, it is spread in the lower part of the intertidal area; harvest is at least 2 years later. Oysters are generally harvested by hand picking at low tide and placed in scows or large containers which are then buoyed and hoisted into boats at high tide for transport to processing plants.

In recent years, other oyster culture methods have been tried. Stake culture has been practiced to utilize areas with marginal (soft) substrate (Quayle, 1988). Although production has been satisfactory, the added costs of this type of culture have prevented widespread acceptance. Rack culture has likewise been tried but discarded.

Floating, hanging, or raft-type culture, like that used exclusively in Japan (Ventilla, 1984), is now becoming more widely accepted in British Columbia. Quayle (1988) estimated the amount of suitable substrate for intertidal oyster culture in southern British Columbia was only about 1,000 ha, but ideal conditions exist for floating culture. Experimental work has shown that floating culture is feasible throughout the Province, although most operations will probably occur in the southern regions since growth is faster and markets are closer. Floating culture operations will undoubtedly continue to expand.

Most British Columbia oyster culture operations are small family enterprises, and the majority of leases are under 10 ha. In 1990 there were 437 lease holders with a total of 1,003 ha in intertidal culture and 710 ha in floating culture.

A major problem for the industry in the initial years was acquisition of seed (juveniles). Beginning in 1925, seed was imported annually from Japan via shipments made to the State of Washington. The amount of seed imported gradually increased over the years and reached a maximum of 5,400 cases (minimum of 70 million juveniles) in 1951 (Bourne, 1979). Since then, importations of seed from Japan declined and ceased in 1977 because of high cost and development of other seed sources. It is estimated that over one billion juvenile Pacific oysters were imported from Japan into British Columbia during this 50-year period (Bourne, 1979).

The Pacific oyster is living at the edge of its range in British Columbia, and breeding is erratic. There have been only four large or general breedings of Pacific oysters in British Columbia (1936, 1942, 1958, and 1961). The first significant breeding in 1936 was in Ladysmith Harbour, and larvae were spread as far away as 70 km in the Strait of Georgia. The 1942 breeding spread Pacific oysters throughout the Strait of Georgia. The 1958 breeding was the largest experienced in British Columbia, and with the reinforced breeding in 1961, it supplied oysters to the industry for a period of about 10 years.

Such erratic breedings were not sufficient to supply the industry with a consistent source of seed for culture purposes. In 1948 an area was found in British Columbia, Pendrell Sound, where consistent breeding occurred. Considerable work was undertaken to establish a spatfall forecasting service for the industry to insure a seed supply. Also a few other local areas were found where Pacific oyster breeding was consistent, and they can be used to supply the industry with seed.

In addition to obtaining seed from natural sets, the practice of remote setting has become established in British Columbia (Roland and Broadley, 1990). Mature larvae are obtained from hatcheries and set on cultch at a grower's facility. This has become the main method for the British Columbia oyster industry to obtain their seed supply.

The British Columbia oyster industry now has sources for a consistent, reliable, and inexpensive supply of seed for the present, and even for greatly expanded production.

The industry is centered in the Strait of Georgia, although some production occurs in inlets along the west coast of Vancouver Island. Experimental oyster culture has been tried in the northern area. Although these have been successful, slower growth rate and distance for markets have prevented commercial operations.

British Columbia oyster production gradually increased from 1940 and peaked at 6,195 t (whole weight) in 1963, mainly because of extensive natural breedings (Fig. 3). Production declined after 1963 and from the mid 1970's to mid 1980's it was generally between 2,000 and 3,000 t. In the last 5 years production has gradually increased and in 1990 it was 4,518 t. Most of the production is shucked and sold fresh or frozen.

The extensive 1942, 1958, and 1961 breedings altered oyster farming practices to some extent. Large quantities of oysters became available to growers on much of the intertidal crown area in southern British Columbia. These oysters were called "wild oysters." Many growers began to harvest these wild oysters in addition to, or instead of, oysters from their leases. This resulted in increased production in the late 1940's and the peak

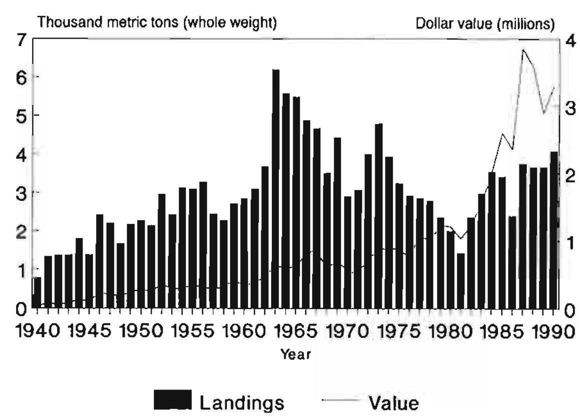

Figure 3
Landings in metric tons (whole weight) of Pacific oysters in British Columbia commercial fisheries, 1940–90.

production in 1963. Many growers no longer bothered to plant seed on their leases, and when the supply of wild oysters fell below commercial levels, production began to decline. There was little seed on leases to give previous levels of production. The practice of harvesting wild oysters has continued to some extent but production from this source is low. The bulk of production is now from oyster culture operations on leased areas. In 1974 the industry began to produce single oysters for the half-shell restaurant trade. These are generally grown in trays that are either suspended from floats or held on racks. Production of half-shell oysters has gradually increased since 1974 and in 1990 it was 786,000 dozen (Fig. 4).

The general increase in oyster production in the last 5 years is due to several factors. Introduction of a "Diligent Use" policy by the Provincial Government has forced growers to actively use their leased areas for oyster production or face the penalty of losing their leases. Most growers now have active seeding practices, and leases are now being seeded much more heavily than before. Several new people have entered the industry and are approaching it as a business operation. Emphasis on quality and a decline in production elsewhere has meant that markets have been strong.

The potential for oyster production in British Columbia is substantial, and the future is promising. There are no major biological problems preventing increased production. Devastating diseases have not been a problem for B.C. oyster culture, although diseases are important in some local areas (Quayle, 1961, 1988; Bower, 1988). As noted, suitable areas for intertidal bottom culture in southern British Columbia are limited, but ideal conditions exist for floating culture. Production from floating culture could be 25 times greater per unit area compared with bottom culture (Quayle, 1988), and annual production from a 610 ha area in the Strait of Georgia using floating culture could be 70,000–110,000 t. Clearly this type of culture would have to be adopted to achieve maximum production levels.

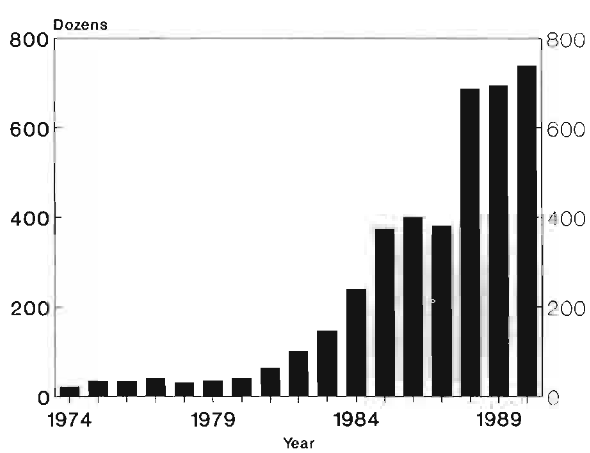

Figure 4

Production in dozens of single oysters in British Columbia commercial fisheries, 1974–90.

Recent developments in genetics are encouraging for expansion of the British Columbia oyster industry. Triploid oysters can now be produced on a commercial scale, and they provide a high quality oyster during summer months (Allen and Downing, 1986; Allen and Chew, 1989). With the advent and widespread use of hatcheries, further advances in oyster genetics are possible, and this could lead to breakthroughs and increased production.

Major problems for the British Columbia oyster industry are guaranteed sites for oyster culture (tenured leases and good quality water) and low-interest capital funding. Encroachment of civilization is a major threat to continuing expansion of the industry because it will reduce the area for culture, make acquisition of new growing sites difficult, and spread pollution. However, with continued research, close cooperation between industry and government, and an aggressive aquaculture policy, it should be feasible to continue expansion of the oyster industry.

Clams

Clam resources have always been important to the native people of British Columbia, as can be seen from the numerous middens along the coast. Clam resources have also supported important commercial fisheries for over 100 years (Quayle and Bourne, 1972). In 1990 clam landings were 56.7% of the landed weight and 72.6% of the landed value of British Columbia molluscan fisheries (Tables 2, 3). Clams are also widely used in the recreational fishery, where an estimated 30,000 people harvest them annually (Bourne et al., 1987). For convenience, clam fisheries are divided into intertidal and subtidal fisheries.

Intertidal Clam Fisheries—Four species of clams comprise virtually all the intertidal clam fishery landings—razor, *Siliqua patula*, and three species from the family Veneridae; butter, *Saxidomus giganteus*; littleneck, *Protothaca staminea*; and Manila, *Tapes philippinarum*. Occasional minor landings of cockles, *Clinocardium nuttallii*, and softshell clams, *Mya arenaria*, have been reported. In the past, small landings of horse clams, *Tresus capax* and *T. nuttallii* have been recorded.

Razor Clams—Razor clams occur on surf-swept sandy ocean beaches along the west coast of North America from the mid intertidal zone to subtidal depths of 20 m

(Lassuy and Simons, 1989). They can attain a shell length of 15 cm. Growth varies with geographic location but is fairly rapid in British Columbia and a shell length of 10 cm is attained in 3–4 years (Bourne and Quayle, 1970; Lassuy and Simons, 1989).

Razor clams have been recorded from several isolated locations along the British Columbia coast, but there are only two centers of concentration, one on the west coast of Vancouver Island (Long Beach) and the other on beaches that extend from Masset to Rose Spit on the north coast of the Queen Charlotte Islands. Commercial fishing at Long Beach was never extensive and has not occurred in the last 15 years, although the resource is used by recreational diggers. A small fishery has existed in the Queen Charlotte Islands since 1924 (Quayle and Bourne, 1972). Landings have never been large and have fluctuated over the years. They reached a peak of 765 t in 1925. In the past 5 years, annual landings have been about 140 t (Table 2, Fig. 5). Harvest is by locating individual clams and digging is by hand using a thin bladed short-handled shovel. In the early 1970's an attempt was made to harvest razor clams at Masset with a mechanical harvester but it was unsuccessful because of mechanical problems. Initially, razor clams were canned and used as human food but in the past 20 years most of the catch has been used as bait in the Dungeness crab, *Cancer magister*, fishery.

The fishery at Masset will never be large because the resource is limited. One study indicated that an annual sustained yield of 250 t was possible, and double that if the subtidal population could be harvested (Bourne, 1969). Although the fishery will remain small, it will continue to be important to local people, particularly native people, in the Queen Charlotte Islands. There are no data on the exact number of diggers employed in the fishery, but 25–50 people probably participate in the fishery. The value of the fishery would be greatly increased if efforts were made to use the clams for human food rather than crab bait.

Butter Clams—Butter clams are common intertidal British Columbia bivalves which are found on protected beaches throughout the Province (Quayle and Bourne, 1972). They occur from the lower third of the intertidal zone to subtidal depths of 10 m, most frequently in mud-gravel-shell substrate. They can attain a shell length of 110 mm, but growth is slow. It requires 5 years to attain a shell length of 63 mm (the minimum legal size in the commercial fishery) under optimum conditions in the southern part of the Province and as much as 8 years to attain this size in northern areas.

Harvest is by hand digging usually with a long-handled potato fork, and generally only during winter months. Attempts were made to use mechanical harvesters, such as one-man hydraulic rakes (Bourne, 1967) and escalator harvesters (Quayle and Bourne, 1972), but they failed for various reasons.

For many years, butter clams were the main clam species harvested in the commercial fishery (Fig. 6). Commercial landings began in the late 19th century and reached a peak of 3,000 t in 1938 (Quayle and Bourne, 1972). Since then, landings have fluctuated greatly while gradually declining. The reasons for these fluctuations and decline are many, but they are due mostly to socioeconomic factors. Part of the decline was due to PSP (Quayle, 1969). Formerly, about half the landings were from the north coast district, but this was closed in 1963 because of chronic low levels of PSP in butter clams from some localities. Although a proce-

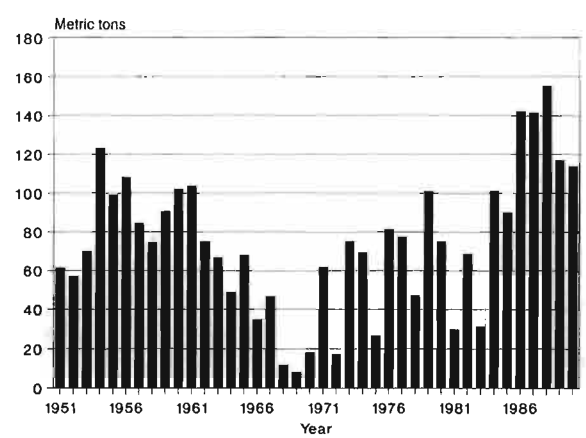

Figure 5
Landings in metric tons (whole weight) of razor clams in British Columbia commercial fisheries, 1951–90.

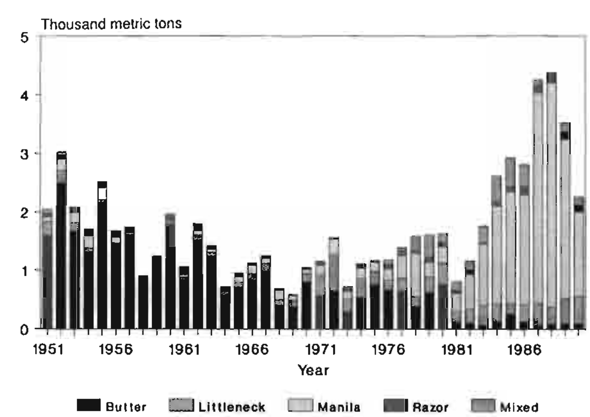

Figure 6
Landings in metric tons (whole weight) of intertidal clams, razor, butter, littleneck, Manila, and mixed, in British Columbia commercial fisheries, 1951–90.

dure was devised to allow harvesting under a controlled permit system, little harvest of butter clams has occurred in the north coast district since 1963. In the last 10 years, butter clam landings have declined to very low levels (Fig. 7) due to vagaries of the market (which began to demand fresh clams for the steamer market) and high processing costs. Butter clams are usually canned, and it became prohibitively expensive to can clams. Canadian processors could no longer compete with imports of cheaper canned clams.

The butter clam fishery could be expanded, because the resource has been underutilized in recent years. A sustained coastwide production of 3,000 t is feasible but expansion of the fishery will depend on markets and the economics of harvesting and processing. Although the butter clam resource will never support large landings, it could provide needed employment and income to coastal communities.

Littleneck and Manila Clams—In the late 1970's, the British Columbia clam fishery shifted from harvesting primarily a canned product (butter clams) to harvesting a live or "steamer clam" product. Two species are harvested for this market: littleneck, *P. staminea*, and Manila, *T. philippinarum*, clams (Fig. 6).

Littleneck clams are one of the most common intertidal bivalves in British Columbia, occurring throughout the Province on protected and semiprotected beaches. They are smaller than butter clams and rarely attain a shell length over 70 mm (Quayle and Bourne, 1972; Chew and Ma, 1987). They are found frequently with butter clams but are more abundant in firmer gravel substrate from about the mid-intertidal zone to subtidal depths of 10 m. Growth varies with geographic distribution and location on the beach. Under optimum conditions in the southern part of the Province, a shell length of 38 mm (minimum size in the commercial fishery) is attained in about 3.5 years. In the north it takes about 5 years.

Littleneck clams have been harvested since the commercial clam fishery began, but they were mostly for local markets. Landings were generally low until the mid 1970's (Fig. 8). Transportation and distribution systems had not been developed to handle large quantities of fresh product for distant markets. However, in the 1970's, extensive markets for steamer clams began to develop. Landings began to increase, and during the 1980's they ranged from 200 to 400 t annually (Table 2, Fig. 8). Landings could have been higher, but the market preferred Manila clams to littleneck clams. In the last 2 years, littleneck landings increased because Manila clam landings declined due to reduced populations, and people began to accept littleneck clams as a good replacement for Manila clams. Although littleneck clams occur throughout the Province and large populations exist in the north coast district, all landings have been from the south coast district. This is due to PSP, transportation costs, and the price, which does not make harvest of littlenecks in the north coast district economically attractive.

Digging is by hand, although attempts were made to harvest littleneck clams with mechanical harvesters along with butter clams. Littleneck clams are harvested along with butter clams using potato forks. More frequently they are dug by pulling rakes or scrapers through the substrate and turfing out the clams.

The British Columbia fishery for littleneck clams could be expanded, if by nothing more than harvesting this species in the north coast district. A sustained yield of

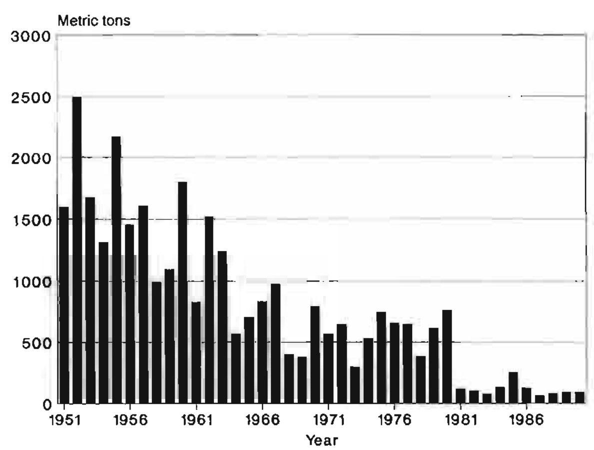

Figure 7
Landings in metric tons (whole weight) of butter clams in British Columbia commercial fisheries, 1951–90.

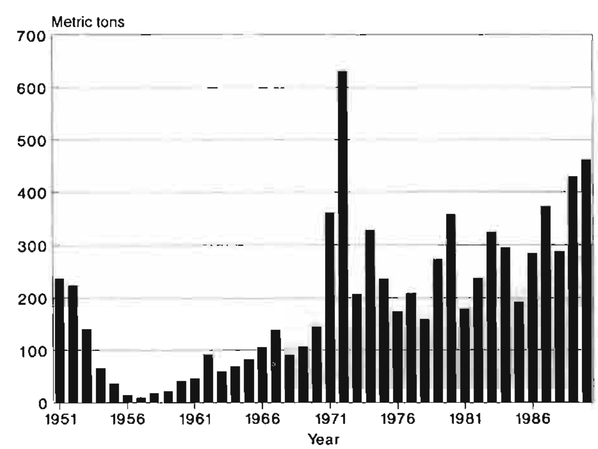

Figure 8
Landings in metric tons (whole weight) of littleneck clams in British Columbia commercial fisheries, 1951–90.

500 t from both the south and north coast districts is not unrealistic. The future of the fishery will depend on development of markets and the efficiency of harvesting and transporting littleneck clams from more remote areas of the Province to markets.

Manila clams are an exotic species that were accidentally introduced into British Columbia from Japan with Pacific oyster seed (Quayle, 1964). They were first discovered on the west coast of North America in Ladysmith Harbour in 1936, and their dispersal throughout British Columbia is well documented (Bourne, 1982). They spread quickly throughout the Strait of Georgia and along the west coast of Vancouver Island, and by the mid 1960's they had reached the northwest tip of Vancouver Island. Further dispersal northward was thought to be impossible because of cold-water barriers at the northern end of the Strait of Georgia and in Queen Charlotte Sound. In 1980 Manila clams were found to have spread to the central coast area, and surveys in 1990 and 1991 showed that large populations were present in this area. Manila clams have also spread to the Queen Charlotte Strait area, but populations are not extensive. Manila clams now occur as far north as lat. 50°34'N (Bourne and Cawdell, 1992).

Manila clams occur in firm sand-gravel substrate from about the 1 m intertidal level to well above the mid intertidal beach, although they are most abundant in the mid intertidal zone. No subtidal populations are known in British Columbia. Growth is moderately rapid, and a shell length of 38 mm (minimum size in the commercial fishery) is attained in about 3 years under optimum conditions in the southern part of the Province.

Until the mid 1970's, landings of Manila clams were minor due to lack of markets and remoteness of many harvesting areas (Fig. 9). In the late 1970's and continuing through the 1980's, strong markets developed for steamer clams, particularly Manila clams. This coincided with a large influx of dedicated clam diggers. This combination led to a large increase in effort in the Manila clam fishery, and landings increased sharply to a peak of 3,833 t in 1988 as accumulated stocks on many beaches began to be harvested (Table 2, Fig. 9). Since then, landings have declined because of reduced stocks. Manila clams are now the dominant species in intertidal clam fisheries, and they have comprised as much as 90% of intertidal clam landings; in 1990 they were 64% of the landed weight of intertidal clams and 72% of the value (Tables 2, 3). All Manila clam landings have been from the southern part of the Province. Minor landings have been reported from the northern area, but they are believed to be in error.

Harvest is by hand, although attempts were made to use mechanical harvesters. Rakes or scrapers are pulled through the substrate, and clams are turfed out, sacked, and taken to processors.

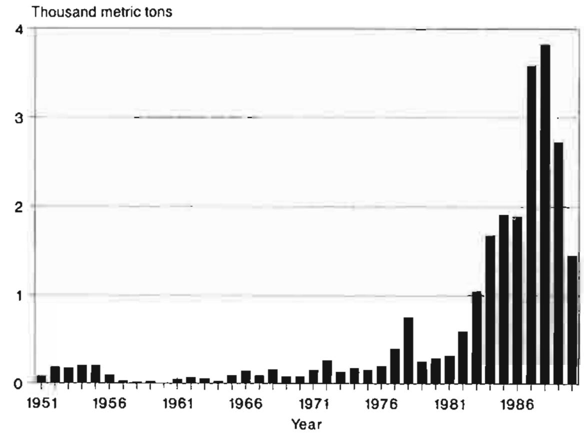

Figure 9
Landings in metric tons (whole weight) of Manila clams in British Columbia commercial fisheries, 1951–90.

For many years the principal management method in intertidal clam fisheries was a size limit, a minimum of 90 mm shell length for razor clams, 63 mm for butter clams, and 38 mm for littleneck and Manila clams. The great increase in effort in the Manila clam fishery caused a change in management policy. A personal clam digging license began in 1989; in 1989 there were 1,879 and in 1990 there were 2,068 licensed commercial clam diggers. The entire coastal area was divided into six regions and diggers could only harvest clams in one region. Opening times and in-season monitoring were introduced for each area, but the excessive effort led to short, intense fisheries that created gluts on the market. Opening times have been greatly reduced and now are down to 1–2 days a week. These new management policies have attempted to reduce effort and spread landings over as long a period as possible so a consistent supply of clams is available.

The fishery for Manila clams has probably reached its peak in the southern part of the Province. The recent decline in landings is the result of accumulated stock being harvested from most of the south coast district. Digging has occurred in many areas where there was no history of previous harvest because these areas had great quantities of rock that made digging difficult. The fishery must now rely primarily on the strength of incoming year classes. The central coast can probably sustain a limited fishery, but recruitment may be erratic, which will lead to restricted harvests. The limited populations of Manila clams has led to considerable interest in clam farming which is discussed below.

Cockles and Softshell Clams—Cockles, *Clinocardium nuttalli*, occur throughout Provincial waters, generally in areas with soft muddy substrate, but they are not found in sufficient abundance in any one locality to support a commercial harvest. Occasionally they are taken in small numbers in commercial fisheries and are used to some extent in the native and recreational fisheries.

The softshell clam, *Mya arenaria*, is also an exotic species that spread throughout the Province (Quayle, 1964). It generally occurs in soft substrate high in the intertidal area but does not occur in sufficient abundance in any locality to support a commercial fishery. It is used to a limited extent in the recreational fishery.

Horse Clams—Both species of horse clams, *Tresus capax* and *T. nuttallii*, occur throughout the Province, generally in the lower third of the intertidal area to subtidal depths of 20 m (Bernard, 1983). They occur deep in the substrate, down to depths of 70 cm. Both species have been harvested in intertidal commercial fisheries. The problem in intertidal fisheries is that because they have a soft brittle shell and live deep in the substrate, they are generally badly broken in digging and hence cannot be processed. In recent years they have been harvested in the subtidal fishery.

Subtidal Clam Fisheries—Fisheries for subtidal clam species are recent, but they have gained significance and are now of major importance. The fisheries involve three species: geoduck, *Panope abrupta*, and the two horse clams, *Tresus capax* and *T. nuttallii*.

Geoducks—Geoducks are the largest bivalve on the west coast of North America and may attain a shell length of 212 mm and weigh 3.25 kg (Goodwin and Pease, 1989). They occur throughout British Columbia coastal waters from the lowest part of the intertidal zone to subtidal depths of 120 m (Bernard, 1983). They are generally found in mud-sand-gravel substrate and can burrow to depths of 1 m in the substrate. Initial growth is rapid, and geoducks attain a shell length of 140 mm, the major part of their growth in shell length, in about 10 years (Goodwin and Pease, 1989; Breen and Shields, 1983). After this, growth in shell length slows greatly. Geoducks are long lived, and animals 150 years of age have been found.

The fishery began in Washington State in 1970 (Schink et al., 1983; Goodwin and Pease, 1989) and spread to British Columbia in 1976 (Harbo and Peacock, 1983). The fishery is for subtidal stock and carried out by divers equipped with hookah or scuba. Hoses with high pressure water jets, called "stingers," are used to wash the substrate away from the clam which is then harvested. Landings in British Columbia increased sharply after the fishery began to a peak of 5,735 t in 1987 but declined since then to about 4,000 t because of management restrictions (Fig. 10). Geoducks are now the most valuable species in British Columbia invertebrate fisheries. In 1990, landings were 3,991 t with a value of C$10.58 million (Tables 2, 3).

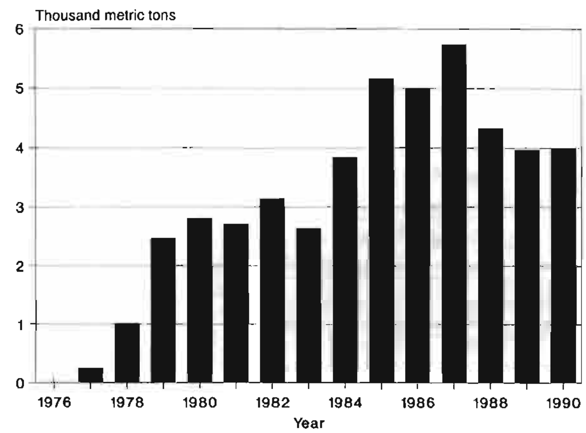

Figure 10
Landings in metric tons (whole weight) of geoducks in British Columbia commercial fisheries, 1977–90.

Initially most of the catch was from the south coast area but in recent years almost half the catch has been from the north coast district. Geoducks were processed, but now much of the catch is sold fresh for the sushi market. Management is by total and area quotas, restricted entrance, and recently by individual boat quotas. The fishery is now limited to 51 licensed vessels, and the quota is equally divided among the boats. Each vessel employs 2 or 3 divers.

The geoduck fishery will probably continue at about the same level as in the past few years because of management policies. Extensive populations of geoducks probably exist in deeper waters than are now harvested, but the technology is not yet available to harvest them economically.

Attempts have been made to enhance geoduck stocks in the State of Washington, but results have not been encouraging (Goodwin and Pease, 1989). There is interest in trying geoduck enhancement or culture in British Columbia but it remains to be seen whether such ventures would be economically viable.

Horse Clams—As mentioned, minor landings of the two species of horse clams have occurred in intertidal fisheries. In recent years there has been a small fishery for subtidal stocks of horse clams and annual landings have fluctuated from 0 to 355 t (Table 2, Fig. 11). Harvest is mostly by geoduck divers after the geoduck quota has been met, using similar harvest methods as in the geoduck fishery. The future of the fishery depends partly on the extent of subtidal populations and the availability of divers and markets.

Other Species—Many surveys have been undertaken throughout British Columbia to assess intertidal bivalve

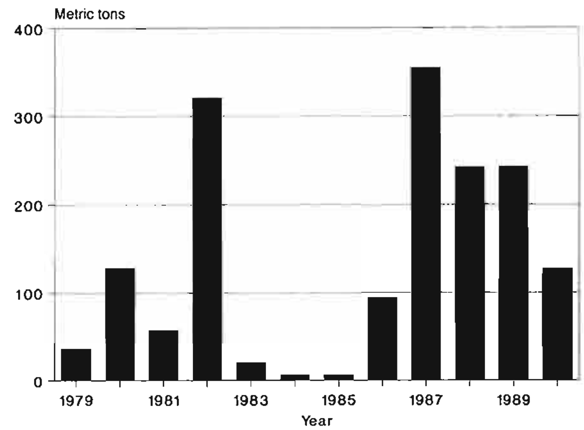

Figure 11
Landings in metric tons (whole weight) of horse clams in British Columbia commercial fisheries, 1979–90.

resources. No large unknown resources that could support continuing fisheries have been found. In 1960 and 1961 extensive surveys were undertaken to assess subtidal bivalve resources in British Columbia and determine if commercially harvestable quantities of any subtidal species existed (Quayle, 1961, 1963). Geoducks were taken in a few areas but no large commercially harvestable quantities of any other bivalve species were found.

Populations of the deep-water clam, *Compsomyax subdiaphana*, were found in a few locations during the 1960 and 1961 surveys. A small experimental fishery for this species began in 1991. The future of the fishery will depend on extent of stocks, economics of harvesting, and markets. There may be extensive populations of geoducks in deeper waters, but otherwise future B.C. bivalve fisheries will depend on known resources.

Clam Culture—There is considerable interest in the development of clam culture in British Columbia for several reasons: limited natural stocks, the success of longstanding oyster culture operations, the apparent success of clam culture operations reported from other parts of the world, and the strong markets that exist for a consistent supply of good quality clams (Anderson et al. 1982; Bourne, 1989; Manzi and Castagna, 1989; Roland et al., 1990). The amount of intertidal area suitable for mollusks is limited in British Columbia, and culture could provide a method to maximize production per unit of area, as well as assist in stabilizing production to provide markets with a consistent supply.

Experimental attempts were made to culture the three intertidal venerid clams—butter, littleneck, and Manila (Bourne, 1989). Butter clams grow too slowly to permit economically viable culture, and there is no seed available. Littleneck clams have a faster growth rate, but there is also no seed available except from experimental research laboratories, and the market prefers Manila clams.

Considerable work has been done to determine the economic viability of Manila clam culture in both the State of Washington and in British Columbia (Anderson et al., 1982; Bourne, 1989; Roland and Gubbels, 1990; Roland et al., 1990). Seed of varying sizes can be supplied from commercial hatcheries, spread in prepared areas, and then covered with mesh. The mesh covering not only protects the seed, but it also enhances greater natural sets.

Results to date have been encouraging, and it appears that Manila clam production can be increased per unit of area by either planting seed or using other enhancement techniques (Toba et al., 1992). By planting the correct size of seed at the proper time of year, it may be possible to produce a crop within a 2-year period. Commercial Manila clam operations have been underway in Washington for several years and have begun recently in British Columbia. There are now 75 lease holders who are licensed for Manila clam farming in British Columbia.

Aquaculture probably presents the only practical method to increase clam production consistently in British Columbia. Whether Manila clam farming will be widely practiced in the future will depend on the availability of seed at reasonable cost, the economics of culture operations, and markets. At present, the only clam species that appears to offer any potential for culture in British Columbia is the Manila clam. Current technology has not developed sufficiently to permit culture of other clam species.

Mussels

Two species of intertidal mussels occur throughout the British Columbia coast: the blue mussel, *Mytilus edulis* (*M. trossulus*), and the sea mussel, *Mytilus californianus*. The former is found along the entire coast, whereas the latter occurs in more oceanic conditions. Attempts have been made to harvest natural populations of both species, but landings have been minor because of harvesting economics and poor quality. It is doubtful that a fishery for wild stocks of either species can be established in British Columbia.

Attempts have been made to culture blue mussels experimentally and commercially in British Columbia (Quayle, 1978; Heritage, 1983). Commercial production has been small, under 10 t annually, and operations are largely in abeyance at present. Major difficulties, including culture economics, fouling, predation by wintering ducks, and summer mortality problems must be solved before large-scale commercial mussel culture can be successful.

Scallops

Thirteen species of scallops have been recorded from coastal British Columbia waters, but most are small or rare (Bernard, 1983). Four species have been or are harvested in commercial fisheries: weathervane, *Patinopecten caurinus*; rock, *Crassadoma gigantea*; pink, *Chlamys rubida*; and spiny, *Chlamys hastata* (Bourne, 1991).

Populations of weathervane scallops are small and local in British Columbia, and commercial landings have been minor (Fig. 12). There has been no fishery for this species in the last 5 years.

Rock scallops have an interesting life history. Until they are 2–3 cm in shell height, they are free swimming. At that time they attach themselves to a rock and remain there for the rest of their lives, frequently becoming large (up to 20 cm shell height) and massive. Rock scallops do not lend themselves to a dragging fishery, but must be chiseled off rocks by divers. Attempts to harvest them commercially were unsuccessful. At present rock scallops can only be harvested in the British Columbia recreational fishery.

Pink and spiny scallops are small, rarely larger than 80 mm shell height. They occur throughout British Columbia coastal waters in subtidal depths to 150 m, although distribution is sporadic and no large beds of either species have been located. Growth is slow, requiring about 4 years to attain a shell height of 60 mm (Bourne, 1991). A commercial fishery began in 1982, but landings have never been large, under 70 t (Table 2, Fig. 12). Most of the landings have been spiny scallops, and they have resulted from scuba diving operations. There is a small boat drag fishery that has landed mostly pink scallops. Generally only the adductor muscle of scallops is marketed in North America. The entire scallop is marketed in the British Columbia pink and spiny scallop fishery, and this makes the fishery economically viable.

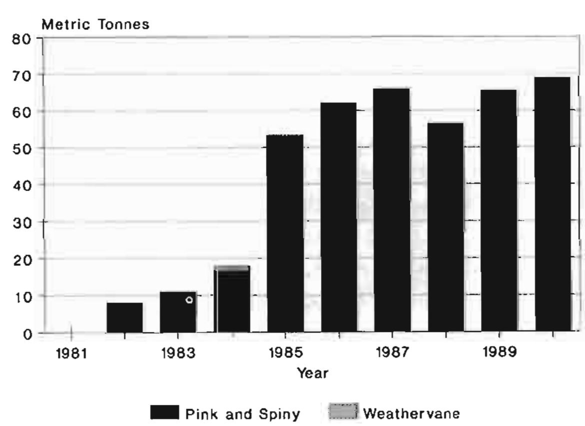

Figure 12
Landings in metric tons (whole weight) of weathervane, pink, and spiny scallops in British Columbia commercial fisheries, 1982–90.

The scallop fishery will never be large. Small unexploited populations of pink and spiny scallops probably exist along the coast, but they are not substantial. The future of the fishery will depend on the extent of populations, economics of harvesting, and markets.

Natural scallop resources are too small to permit development of a large scallop industry. If such an industry is to develop, it will have to depend on culture operations. During the 1980's, a program at Canada's Pacific Biological Station studied the feasibility of scallop culture in British Columbia using the Japanese scallop, *Patinopecten yessoensis* (Bourne et al., 1989). As a result of this work, a private company built a scallop hatchery in 1989 and began operations in 1990 (Bourne and Bunting, 1995). Culture to commercial size will use similar methods to those used in Japan (Ventilla, 1982).

The Future

The future of British Columbia molluscan fisheries appears promising. The industry will never be large, at least compared to molluscan fisheries in other parts of North America or in other parts of the world, but it will continue to be important to many British Columbia coastal communities and provide much needed employment. It is unlikely that new species will greatly expand landings, and the future of the fishery will thus depend on known resources. However, as discussed, increased landings are capable from these resources, and further, active culture operations are capable of significantly increasing landings of some species. The future of the industry depends to some extent on markets, the economics of harvesting operations, and solutions to some problems.

The occurrence of PSP is an intermittent but recurring problem in British Columbia. Although the industry has learned to live with such outbreaks, it will continue to be a major problem for bivalve fisheries. Not only does it restrict use of the resource, but it can cause serious difficulties in assuring the market of a continuous supply of product. Installation of an improved monitoring system for PSP would greatly alleviate the situation and permit wider harvest of bivalves in the north coast district.

Pollution, domestic or industrial, will be an increasing problem for shellfish fisheries, particularly for bivalve fisheries. Although British Columbia is relatively free of pollution when compared with other parts of the world, nevertheless it is a serious problem. Over 40 areas in southern British Columbia are closed to the harvest of shellfish because of pollution. Human populations are increasing steadily in coastal areas of southern British Columbia, and pollution threatens to become worse. More shellfish areas will be affected unless measures are taken to stop it and even clean up and reclaim areas that are presently polluted. Depuration facilities can be built which will permit use of bivalves from mildly polluted areas. However, this adds to cost and sometimes makes utilization of shellfish from polluted areas unprofitable. The only solution is to control pollution and preserve shellfish growing areas.

Probably the most promising area for expansion of the British Columbia molluscan fishery is in the field of aquaculture. Considerable interest continues in abalone culture, but current technology does not appear to be sufficient to permit economically viable culture operations. However, aquaculture could be widely practiced with bivalves and it provides an excellent method to increase yields.

The British Columbia oyster industry is essentially a culture operation, and production could be greatly increased with application of new technology. Manila clam and scallop culture has begun in the Province, and future landings could expand greatly. The advent of hatcheries assures a continuing supply of seed for culture operations. Continued research in all phases of bivalve culture could improve culture technology and lead to greater production at lower costs. Developments in the field of genetics could produce bivalves that are more suited to British Columbia growing conditions and hasten development of bivalve culture.

The future of the British Columbia molluscan industry is promising. With ongoing research and proper management of the resource, molluscan fisheries should continue to remain an important part of the life of many British Columbia coastal communities.

Note added in proof: This manuscript was submitted for publication in October 1991.

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The Molluscan Fisheries of Alaska

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ABSTRACT

Alaska's long coastline and broad continental shelf support large populations of mollusks. Commercially harvested mollusks are abundant on the south coast of the Alaska peninsula and further south, but they are scarce on western coasts facing the Bering Sea. Weathervane scallops, *Patinopecten caurinus*, and razor clams, *Siliqua patula* and *S. alta*, have dominated the landings, but others such as butter clams, *Saxidomus giganteus*; cockles, *Clinocardium nuttalli*; oysters, *Crassostrea gigas*; abalone, *Haliotis kamtschatkana*; geoducks, *Panope abrupta*; and mussels, *Mytilus edulis* or *M. trossulus*, have also been important. Between the 1970's and 1987, the Japanese potted large quantities of whelks (*Neptunea pribilofensis*, *Buccinum angulosum*, *B. scalariforme*, and other species) in the Bering Sea. The fisheries for butter clams, cockles, and Bering Sea whelks have since nearly disappeared. Alaska's earliest inhabitants harvested the abundant bivalves, snails, and chitons along with other sea life, and Native residents today continue to harvest mollusks in intertidal zones as subsistence foods. Weathervane scallops are harvested by large sea-going vessels using dredges and modified beam and otter trawls. Fishermen once dug large quantities of razor clams on beaches using shovels and took them to canneries for sale, but that fishery has become much smaller because of contamination by parlaytic shellfish poison (PSP). In 1991 the value of scallops, oysters, mussels, clams, abalone, and whelks was just over $3 million, most from the scallop fishery. The culture of oysters, mussels, and scallops has some promise as Alaska's waters are productive and relatively free of pollutants.

Introduction

Alaska's long coastline (over 6,000 miles; 9,675 km) and broad continental shelf (Fig. 1) support large populations of mollusks. Nine species are harvested commercially and some others have economic potential. Of the species that have been or are now harvested, only the most valuable fisheries, those for weathervane scallops, *Patinopecten caurinus*, and razor clams, *Siliqua patula* and *S. alta*, and the cultured Pacific oyster, *Crassostrea gigas*, will be considered in detail in this chapter.

The major fishing grounds for mollusks in Alaska are in the Alexander Archipelago of southeastern Alaska, Kodiak Island waters, Cook Inlet, the Alaska Peninsula, and the Bering Sea shelf. Principal mariculture areas are the Alexander Archipelago, Prince William Sound, Cook Inlet, and Kodiak Island.

Alaska fisheries are characterized by boom-and-bust cycles, and those for scallops and razor clams are no exceptions. Scallops and razor clams have dominated the landings, but others such as butter clams, *Saxidomus giganteus*; cockles, *Clinocardium nuttallii*; oysters; abalone, *Haliotis kamtschatkana*; geoducks, *Panopea abrupta*; and mussels, *Mytilus edulis* or *M. trossulus*, have also had some importance (Table 1). Fisheries for butter clams, cockles, and Bering Sea whelks (*Neptunea pribilofensis*, *Buccinum angulosum*, *B. scalariforme*, and other species) have nearly disappeared.

In 1991, the value of scallops, oysters, mussels, clams, abalone, and whelks from Alaska was just over $3 million, most from the scallop fishery (Johnson, 1990). Four reasons account for the low value of Alaskan mollusk fisheries, especially when compared with the Pacific halibut, Pacific salmon, groundfish, and crab fish-

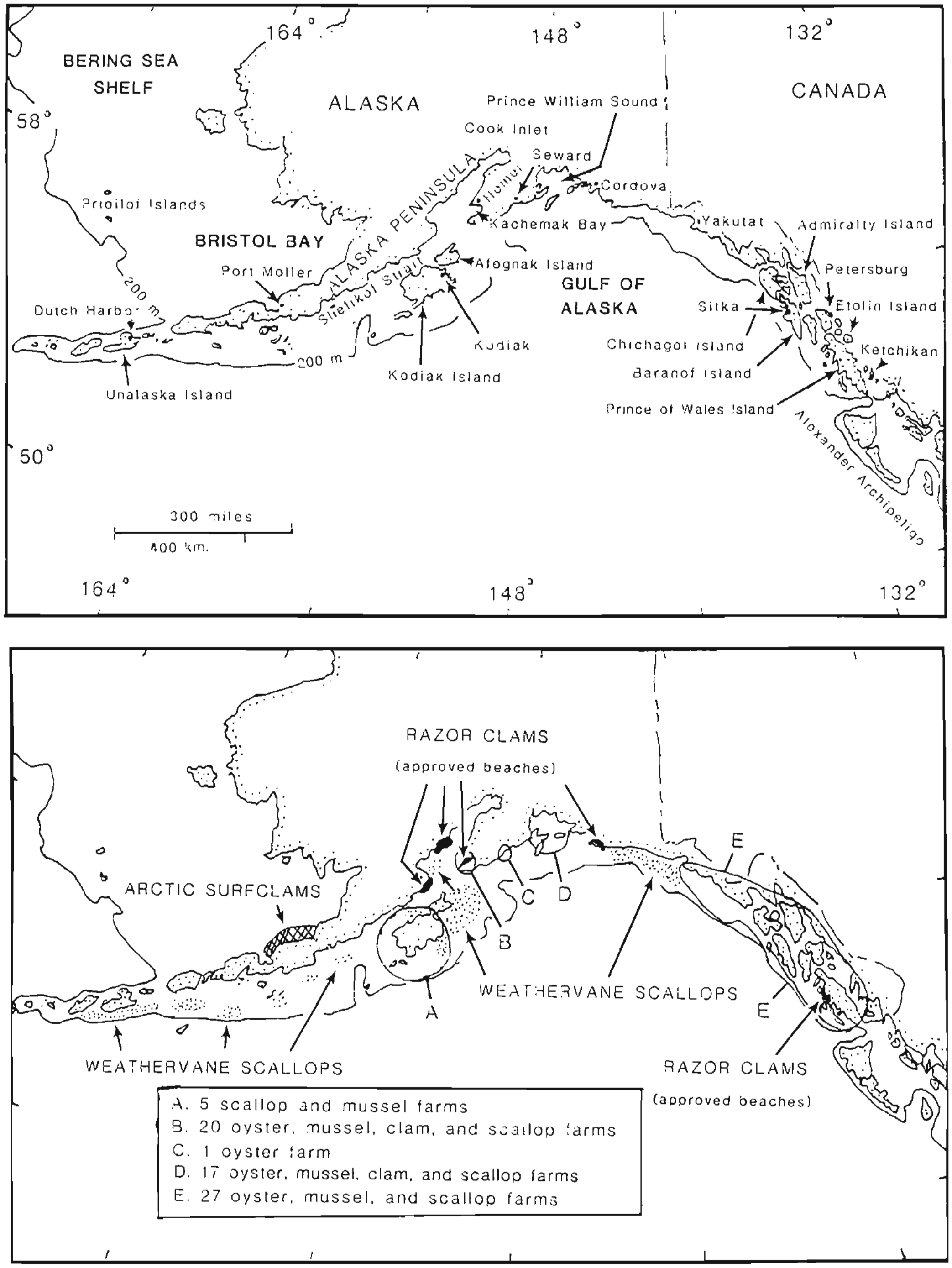

Figure 1

Localities, shellfish beds, and shellfish farms in Alaska. Figures for the number of aquatic farms are from M.A.P. (1992).

eries that were valued at over $1 billion. First, transportation from the often remote growing and harvesting areas is expensive. Second, paralytic shellfish poisoning (PSP) is present and time-consuming testing is required to verify a safe product. Third, the cost of starting a mariculture venture is high, and finally, shellfish grow slowly in Alaska (Smiley, 1992).

The culture of oysters, mussels, and scallops has some promise as Alaska's waters are productive and relatively free of pollutants (Ballentine and Ostasz, 1987). Oyster growing in Alaska dates from 1910 (Yancey, 1966), but has developed slowly.

Table 1

Representative catch and dollar value figures (in thousands) for Alaska molluscan fisheries, 1950–90. Data[1] were not available for all fisheries and all years.

	Scallops		Razor clams		Butter clams		Cockles		Oysters		Abalone		Other	
Year	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value
1950			2,200	264			73	4						
1955			2,000	265	6	0.5								
1960			81	10			5	0.9						
1965			87	40	1.5	1								
1970	1,505	1,505	196	58										
1975	436	609	32	58										
1980	607	2,221	154	121							279	1,116		
1985	313	1,288	206	406	1.5	1.5					56	238	150	75
1990	898	3,170	232	232					16	73.5			1.7	3

[1] Data from ADFG, 1986, 1990b, 1992a, 1992b; Johnson, 1990; and Nosho, 1972.

Origins

Evidence that Alaska's earliest inhabitants harvested the abundant bivalves, snails, and chitons along with other sea life is seen in prehistoric coastal middens of southcentral and southeastern Alaska (de Laguna, 1972; Emmons, 1991). The earliest midden, at least 8,000 years old, is at Chuck Lake on Hekta Island (Dixon[1]). Aleut, Pacific Eskimo, Eyak, Tlingit, and Haida cultures were based on marine resources, but compared with sea mammals, Pacific salmon, Pacific halibut, and other fishes, mollusks were a minor part of people's diets (Josephson, 1974; Blackman, 1990; de Laguna, 1990). Mollusks were gathered by hand in the intertidal zone, year-round by men and women. They were usually consumed fresh, although it is reported that the Tlingits occasionally dried or smoked clams for winter (de Laguna, 1990). Mollusk shells were fashioned into tools and were highly valued for decoration (Stewart, 1973). Subsistence living was and is deeply involved with the culture of the Natives. Almost no intertidal harvesting of mollusks ever took place in Bristol Bay and along the northern coasts, because ice in the Bering Sea scours the shorelines and intertidal mollusks are scarce along them.

Today, Native residents of coastal villages continue to harvest mollusks in intertidal zones as traditional subsistence foods (Emmons, 1991; Blackman, 1990; de Laguna, 1990). People other than Natives also harvest them. The mollusks include Pacific littlenecks, *Protothaca staminea*; butter clams, *Saxidomus gigantea*; fat gapers, *Tresus capax*; razor clams; mussels; pinto abalone; gumboot chitons, *Cryptochiton stelleri*; black katy chitons, *Katherina tunicata*; and octopus.

[1] Dixon, E. J. 1992. Curator, Archaeology, University of Alaska Museum, Fairbanks. Personal commun.

Natives harvest mollusks using ordinary garden shovels and forks. They get the razor clams with a standard shovel designed for them; its blade is about 35 cm (14 inches) long, 15 cm (six inches) wide at the top and 10 cm (4 inches) wide at the bottom, and it has a 1 m (3-foot) handle. Natives pick mussels off rocks by hand and pry off chitons with a knife. The clams are usually prepared by frying or steaming, or are canned or frozen for later consumption (Cooperative Extension Service, 1991), but the older Natives commonly eat clams raw. Chitons are usually eaten raw at collection sites; only the foot is eaten[2].

Paralytic Shellfish Poisoning

The problem of PSP in the mollusk fisheries is substantial, as it often largely influences their history, economics, and current status. In Alaska, PSP in humans is caused by consuming bivalves that have fed on the dinoflagellate *Alexandrium* sp. The dinoflagellates synthesize neurotoxins, which cause paralysis of skeletal

[2] Ed. note: Gmelch and Gmelch (1985) conducted a survey of resource use by residents of the city of Sitka (population, 7,803: 74% white; 21% Natives [Eskimo, Indian, and Aleut]; and 5% others). Their observations about shellfishing, mostly intertidally, are summarized below. During 1982, a total of 50% of all households harvested butter and littleneck clams; 19%, cockles; 19%, razor clams, 32%, abalone; 12%, gumboots; 6%, scallops; 4%, mussels; and 4%, limpets. Intertidal gatherers harvested an average of 7.4 times. The butter clams, which average about 100 mm (4 inches) long and the littleneck clams about 50 mm (2 inches) long, are found in gravel and rock beaches. Both were harvested with a pitchfork and taken home in a bucket. The average annual quantity of butter and littleneck clams taken by harvesting household was just under 1 bushel (338 clams). The total annual harvest for the population of Sitka was 800 bushels. The Natives took clams in

Footnote 2 continued on next page

muscles in warm-blooded animals. Neurotoxins accumulate in clam tissues when the dinoflagellates are sufficiently concentrated in the surrounding water. Different bivalve species accumulate the toxins at different concentrations and for different lengths of time (Ballentine and Ostasz, 1987; Foster, 1991). PSP outbreaks in Alaska are not necessarily correlated with the dinoflagellate blooms commonly called "red tides."

[2] *continued from previous page*
the fall and winter and rarely in the summer and early autumn to avoid PSP poisoning that is prevalent then. Many residents took precautions when preparing and eating clams by carefully cleaning them before cooking. They discarded the dark digestive organs, the dark tip of the siphon, the gills, and the broth in which they were cooked. Most meats were grilled or fried but large clams were usually cut or ground up and used in chowder.

Natives dried clams to preserve them and pulverized some into powder which was later used like a soup stock. Today, excess clams are frozen, either in the shell or cleaned and packaged. Some people also put up canned clams.

The average annual quantity of cockles taken by a harvesting household was 0.29 bushels (80 cockles). The total annual harvest for Sitka residents was 75 bushels. Cockles, like clams, were harvested in the winter and spring. They may occur with butter and littleneck clams, but are often found in separate beds, preferring fine sand or mud to coarse gravel. Historically, Natives smoked and dried cockles in contrast to clams which were usually eaten immediately. First, they were boiled, then split open, strung, and smoke dried. They lasted for long periods. Today, households that collect cockles prepare them like abalone, pounding them to tenderize and then frying them.

The average annual quantity of razor clams taken per harvesting household was 0.7 bushels (86 razor clams). The total annual harvest for the population of Sitka was 275 bushels. Razor clams may also become contaminated with PSP, but they accumulate the toxin less readily and are safe to eat once the siphons, gills, and digestive tract have been removed. With other clams, any part may contain a high concentration of toxin.

The average quantity of abalones taken per household that gathered was 0.65 bushels (104 abalones). The population of Sitka harvested a total of 375 bushels. Abalone can be taken throughout the year. They were pried off rocks with a knife or prying bar in the intertidal zone and by diving usually in depths of 6–7.6 m (20–25 feet). Some people wore wet suits and snorkled around rocks. Intertidal harvesting is best in fall and winter when tides are minus and the water is clear. Some 65% of abalone harvesters picked them intertidally, 17% used scuba, 2% used snorkles, and 16% used a combination of methods.

Abalone are a highly prized delicacy. Shucked meats are grilled and fried and most Native households also freeze some for winter use. Natives have long used abalone as a supplemental food and trade item, and the shell makes iridescent decorations for their carvings, ceremonial dress, and fish lures.

Gumboots are a special occasion food. They are served at feasts, celebrations honoring an individual, and holidays. Gumboots are eaten raw, sauteed quickly, or gently simmered.

Limpets are easily pried off rocks. The edible portion is easily popped out of its shell, and can be eaten raw, steamed, fried, or added to chowder. Like abalones and chitons, they do not carry PSP.

Mussels are harvested intertidally. Like clams, they are harvested only in winter or spring and are susceptible to PSP. Mussels can be prepared the same way as clams and mussels.

Intertidal resources were used primarily as food, but shells, starfish, and seaweed are used in craft art.

So far, the toxin can be detected only by mouse bioassay, and under the provisions of the National Shellfish Sanitation Program (NSSP) clams intended for human consumption can be shipped interstate only after they have been found safe by a state testing program. The only laboratory in the state with that capability is located in Palmer, north of Anchorage (Orth et al., 1975; Ballentine and Ostasz, 1987). Testing for the presence of the toxin hinders the shellfishery, as the turnaround time to process a sample of shellfish is 7–10 days, during which time the shellfish's quality is likely to degrade (Smiley[3]).

The Regulatory Environment

Molluscan fisheries in Alaska are regulated by the NSSP, State of Alaska Shellfish Program, Alaska Department of Fish and Game (ADFG), and applicable tax statutes. The NSSP regulates filter-feeding bivalves and is intended to ensure a product free of bacterial contamination, PSP, and pollutants, by regulating sanitation, growing areas, handling, and processing. The Alaska Shellfish Program ensures compliance with Federal standards. The ADFG and Alaska Department of Health and Social Services jointly control shellfish harvesting (Orth et al., 1975). Other regulations include commercial fishing licenses, vessel licenses, and entry or interim-use permits (Schink et al., 1983).

Alaska's Aquatic Farm Act of 1988 is intended to encourage aquaculture in the state, contribute to the economy, and strengthen the competitiveness of Alaska seafood in the world market. Through the Act's provisions, the Commissioner of the ADFG is authorized to issue permits for the construction and operation of aquatic farms for shellfish and aquatic plants only. Oysters and mussels have the most commercial potential, although pinto abalone; rock scallops, *Crassadoma gigantea*; weathervane and pink scallops, *Chlamys* spp.; littleneck and butter clams; sea urchins, *Strongylocentrotus* spp.; and aquatic plants show promise and are under development (Cochran, 1991). Subsistence and personal use fisheries are also regulated by the ADFG.

Scallop Fishery

The weathervane scallop (Fig. 2) supports the most valuable molluscan fishery in Alaska. Nationally, the Alaska harvest accounted for only about 2.5% of scallops, i.e., 1 of the 40 million pounds taken in the United States in 1991 (NMFS, 1992). Weathervane scallops occur on sand substrates from the Pribilof Islands

[3] Smiley, S. T. 1992. Biology and Wildlife Department, University of Alaska, Fairbanks. Personal commun.

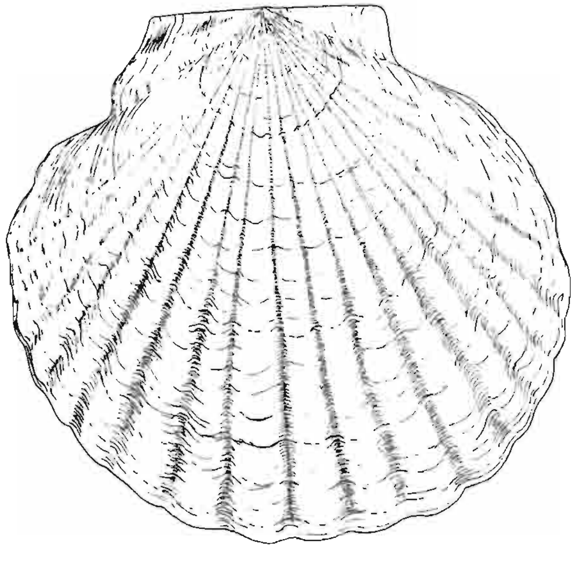

Figure 2
Weathervane scallop, *Patinopecten caurinus*: 16.5 cm anterior to posterior and 15.5 cm high.

in the Bering Sea to Point Reyes, Calif., in 2–300 m depths (Foster, 1991). The species has been found in abundance at 73–100 m depths from Cape Spencer to Cape St. Elias in the northeast Gulf of Alaska, around Kodiak Island, and along the Alaska Peninsula (Fig. 1) (Kaiser[4]). The fishery is limited to offshore waters in the Yakatut area, near Kodiak Island, along the Alaska Peninsula, and in the eastern Aleutians (Johnson, 1990). For statistical purposes, the ADFG divides the fishing grounds into three Regions: Southeast, Prince William Sound, and Westward (Kaiser[4]).

The value of the scallop fishery has varied with demand, market price, and alternative opportunities for scallop vessels. Like many other fisheries, the scallop fishery has seen extreme fluctuations in landings, market demand, and value of the catch. Landings vary among regions; as stocks are dredged out in one area, the boats move to another. Boats land most of the scallops at Kodiak and Seward, and the remainder at Juneau and Cordova (Kaiser[4]).

Alaska's scallop fishery began in 1967, when commercial scallop stocks were found at the same time the king crab, *Paralithodes* spp., fishery was declining in the Gulf of Alaska (Kaiser[4]). By 1968, 19 vessels had entered the fishery; they made 125 landings totalling 1,777,268 pounds of shucked meats (the central muscle). In 1969, the fishery peaked when 1,850,187 pounds were landed. Between 1968 and 1973, the catch averaged 1,370,000 pounds/year, but it declined sharply from 1973 to 1978 when no landings were recorded. The decline is attributed to regulations restricting the dredging areas and seasons, to a limited distribution of the commercial beds, and to increasing fishing costs (Kaiser[4]). In the Kodiak area, particularly, some vessels switched from the scallop fishery to the more lucrative king crab fishery (ADFG, 1988).

The fishery was reestablished during 1978–81, particularly due to nonresident fisherman interest. In 1981, 18 vessels made 98 landings totalling 890,000 pounds of meats (Kaiser[4]). The Westward Region, and especially the Kodiak Island waters, has accounted for most of the recent harvests. In 1991, 7 vessels made 75 landings totalling 683,261 pounds of meats, valued at $3.91/pound (ADFG, 1992a). The total scallop catch for 1991 was 1,006,332 pounds valued at $3,773,745 (Kruse et al., 1992).

The Cook Inlet scallop fishery began in 1983 with beds near Augustine Island, and they were quickly depleted (Johnson, 1990; ADFG, 1990c). The last scallop landings reported for the area were in 1985, when 4 vessels made 11 landings totalling 21,836 pounds of meats. In recent years, scallop harvests from southeastern Alaska and Prince William Sound have been insubstantial (ADFG, 1990c).

Fishermen harvest weathervane scallops with a standard type of dredge, similar to that used on the U.S. east coast. A mesh bag of metal rings, at least 4 inches (10 cm) in diameter, is attached to a frame, 3–4.9 m (10–16 feet) wide. Halibut, shrimp, and crab vessels were converted for the scallop fishery during its peak years in the late 1960's and early 1970's. The fishermen also modified beam and otter trawls for scallop fishing. Between 1967 and 1970, the more efficient east coast scallop vessels, using dredges, accounted for most scallop landings. By 1981, about equal numbers of converted shrimp or bottomfish vessels and more conventional scallop vessels were involved in the fishery (Kaiser[4]).

Recently, vessels operating as catcher-processors have entered the fishery, and in 1991 they accounted for most of the catch in the Kodiak area (ADFG, 1992a). Fishermen shuck the scallops aboard their dredging vessels. Some crews freeze the meats aboard, while others bring the meats to processing plants ashore, where they are washed, packaged, and frozen (Kaiser[4]).

Scallop dredging may also adversely affect associated benthic organisms (Kruse et al., 1992; Kaiser[4]). Three impacts have been described: 1) The physical disruption of soft-bottom communities, which include food organisms for commercially important groundfish, shrimp, and crabs, 2) destruction of some younger scallops, and 3) incidental catches in the dredges of red

[4] Kaiser, R. J. 1986. Characteristics of the Pacific weathervane scallop (*Pecten* [*Patinopecten*] *caurinus*, Gould, 1850) fishery in Alaska, 1967–1981. Alaska Dep. Fish Game, Div. of Commer. Fish. Unpubl. Rep. Catalog RUR-5J86-01, 29 p.

king crabs, *Paralithodes camtschatica*; Dungeness crabs, *Cancer oregonensis*; and tanner crabs, *Chionoecetes* spp. (Kaiser[4]).

The ADFG through the Alaska Board of Fish and Game currently regulates the fishery within the state's territorial waters and the U.S. Exclusive Economic Zone under miscellaneous shellfish regulations. Since 1969, it has regulated time and area closures and gear requirements. The main concern of management is to prevent conflicts with the shrimp and crab fisheries, especially in Kodiak Island waters. Fishing gear is limited to dredges, and the dredges must have rings at least 4 inches (10 cm) in diameter to allow small scallops to escape (Kaiser[4]).

In 1992, new management regulations were proposed for the scallop fishery and subjected to public comment. The regulations are intended to address: 1) conservation of the stocks, 2) bycatch and alteration of the habitat by dredging gear, 3) long-term benefits of a sustainable fishery, 4) availability of the resource to subsistence users, and 5) research for future management of the fishery (Kruse et al., 1992).

Razor Clam Fishery

The Pacific razor clam, *S. patula* (Fig. 3), is abundant in exposed sand beaches in the intertidal zone to depths up to 55 m from Cook Inlet, Alaska, to California (Foster, 1991). Alaskan beaches supporting razor clam populations extend from the outer coast of Chichagof Island in southeastern Alaska to Unalaska Island in the eastern Aleutian Islands and Port Moller on the north side of the Alaska Peninsula (Fig. 1) (Schink et al., 1983). The Alaska razor clam, *S. alta*, which accounts for some of the Kodiak Island fishery, has a more restricted distribution from Bering Strait to Cook Inlet (Foster, 1991). Cook Inlet beaches support the larger of two razor clam fisheries, and the Cordova area supports a smaller clam fishery at Kanak Island west of Cordova (Savikko, 1989; Johnson, 1990).

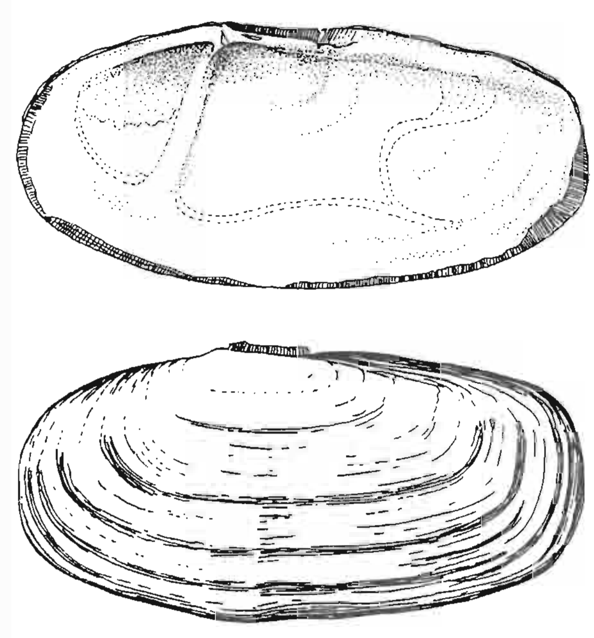

Figure 3
Pacific razor clam, *Siliqua patula*: 14 cm anterior to posterior and 5.5 cm high.

The commercial razor clam harvest on the Pacific coast began in Oregon in 1894 (Nickerson, 1975). Alaska's razor clam fishery grew out of successful canning ventures of razor clams in Washington, Oregon, and British Columbia. Alaska razor clams showed economic promise because the supply was apparently abundant and the demand could not be met by the Washington and Oregon production of razor clams. Clam beds in the sand beaches in the western Copper River Delta and Orca Inlet near Cordova were first exploited commercially in 1916. At least two firms employing a total of 76 people were canning clams on a full-time basis by 1916. They packed 10,093 cases (of 48 half-pound cans each) valued at $35,622 (Orth et al., 1975; ADFG, 1990b).

Fishermen dug the clams by hand with razor clam shovels. A skilled digger could harvest 200–400 pounds and even up to 500 pounds of clams during the 3–5 hours that the clam beds were exposed at low tide. He then weighed and cleaned the clams and took them to the cannery (Orth et al., 1975).

Clams were canned whole or minced, and were shipped to Seattle, Wash., for west coast distribution. In 1917, production reached a high of 93,343 cases. The Alaska pack declined after 1917, when the clams became scarce in the Cordova beds and economic conditions were poor, and, in 1921, only 1,600 cases were produced. Since then, production and value of razor clams has varied widely as supply and demand changed. Discovery of unexploited clam beds has led to increases in production until those beds were depleted.

In the early 1920's, fishermen harvested razor clams in beds west of Cordova, Snug Harbor in Cook Inlet, Kukak Bay on the Alaska Peninsula, and Alitak on Kodiak Island (Fig 1). In 1924, Federal regulations set a minimum size limit of the clams of 4.5 inches (11.4 cm), and, in 1933, harvest seasons, restricted areas, and pack limits were established (Orth et al., 1975). In the early 1930's, razor clam production increased, and Alaskan beaches supplied more than half the pack of the entire U.S. west coast (Orth et al., 1975). Clam production from the 1930's to the mid-1950's averaged between 1 and 2 million pounds/year. By the mid-1950's, however, the high cost of production compared with that of dredged surfclams, *Spisula solidissima*, and mahogany quahogs, *Arctica islandica*, from the U.S. east coast led to a sharp decline in production (Orth et al., 1975;

ADFG, 1990b). Changes in the sediments of the Copper River Delta also led to low survival of juvenile clams in the 1950's (ADFG, 1990b).

In 1954, PSP was detected in the stocks of Alaska hardshell clams, and the U.S. Food and Drug Administration (FDA) withdrew Alaska's membership in the NSSP, because the territory could not comply with provisions of the program. As a result, razor clam harvests were sold increasingly as bait for Dungeness crabs (Schink, et al., 1983).

Natural disasters also affected the razor clam fishery. In 1964, a massive earthquake severely impacted the razor and other clam fisheries in southcentral Alaska. The Prince William Sound and Copper River area was raised about 2 m (6 feet), causing considerable mortality to clams and loss of their habitat. In Cook Inlet, clam beds subsided, making them inaccessible to clam diggers (Schink et al., 1983; ADFG, 1990b). In the 1970's nearly all the razor clam catch was processed for crab bait (Orth et al., 1975).

Beginning in the 1970's, interest in potential clam fisheries increased. Alaska regained NSSP status in 1971, but areas from which clams may be harvested for human consumption are limited (Fig. 1). Bait clams may be harvested from unapproved areas, but must be marked with a dye to designate them as not for human consumption (Schink et al., 1983; Johnson, 1990). Data for the value of the bait clam fishery are not available.

Floating dredges, used to harvest razor clams in Cook Inlet in recent years, were prohibited in 1990, and the clams are now dug only by hand. The Cook Inlet fishery is sporadic, because effort and market opportunities vary (ADFG, 1992b). In 1991 the Cook Inlet fishery had 24 diggers, whose harvest was 210,320 pounds valued at about $100,000 (ADFG, 1990a, 1992a, 1992b). Since 1986, no commercial harvests have been reported for the Kodiak Island region, and the Cordova area had a 2,903-pound subsistence harvest.

Razor clams also provide a popular recreational and personal-use fishery. The most popular and accessible clamming areas are on the east side of Cook Inlet and in Prince William Sound (Schink, et al., 1983). Use of the clams grew with the construction of the Sterling Highway from Anchorage to Homer in 1958–59 and with construction of access roads down steep bluffs on the east side of the inlet. The ADFG regulates the fishery; it allows fishermen to dig the clams year-round (ADFG, 1990a).

Other Mollusk Fisheries

Whelks

Whelks occur throughout the continental shelf off the Alaska coast, but are especially numerous on the Bering Sea shelf (MacIntosh and Somerton, 1981). From the 1970's until 1987, the Japanese fished them in the eastern Bering Sea with pots strung at intervals on a groundline (Fig. 4). They processed them on their catcher vessels by cooking them briefly, separating the meats from the shells by crushing, and then cleaning, grading, and freezing them (Fig. 5). In the years 1972–78, for which data are available, the fishery had as many as 21 vessels and annual harvests of edible meat ranged from 808,000 to 907,400 pounds (MacIntosh, 1980). Currently, there is no foreign fishery for the whelks (NMFS, 1991). Alaska boats occasionally land minor quantities of whelks in other pot fisheries or when they catch shrimp. The Bering Sea has a large stock of whelks, but Alaskan fishermen have not harvested them be-

Figure 4
Whelk (snail) pots were baited, then conveyed to stern where they were stacked before setting. These three men 1) removed old bait, 2) put new bait (Pacific sardine, *Sardinops sajax*) in the bait bag and on the "hanging bag" hook (usually small pollock, *Theragra chalcogramma*), and 3) pursed up the bottom of the pot (web). Photograph by R. MacIntosh.

Figure 5
Feeding whelks (snails) onto a conveyor that led to the crusher. Stacks of bait fish in the background are Pacific sardine. Photograph by R. MacIntosh.

cause the market is poor and they are engaged in other more lucrative fisheries (MacIntosh, 1980).

Pinto Abalones

A minor fishery for pinto abalones (Fig. 6) exists in southeast Alaska, the wave-exposed west coasts of Baranof and Chichagof Islands, and the south and west coasts of Prince of Wales Island (Fig. 1). Divers using hookah or scuba gear harvest the abalones in waters about 15 m (50 feet) deep by prying them from rocks. The abalones are frozen on the catcher vessel or by shore processors. The minimum legal size for the abalone, a much smaller species than those harvested off California, is 3 inches (76 mm). The fishery begins 1 October and continues till harvest quotas are met (Johnson, 1990).

In 1989, the abalone fishery employed 68 divers, who harvested a total of 61,800 pounds of abalone meats that sold for an average of $4.01/pound for a total value of $248,000 (Johnson, 1990). Prospects for abalone culture are not especially good owing to a lack of adequate seed animals from wild stocks, slow growth rates, and a high cost of regular feeding and tending of the animals (ASGA, 1991).

Figure 6
Pinto abalones, *Haliotis kamtschatkana.*

Geoducks

Geoducks occur from Sitka, Alaska, to San Diego, Calif., in the intertidal zone and to a depth of 70 m. They burrow deeply into mud flats in protected bays (Foster, 1991). The bivalves are found in abundances considered adequate for commercial harvesting near Gravina, Noyes, and Kah Shakes, and Biorka islands near Ketchikan in southeastern Alaska. Divers using hookah gear and high-pressure water jets harvest geoducks in 6–15 m (20–50 feet) of water. The fishery was developed in the late 1970's, and commercial harvesting was begun in 1985 (Johnson, 1990). In 1989, 203,700 pounds of geoducks were landed and sold for $0.50/pound, for a total value of $100,000 (Johnson, 1990).

Butter Clams

Before 1916, butter clams were canned in southeastern Alaska, incidentally to salmon processing. In 1930, 25,000 pounds were harvested, and the harvest remained low until 1942 when wartime demand increased production. In 1946, PSP was discovered in the canned product, and that, along with increased Federal regulation and competition from the U.S. east coast clam fisheries, led to the end of this fishery (Schink et al., 1983).

Cockles

The history of the cockle fishery parallels that of the butter clam fishery (Orth et al., 1975). The modern fishery for butter and other hardshell clams is small; data on their value are not available.

Arctic Surfclams

In 1977, exploratory fishermen found extensive stocks of the Arctic surfclam, *Mactromeris polynyma* (locally called the pink-neck clam), in the southeastern Bering Sea between Ugashik Bay and Port Moller north of the Alaska Peninsula (Fig. 1) (Hughes and Nelson, 1979; Hughes and Bourne, 1981). As stocks of the Atlantic surfclam declined on the U.S. east coast, it was believed that a fishery for Arctic surfclams could be established and yield as many as 19–25 million pounds of meats/year. The fishery never became active after the initial research, possibly because the financial climate was poor. Besides, people with environmental concerns have had reservations about the impact of the fishery on marine mammals and the food chain of the southern Bering Sea (Stoker, 1977).

Mollusk Culture

Alaska oyster farms and other mariculture ventures are usually small-scale operations run to supplement seasonal incomes from fishing, trapping, or other occupations (Fig. 1) (Yancey, 1966; Else and Paust, 1987). From 1937 till statehood in 1960, tidelands were leased from the Federal government under the Oyster Bottom Leasing Act. Before 1937, use was by right of occupancy. In 1960, the State of Alaska assumed responsibility for tideland leases.

Oyster Culture

Pacific oysters (Fig. 7) were introduced from Japan in the early 1900's and grown in southeastern Alaska and Prince William Sound. Since then, small-scale, underfunded oyster culture ventures have been attempted and have met with limited success, partly because the growers lacked experience.

Oyster culture was first attempted in 1910, with plantings made near Ketchikan, first in George Inlet and later at Coon Cove and Carroll Inlet. Growers have since attempted to raise oysters in various localities from Kachemak Bay (Fig 1) to southeastern Alaska at various times between 1910 and 1961, but by 1961 success was limited to the Ketchikan area (Yancey, 1966).

Details of the first commercial oyster growing ventures are lacking; however, from 1938 till it went out of business in 1953, the Alaska Oyster Company[5] marketed oysters grown in Coon Cove in the local Ketchikan area. The beds were nearly exhausted by 1945, because no Japanese seed oysters were imported between 1941 and 1947. Growers used beach culture methods, the oysters needed 3 years to grow to maturity, and total mortality in that time was abot 60% (Yancey, 1966; Else and Paust, 1987).

In 1955, the North Gem Oyster Company of Ketchikan began planting spat and also experimenting with raft culture. Oysters grown on rafts matured in 2 years. In 1960, this company was taken over by the Alaska Oyster Company. That year, it was leasing 227 acres, and it produced 100 gallons of shucked oysters.

Experimental culture of oysters is currently under way in Cook Inlet and Kodiak Island (Dick and Hatrick, 1987; Cochran, 1991). In 1986, 7 of 20 permitted oyster farms were producing commercial quantities of oysters (Else and Paust, 1987; House Research Agency, 1987). They sold 30,000 to 32,000 individual half-shell oysters. The oysters grow to market size in 2 seasons, and sell for $0.50 each, or about $3.00/pound in the shell (House Research Agency, 1987).

As oysters do not reproduce in the cold Alaskan waters, growers depend on imported seed. Seawater temperatures in southeastern Alaska average 6.5°C in

[5] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

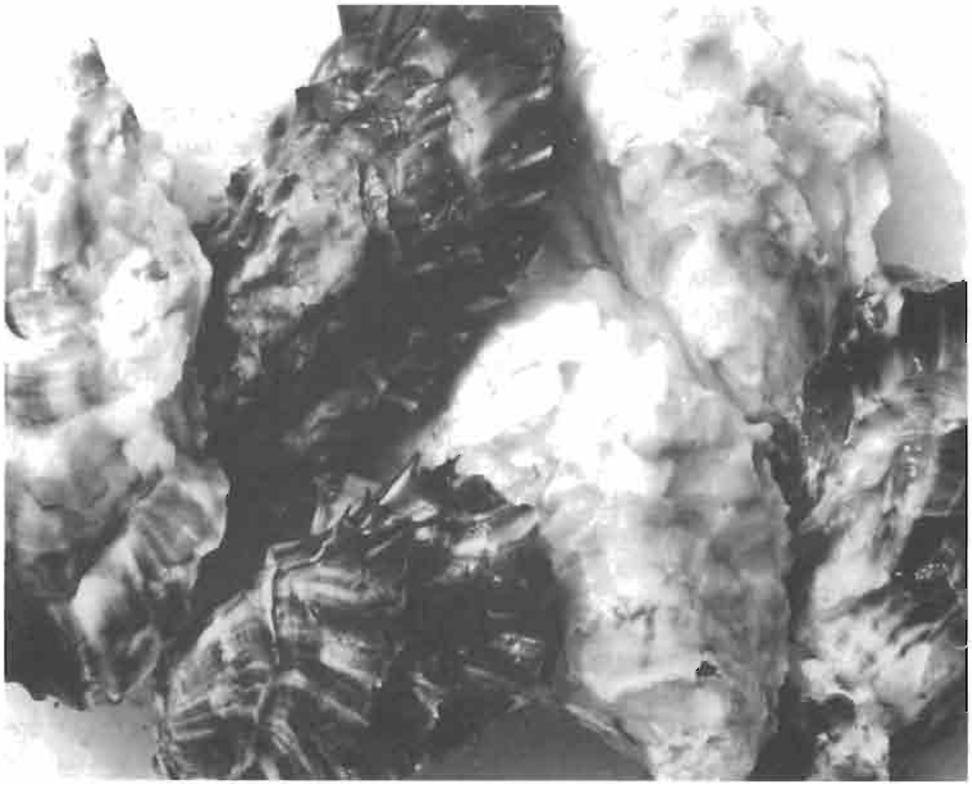

Figure 7
Pacific oysters, *Crassostrea gigas*. Photograph courtesy of the Alaska Shellfish Growers Association.

February and 13.3°C in July (Brower et al., 1988). Although warmer temperatures are common in oyster growing areas, they rarely remain at 21°C long enough for the oysters to spawn (House Research Agency, 1987). The Board of Fisheries permits the importation of seed oysters, but only from the west coast of North America (Else and Paust, 1987). Oyster hatcheries in Washington and British Columbia supply most of the spat. Oyster growers purchase seed oysters attached to bits of oyster shell or other cultch and are considered as cultchless spat (Else and Paust, 1987; House Research Agency, 1987).

Surface trays made from plastic nets floated by salvaged logs from beaches have been the standard type of raft used in southeastern Alaska (Fig. 8). The trays are placed 15–30 cm (6–12 inches) below the water surface where the oysters are held in the warmest temperatures. This method is inexpensive but requires more of the grower's attention than others, and the trays are susceptible to wave damage. Several Alaskan growers are moving away from the surface trays and adopting net systems to hold oysters in multiple layers from rafts, buoys, or longlines (Fig. 9) (Else and Paust, 1987). Oyster farms in Prince William Sound are using or intend to use longlines (Else and Paust, 1987; ASGA, 1991).

In 1990, 24 farms in southeastern Alaska, 9 in Prince William Sound, and 3 in Cook Inlet were growing oysters. Sales valued at $73,537 came from 10 farms: 2 in Prince William Sound and 8 in southeastern Alaska. In southeastern Alaska, the oysters were sold to a processing plant that has been responsible for processing, PSP testing, and marketing. The market for Alaska oysters is underdeveloped; most are sold to local restaurants and food stores (Else and Paust, 1987). The average price for southeastern Alaska oysters was $3.29/dozen. The two growers in Prince William Sound sold most of their oysters directly to restaurants and retail stores. The average price of these oysters was $5.79/dozen (ASGA, 1991).

Mussel Culture

Mussels inhabit rocky coasts throughout the state. Nine commercial growers have had an interest in culturing and harvesting them (ASGA, 1991). Growers easily col-

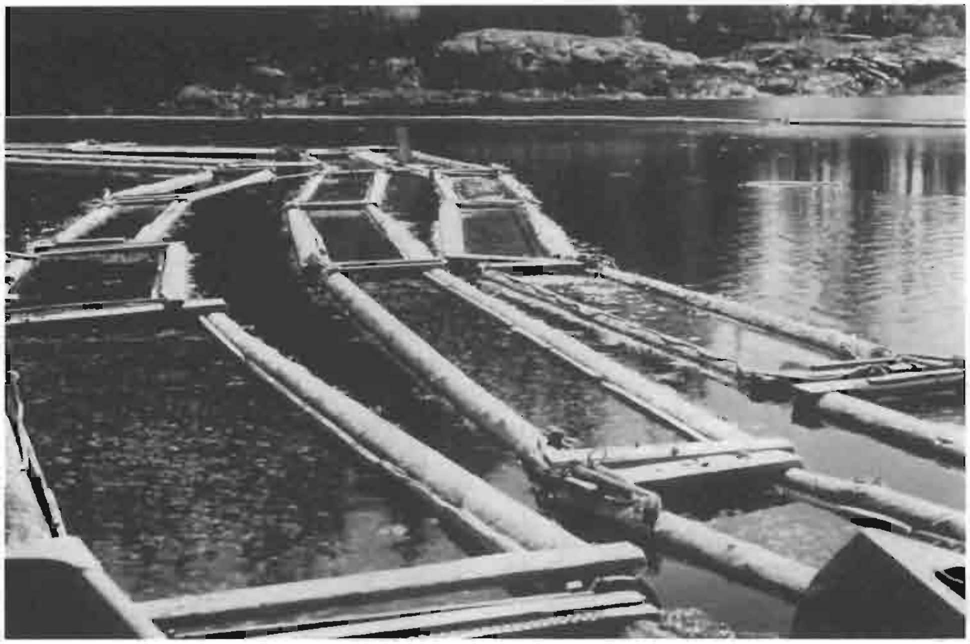

Figure 8
Surface trays were used by Alaska's first oyster growers. The trays consist of plastic mesh hung between two logs. Photograph courtesy of the Alaska Shellfish Growers Association.

lect mussel spat from lines in the water or from cliffs and rocks at low tide. They hold the spat in sock nets until they attach; then the spat are grown on lines suspended from rafts where they take 12–18 months to reach market size. When workers harvest the mussels, they grade them by size and pack them in onion bags, 10–20 pounds/bag. Mussels sell for $1.45/pound wholesale in Anchorage and retail for $2.99/pound (House Research Agency, 1987).

In 1987, Alaska had 5 permitted mussel farms in 1987: 3 in Kachemak Bay and 1 each on Kodiak Island and in Prince William Sound. Of these, one was producing mussels in commercial quantities (10,000 pounds [165 bushels] in 1986) (House Research Agency, 1987). In 1991, the value of the mussel crop was $3,718 (ASGA, 1991).

Scallop Culture

The Japanese scallop, *Patinopecten yessoensis*, has been raised successfully in Japan for years, and there is considerable interest in adapting Japanese culture methods to the weathervane scallop in Alaska. Attempts to develop such enterprises have been centered in Kodiak Island waters that are regarded as favorable for scallop culture (Fig. 10). But in 1987, 4 projects targeting weathervane scallops met with little success in collecting larvae or in artificially spawning the scallops (House Research Agency, 1987; Anonymous, 1989).

In 1989, larvae of pink scallops were collected successfully, however, and in response to a growing market for small scallops, research on the feasibility of culturing this species continues. The Kodiak Island Mariculture Feasibility Project seeks to develop new or adapt old technology to growing the pink scallops, and to overcome problems posed by their slow growth and short shelf life (Anonymous, 1989).

The Future

Projections of the value of oyster and mussel culture in Alaska, based on development plans by permitted farms, show possible growth to $1.9 million in 1993, and to over $2.5 million by 1994 (ASGA, 1991). Kachemak Bay, Prince of Wales and Etolin Islands in southeast Alaska (Fig. 1), and several areas in Prince William Sound are developing as the principal oyster and mussel growing areas (ASGA, 1991). Mariculture ventures may become a source of much-needed income for rural communities. Alaska Native corporations in Klawok, Angoon, and Yakutat in southeast Alaska, Akhiok on Kodiak Island, and Tatitlik, English Bay, and Port Gra-

Figure 9
Preparing a lantern net for deployment by lacing closed the opening, allowing access to 10 tiers where oysters are planted. Visible in the background is a longline grid. Each float supports a lantern net or stack of plastic trays. Photograph courtesy of the Alaska Shellfish Growers Association.

Figure 10
Weathervane scallops, *Plactinopecten caurinus*, grown in a lantern net. In 1992, Yakutat Mariculture, Inc. was testing the feasibility of growing undersize scallops gathered by dredging in Yakutat Bay. Photograph courtesy of the Alaska Shellfish Growers Association.

ham (Fig. 1) in southcentral Alaska are developing mariculture projects (Cochran, 1991).

Research Needs

An inexpensive, easy-to-use test for the presence of PSP is the most important need for molluscan fisheries and culture to prosper in Alaska (Smiley, 1992; Else and Paust, 1987). Currently, the Alaska Science and Technology Foundation and the Alaska Department of Environmental Conservation fund research to develop the technology for a monoclonal antibody test for the presence of saxitoxin and neosaxitoxin (Smiley[3]).

Mariculturists need ways to predict when fouling organisms, such as bryozoans, hydroids, annelids and other worms, and barnacles will attach to oysters or culture gear. Controlling fouling organisms and predators is important to oyster growers (Dick, 1987). Research on oyster genetics and an oyster breeding program are needed to develop an oyster stock adapted to regional conditions. Research on oyster diseases and parasites is also needed (Else and Paust, 1987). Other mariculture-related research seeks to adapt new techniques for growing scallops and venerid clams, and practicing mixed mariculture in Alaska.

For other molluscan resources such as scallops, Arctic surfclams, snails, and venerid and softshell clams (*Mya* spp.), basic research to determine the age structure of stocks, life cycle, and impact of the fisheries on stocks is needed.

Development

Aquatic farmers have identified several ways that State of Alaska programs can benefit the developing mollusk culture industry. Constraints on development include the lack of investment capital, transportation logistics for setting up aquatic farms on the sparsely settled Alaskan coast, time spent in holding shellfish samples for PSP testing, and the lack of hatcheries to produce spat (Cochran, 1991). The high cost of site permits from the Alaska Department of Natural Resources is regarded as a deterrent to investment in new aquaculture ventures (House Research Agency, 1987). It has also been suggested that incentives and disincentives might be better documented through a test farm and pilot program to answer technical questions and provide encouragement (Else and Paust, 1987).

Specific needs brought to the attention of the Alaska State Legislature in 1987 (House Research Agency, 1987) were: an oyster hatchery to produce spat, a PSP testing facility near the growing areas of southeastern Alaska, and a loan program to help meet the cost of setting up mariculture ventures. Mariculture may also be encouraged by establishment of cooperatives (Else and Paust, 1987) and by targeting the enterprises to benefit rural coastal communities (Anonymous, 1989).

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Editors' Addendum

The following paper was published in the Journal of Shellfish Research, Volume 14, No. 1. pages 71–78, 1995, while this chapter on Alaska's mollusk fisheries was in press. We herewith publish its title, author's names and affiliations, and abstract.

"Development of the Fishery For Weathervane Scallops, *Patinopecten caurinus* (Gould, 1850), in Alaska," by Susan M. Shirley* and Gordon H. Kruse**

Abstract: The Alaska scallop fishery harvests weathervane scallops, *Patinopecten caurinus* (Gould 1850), in the Gulf of Alaska and Bering Sea, although small quantities of *Chlamys* spp. were harvested in recent years. The fishery began in 1967 and evolved from a sporadic, low-intensity fishery to one characterized by a highly specialized fleet by 1993. An influx of larger, more efficient vessels from 1990 through 1993 increased harvests and altered the character of the fishery. Vessel length increased 85% from a mean of 18.5 m to 34.3 m in 1991, and crew sizes doubled. The number of scallop landings increased significantly from 65.9 per year during 1980 through 1989 to 140.7 per year during 1990 through 1993, although the mean number of vessels did not change significantly between the two periods. Scallop harvests averaged 667.1 t of shucked meats from 1990 through 1993, three times the average harvest of 216.7 t from 1983 through 1989. The percentage of the fleet's total Alaskan fishing income derived from the scallop fishery increased from 57.7% in 1983 to 100% by 1990. The decreased diversification of scallop vessels into other fisheries represented a shift from a part-time fleet to a dedicated, full-time scallop fleet with greater harvesting efficiency. New management measures were adopted to address the changing nature of the fishery and included altered fishing seasons, observer coverage, area, harvest limits, ceilings on catch of incidental species, restrictions on crew size, and a moratorium on vessels fishing in the exclusive economic zone.

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The Importance of Shellfisheries to Coastal Communities

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ABSTRACT

It is difficult to generalize about the importance of shellfisheries to coastal communities, owing to the variation in the shellfisheries and the coastal communities and in their ecological, cultural, and political settings. Shellfishing is a difficult and not always remunerative way to make a living. In bay fishing, almost anyone can enter it. In digging for hard clams, *Mercenaria mercenaria*, all one needs is a rake, a rowboat, and a small outboard motor. If a person harvests hard clams or soft clams, *Mya arenaria*, in shallow water, one needs only a scratch rake or hack and a bag for his harvest. Success depends on much more. Some people see shellfishing as unskilled labor that "anyone" can do, but the required skills are not easily acquired. The ones who are unskilled quit. Most of the learning is trial and error and learning from the older men. Anyone familiar with shellfishing knows that freedom or independence is one of the most important personal and social values. Shellfishing is selective for people who are capable of working on their own and who are "self-starting," in contrast to those who lack motivation or direction unless it is imposed by others. Security is gained from experience and acquired knowledge. Most people will not trade the security of a job ashore for shellfishing but like the extra money they can make doing it, and so there are part-timers who work at shellfishing as a second job. And shellfisheries are important hedges for someone who loses a land job. Health insurance and other benefits and a steady income are not available to most shellfishermen. Shellfishing is partly a gamble, as are other activities dependent on wild and unpredictable resources. When shellfish are scarce and seem to be on the verge of extinction, there remains the possibility of a good set and hence good times for the shellfishermen.

Introduction

It is very difficult to generalize about the importance of shellfishing to coastal communities, except to say that by and large, shellfish are among the most accessible and valuable food resources available and thus tend to be heavily exploited where they exist. Beyond that generalization, time and space, and culture defy easy theorizing or generalizing.

Time and the change it portends pose major obstacles to saying anything simple about shellfishing and human communities. For example, shellfisheries were probably far more central to the economy and diet of residents of New York City in the 18th and early 19th centuries than later (Kochiss, 1974). Taking even larger leaps backward in time we would have to explore the roles of shellfish consumption and trade in the development of Mesolithic and Neolithic societies as well as in the development of early states and empires.

Shellfish middens are major features of coastal archaeological sites throughout the world, testifying to the critical role of this source of food and trade for human communities as well as the comparatively lower rate of decomposition of shells than bones and other organic matter. The Maglemosians who lived on the margins of the Baltic Sea some 10,000 years ago, during the Mesolithic area, are known as the world's first "maritime" people (Clark, 1948, 1952); they were able to live a relatively sedentary way of life, supported by a high reliance on shellfish. Maritime communities utilizing shellfish were well established in Africa as early as 8,000 years ago (Clark, 1970), Baja California, Mex., around 8,000 years ago (Hubbs and Roden, 1964), and in Japan by 5,000 years ago (Nishimura, 1973). In the case of coastal Peru, human settlements dependent on shellfish and fish appeared on the coast about 5,000 years ago (Moseley, 1975); the shellfish resources of the coast—as well as periodic crises of resource depletion and the ways people responded to them—contributed to the development of more diversified forms of social organization, leading the way to the Incan civilization (Moseley, 1975; McGoodwin, 1990). Middens (archaeological dump-heaps) also provide evidence for changes in the abundance of different species which can be used to make conjecture about the effects of human activities on shellfish populations in the distant past (Swadling, 1976; Braun, 1974).

Although harvest technology may not have changed very much over the millenia since humans began exploiting shellfish, the early fisheries took place in sociopolitical and cultural contexts far different from those of the industrialization and urbanization that has transformed the world in the past century or more. Even within modern industrial and urbanized societies, it is difficult to generalize about the role of shellfisheries for coastal communities. There is great variation in the shellfisheries, in the coastal communities where they are found, and in their ecological, cultural, and political settings.

For example, how can we weigh the importance of shellfisheries to urban, coastal communities—where the industry is close to markets but also to sources of pollution and competing jobs (the list of communities like this gets longer all of the time, with coastal population growth [Maiolo and Tschetter, 1981])—against their importance to rural coastal communities, where shellfishing may be one of the few ways to make a living? There are also strong differences in rural shellfishing. In some rural coastal communities people are involved in a broad spectrum of land- and/or sea-based activities, such as the watermen of the Chesapeake Bay (Warner, 1976; Peffer, 1979) the baymen of the Pine Barrens region of New Jersey (Berger and Sinton, 1985; Lund, 1987) and the North Fork of Long Island (Matthiessen, 1986), and the fishermen of Raritan Bay, N.J. (MacKenzie, 1991; McCay, 1985). There are also communities where the shellfishermen and -women are highly specialized producers for markets, such as the oystermen of Great South Bay, Long Island, N.Y., including hard-working Calvinist immigrants from Holland (Taylor, 1983), those of the Delaware Bay, N.J. (Moonsammy, 1987; Del Sordo[1]) and the Chesapeake Bay (McHugh, 1972); the oystermen and mussel growers of Zeeland and other parts of the Netherlands (van Ginkel, 1988, 1989), and the marisquadoras or female clammers of Galicia, Spain (Meltzoff and Broad[2]).

The technology and ecology of modern shellfisheries also differs enough to forestall easy generalization. For example, some shellfisheries take place in the open ocean, using large, costly, and technologically sophisticated enterprises: hydraulic dredging for surf clams and ocean quahogs in the North Atlantic is one example, dredging for sea scallops is another, and setting pots for conch is yet another. Each has its own structures of linkages to markets, types of work and labor relations, and traditions. Other shellfisheries (historically most of them) take place in inshore waters, lagoons, bays and estuaries, and within that domain there is great variety in the methods used, ranging from hands and toes (as in "treading" for clams in the U.S. Mid Atlantic states) to mechanized and powered dredges. The ecology of shellfisheries also has obvious geographic differences. Some are tropical, some temperate, some sub Arctic. Finally, every species and population has its own biological patterns, responsiveness to environmental conditions and harvesting pressures, and so forth.

In this essay we have chosen to avoid the risks of generalizing by narrowing our focus to the bay shellfisheries, mostly for northern quahogs (hard clams), *Mercenaria mercenaria*, mostly in New Jersey, and even there, mostly in central and northern New Jersey (Fig. 1). We try, nonetheless, to offer generalizations about the meaning and human values of shellfishing that could be tested or weighed against other experiences and settings.

Our essay focuses on the positive side of bay shellfishing, so it is appropriate to include in this introduction a brief comment on the other side of this difficult, risky, and not always remunerative way to make a living: "I lived it and that's all I can say. It's all a memory, a bad memory" (the wife of a New Jersey clammer, when asked to contribute to this essay). Although women are far more likely to be involved in shellfishing than other kinds of marine fisheries (Nadel-Klein and Davis, 1988), as harvesters, processors, and marketers, time and space do not allow us to give proper attention to questions about either gender or the hard times.

The Baymen's Perspective: ". . . a maverick sort of life,"

One thing clear about bay shellfishing[3] is that just about anybody can get into it. As far as hard clams go: "The

[1] Del Sordo, S. G. 1985. Oysters and bayshore towns. Pap. pres. to "Man & Bay Together," cosponsored by Lehigh Univ. and Wetlands Inst., Newark, Del., May 18, 1985.

[2] Meltzoff, S. K., and K. Broad. 1992. The rise of women in fisheries management: the marisquadoras of Illa de Arousa, Galicia. Pap. pres. to World Fisheries Congress, Athens, Greece, May 1992.

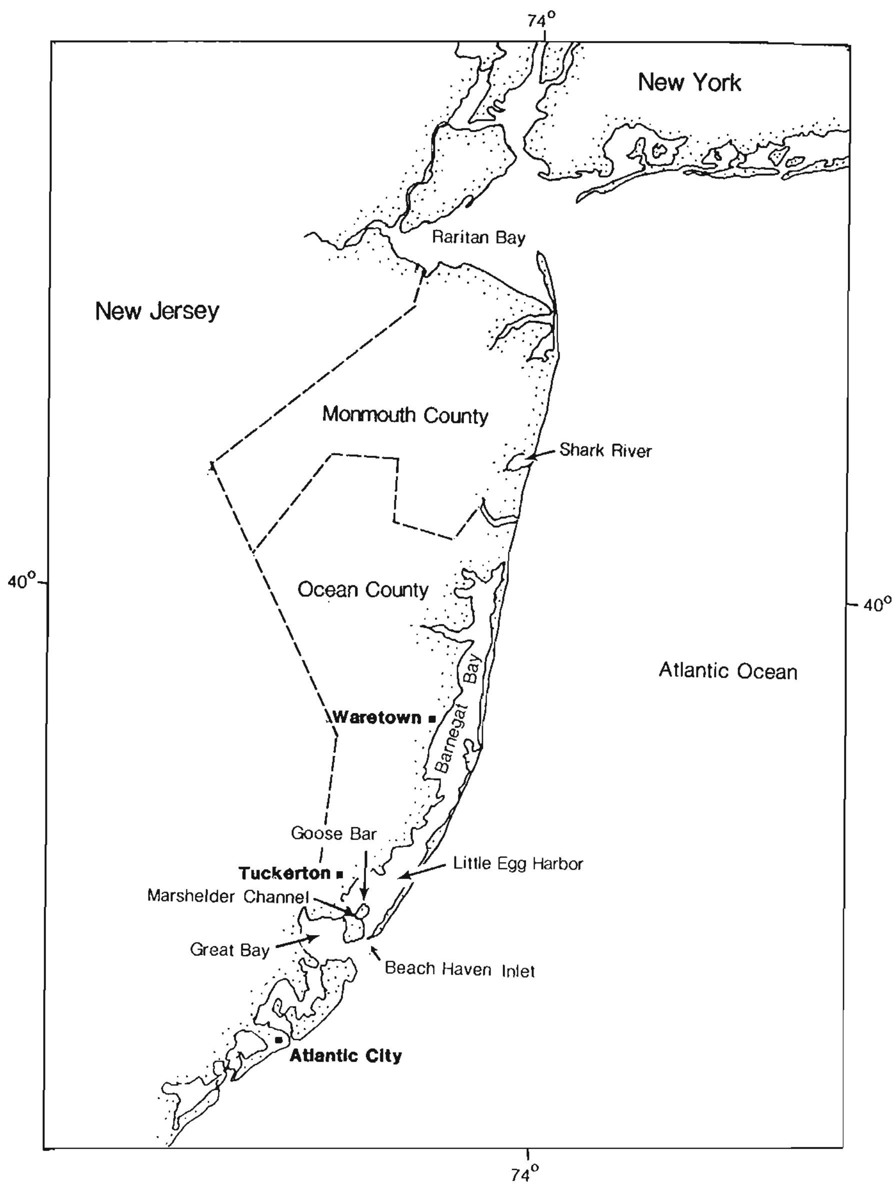

Figure 1
The east coast of New Jersey with place names mentioned in the text.

capital outlay is not like buying a dragger. All you need is a clam rake, a rowboat, and a small used outboard, and you're a businessman" (William Jenks, hereafter the author of the quotations in this paper). In fact, if one wants to "tread" for clams (use one's toes to find and retrieve them from the bottom), he or she needs little more than some protection for feet and a wire basket or some other device to hold the clams, and if they are content to take hard clams, or soft clams, *Mya arenaria,* in shallow waters at low tide, they need only a little scratch rake and a bag for the harvest.

[3] As distinct from ocean shellfishing, which in the Eastern United States means using large, expensive vessels and gear to capture sea scallops, surf clams, and ocean quahogs.

Shellfishing and Common Property Rights

Success as a shellfisherman has historically depended heavily on the right to use shellfish beds freely, a right that has disappeared in some areas because of other claims to property, either industrial (i.e. dockage or wharfage) or aesthetic (residential property owners' claims to exclusive riparian property to keep a view pure). This is the "common property" right that is so important to the nature of shellfishing at a particular junction of time and place: where it exists, shellfishing is an activity open to many people, who may freely move in and out of it. Where it does not exist, where the shellfish beds have become either privatized or "condemned," as we say in New Jersey, because the state has evidence that they are public health hazards, shellfishing becomes a specialized activity open to only a few, and increasingly it may become the specialization of shellfish mariculturists.

The notion of a "tragedy of the commons" (Hardin, 1968) appears appropriate to many shellfisheries: because they are open access, there are typically too many people in them for the resource to be sustainable (Valliant, 1985, on the Chesapeake Bay oyster fishery as a case of tragedy of the commons; Brooks, 1891, for the same theory for the problem of declining oysters in the Chesapeake Bay). Moreover, economic efficiency would be gained by privatizing the resource, as Agnello and Donnelley (1975a, b; 1984) have argued for the oyster fisheries of the Mid-Atlantic region of the United States.

When shellfish beds are privatized, or the government imposes limits to entry, there are major social costs in losses of opportunity (van Ginkel, 1988, 1989; McCay and Creed, 1990). This is an important reason why there has been strong political and private resistance to privatization in many of the shellfisheries of the world, including some of the states of the United States (Santopietro and Shabman, 1992). The concept of a "public trust" in tidewater resources, including shellfish, is very well entrenched in U.S. culture and has parallels in the "common property" law in other nations. For shellfish, in particular, this has meant recognition of the dependence of many people on the resource for food and income. It also can be interpreted to suggest that the shellfishermen themselves may have interest in effective management of the shellfish "commons," as will be suggested below in a discussion of attempts at cooperative management.

Apprenticeship, Knowledge, and Success

Success at shellfishing depends on much more than the right and ability to enter. Some people see shellfishing as unskilled labor that anyone can do. But the fact that capital requirements might be low does not mean that skills are as easily acquired. "The ones that are unskilled quit. . . . Most of it's trial and error, following the older men, not literally following them, but learning from them. It's almost an apprenticeship. . . .The intelligent young man who goes into clamming doesn't follow the dullard, he follows the expert." Jenks, for example, went into clamming when he was a young boy, from about 1939 on, to make money for his school clothes. He was "kind of adopted" by two older clammers who were treaders in Shark River on the northern New Jersey coast.

"It's always a challenge to see another clammer, usually an older person, with an expertise that you don't have. I remember ________ , from Chincoteaque, Virginia; he was 43, I was 27 then [the mid 1950's]. I approached him in Barnegat Bay, where he was diving for clams.[4] There was this old guy with two front teeth missing, and doing something that I didn't know about. So I introduced myself, said 'How are you doing?,' and he said 'Pretty good.' I hinted around at the question of how much he was catching—no one wants to answer that question—and he said 'I have 1,500 [clams] in the boat.' So I adopted him, or rather he adopted me."

Freedom and Clamming

"Clamming gives you pride, in your body, your abilities, your knowledge, and the pride of being free." Just about anyone familiar with fishing and shellfishing will mention "freedom" as one of the important personal and social values. A large study of job satisfaction among New Jersey fishermen found that freedom or independence is particularly important to bay shellfishermen in contrast with ocean shellfishermen and other fishermen (Gatewood and McCay, 1988, 1990).

Shellfishing is selective for people who are capable of working on their own, who are "self-starting," in contrast with people who lack motivation or direction unless it is imposed by others. Even more, is the American notion of the freedom to work hard, the freedom of deciding how hard you want to work and then doing it. This is not to be confused with laziness because it includes "The freedom of [putting in] all the overtime

[4] Diving is one among many of the specialized ways to harvest hard clams. The first time Bill ever did it was in 1955, when he learned how from the Chincoteague clammer. It was the end of a summer, when the bay cabbage, or sea lettuce, had gone down, but another grass was growing, softening the bottom so that it was difficult to "toe" the clams (the technique used in treading, involving slipping one's toes under a clam and lifting it, with the foot, until one can reach it by hand). The place they were working was too deep to pick up the clams by hand or to scratch-rake. It was chest high water. This man from Chincoteague had a Canton flannel slipper, with a stainless steel diaper safety pin, and finger stalls on two fingers. He'd feel the clam with his heel, then go straight down, head underwater, to pick it up by hand. Bill learned that you didn't hold your breath, but breathed out on the way down and breathed in once your head came up. After a while you could catch a clam every time you took a breath; he remembers coming close to 500–700 clams an hour. And this might involve as many as 4,700 kneebends in one day. Diving might be done, depending on the water depth, in hard bottom or semi-hard bottom. You can cover a lot of ground that way.

you want until you drop in your tracks." Another way fishermen describe this is, "What you make is up to you." Bill Jenks remembers times in the past when he worked long days, tonging (using pincers-like iron rakes), sunup to sundown in the winter months, and then still had to "count off" (cull and bag the clams).

This freedom is partly the freedom to control many of the conditions, including the hours, of your work. It's the freedom to determine how long you work or whether you work: ". . . the freedom to take time off when you want it, too." But it's more than that. It is the freedom to pursue something that, while hard, can bring the joy and pride and income from discovering a good "spot" of clams or mussels.

"Freedom, that's the main thing. It's not so much freedom to take days off, but more freedom to work where you want, as long as you want, and of course the excitement of finding a new spot, when you find it yourself, and protecting that spot . . . it's just a joy. That spot that you find, you measure it, by eye, you approximate what is there, and as long as you can keep that to yourself, that's money in the bank."

Pride of accomplishment and competition are involved, as are pressures to work beyond normal endurance.

"We would clam until we were ready to drop, me and ________ [Jenks' partner for a time]. And when we were finished, I'd say, '________ , now let's make a pound of hamburger . . . it's 3 pounds for a dollar (it was in those days), should we make that extra pound?' Percentage wise, it wasn't much, a day's pay was about $25. It was that little extra you'd work for. Like treading in the water up to your neck, when everybody else is gone [from the clamming grounds], you stay, it's up to you, and you can make that pile [of clams on your boat] much bigger, you get another hour and a half."

Security and the Value of Knowledge and Experience

Most people want some degree of security, and to outsiders occupations like clamming are unattractive because they seem to offer very little. Returns are dependent on vagaries of wind, tide, shellfish biology, government regulation, much like farming, but without even the security of owning land (or holding large mortgages). However, some clammers have a strong sense of security because they know how to clam. No matter what the vagaries of the larger economy or their personal lives, "nature" and the clams are always there (one hopes). Thus, Jenks argues, "There's as much or more security in knowing how to clam as there is to having a job."

"The more you know about it, a wide area to clam, that's your security . . . It's the ability to read a chart and navigate, trial and error, and a lot of looking and listening all your life.

"You don't get Blue Cross/Blue Shield[5] [health insurance] . . . but you are never broke, as long as you know how to clam. ["poor but not broke," Bill's wife Vivian added]. Within 2 hours I could have a hundred dollars . . . And in better times, prior to '61 [when northern New Jersey's bays were largely closed], if you were broke you were only, say, 5 hours away from a day's pay. Which cannot be said for a job. In the first place they would withhold a lot of your pay. Remember, clamming is a cash business, it's immediate money, like piecework. Piecework, but with knowledge and skill."

Security is part of the value of experience and acquired knowledge in clamming, but there are more intrinsic values too.

"And the more of these spots that you know, and you can go back to, like a chessboard—it's like a game of chess—the better clammer you are. That's what shellfishing means to me, or did."

On the other hand, health insurance and other benefits and a steady income are definitely not available to most shellfishermen, and thus "security" might mean finding another kind of work and working only part-time on the bays. Many people do not want to trade off the security of a job but like the extra money they can make. Hence there are quite a few part-time clammers on this their second job, clamming, wherever clammers live in areas with good job opportunities. This second job has real attractions: if they miss a day on the water, they don't get fired; and they have the pride of boat ownership while being able to make some money with it. Yet they won't break the tie with that secure job and the benefits attached to it.

Clamming as the Center of Coastal Adaptations

Clamming is often part of a diversified coastal way of making a living, part of the seasonal round, or the life experience, of a "waterman," a "bayman," an "inshore fisherman," who adjusts to variation and unpredictability in abundance and markets by doing whatever can be done with the equipment and knowledge at hand.

For example, in northern New Jersey commercial clammers have often done other things, such as crab dredging, which can be done with a small boat and dredge (e.g. a 3-foot dredge), to help eke out a living in the winter months.

"If clamming was poor, and eeling or crabbing was more lucrative and could use the same vehicle or boat, we would jump right into that. It could make the differ-

[5] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

ence between survival or defeat as a bayman, especially in the winter time. It's tough. Occasionally, about every third winter, the men will be frozen in for approximately a month; this is very hard on the men. Of course, they don't always have to go into other fisheries. I've seen them in Barnegat Bay having their boats lifted out and trucked up the road, to Waretown, where the plume from the Oyster Creek plant [a nuclear generating station] kept it open, to make a few bucks."

This aspect of shellfishing is particularly vulnerable to government management programs that involve restrictions on entry or limited licenses. In New Jersey, for example, proposals to regulate crab dredging in the bays threaten the adaptability of some baymen, because of a provision in a preliminary draft that only those who crabbed for a certain number of years prior to the new regulations will be eligible to continue. Some baymen, including some who introduced important technological innovations such as the Maryland crab pot, have not crabbed for many years, but did and had counted on being able to do so in the future. This kind of regulation strikes at the core of the "bayman" or "waterman" strategy, which requires some freedom to move among fisheries.

In the New Jersey region, though, "the real backbone of working on the bay has always been the hard clam. It's the most steady and dependable money that there is on the bay. Other things can come and go, but the clams are always there—or were always there, and legally available, until 1961. The hard clam, in particular, he lives a long time out of water, almost like cash, negotiable; is it any wonder they call it *Mercenaria mercenaria.*"

Generally there is a large difference between people who fish in the open ocean and the "baymen" who clam and perhaps harvest eels, crabs, and other species in estuaries and embayments. But shellfisheries can be important to the former, too, as an alternative, particularly when times are bad. Very recently in New Jersey a few captains, mates, and owners of offshore sea clammer dredge boats or finfish draggers have entered bay clamming. In some cases, this is a case of reentry: the young clammers are children and grandchildren of people who clammed, particularly in the pre-1961 days of large-scale, deep-water clamming in Raritan Bay. The context includes regulatory changes, including individual transferable quotas, that have made it difficult for smaller operators to remain in the sea clam fishery, as well as fish scarcity and regulations, including limited entry, for summer flounder and other species, hurting the offshore dragger fishery. The relatively low costs of entry, as well as family traditions and the fact that clamming is still a way to work on the water, even if it is not at sea, contribute to this pattern, which may intensify in the future.

The Goose Bar Story and Promises of Good Sets

Gambling is part of shellfishing, as it is part of any other activity dependent on wild and hence unpredictable resources. The sporadic and essentially unpredictable nature of recruitment in most shellfish populations makes it clear to shellfishermen, excepting those engaged in mariculture (who are not, however, free of the challenges of dealing with nature, and, indeed, may be even more at its peril, having invested so much and constricted their ranges of options).

Some might call it just plain optimism. Even when the clams, mussels, scallops, or oysters seem scarce enough to be on the verge of extinction, there is always the possibility of a good set. Awareness of this possibility is made even more vivid by the telling and retelling of stories about the great sets of the past. Stories are among the ways that humans make sense of their experiences and provide direction for their behavior. They are thus central to an understanding of the human ecology of shellfishing.

For example, hope of good sets in the future is fueled by reports of better conditions elsewhere. In 1993 clammers in New Jersey talked about tremendous sets of oysters in Galveston Bay, Tex., that were reportedly helping keep the shucking houses of the Chesapeake Bay and New Jersey alive by shipments of oysters (Chesapeake Bay and Delaware Bay oyster populations are suffering from oyster diseases). In New Jersey itself there have been phenomenal although rare and localized sets of shellfishes that keep hopes up. For example, in 1974 mussels, otherwise sparse in New Jersey's estuaries, were "so thick, it was not a matter of how many you could catch with tongs but how many you could sell" in Marshelder Channel, which leads from the town of Tuckerton to the Atlantic Ocean via Beach Haven Inlet.

In New Jersey hard clamming, there have been a few exceptional sets of hard clams that, for a short while, helped to revitalize the industry and, for a longer period, keep hopes alive. Among these were two in the 1930's, one in Raritan Bay, northern New Jersey, the other in an area known as the Mile Stretch, near Atlantic City, southern New Jersey. The sets were quickly noticed, and brisk, somewhat illicit, trade in "seed" clams or "buttons" developed, helping to provide more capital for the industry. But in some cases, the sets also promoted experiments in hard clam husbandry, in the kind of "planting" long known for oysters.

The best example, and the last biggest "set" of hard clams in the state, was the Goose Bar set of 1972. The Goose Bar is a very shallow bar in the Great Bay region of New Jersey. Jenks' ledger provides the details. In early 1972, Jenks, who was a part-time clammer then in waters to the north of the Goose Bar, had heard rumors of the set and tried to convince his buddies to go with him to check them out. "Guys said they had bushels of these little bitty seeds, beautiful, like corn." He went on his own, rigged up a garden rake for the purpose, and on the first day, April 6, caught a large number of bushels from the Goose Bar. The next day he caught 6 bushels, the next one and a half. And so it went. Each bushel was of very small, seed clams. At first, he, like most others, was selling these bushels to local dealers (or to out-of-state dealers) for $18 or $20 a bushel.

Although the clams were under minimum size, the state allowed a restricted harvest. Social allocation is a major issue in the clam fisheries, as it is with all others (McHugh, 1972). Here the issue was whether the "true" commercial clammer, the full-timer, should have the benefit of this instance of the largesse of nature or whether he should share it with recreational and part-time clammers. Leaders of the commercial industry pushed for permission to harvest the undersized clams because of the shallowness of the bar and hence the probability that this phenomenal set would die during low water in the winter months. Moreover, leaders of the South Jersey Shellfishermen's Association, the most influential shellfishermen's group at the time, argued that the set should be restricted to commercial harvesters, and thus that the Goose Bar should be closed during the summer months when recreational clamming is popular. However, some of the tributaries to the Goose Bar were outside the staked closed area and also full of seed clams, enabling some clammers to continue this fishery during the summer. Moreover, illegal clamming was, as always, very tempting: "guys were sneaking onto the Goose Bar just because it was illegal. . . ."

The money was good. Jenks noticed another clammer with a rake apparently designed for the purpose, so he asked who made it, and was told to talk to an older man, a welder who was out there on the Goose Bar too. Jenks walked over to him—it was only knee-deep water on the bar—and asked him if he could buy a rake and if so for how much. Said the welder, "Yes, for $60, but you'll have to wait six weeks." Jenks was desperate and asked, "How fast could I get one for $100?" The welder/clammer said, "Tomorrow morning." The next day, with his new rake, Jenks was able to catch 9 bushels, worth $180, clearing $80 for the day. That wasn't bad at all.

After the initial excitement and quick money coming in, Jenks, like others, began thinking about the future, about planting the seed clams to take them up later, when they were at minimum size for the high-priced "necks." The idea came at least partly because Jenks remembered an older clammer who had "run seed," planting in the spring and taking up in the fall. "Knowing this, I thought, my God, here we have a fortune before our eyes." That older clammer just dumped the seed in public grounds, "the wilds," but it seemed wiser to use shellfish leases and thus have some legal protection. The State of New Jersey leases shellfish beds for clam and oyster cultivation if they are not naturally productive.

Through a fellow clammer, Jenks and his sons got access to reaches in a lease in the area, and they started planting some seed, selling the rest. By May 5th, his family had 294,000 clams on the lease. By June 3rd, when they had stopped selling and were just planting as well as tonging for legal sized clams nearby, they had about 350,000 "buttons" in each of two places.

There was a lot of uncertainty based on fear that the seed clams would just disappear, and thus most people continued to sell the seed. "The lure of the immediate dollar forced many clammers to sell to dealers out of state, which was a shame for New Jersey because there hasn't been a good set there since." Dealers were also cautious about how much they bought to plant on their leases. But for some clam planters, the payoffs were tremendous. The clams grew well.

Jenks found that one year they were 4,000 to the bushel, but the next, in Parker Run, they had grown to a count of between 800 and 1,000 to the bushel. Jenks' ledgers show the high production, two years later, of the leases where he and his son had planted their seed: July 2, 1974, "took up 21,500 necks off lease $837"; July 3rd, 10,000 for $500, and so forth. For that week—typically the best of the year in terms of marketing—he and his sons made $1,760, an otherwise almost unheard of income from hard clamming at the time.

As Jenks notes, "This is what keeps us going, in the mind: $1,760 for the week." He also remembers this from the first day, when in 5 hours he and his boys took up 21,500 saleable clams: "When I left Parkertown Dock . . . I didn't have a clam in the truck; my wallet was so thick, I had to put it into my pocket unfolded. But a lot of planning went into it." The point is not so much the bonanza as the fact that with planting, the clammers could plan for their future, an otherwise almost impossible task unless one is engaged in full-scale mariculture.

Clammers and ex-clammers still talk about how much they regret their caution about taking risks with the Goose Bar clams. One who was a major dealer at the time told Jenks that when he was cleaning up his oyster house in south Jersey, many years later, he found a sign from 1972 reading "I will not buy any more Goose Bay seeds," and almost cried, remembering the lost opportunity.

Goose Bar stories are also stories about another sorry reality of clamming: Pollution. The lease that Jenks and others obtained was condemned because of poor water quality by the next year. The men had to move the clams they'd planted, as best they could, to another lease in Parker Run, in a state-supervised "relay" program in which they were required to leave the moved clams untouched for at least 30 days in the new, approved waters. In addition, some of the clams that were planted by baymen were planted in already condemned waters, in part to experiment, in part to help provide "sanctuaries" for general production in the bays.

Clam Relays and the Business of Clamming

Much of the story of clamming in urbanized regions like New Jersey is the story of condemned (closed) waters and illegal clamming, which contribute to the maintenance of a culture of "piscatorial piracy" (McCay, 1984) against the odds posed by sharp restriction of what were once free and common resources. The story is also of the development of relay and depuration programs to help provide safe clams for the markets. Depuration involves the use of ultraviolet-treated water in controlled conditions to encourage clams to pump out contaminating bacteria. The relay programs involve the use of nature to do the same thing, by moving shellfish to clean waters where, over a longer period of time, they will cleanse themselves of bacterial and viral contaminants. Clam relays are almost as old as the official condemnation of shellfish waters in New Jersey. They involve the harvest of clams in public waters and their transplantion to private leaseholds, supervised by the state, where they remain for a designated period of time (e.g., 30 days) before legally harvested.

The first hard clam relays in New Jersey took place in northern New Jersey in 1920 and in southern New Jersey in 1925 and 1926. Their major purpose was to deplete clam stocks in polluted waters to reduce the risk of shellfish-borne disease epidemics. They were short-lived, but were revived during the Depression years for a time because of strong social pressure to provide more opportunities for the unemployed of the state—a second important goal of relays and depuration. The closure of almost all the waters of Monmouth County, northern New Jersey, in 1961–62 in response to an epidemic of viral hepatitis led to experimentation in hard clam depuration and a new hard clam relay program, which began in 1970 in the Atlantic City area, south Jersey. In 1980 the relay accounted for 20% of total hard clam landings in New Jersey; in 1993 relay and depuration clams were 50% of the total. In 1983, a second major relay program was begun in northern Monmouth County, in conjunction with a depuration operation (Jenks and McCay[6]). Since 1983 these programs have provided income-generating opportunities for varying numbers of men, especially those of traditional fishing and shellfishing communities.

Bill Jenks worked as hard as anyone for the northern Monmouth County relay program, and in the process he generated a set of reasons why a relay would be seen as advantageous to clammers, including the ability to get access to clams. We recount these here (McCay, 1985) because of the continuity some of them show with the reasons Jenks and others tried to plant the Goose Bar clams, which can be summed up as the opportunity to plan for and influence the future.

"Seven advantages of a hard clam relay from a clammer's perspective:

"1) Makes a businessman out of a clamdigger, because he has an inventory of clams on his lease. He is more dependable and valuable to a dealer or a fish market.

"2) He can continue clamming when the market is oversupplied (glut).

"3) He has access to better clamming, in a situation, increasingly the case in New Jersey, in which clams are scarce in unpolluted waters [at the time, in the "wilds" of South Jersey, 400–500 clams were considered a 'good day's take'; on the northern Monmouth County hard clam relay 2,000–3,000 were seen as a 'good day'].

"4) He is depleting the thick clamming in condemned waters, making pirating unprofitable.

"5) He is utilizing a renewable resource that is otherwise wasted or marketed through piracy.

"6) After a day of relaying he is just too darn tired to think about pirating that night!

"7) It is endorsed by the Federal Government (FDA, EPA)."

Cooperative Management

The story of the depuration plants and hard clam relays is also a narrative about relationships between baymen and state agencies. The supreme paradox about choosing fishing as a way of life is that it promises freedom and independence, but a condition is that public resources are used, hence public laws and bureaucracies have immediate effects on the lives and attitudes of shellfishermen. The hard clam relay program in New Jersey brought clammers and state officials together in uneasy but ultimately working relationships (McCay, 1985; Jenks and McCay[6]), some of which laid the groundwork for an experiment in using the principle of transplantation to rehabilitate a depleted bay in southern New Jersey. Following the spirit of MacKenzie's work with oystermen of Prince Edward Island (MacKenzie, 1975; 1989), and with stimulus from a hard clam "spawner sanctuary" program taking place in Great South Bay, Long Island (Kassner, 1988), an unusual ex-

[6] Jenks, W. P., III, and B. J. McCay. 1984. New Jersey's hard clam relay program. Pap. prep. for Hard Clam Management Alternatives Working Group, Suffolk County and SUNY Marine Sciences Research Center, Stony Brook, N.Y., October 30, 1984, 14 p.

periment in cooperation among scientists, shellfishermen, shellfish dealers, and state officials was undertaken.

Although our "spawner sanctuary" program apparently did not result in major new sets of clams in the area (Barber et al., 1988), it was an important case of both cooperative management (Pinkerton, 1989) and "adaptive management" (Hilborn, 1987), or trying to make decisions in a setting of high degrees of ignorance and uncertainty by trying to learn while doing (McCay, 1988; McCay[7]). The experience also underscored for those of us who were central to it the importance of recognizing that "the shellfishing community" is a very diverse, often conflicted, sometimes consensual, group of people ranging from harvesters (from different areas, with different objectives), to their family members, to dealers, to scientists (academic, state, federal, social, biological), to bureaucrats from different agencies with different objectives and degrees of authority and responsibility.

Regulating Inefficiency and Social Relations

"This clamming, hand clamming, is the thing for the people of the earth. I don't believe it's meant to be mechanized. . . . The resource is finite; we only have so many tens of thousands of acres, it's not like the ocean."

The bay shellfisheries are notorious for what economists, and some biologists, see as inefficient, if not foolish, regulations. Most obvious in North America is the proliferation of regulations, at the level of municipalities, counties, and states, forbidding the use of certain tools, such as motor-powered dredges, or forbidding or sharply restricting private property claims in shellfish beds. From the 19th century (Brooks, 1891) to the recent past (McHugh, 1972; Agnello and Donnelley, 1975a, b, 1984; Hargis and Haven, 1988), people have observed, studied, and lamented the situation. New Jersey provides one example among many: Except in the oystering regions of Delaware Bay, and, until the 1960's, in the deep-water clamming areas of Raritan Bay, dredges cannot be used for clamming or oystering, and motor-powered dredges can be used only in the Delaware Bay. What this means is that most bay shellfishermen can use only rakes, tongs, and their toes in their pursuit of clams and oysters. New Jersey is more liberal about property than some other states in the region. Today, leaseholds from the state are allowed and numerous, but they must be in areas of the bays that are shown not to be naturally productive of shellfish. Other states vary in these regulations; Maryland tends to be against leasing and power dredging, Virginia for, and New York State has had its ups and downs.

The social meaning and community implications of the regulations are fairly clear-cut but should be underscored. They are about the distribution of access to shellfish resources, and they support the populist and utilitarian view that as many people as possible should be able to benefit (McHugh, 1972; Santopietro and Shabman, 1992). Over the past 200 years these regulations were articulated—or challenged and then reinstated—in the context of attempts by local entrepreneurs as well as outsider firms to "develop" the industry along more industrial lines, where efficiency of production, in the short-term, is what counts the most. Hovering around and sometimes entering these arguments is the English and American common-law idea of "public trust," the idea that there is something very special about property rights in navigable rivers and tidewaters. In some readings this is little more than a statement that public rights of fishing, navigation, and maybe recreational bathing can't be curtailed without some justification that doing so is in the public interest. But in other readings, one can find the notion that the poor are particularly deserving of protection from privatization of public trust waters, or that the public trust rights are absolutely inalienable (McCay, 1993). The freedom of the shellfishermen is founded upon those rights.

Baymen usually express their opinion about these matters in a way that makes no distinction between conservation and social goals. For example, Jenks spoke to the issue of power-dredging in New Jersey's bays this way: "I feel very strongly about it. . . . It's a conservation measure. Our bays are limited in size, and if power was ever used, only the big outfits would survive, and then not for long. It would wipe out the resource." In competition for a limited resource, only the "big outfits," the ones able to use advanced technology or to make it through a competitive scramble, will survive; the smaller operations will disappear. That is the "chain-store" vs. "Mom-and-Pop" grocery store problem, or the industrial factory vs. artisan problem (the "Luddite" problem in 19th century English history), and no small one at that. But the argument goes farther, claiming that bigness is not better for shellfish conservation: "It would wipe out the resource."

Neither argument has been thoroughly addressed in research or policy for U.S. shellfisheries, even though the issue is central to most shellfish policy. It may be that the conservation part of the argument is really a "front" for the social distribution part, as it has been very difficult for people to raise social questions of this sort at least since the onset of the industrial revolution in the early 19th century.

For example, in debates in New Jersey about whether one should be able to use a powered dredge on one's

[7] McCay, B. J. 1989. Why the oysters aren't all private property. Pap. pres. to Annual Meetings of the American Ethnological Society, Santa Fe, N.M., 5-8 April 1989.

own lease (to take up clams that have been planted in a hatchery or "grow-out" aquaculture operation or perhaps from a relay from polluted waters), it is difficult to make a conservation argument against the practice. One concern expressed is that it may be a way for leaseholders to illegally use a dredge on "natural" rather than "planted" clams if the former are in the leasehold. But that is really a distribution issue: The leaseholder is not supposed to have exclusive rights to "natural" clams (or oysters). For broader conservation issues, it is possible to argue that those "natural" shellfish should stay on the lease, or be taken up more slowly, because they provide a "sanctuary" that helps replenish the waters of the larger bay. But that seems forced. The only direct biological conservation argument concerns effects of dredging on the bottom, another contentious matter.

More likely, the concerns behind the argument are grounded in fears about changes in competitive position (i.e. being able to "take up" large quantities and hurt local and regional markets in the short term); and a stubborn insistence that having more employed than fewer is better. The act of taking up clams on leased grounds has social meaning in the community. If the leaseholder's practice is, as it often is or was, to pay people to take up planted clams, then forbidding the use of powered dredges is, as Bill Jenks concluded in our conversation, a way to "keep the money local: if the dealer had a rig to take them up, he would do it himself and these guys would not make any money."

One way or the other, regulations for natural resource management affect both ecological and social relationships. This point could have been made about other shellfisheries as well, including the more highly industrialized and offshore U.S. surf clam and ocean quahog fisheries, where the social dimensions of regulation have very strong roles in scenarios overtly dominated by economic and biological concerns (McCay and Creed, 1990; McCay et al., 1990).

Regulations are only part of the pressures for change. As Jenks notes, there have been profound changes in New Jersey's clamming industry even in the past decade.

"For years, even to ten years ago, you could go to Waretown, Little Egg Harbor, places like that [in southern New Jersey], and you'd know the boats; the clammers kept their garveys in the same slips, and had the same garveys, for years, 40 years. You knew where, say, ________ 's boat was, and if it wasn't there, you knew he was out on the water. Now it's different; it's "trailerized," the clammers move [and get new boats, and move into and out of the business]. Dock space is more costly, too." Nonetheless, a person can still make a living from shellfishing, if he's smart enough, strong enough, lucky enough, and optimistic enough. Even in urbanized, industrial regions like New Jersey a shellfisherman has a chance, and sometimes an unexpected one. A shellfisherman may join up with wealthier residents of coastal communities to help protest development activities that will degrade the natural environment, as was the case for the hard clam relay fishermen and a group of citizens concerned about a planned marina development in Barnegat Bay in the late 1980's and early 1990's. Someday there may be advertisements in the telephone book, under "Environmental Protection," for "rent-a-clammer." Shellfishermen are nothing if not adaptable.

Acknowledgments

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Environmental Challenges Facing the Shellfishing Industry

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ABSTRACT

North American molluscan fisheries have been traditions since colonial times, but few specifics have been learned about effects of molluscan harvesting and culture on habitats. The relative effects of fishing gear on the seafloor remain an open question, except that government surveys of the benthos have shown that invertebrate populations are abundant and species compositions are diverse in areas where shellfish harvesting has taken place for at least 50 years. Effects of fishing gear are temporary, because even if numbers of associated invertebrates are slightly reduced they rebound when new generations settle. From an environmental viewpoint, oyster culture has modified habitats in a positive way. The presence of transplanted oysters on previously unplanted bottoms has provided much more surface area and a larger number of niches for various invertebrates to inhabit. The washing of silt off beds of shells to clean them for receiving sets of oyster spat injects silt into the water, but accounts for an inconsequential amount compared with the quantity lifted during every lengthy wind storm. Mussel culture using rafts has brought about large changes in the ecosystem of the Ria de Arousa in Spain. The infauna macrobenthos is depauperate, but the biomass of the megafauna has increased due to the food contribution provided by the mussels and their associated epifauna. Similar effects probably have taken place in areas of North America and Europe where mussels are grown on suspended lines. Consumer interest in shellfish products is growing and more shellfish will be grown by culture enterprises in the future. Facilities designed for shoreside construction are likely to elicit concerns about habitat degradation, particularly if the locations are undeveloped. The shellfish industry needs to be wary of secondary impacts of construction and operation on water quality, but the industry can expect to be allied with other coastal enthusiasts arguing for water and sediment quality standards that will support shellfish culture.

Introduction

Cave drawings and shell middens suggest that mollusks have been a staple food for millennia. In North America, molluscan fisheries and culture have been traditions since colonial times. The earliest North American settlers learned well from the Native Americans. Besides finfish, their diet included wild populations of oysters, *Crassostrea virginica*; softshell clams, *Mya arenaria*; northern quahogs, *Mercenaria mercenaria*; and other shallow-water species such as bay scallops, *Argopecten irradians*. By the 1800's, coastal waters also supported commercial enterprises to culture oysters as the demand for them was great. The other species were simply harvested.

In the early 1900's, waters began to show the effects of coastal population growth. Water pollution and shellfish quality were bona fide concerns. Shortly after World War II, ocean-going vessels began to harvest Atlantic surfclams, *Spisula solidissima*; ocean quahogs, *Arctica islandica*; and sea scallops, *Placopecten magellanicus*, on a large scale, thereby broadening the public's taste for molluscan foods and establishing the basis for an expanding aquaculture industry which included blue mussels, *Mytilus edulis*. Shellfish production now is gaining emphasis along our coasts as wild-caught harvests are slumping and aquaculture gains in appeal.

The Need for Shellfish Culture

Consumer interest in shellfish products is increasing while existing, traditional sources (domestic and imported) are often unable to meet those needs. As a result, the United States needs a viable culture industry and an accepting seafood consuming public.

Culture of marine organisms has existed for centuries, but in the United States it is still embryonic compared with global norms and domestic possibilities. In 1988, U.S. marine aquaculture production was about 75,000 t, of which about 80% were oysters. Culture of other marine species is in the early stages of development (NRC, 1992). Current trends suggest that the culture industry might be better equipped than ever before to meet consumer needs. Problems with habitat quality and ecosystems persist, but supporting sectors are stronger than ever, and skilled workers usually abound in coastal communities.

While U.S. per capita consumption of fishery products continues to grow (now 14.8 lb/person) (NMFS, 1993), the culture industry can add to the molluscan shellfish portion. Culture firms are supported by an infrastructure that now spans from feeds to marketing, and they are benefiting from the global expertise in shellfish culture.

Shellfish Culture and Harvesting Effects

Few specifics have been learned about effects of molluscan harvesting and culture on habitats. An accounting of the effects of fishing on the environment has gained attention since the Magnuson Fishery Conservation and Management Act amendments through 1990 required fishery management regimes to do so.

The effects of gear on some shellfisheries have been observed by researchers at the NMFS Northeast Fisheries Science Center's Woods Hole Laboratory. A videocamera has been towed in front of a hydraulic dredge to observe the effects of mid-Atlantic surfclam and ocean quahog gear. Sediment disruption appeared minimal, few clams seemed to be crushed by the gear, and most clams appeared to be harvested. The gear left a perceptible furrow that was too shallow to disrupt trawls or other gear.

Fears remain owing to the lack of documented information about bottom harvest impacts. When a new fishery for Arctic surfclams, *Mactromeris polynyma*, developed in Massachusetts in the late 1980's, bottom finfish trawlers had serious concerns about troughs left by the hydraulic clam dredges. Finfishermen submitted testimonials about losing gear in the troughs. Complaints ended only when the clam fishery collapsed owing to dwindling supplies and sporadic markets.

The relative effects of all fishing gear (shellfish and finfish, i.e., dredges and trawls) on the seafloor remain an open question. Finfishermen fear that any amount of ocean mining or disposal of sediments and sewage may increase turbidity, decrease habitat suitability, or otherwise compromise the ecosystem, but the effects of those activities have never been compared with gear impacts, storm events, and natural sediment transport. Side-scan sonar traces reveal that in some areas bottom fishing gear can leave noticeable scars for at least several months. The fishing industry possibly disturbs more bottom habitat with its gear than other ocean users disturb with mining and disposal operations. Of course, such comparisons are often complicated because dredged materials from urban harbors frequently are contaminated with a suite of chemicals and sewage discharges may include heavy metals.

Surveys of the benthos using Smith-McIntyre grabs have shown that invertebrate populations are abundant and species compositions are diverse in areas where shellfish harvesting has taken place. In Long Island Sound (Reid et al., 1979) and on the eastern continental shelf of the United States (Rowe, 1971; Steimle and Stone, 1973; Pearce et al., 1977; Reid et al., 1982), invertebrates were abundant and diverse in areas where mollusks have been harvested for many years, including about 50 years on the continental shelf. Effects of fishing gear are temporary because even if invertebrate numbers are slightly reduced, they soon rebound when new generations settle.

Oyster Culture

From about 1825 to the early 1900's, around 2–3 million bushels of oysters/year were transplanted by schooners from beds in Chesapeake Bay to beds in Delaware Bay; Raritan Bay, N.Y. and N.J., Long Island Sound, and Wareham, Mass., for growth and ultimate sale. Within Chesapeake Bay, transplants of seed oysters were made from especially Virginia's James River (at least 2 million bushels/year) to beds where salinities were mostly above 20‰. The seed oysters in the northern bays and Chesapeake Bay were grown for 1–2 years before being harvested.

In the late 1800's and thereafter, oyster companies spread 2–3 million bushels of shells on Connecticut beds. The seed that set on the shells was transplanted for growth and harvesting to Narragansett Bay, R.I., and bays on Long Island and in Massachusetts, besides other beds in Connecticut. There were also transplants of oysters within Great South Bay, Long Island.

Additional shelling of seed beds and transplants took place in Delaware Bay and along the U.S. Gulf of Mexico.

In nearly every area, the initial transplants of seed oysters were to bottoms that rarely had oysters growing on them. The oysters were spread at rates of 500–750 bushels/acre. From an environmental viewpoint, the presence of the oysters provided much more surface area and a large number of niches for a variety of invertebrates to inhabit. The bottoms were changed, mostly in a positive way, though a few species which were adapted to smooth bottoms probably declined.

Oyster culture today is practiced in several areas on the east coast of North America. In all areas, shell planting is involved. After collecting a set of oysters, the shells are transplanted to growing grounds. The most complex culture takes place on leased grounds controlled by the Tallmadge Oyster Company[1] in Connecticut. Connecticut grounds would be barren of oysters without any culture as was true in the early 1800's (MacKenzie, 1981). Grounds containing oysters have a much larger variety and biomass of associated invertebrates and also more fish than similar grounds without oysters. The actions the company takes on its grounds are:

1) Before spreading shells, suction dredges clean the grounds of old shells that are fouled with various invertebrates, oyster drills (mainly *Urosalpinx cinerea*), and starfish, *Asterias forbesi.* (The drills are dumped alive off the oyster grounds, whereas the starfish are destroyed.)

2) In July, shells are spread at a density of about 1,000 bushels/acre. (The shells had been dredged from old oyster beds and put on docks for storage which cleans them; they then are taken from the docks and spread directly on the beds.)

3) If the shells collect a set of oyster spat, they are left in place until the following spring; during this time, the shells also collect sets of many additional species.

4) In the spring, shells with spat are transplanted to other grounds; in the process, some spat are broken loose from the shells as singles or doubles. On the new grounds, the oysters continue to grow and act as hosts for more invertebrates and fish.

5) The oysters are similarly transplanted and grow two additional seasons before they are harvested and sold. When the oysters are harvested, many associated invertebrates are taken with them to a processing plant and are not returned to the bottom.

6) The company also uses two boats to tow 3.5 m wide cotton mops over the bottom to remove starfish from its beds.

The Tallmadge Company has about 10,000 acres of ground planted with oysters and shells at any one time. Besides harboring a great many invertebrates and fish, the oysters also remove large quantities of plankton from the water. The effect of the latter in Connecticut waters is unknown, but reduction in turbidity is one likely result. From an environmental viewpoint, oyster culture by the company has a positive effect on the habitat.

Oysters are also cultivated on public beds in eastern North America. From north to south, the most notable examples are in Prince Edward Island, Maryland, Florida, and Louisiana. Shells are mined from fossil deposits in rivers and bays and spread on oyster setting grounds and the spat that set on them are often transplanted to growing grounds before they are harvested. If the spread shells do not collect a set of oysters, they commonly collect a layer of silt that reduces setting in the following years. In Prince Edward Island and Maryland, silt sometimes is washed off the shells by boats towing planning boards or bagless dredges to recondition them for oyster setting. Silt washing injects silt into the water, but probably accounts for an inconsequential amount of silt compared with the quantity that is lifted during every lengthy wind storm.

Mussel Culture

On the east coast of North America, blue mussels, *Mytilus edulis,* are cultured by growing them suspended from lines in the Canadian Maritime Provinces, and by transplanting mussel seed from wild grounds onto leased growing grounds in Maine. In California, *M. edulis* is cultured on suspended lines, and *M. galloprovincialis* on legs of oil drilling platforms. The environmental effects of intensive mussel culture have been studied in Spain where the mussels, *M. edulis,* are suspended from rafts. The Ria de Arosa in northwestern Spain has about 2,000 rafts. The excrement from the mussels rains through the water onto the seafloor where it accumulates.

Mussel culture has brought about great changes in the ecosystem of the Ria de Arosa. The total biomass of the epifauna of the rafts is extremely high. In contrast, the infaunal macrobenthos in the area of the rafts is depauperate and is dominated by species typical of eutrophic environments (Lopez-Jamar, 1982). The infauna is scarce because the quantity of organic detritus settling from the rafts cannot be utilized entirely by the infaunal organisms, resulting in anoxic sediments (Tenore et al., 1982). On the other hand, production and biomass of the megafauna have increased considerably (Iglesias, 1981; Olaso, 1982; Romero et al., 1982) due to the food contribution provided by the mussels and their associated epifauna (Chesney and Iglesias, 1979; Lopez-Jamar et al., 1984; Gonzalez-Gurriaran, 1978; Gonzalez-Gurriaran et al., 1989, 1990; Freire et

[1] Mention of commercial firms or trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

al., 1990). Demersal fishes (Chesney and Iglesias, 1979) and crabs (Gonzalez-Gurriaran, 1982) use the epifauna as food. One effect of the mussel culture has been to change the food habits of at least 3 fishes from a predominantly infauna to a raft epifauna diet (Lopez-Jamar et al., 1984). Somewhat similar effects presumably have taken place in the areas of North America where mussels are cultured on suspended lines.

In Maine, some lobster fishermen have objected to the dredging of seed mussels from beds, believing the habitats for lobsters are damaged. But observations by the State of Maine Department of Marine Resources have shown that lobsters have low densities in mussel seed beds, and damage to the lobster habitat by the dredging is slight. Live lobsters can evade the dredges.

In 1994, private companies grew mussels on about 100 acres of Maine's bottom. Invertebrates, mainly crustaceans and polychaetes, collect in the beds of growing mussels. When the mussels are harvested, most associated invertebrates probably are taken ashore with the mussels and die as they do when oysters are harvested.

Raking Northern Quahogs

Northern quahogs have been raked from sandy and muddy bottoms in bays along the eastern seaboard of North America since probably the 1600's. For many decades, the fishermen raked at wading depths, but since the mid-1800's they have done so mostly from boats in depths up to about 7 m. The teeth of the rakes penetrate about 5 cm as fishermen pull them through the bottom. Such raking probably releases gasses trapped in the bottom into the water besides stirring the sand.

The only known study of raking effects was conducted in clam beds in Rhode Island's Narragansett Bay (Glude and Landers, 1953). The beds had been dug for many years and contained many invertebrates including several species of clams and polychaetes. In the study, one bed was fished with bull rakes, another with a dry dredge towed from a boat, and a third was used as a control. Afterward, the upper layers of sediment were mixed somewhat and the bottoms were softer in the raked and dredged bottoms. The raking and dredging reduced the numbers of invertebrates, especially the associated polychaete *Cistenides gouldi*, somewhat. The authors concluded that the biological effects of the raking and dredging were slight.

Ocean Clamming with Hydraulic Dredges

The water jets of hydraulic dredges used to harvest surfclams and ocean quahogs penetrate about 15 cm into the bottom. Trapped gasses are released, the sediments are resorted, and tracks are left in the bottom. Immediately after a dredge passes over the bottom, a track is left about 20 cm deep, the tracks have softer sand than areas alongside, and they may have shell fragments, polychaetes, and small bivalve mollusks in them. In bottoms that previously had a mixture of sand particles, the largest sediments are at the bottom of dredged tracks and the finest sediments are at the top (Medcof and Caddy, 1971). Hydraulic dredging for ocean quahogs does not significantly alter the abundance and species composition of associated benthic invertebrates. Many polychaetes and bivalves presumably are moved to the bottom surface by the dredging but later are able to reburrow and survive (MacKenzie, 1982).

Harvesting Softshells

From the Canadian Maritime Provinces to northern Massachusetts, fishermen dig softshell clams on intertidal flats with short-handled rakes or "hacks." They turn over the sediments and pick out the clams. The digging probably has only a minor effect on associated invertebrates.

Since the 1950's, fishermen in Maryland have been using hydraulic escalator dredges to harvest softshell clams in bottoms at depths from 4.6 to 6 m. Water jets penetrate about 15 cm into the bottom and wash the softshells onto an escalator belt. The associated invertebrates probably are washed into the water, fall onto the bottom, and reburrow with little mortality or permanent alteration of their habitat.

Dredging Bay Scallops

The primary grounds where bay scallops occur along the Atlantic coast are in Massachusetts, Rhode Island, New York, and North Carolina. Nearly all scallops are harvested with light-weight dredges, about 90 cm wide, in the fall and winter. The dredges are towed across sand bottoms where eelgrass, *Zostera marina*, and other plants grow. Besides the scallops, the dredges also pick up some eelgrass, other plants, and crabs.

Harvesting of the scallops would seem to do little environmental harm. While some eelgrass blades are torn loose from their roots, nearly all blades wither and break loose by winter's end where dredging does not take place. Eelgrass grows new blades the following spring.

Based on current understanding of submerged aquatic vegetation value to scallops and other species, this type of fishery is under greater scrutiny. Stephan and Bigford (1987) summarized information on how such grasses are affected by coastal fisheries.

Dredging Sea Scallops

Sea scallops are harvested off the east coast of Canada and the United States by boats towing dredges made of a heavy 3–4 m wide metal frame and a bag made of steel rings. The effects of sea scallop dredging in the Gulf of St. Lawrence, Canada, have been reported by Caddy (1973):

1) Dredging lifts fine sediments into suspension, buries gravel below the sand surface, overturns large rocks embedded in the sediment, and appreciably roughens the bottom.

2) Dredging kills some scallops and causes considerable sublethal damage to scallops left in the track, the damage being greatest on a rough bottom. Mortalities to scallops with a standard dredge were at least 13–17% per tow.

3) Predatory fish and crabs are attracted to dredge tracks and had densities 3–30 times greater inside than outside the tracks soon after the dredging.

The possible effects of scallop dredging on finfish habitats have not been examined.

Lobster fishermen in Maine and Massachusetts have concerns about the impacts on lobster habitats of sea scallop dredging in inshore waters. Those state fishery departments have studies underway to document any possible damage to them.

Hatchery and Growout Systems

Each culture facility or hatchery demands sufficient and regular flow of clean water. Beyond the usual salinity and temperature requirements, shellfish need waters devoid of unusual concentrations of chemical contaminants and other unnatural additions, algae, and turbidity.

All plans for construction of coastal facilities capture public attention. Physical location is the primary concern, and related effects depend greatly on whether the site is pristine or already developed. Culture systems may be placed in or over water, which may attenuate natural lighting. The effects of shading usually are minimal unless the overall facility footprint is sizable and consistent. Typical floating systems swaying with the currents and lacking the mass of a fixed platform should pose little risk. A facility designed for shoreside construction is more likely to elicit concerns about habitat degradation, particularly if the location is undeveloped. Those problems can be minimized by selecting a preexisting site with waterside access.

Some hatcheries seek improved growth by adding chemical or food supplements. Some of those additives escape the culture operations and are released into adjacent waters. The effects of specific releases are often illusive, especially in waters already subject to other uses. Environmental quality should be monitored to ensure full accountability.

The effects of excess nutrients and shellfish excrement on nearby habitats must be considered. Culture facilities often stock shellfish in trays or strings or in other arrangements at organism concentrations far above those observed in nature. Any negative environmental effects would hinge on facility size and operations and hydrographic conditions.

Excess nutrients from all sources have been blamed for water quality degradation in estuaries and coastal waters. With a more direct route than agricultural runoff, shellfish culture could be implicated as a type of waterborne nonpoint source pollution or even as a point discharge. State and Federal water quality agencies now require discharge permits as well as construction permits before most aquaculture facilities are permitted for operation.

The shellfish industry should be wary of secondary impacts of construction and operation on water quality. Like any other coastal facility, whether located on coastal lands, astride the coastal fringe on a raised platform, or floating in coastal shallows, there will be discharges, overwash, byproducts, and other evidence of commercial operations. Each must be addressed thoroughly in facility design, permit procedures, and public review.

Shellfish culture can affect waters in several ways, ranging from the obvious to the nearly imperceptible and from beneficial to negative. The size and operations of each culture facility are among the major determinants of effects. Some effects may be associated with facility construction rather than operations.

Other effects could be secondary to culture operations. All must be considered in the total environmental equation.

One positive effect is also among the least well-recognized impacts of shellfish on the marine environment. Cultured shellfish are excellent biological filters of minute particles suspended in coastal waters. Since a typical adult oyster may filter about 24 l of water per hour of active feeding (Galtsoff, 1964), a shellfish bed could have a substantial benefit to overall water quality. That point has been emphasized in Chesapeake Bay, where the demise of natural stocks will not ease efforts to improve water clarity and submerged vegetation. Cultured shellfish would provide some measure of filtration benefits.

Impacts of Storms

The impacts of storms on benthic habitats have been little studied. Because benthic animals are found alive in bottoms following severe storms, including hurricanes that churn surficial sediments, it is clear that they can survive severe bottom upheavals. Few comparisons have been made of precise numbers of animals immediately before and after storms.

A Negative Thrust from Local Governments

A disquieting note to the possibility of expanded shellfish culture recently has taken place in southern New England. Some local governments there have come to regard shellfisheries in a negative way when they regulate the uses of estuaries and their borders.

Traditional shellfishing activities and aquaculture operations usually generate small revenues, and they compete for space with other users (i.e. especially industry, restaurants, and recreational boating) that all generate much more revenue. Legal actions over noise from shellfishing boats, potential degradation of water quality, and concern over introductions of shellfish believed to be carrying disease have stimulated feelings of resentment. Another issue is the use of public bottoms in estuaries by private culturists. The frequency and ferocity of confrontations over the issues has increased (Ludwig, 1994). In the future, biologists are going to be concerned about effects on ecosystems if culturists introduce exotic shellfish and manipulate the genetics of shellfish.

Discussion

Biologists would like to obtain precise information on the effects of the various shellfish harvesting methods. For now, however, they are satisfied that harvesting mollusks in estuaries and bays and on the continental shelf has some effect on benthic habitats, but they are minor compared with the effects of storms.

Methods will be developed in future years to advance the state of shellfish culture sufficiently to greatly expand the quantity of shellfish now grown in the estuaries and bays of North America. At the same time, recreational use of water bodies and population growth around them will increase, and they will add further stresses to the fragile habitats on which culture operations depend. Will society decide to sacrifice the needs of some groups to allow marine areas to be used mostly for growing shellfish? This question may often be answered through regulatory channels or via court action.

On the positive side, aquaculture can expect to be allied with other coastal enthusiasts arguing for water and sediment quality standards that will support culture. Society has not yet met this challenge, and the multimillion dollar aquaculture industry could shift the balance from other development interests.

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The opinions expressed in this paper are those of the authors and do not necessarily reflect those of the National Marine Fisheries Service, NOAA. Much of this work was completed in the early 1990's and could be supplemented with evolving research and management experience.

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U. S. Regulatory Strategies for Ensuring the Safety of Molluscan Shellfish

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ABSTRACT

Seafood consumption carries potential health risks from chemical compounds, including natural toxins, and from infectious organisms such as bacteria and animal parasites. In 1924, a typhoid outbreak causing many illnesses and deaths was traced to sewage-contaminated oysters. The severity of the outbreak prompted state and local health officials and members of the shellfish industry to request the development of control measures by the Surgeon General of the U.S. Public Health Service to protect the public. A conference held in 1925 made several recommendations for the sanitary control of the shellfish industry and established a committee to further develop control practices for that industry. This conference marked the beginning of the National Shellfish Sanitation Program, which the Food and Drug Administration (FDA) continues to administer. One of the recommendatons of the 1925 conference was that the beds on which shellfish are grown must be determined, inspected, and controlled by some official state agency and the Public Health Service. The first growing-water standards, adopted in 1944, stipulated that total coliform bacteria concentrations not exceed 70 MPN/100 ml for approved water and 700 MPN/100 ml for restricted waters. The concept of avoiding contaminated oysters by not harvesting them from contaminated growing waters has been the cornerstone of the U.S. shellfish safety program ever since. The first Shellfish Sanitation Workshop held in Washington, D.C., in 1954 might be regarded as the beginning of the modern program. The Federal and state governments share the responsibility for ensuring that shellfish are harvested from safe waters and that a raw product can be marketed immediately after harvesting. Sanitary harvesting, processing, and distribution are required to prevent subsequent contamination and deterioration. A substantial portion of mollusks consumed in the United States is imported, and the same concepts of shellfish sanitation apply to these products. When the FDA is satisfied that a foreign shellfish is at least equivalent to the U.S. program, the agency enters into a bilateral agreement with that government. In 1991, the Office of Seafood was established in the FDA Center for Food Safety and Applied Nutrition, to centralize FDA headquarters seafood policy, including the shellfish program.

Introduction

The consumption of seafood, as with many foods, carries potential health risks from chemical compounds, including natural toxins, and from infectious organisms such as bacteria and animal parasites. Most of these hazards, and particularly those from foodborne bacteria and parasites, are eliminated by cooking. This is not necessarily true for toxins. In spite of this knowledge, some people continue to consume both raw and lightly cooked molluscan shellfish and finfish.

Consumers of raw shellfish have always been at risk of disease from both toxic and infectious agents. As coastal development has expanded and estuaries have become increasingly fouled with contaminants of human origin, the threat of illness from consumption of uncooked, contaminated shellfish harvested from these waters has increased significantly. One of the earliest recorded episodes of shellfish-related illness occurred in 1901 in Boston, where public health officials were faced with an outbreak of typhoid fever. With considerable insight, they set microbiological standards for molluscan shellfish based on an indicator bacterium (not the pathogen) that demonstrated a relative level of fecal contamination in either the shellfish meats or their harvest waters. Shellfish were tested for the presence of what was then described as the colon bacillus. The theory held that the shellfish did not have to be shown to carry the pathogen. However, the indicator organism demonstrated the potential for the shellfish to be contaminated with the typhoid bacterium.[1]

History of the National Shellfish Sanitation Program through 1968

In 1924 the American Public Health Association (APHA) established a standard for waters and shellfish based on a bacterial organism known at the time as the colon bacillus. The standard is equivalent to the modern most probable number (MPN) of not more than 2,400 coliforms/100 g in shucked and shell oysters and not more than 70 MPN/100 ml in waters.[2] That year, a typhoid outbreak was reported in New York and over 1,500 cases and 150 deaths were traced to sewage-contaminated oysters. The severity of the outbreak prompted state and local health officials and members of the shellfish industry to request the development of control measures by the Surgeon General of the U.S. Public Health Service (PHS) to protect the public. The Surgeon General convened a meeting with state and municipal health authorities, the U.S. Department of Agriculture's Bureau of Chemistry, now the U.S. Food and Drug Administration (FDA), and the Bureau of Commercial Fisheries, now the Commerce Department's National Marine Fisheries Service (NMFS).

The conference, held 19 February 1925 in Washington, D.C., made several recommendations for the sanitary control of the shellfish industry and established a committee to further develop control practices for that industry. The conference resolved that:

1) The states were directly responsible for the regulation of the sanitary practices of the shellfish industry,

2) Producing states would issue certificates to shellfish shippers that met their sanitary requirements,

3) The PHS would systematically review the progress of state efforts to accomplish their responsibilities,

4) The PHS would make the results of these evaluations known to the other states, and

5) The PHS would continue to provide support, including scientific investigations, and serve as a clearinghouse for the exchange of information on technical matters, policy, and the effectiveness of state control programs.

This conference marked the beginning of the National Shellfish Sanitation Program (NSSP), which FDA continues to administer.

The APHA had considered the use of shellfish growing-water standards as early as 1910 and viewed the growing area sanitary survey of equal importance to that of the quality of meat. By 1925 officials were pressing for the use of growing water criteria to respond to one of the recommendations of the February 1925 conference: "The beds on which shellfish are grown must be determined, inspected, and controlled by some official state agency and the Public Health Service."

However, various criteria continued to be used by individual states until the adoption of the first growing-water standards in 1944 (PHS, 1946). These standards stipulated that total coliform bacteria levels not exceed 70 MPN/100 ml for approved water and 700 MPN/100 ml for restricted waters. The concept of avoiding contaminated oysters by not harvesting them from contaminated growing areas has been the cornerstone of the U.S. shellfish safety program ever since.

During the 1960's the Federal shellfish program expanded under the PHS. By 1963, three laboratories provided shellfish-related research and technical assistance to the states. The major research work was on depuration, the process of placing marginally contaminated shellfish in land-based facilities and giving them a sufficient amount of time to purge themselves of potentially infectious biological contaminants.

The Purdy, Wash., Laboratory, a cooperatively owned Federal-state facility, was originially established in 1948 at Woods Hole, Mass. The laboratory was moved to Pensacola, Fla., in 1953, and finally to Gig Harbor, Wash., in 1959, where William Beck served as director. A second laboratory, located on the Davisville Naval Construction Battalion Base in North Kingstown, R.I., was headed by Ronald G. MacComber. A third laboratory, at Dauphin Island, Ala., opened in 1963 under the direction of Richard J. Hammerstrom. The newest research laboratory in the shellfish program opened in Narragansett, R.I., in 1964 on property adjacent to the then fledgling University of Rhode Island School of Oceanography. Carl N. Shuster, Jr. was the first director. The neighboring Davisville facility was retained as the field unit and state technical support group for the eastern seaboard shellfish producing states.

By the late 1960's the Federal component of the NSSP was decreasing in size as parts of the PHS programs were assigned to other organizations within the Department of Health, Education, and Welfare or, in 1970, within the newly created Environmental Protection Agency (EPA). The shellfish program became the

[1] Furfari, S. A. 1968. History of the 70 MPN/100 ml standard. U.S. Food Drug Admin., Wash., D.C. Unpubl. rep., p. 1–6.

[2] Miescier, J. 1990. Brief history of U.S. shellfish meat market guidelines and standards. U.S. Food Drug Admin., Wash., D.C. Unpubl. rep., p. 1–8.

Shellfish Sanitation Branch in the FDA Bureau of Foods. The Purdy facility functioned under EPA from 1970 until it closed in 1973. The Dauphin Island laboratory was assigned to several PHS organizations between 1967 and 1970 and to the EPA from 1970 to 1973, when it was reassigned to FDA. In 1970 the Narragansett laboratory was acquired by EPA with the subsequent termination of all NSSP responsibilities. The FDA's Shellfish Sanitation Branch retained the Davisville facility. This facility was closed in 1995 with the technical assistance capability moved to Washington, D.C., and the microbiological research capability relocated to Dauphin Island, Ala.

The Current National Shellfish Sanitation Program

The philosophy and structure of the Federal component of the NSSP were established at the 1925 PHS Conference, although the first Shellfish Sanitation Workshop held in Washington, D.C., in 1954 might be regarded as the beginning of the modern program. The Federal and state governments and the shellfish industry share the responsibility for ensuring that shellfish are harvested from safe waters and that a raw product can be marketed immediately after harvesting. Sanitary harvesting, processing, and distribution are required to prevent subsequent contamination and deterioration.

Shellfish must come from a clean environment with a minimum of human fecal wastes, other hazardous contaminants of human origin, and hazardous levels of marine toxins. The greatest threat to the public health, other than that from marine biotoxins, comes from human-associated contamination, including sewage treatment plant effluents, combined sewer/stormwater overflows, failing septic systems, and boat and marina wastes.

The first step in the classification of a harvest area under NSSP is a sanitary survey (FDA, 1977). This includes a shoreline survey to identify and evaluate pollution from point (e.g. sewer outfalls) and nonpoint (e.g. cattle or pig farms) sources of fecal contamination to shellfish beds. It also includes water sampling to test for indicator bacteria which show the potential presence of fecal wastes. Because of variability among samples, meat tests on shellfish are unreliable as a principal factor for assessing the quality of the growing waters. Meat tests are used to support the decision to reopen an area after closure, to evaluate waters to which shellfish may be relayed, and to judge the effectiveness of relaying and depuration operations. The surveys may include hydrographic studies in which dyes are used to evaluate the dilution/dispersion characteristics of waste effluents as well as to track the movements of waste effluents within the receiving waters. The effectiveness and reliability of wastewater treatment facilities are routinely evaluated.

Under the NSSP, the FDA (1990) produces and publishes a "Manual of Operations" that describes the principles to be followed for the classification of growing areas and for the performance of laboratory tests. The manual also describes the general sanitary procedures for handling, processing, and shipping shellfish. In producing and revising the manual, the FDA seeks the advice and technical expertise of the NSSP members. The FDA also uses information from the states to publish a monthly list of certified shellfish shippers. This list is available to states that receive shellfish and want to know whether a shipper is adhering to the procedures in the manual.

To provide a mechanism for dialogue among the FDA, the states, and industry, FDA formally recognized the Interstate Shellfish Sanitation Conference (ISSC) under a 1982 Memorandum of Understanding (MOU). This annual conference discusses ways to improve shellfish sanitation and better protect the public health. Participants in the ISSC include other Federal agencies with responsibilities in areas affecting shellfish waters and industry. Meetings are attended by non-voting industry and consumer representatives. A major aim of the ISSC is the timely and uniform adoption of periodic revisions in the NSSP operations manual.

Although the Federal government has not set the NSSP requirements into Federal law by issuing the requirements as regulations, many states have codified all or parts of the manual into their regulations and guidelines. Provisions from retail food protection model codes have also been adopted in whole or in part into the regulations of many states. They require that shellfish sold at retail (i.e. stores and restaurants) be obtained from certified sources. The Procedures for the Safe and Sanitary Processing and Importing of Fish and Fisheries Products: Final Rule (the "HACCP regulation") which becomes mandatory 18 December 1997, requires that all shellfish be harvested from waters approved for harvesting by a shellfish control authority. Processors are required only to accept shellfish properly tagged with information on the harvester and the date and place of harvest.

Enforcement of the provisions of the NSSP rests primarily with the states. Until the HACCP regulation goes into effect, in order for the FDA to take regulatory action against a shipment of shellfish, the agency must demonstrate that the specific lot contains pathogenic microorganisms or toxins at hazardous levels.

States with the requirements of the NSSP encoded into their laws need only demonstrate that provisions of those requirements have not been met in order to declare the shellfish in violation of their laws. Also, states may condemn shellfish at the retail level that are not from certified sources of origin (i.e. suppliers listed on the shellfish shippers' list) in conformance with state regulations based on codified portions of the model retail food protection codes.

Occasionally, the Federal law is used to reinforce state shellfish regulations. The Lacey Act makes violation of state or foreign wildlife laws a Federal offense. This authority has been used in combined Federal-state undercover operations to take Federal action against harvesters and shippers of shellfish obtained in violation of state or foreign laws. Under the Lacey Act, Federal resources and Federal penalties are brought to bear against criminal offenders.

A substantial portion of molluscan shellfish consumed in the United States is imported, and the same concepts of shellfish sanitation apply to these products. When the FDA is satisfied that a foreign shellfish program is at least equivalent to the U.S. program, the agency enters into a bilateral agreement or an MOU with that government. Reliance is placed on the foreign government to ensure that provisions of the NSSP are met much as the state governments provide this assurance for domestically produced shellfish. Also, the FDA monitors foreign shellfish programs in much the same way that it reviews state shellfish programs. Under the agreements of the MOU, FDA specialists and laboratory scientists regularly visit the participating countries to evaluate their programs. They visit growing areas, examine the results and conclusions of sanitary surveys, and evaluate laboratory equipment, procedures, and staff qualifications. They also inspect shellfish processing plants. Visits are made annually and have resulted, in some countries, in removal of processors from the Interstate Certified Shellfish Shippers List (ICSSL). Most states require that fresh or frozen molluscan shellfish imports originate from a dealer certified by a program that meets FDA/NSSP criteria.

Recent Changes in the Program

The abbreviated history of the NSSP described above does not do justice to the complexity of the program, but is intended to set the context for discussions of current issues and of the current FDA role in issues regarding shellfish sanitation.

Although many changes of historical interest have occurred since 1968, the most significant changes affecting FDA happened during 1991. On 19 February of that year, a new organization, the Office of Seafood, was established in the FDA Center for Food Safety and Applied Nutrition (formerly the Bureau of Foods). The Office of Seafood is presently organized into two divisions: the Division of Programs, Enforcement, and Policy, which has responsibility for policy development regarding shellfish, and the Division of Science and Applied Technology, which is responsible for developing shellfish research programs. The present staff of the Office of Seafood includes about 50 research, technical, and support staff. Research is conducted by the Washington, D.C., Seafood Laboratory Branch and the Gulf Coast Seafood Laboratory Branch on Dauphin Island, Ala. Other laboratories within FDA, but not directly linked to the Office of Seafood, conduct research relevant to shellfish issues. These include the microbiology, chemistry, and physical sciences laboratories in the Washington, D.C., area; laboratories at several of the regional FDA field offices; and the Seafood Products Research Center, which is part of the District Laboratory in Bothell, Wash. Trained shellfish specialists in the FDA Regional Offices routinely evaluate state programs within their jurisdictions and provide reports to the Regional Directors and to the Office of Seafood. The laboratory research conducted or supported by FDA comprises a significant part of the agency's total food research work.

With the establishment of the Office of Seafood, a major effort has been initiated to enhance shellfish safety. This initiative includes strengthening FDA research efforts, promoting state efforts to conform more closely to the requirements of the NSSP, and encouraging states to better meet their responsibilities under the cooperative program.

Shellfish-vectored Hazards and Government Responses

Diseases associated with the consumption of raw or partially cooked molluscan shellfish have been, and continue to be, a worldwide public health problem (Fig. 1). Since the late 1800's, over 400 outbreaks and 14,000 cases of shellfish-associated infectious disease have been reported in the United States (Table 1). Typhoid fever was a serious public health problem that alone accounted for nearly 25% of all shellfishborne disease outbreaks. However, the derivation and institution of a bacterial water quality standard were effective in resolving the typhoid problem. This disease has not been reported among shellfish consumers for four decades.

Current Problems

The new public health concern faced by the NSSP is that of enteric viral pathogens and bacteria of the *Vibrio* genus. The sanitary indicator organisms (total and/or fecal coliforms) currently used for assessing estuarine growing area water quality do not index the possible presence of naturally occuring marine vibrios and may not reliably index the potential presence of enteric viruses. This assessment poses a problem in safeguarding the public health.

Other emerging problems, which include newly described toxins produced worldwide by marine dinoflagellates, range from relatively mild neurologic and gastroenteric intoxications (i.e. neurotoxic and diarrhetic shellfish poisons, respectively) to a poison with potentially much more serious neurological effects (i.e. amnesic shellfish poison). Reports of paralytic shellfish poison (PSP) are still prevalent; however, the relatively rare occurrence of PSP in the United States, despite frequent coastal blooms of the causative dinoflagellate, attests to the success of the NSSP in preventing illness from that toxin.

Table 1
Cases and outbreaks of shellfish-vectored infectious disease from microorganisms associated with sewage wastes (1890–1993).

Disease or agent	No. of outbreaks (% of total)	No. of cases (% of total)
Unknown (no agent identified)	238 (59.2)	8293 (58.1)
Typhoid fever	78 (19.4)	3270 (22.9)
Hepatitis A	44 (10.9)	1845 (12.9)
Cholera (all serotypes)	16 (4.0)	171 (0.1)
Several (more than one agent isolated)	10 (2.5)	168 (1.2)
Shigella spp.	4 (1.0)	111 (0.8)
Salmonella spp.	3 (0.7)	130 (0.9)
Norwalk virus	3 (0.7)	175 (1.2)
Snow Mountain virus	2 (0.5)	71 (0.5)
Campylobacter	1 (0.2)	27 (0.2)
Staphylococcus	1 (0.2)	5 (0.0)
Bacillus cereus	1 (0.2)	4 (0.0)
Escherichia coli	1 (0.2)	2 (0.0)
Totals	402	14,272

Viral Diseases

Viral pathogens, including the Norwalk and Norwalk-like viruses, are associated with human fecal waste and sewage discharges. The pathogens are accumulated by filter-feeding shellfish from waters containing these contaminants. The consumption of raw or lightly cooked shellfish harvested from these waters presents an elevated (and, so far, nonquantifiable) risk of mild gastroenteritis. An overwhelming number of case reports involve incidents of shellfish-associated disease attributable to, or suspected to be caused by, viral agents (Fig. 2). Hepatitis A virus is another shellfish-vectored pathogen that is associated with human fecal waste and sewage. This pathogen's onset ranges from 2 to 8 or more weeks and frequently follows common source outbreaks (Fig. 3). The extended incubation period makes it very difficult to categorically implicate a given food source except in those instances of multiple case reports for a single outbreak. Illnesses have not been confirmed from areas meeting all NSSP criteria; however, improper classifications are more likely to be made if the fecal coliform standard does not index the potential presence of both viral and bacterial pathogens.

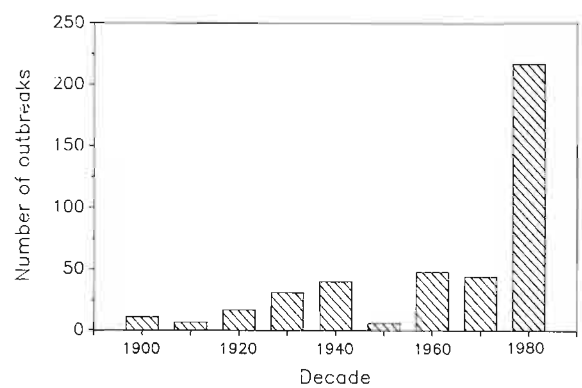

Figure 1
Shellfish-associated disease outbreaks by decade for all infectious agents, including illnesses for which no agent was identified.

Autochthonous Bacterial Species

Vibrio pathogens are native to a wide variety of marine and estuarine environments, including shellfish, and are found in widely fluctuating densities therein. The factors that influence their occurrence and density are not well understood. Current sanitary fecal indicator organisms are of no use in indexing the presence of these naturally occurring bacteria in marine waters. Pathogenic organisms include *V. vulnificus*, *V. cholera* (both toxigenic and nontoxigenic), *V. parahaemolyticus*, and several other less notorious, naturally occurring *Vibrio* species.

In general, the diseases caused by these bacterial organisms are considerably more severe than those caused by viral pathogens of the Norwalk and Norwalk-like group, although some illnesses from *V. parahaemolyticus* may be mild. *V. vulnificus* is often fatal in medically compromised individuals. Fortunately, few incidents are reported annually (Fig. 4). How will the NSSP deal with these new and emerging pathogens and toxin producers? Program responses will have to be creative, innovative, and strongly supported to effectively protect public health.

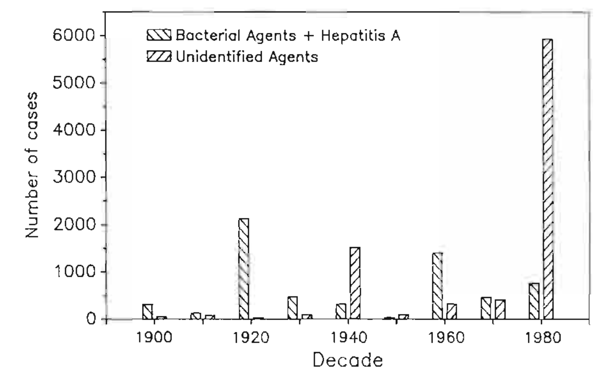

Figure 2
Shellfish-associated disease cases by decade for all infectious agents, including cases for which no agent was isolated or identified.

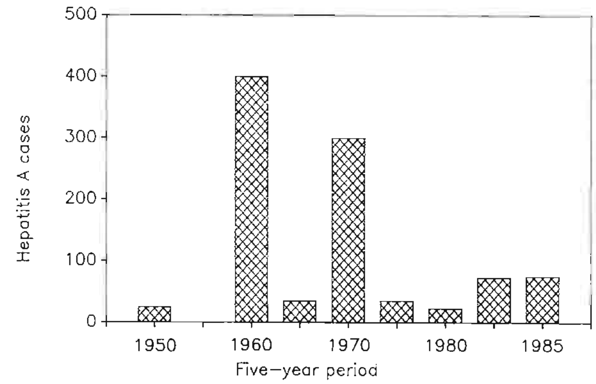

Figure 3
Shellfish-associated hepatitis A cases by 5-year intervals, 1950–85.

Better Illness Data Needs

Public health problems associated with shellfish consumption are well documented. However, more reliable, quantitative information on the principal health problems is needed to ensure that regulatory and research efforts are directed to the most significant hazards in the most effective manner. Epidemiologists recognize that foodborne illnesses generally are under-reported. Illnesses with a rapid onset and dramatic manifestations are more likely to be reported than those with mild or generalized symptoms and a delayed onset. The latter are more difficult to associate with a specific food vehicle because of the time delay between exposure and clinical illness.

Cases of marine intoxications and *V. vulnificus* septicemia are more likely to be recognized, reported, and attributed to the causative food than are episodes of mild gastroenteritis. Individual cases are less likely to come to the attention of authorities because it is difficult to implicate a specific food source and because illness reporting is geared toward outbreaks rather than isolated or sporadic cases. Although certain diseases are designated by the Centers for Disease Control (CDC) as reportable by the Council of State and Territorial Epidemiologists, they are not reported unless there is an outbreak, which is defined as two or more cases resulting from the same food source. Even when outbreaks are reported, the food vehicle is frequently not identified. In past years, shellfish-related illness information was collected by the FDA Northeast Seafood Laboratory in Rhode Island. Health authorities were contacted periodically to determine if any single cases had been reported at the state level or to follow up on any cases that have come to the agency's attention. Although this effort provided considerable insight into the types of illnesses associated with shellfish consumption and a rough estimate of the magnitude of shellfish-related illnesses, a more effective approach is needed for obtaining better estimates on types and numbers of cases. This information will provide a basis for the risk assessment studies necessary to develop effective risk management strategies.

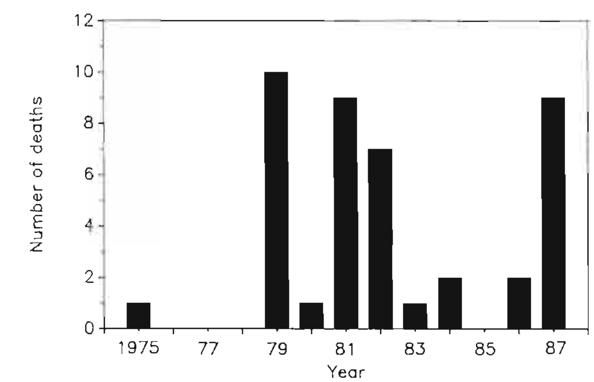

Figure 4
Vibrio vulnificus deaths by year (with a shellfish vector).

The FDA is currently funding a study designed to gain a better understanding of the relationships among several important foodborne pathogens, foods as vehicles, and particularly susceptible segments of the population. This Sentinel Surveillance Project, which is being conducted by CDC, investigates the role of seafood in human illnesses caused by *Campylobacter*, *Salmonella*, and *Vibrio* species among residents in preselected counties. A concurrent but separate project is the Behavioral Risk Factor Survey with questions targeted to profile those persons who consume raw molluscan shellfish and their perceived risk associated with that practice.

These two surveys will provide a clearer understanding of who is at greatest risk of becoming ill from the consumption of various types of foods (including seafood) and an assessment of the risk related to the consumption of raw molluscan shellfish relative to other foods.

Marine Intoxications

Illnesses resulting from the ingestion of toxic shellfish have been recognized for over two centuries. As early as 1790, explorers on the west coast of North America reported illnesses and deaths that rapidly followed the consumption of molluscan shellfish.

The most common toxin reported in the United States, paralytic shellfish poison, is only one of several shellfish-associated toxins. Outbreaks of amnesic shellfish poison (ASP), caused by domoic acid, were reported for the first time in North America on Prince Edward Island in 1987. An outbreak of neurotoxic shellfish poison (NSP), which is endemic to the U.S. Gulf Coast, wreaked havoc on the commercial fishery in North Carolina in the late 1980's. A major toxin producing bloom forced closure of virtually all Gulf coast shellfish harvests from November through January 1996–97. A fourth toxin, diarrhetic shellfish poison (DSP), has not appeared to be a problem in the United States but is a major source of shellfish-related illness in Japan and certain other countries. The sources of these various toxins are species of phytoplankton, which, when concentrated from overlying waters by the filter-feeding mollusks, cause the shellfish to become toxic.

In late 1991, ASP was identified for the first time on the west coast of the United States in razor clams, crabs, and finfish. Anchovies were the first discovered source of the toxin. Rapid state and Federal action, with the cooperation of Canada, was effective in preventing all but a few illnesses in some recreational razor clam harvesters. The quick response of the various agencies was exemplary; the occurrence, however, served to illustrate the need for monitoring systems to predict occurrences of marine toxins and to prevent toxic food organisms from reaching the consumer. Such a system is in place for PSP and NSP under the national program. Despite the large potential for illnesses from these toxins, effective control measures have made them rare. However, the domoic acid episode illustrates the need for a broader approach to identify marine toxins. The FDA has been working with several interested states to establish an early warning system based on environmental monitoring to detect the beginning of toxic algal blooms.

Some shellfish are harvested from waters outside state jurisdiction. In the past 2 years, some offshore shellfish beds have been found to be contaminated with PSP. The FDA and the NMFS have been successful in defining the geographical regions affected and, at FDA's request, the NMFS has used its authority, under the Magnuson Act, to close Federally controlled waters to harvest. Similar cooperation and joint agency action were carried out after a spill of drums containing arsenic off New Jersey during a storm in early 1992.

Conclusions

Through the combined efforts of government agencies, industry, and consumers, the health risks associated with the consumption of molluscan shellfish can be minimized. Effective regulation and sound industry and consumer practices, all based on scientific knowledge, must be instituted and observed. An environment clean enough to supply wholesome shellfish as well as an effective monitoring system to ensure that shellfish from unacceptable sources do not enter the marketplace must be available. These basic needs fall into five categories:

1) Consumption and illness data that are accurate and complete and will aid in targeting and developing effective consumer education programs.

2) Uniform enforcement by states of the provisions of the NSSP manual and any derived model code.

3) An improved indicator system.

4) Sufficient state and federal resources to carry out their risk assessment and risk management responsibilities.

5) Control and elimination of the contamination of our marine and estuarine coastal environments from which our shellfish and other seafoods are harvested.

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Resource Economics Issues Concerning Molluscan Fisheries in the United States

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ABSTRACT

A growing demand for molluscan shellfish products and a perpetual pursuit of enhanced gear efficiency has generated an imposing array of socioeconomic issues confronting state and Federal management agencies. As a result, economic considerations have begun to play an important role in guiding management decisions, particularly regarding the economic and social consequences of imposing alternative allocation rights among competing user groups. Serving as a link between habitat and demand considerations, recent changes in consumer perceptions of mollusk safety and quality extends into the marketplace and increases the range of topics to be considered by resource managers. In molluscan fisheries, biological equilibrium is a function of the underlying relationships governing recruitment, growth rates, and fishing effort. By contrast, economic equilibria are a function of the biological relationships, institutional context, and incentives under which harvest takes place. Economic incentives affecting an economic equilibrium consist of input and output prices. The Federal management efforts for Atlantic sea scallops and surf clams highlight the disparate set of objectives under which some of the nation's major molluscan resources are managed. The management histories for each of these species suggest goals that are similar in a biological sense, yet potentially divergent in terms of ultimate socioeconomic goals and the strategies employed to achieve those goals. Uncertainty in safety of mollusk consumption, as measured by perceived risk, can be introduced by a reduction in demand for mollusks at all prices, i.e., a downward shift in the demand curve. The issues that confront managers of U.S. molluscan resources are numerous and complex. The resources themselves are extremely dynamic from a biological perspective, with the harvest activities being further influenced by a varied complement of political and socioeconomic factors. Managers of estuarine molluscan shellfish stocks must be cognizant of the economic consequences that arise from the deterioration of habitats, both human-induced and otherwise, because the economic losses that can occur from reductions in estuarine mollusk shellfish production and decreased consumer confidence have been shown to be substantial.

Introduction

Commercial mollusk fisheries comprise an important component of the North American seafood industry. Although many species of the phylum Mollusca are indigenous to the continent, the most important classes of commercial interest are the bivalves (oysters, clams, scallops, mussels) and gastropods (conchs, whelks, abalones, periwinkles). For the purposes of this paper, cephalopods (octopi, squids, cuttlefish) will not be emphasized.

The wide geographic distribution of mollusks, their varied habitats, and their economic importance has resulted in an interesting set of domestic resource management issues from both biological and economic perspectives. For example, the relatively sedentary nature of most molluscan stocks renders them particularly vulnerable to the effects of human-induced or natural short-term variations in the quality of nearshore marine waters and bottom habitats. This characteristic brings into the realm of resource management a multitude of issues which result from a rapidly urbanizing coastal population.

In addition, a growing demand for molluscan products and the perpetual pursuit for enhanced commercial gear efficiency have generated an imposing array of socioeconomic issues confronting state and Federal management agencies. As a result, economic considerations have begun to play an important role in guiding management decisions, particularly regarding the economic and social consequences of imposing alternative allocation rights among competing user groups. Serving as a link between both habitat and demand considerations, recent changes in consumer perceptions of mollusk safety and quality extends into the marketplace and increases the range of topics to be considered by resource managers.

This paper addresses some of the resource economics issues relevant to the utilization and management of the domestic molluscan stocks. An overview of the relative importance of these fisheries in North America, eventually focusing on trends in the U.S. industry, is provided.[1] Changes in supplies and dockside value are briefly addressed with respect to the major commercial species groups—clams, oysters, and scallops. Resource economics concepts influencing molluscan fisheries management decisions are discussed within a generalized conceptual framework, followed by discussions specific to the management of major domestic fisheries for sea scallops and surf clams. Finally, the economic relevance of considering exogenous factors, such as mollusk aquaculture and habitat degradation, in molluscan fisheries management decisions is stressed.

[1] The discussion draws upon data from several sources. Landings data by country within the North American region were obtained from annual fisheries landings documents published by the U.N. Food and Agriculture Organization (FAO). Landings and value data specific to the United States were taken from National Marine Fisheries Service (NMFS) published annual fisheries landings and dockside value documents. In certain cases, FAO and NMFS landings data (when converted to standardized units) do not agree in terms of relative or absolute magnitude of landings volumes. These differences are likely inherent in the varying methods of collecting and presenting the data. Bureau of Labor Statistics (BLS) (USDOL) information was utilized for indices necessary to adjust nominal price data. Views or opinions expressed or implied are those of the authors and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA.

North American Regional Production Trends

Molluscan shellfish are harvested commercially in virtually every country within North America which, for the purposes of this discussion, encompasses Canada, United States (excluding Hawaii), Mexico, Central America, and the various island nations and possessions that comprise the West Indies. Within this region, total molluscan landings during the 1985–89 period represented 12% of the total landings (live weight basis) of all commercial species landed in North America (FAO, 1985–89).

Canada

Mollusks represented an average 6% of Canada's total commercial fishery landings by weight during 1985–89. Canadian landings of all mollusk species increased from 72,545 metric tons (t) in 1985 to 125,614 t in 1989 (Table 1). Canadian mollusk landings represented an average of 9% of the total annual North American landings of all mollusks (Fig. 1). The most important species group targeted by the Canadian industry in

Table 1
Canadian mollusk landings, 1985–89, live-weight basis.[1]

	Landings (1,000 t)				
Year	Oysters	Scallops	Clams	Other[2]	Total
1985	5.5	47.2	15.8	4.1	72.6
1986	5.2	56.9	16.1	5.7	83.9
1987	5.8	73.8	18.4	4.1	102.1
1988	6.5	77.8	16.4	7.5	108.2
1989	6.0	91.6	20.0	8.1	125.7
Avg. percent of total	6%	70%	18%	6%	

[1] Source: FAO fishery statistics, 1989, vol. 68.
[2] Includes squid, mussels, periwinkles, octopus, abalone, etc.

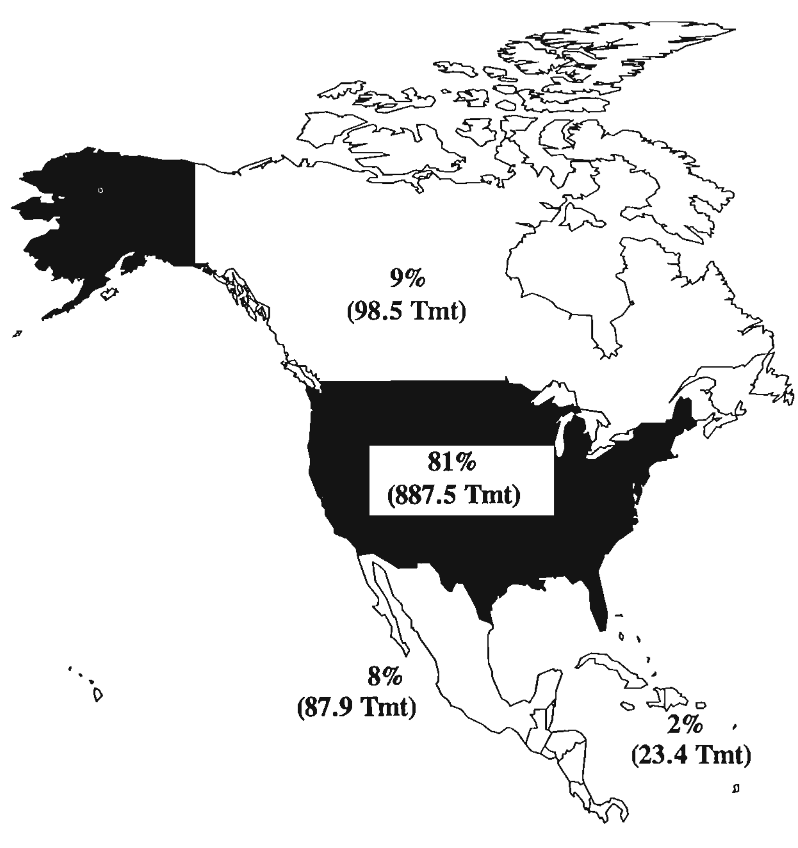

Figure 1
North American mollusk landings by FAO region, in thousands of metric tons.

terms of volume was scallops, averaging 70% of the total volume of mollusk landings. Landings of scallops in 1989 were 91,553 t, with sea scallops, *Placopecten magellanicus*, being the dominant single species. Over the 5-year period, scallop landings increased almost twofold. Also during the same period, clams represented 18% of total mollusk landings, followed by various species of oysters (6%) and other assorted species groups, such as squid, mussels, periwinkles, octopi, whelks, etc. (6% in aggregate).

Mexico

Mexico accounted for an average 8% of the total North American mollusk landings during 1985–89. Mollusks represented an average of 6% of Mexico's total fisheries landings. Mexican landings of mollusks increased almost 50% during the same period. Total landings of all species increased steadily from 72,598 t in 1985 to 107,117 t in 1989 (Table 2). The dominant species group was oysters, averaging 57% of total mollusk landings. *Crassostrea virginica*, the eastern oyster, was the most important single species of oyster harvested in Mexico. Clams constituted the second most important species group, comprising an average 19% of the 5-year

Table 2
Mexico's mollusk landings, 1985–89, live-weight basis.[1]

Year	Landings (1,000 t)					
	Oysters	Clams	Octopus	Conch	Other[2]	Total
1985	42.7	9.5	6.7	5.7	8.0	72.6
1986	42.4	15.3	9.8	5.2	6.0	78.7
1987	50.7	15.0	8.4	5.1	4.5	83.7
1988	56.1	20.5	8.3	5.2	7.2	97.3
1989	56.3	25.2	13.1	6.2	6.4	107.1
Avg. percent of total	57%	19%	11%	6%	7%	

[1] Source: FAO, fishery statistics, 1989, vol. 68.
[2] Includes abalone, squid, mussels, etc.

total. Clams belonging to the family Veneridae (Venus clams) represent the most important commercial species group of clams. Octopus and conch averaged 11 and 6% of the total mollusk landings, respectively. Other species and groups of species, such as abalone, squid, mussels and others collectively contributed about 7% of the total.

Other Regions

Mollusk landings in the remaining non U.S. regions of North America accounted for an annual average of only 2% of the total during 1985–89. The dominant species groups included squid, cuttlefish, octopi, conch, and oysters. Lesser volumes of other molluscan species accounted for the remainder. The overall production from this region, though a small proportion of the total, has steadily increased over the 5-year period. Landings increased from 17,516 t in 1985 to 29,922 t in 1989 (Table 3). The major countries in terms of landings volume include Cuba, Dominican Republic, Honduras, Panama, and St. Vincent.

Table 3
Mollusk landings from other North American regions[1], 1985–89, live-weight basis.[2]

Year	Landings (1,000 t) of squid, cuttlefish, octopus, conch, oysters, clams
1985	17.5
1986	22.6
1987	22.5
1988	24.3
1989	29.9

[1] Major single country producers: Cuba, Dominican Republic, Honduras, Panama, St. Vincent.
[2] Source: FAO, fishery statistics, 1989, vol. 68.

United States

The majority of mollusks landed in this North American region is harvested by the United States. During the 1985–89 period, U.S. landings averaged 81% of the total volume of mollusks produced in North America. Mollusk landings represented an average 16% of the total annual U.S. landings of finfish and shellfish during the 5-year period. Although the United States has maintained regional dominance in mollusk production, landings have trended downward since 1985. Landings decreased from 954,144 t in 1985 to 852,346 t in 1989, a 2.4% average annual rate of decrease.

Most of the decline is attributable to decreases in the landings of two major bivalve groups—clams and oysters. Landings of various species of clams accounted for an average of 47% of total U.S. mollusk landings (live-weight basis) during 1985–89 (Table 4). Oysters represent the second most important species harvested on a live-weight basis, accounting for 23% of mollusk landings. Oysters, however, exhibited the most dramatic decline in landings. The live-weight equivalent of harvested oysters steadily declined from 260,449 t in 1985 to 158,425 t in 1989, a decrease of about 40%. The third most important U.S. species group on a live-weight basis is scallops. Scallop landings were extremely erratic during 1985–89, with landings ranging from 97,617 t in 1986 to 240,862 t in 1988.

Annual mussel and squid landings averaged 3 and 5%, respectively, of the total landings of U.S. mollusks during 1985–89. Lesser landings of mollusks, including octopi and such gastropods as whelks, periwinkles, abalones, conchs, and others, represented only about 1% of the total mollusk landings. A more detailed discussion of species specific trends for the U.S. mollusk industry is given below.

Table 4
U.S. mollusk landings, 1985–89, live-weight basis.[1]

	Landings (1,000 t)						
Year	Oysters	Mussels	Scallops	Clams	Squid	Other[2]	Total
1985	260	16	192	454	26	6	954
1986	234	21	98	426	38	7	824
1987	218	22	211	403	41	9	904
1988	168	36	241	392	58	11	906
1989	158	24	185	417	59	10	853
Avg. percent of total	23%	3%	21%	47%	5%	1%	

[1] Source: FAO, fishery statistics, 1989, vol. 68.
[2] Includes whelks, periwinkles, abalone, conchs, etc.

Clams—The total supply of clam meats remained fairly steady during recent years, with total supply declining only about 8% from 1985 to 1990. The most important clam species were the surfclam, *Spisula solidissima*; ocean quahog, *Arctica islandica*; and hard clam, *Mercenaria mercenaria*. The distribution of landings across species has remained about the same, with surfclams representing 52% of the total supply in 1990, followed by hard clams (7%) and soft clams (4%) (Table 5). Ocean quahogs make up the majority of the remainder, accounting for 35% of the total clam landings. Landings of ocean quahogs increased in 1976 as effort was redirected from dwindling stocks of surfclams (MAFMC, 1990). Hard clam landings decreased substantially since 1985, with landings decreasing by an annual average of 9% during 1985–89. Soft clam landings also decreased by an average annual rate of about 4% during the same period, while surfclam and ocean quahog landings remained about steady.

In terms of nominal ex-vessel value, the distribution across species is somewhat different. Hard clams account for the largest share of total dockside value among the four major species, representing 37% of the total in 1990. Surfclams, soft clams, and ocean quahogs accounted for 29, 20, and 14% of the total, respectively. These percentage distributions have remained about steady since 1985. Real ex-vessel prices per pound of meats (adjusted for inflation using the Producer Price Index for all foods, 1982 base year) for ocean quahogs and surfclams have declined by 7 and 31%, respectively, during 1985–90 (Table 6). Alternatively, real prices for hard and soft clams have increased by 17 and 20%, respectively, over the same period.

Scallops—The total U.S. supply of scallop meats increased overall during 1985–90 by 40%, from 29.6 million pounds in 1985 to 41.5 million pounds in 1990 (Table 7). The most important species landed in terms of volume were the sea scallop; calico scallop, *Argopecten gibbus*; and bay scallop, *A. irradians*; with lesser landings of other species, such as Icelandic scallop, *Chlamys islandica*; and giant Pacific scallop, *Pecten caurinus*. Suggesting just a general increase in U.S. scallop landings, however, tends to mask substantial variability during that period. Most of this variability is linked to calico scallop production. Supplies of calico scallop meats fluctuated dramatically during 1985–89, exhibiting production levels ranging from 12.5 and 11.9 million pounds in 1985 and 1988, to 1.6 and 1.1 million pounds in 1986 and 1990, respectively. In contrast, supplies of sea scallop meats increased steadily from 15.8 million pounds in 1985 to 39.9 million pounds in 1990. During this same period, however, supplies of bay scallop meats declined to 500,000 pounds, a decrease of over 60%.

The distribution of dockside value for all scallop species mirrors their respective landings totals. During 1990, bay and calico scallops in aggregate represented only 3% of the total scallop dockside value (Table 8). The remaining 97% was accounted for by sea scallops.

Table 5
U.S. supply of clam meats (meat weight).[1]

	Commercial clam landings (million pounds)						
Year	Hard	Soft	Surf	Ocean quahog	Other	Total	Imports
1975	15.0	9.2	86.9	1.0	1.3	113.4	2.4
1980	13.4	8.9	37.7	33.8	1.5	95.3	6.9
1985	16.7	7.9	72.5	51.9	1.6	150.6	13.0
1986	11.8	5.9	78.7	45.4	3.6	145.4	16.9
1987	11.4	7.5	60.7	50.3	4.4	134.3	17.6
1988	12.4	6.8	63.5	46.3	2.7	131.7	14.9
1989	9.3	6.8	67.1	46.7	8.3	138.2	13.3
1990	9.8	5.8	71.8	49.1	2.7	139.2	15.8

[1] Source: Fisheries of the United States, var. iss.

Table 6
U.S. ex-vessel value/price for clams.[1]

	Hard clams		Ocean quahog		Soft clams		Surfclams	
Year	V[2]	P[3]	V[2]	P[3]	V[2]	P[3]	V[2]	P[3]
1975	$20.4	$1.98			$7.7	$1.26	$12.6	$0.20
1980	44.1	3.57	$10.2	$0.32	15.4	1.86	19.1	0.55
1985	51.3	2.93	15.9	0.30	21.5	2.61	38.9	0.52
1986	46.8	3.70	15.7	0.32	18.4	2.92	42.6	0.50
1987	49.6	3.96	16.6	0.29	19.8	2.42	28.0	0.42
1988	67.8	4.87	14.9	0.28	18.7	2.43	29.2	0.41
1989	44.9	4.08	16.4	0.27	19.9	2.45	30.7	0.39
1990	41.9	3.42	16.2	0.28	22.4	3.12	32.2	0 .36

[1] Source: USDOC and USDOL data.
[2] V=Million dollars U.S. (nominal).
[3] P=Real price per pound meats (1982 = 100, adjusted with the Producer Price Index, all foods).

Table 7
U.S. supply of scallop meats (meat weight).[1]

Year	Commercial landings (million pounds) Bay	Calico	Sea	Total	Imports
1975	1.6	2.0	10.1	13.7	19.7
1980	1.0		28.8	29.8	20.9
1985	1.3	12.5	15.8	29.6	42.0
1986	.7	1.6	20.0	22.3	47.9
1987	.6	8.2	32.0	40.8	39.9
1988	.6	11.9	30.6	43.1	32.0
1989	.3	6.6	33.8	40.6	40.9
1990	.5	1.1	39.9	41.5	39.8

[1] Source: Fisheries of the United States, var. iss.

Table 9
U.S. supply of oyster meats (meat weight).

Year	Commercial landings (million pounds) Eastern	Pacific	Total	Imports
1975	47.4	5.8	53.2	20.5
1980	42.4	6.6	49.0	21.7
1985	43.1	7.8	50.9	45.9
1986	39.1	9.6	48.7	50.0
1987	30.0	9.9	39.9	52.1
1988	23.9	8.0	31.9	46.4
1989	21.4	7.9	29.3	37.7
1990	18.4	10.8	29.2	27.5

[1] Source: Fisheries of the United States, var. iss.

Table 8
U.S. ex-vessel value/prices for scallops.[1]

	Bay		Calico		Sea	
Year	V[2]	P[3]	V[2]	P[3]	V[2]	P[3]
1975	$3.5	$2.59	$0.8	$0.83	$18.0	$2.65
1980	3.9	4.35			110.4	4.16
1985	5.9	4.26	12.5	0.96	74.6	4.50
1986	6.5	8.28	3.1	1.78	97.4	4.53
1987	3.2	4.97	8.9	1.00	132.3	3.77
1988	3.4	5.33	12.5	0.93	128.2	3.72
1989	1.7	5.16	5.9	0.76	132.6	4.56
1990	3.1	4.63	1.3	0.91	153.7	3.09

[1] Source: USDOC and USDOL.
[2] V=Million dollars U.S. (nominal).
[3] P=Real price per pound meats (1982 = 100, adjusted with Producer Price Index, all foods).

Table 10
U.S. ex-vessel value/price for oysters.[1]

Year	V[2]	P[3]
1975	$42.7	$1.15
1980	70.1	1.54
1985	70.1	1.52
1986	78.1	1.78
1987	92.4	2.12
1988	78.5	2.18
1989	83.6	2.35
1990	93.7	2.58

[1] Source: USDOC and USDOL.
[2] V=Million dollars U.S. (nominal).
[3] P=Real price per pound of meats (1982 = 100, adjusted with Producer Price Index, all foods).

Real ex-vessel price per pound for bay scallop meats typically exceeds that for sea scallops. Real ex-vessel bay scallop prices averaged $5.40 during 1985–90, while calico scallop prices averaged about $1.06. Nevertheless, since sea scallop landings far exceed that of bay scallops, the total value of sea scallops landings dominates. Sea scallop prices experienced an overall downward trend during the same period, as supplies increased dramatically. Real ex-vessel prices for sea scallops decreased from $4.50/pound of meats in 1985 to $3.09 in 1990.

Oysters—The total supply of oyster meats declined 43% from 1985 to 1990 (Table 9). The majority of this decrease is attributable to declines in the production of the eastern oyster. The majority of this decline has resulted from decreases in production from natural (public) oyster beds along the eastern seaboard and Gulf of Mexico. Specifically, production of oyster meats on the eastern and Gulf coasts each declined about 60% during this period. In contrast, production of oyster meats on the Pacific coast increased nearly 40% during 1985–90. Much of this increase is attributable to a growing aquaculture (private) component focusing on the culture of the Pacific oyster, *Crassostrea gigas*. However, this increase was not sufficient to counteract the downward trend in oyster landings of all species.

Although the overall volume of oyster meats declined dramatically during 1985–90, ex-vessel value (and "farmgate" value for cultured oysters) increased in nominal terms by 34% (Table 10). This increase was in large part due to a 70% increase during the same period of the aggregate (public and private product sources), real ex-vessel price per pound of meats. Although data were not available to address the relationship explicitly, the relative movement of value and price for oysters produced by public and private sources may be dissimilar.

The above discussion characterizes the U.S. molluscan fisheries as economically important, with some species exhibiting erratic or declining availability. These characteristics suggest the need for effective resource management from a biological and socioeconomic perspective. The following discussion focuses on economic concepts relevant to the proper management of these important species.

Economic Concepts Relevant to Management

The utilization of a molluscan resource (or finfish resource for that matter) may be typified, historically, by a pattern of discovery, expansion, and, in some cases, eventual overharvesting. To avoid the potential endpoint in this historical pattern, regulation of the fishery in some form by state or Federal efforts is usually adopted. The appropriate form for fisheries regulation has been a subject of economic inquiry since the seminal article by Gordon (1954). In the following discussion, the economic concepts used to analyze and explain fishery resource problems will be presented within the context of molluscan shellfish resources in a primer fashion.

Basic Concepts

For simplicity, we initially develop a simple bioeconomic model. Following Anderson (1986), we begin with the Schaeffer population equilibrium analysis (Schaeffer, 1954). Murawski and Idoine (1989) demonstrate that due to the inherent variability of mollusk recruitment, the surplus production model may be an inappropriate basis for fishery management decision making. However, our objective is to develop a general conceptual framework for defining objectives for management and not to draw inferences for any specific management instrument or specific level of catch or effort. Given the scope of our objective, the Schaeffer model offers a simple analytical tool for demonstrating the molluscan resource economics (Kahn and Kemp, 1985). Further, the general conclusions that one reaches using the simpler surplus population models are essentially the same as that compared to more complex dynamic pool models.

The sustained revenue curve is a monotonic transformation of the sustained yield curve assuming a constant price for fish (Fig. 2). The sustained yield curve is based on the Schaeffer-style growth curve, the short run effort/yield response, and the population equilibrium curve. Assuming a constant cost per unit of effort, the relevant components of a bioeconomical equilibrium and the objectives for management can be discussed. A biologic equilibrium may be said to have been reached for any combination of sustained effort, population, and landings that lies on the sustained yield curve. However, even though they may be argued to be in equilibrium, not all combinations of effort and landings may be deemed biologically desirable. This is illustrated by the fact that, with one exception, for any given level of landings there are two corresponding combinations of effort and population equilibria. Only at the maximum of the sustained yield curve is the combination of effort and population size unique. This is the well known maximum sustainable yield (MSY). Any level of sustained effort beyond MSY will result in lowered population sizes, hence lower sustained yields. Similarly, any combination of sustained effort to the left of MSY will result in lower landings, even though equilibrium population sizes are greater than that of MSY. Thus, the management objective from a biological perspective may be said to be to attain MSY (although other biological objectives related to year class distribution, spawning stock biomass, recruitment, and others may be relevant). Based on an MSY management objective, overfishing would be characterized by any sustained harvest level in excess of MSY. Thus, all effort levels to the right of MSY would be considered to be biological overfishing.

In molluscan as well as other fisheries, the biological equilibrium is a function of the underlying relationships governing recruitment, growth rates, and fishing effort. By contrast, economic equilibria are functions of the biological relationships, institutional context, and

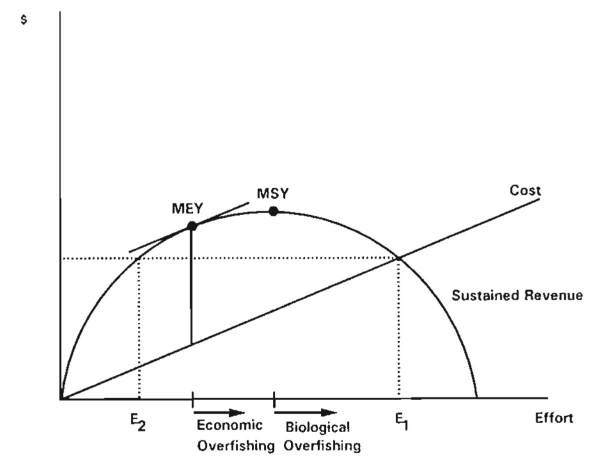

Figure 2
Biological and economic management objectives.

incentives under which harvest takes place. Economic theory demonstrates that maximum return to the resource is achieved at the point where marginal cost and marginal revenue are equal. In the case of natural resources this condition leads to maximization of resource rent. Maximum rent in a fishery is achieved at the effort/yield combination where the slope of the total cost and sustained revenue curves are equal, this is known as maximum economic yield (MEY). To see that this is the case, consider any given level of effort to the left of MEY. The marginal value of an increase in effort, as given by the slope of the sustained revenue curve, is greater than its marginal cost (the slope of the total cost curve). This can be seen through visual inspection of the slopes of the cost and sustained revenue curves evaluated at any point leftward of MEY. The opposite may be said for any level of effort (including that of MSY) to the right of MEY, where the marginal value of additional effort is less than its marginal cost. MEY is, therefore, the molluscan fisheries management objective from an economic perspective. Economic overfishing is characterized by any level of effort to the right of MEY since any effort level greater than MEY would represent an excessive allocation of resources to fishing. Overcapitalization, a phenomenon with which managers of molluscan resources are all too familiar, is therefore a symptom of economic overfishing.

While MEY is the economic objective for molluscan fisheries management, the economic equilibrium will not only be a function of biological conditions but will depend upon economic incentives and social institutions. Economic incentives affecting an economic equilibrium consist of input and output prices. These prices affect the slopes of the cost and sustained revenue curves, and in so doing, affect effort levels. For example, if the cost of fishing was to increase, the new MEY would lie somewhere to the left of the previous one due to the slope of the sustained revenue curve. Note also that 1) only in the case where marginal fishing costs are zero does MEY and MSY coincide at the same effort/yield combination and 2) that for all other cases, MEY will always lie somewhere to the left of MSY; i.e. at effort/yield combinations that are less than that of MSY.

Open-access vs. Rights-based Management

Social institutions in the form of property rights to molluscan fishery resources play an important role in determining the economic and biological exploitation of a fishery. Property rights serve the function of determining rights to use a resource and sanctions for abuse of rights or damage to holders of rights. A system of property rights that is perfectly specified includes the following elements: rights are completely specified including rights and restrictions on use, rights are exclusive so that all rewards and punishments accrue solely to the owner of the rights, rights are transferable, and rights are enforceable and completely enforced (Randall, 1987). Such a system of property rights is what is typically associated with private property. In fact, much of the fishery economics literature that is prescriptive in nature argues for some system of property rights analogous to private property (Gordon, 1954; Scott, 1955; Alford, 1975; Keen, 1983). Note, however, that sole ownership is not necessary for complete specification of rights (Hanna, 1990).

Complete specification of property rights is consistent with MEY. To see that this is the case, consider the case of a hypothetical fishery in the absence of property rights. Figure 3 illustrates such a case. Assume that the initial state of this fishery is at MEY and effort is E_{MEY}. At this point profits are being earned. If property rights are completely specified there would be no incentive to increase effort beyond E_{MEY} because to do so would result in lower landings and hence lower profits. Furthermore, because property rights would be exclusive the resource owner would have an incentive to not only refrain from overharvesting but would have an incentive to engage in resource enhancement. This is particularly relevant for sedentary nearshore mollusks such as oysters, hard clams, and mussels. As long as property rights are exclusive, the benefit of productivity enhancing activities will accrue to the owner (Agnello and Donnelley, 1976). However, since fisheries are common-pool resources, the benefits of engaging in conservation activities are not exclusive. Thus, there is an incentive to take the best first and fastest and continue to do so as long as revenues cover costs. This process is

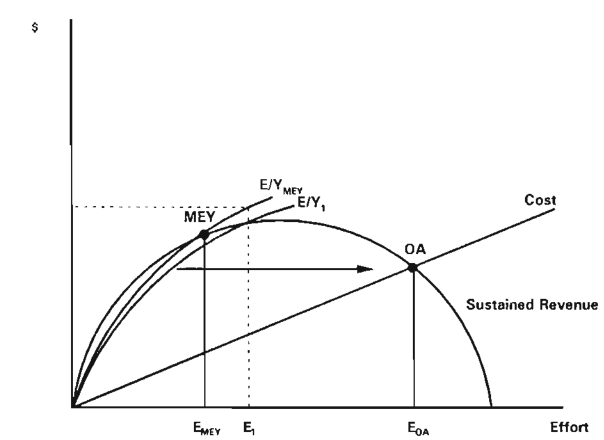

Figure 3
Maximum economic yield contrasted with open access.

illustrated as follows. In the short run, the fishery is supported by a given population size and a given effort/yield relationship (E/Y_{MEY}). Initial expansion of effort beyond E_{MEY} to E_1 will result in a short run increase in yield and industry profits. However, at E_1 the catch rate exceeds natural increase in the underlying population, consequently population size and yield declines to a new, lower short run effort/yield curve E/Y_1. As long as profits remain greater than zero, effort will continue to increase and population sizes and landings will decrease. In the absence of specified property rights, an economic equilibrium is not reached until profits equal zero. This point is known as the open access equilibrium and is shown as OA in Figure 3. At OA the fishery suffers from both biologic and economic overfishing. Again, this is an issue familiar to U.S. molluscan fisheries managers. The fishery management task, therefore, is to design management policy that addresses these biological and economic problems.

In designing fishery management policy, economists usually advocate property rights-based strategies. The reason for this can be seen by examining the economic implications of regulation-based management. In the absence of regulation, harvesters are likely to select the most cost-effective harvest method. Thus, the cost curve associated with the open access fishery may be presumed to represent the least cost method of harvesting mollusks (C_1 in Figure 4). The imposition of restrictions on harvest methods, areas, or seasons fished may indeed meet the biological objective of increased population sizes and increased landings. However, such regulations tend to simply force the cost of fishing to increase (C_2 in Figure 4). The incentives to take the best first and to discourage conservation activities are not removed; hence, the fishery will still continue to operate at an open access level of landings and effort OA_2 (albeit with higher levels of the former and lower levels of the latter).

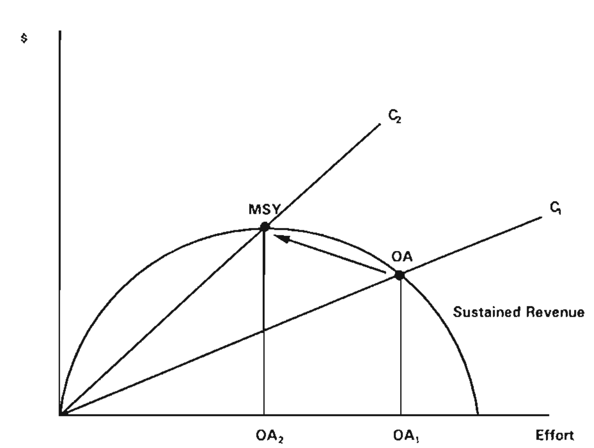

Figure 4
Effect of regulation on harvesting costs.

A fishery management policy may be said to be preferred if it results in an increase in the net value of a fishery (rent distribution may also be an important consideration). Under open access exploitation, the net value of a fishery is zero; total harvest costs are equal to total revenues. Thus, given our criterion, such regulatory approaches to fishery management result in no net gain in social well-being. Furthermore, since marginal costs of fishing still exceed marginal benefits at OA_2, the fishery is still overcapitalized and the unit cost of fishing has increased.

Property rights in a fishery remove the negative externalities[2] associated with open access fishing effort. That is, the benefits and costs of conservation accrue to resource owners. For sedentary mollusks, such as clams and oysters, systems of open access and private ownership rights have coexisted for a long time. In many coastal states, the leasing of submerged lands for private use in shellfish is common. Although lease arrangements differ among states, the lessee is usually granted the right to produce shellfish using various intensive or extensive aquaculture methods. For example, in samples taken throughout the Baylor grounds of Virginia's portion of the Chesapeake Bay, Haven et al. (1981b) found oyster population densities ranging from a low of 20 bushels per acre in the Piankatank River. By contrast, owners of leased bottom in Virginia typically seed their beds at a rate of 650–750 bushels of seed oysters per acre and expect about 1 bushel of marketable oysters for each bushel of seed oysters planted (Haven et al., 1981a). Recognizing that the majority of seed oysters planted on private beds come from public bars (primarily in the James River), the very process of transplanting seed oysters from public to private oyster beds is only made possible by the existence of property rights that assure the owner will reap the rewards for his or her labor. Without such assurances, there is little incentive for oyster producers to engage in extensive or intensive forms of oyster culture.

The estuarine habitat and sedentary nature of oysters, and to some extent clams, make the leasing of designated areas possible. For deeper water mollusks, such as surfclams, ocean quahogs, or sea scallops, the leasing of geographic areas poses considerable difficulties. Nevertheless, property rights-based management of some of these types of species is made possible through the establishment of resource harvest rights.

[2] An externality occurs when the action of one economic entity affects the utility or production possibilities of another in a way that is not reflected in the marketplace (Just et al., 1982).

At this time the most common form of rights-based management is an individual quota (IQ). In cases where an ownership of IQ may be transferred, the system is known as an individual transferrable quota (ITQ). The merits and potential shortcomings of IQ's and ITQ's are well documented elsewhere (Copes, 1986; Sissenwine and Mace, 1992) and are not detailed here. The key point is that economic problems require economic solutions. In the following section we briefly review the management history of two different molluscan shellfisheries, one in which biological objectives guide management decision-making, and one in which economic approaches have been adopted.

Contrasting Management Histories

The previous discussion suggests that some form of property rights structure imposed within the management regime of a fishery resource generates greater overall economic benefits and provides disincentives for engaging in biological overfishing. However, cursory examination of the current complement of molluscan fishery management efforts, particularly at the Federal level, exposes a paucity of attempts to impose some alternative to open-access management for molluscan fishery resources and, thereby, realize these potential economic and biological benefits. This historical absence suggests the existence of significant conceptual or other constraints to the implementation of such programs for specific molluscan shellfish stocks. It may also serve to reemphasize the complex nature of the biological, socioeconomic, and political environment in which the nation's molluscan fishery resources are managed.

The Federal management efforts for Atlantic sea scallops and surf clams highlight the disparate set of objectives under which some of the nation's major molluscan resources are managed. The management histories for each of these species suggest goals that are similar in a biological sense (i.e. long-term viability of the stock), yet potentially divergent in terms of ultimate socioeconomic goals and the strategies used to achieve those goals.

Sea Scallops

The Atlantic sea scallop fishery appears to be an example of a molluscan fishery that is being managed with biological objectives receiving primary importance. The fishery has been characterized by effort, landings, and value rapidly increasing over the last few years (NEFMC, 1982; NEFMC[3]). And although recruitment into the fishery has been high, fishing mortality has been excessive on incoming year classes. To address this problem, an initial management plan for sea scallops was implemented in 1982. Management concern centered on restoring adult stock abundance and age-class distribution and addressing the subsequent effects on yield per recruit and stock biomass relationships. Although economic symptoms of overcapitalization and rent dissipation in the fishery have been alleged, management efforts have focused on biological goals using classic open-access management strategies.

A major element of the management effort has been the implementation of a meat-count standard designed to prevent excessive fishing mortality on incoming year classes of scallops. This management feature recognized the benefits of reducing effort directed toward incoming year classes to allow for extending the length of time the incoming year classes can be fished and providing for a larger yield per scallop. This controversial management tool, however, has been saddled with major problems of enforceability and compliance. The latest in a series of proposed amendments to the fishery management plan proposes to replace the meat-count standard with a vessel moratorium (coupled with limits on fishing power), days at sea allocations, trip limits (designed to address product quality concerns), restrictions on crew and gear, offloading windows, and permitting/reporting requirements. These efforts seek to protect the fishery from poor year-class recruitment through a systematic reduction in fishing effort and, thus, mortality over a given time period.

The management measures historically imposed and currently proposed for sea scallops adhere to classic open-access management strategies in lieu of rights-based resource management, the latter of which may allow the economic forces of the market to play a more direct role in reducing overfishing and overcapitalization. Although theoretically valid and of growing political popularity, rights-based management regimes may yet face substantial local and regional sociopolitical reluctance to depart from the traditional open-access management scheme (Agnello and Donnelley, 1984). Sea scallop management may provide a good case in point.

Surfclams

In contrast to the open-access style of management adhered to for sea scallops, the Atlantic surf clam fishery has recently opted for an innovative management plan based on the assignment of individual harvest rights. The nature of the fishery has allowed economic management objectives to play a greater role in guiding regulation and policy development.

[3] NEFMC. 1991. Public hearing summary document related to proposals for Amendment #4 to the Atlantic sea scallop fishery management plan. NEFMC, Saugus, Mass. Unpubl. doc.

The initial surfclam FMP was implemented in 1977. The resource had experienced high levels of mortality due to an incident of anoxia in major habitat areas (MAFMC, 1990). At the time the FMP was adopted, the industry was characterized by dramatically declining harvest levels and resulting economic instability. In response, resource managers initially imposed classic open-access measures, such as harvest quotas, effort limitations, and permit/logbook provisions.

As the resource recovered, however, vessel overcapitalization quickly occurred and attention turned to the mounting economic problems confronting the industry. A permit moratorium was imposed in an attempt to limit the number of vessels in the fishery. In addition, quarterly quotas were implemented to provide processors with a more consistent product supply. However, these and other open-access measures, such as size limits and harvest region adjustments, met with little success in reducing excess harvest capacity and achieving economic efficiency[4] in the fishery. The potential economic advantages of assigning harvest rights in the fishery were then examined and brought to the industry. After considerable debate and discussion regarding allocation, eligibility, and other issues, an ITQ system was adopted for the surfclam fishery in 1990. The complicated and burdensome system of effort control which had proven unworkable was retired.

Detractors remain, however, suggesting that the ITQ system has resulted in layoffs, increased concentration, and greater processor influence in the industry. Whether these suggested characteristics exact a short-term negative (or positive) influence on the fishery must be weighed against the long-term economic benefits that such a program can potentially generate. A similar management program has also since been implemented for the Atlantic ocean quahog fishery.

Managing at the State Level

State fishery management agencies are also involved with the management of molluscan resources. There are many species that present viable populations within state waters. Examples would include hard clams, bay scallops, softshell clams, and oysters found within the waters of many eastern and southern states. Butter clams, geoducks, razor clams, and abalones represent species found in nearshore waters of western states. The management of these species most often is accomplished with open-access management measures, such as gear restrictions, size limits, bag limits, etc. Such management scenarios are often complicated by the need to consider the nearshore recreational interests. Some states, however, have encouraged a management philosophy which embodies a more rights-based management approach, such as private oyster leases in Texas and Louisiana, and harvest-rights auctions for geoducks in Washington.

[4] Efficiency in the context of this discussion regards an allocation of resources such that the value of the fishery to society is maximized (Anderson, 1986).

Consequences of Environmental Deterioration

Commercial and/or recreational harvests of mollusks (oysters, clams, and mussels) occur in 22 states (USDOC, 1977). As a result of both natural and human-induced factors, most, if not all, of these states have experienced deterioration of their coastal shellfish growing waters. The following discussion addresses the reasons, extent, and impacts of environmental deterioration of shellfish growing waters from within a resource economics framework.

Sources of Environmental Deterioration

About 70% of the U.S. population currently lives within 50 miles of the coast, and between 1950 and 1984, the population in coastal counties grew by more than 80% (USEPA, 1989). This rapid rate of growth, in conjunction with the absolute number of people living along the coast, about 350 mi^2, has strained the fragile ecosystems which support mollusk populations, destroying many of the traditionally productive shellfish beds while leaving others unsuitable for human activities due to excessive pollution.

Some specific human-induced causes for deterioration of mollusk growing areas, as cited by the Environmental Protection Agency (USEPA, 1990), are presented below.

1) Industries: According to EPA estimates, 1,300 major industrial facilities discharge directly into estuarine and near coastal waters.

2) Sewage treatment plants: Almost 600 municipal treatment plants discharge effluents into estuaries and near-coastal waters.

3) Dredge materials: Annually, about 150 million t of dredged materials are released into estuaries and near-coastal waters.

4) Hazardous waste: From 75 to 100 hazardous waste sites in U.S. coastal counties are considered to present some threat to marine resources.

5) Nonpoint sources: Over half of coastal water pollution is attributable to urban and agricultural nonpoint sources.

6) Combined sewer overflows: Raw sewage and urban

runoff is discharged into the estuaries after rainstorms in urban areas.

7) Upstream sources: Discharges from thousands of industrial and municipal plants enter rivers that subsequently enter estuaries.

8) Landfill and development: Landfill and development in environmentally sensitive coastal areas have destroyed critical spawning, nursery, and habitat areas traditionally used by much of the nation's fish and shellfish resources.

From an economic perspective, these human-induced causes of estuarine deterioration reflect externalities that exist in the utilization of molluscan shellfish habitat. These externalities occur because many of the resources associated with mollusk production, including the estuarine growing areas and the shellfish found there, are often not privately owned, and entitlements are not properly specified. Since the polluters do not pay a market price for the use of all necessary resources (including the estuarine waters needed for the production of shellfish), discharges may be excessive from a societal viewpoint. Therefore, externalities which occur as activities under control by one party, in this case the polluters, negatively impact activities of other parties, such as shellfish harvesters, other sectors of the economy dependent on shellfish production (e.g. processors, wholesalers, and distributors), and consumers (via an increased risk related to the consumption of raw shellfish products originating from waters of questionable quality). An externality may also exist when environmentally sensitive coastal areas are developed in a manner that reduces production from unaltered estuarine environments.

Human-induced discharges may also lead to increased monitoring and enforcement costs by state and federal agencies to ensure shellfish safety standards. According to a recent study (USDOC, 1991), expenditures per state on shellfish management programs averaged about \$0.50/acre in 1990[5] and ranged from \$0.085 (Maine) to \$6.04 (Washington) on a per state basis. A substantial proportion of these costs, which have increased by almost 40% since 1985 (after adjusting for inflation), is devoted to routine monitoring of the release of human-induced pollutants in the estuarine growing areas of the shellfish-producing states.

Extent of Deterioration

Table 11 helps to document the deterioration of U.S. estuarine shellfish growing waters. In 1990, total classified growing waters equalled 17.2 million acres. Of this total, 63% (10.9 million acres) was approved for harvest. More than one-third (6.3 million acres), however, was harvest limited. The biggest share of the 6.3 million

[5] Numbers given in the report were adjusted for inflation to 1989 dollars. There were converted to 1990 dollars herein.

Table 11

Shellfish estuarine waters classification trends, 1971 and 1990 (1,000 acres), not including classification of offshore growing areas. Sources: Bell (1978) and USDOC (1991).

	Approved			Conditional			Restricted			Prohibited			Total		
Region[1]	1971	1990	% change	1971	1990	% change	1971	1990	% change	1971	1990	% change	1971	1990	% change
North Atlantic[2]	1,250	781	–37.5	7	9	+28.6	11	11	0	122	332	272.1	1,390	1,132	–18.6
Middle Atlantic	3,895	4,221	+8.4	121	217	+79.3	19	217	L[3]	560	688	22.9	4,595	5,343	+16.3
South Atlantic[4]	1,786	2.091	+17.1	<1	119	L	0	102	L	676	630	–6.8	2,463	2,940	+19.4
Gulf of Mexico	3,226	3,434	+6.5	282	1,153	+408.9	0	103	L	1,618	2,405	48.6	5,126	7.095	+38.4
Pacific[5]	204	338	+65.7	<1	73	L	0	31	L	322	201	–37.6	526	6,643	+22.2
Total	10,361	10,865	4.9%	410	1,571	+383.2	30	464		3,298	4,256	+29.1	14,100	17,153	+21.7%

[1] Regions are defined as follows: North Atlantic includes the States of Maine, New Hampshire, and Massachusetts; Middle Atlantic includes the States of Massachusetts (lower portion), Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, and Virginia; South Atlantic includes the States of North Carolina, South Carolina, Georgia, and Florida (east coast); Gulf of Mexico includes the States of Florida (west coast), Alabama, Mississippi, Louisiana, and Texas; Pacific includes the States of California, Oregon, Washington, and Alaska.

[2] For 1971, all of Massachusetts was included in the North Atlantic Region. In the 1990 data, a small section of Massachusetts was included in the Middle Atlantic Region.

[3] The "L" denotes a very large amount of change between 1971 and 1990.

[4] For 1971, all of Florida was included in the Gulf of Mexico.

[5] Alaska was not included in 1971 survey.

harvest-limited acreage was classified as prohibited (some 4.3 million acres), indicating that no harvest is allowed for human consumption at any time. Another 1.6 million acres were classified as conditional, indicating that harvest can occur only when certain criteria are met. Finally, 464,000 acres were classified as restricted, indicating that harvesting could take place only if shellfish were subjected to a suitable purification process, such as relaying or depuration.

As indicated in Table 11, the total classified shellfish estuarine acreage expanded almost 22% from 1971 to 1990, from 14.1 million acres to 17.2 million acres. Because of the increase in harvest-limited waters during the period, however, approved shellfish estuarine growing waters increased by <5%, from 10.4 million acres to 10.9 million acres (almost 200,000 of the half-million acre increase resulted from the inclusion of Alaska in the 1990 data). Shellfish-harvest limited acreage increased from 3.7 million acres in 1971 to 6.3 million in 1990. Acreage classified as prohibited increased by almost 30% and acreage classified as conditional increased almost fourfold.

While the Gulf of Mexico region accounted for 41% of the total classified shellfish estuarine growing waters in 1990, it accounted for almost 60% of the nation's shellfish-limited acreage. Overall, the Gulf of Mexico region accounted for 57% of the nation's prohibited shellfish acreage and almost 75% of all conditional shellfish growing waters in 1971 and 1990. The greatest percentage increase in prohibited growing waters, however, was attributed to the North Atlantic region (272%) while the prohibited growing waters in the Pacific region actually showed a large percentage decline (38%).

Sewage treatment plants are the primary point-source of pollution at the national level (Table 12), while septic systems and urban runoff are the primary nonpoint sources. Sewage treatment plants and urban runoff were the primary upstream pollution sources.

Overall, sewage treatment plants were the primary point-source of pollution in all regions considered except the Pacific region where industry was the primary point-source of pollution. The impacts of sewage treatment plants were particularly apparent in the North Atlantic and Mid Atlantic Region where 67% and 57%, respectively, of harvest-limited acreage was a result of this pollution source. Direct discharge of pollutants, in addition to sewage treatment plants, was a substantial point-source of pollution in the Gulf of Mexico region.

The five sources of nonpoint pollution—septic systems, urban runoff, agricultural runoff, wildlife, and boats—were generally all significant contributors to closures of shellfish waters in all regions (Table 12). With respect to upstream sources of pollution, sewage treatment plants and urban runoff were the primary contributors affecting shellfish harvest-limited acreage.

Table 12

Pollution sources affecting harvest-limited acreage (× 1,000), 1990.[1,2] Source: USDOC (1991).

	North Atlantic		Middle Atlantic		South Atlantic		Gulf of Mexico		Pacific		Nationwide	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Point sources												
Sewage treatment plants	238	67	641	57	374	44	973	27	75	25	2,301	37
Combined sewers	21	6	224	20	0	0	211	6	0	0	456	7
Direct discharge	1	<1	84	7	5	1	920	25	6	2	1,106	16
Industry	21	7	223	20	180	32	522	14	129	42	1,075	17
Nonpoint sources												
Septic systems	91	26	123	11	288	34	1,763	48	57	19	2,322	37
Urban runoff	75	23	655	58	290	34	1,276	35	110	36	2,406	38
Agricultural runoff	5	3	130	12	233	28	301	8	41	13	710	11
Wildlife	19	7	112	10	306	36	1,115	30	39	13	1,591	25
Boats	55	17	353	31	146	17	507	14	47	15	1,108	18
Upstream sources												
Sewage treatment plants	2	1	104	9	9	1	1,174	32	45	16	1,334	21
Combined sewers	0	0	5	<1	0	0	134	4	0	0	139	2
Urban runoff	3	1	72	6	8	1	793	22	43	14	919	15
Agricultural runoff	0	0	1	<1	0	0	435	12	0	0	436	7
Wildlife	0	0	28	2	35	4	210	6	0	0	273	4

[1] % is percent of all harvest-limited acreage in region.

[2] Since the same percentage of a shellfish area can be affected by more than one source, the percentages shown above cannot be added. They will not sum to 100.

Economic Consequences of Environmental Deterioration

Deterioration of U.S. shellfish growing waters has at least two potential impacts on the shellfish industry. First, deterioration of shellfish growing waters results in a reduction in the harvestable supply of mollusks. Second, deterioration, especially with respect to pollution of the shellfish growing waters, can result in a reduction in demand for shellfish products. This reduction in demand can result in lower dockside prices for molluscan products which, in turn, can lead to reductions in quantities supplied by the harvesting sector.

To illustrate how deterioration of shellfish growing waters can impact the harvestable supply of mollusks, consider Figure 5, which relates long-run catch as a function of effort.[6] Mathematically, this long-run quadratic relationship between catch and effort can be represented as follows (Bell, 1989, gives a derivation of the model):

$$C(t) = kB*E(t) - \frac{B*k^2}{a}E^2(t)$$

where $C(t)$ is the quantity of stock harvested during time period t, $B*$ is the maximum potential biomass under various constraints, $E(t)$ is the amount of effort employed in the fishery during time period t, k is equal to the catchability coefficient, and a is a parameter. Note that B^*, which is a reflection of the carrying capacity of the fish stock, is also interactive with $E(t)$ and $E^2(t)$. Reductions in carrying capacity emanating from increases in natural or human-induced discharges results in a lower catch at any level of effort, as indicated in the previous equation, and can be represented in Figure 5 by an inward shift in the sustainable yield curve. For illustrative purposes, the maximum potential biomass (B^*) is assumed to fall from $B^*(0)$ to $B^*(1)$ in Figure 6 as a result in estuarine deterioration. This causes the sustainable yield curve to fall from $SY(0)$ to $SY(1)$ and, hence, long-run yield declines at all levels of effort.

While empirical studies evaluating the loss in mollusk production are few and possibly flawed due to simplifying assumptions (such as an assumption of no price response), value losses have been calculated for the years 1966, 1971, and 1975 (Table 13). These likely represent upper-bound estimates of losses. Expressed in terms of 1990 dollars, the 1975 losses nationwide approximate $70 million.

Between 1961 and 1989, 10,384 cases of shellfish-associated viral diseases and 1,400 cases of oyster- and clam-associated hepatitis A have been documented in the United States (USDOC, 1991). These illnesses, and

Table 13
Estimated value loss from habitat deterioration, 1966, 1971, and 1975. Source: USDOC (1977).

Species	1966	1971	1975
Oysters	$7,005,243	$17,486,457	$18,017,693
Clams	3,533,836	10,643,255	11,069,088
Mussels	14,019	82,840	99,518
Total	$10,553,098	$28,212,552	$29,186,299

[6] The relationship between effort and long-run yield, as shown in Figure 6, is often referred to as the Schaefer sustainable yield curve. While its applicability to molluscan resources is at best questionable, it is used here because of its simplicity and its exposure to a wide range of audiences.

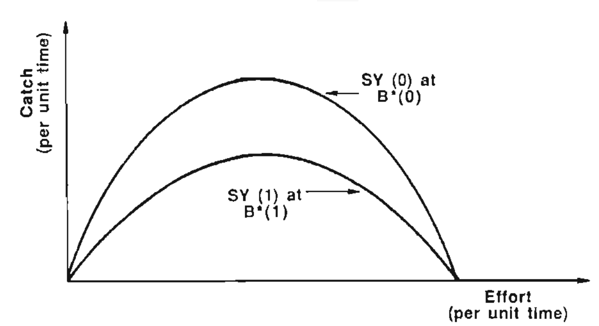

Figure 5
Hypothetical shift in sustainable yield curve for shellfish related to estuarine deterioration.

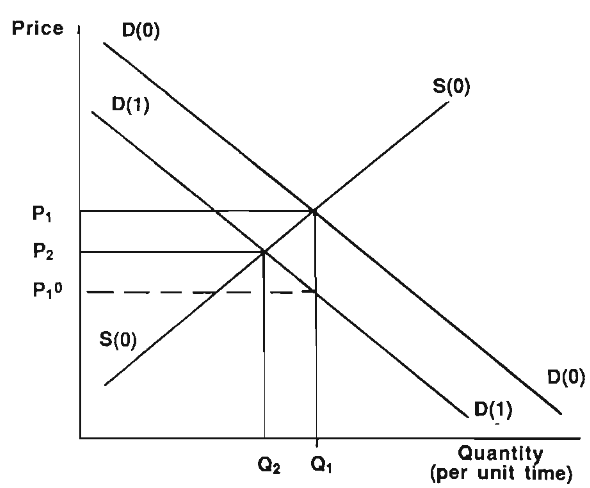

Figure 6
Hypothetical response in demand from an increased perceived risk of shellfish consumption.

reports of phytotoxins (paralytic shellfish poisoning) and contaminants such as pesticides, metals, etc., in mollusk producing waters, have created consumer uncertainty about the quality of the shellfish they purchase, especially if intended for raw consumption, as in the case of oysters (Lin et al., 1991; Swartz and Strand, 1981).

The impact of consumer uncertainty with respect to raw mollusks can be theoretically evaluated with the aid of Figure 6. The demand curve for mollusks, assuming no uncertainty or risk, is given by D(0), while industry supply is represented by S(0).[7] Under this scenario, equilibrium quantity and price are given as Q_1 and P_1, respectively.

Uncertainty in safety of shellfish consumption, as measured by perceived risk, can be introduced by a reduction in demand for molluscan shellfish at all prices, i.e., a downward shift in the demand curve. For our purposes, demand is assumed to fall to D(1), though the actual decline in demand will ultimately depend upon the perceived risk and consequences thereof.

The reduction in demand from an increase in perceived risk results in an immediate reduction in price to P_1^0. This price reduction results in a reduction in the quantity supplied by the fishermen (assuming quantity supplied is responsive to changes in price) and, hence, some upward movement in price. In equilibrium, the quantity supplied, as a result of an increase in perceived risk, is reduced from Q_1 to Q_2 while the equilibrium price falls from P_1 to P_2.[8] Therefore, decreased consumer confidence regarding the consumption of raw shellfish may manifest itself by lower prices in the marketplace and reduced output from the harvesting sector. Total revenues generated by the industry may decline significantly, through both reduced product prices and lost market share.

Summary and Conclusions

Molluscan fisheries comprise an important component of the total North American commercial fishing industry. Many species of bivalves and gastropods are of commercial importance. The U.S. fishery, however, represents the most important single source of many molluscan species, in particular oysters, clams, and scallops. The issues that confront molluscan resource managers in the United States are many and complex. The resources themselves are extremely dynamic from a biological perspective, with the harvest activities being further influenced by a varied complement of political and socioeconomic factors. Though open-access management techniques seem appropriate for the current biological problems facing some molluscan stocks in U.S. waters, the adoption of a rights-based management policy holds greater promise of achieving long-run economic goals. Rights-based strategies have been recently designed to address economic issues confronting the management of surf clams and ocean quahogs, while the management regimes adopted for most other species continue to adhere to open-access regulatory measures in the face of growing economic problems. Managers of near-shore or estuarine molluscan stocks must also be cognizant of the economic consequences that arise from the deterioration of habitat, both human-induced and otherwise. The economic losses that can occur from reductions in estuarine mollusk production and decreased consumer confidence have been shown to be substantial. Such concerns provide a need for molluscan resource managers to be more fully aware of the economic forces that come to bear on all sectors of the industry—from harvesters to consumers—and to adopt a management policy that can effectively address these economic issues.

[7] This supply response assumes that long-run catch is positively related to price. In some resources that are overfished, supply could respond negatively to price increases.

[8] McConnell and Strand (1989) demonstrated that improved water quality in certain situations will reduce social returns to the resource. While the concepts are outside the scope of this paper, readers are referred to their work for a more detailed analysis of the effects of water quality on consumption and production of seafoods.

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Mollusk Statistical Data Collection in the United States

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ABSTRACT

Molluscan fishery and industry data are collected for commercial landings, cold storage holdings, market prices, processed products, and trade. The data are collected by census rather than estimated from random samples. Landings data collection began in 1880 and is often a joint state and Federal responsibility. Commercial landings are collected by a variety of mandatory and voluntary reporting systems including trip tickets, dealer weigh-out slips, logbooks, interviews, and sampling. NOAA's National Marine Fisheries Service conducts supplemental surveys to compensate for the great diversity in data collection methods by more than 20 coastal states that collect landings data. The Service also gathers fishing effort data. Seven factors that affect the collection and interpretation of landings data are: 1) different reporting periods, 2) underreporting, 3) lack of species identification, 4) combining landings and aquaculture data, 5) lack of uniform reporting units, 6) confidentiality, and 7) data accessibility. Cold storage holdings, market price, and processed product data are entirely dependent on voluntary data submissions by industry. Although the NMFS takes great care to ensure that the data are accurate and complete, voluntary reporting is subject to bias as all possible contributors may not be identified or report. The Bureau of the Census compiles monthly trade data on 41 import and 29 export mollusk commodities and many other items.

Introduction

The National Marine Fisheries Service (NMFS), an agency of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration, and its predecessor agencies have a long history of collecting and reporting molluscan fisheries data. National statistics have been compiled on fishery landings, processing volume, wholesale market prices, supply of fresh and frozen products, and foreign trade. The history of data collection efforts, data collection methods, data reporting, and other issues and changes affecting the completeness and accuracy of national statistics are discussed.

Landings

History

U.S. commercial landings of mollusks and finfish, along with other fisheries effort data, were first reported for 1880 by the Assistant Director of the U.S. National Museum in cooperation with the U.S. Commission of Fish and Fisheries (Goode, 1884). The data were also reported for general surveys of a limited number of states or limited areas of the United States during 1881–1907 and for 1909–28 (NMFS, 1984). A comprehensive statistical canvass of fishery landings for the entire United States was first made in 1908 by the Bureau of the Census (1911). The canvass included catches taken in oceans, bays, coastal rivers, and inland waters—wherever commercial fishing was conducted. Comprehensive surveys by the U.S. Fish Commission and its successor agencies, the Bureau of Commercial Fisheries (BCF) and NMFS, have been conducted annually since 1929 with the exception of some inland waters and partial surveys conducted between 1941 and 1951. Lists of partial and complete landing canvasses by year are given in Fisheries Statistics of the U.S., 1977 (NMFS, 1984) and Fisheries of the U.S., 1992 (NMFS, 1993). Landings data have been entered into NMFS computerized databases since 1962; prior to that only published data usually are available.

Methods

The collection of U.S. fishery data is a joint state and Federal responsibility. These fishery data collection systems obtain landings data from state-mandated fishery or mollusk trip tickets, landing weigh-out reports provided by seafood dealers, logbooks of fishery catch and effort, and shipboard and portside interviews and biological sampling of catches. The fishery agency of a respective state usually is the primary collector of landings data. In some states, however, NMFS and state fishery personnel cooperatively divide data collection efforts based on such criteria as inshore vs. offshore fishing effort by fishermen, geographic distribution of port agents or seafood dealers, or fisherman participation in selected fisheries. Landings data for each state represent a census of reporting fishermen and seafood dealers rather than an expanded estimate based on sampling data.

Principal data gathered during cooperative state-Federal landing censuses consists of: the pounds, ex-vessel values, and species caught; the state, county, and port of landings; and landing dates. Census methodology has evolved over many years and differs by state, but supplemental surveys are made by NMFS to ensure that the data from different years and states are comparable.

Mollusk landings in NMFS databases are used in fishery and economic studies and modeling. A sophisticated relational database system allows rapid and easy data extraction, transformation, and summarization. Landings volume in metric tons (t), the actual price per kilogram, and the deflated (using Producer Price Index) price per kilogram are shown for several economically important mollusks in the northeastern United States at state and regional levels. To illustrate the volume and value from 1965 to 1996 of Massachusetts sea scallop, *Placopecten magellanicus* (Fig. 1), New Jersey surfclams, *Spisula solidissima* (Fig. 2), and ocean quahogs, *Arctica islandica* (Fig. 3), landings are presented along with northeast regional landings (Maine to Virginia) for softshells, *Mya arenaria* (Fig. 4), eastern oysters, *Crassostrea virginica* (Fig. 5), and northern quahogs, *Mercenaria mercenaria* (Fig. 6). Some states record landings of northern quahogs by market categories such as littleneck, topneck, cherrystone, and chowder. NMFS reports all northern quahog landings as a single species/market category because the market categories are not always clearly defined and may vary with locale, season, and spawning condition. Landed prices of various mollusk species vary widely. Prices for 1993 collected from local port agents, including size categories of northern quahogs, are listed in Table 1.

NMFS also conducts surveys each year to gather information about fishing effort. Data collected during the surveys include the number of full- and part-time fishermen; the number of commercial fishing vessels (craft of at least 4.5 t [5 net tons]) and boats (craft <4.5 t); physical characteristics data of vessels; distance-from-shore fishing information; and the types, sizes, and numbers of gears fished.

As of 1992 seven states (Alaska, Washington, Oregon, California, Hawaii, North Carolina, and Florida) have mandatory fishery trip-ticket reporting systems. Two additional states, Maine and South Carolina, have state-mandated trip-ticket reporting systems only for shellfish. North Carolina and Louisiana recently have authorized the implementation of a trip-ticket reporting system. Seafood dealers in trip-ticket states must send their respective state fishery agency a ticket that documents the catch for each fishing trip taken by a commercial fishing craft. Trip-ticket data usually include the pounds and ex-vessel value of each species landed

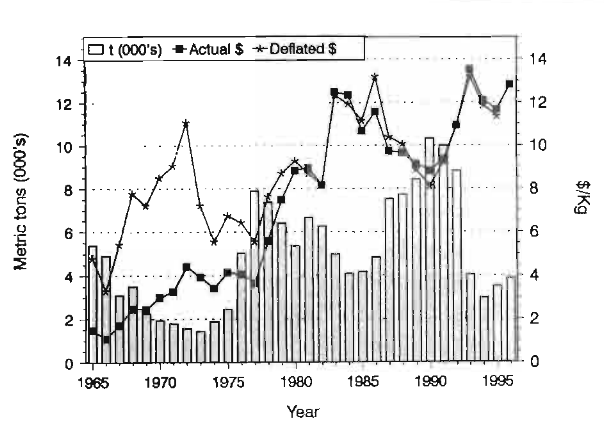

Figure 1
Volume and ex-vessel actual and deflated (using product price index [PPI], 1982 = 100) values of sea scallop landings in Massachusetts, 1965–96.

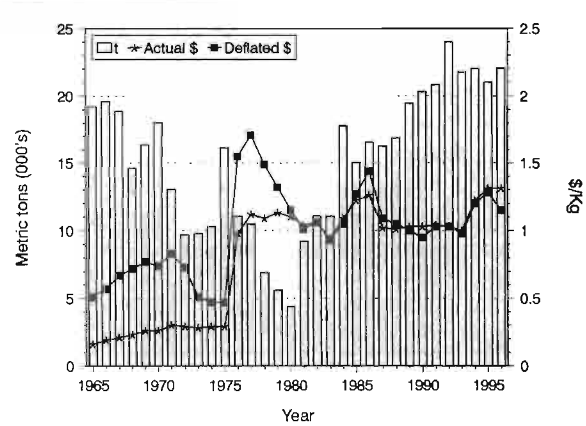

Figure 2
Volume and ex-vessel actual and deflated (using PPI, 1982 = 100) values of surfclam landings in New Jersey, 1965–96.

along with such other information as vessel identification number, fishing area, gear type, and commercial license number. The data are compiled by the state and usually made available to NMFS within 8–12 months after the end of the year. Florida, however, does not require that trip-tickets include ex-vessel price data or vessel identification. To fill the data gaps in Florida, NMFS conducts supplemental market surveys to determine the ex-vessel value of landings. The commercial license numbers on Florida trip-tickets are cross-matched with U.S. Coast Guard files to determine vessel identification numbers; however, boats are not individually identified.

Landings in other states are based on various voluntary or mandatory reports submitted by seafood dealers. Connecticut, Maryland, Virginia, Alabama, Mississippi, Louisiana, and Texas require seafood dealers to submit weigh-out slips or monthly reports of commercial landings. Seafood dealers in northeastern states from Maine to Virginia usually list the vessel identification number on each weigh-out slip, but all landings by boats are combined and reported as a single boat code number. Southeast states from North Carolina to Texas (excluding Florida) list only vessel identification numbers for shrimp landings; boat registration numbers are not reported. State landings usually are reported on a

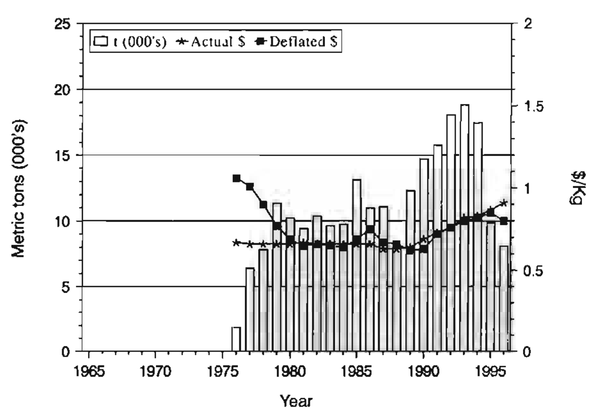

Figure 3
Volume and ex-vessel actual and deflated (using PPI, 1982 = 100) values of ocean quahog landings in New Jersey, 1965–96.

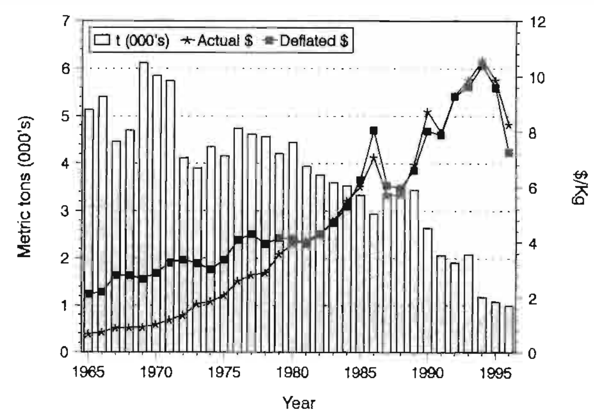

Figure 4
Total annual volume and ex-vessel actual and deflated (using PPI, 1982 = 100) values of softshell landings for Maine to Virginia, 1965–96.

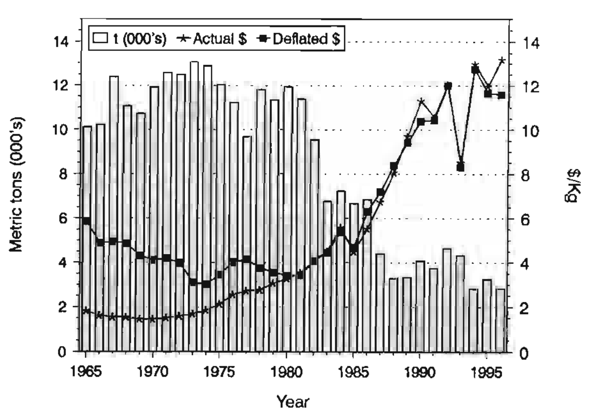

Figure 5
Total annual volume and ex-vessel actual and deflated (using PPI, 1982 = 100) values of eastern oysters for Maine to Virginia, 1965–96.

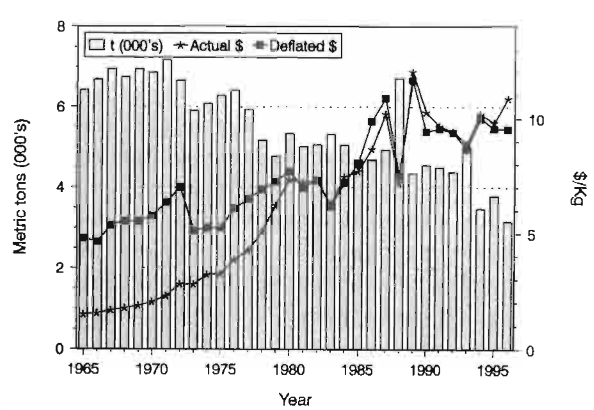

Figure 6
Total annual volume and ex-vessel actual and deflated (using PPI, 1982 = 100) values of northern quahog landings, 1965–96.

Table 1
Approximate landed prices per bushel of U.S. east coast mollusks in 1993. Data are from various NMFS and State port agents.

Species and area	Value ($)
Bay scallop	
Massachusetts	60.00[1]
Softshell	
Maine	61.69
Maryland	45.93
Northern quahog	
New York	
Littlenecks	56.00[2]
Cherrystones	20.00
Chowders	12.00
Conch	
Massachusetts	42.25
Sea scallop	
Massachusetts	26.64–40.50[3]
Oyster	
New York	26.43
Maryland	21.20
Gulf coast	12.50
Surfclam	
New Jersey	7.73
Calico scallop	
Florida	6.67[4]
Blue mussel	
Massachusetts	4.90

[1] Based on landed price of $10/pound of meats.
[2] Based on 400 count "bushel (A level U.S. standard bushel has 750 littlenecks).
[3] Based on landed prices of meats ranging from $4.44 to $6.75/pound (the larger the meats, the higher the price).
[4] Based on landed price of $10/gallon of meats.

monthly basis and summed to obtain annual totals. Complete mollusk landings for Connecticut, Delaware, Maryland, and Massachusetts are available only on an annual basis.

In addition to trip tickets or dealer weigh-out slips, fishermen who participate in Federally permitted fisheries, regardless of the state in which the fish or shellfish are landed, must submit a logbook of their catch and effort to the appropriate NMFS Science Center Director. Logbook submissions are required for two molluscan fisheries, Atlantic surfclam and ocean quahog. A mandatory Federal reporting requirement also exists for seafood dealers who handle fishes and mollusks from regulated fisheries. In Federally permitted fisheries, NMFS observers may be placed on fishing craft to record catch, effort, and biological data while the craft is at sea. Some states may also require a commercial fishing craft to carry state personnel if fishery operations are conducted within territorial waters.

Issues

Several factors and changes in statistical reporting have occurred since fishery data collection began in 1880 that may affect the accuracy, completeness, consistency, and accessibility of national landings data. The factors and changes include:

1) Differences in time periods for reporting some mollusk landings and changes in the port listed as the landing site,
2) Underreporting of landings,
3) Landings not identified to species,
4) Combined reporting of aquaculture and wild harvest,
5) Lack of uniform units for reporting landings,
6) Data confidentiality, and
7) Data accessibility.

Changes in reporting time periods and in the stated port of landings may affect total annual mollusk landings at the state level. Annual landings of oysters were reported by fishing season (September to April) until 1930. Since 1930, oyster landings have been reported by calendar year. Prior to 1942, all landings from an individual vessel were credited to a single, principal port at which most fish and shellfish were unloaded. This policy was discontinued because it often resulted in crediting catches to ports far removed from the actual landing site. Since 1942, the pounds and value of landings have been credited to the actual ports of landings by seafood dealers and fishery port agents.

Some landings of mollusks may be intentionally or unintentionally underreported owing to special taxes on mollusk landings, incomplete voluntary reporting of landings, landing quotas, and lack of a landings census by states during some years. Reported landings of mollusks decreased coincident with implementation of special taxes on mollusks in some states. Landings are confounded by other factors (e.g. red tide, fishing seasons, trip limits, etc.), however, and the extent of unreported mollusk landings are not quantifiable.

Landings data in some states or for selected species may be incomplete because they are based on voluntary rather than mandatory reporting requirements. For instance, one fishery cooperative in New York trucks its catch directly to the Fulton Fish Market in New York City, bypassing local wholesale seafood dealers who voluntarily report landings. Although NMFS collects weekly market price data at the Fulton Fish Market and at several other major fish markets, the poundage of fish and shellfish processed is not reported because the fishery data collection system is designed to census the data at the port of landing.

Reported landings data may also be biased because there are occasions (e.g. under a fishery quota system) when fishermen or seafood dealers may have financial incentives to underreport actual landings. However, data accuracy and completeness presumably are increasing because many recently implemented Federal Fishery Management Plans include mandatory reporting requirements and allocate future fishery harvests to individual fishing vessels based on recent year's landings. It therefore is advantageous for fishermen to ensure that their entire landings are recorded accurately by the data collection system.

Although recent landings data usually record mollusk landings by species, long time-series of landings usually are available only at the family level. Some states did not report landings of mollusks by species until the late 1970's and even into the mid-1980's. Oyster landings of multiple species were often combined and reported as a single predominant species or generically listed. The oyster data, however, provide useful information about changes in relative quantity and value of U.S. landings (Fig. 7).

NMFS (1990) summarized 1880–1989 Atlantic and Gulf coast mollusk and finfish annual landings for selected family or species groups. However, landings prior to 1930 and from 1941 to 1951 may reflect incomplete data collection at the state level due to budgetary and personnel limitations during the Depression and World War II eras. Abalone (*Haliotis* sp.) reflect the decreased reported landings during these periods and the absence of value data during the early 1920's (Fig. 8). The anomalously high volume of abalone landings in 1888 reported in past publications reflects the fact that whole live weight was reported while meat weights were reported during all other years.

Historically, landings data usually have included all mollusks sold to seafood dealers, regardless of their source. But they have recently included mollusks from leased beds and those produced by aquacultural practices. When landings are reported from leased beds, it is not always evident whether those data represent true aquaculture production or wild harvest. For statistical purposes, NMFS uses the FAO (1993) definition of aquaculture:

"Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while organisms which are exploitable by the public as a common property resource, with or without appropriate licenses, are the harvest of fisheries."

A few states currently do not differentiate between landings from public and private leased bed areas or may not report aquaculture production. Mollusks from leased bed areas traditionally are combined with those taken from public bed areas and are reported as commercial landings. Mollusks from leased beds may also be reported separately as aquaculture production. For instance, some of the total U.S. commercial landings listed in Table 2 include mollusks raised on leased beds, and the aquaculture production data may not be complete because all states do not report or differentiate aquaculture in landings.

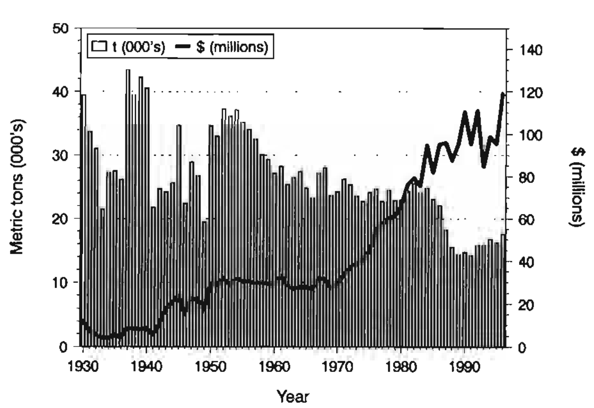

Figure 7
Total annual volume and value of United States oyster (eastern and Pacific) landings, 1930–96.

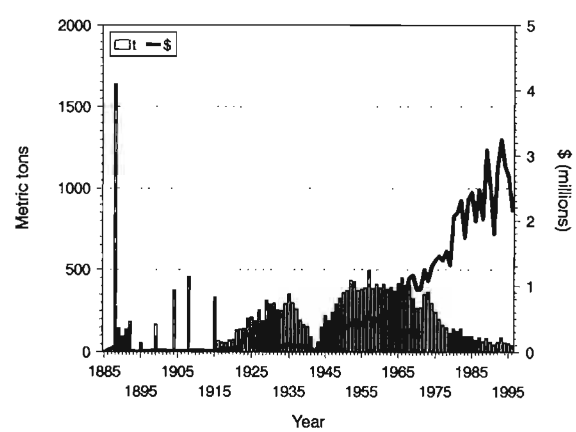

Figure 8
Total annual volume and value of United States abalone landings, 1880–1995.

Table 2
U.S. mollusk domestic commercial landings and aquaculture production[1] in metric tons (t) of meats and thousands of dollars.

	Commercial landings		Aquaculture production	
Year	t	$	t	$
1985	126,195	317,456	11,392	44,222
1986	136,888	356,876	12,798	58,871
1987	136,163	398,461	12,474	60,884
1988	156,141	405,103	12,515	71,350
1989	171,559	426,680	11,450	71,939
1990	158,192	442,052	12,010	92,608
1991	162,910	428,375	11,170	75,543
1992	152,147	454,552	12,950	95,133
1993	174,680	405,928	13,985	89,162
1994	195,061	413,521	15,111	85,200
1995	198,353	399,812	12,681	91,558

[1] Data source: NMFS, Fisheries Statistics and Economics Division, 1315 East-West Highway, Silver Spring, MD 20910.

Uniformity of landing units of measure, especially for oysters, is also a problem in data collection activities. Although statistics on the quantity of finfish landed represent round (live) weights, bivalve mollusk landings are traditionally reported as meat weights (without shell). With the exception of sea scallops that are shucked at sea, the ex-vessel value of landings represents the price paid before shucking or other processing.

Great variation exists within and among states in how oyster landings are reported. The variation in landing units includes gallons of meats, bushels of varying sizes, totes, and number of individual oysters harvested. Conversion factors are used to change the original reporting units to a standardized unit of pounds of meat landed. Since species, season, spawning condition, and geographic area of harvest affect the shucked weight yield of mollusks, the most accurate conversions of landings from whole to meat weights occurs when the factors are included in the conversion factor. Unfortunately, landings often are combined or the factors are not recorded, and an NMFS standard generic conversion factor may be used to estimate meat weight.

Data confidentiality sometimes limits the public dissemination of statistical data. Federal statutes limit public access to fishery statistics to prevent trade secrets from being revealed or otherwise place someone at a competitive disadvantage. If fewer than three vessels or companies land a species or fewer than three seafood dealers process a species, the data are considered confidential and cannot be released to the public. Confidential data must be combined with similar landings so it cannot be individually identified after release to the public.

Landings data were recorded as early as 1880, but only the data in electronic databases are readily accessible. Most landings data prior to 1962 exist only in out-of-print publications, although NMFS has electronically compiled 1880–1989 annual landing statistics (NMFS, 1990) for a few selected mollusk species groups from Atlantic and Gulf Coast waters. To increase the accessibility to historical landings data for other species, NMFS has contracted to digitize 1930–61 published landings data into a computerized landings database.

The harvest of mollusks by recreational fishermen is believed to be substantial, but complete national data on recreational mollusk fishing are lacking. A few states report recreational licensing or catch and effort for a few mollusks, but most recreational mollusk fishing is undocumented. The State of Washington has a separate mollusk sport license to harvest razor clams, *Siliqua patula,* and reports the number of licenses and license revenues (WDF, 1990). Alaska annually estimates the sport harvest of razor clams, *S. patula* and *S. alta,* from a mail survey of state recreational fishing (Mills, 1992). NMFS conducts annual Marine Recreational Fishery Statistical Surveys (MRFSS), but the surveys usually gather only recreational finfish catch and effort data. However, catch and effort data for abalone sport divers are gathered during supplemental MRFSS California surveys that are state funded.

Processed Products

History

Processing of mollusks (canned oysters and clams) was first reported in "Fisheries of the United States, 1908" by the Bureau of the Census (1911). Limited surveys of canning production were conducted from 1909 to 1929 for only a few areas. Comprehensive annual surveys of U.S. processed products that included shucked as well as canned products began in 1930 and continue to date.

Methods

NMFS is the primary agency conducting an annual survey of the volume of U.S. processed products. In a few states, cooperative state-Federal agreements have been reached for the exchange of information. Approximately 4,500 firms are surveyed, of which about 450 handle mollusk products. Volume, plant value, and employment are the typical types of information collected at the plants. Volume data for raw products are collected in gallon equivalents for shucked oysters, clams, and scallops. Data for other mollusks such as squid, abalone, and octopus are collected in pounds. Data for such processed products as canned clams and oysters are collected by case pack, while items such as breaded oysters are reported in pounds. For data consistency, NMFS began reporting the various volume measurements as pound equivalents in 1987.

Issues

The annual processing survey is conducted on a voluntary basis. Although most of the industry is cooperative in completing the survey, the loss of a single dealer may in certain cases bias the reporting of totals due to confidentiality regulations. To minimize potential errors, quality control edits are conducted as part of the normal data entry programs. The majority of errors are the misreporting of pounds instead of gallons, or the use of an ex-vessel value rather than the processed value. Companies are recontacted for clarification of data that is suspect.

Market Prices

History

Market price data at five major wholesale fishery markets around the nation have been reported since 1937. NMFS Market News offices collect wholesale market data from participating wholesale dealers at Boston, New York, New Orleans, Seattle, and Long Beach markets. High, low, and mean price data are reported three times each week for each species and market.

Methods

At the Fulton Fish Market, NMFS personnel interview about 60 dealers each day to obtain data on wholesale prices of mollusks and finfish; 25–30 dealers are phoned each week to gather market price data on frozen seafood. Wholesalers voluntarily report the price/pound, market category, and product state (shucked or whole) of mollusks such as scallops, clams, conchs, oysters, mussels, periwinkles, and cockles (*Clinocardium nuttallii* from Pacific coast). Market data are reported to NMFS orally, by computer printouts, and by transaction logbooks provided by dealers. Wholesalers often report the poundage (receipts) of mollusks and finfishes that are brought to the market for sale.

Issues

Published market price and receipt data represent a summary of voluntarily reported data by wholesale dealers. However, all dealers may not be available or willing to provide data each day. The large number of dealers interviewed and numerous prices obtained each day ensures that all marketed species are reported and that representative estimates of their minimum, mean, and maximum wholesale prices are calculated.

Cold Storage Holdings

History

The supply (weight) of fresh and frozen fish and shellfish held in cold storage at public and private warehouses across the United States are reported by product, species, month, and region. In addition to the weight of holdings, percentage changes in holdings for the most recent month and year are also published.

The U.S. Department of Agriculture began collecting data on the freezing and storing of fishery products in 1916 (BCF, 1964). The Interior Department's Bureau of Commercial Fisheries took over data collection in 1945, but it had been publishing the data since 1941 (USFWS, 1941). Fresh and frozen holdings data have been published monthly from 1941 to date.

Methods

Cold storage facilities that warehouse fishery products for a minimum of 30 days voluntarily submit monthly reports of their holdings for the last day of each month. Public, private, and semiprivate refrigerated facilities and specialized storage facilities such as fish houses and manufacturing and processing plants are included in the survey. Excluded from the holdings are stocks in facilities whose entire inventory are turned over more than once per month. Mollusk holdings (pounds of meats) are reported for clams, oysters, scallops, squids, and unclassified shellfishes. Cold storage holdings are inclusive of imported fishery products as well as domestic production.

Issues

Estimates of the total U.S. supply of fresh and frozen seafood are based on monthly reports that are voluntarily submitted by suppliers. Biased data can occur if a storage facility chooses not to participate in the survey, provides incomplete or inaccurate data, or if a facility is not included in the survey because NMFS is unaware of its existence. Although mollusk holdings are identified by generic categories, they are not reported by species.

Foreign Trade

History

Data on U.S. foreign trade have evolved gradually from imprecise estimates of the early 19th century to the current broad range of highly detailed statistics. The trade system is dynamic, with commodities being added or removed over time as required by either legislation or industry needs. Information on imports and exports of fresh, frozen, and prepared mollusks, specifically oysters and clams, have been recorded since at least 1890. In recent years, 41 import and 29 export commodity codes are reported for shellfishes such as abalone, conch, mussels, scallops, octopus, squid, and snails. The United States has a long history of importing mollusk commodities, but it has begun exporting mollusks only recently. The 1996 U.S. imports (product weight) of oysters, clams, and scallops were about 8 times larger than exports (Table 3).

Methods

Importers and exporters are required to file documentation by paper or electronically for each transaction with the Treasury Department's Customs Service. The Customs Service in turn transmits the data to the Commerce Department's Bureau of the Census for monthly compilation and release to the public. Types of information in the documentation include date of transaction, commodity, various types of value and volume, country of origin or destination, and the customs district of lading or unlading.

Table 3
U.S. imports and exports[1] of oysters, clams, and scallops in metric tons (t) of meats.

	Imports (t)			Exports (t)		
Year	Oysters	Clams	Scallops	Oysters	Clams	Scallops
1985	20,832	5,887	19,067	N/A[2]	440	506
1986	22,697	7,657	21,735	N/A	564	547
1987	23,626	8,002	18,114	N/A	525	609
1988	21,053	6,746	14,533	N/A	661	621
1989	17,083	6,012	18,540	494	845	1,133
1990	12,495	7,180	18,071	455	1,343	3,220
1991	13,856	5,575	13,394	335	1,337	3,213
1992	12,033	6,469	17,546	362	754	1,628
1993	12,811	4,345	23,575	513	821	1,881
1994	11,201	7,034	25,708	902	1,187	2,717
1995	10,977	5,736	21,923	865	1,294	2,688
1996	9,847	6,505	26,620	748	1,564	2,808

[1] Data source: NMFS Fisheries Statistics and Economics Division, 1315 East-West Highway, Silver Spring, MD 20910.
[2] Data not available or incomplete.

Issues

With millions of import and export transactions taking place, errors do occur. Many errors are corrected before data are released publicly by using computerized edit checks and having discussions with knowledgeable persons about specific products in question. Sources of errors may include misidentification of a commodity, incorrect volume or value information, miscoding of countries, or errors in processing the documentation. The Census Department historically notes a 5% error rate at a monthly level and recommends that users of trade data use quarterly time frames or longer to smooth out discrepancies in the data.

Summary

Mollusk fishery and industry data are collected for commercial landings, cold storage holdings, market prices, processed products, and trade. The data are collected by census rather than estimated from random samples.

Landings data collection began in 1880 and is often a joint state and Federal responsibility. Commercial landings data are collected by a variety of mandatory and voluntary reporting systems including trip tickets, dealer weigh-out slips, logbooks, interviews, and sampling. NMFS conducts supplemental surveys to compensate for the great diversity in data collection methods by more than 20 coastal states that collect landings data. NMFS also gathers fishing effort data. Seven factors that affect the collection and interpretation of landings data are different reporting periods, underreporting, lack of species identification, combining landings and aquaculture data, lack of uniform reporting units, confidentiality, and data accessibility.

Cold storage holdings, market price, and processed product data are depend entirely on voluntary data submissions by industry. Although NMFS takes great care to ensure that data are accurate and complete, voluntary reporting is subject to bias as all possible contributors may not be identified or report. The Bureau of the Census compiles monthly trade data on 41 import and 29 export mollusk commodities and many other items.

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Shellfish Marketing in the United States: Past, Present, and Future

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ABSTRACT

The shellfish industry tends to be product driven. The business starts with what can be harvested, then looks for outlets willing to buy the product. Most shellfish are sold as commodities, with little attempt to persuade the customer to buy mollusks specifically, rather than one of the many competing foods. Most mollusks simply are shipped to retail markets which display them in refrigerated showcases with price tags, with little promotional activity. Clams are the most important bivalve marketed in the United States in terms of meat weight. The supply of clam meats amounted to 155 million pounds, compared with 69 million pounds of scallop meats and 50 million pounds of oyster meats in 1992. Most clam production consists of surf clams, *Spisula solidissima*, and mahogany clams, *Arctica islandica*, landed on the east coast and processed into products such as minced clams, stuffed clams, clam strips, and chowder. Apart from chowders and breaded clam strips, which are popular throughout the country, few clam products are eaten inland. Northern quahogs, *Mercenaria mercenaria*, are mainly sold alive. Small sizes, up to about $1^1/_2$ inches hinge width, may be eaten raw on the half-shell. Softshell clams, *Mya arenaria*, are never eaten alive, but are eaten steamed or are shucked and sold in gallon cans to restaurants, which bread and fry them. Americans eat only the adductor muscle of scallops, discarding the roe (savored by Europeans) and the viscera. Consumers divide scallops into three categories: sea, bay, and calico. Eastern oysters, *Crassostrea virginica*, are often graded by size: standards, selects, and large or extra selects. Pacific oysters, *C. gigas*, are also graded. Unlike in Europe, eating oysters raw in the shell is not common in the United States. Much of the production is shucked. Fresh oyster meats in containers ranging from eight ounces to one gallon are the staple product. Breaded oyster meats are also an important item. Canned oysters are packed in retail sizes for sale to consumers and in larger cans for further processing into products such as stews, chowders, and hashes. The blue mussel, *Mytilus edulis*, supplies almost all the market for mussels, but Americans have never taken to mussels, and the market is limited. Some other species, such as abalones and whelks, are also available to American consumers in small quantities. Clams, oysters, and mussels all share the risk that food poisoning could seriously affect their markets. Overcoming that problem is the most difficult task facing the industry.

Introduction

The marketing concept (Chaston, 1983) starts with consumer needs and preferences and works to supply an appropriate product. Shellfish, like most of the seafood industry, tends to be product driven: the business starts with what can be harvested, then looks for outlets willing to buy the product. This is common to many industries. In 1984, 70% of respondents to a marketing survey named marketing and sales capacity as the areas that most needed improvement in their businesses (Anonymous, 1984). A useful definition is provided by Bangs (1987): "Marketing is the complex process of creating customers for your products/services."

In the opinion of the author, mollusk marketing is not yet a well developed skill, even in the United States.[1] It remains unfortunately true that most shellfish are

[1] Views or opinions expressed or implied are those of the author and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA, nor does mention of trade names or commercial firms imply NOAA or NMFS endorsement.

sold as commodities, with little attempt made to differentiate sources or qualities and almost no attempt made to persuade the consumer to buy mollusks rather than one of the many competing foods which clamor for attention and scarce money. Most mollusks are simply shipped to retail markets which display them in refrigerated showcases with a price tag. Promotional activity is generally lacking. The lack of marketing of mollusks has been remarked for decades in the developed world. Cole (1949) commented "It is impossible to give a comprehensive survey of the difficulty facing British oyster planters without making some reference to the problems of marketing." Later, another British-based observer (Nowak, 1970) pointed out that the U.S. shellfish industry "is one of the most highly organized in the world" but his admiration was directed mainly at sellers of shrimp, crab, and lobster rather than those selling mollusks.

Clams

Clams are the most important bivalve in the United States in terms of meat weight: according to the National Marine Fisheries Service (NMFS, 1993), the supply of clam meats amounted to 155 million pounds in 1992, compared with 69 million pounds of scallop meats and 50 million pounds of oyster meats. U.S. harvests of clams in 1990 amounted to 27.8% of world production (live weight): 413,300 metric tons (t) in 1990 of reported world production of 1,488,200 t, according to FAO figures (FAO, 1990). A breakdown of U.S. production by type is given in Table 1. FAO figures permit international comparisons.

The greatest part of U.S. clam production consists of surfclams, *Spisula solidissima,* and ocean quahogs, *Arctica islandica,* which are processed into products such as minced clams, stuffed clams, clam strips, and chowders.

Table 1
Clam landings (1,000 t), 1986–90.[1]

Species	1986	1987	1988	1989	1990
Ocean quahog	169.7	187.6	171.7	191.7	177.3
Surfclam	195.2	149.2	156.2	163.7	173.5
Hard clam (*Mercenaria*)	32.7	34.6	31.7	22.0	23.9
Soft clam	11.8	16.1	14.9	14.5	12.4
Other clams	16.5	15.1	17.3	24.6	26.2
U.S. total	379.9	409.6	399.3	426.3	413.3
World total	1,420.7	1485.3	1464.4	1479.9	1488.2
U.S. as percent of world	26.7	27.6	27.3	28.3	27.8

[1] Source: FAO, 1990.

Production of hard clams or quahogs, *Mercenaria mercenaria,* is falling, despite increasing aquaculture efforts. Harvests of soft clams, *Mya arenaria,* which are harder to farm, are also declining. Geoducks, *Panopea abrupta;* razor clams, *Ensis* spp. and *Siliqua* spp.; and other gourmet mollusks are extremely small business.

It should be noted that the U.S. clam industry is essentially restricted to the east coast, where almost all clams are harvested. Apart from chowders and breaded clam strips, which are popular throughout the country, few clam products are eaten inland. On the west coast, locally farmed Manila clams, *Tapes philippinarum,* and similar species supply small regional markets.

Clams and Their Uses

Quahogs or hard clams are mainly sold live. Small sizes, up to about 1 1/2 inches hinge width, may be eaten raw, on the half shell. Larger specimens are cooked. Littleneck clams, the smallest size of the quahog, is the most valuable. Alternatives such as Manila clams and even bleached mahogany clams may be offered as substitutes.

Softshell clams are never eaten raw, but some are sold live for steaming. Most are shucked at shoreside plants and distributed in gallon cans to restaurants which bread and fry them. Breaded, frozen softshell clams are also readily available from processors, usually packed in individual portions of 4–6 ounces. Known as Ipswich clams, belly clams, and fryers, this product is important in the northeast and middle Atlantic areas, but hardly known in the rest of the country, where "fried clams" generally means breaded strips of surfclam mantle.

Surfclams (one word rather than two is preferred by the American Fisheries Society [Turgeon et al., 1988]) are processed into chopped meats, clam juice, chowders, clam strips, and steaks. Ocean quahogs or mahogany clams are used for mincing. The mantles are generally considered too tough for use as strips or steaks. The bellies are removed because they darken minced meat products.

Many other clams are available in small quantities. The southern quahog, *Mercenaria campechiensis,* is similar to the hard clam, although its shelf life is reported to be rather shorter. It has a somewhat thicker shell, but is otherwise indistinguishable in the trade. Stimpson's surfclam, *Mactromeris polynyma,* often called red clam because the tongue turns red when cooked, is available in small quantities from Canadian suppliers who sell most of their production to Japan. Geoducks, the giant softshell clam of the Pacific Northwest, are also exported to Japan. They are prized locally in Washington and British Columbia, but are little seen or known elsewhere. Also on the west coast, Manila clams and Pacific littlenecks are used for steaming. The meats are tougher than the quahog; these species are not suitable for eating raw, although they may occasionally be substituted illegally for quahogs.

By now, it will be apparent that clam nomenclature is not clearly defined. The Food and Drug Administration (FDA, 1988) has codified the names of commercially distributed finfish in "The Fish List." The agency is still working on a similar codification of shellfish names. Table 2 summarizes the names found in commercial literature. Names preferred by the American Fisheries Society (Turgeon et al., 1988) are given for reference. Most of these are appropriate for commercial use. However, it is unlikely that marketers of Manila clams would care to offer their product as "Japanese littlenecks." *Arctica islandica* might be better called "mahogany clam" than the recommended "ocean quahog" to reduce any confusion with the much more valuable quahog. Common names are those that appear to be most often used in commerce. The column "Other vernacular names" includes names that are regionally or occasionally used. Note that those listed for *Mercenaria* spp. refer to sizes: littlenecks are the smallest, served mainly raw on the half shell; cherrystones and topnecks are larger, used for clams casino and similar cooked recipes; chowder clams and pumpkins are the largest. These are shucked and the meats used in chowders, stuffed clams, and other recipes.

The column "Common names" and "Other vernacular names" in Tables 2, 4, and 6 are the result of extensive surveys of books, periodicals, and other contemporary literature. "Common names" are those most frequently found. The distinction is not intended to express an opinion about the correctness or otherwise of particular nomenclature.

Raw Clams—Small quahogs are sold live for eating raw. Concerns over health and safety are paramount for marketers in this sector. This matter is the subject of other papers so will not be mentioned here, except to underline its great importance. Live clams are usually sold by the bushel. Weights and counts of bushels vary, because the thickness and density of the shell varies. Softshell clams are extremely delicate and must be handled with great care. One of the more depressing sights is a retail display of dead or dying softshell clams with the siphons hanging limply on a bed of discolored ice. This is the antithesis of marketing.

Shucked clam meats are sold by the gallon for foodservice and retail display and in smaller containers for resale to consumers. Shucked meats of softshell clams and quahogs are widely available in the east. Western clams are almost all sold in the shell. Shucked meat demand is met by other, more processed products.

Table 2
Scientific and commercial common names of clams in the United States (see text for source data).

Scientific name	AFS name	Common name	Other vernacular names
Mercenaria mercenaria	Northern quahog	Quahog, hard clam	Littleneck, cherrystone, topneck, chowder clam, pumpkin (see text)
Mercenaria campechiensis	Southern quahog	Quahog, hard clam	Littleneck, cherrystone, topneck, chowder clam, pumpkin (see text)
Spisula solidissima	Atlantic surfclam	Surf clam, surfclam	
Rangia cuneata	Atlantic rangia	Rangia clam	
Arctica islandica	Ocean quahog	Mahogany clam, ocean clam, ocean quahog	Black clam
Mactromeris polynyma	Arctic surfclam	Red clam, Stimpson's surfclam	
Mya arenaria	Softshell	Softshell clam, Ipswich clam	Belly clam, fryer, steamer, gaper, squirt
Panopea abrupta	Pacific geoduck	Geoduck	Giant clam
Tresus nuttallii	Pacific gaper	Horse clam, gaper	
Tresus capax	Fat gaper	Horse clam, gaper	
Tapes philippinarum	Japanese littleneck	Manila clam, Pacific littleneck	Steamer, littleneck
Protothaca staminea	Pacific littleneck	Pacific littleneck, steamer	
Saxidomus giganteus	Butter clam	Butter clam	
Saxidomus nuttallii	Washington clam	Butter clam	
Tivela stultorum	Pismo clam	Pismo clam	
Clinocardium nuttallii	Nuttall's cockle	Basket cockle, cockle	
Ensis directus	Atlantic jackknife	Razor clam	
Siliqua costata	Atlantic razor	Razor clam	
Siliqua patula	Pacific razor	Razor clam, Pacific razor clam	

Chopped or Minced Clams—Chopped clams are an important foodservice item in their own right as well as the basic raw material for many processed clam products. Surfclams and mahogany clams are used. Mahogany clam mantles are minced as an alternative to surfclams, but generally only when the supply of surfclams is inadequate. Mahoganies tend to be tougher and the meat is somewhat darker. Chopped clams are sold with varying percentages of clam juice, which should be the liquid enclosed in the shell with the clam. For most purposes, a pack ratio of 75:25 for meat:juice is appropriate. Specifications vary as does the ability of processors to meet them accurately.

Chopped clams are sold in containers ranging from 8 fluid ounces to 1 gallon. For further processing, 15-pound frozen packs are offered. Chopped clams are often frozen, since the shelf life of the fresh product is limited and freezing does not appear to affect the taste or texture of the product.

Clam Juice—Pasteurized clam juice is bottled for retail sale. Frozen clam juice is available in gallon containers for foodservice and manufacturing.

Clam Strips—In most parts of the United States, "fried clams" are breaded strips of surfclam foot. The strips are available in various widths, packed in gallon, half-gallon, and 5-pound containers. Breaded strips are packed for retail sale, in portions of 4 or 6 ounces and in bulk. There is a range of choice of percentages and types of breading. Clam steaks and medallions are breaded products derived from adductor muscle, foot or "tongue" of the surfclam. These products have interesting applications but have not yet made a significant impact on the market.

Chowder—Clam chowder is one of the few mollusk products with a broad appeal to consumers nationwide. White (New England, cream base) and red (Manhattan, tomato base) chowders are available fresh, frozen, and canned, and in ready-to-serve forms or as concentrates. There are almost as many recipes as producers.

Prepared Half-shell Products—Stuffed clams are a popular U.S. northeast item. They are made by mixing a bread-based stuffing with chopped clams and clam juice, then baking the mixture on a real or imitation clam shell. Easily heated in the microwave, they are popular in bars and for snacks. More sophisticated half-shell products include clams oreganata and clams casino. These and similar recipes are available frozen, ready to heat and serve.

Oysters

In volume terms, the oyster business is in long-term decline. This is no doubt partly due to lower production because of overharvesting, diseases, and polluted water. According to FAO (1990) data (Table 3), U.S. production of oysters (live weight) declined from 213,900 metric tons (t) in 1986 to only 148,700 t in 1990. The decline started much earlier, of course, and continues. The United States, once the largest producer of oysters in the world, now contributes less than 15% of the planet's production.

Production of Pacific oysters, *Crassostrea gigas,* on the U.S. west coast has been steady (and in some areas increasing), while the traditionally much larger harvests of eastern oysters, *C. virginica,* in both the Atlantic states and the Gulf of Mexico has dropped precipitously (NMFS, 1993). By 1990, the Pacific region had overtaken the Gulf of Mexico as the largest producer of oysters.

In recent years, imports of oysters (in terms of meats) have become more important, accounting for about one-third of available supplies between 1979 and 1982, rising to as much as 59% in 1988 (NMFS, 1993). Imports continue to supply about half of the market. Domestic production supplies live and fresh shucked product. Imports are chiefly frozen meats (used by processors for a wide range of products) or canned meats for retail sale.

Oyster Products

Raw Oysters—Unlike in Europe, oysters in the shell are a comparatively unusual item in the United States: much of the production is sold shucked. Nevertheless, the raw oyster on the half shell is the definitive oyster dish: it is the way people expect to see oysters served, even if they themselves, like most other Americans, prefer to eat them fried or in oyster stews.

Live oysters are traditionally sold in bushel bags or other volumetric measures and are graded by size. Some states, such as Florida, Louisiana, and Texas have laws

Table 3
Oyster landings (1,000 t), 1986–90.[1]

Species	1986	1987	1988	1989	1990
Pacific, *C. gigas*	20.4	36.2	29.2	28.6	39.5
Eastern,					
C. virginica	213.9	181.0	137.9	128.6	97.9
Other		0.4	0.6	1.3	11.3
U.S. total	234.3	217.6	167.7	158.5	148.7
World total	1,082.6	1,112.1	1,094.5	1,042.5	1,028.7
U.S. as percent					
of world	21.6	19.6	15.3	15.2	14.5

[1] Source: FAO, 1990.

defining the volumes. Eastern oysters are often graded (smallest to largest) as standards, selects, and large or extra selects. There are no standard definitions for these size gradings. Pacific oysters are also graded. Terms such as yearling, petite, and bakers are used. Again, there are no standard definitions. Size consistency is also not defined.

Some producers, especially on the west coast, pack oysters in trays in boxes to extend storage life. These same packers also attempt to keep size grades consistent. Oysters that have been raised on ropes or in trays are more likely to be separate than oysters which are dredged in clusters from enhanced growing beds. These farmed oysters can be graded more easily. They are also easier than clumps to pack in boxes, which are more protective and more attractive than the traditional onion bags.

Frozen Oysters: Whole and Half Shell—Oysters can easily be frozen, either whole or opened on the half shell. Unfortunately, there is a strong prejudice against freezing them. Consequently, oyster producers are denied the many advantages that freezing offers the industry, including easier handling and much longer storage life.

Frozen half-shell oyster products are acceptable: oysters Rockefeller, oysters in mornay sauce, and many other recipes are distributed in this form. Experiments with skin packs have had poor results because points and edges on the oyster shells puncture the wrap. However, similar products can be packaged in this way using artificial oyster shells which are smoother than real ones.

Oyster Meats—Fresh oyster meats in containers ranging from 8 fluid ounces to 1 gallon are the staple product of the domestic industry. The Code of Federal Regulations (CFR 21) defines five size grades and size uniformity for eastern and four size grades for western oyster meats (CFR, 1992). However, it appears that few packers pay attention to these rules, preferring their own grades and definitions. Water content of shucked oysters is a contentious issue between packers and buyers. AOAC method 18.013–015 provides a standard test (AOAC, 1990).

Individually quick frozen (IQF) and bulk or block frozen oyster meats are imported from the Republic of Korea and Japan in large quantities. IQF product is frozen in molds, giving an even shape ideal for breading. Block frozen oyster meats are used for soups, chowders, stews, and other products.

Coated Oysters—Breaded oysters are an important foodservice item. Battered oysters are less frequently found. Coated products are sold in the frozen food sections of supermarkets as well as from seafood counters, where bulk packs are displayed and individual orders weighed out for customers.

Canned Oysters—Canned oysters are packed in retail sizes for sale to consumers and in larger cans for further processing into products such as stews, chowders, and hashes. Federal regulations (CFR 21) require that the drained weight of canned oysters be at least 59% of the volume of the can (CFR, 1992). Domestic production has largely disappeared: this market is now met by imports from Korea.

Types of Oysters and Their Uses

The eastern oyster is still the most important domestic species, although it is being rapidly overtaken by the Pacific oyster as production declines on the Atlantic and Gulf coasts. In the 1950's and 1960's, Chesapeake Bay produced 2.5–3.5 million bushels a year. By 1987–88, production was only 335,000 bushels (Shaw, 1989). Most of the production is shucked and sold as fresh meats.

The Pacific oyster, introduced from Japan in the 1920's and flourishing in Washington, British Columbia, and other Pacific coast areas, is also often shucked, although a higher proportion of the output appears to be sold live in the shell. Growers have worked to differentiate their strains. They have also introduced triploid oysters and strains such as the Kumamoto[2] which has a particularly deep cup and is attractive for the raw half-shell trade.

Most imported frozen and canned oysters are Pacific oysters or the closely related *C. rivularis.* Worldwide, the Pacific oyster is the most important and abundant oyster species, accounting for perhaps 75% of world production (FAO, 1990).

European flat oysters, *Ostrea edulis,* sometimes called "Belon" by marketers (although strictly speaking this word denotes oysters from a particular area of Brittany in France) are grown in Maine and California. They are reserved for high-priced restaurants where they are sold raw on the half shell.

The Olympia, native, or western oyster, formerly *Ostrea lurida,* and now *Ostreola conchaphila,* is no longer abundant in its native Pacific coast waters, and the remaining small production is also sold live for the specialist half-shell trade. Chilean oysters, *Ostrea chilensis,* and the similar New Zealand oyster (which is either the same species or *Ostrea lutaria*–experts differ) are imported for the same use. Since they are at their winter peak during the American summer, they are useful for restaurants that want to offer live raw oysters throughout

[2] Named after the Japanese bay where the strain originated.

the year. The names used for the different species of oysters are shown in Table 4, with sources mentioned in the text concerning Table 2.

Scallops

For the most part, Americans eat only the adductor muscle of scallops, discarding the roe (savored by Europeans) along with the viscera, which are eaten in some Asian countries. Scallop production and sales fluctuate wildly from year to year, but the underlying trend is strongly upward. More Americans are eating more scallops whenever they are available (Table 5).

Types of Scallops and Their Uses

The U.S. scallop market was developed on the basis of the Atlantic sea scallop, *Placopecten magellanicus,* which still dominates the market. Consumers, as well as institutional buyers, tend to divide scallops into three categories: sea, bay, and calico scallops. Less informed buyers equate these categories with size: seas are larger than bays, which are larger than calicos.

Sea scallops are caught by American fishermen and large quantities, both fresh and frozen, are imported from Canada. Supplementary supplies of the Japanese scallop, *Patinopecten yessoensis,* are imported from Japan. Occasionally, large scallops are imported from Australia and other countries. Scallops are being brought in under the controls of the National Shellfish Sanitation Program (NSSP), which may make it more complicated to import scallops from new sources in the future. Sea scallop meats generally run between 10 and 40 per pound. Sea scallops are sold fresh in 30-pound bags or frozen in 5-pound blocks and in IQF packs.

The Atlantic bay scallop, *Argopecten irradians,* is much smaller, around 70–110 per pound. Most of the limited domestic production is sold fresh. Supplementary supplies are imported from northern Europe: the queen scallop, *Chlamys opercularis,* is similar and is often marketed here as a bay. In recent years, large quantities of frozen bay scallops have been imported from China, where the species is now being farmed; the industry is based on seed from the United States. At least one local Chinese species, *C. farreri,* may be mixed with the bay scallops. Although the Chinese product is often the true bay scallop species, the quality is frequently reported to be poor, owing to inadequate handling and processing facilities.

The Atlantic calico scallop, *Argopecten gibbus,* is a boom-and-bust fishery with periods of glut alternating with periods of scarcity. Calicos are small, down to about 150 count and distinguishable from bay scallops by their shape, which is longer and thinner. Calicos are generally much less expensive than bays, an indication of the market's opinion of the relative taste and texture differences. Nevertheless, calico scallops are sometimes mislabeled as bay scallops, both in retail markets and in restaurants. Pacific calico scallops, *Argopecten ventricosus,* mostly imported from Mexico, are often labeled and sold as bay scallops in West Coast markets.

Few scallops are landed on the west coast, and attempts to farm the Japanese scallop in British Columbia are still tentative. Weathervane scallops, *Patinopecten caurinus,* are available, especially in Alaska but are little fished, partly because of the risk of scallop dredges breaking up nursery grounds for the valuable king crab. When available, they are similar to sea scallops. Pink and spiny scallops, *Chlamys rubida* and *C. hastata,* are harvested the length of the Pacific coast. Although different, they are frequently sold together, usually live (or fairly recently dead) in the shell. For reasons unknown, they are sometimes called singing scallops. Common names of scallops are shown in Table 6, with sources mentioned in the text concerning Table 2.

There has been a small trend towards eating pink and spiny scallops steamed whole. This may carry some risk, because scallops are not at present monitored for toxins such as paralytic shellfish poisoning (PSP). Some marketers of bay scallops are also suggesting that their

Table 4
Scientific and commercial common names of oysters in the United States (see text regarding Table 2 for source data).

Scientific name	AFS name	Common name	Other vernacular names
Crassostrea virginica	Eastern oyster	Eastern oyster, American oyster, oyster	Cove oyster, numerous geographical names
C. gigas	Pacific oyster	Pacific oyster, oyster	Japanese oyster
Ostrea lurida/ Ostreola conchaphila	Olympia oyster	Olympia oyster, native oyster	Western oyster
Ostrea edulis	Edible oyster	Flat oyster, European oyster	Belon
C. rivularis	none	Suminoe oyster	
Ostrea chilensis	none	Chilean oyster, chiloe	

product be prepared whole, which I view as a problem. Scallops are now being brought under NSSP controls so that consumers can be assured of a safe product. (Note: although some scallops appear to store toxins in the muscle, the amounts are insignificant. The roes and viscera, however, may contain dangerous amounts of some toxins.)

Many domestic and foreign processors treat scallop meats with sodium tripolyphosphate (STP) or other phosphates. Properly used, phosphates make an important contribution to maintaining weight and improving the appearance of the meats. However, phosphates can be misused to add water and camouflage spoilage. In response to complaints, the FDA has drafted regulations to cover the use and labeling of phosphates in scallops.

Mussels and Other Mollusks

There are limited harvests of mussels in Massachusetts and Maine, with a growing farming industry in Atlantic Canada (mainly Prince Edward Island). American consumers have never taken to mussels. Although they are inexpensive, tasty, and a good alternative to clams in many preparations (such as fried or in pasta sauce), mussels are hard to sell. Producers certainly try: mussels are available in a wide variety of packs, processes, and prepared products; unfortunately, none of them yet sells in large quantities.

The blue mussel, *Mytilus edulis,* supplies almost all of the market. Abundant but small in the wild, the quality improves if it is thinned and cultivated. Farmed mussels have certain advantages: they grow fast so do not contain the occasional "pearl" which can crack a diner's tooth. A small number of farmers have succeeded in establishing niche markets for their particular mussels, but these successes have been limited.

The most noticeable success in mussel sales in recent years has been the green-lipped mussel, *Perna canaliculus,* from New Zealand. This is a large mussel, mostly farmed. It has been successfully promoted in the U.S. as a distinct product at much higher prices than other mussels.

Abalones, *Haliotis* spp.; whelks, *Busycotypus* spp. and *Busycon* spp.; periwinkles, *Littorina littorea;* and conchs, *Strombus* spp., are among the other shelled mollusks available to American consumers. Abalone is expensive and scarce. The problem here is finding enough product to meet overseas demand. U.S. buyers generally get what is not sold to Japan. Whelks (also known as scungili and sea snails) are a specialty of the northeast and are

Table 5
U.S. supply of scallop meats in millions of pounds, 1986–92.[1]

	U.S. commercial landings					
Year	Bay	Calico	Sea	Total	Imports	Total supply
1986	0.7	1.6	20.0	22.3	47.9	70.2
1987	0.6	8.2	32.0	40.8	39.9	80.7
1988	0.6	11.9	30.6	43.1	32.0	75.1
1989	0.3	6.6	33.8	40.7	40.9	81.6
1990	0.5	1.1	39.9	41.5	39.8	81.3
1991	0.4	n.a.	39.3	39.7	29.5	69.2
1992	0.4	n.a.	33.5	33.9	38.7	72.6

[1] Source: NMFS, 1992.

Table 6
Scientific and commercial common names of scallops in the United States (see text regarding Table 2 for source data).

Scientific name	AFS name	Common name	Other vernacular names
Argopecten circularis	Pacific calico scallop	Mexican scallop, Panama scallop	Mexican bay scallop (incorrect)
Argopecten gibbus	Atlantic calico scallop	Calico scallop	Brazil scallop
Argopecten irradians	Bay scallop	Bay scallop	Cape Cod scallop, Long Island scallop, Peconic bay scallop
Argopecten purpuratus (*Chlamys purpuratus*)	None	Peru scallop, calico scallop	
Chlamys farreri	None	Chinese scallop	
Chlamys hastata	Spiny scallop	Pink scallop	Singing scallop (fanciful)
Chlamys islandica	Iceland scallop	Iceland scallop, Norwegian scallop	
Chlamys opercularis	None	Queen scallop	
Chlamys rubida	Reddish scallop	Pink scallop	Singing scallop (fanciful)
Patinopecten caurinus	Weathervane scallop	Sea scallop, Alaska scallop	Giant Pacific scallop
Patinopecten yessoensis	None	Japanese scallop	
Placopecten magellanicus	Sea scallop	Sea scallop	

exported to the Orient. Conch is little known outside the southeast and a few large cities such as New York and Chicago. Periwinkles are available in sacks in New York's Fulton Fish Market, but the total consumption is small.

Some Marketing Examples

There are many examples of mollusk creative marketing. Since the demise at the end of 1991 of the short-lived National Fish and Seafood Promotional Council, there has been no nationally organized attempt to sell shellfish. (The Council promoted all seafood and did not distinguish its efforts between finfish and shellfish.) Several states promote their own shellfish industries, and coastal states with marketing activities were polled. The following notes are highlights based on material supplied by those who responded to the inquiry. The coverage is not intended to be complete.

In Maryland, the St. Mary's County Oyster Festival and the associated National Oyster Cook-Off are held each October, attracting thousands of consumers and potential consumers to oyster shucking contests and the cooking competition. Oyster recipes selected from the entries are published.

Rhode Island holds an international quahog festival, although the international aspects of a shellfish found commercially only in the western Atlantic would seem to be limited.

Virginia's Marine Products Board is one of the more visible state organizations promoting seafoods. Shellfish are important in Virginia. Virginia Seafood promotes oysters, scallops, and clams with specification and fact sheets, recipes, posters, and trade show representation (nationally and internationally) of producers. The organization's material on oysters answers common questions about oyster diseases and pollution.

Alaska, early in this century, supplied large quantities of razor clam meats, but is not currently an important producer of any mollusks, partly because of red tide toxins. Oyster farming has recently started in the state. The Alaska Shellfish Growers Association provides promotional material and offers trade show representation to its members. It is also working on a quality assurance program.

West coast shellfish growers represented by the Pacific Coast Oyster Growers Association (PCOGA) have benefitted from regional initiatives of the group, including participation in a number of the promotions described below. The PCOGA encourages members to use standardized shellfish tags as a way of identifying the origin of their shellfish.

Long Island, N.Y., growers adopted a similar tag approach with their "green seal" scheme which works to assure consumers that the clams and other shellfish packed under the logo are properly and legally harvested. This is in response to problems caused in the marketplace by illnesses traced to bootlegged mollusks. The Chamber of Commerce of the town of Oyster Bay on Long Island sponsors an annual Oyster Festival which attracts thousands of consumers. This type of event, mostly based on oysters, is held in many coastal locations. Other state bodies such as those in Louisiana, New Jersey, and California, promote shellfish as part of their overall work on seafoods.

Independent promotions designed to benefit specific commercial groups are often imaginative and well funded. Shaw's Crab House in Chicago, a large restaurant, held "Royster with the Oyster" in October 1991. The restaurant featured and promoted oysters in many ways, including cutting the price. Lectures and entertainments were accompanied by a "celebrity oyster slurp" competition in which well-known people swallowed as many oysters as possible with their hands tied behind their backs. The restaurant's sales of oysters during and after the promotion are reported to have increased substantially. One of the purposes of this and similar promotional events is that they draw a great deal of press coverage, promoting the sponsor as well as the product. The Charleston (S.C.) Restaurant Association sponsors "The world's longest oyster roast" each winter, attracting some 6,000 people to an event which both promotes the shellfish and raises money for charity.

A similar promotion in Seattle featured wines but at the same time gave great exposure to oysters. The Pacific Northwest Oyster Wine Competition was designed to identify wines that go well with oysters. Teams of experts swallowed oysters and sampled wines to determine the wines which best complemented the oysters.

Perhaps the most spectacular promotion was the Oyster Olympics, also held in Seattle. Teams representing seafood restaurants competed in three events. Oyster identification required contestants to determine the species, market name, common name, variety, and growing method of 12 different oysters by sight and taste. The shucking competition required them to open one dozen oysters of each of these species and to present them attractively on a platter. The oyster wine competition offered contestants the opportunity to identify 10 different wines in a blind tasting.

A number of associated events and entertainment accompanied the Oyster Olympics to benefit a local organization dedicated to maintaining and improving the quality of the water in Puget Sound.

It is impossible to quantify results from promotions such as the Oyster Olympics. The benefits extend from the considerable press coverage, which helps to make consumers more aware of and familiar with the shellfish, to improved team spirit and morale among the employees of competing restaurants. Not the least of the benefits is that by educating restaurant staff, such promotions help them to sell shellfish to the customers.

The Future

Demand for mollusks is generally increasing, yet promotional activity is almost entirely devoted to oysters, consumption of which is way down from historical levels. Scallops, which are of great importance to the seafood industry, are sold as a commodity. Scallops are advertised in trade magazines, but there is little attempt to reach the consumer. Perhaps the fact that the scallop market is growing without marketing efforts is sufficient for the producers.

Oysters and clams are popular shellfish. Mussels, for reasons that are not clear, have never become popular. All three, however, share the risk that an outbreak of food poisoning could seriously affect their markets. Overcoming that problem is the most important task facing the industry. It is difficult for industry groups to handle and promote particular shellfish as safe if the industry as a whole operates in ways which arouse consumer concern. Regional efforts to identify shellfish as especially safe (such as the Long Island Green Seal program) are a start, but cannot be effective without two things: 1) they must be able to distinguish themselves from competitors' products in such a way that consumers would continue to buy them, even if other clams, mussels, or oysters were compromised; and 2) the controls required by the NSSP must be fully implemented and enforced so consumers have automatic confidence in the safety of shellfish instead of an underlying suspicion.

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United States Trade in Bivalve Mollusks in 1990 and 1991

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ABSTRACT

In recent years, United States trade in bivalve mollusks has largely involved imports. In 1990, imports were more than five times larger than exports, and four times greater in 1991. In 1991, U.S. exports of bivalve mollusks products amounted to $38.6 million, an increase in value of 12% over 1990. Exports went to 44 countries in those two years, with Canada the largest single market and the EC second. Together they accounted for over 80% of U.S. export of bivalve mollusk products in 1991. The most important products were scallops, fresh and frozen, which accounted for about $20 million. U.S. exports of clams increased sharply between 1990 and 1991. In 1991, the U.S. imports of bivalve mollusks were valued at about $162 million. The imports came from 61 countries, of which Canada was the largest single supplier, and Canada, China, and Japan supplied more than 70% of the total. Scallops, fresh or frozen, dominated the list of imports. Canada is the largest single source of U.S. imports of scallops.

Introduction

The United States has become a large market for fish products, including bivalve mollusks from around the world, and it also exports many mollusks. The U.S. trade in bivalve mollusk products in recent years has been largely one way—imports (Fig. 1). Imports in 1990 were more than five times greater than exports ($174,249,337 vs. $34,422,506). The situation improved only slightly in 1991, when imports were four times as large ($162,383,676 vs. $38,629,780). In 1991, the percentage growth in exports (12.2%) was larger than the decline in imports (6.8%).

Historical Perspective

The first U.S. international trade in bivalve mollusks involved sales of eastern oysters, *Crassostrea virginica*, to Europe and eastern Canada, beginning in about 1870. Most went to England, although small amounts went to France and Germany, and about one-quarter went to Canada, where the largest market was Montreal. The quantity of oysters shipped to Europe from New York City between October 1880 and May 1881 was 70,768 barrels (about 175,000 bushels) (Ingersoll, 1881). The export of oysters to Europe ended in the 1930's but continued to Canada into the 1990's.

In about 1890, softshells, *Mya arenaria*, harvested in New Brunswick and Nova Scotia, Canada, began to be shipped to New England whole, and as shucked and canned meats. Canning became less important in the 1920's and 1930's, as the demand for fresh meats and whole softshells rose (Newcombe, 1933). The imports of softshells to New England have continued in the 1990's.

In the early 1900's, the west coast states of Washington and Oregon began importing seed of the Pacific oyster, *C. gigas*, to grow on local beds, and a large industry resulted.

In the latter half of the 1900's and increasingly so in recent decades, international trade in bivalve mollusks has expanded considerably, especially with an increasing harvest of deep-sea scallops and the development of good means to preserve shellfish, such as freezing.

Current Exports

The United States exported bivalve mollusk products to 44 countries in 1991 and 1992; 22 countries received them in both years. Canada and the European coun-

Table 1
U.S. bivalve mollusk exports by country, 1991.

Country	Quantity (kg)	Value ($)	Country	Quantity (kg)	Value ($)
Canada	4,886,250	19,198,064	Denmark	7,048	33,796
Other E.C.	1,685,348	13,071,415	Aruba	3,706	32,503
France	982,149	10,092,305	New Zealand	1,734	26,320
Japan	511,419	3,861,481	Norway	5,486	23,000
United Kingdom	435,002	1,597,118	Philippines	17,206	20,275
Taiwan	152,559	1,231,829	Bahamas	4,550	15,015
Netherlands	107,042	585,689	Singapore	1,360	11,280
Italy	64,345	403,054	Germany	1,171	8,752
Rep. of Korea	31,652	293,952	St. Kitts-Nevis	940	6,279
Bermuda	36,498	287,729	Jamaica	499	6,050
Spain	82,442	279,097	Br. Virgin Is.	362	5,674
Hong Kong	20,986	153,167	French Polynes	400	4,048
Sweden	6,312	91,902	Mexico	15,296	88,198
China	16,594	86,325	Belgium	6,148	71,604
St. Lucia	975	3,000	Indonesia	8,770	64,772
Neth. Antilles	7,051	47,511	Total	9,101,300	51,701,204

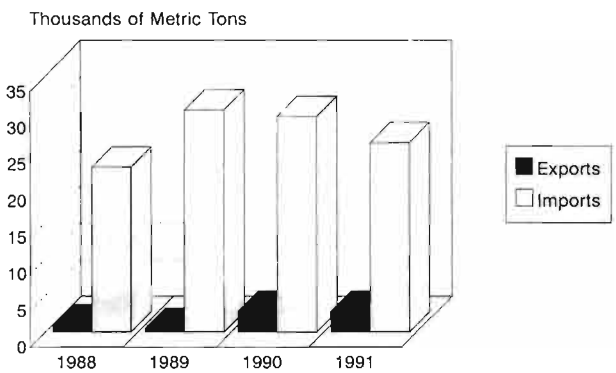

Figure 1
Comparison of U.S. bivalve mollusk trade, 1988–91.

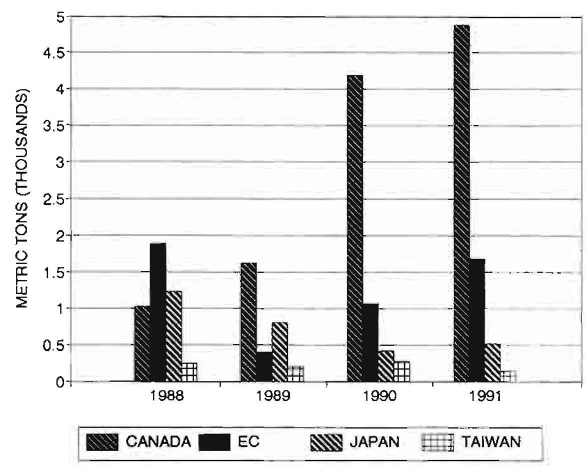

Figure 2
U.S. bivalve mollusk exports by country, 1988–91.

tries accounted for about 86% in 1991. Canada was the single largest market, and its imports increased from 1988 to 1991. The European Community (EC) was second largest; its imports fell sharply from 1988 to 1989 but then rose sharply in 1990 and 1991. Exports to Japan, which in 1988 led the market, have declined, and accounted for about 6% of the total in 1991 (Table 1; Fig. 2).

The most important product was fresh and frozen scallops, which accounted for about $20 million, or more than half the total value of all bivalves exported in 1991. The U.S. exported scallops to 24 countries (counting the EC countries as one market) in 1991. The market is highly concentrated because Canada, Japan, and the EC accounted for about 80% of the total (Table 2). The quantity exported to Canada did not change much in the two years (Fig. 3), but exports, predominately frozen scallops, to the EC increased by more than 85%. Within the EC, France is the largest market for bivalve mollusk products. In 1991, 88% of its purchases of U.S. bivalve mollusks were frozen scallops (Table 3).

The highest-valued bivalve exports to Japan were nonspecified frozen products (dried, salted, and in-brine products, as well as frozen), which accounted for over half of U.S. bivalve mollusk products exported there. Frozen clams were second at 38%, while frozen scallops were fourth but accounted for only 2% of total bivalve mollusk exports.

Table 2
U.S. scallop[1] exports, 1991.

Country	Quantity (kg)	Value ($)	Country	Quantity (kg)	Value ($)
Canada	3,294,010	9,755,234	New Zealand	1,734	26,320
Japan	438,413	3,768,952	Norway	5,486	23,000
E.C.	644,721	2,441,577	Philippines	17,206	20,275
Denmark	7,048	33,796	Bahamas	4,550	15,015
United Kingdom	358,765	799,592	St.Kitts-Nev.	940	6,279
Taiwan	90,410	687,666	Br. Virgin Is.	362	5,674
France	80,702	682,528	Singapore	680	4,005
Netherlands	92,823	416,723	Fed. Rep. of Germany	708	3,397
Italy	62,928	389,572	Hong Kong	20,539	146,667
Rep. of Korea	25,261	237,512	Mexico	11,428	65,589
Spain	41,747	115,969	Bermuda	7,670	53,039
St. Lucia	975	3,000			
Neth. Antilles	5,489	41,901	Total	5,214,595	19,743,282

[1] Tariff codes 0307210000 and 030729000.

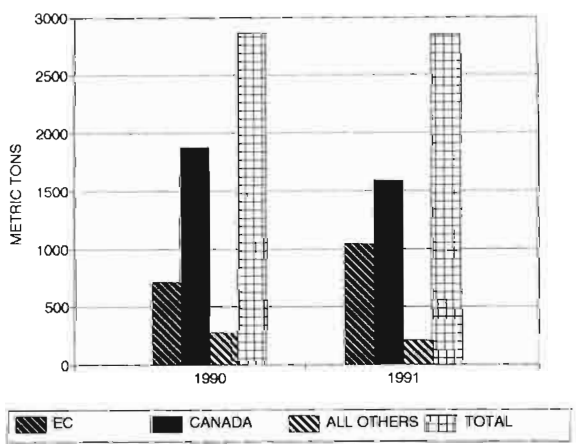

Figure 3
U.S. exports of scallops to major trading partners, 1990–91.

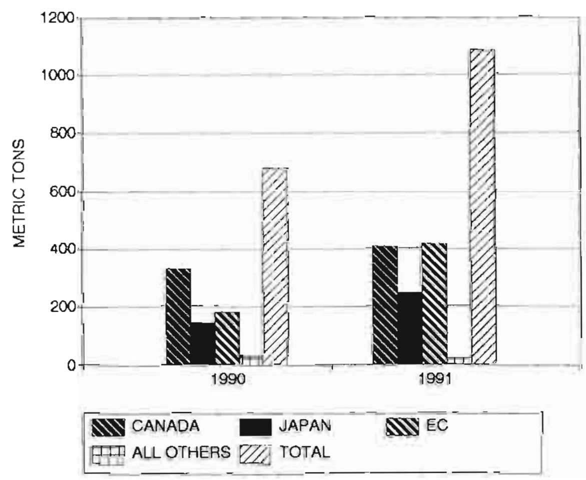

Figure 4
U.S. exports of clams to major trading partners, 1990–91.

Frozen mollusks were also the most valuable export to Taiwan. Nonspecified frozen mollusks accounted for more than 50% of exports in 1991. Scallops were second, at 36% of the total.

U.S. exports of clams increased sharply between 1990 and 1991 (Fig. 4). They were worth about $4 million in 1991, comprising 10% of total mollusk exports. Japan, Canada, and EC shared the markets, taking 38, 31, and 27%, respectively, of the 1991 total, leaving only 4% for other countries.

U.S. exports of whole oysters and fresh and frozen meats have a current value of about $2 million dollars. In 1991, Canada took about 65% of the total oyster exports, in terms of value. In the same year, oyster exports to the EC, mainly France, were about 75 t, valued at $690,000—about 29% of the total. The share of U.S. oysters in the EC market is minimal.

Current Imports

In 1991, the U.S. imported bivalve mollusks from 61 countries, with a value of $162 million, 7% below that of 1990. Most imports came from only a few countries. Canada was the largest single supplier and, along with

Table 3
U.S. bivalve mollusk exports by product, 1991.

Product	Exports (kg) Canada (kg)	E.C. (kg)	(France)[1] (kg)	Japan (kg)	Taiwan (kg)	Total[2] (kg)	Export value ($)
Scallops[3]	431,629	1,004,915	(868,041)	73,006	51,649	1,633,965	15,384,925
Scallops[4]	1,160,611	35,712	(33,406)	0	10,500	1,212,114	5,943,150
Mollusks[5]	569,161	77,132	(51,322)	166,890	80,898	921,206	5,172,905
Clams[6]	404,371	414,405	0	243,300	0	1,081,803	3,923,006
Mollusks[7]	1,349,656	107	0	16,686	9,512	1,382,846	3,910,968
Oysters[8]	311,851	74,971	(29,380)	9,541	0	420,671	2,397,750
Mussels[9]	504,817	9,682	0	0	0	515,641	1,005,727
Mussels[10]	154,154	64,444	0	1,996	0	240,497	858,681
Oysters[11]	0	3,980	0	0	0	7,210	32,668
Total	4,886,250	1,685,348	(982,149)	511,419	152,559	7,415,953	38,629,780

[1] France included in E.C.
[2] Total is for all countries.
[3] Frozen/dried/salted (tariff code [t.c.] 0307290000).
[4] Live/fresh (t.c. 0307210000).
[5] NSPF frozen/dried/salted (t.c. 0307990080).
[6] NSPF frozen/dried/salted (t.c. 0307990040).
[7] NSPF live/fresh (t.c. 0307910040).
[8] Live/fresh/frozen/dried (t.c. 0307100040).
[9] Live/fresh (t.c. 0307310000).
[10] Frozen/dried/salted/breaded (t.c. 0307390000).
[11] Seed (t.c. 0307100020).

Table 4
U.S. bivalve mollusk imports by country, 1991.

Country	Quantity (kg)	Value ($)	Country	Quantity (kg)	Value ($)
Canada	11,048,025	82,492,196	France	12,655	171,985
China	3,464,140	18,426,574	United Kingdom	19,694	159,914
Japan	1,603,421	17,148,538	Venezuela	23,642	132,750
Mexico	1,691,926	8,930,952	Singapore	15,270	132,610
New Zealand	2,863,844	7,708,651	Papua New Guinea	8,000	132,514
Rep. of Korea	1,337,143	7,237,978	Philippines	27,627	102,308
Honduras	1,070,202	4,799,171	Bahamas	23,758	102,178
Australia	451,284	3,507,454	Italy	8,808	98,794
Peru	329,583	1,926,080	Spain	17,999	71,362
Jamaica	433,722	1,642,804	Kenya	10,650	57,157
Columbia	270,545	1,544,449	Macao	42,912	53,912
Hong Kong	227,388	1,000,638	Haiti	2,360	14,386
Malaysia	328,002	857,288	Morocco	2,060	6,022
Chile	109,456	738,681	Kiribati	224	4,346
Belize	79,221	629,663	Marshall Is.	130	2,166
Namibia	6,000	47,619	Bermuda	20	1,725
E.C.	70,489	552,257	Norway	171	1,680
Denmark	3,081	9,840	Portugal	191	1,387
Uruguay	1,787	9,450	Neth. Antilles	73,623	479,668
Argentina	71,513	377,536	Faroe Islands	38,827	274,844
Taiwan	40,655	274,691	South Africa	50	2,000
Indonesia	13,865	259,405	Fiji	16,320	212,805
Thailand	78,322	194,389	Iceland	20,264	180,482
Cayman Islands	35,154	174,376	Total	25,994,023	162,887,675

Table 5
U.S. bivalve mollusk imports by product, 1991.

Product	Canada (kg)	China (kg)	Japan (kg)	Australia (kg)	Total[1] (kg)	Value[1] ($)
Scallops[2]	3,282,466	3,074,870	1,180,165	450,977	9,064,870	72,563,802
Scallops[3]	3,261,678	73,103	24,778	0	4,329,337	38,069,574
Mollusks[4]	93,245	194,091	203,778	157	3,512,936	17,484,063
Clams[5]	1,951,159	13,361	319	0	2,405,378	10,200,109
Oysters[6]	443,211	3,821	59,779	0	1,269,985	6,399,609
Mussels[7]	17,152	1,680	3,395	0	1,444,902	3,698,313
Oysters[8]	206,324	23,124	107,085	0	546,563	3,412,564
Oysters[9]	432,244	900	0	0	670,827	2,156,069
Mussels[10]	326,337	1,224	0	0	839,083	1,927,802
Clams[11]	244,539	54,560	2,507	0	444,177	1,636,395
Mussels[12]	222,139	0	0	0	605,073	1,234,564
Clams[13]	236,649	0	0	0	238,234	1,163,506
Clams[14]	126,991	21,521	1,981	80	255,114	1,055,146
Clams[15]	108,584	0	0	0	109,264	706,202
Mollusks[16]	9,448	525	15,270	70	77,809	304,500
Mussels[17]	84,941	1,360	0	0	103,214	227,881
Oysters[18]	918	0	4,364	0	15,388	143,577
Total	11,048,025	3,464,140	1,603,421	451,284	25,932,154	162,383,676

[1] All countries.
[2] Frozen, dried, salted, breaded (tariff code [t.c.] 0307290000).
[3] Live/fresh (t.c. 0307210000).
[4] Mollusks NSPF frozen/dried/salted (t.c. 0307990060).
[5] NSPF live/fresh (t.c. 0307910070).
[6] Live/fresh/frozen/dried (t.c. 0307100040).
[7] Frozen/dried/salted/breaded (t.c. 0307390000).
[8] Live/fresh/frozen/dried (t.c. 03071000080).
[9] Live/fresh/frozen/dried (t.c. 030710060).
[10] Live/fresh (t.c. 0307310000).
[11] NSPF frozen/dried/salted (t.c. 0307990055).
[12] Live/fresh/farmed (t.c. 0307310010).
[13] Geoduck live/fresh (t.c. 0307910050).
[14] NSPF frozen/dried/salted (t.c. 0307990050).
[15] geoduck frozen/dried/salted (t.c. 0307990030).
[16] NSPF live/fresh (t.c. 0307910090).
[17] Live/fresh wild (t.c. 0307310090).
[18] Seed (t.c. 0307100020).

China and Japan, supplied about 72% of the total. The value of imports from Australia was not great, but increased sharply from $150,000 in 1990 to $3.5 million in 1991 (Table 4).

Seventeen bivalve mollusk products were imported, but two scallop products accounted for about 52% of the total (Table 5). The quantity was slightly less in 1991 than in 1990.

Imports from Canada, the largest supplier of bivalves, were mostly fresh and frozen scallops, with clam products the next largest category in 1991. Scallop and clam products together accounted for nearly 95% of total bivalve imports from Canada. Scallops also dominated (>90%) the bivalve imports from China. Its number of products increased from 6 in 1990 to 13 in 1991. Imports from Japan were slightly less in 1991 than in 1990; frozen scallops accounted for most of the value in both years.

Canada is the largest supplier of scallops, with about 50% of the total value of U.S. imports from all countries; China and Japan are second and third. The three countries together supplied about 87% of all imported scallops in 1991 (Table 6). The most dramatic change is the increase in scallop imports from Australia; the imports in 1991 were valued at nearly $3.5 million, whereas none were imported in 1990.

Table 6
U.S. scallop[1] imports, 1991.

Country	Quantity (kg)	Value ($)	Country	Quantity (kg)	Value ($)
Canada	6,544,144	65,864,252	Hong Kong	18,989	169,515
China	3,147,973	17,410,464	United Kingdom	19,694	159,914
Japan	1,204,943	13,123,320	New Zealand	22,088	147,654
Mexico	1,419,935	6,795,543	Venezuela	21,758	122,623
Australia	450,977	3,493,965	Thailand	20,941	98,755
Peru	311,085	1,833,364	Argentina	7,915	57,126
Chile	64,648	465,508	Namibia	6,000	47,619
Other E.C.	32,349	331,899	Uruguay	1,787	9,450
Faroe Isl.	38,827	274,844	Philippines	667	3,308
Rep. of Korea	58,746	202,005	Norway	171	1,680
Iceland	20,264	180,482			
France	12,655	171,985	Total	13,426,556	110,965,275

[1] (Tariff Codes 0307210000 and 0307290000).

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Markets for Bivalve Mollusks in the European Community

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ABSTRACT

The market for bivalve mollusks in the European Community (EC) is strong, but EC member states have supplied most of the market with trade amongst themselves. EC imports from outside the Community ranged from only 2% for mussels to 69% for frozen scallops in 1991. The only important EC market for U.S. exporters was the French scallop market. It was the biggest and nearly the only roe-on scallop market in Europe. French market preference is for large scallops (10/20–30/40 count/kg). Japan was the biggest and most reliable supplier to the French roe-on scallop market until May 1990, but since then the list of suppliers has become longer, to include the Republic of Korea, Chile, and many other countries. The European flat oyster, *Ostrea edulis*, and the Pacific oyster, *Crassostrea gigas*, are usually marketed live in Europe. EC production and intra-EC trade in oysters is substantial and has accounted for about 90% of the EC supply, with the remaining 10% imported mainly from Turkey. France is by far the leading consumer of oysters, followed by Italy, Belgium, Spain, and Germany. About 95% of the European market for mussels has been supplied by EC countries, with the remainder from Turkey and Sweden. Nearly all mussels are traded live, rather than processed. The European market for clams, the principal species being *Tapes decussatus* and *Venus verrucosa*, is mainly in Spain, France, and Italy. Trade within countries is extensive, with some imports coming from Turkey, Morocco, and Tunisia. Some frozen clam meat is imported from Asia and from India. The only mollusk harvested in North America that can be sold in Europe in any quantity is the scallop. To remain an important supplier, U.S. producers must be allowed and encouraged to export roe-on scallops.

Introduction

The market for bivalve mollusks in the European Community (EC) is strong, but the EC member States supply most of the market with trade amongst themselves. Imports to Europe have ranged from only 2% for mussels to 69% for frozen scallops (Fig. 1). The only important EC market for U.S. exporters is the French scallop market which represents about 75% of U.S. scallop exports to the EC.

French Scallop Market

The French scallop market (Fig. 2, 3) is the largest and is almost the only roe-on scallop market in Europe. French preference is for large scallops (10/20–30/40 count/kg).

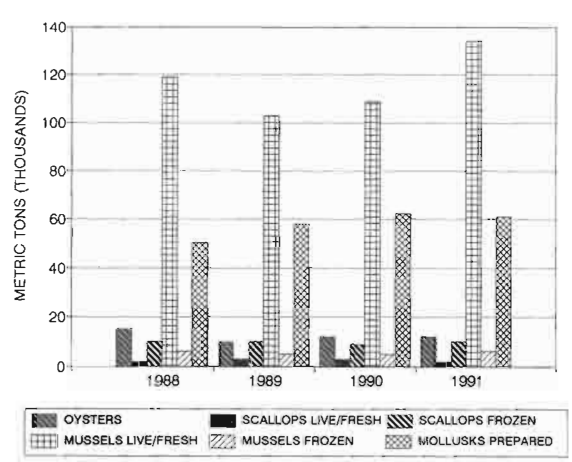

Figure 1
Imports of bivalve mollusks to the EC, 1988–91.

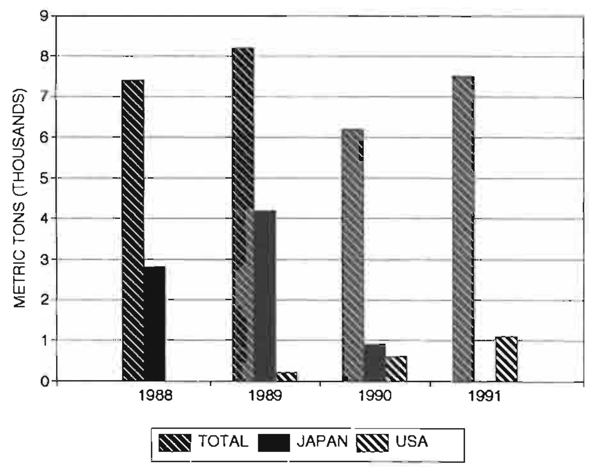

Figure 2
Imports of frozen scallops by France, 1988–91.

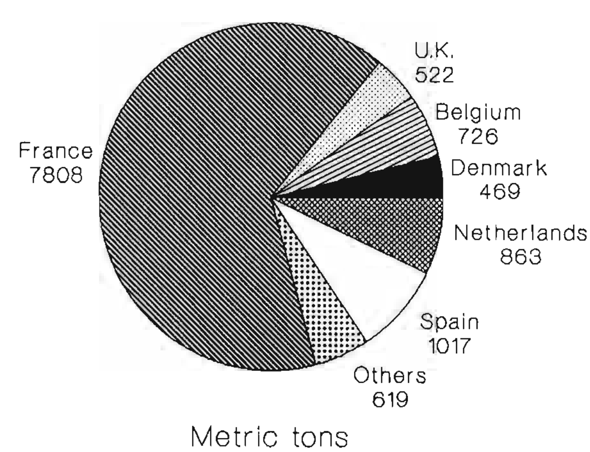

Figure 3
Imports of frozen scallops by EC countries, 1991.

This market is governed by two regulations. The first prohibits the soaking of meats in water (an economic fraud). The humidity/protein ratio (H/P) must be under 5 in all samples, and all scallop shipments entering France are tested. The ratio has been difficult to reach for some scallop species, even those known to be unadulterated, and some producers have had to dry their scallops before exporting them to France. Experiments conducted on Icelandic and Scottish scallops showed that, even if near the limit, they usually passed the test. This French regulation has been in effect since 1 January 1993, even without a European regulation. This would not have been the case if it were a sanitary measure.

The second regulation has prohibited the import of scallops from Japan since 18 May 1990, for sanitary reasons; the scallops had contained paralytic shellfish poison (PSP). The prohibition was extended to all EC countries on 8 April 1992, after further investigations showed the continuing presence of toxins in the scallops.

Japan had been the biggest and most reliable supplier to the French roe-on scallop market until May 1990, supplying up to 55% of scallops imported to France. The ban forced French buyers to find other sources, and the United States, Canada, and the United Kingdom became the suppliers. U.S. exports of scallops to France increased from 230 metric tons (t) in 1989, to 566 t in 1990, and to 1,086 t in 1991 (Fig. 2).

By 1991, the remaining scallop-producing countries had learned of the French market potential and of the market share they could gain if they moved quickly to offer a roe-on scallop. New Zealand, a traditional supplier of high quality (and high priced) roe-on scallops, increased its sales to France from 144 t to 473 t between 1990 and 1991. Other countries, whose supplies were expected to increase, were also likely to try to penetrate the French market. For instance, Australia reopened its scallop fisheries in Tasmania after 3 years of closure for resource conservation, and Canada, which was monitoring water quality, found that PSP remained at a safe concentration, thus was provided for a good 1991 season.

The French market, after a year of uncertainty, rejected all roe-off scallops. Imitation roe-on scallops had better sales in the south of France than real roe-off products. As a result, the list of suppliers became longer than ever, to include the Republic of Korea, Chile, and many other nations. United States scallop supplies in 1992 failed to keep pace because of increased competition and other factors, including the high cost of sampling and analysis for PSP. The National Marine Fisheries Service analysis for PSP on roe-on scallops costs $50 per sample, and five or six samples are needed. The quantity of U.S. exports to France thus fell sharply, in 1992 totaling only 216 t, a drop of 80% from 1991. The total dropped further, to only 50 t, in 1993, just one-third of the amount the United States had exported to France when Japanese scallops were still allowed.

One new factor was thought to potentially favor U.S. roe-off producers: because the French market would be short of roe-off scallops, prices for them would probably be higher than for roe-on. Still, higher prices would not cover the loss in overall volume, as the market for roe-off scallops remained small.

Meanwhile, the market in the U.S. became much stronger; it is unlikely that U.S. exports will again reach the 1991 quantity.

Markets for Other Bivalve Mollusks

Oysters

The European flat oyster, *Ostrea edulis*, and the Pacific oyster, *Crassostrea gigas*, are marketed, mainly live, in Europe. EC production and intra-EC trade of the oysters is substantial, accounting for about 90% of the EC supply. The remaining 10% of imports are mainly from Turkey. EC markets vary considerably, as shown by national per capita consumption. France is by far the leading country, with a consumption of 1.9 kg per person per year. Then comes Italy (175 g), followed by Belgium (170 g), Spain (115 g), and Germany (8 g). The French market, after low prices in 1990, was firmer in 1991. The English market, which is concentrated in restaurants and bars, is still small, but increasing. The Spanish and Italian markets are difficult to penetrate due to strict water quality regulations, but it appears that Spain has a particular interest in U.S. flat oysters. Oysters nearly always must be depurated in the buying country, even if a bilateral agreement exists between the producing and importing countries.

Mussels

About 95% of the European market for mussels is supplied by EC countries, the remainder coming from Turkey and Sweden. Nearly all are mussels traded live rather than processed.

Clams and Scallops

The main species are *Tapes decussatus* and *Venus verrucosa*. The European market for clams is centered largely in Spain, France, and Italy. Trade within countries is also extensive, and some imports come from Turkey, Morocco, and Tunisia. Some frozen clam meat was imported from Asia, mainly from Thailand and China, but also India. It is used for dishes such as paella and seafood cocktails.

In July 1997, the European Commission (the Executive Branch of the European Union) made a decision to list countries outside the European Union from which imports of bivalve mollusks are allowed. This decision concerns all live and processed (frozen, shucked, canned, etc.) bivalve mollusks, except wild roe-off scallop muscles. In November 1997, only the following 12 countries were listed in two groups: Turkey, Morocco, Peru, South Korea, Chile, Greenland, the Faroe Islands, Canada, United States, Thailand, Australia, and New Zealand. China, India, and many other former suppliers to Europe have been excluded. Supplies of scallops that came from China or frozen clam meats from India (for seafood cocktails) need to be replaced in European markets. Opportunities exist for suppliers in North America and the listed countries to fill the markets.

Prepared and Preserved Mollusks

The importance of the market for prepared and preserved mollusks is difficult to describe, as this category includes mussels, oysters, clams, squid, cuttlefish, and snails.

North American Mollusks

The only mollusk harvested in North America that can be sold in any quantity in Europe is scallops. The scallop market, especially in France, was and is important to the United States. To become again an important supplier, U.S. producers must be allowed and encouraged to export roe-on scallops, to participate in the race to regain the 1992 loss of its market share. Since scallops have high value, competition among suppliers is strong. If the United States reacts too late, it will lose this potential market. The demand for other mollusks produced in North America, such as eastern oysters, *C. virginica*; Pacific oysters; surfclams, *Spisula solidissima*; ocean quahogs, *Arctica islandica*; blue mussels; and northern quahogs, *Mercenaria mercenaria*, currently is extremely weak in the EC, but niche markets exist.

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