SCALLOP FISHERIES, CULTURE AND ENHANCEMENT IN THE UNITED STATES

SANDRA E. SHUMWAY AND MICHAEL CASTAGNA

Shumway, S.E. & Castagna, M. 1994 08 10: Scallop fisheries, culture and enhancement in the United States. *Memoirs of the Queensland Museum* **36**(2): 283–298. Brisbane. ISSN 0079-8835.

Information is provided on distribution, commercial landings and landed value of: sea scallop, *Placopecten magellanicus*, bay scallop, *Argopecten irradians*, calico scallop, *Argopecten gibbus*, pink scallop *Chlamys rubida*, spiny scallop, *Chlamys hastata* and weathervane scallop, *Patinopecten caurinus*. Where applicable, information is provided on fishing regulations and management plans. Aquaculture of scallop is limited to a few ventures utilizing the bay scallop, *A. irradians*. Enhancement programs are designed to reinstate populations of *A. irradians* to areas decimated by the 'brown tide' *Aureococcus anophagefferens* and regional efforts to provide some stability to local fishing efforts.

Sandra E. Shumway, Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, Maine 04575, USA (present address: Natural Science Division, Southampton College LIU, Southampton, New York 11968, USA) & Michael Castagna, Virginia Institute of Marine Science, Wachapreague, Virginia 23480, USA; 20 June 1994.

Scallops are commercially important shellfish worldwide (Table 1); US landings of all scallops were 40 million pounds of meat (18,000tonnes) valued at \$US162.5 x 10^6 for 1991 (O'Bannon, 1991a). This represented a decrease of 1.6 million pounds (700 tonnes) (4%) but an increase of \$US4.4x10^6 (3%) compared with 1990. Four species (sea scallop, calico scallop, bay scallop, and weathervane scallop) contribute to the major wild fisheries in the US with minor fisheries for pink scallop and spiny scallop. In 1983 and 1987 Massachusetts reported 418,800 and 29,400 pounds (190 and 13tonnes) respectively) annual landings of the Icelandic scallop, *Chlamys islandica* and Rhode Island reported landing 2,800 pounds (1.2tonnes) of this species in 1983. *C. islandica* is not regularly fished in US waters.

Aquaculture and enhancement efforts are limited activities in the US to the extent that scallop aquaculture is not even listed by FAO in their annual statistics reports (FAO,1992); however, where these activities do occur they contribute to local economies. Further, production from domestic activities (fisheries, aquaculture and enhancement) does not totally meet supply requirements and scallops are regularly imported from other countries (Tables 2,3).

We present a brief overview of US scallop fisheries, aquaculture and enhancement efforts. It is not intended to be comprehensive.

COMMERCIAL FISHERIES

Sea Scallop, *Placopecten magellanicus*

This large, long-lived species attains shell heights of 8.5ins (20cm) and supports an intensive fishery throughout its range from Newfoundland to North Carolina. American commercial fishing efforts centre on Georges Bank, coastal New England and mid-Atlantic states (Naidu,1990; Fig.1). The fishery is >100 years old and *P. magellanicus* is the most important pectinid in the world (Naidu,1990). During 1976–1987 it accounted for 30% of mean annual global production of all scallop species combined (Table 1). In some years, *P. magellanicus* has contributed >0.5 of global scallop production. Enhancement of some species (particularly the Japanese scallop, *Patinopecten yessoensis*) and sporadic booms in natural production of calico scallops (*A. gibbus*) have relegated sea scallop landings to a seemingly secondary role. The adductor muscle (meat) is the only portion commonly marketed in the US, although there is steady interest in developing a 'roe-on' product.

Sea scallops comprise the bulk of scallops landed in the US (Table 2) with New Bedford, Massachusetts being the leading producer in 1991, landing of 21.9 million pounds (10,000 tonnes) of meats (56% of national total) (O'Bannon,1992a). The average ex-vessel price per pound of meat increased from \$US3.85 (\$US1.75 /kg) in 1990 to \$US4.04 (\$US1.84/kg) in 1991. Total catch and landed values are given (Figs 2,3; Table 4). Regional landings vary; the New England region consistently produces most scallops and more southerly regions the least (Fig.2).

The commercial fishery operates year-round using otter trawls and dredges. Recreational

TABLE 1. Nominal landings (MT, round weight) of scallop species. Figures in parentheses are % contribution to global production in any given year. Source: Yearbook of Fishery Statistics, FAO, Rome, Vol. 70.

SPECIES	1984	1985	1986	1987	1988	1989	1990
* *Argopecten gibbus* (Atlantic calico scallop)	395,710 (47.2)	125,609 (20.8)	16,916 (3.2)	85,363 (11.6)	121,720 (14.0)	67,330 (8.0)	11,220 (1.3)
* *Argopecten irradians* (bay scallop)	6,597 (0.8)	5,153 (0.8)	4,714 (0.9)	2904 (0.4)	2,329 (0.3)	1,360 (0.2)	2,596 (0.3)
Argopecten purpuratus (Chilean scallop)	23,190 (2.8)	51,578 (8.5)	16,563 (3.1)	5,602 (0.8)	7,878 (0.9)	4,062 (0.5)	7,467 (0.9)
Chlamys islandica (Iceland scallop)	15,583 (1.8)	17,068 (2.8)	16,429 (3.1)	13,385 ((1.8)	10,059 (1.2)	10,772 (1.3)	12,117 (1.4)
Chlamys opercularis (queen scallop)	13,472 (1.6)	10,913 (1.8)	11,761 (2.2)	14,343 (1.9)	15,613 (1.8)	13,129 (1.6)	17,489 (2.0)
Patinopecten yessoensis (Japanese scallop)	214,569 (25.6)	238,236 (39.4)	276,596 (52.1)	344,519 (46.6)	466,530 (53.7)	502,136 (59.8)	571,003 (65.1)
* *Patinopecten caurinus* (weathervane scallop)	5,445 (0.6)	3,649 (0.6)	2,608 (0.5)	2,714 (0.4)	961 (0.1)	1,398 (0.2)	2,415 (0.3)
Pecten maximus (giant scallop)	22,253 (2.6)	20,128 (3.3)	17,353 (3.3)	15,357 (2.1)	15,812 (1.8)	15,852 (1.9)	14,433 (1.6)
Pecten jacobeus (Pilgrim's scallop)	7 –	2 –	4 –	4 –	4 –	1 –	1 –
Pecten novazealandiae (New Zealand scallop)	4660 (0.6)	3204 (0.5)	4,570 (3.3)	937 (0.1)	723 (0.1)	533 (0.1)	563 (0.1)
**Placopecten magellanicus* (sea scallop)	103,113 (12.3)	104,946 (17.4)	130,281 (24.5)	193,519 (26.2)	193,700 (22.3)	206,262 (24.5)	216,865 (24.7)
other Pectinidae	33,468 (4.0)	23,729 (3.9)	32,944 (6.2)	59,959 (8.1)	32,766 (3.8)	15,963 (1.9)	20,467 (2.3)
World total	838,067	604,215	530,739	738,606	868,095	840,223	876,636

*species fished commercially in the US.

fisheries are rare and occur predominantly in Maine where scallops are collected by divers.

Management of sea scallop resources has historically been a local issue. US scallop management efforts started when Maine imposed a summer closure sometime between 1901 and 1917. Many local management regulations are still in effect and many more have been implemented to conserve stocks and control gear conflicts. No regulation of the offshore fishery existed prior to 1983 other than what the industry imposed upon itself. In inshore waters, scallop management has existed for a long time (Shumway & Schick,1987). Maine has had long-standing regulations for conservation of scallop stocks within its 3mile territorial limits; New Hampshire has had conservation regulations of a 3.25inch (8.25cm) minimum shell height and an April 15 through October 31 closed season since 1977. Massachusetts, with the largest offshore scallop fishery out of New Bedford, has had no regulations as it has no large inshore beds of sea scallops. Each state has modified their regulations to at least comply with the US federal regulations for the Fisheries Conservation Zone (FCZ), but Maine's regulations remain even more restrictive, with specific area restrictions on season, gear type and gear size, a ban on nighttime fishing for scallops, drag size limits which vary with season and a requirement for a hand-fishing license for divers and a boat license for draggers.

Regulations in the US offshore scallop fishery, which includes Georges Bank, Gulf of Maine and mid-Atlantic Bight as far south as Cape Hatteras (Fig.1) have been imposed by industry in the form of crew size, maximum allowable time at sea per trip, minimum time at the dock between trips and a maximum of two tows dumped on deck at one time prior to shucking. With advent of the 200 mile Fisheries Conservation Zone, New England and mid-Atlantic Fisheries Management Councils developed and implemented the Sea Scallop Fisheries Management Plan (FMP) to regulate the fishery. The

TABLE 2. U.S. supply of scallop meats 1972–89) (meat weight in million pounds) (after Dore,1991)

Year	U.S. commercial landings			Total Domestic	Imports	Total Supply	Percent Imports
	Bay	Calico	Sea				
1972	2.0	1.4	7.0	10.4	20.8	31.2	66.7
1973	1.0	0.6	6.4	8.0	19.8	27.8	71.2
1974	1.5	1.1	6.4	9.1	18.1	27.2	66.5
1975	1.6	2.0	10.1	13.7	19.7	33.4	59.0
1976	1.6	2.3	19.9	23.7	25.3	49.0	51.6
1977	1.7	1.1	25.0	27.8	29.8	57.6	52.3
1978	1.4	0.9	31.0	33.3	28.4	61.7	46.0
1979	1.8	0.9	31.5	34.1	25.2	59.3	42.5
1980	1.0	–	28.8	29.7	20.9	50.6	41.3
1981	0.7	14.6	30.3	45.6	26.2	71.8	36.5
1982	1.8	11.0	21.3	34.1	20.9	55.0	38.0
1983	2.3	9.6	20.5	32.4	34.3	66.7	51.4
1984	1.7	39.3	18.4	59.5	27.3	86.8	31.4
1985	1.3	12.5	15.8	29.7	42.0	71.7	58.6
1986	0.7	1.6	20.0	22.3	47.9	70.3	68.1
1987	0.6	8.2	32.0	40.8	39.9	80.7	49.4
1988	0.6	11.9	30.6	43.0	32.0	75.0	42.7
1989	0.3	6.6	33.8	40.6	40.9	81.5	50.2
1990	0.5	1.1	39.9	41.5	39.8	81.3	48.9
1991	0.4	0.3	39.3	40.0	29.5	69.5	42.5

basis for managing the Georges Bank, Gulf of Maine and mid-Atlantic scallop fisheries under the FMP has been to increase yield per recruit by controlling age/size of recruitment by imposing a maximum average meat count. The FMP was implemented in May,1983, and imposed a 30 meat count per pound maximum with an equivalent shell height of 3.5inches (8.9cm). The

TABLE 3. Domestic and imported scallop species on the U.S. market

DOMESTIC	
Sea scallop	*Placopecten magellanicus*
Calico scallop	*Argopecten gibbus*
Bay scallop	*Argopecten irradians*
Weathervane scallop	*Patinopecten caurinus*
Pink scallop	*Chlamys rubida*
Spiny scallop	*Chlamys hastata*
IMPORTED	
Japanese scallop	Pecten yessoensis
Queen scallop	*Chlamys opercularis*
Icelandic scallop	*Chlamys islandica*
Pacific calico scallop	*Argopecten circularis*
Bay scallop	*Argopecten irradians*
Peruvian scallop	*Argopecten purpuratus*

Regional Director of National Marine Fisheries Service (NMFS) immediately increased the count to 35/pound with a shell height minimum of 3.275inches (8.6cm) due to the unwillingness of Canada to go along with a 30 count maximum. This temporary change in the limits was to be in effect until January,1984, when the limits would go to 30 meats per pound and 3.5inch (8.9cm) shell height. The 30 count regulation was delayed until January 1986 due to industry and political pressures and the 35 meat count was retained. Under this scheme of an average meat count, small scallop meats may be mixed with large meats as long as the average meets the maximum count requirement.

In 1984, a large set of scallops in the Great South Channel of Georges Bank promised to sustain the scallop fishery for some time; however, most of this set was harvested at a small size and the meats were mixed with larger meats to achieve the 35 count maximum. Almost the entire set was harvested at well below its potential yield per recruit and before it was able to significantly contribute to reproduction. To prevent this from happening again, the Councils proposed Amendment 1 to the FMP that would institute a 40 count minimum meat size, which would create an

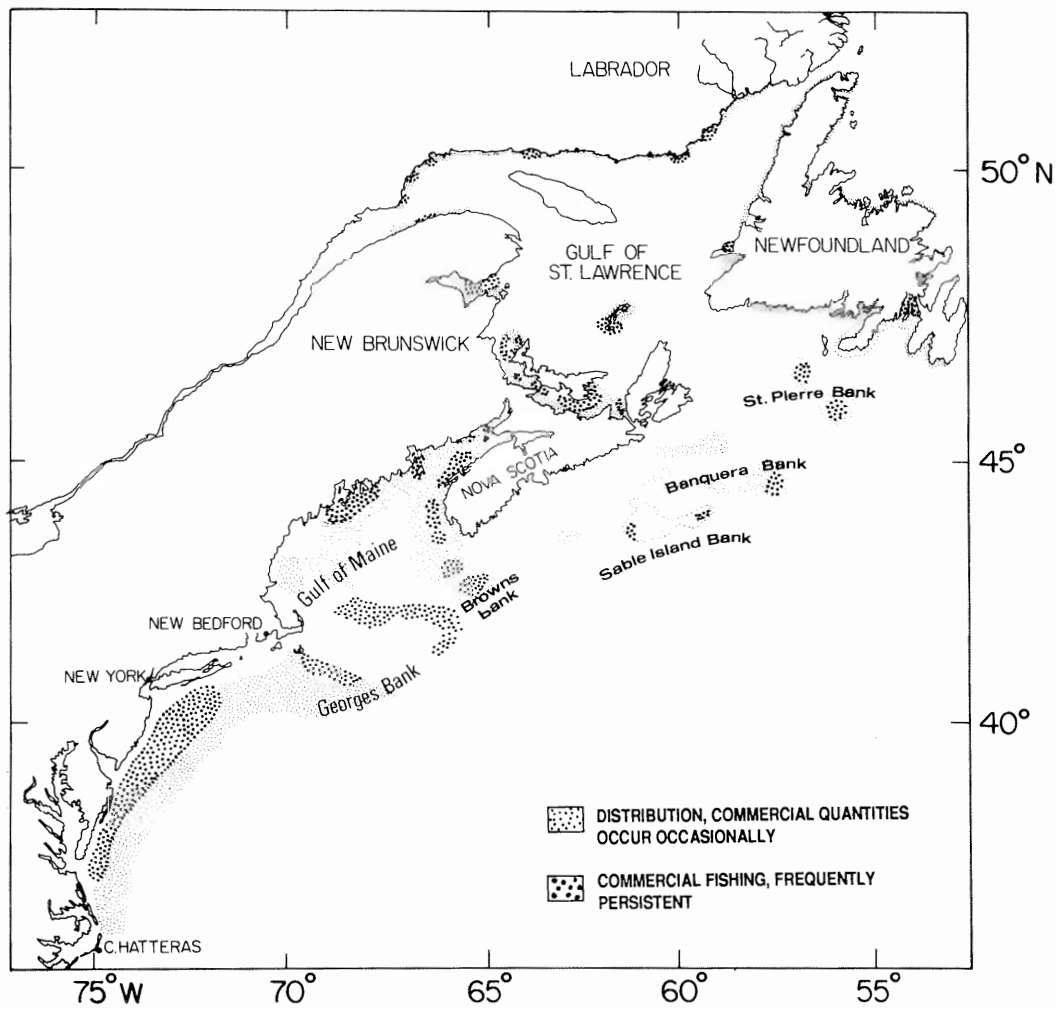

FIG.1. Distribution of the sea scallop, *Placopecten magellanicus*, and commercial fishing grounds.

average meat count of around 30, but would prohibit the mixing of scallops much smaller than the minimum size. This effort brought much criticism from the industry.

Amendment 1 to the FMP went into effect on January 1,1986, but was delayed by the Regional Director of NMFS and was rescinded May 28,1986. Scallop management then returned to the FMP and the 30 count average with a 10% tolerance (effectively a 33 count average) and 3.5inch (8.9cm) shell height was imposed. The shell height of 3.5inches is based on an average shell height to meat weight regression showing the shell height for a 30 count scallop meat. Industry criticism has been levied against the 3.5inch (8.9cm) shell size as well. The industry arguments centred on the fact that the shell height to meat weight relationship is highly variable from location to location and from season to season (Fig.12; Serchuk,1983; Serchuk & Rak, 1983; Schick et al.,1988). With scallop sets occurring at different locations in different years, or even in the same year, having one shell height to meat weight regression represent the whole fishery they claim is unreasonable. Currently shellstockers can harvest scallops in the mid-Atlantic Bight at 3.5inch (8.9cm) shell height that have meats too small for the at-sea shuckers to

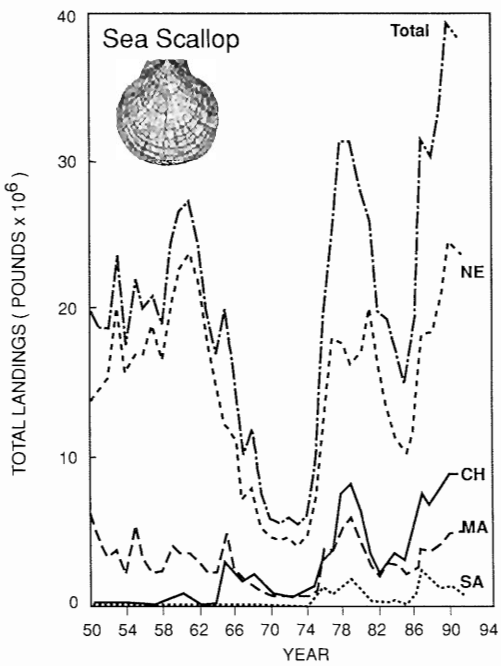

FIG.2. Landings of sea scallop, *Placopecten magellanicus*. Data from O'Bannon 1992b)

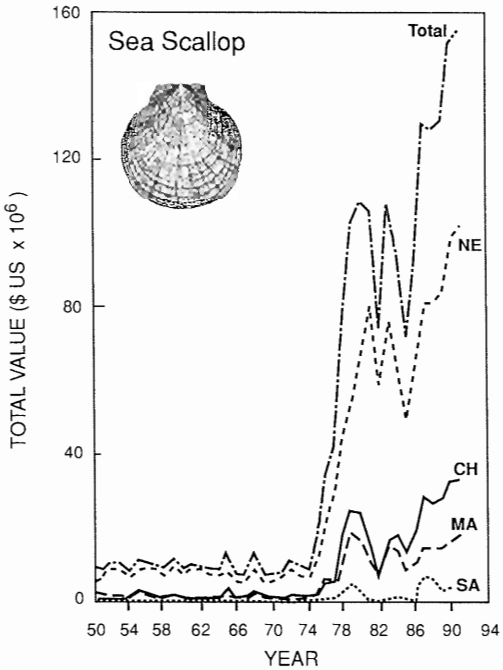

FIG.3. Landed value of sea scallops, *Placopecten magellanicus* (meats). Data from O'Bannon 1992b)

harvest even at 33 count. With the large recruitment of recent year classes producing a bonanza for the shellstockers and little for the at-sea shuckers, there is much asperity in the industry with cries of unfair management practices.

In response to industry criticism, the Councils put forth Amendment 2, which contains options for management of the scallop resource. During several hearings industry spokesmen made it clear that most options were untenable, or at least unpalatable to them. Current regulations require a 30 average meat count per pound standard for shucked scallops and a 3.5inch (8.9cm) minimum shell height standard for unshucked scallops. 'Fishing effort on Georges Bank is at record levels and far beyond what the resource can sustain in the long run' (Anonymous,1992).

Discussions are now focussed on implementation of Amendment #4 (designed to replace the meat count system) which includes the following common elements (Commercial Fisheries News, Dec. 1992): a moratorium restricting entry into the fishery; maximum crew size of nine, including the captain; 3.25inch (8.3cm) ring size minimum that would increase to 3.5inches (8.9cm) the third year of the plan; 5.5inch (14.0cm) minimum mesh size for trawl gear; 30 foot (9.2m) limit on the total width of all dredges and a 144 foot (44m) limit on the sweep of trawl gear; no onboard shucking and sorting machines on boats that land shucked scallops; continuation of the 12h landing windows and no at-sea transfer of scallops; continuation of the 3.5inch (8.9cm) minimum shell height standard for shellstockers (fishermen who land scallops in their shells); no chafing gear, cookies or other devices which obstruct the top or sides of the scallop dredge and a 5.5inch (14.0cm) minimum twine top on top of all dredge gear; annual permits and mandatory data reporting for vessel owners, dealers, brokers and processors as well as licenses for vessel captains; continuation of the meat count as an alternative to the following gear restrictions: increased ring size, 5.5inch (14.0cm) trawl mesh, 5.5inch (14.0cm) twine top, and prohibitions on chaffing gear, cookies and other obstructing devices. In additions, there are four alternatives proposed: 1) (preferred) limited days at sea by vessel group (full-time fleet, part-time fleet, occasional fleet); 2) limits on days at sea; 3) adjustable trip limit with fixed layover; 4) fixed trip limit with adjustable layover.

Inasmuch as the goals of management are to optimize yield while at the same time stabilizing

TABLE 4. Historical catch statistics (total catch by regions) for sea scallops, (*Placopecten magellanicus*), for the period 1950—1991 (numbers in thousands). (O'Bannon,1992b)

Year	New England		Middle Atlantic		Chesapeake		South Atlantic		Total	
	Pounds	Dollars	Pounds	Dollars,	Pounds	Dollars,	Pounds	Dollars	Pounds	Dollars
1950	13,753	6,384	6,135	2,781	92	39	—	—	19,980	9,204
1951	14,444	6,471	4,259	1,825	43	28	—	—	18,746	8,324
1952	15,392	9,093	3,205	1,721	32	18	—	—	18,629	10,832
1953	19,987	8,864	3,590	1,595	41	17	—	—	23,618	10,476
1954	15,594	7,028	2,037	948	—	—	—	—	17,631	7,976
1955	16,848	8,821	5,244	2,610	33	18	2	2	22,125	11,449
1956	16,881	9,109	3,164	1,700	21	13	—	—	20,066	10,822
1957	18,781	9,119	2,167	1,040	46	21	—	—	20,994	10,180
1598	16,410	7,941	2,324	1,097	243	102	—	—	18,977	9,140
1959	20,259	9,825	3,949	1,814	436	166	—	—	24,644	11,805
1960	22,462	7,823	3,356	1,153	781	290	—	—	26,599	9,266
1961	23,775	9,035	3,368	1,238	318	131	—	—	27,461	10,404
1962	21,724	8,857	2,815	1,134	95	33	—	—	24,634	10,024
1963	17,794	8,257	2,099	978	46	22	—	—	19,939	9,257
1964	14,536	7,955	2,184	1,194	194	95	—	—	16,914	9,244
1965	12,335	8,350	4,813	3,051	2,830	1,725	92	56	20,070	13,182
1966	11,147	5,520	2,528	1,186	2,300	919	—	—	15,975	7,625
1967	7,025	5,438	1,585	1,174	1,632	1,154	—	—	10,242	7,,766
1968	7,938	8,850	1,978	2,194	2,112	2,268	42	42	12,070	13,354
1969	5,107	5,636	912	982	1,378	1,474	13	13	7,410	8,105
1970	4,467	6,028	635	835	750	995	—	—	5,852	7,858
1971	4,346	6,418	514	771	546	802	—	—	5,406	7,991
1972	4,422	8,628	468	933	960	1,856	—	—	5,850	11,417
1973	3,949	7,072	569	1,067	773	1,347	—	—	5,291	9,486
1974	4,611	7,174	534	817	872	1,276	—	—	6,017	9,267
1975	7,081	13,382	981	1,780	1,270	2,330	421	421	9753	17,913
1976	11,970	22,247	3,633	6,029	2,878	4,865	1,107	1,432	19,588	34,573
1977	17,951	29,721	3,596	5,747	3,627	5,529	657	954	25,831	41,951
1978	17,688	44,876	5,040	12,185	7,456	18,029	984	1,828	31,168	76,918
1979	16,202	55,037	5,772	18,717	7,676	24,376	1,694	4,989	31,344	103,028
1980	17,018	65,571	4,143	16,274	6,140	23,776	861	2,979	28,162	108,600
1981	19,910	80,212	2,570	10,709	3,350	14,467	125	478	25,955	105,866
1982	15,822	58,995	1,920	7,244	2,194	8,370	2	1	19,936	74,590
1983	13,574	76,385	2,719	15,436	2,915	16,296	26	151	19,234	108,268
1984	11,124	62,652	2,,573	13,813	3,324	17,747	170	816	17,191	95,028
1985	10,223	50,078	1,849	8,532	2,873	13,380	13	56	14,958	72,046
1986	11,707	61,669	2,317	10,388	4,264	18,914	974	3,952	19,262	94,923
1987	18,280	81,038	3,558	13,979	7,352	28,345	2,213	6,889	31,403	130,251
1988	18,388	81,234	3,431	14,214	6,631	26,468	1,851	6,579	30,301	128,495
1989	20,576	84,034	4,024	15,000	7,719	28,470	1,013	3,638	33,332	131,142
1990	24,661	99,057	4,664	16,432	8,785	32,147	1,165	4,036	39,275	151,672
1991	24,031	101,932	4,845	18,119	8,851	32,,897	635	2,324	38,362	155,272

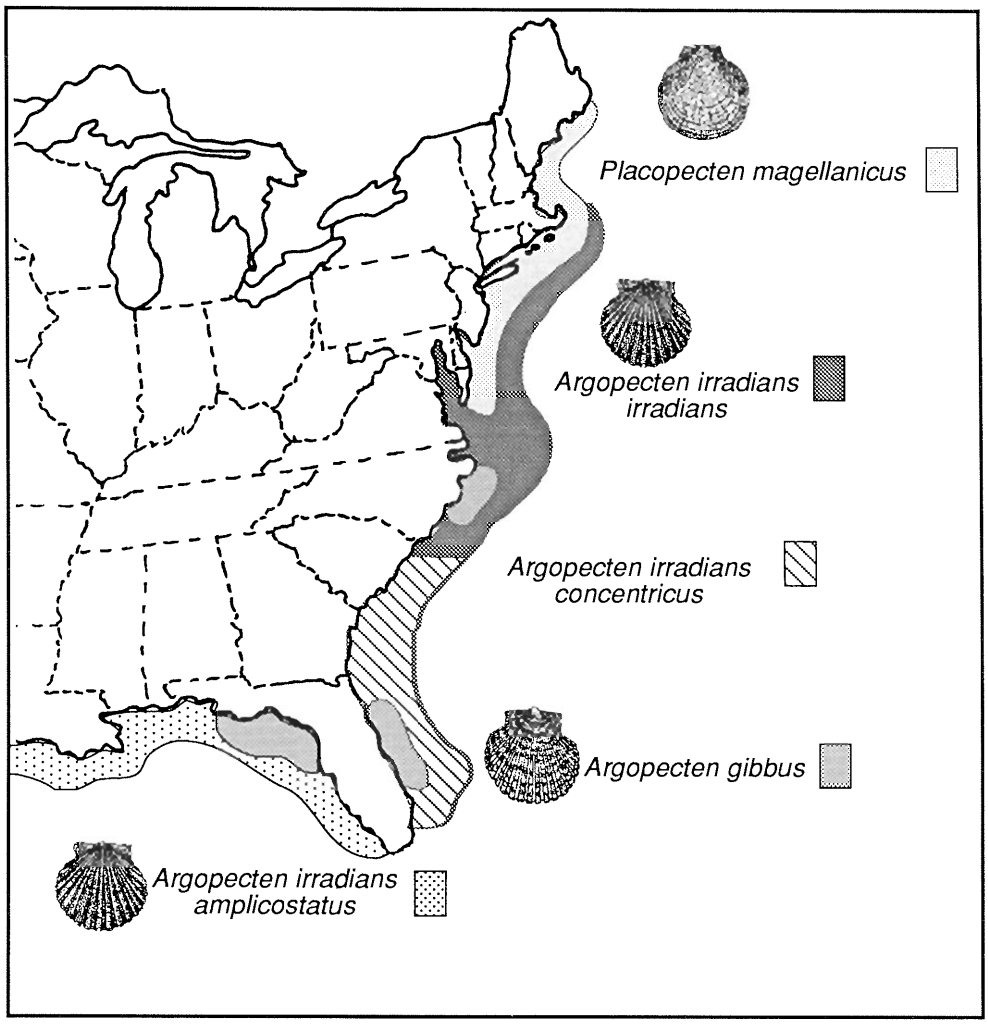

FIG.4. Distribution of bay scallops, *Argopecten irradians*.

the catches, it seems reasonable that considerable attention should be paid to the high level of variability that can occur in meat weight within a given fishing area. Since a single meat count is not going to be valid 'across the board', different meat count and/or shell height regulations are needed for separate fishing zones. It is further suggested that, since seasonal and yearly variation in meat weights have been demonstrated, meat count regulations should be based on yearly sampling and set on a seasonal and area-specific basis. While a constantly changing count/size limit will cause problems with regard to compliance and enforcement, it will strip away inequities between harvesting techniques and increase yield to the fishermen by effectively increasing yield-per-recruit and allowing management closer to the limits of the resource.

At a time when the scallop fishery is increasing, and for a species which experiences such drastic fluctuations, management cannot be too careful in the regulations it imposes.

Bay Scallop, *Argopecten irradians*

The species range is discontinuous along the Atlantic coast of North America between Nova Scotia and Colombia. *A. irradians irradians* occurs from Cape Cod to New Jersey where it is

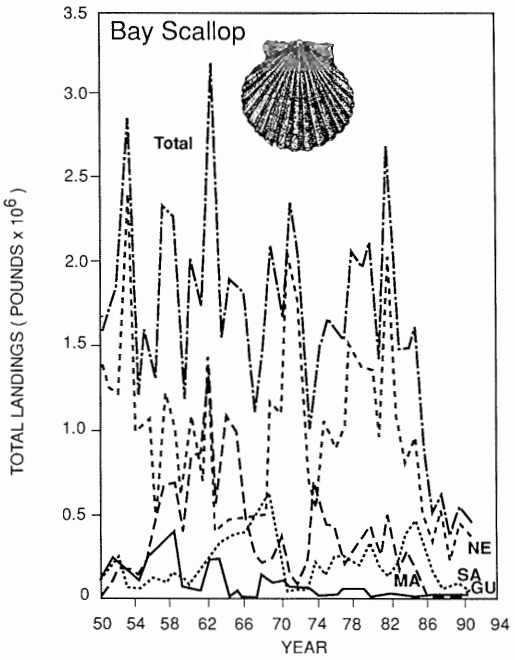

FIG.5. Landings of bay scallops, *Argopecten irradians*. Data from O'Bannon 1992b).

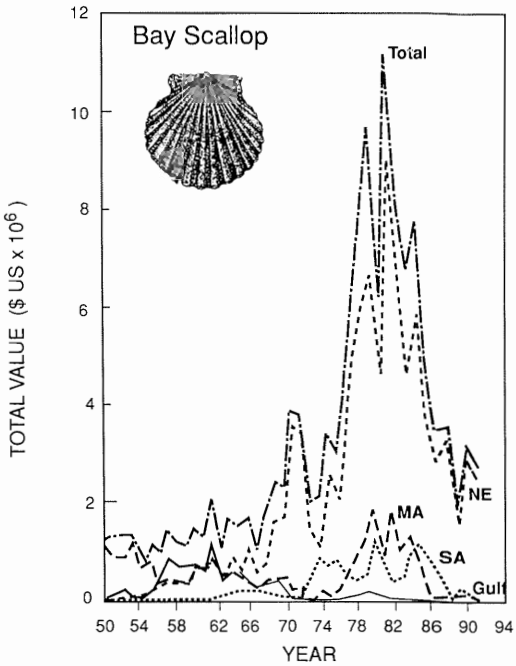

FIG.6. Landed value of bay scallops, *Argopecten irradians*. Data from O'Bannon 1992b)

replaced by *A. irradians concentricus* which extends from New Jersey to Florida. *A. irradians amplicostatus* is found in the western Gulf of Mexico to Colombia (Fig.4). While this species represents only a minor component of US commercial fisheries (Tables 1,2), it is extremely important to local economies.

Rhodes (1990) reviewed the biology and fishery of *A. irradians* which is a small, short-lived species, usually spawning only once; however, a second spawning by some individuals takes place in some regions. They occur in shallow water (<10m) in protected bays and estuaries, reaching a size of c.4inches (10cm) in 16 months. Meat counts are 50–100/pound (23–45/kg).

Landings vary between seasons (Table 5) and populations are dependent upon natural recruitment for continuation, although some enhancement efforts have been attempted. In 1985, bay scallop populations in the northeast were decimated by blooms of a previously unknown microalga, *Aureococcus anophagefferens* ('brown tide') (Tettelbach & Wenczel,1993; Fig.11). Three successive years of algal blooms resulted in virtually all native stock in the Peconic Bays and the New York fishery being eliminated. Eelgrass beds were also depleted, reducing the total area of suitable habitat for scallop settlement. Landings for 1991 were 438,000pounds of meats (200tonnes) valued at $US2.7 million. This is a decrease of 101,000 pounds (46tonnes) (19%) and $US436,000 (14%) compared with 1990 (O'-Bannon,1992a). Massachusetts was the leading state with 375,000 pounds (170tonnes) of meats, 86% of the national total. The average ex-vessel price was $US6.09/pound ($US2.77/kg) of meats compared with $US5.76 ($US2.62/kg) in 1990 (Figs 5,6; Table 5).

Commercial fishing records for *A. irradians* date back to 1858 (Ingersoll,1886) and the introduction of the dredge in 1874. Commercial fishing for *A. irradians* is strictly limited and there is a large recreational fishery. Harvest is usually limited to September–December. In most areas, the bay scallop fishery is a protected resource. Scallops are usually collected by diver, hand-picking or rake. Some fishermen use small boats equipped with outboard engines and one or two small dredges. Scallops are culled on board and only the meats are harvested. Catch limits are determined on a season-by-season basis by fisheries officials in accordance with population fluctuations (Rhodes,1990).

TABLE 5. Historical catch statistics (total catch by regions) for bay scallops (*Argopecten* sp.) for the period 1950–1991 (numbers in thousands). (O'Bannon,1992b)

Year	New England		Middle Atlantic		South Atlantic		Gulf		Grand Total	
	Pounds	*Dollars*	*Pounds*	*Dollars*	Pounds	Dollars,	*Pounds*	*Dollars*	*Pounds*	*Dollars*
1950	1,376	1,130	27	32	72	39	125	63	1,600	1,264
1951	1,253	959	101	121	183	96	252	161	1,789	1,337
1952	1,188	913	182	255	254	126	210	48	1,834	1,342
1953	2,397	1,222	162	102	65	33	229	53	2,853	1,410
1954	987	688	127	110	52	26	43	10	1,209	834
1955	1,070	837	226	210	78	39	223	53	1,597	1,139
1956	433	433	464	426	125	63	278	70	1,300	992
1957	1,230	880	674	447	109	37	315	91	2,328	1,455
1958	1,013	680	688	413	169	58	401	75	2,271	1,226
1959	591	700	385	386	128	51	82	19	1,186	1,156
1960	1,063	759	843	674	69	27	56	14	2,031	1,474
1961	704	671	862	621	106	42	36	14	1,708	1,348
1962	1,425	1,081	1,353	851	168	67	213	68	3,159	2,067
1963	391	492	577	404	321	122	228	59	1,517	1,077
1964	466	595	1,063	886	340	173	18	14	1,887	1,668
1965	459	562	982	766	379	196	39	24	1,859	1,548
1966	880	1,076	492	408	399	184	9	4	1,780	1,672
1967	455	579	248	258	387	211	7	5	1,097	1,053
1968	491	776	218	374	639	422	143	122	1,491	1,694
1969	1,172	1,592	249	377	613	383	80	61	2,114	2,413
1970	1,101	1,704	365	470	130	91	104	56	1,700	2,321
1971	2,063	3,531	144	234	60	42	48	39	2,315	3,846
1972	1,776	3,407	93	215	128	110	35	40	2,032	3,772
1973	694	1,462	230	467	37	33	53	63	1,014	2,025
1974	567	1,014	694	872	220	199	16	18	1,497	2,103
1975	1,054	2,568	444	713	135	105	14	16	1,647	3,402
1976	890	1,973	438	816	248	194	14	24	1,590	3,007
1977	1,044	3,085	199	489	257	509	46	58	1,546	4,141
1978	1,521	4,982	280	837	221	393	49	91	2,071	6,303
1979	1,382	5,967	346	1,243	193	514	62	137	1,983	7,861
1980	1,356	6,671	431	1,840	328	1,107	11	29	2,126	9,647
1981	964	4,630	244	891	189	656	22	62	1,419	6,239
1982	2,022	8,949	500	1,809	137	352	13	35	2,672	11,145
1983	1,083	6,491	167	992	205	509	22	75	1,477	8,067
1984	808	4,573	279	1,264	384	876	10	26	1,481	6,739
1985	958	5,812	174	828	456	1,072	4	10	1,592	7,722
1986	509	3,797	13	65	306	838	27	86	855	4,786
1987	341	2,813	2	3	155	501	19	80	515	3,397
1988	530	3,339	2	2	39	73	39	73	608	3,487
1989	215	1,494	2	22	84	214	57	162	358	1,892
1990	450	2,812	11	132	78	158	–	–	539	3,102
1991	375	2,438	15	117	45	100	3	11	438	2,666

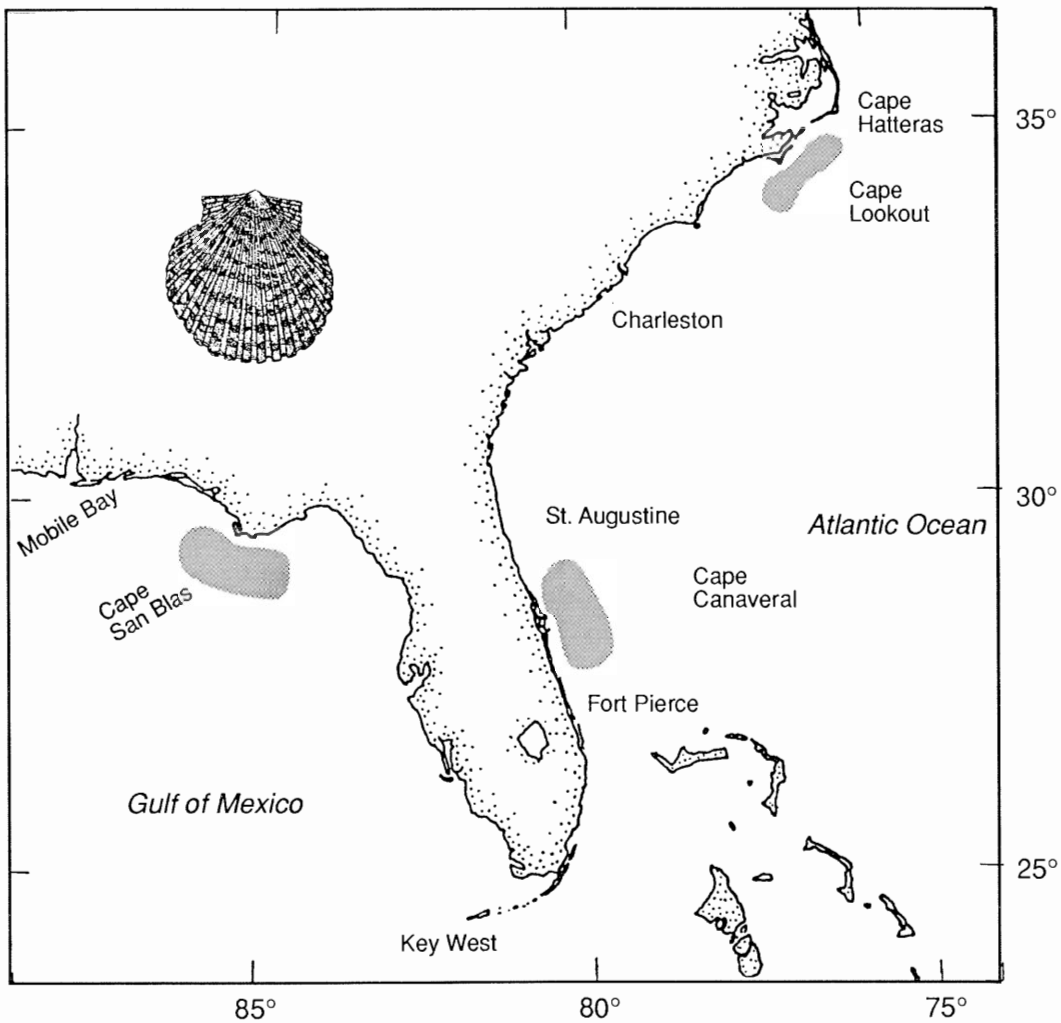

FIG.7. Commercial fishing grounds for the calico scallop, *Argopecten gibbus* (after Blake & Moyer,1990)

CALICO SCALLOP, *ARGOPECTEN GIBBUS*

This species supports a variable fishery off Florida (Fig.7). Locations of commercial stocks vary from year to year; however, Cape Lookout, Cape Canaveral and Cape Sand Blas are key areas. The fishery and biology were reviewed by Blake & Moyer (1990). The scallops grow to <3inches (7.5cm) and the adductor muscle (meat) is small and brownish (meat count 100–300 per pound; normally 150–200). Hand-shucking is not economically feasible; thus, even though large stocks of calico scallops were known as early as 1949, the species was not harvested commercially prior to automation in the late 1970's.

During its peak (1984), landings exceeded 39 million pounds (17,700tonnes) and the fishery was almost non-existent in the late 1980's and early 1990's (Tables 1,2; Fig.8). Annual variations in production impact not only the total US catch, they also determine the position of the US among world scallop producers. Landings were 286,000 pounds (122tonnes) of meats valued at $US858,000 in 1991. According to O'Bannon (1992a), this represented a decrease of 849,000 pounds (390tonnes) (75%) and $US423,000 (33%) compared with 1990. All calico scallops were landed on the east coast of Florida in 1991. The average ex-vessel price was $US3.00/pound

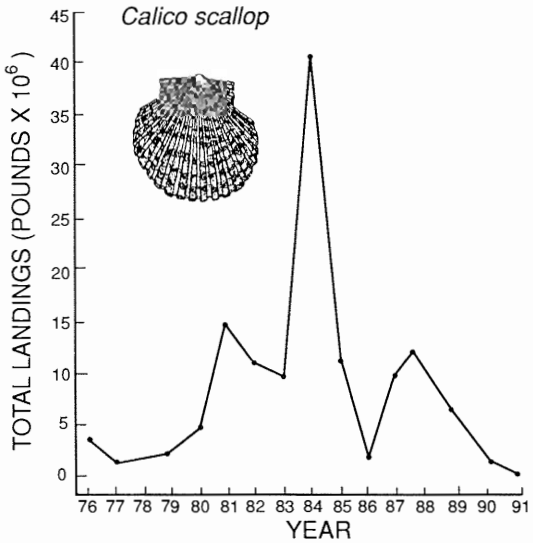

FIG.8. Landings of calico scallops, *Argopecten gibbus*. Data from Blake and Moyer 1990; O'Bannon 1992b).

($US1.36/kg) of meats compared to $US1.13 ($US0.51/kg) in 1990.

Since stocks of *A. gibbus* are annual, over-fishing is not considered a problem, thus there are no state or federal fishery management programs. The fishery is totally dependent upon the natural population and regulation of landings is governed by a self-regulating association of industry members. Fishing efforts are limited until at least 75% of the stock at a particular location reaches a shell height of at least 38mm, the point at which much of the population will have undergone their first spawning event. A second spawning is not guaranteed and only takes place when environmental conditions are optimal.

Weathervane Scallop, *Patinopecten caurinus*

This large, long-lived species reaching up to c.10inches (25cm) and 28 years of age (Hennick, 1973) occurs from Alaska to Oregon (Fig.9). It requires 5–6 years to attain a shell height of 4inches (10cm) and reaches sexual maturity at c.3inches (7cm) shell height. Scallop meats are large, similar in appearance to those of *P. magellanicus*, and average counts are 10–40/pound (5–18/kg). Bourne (1990) reported that minor landings of weathervane scallops occurred sporadically along the coast of Washington until the late 1950's with recorded landings for this period (1935–1952) averaging about 360t (320tonnes) (Cheney & Mumford,1986). A small fishery was developed in Alaska in 1967 and landings have fluctuated widely (Fig.10; Table 6). Oregon landings for 1989–1992 were less than 500 pounds (200kg) per year; Washington landings for the same period ranged from 13,000 pounds (6tonnes) in 1989 to 6,700 pounds (3tonnes) in 1992. Alaska reported landings of 464,000 pounds (210tonnes) for 1989. These values do not include confidential data; however, landings of *P. caurinus* continue to fluctuate and represent a small % of the US scallop fishery (NMFS).

Gear utilized ranges from old shrimp trawls to typical east coast drag (Bourne,1990) and methods of management vary. Alaska has had a seasonal restriction (June 1–March 31) in some areas, area closures and gear regulations. Many regulations were designed to protect crab resources (Bourne,1990). Minimum ring size on drags must be 4inches (10cm) inside diameter (some areas permit use of a 3inch (7.5cm) ring) and trawls have been eliminated from the legal gear restrictions. Washington regulates its fishery by gear size and mesh or ring size; Oregon by limited entry, gear and mesh or ring size; and California management is by permits (Bourne,1990).

Pink Scallop, *Chlamys rubida*
Spiny Scallop, *Chlamys hastata*

Pink and spiny scallops are small and co-exist in discontinuous populations along the US west coast from Alaska to California (Fig.9); they are often referred to as 'singing scallops'. They are slow-growing, rarely attaining shell heights greater than 3.5inches (8cm). These species support a small commercial fishery in Washington and landings are small (Fig.10). The small size of these scallops has encouraged a market for whole scallops, often consumed steamed as one would eat mussels or clams. This is a dangerous venture given the paralytic shellfish toxins in the region and ability of scallops to concentrate and retain these toxins for extended periods of time (Shumway & Cembella, this memoir).

Fishing is by small drags or diving (Bourne, 1990) and the fishery is regulated by gear and mesh size in Washington.

AQUACULTURE AND ENHANCEMENT

During 1920–1926, William Firth Wells carried out some bivalve culture investigations which he reported in his annual reports to the New York State Conservation Commission. Besides propagating the eastern oyster, *Crassostrea virginica*, he cultured quahogs, *Mercenaria mer-*

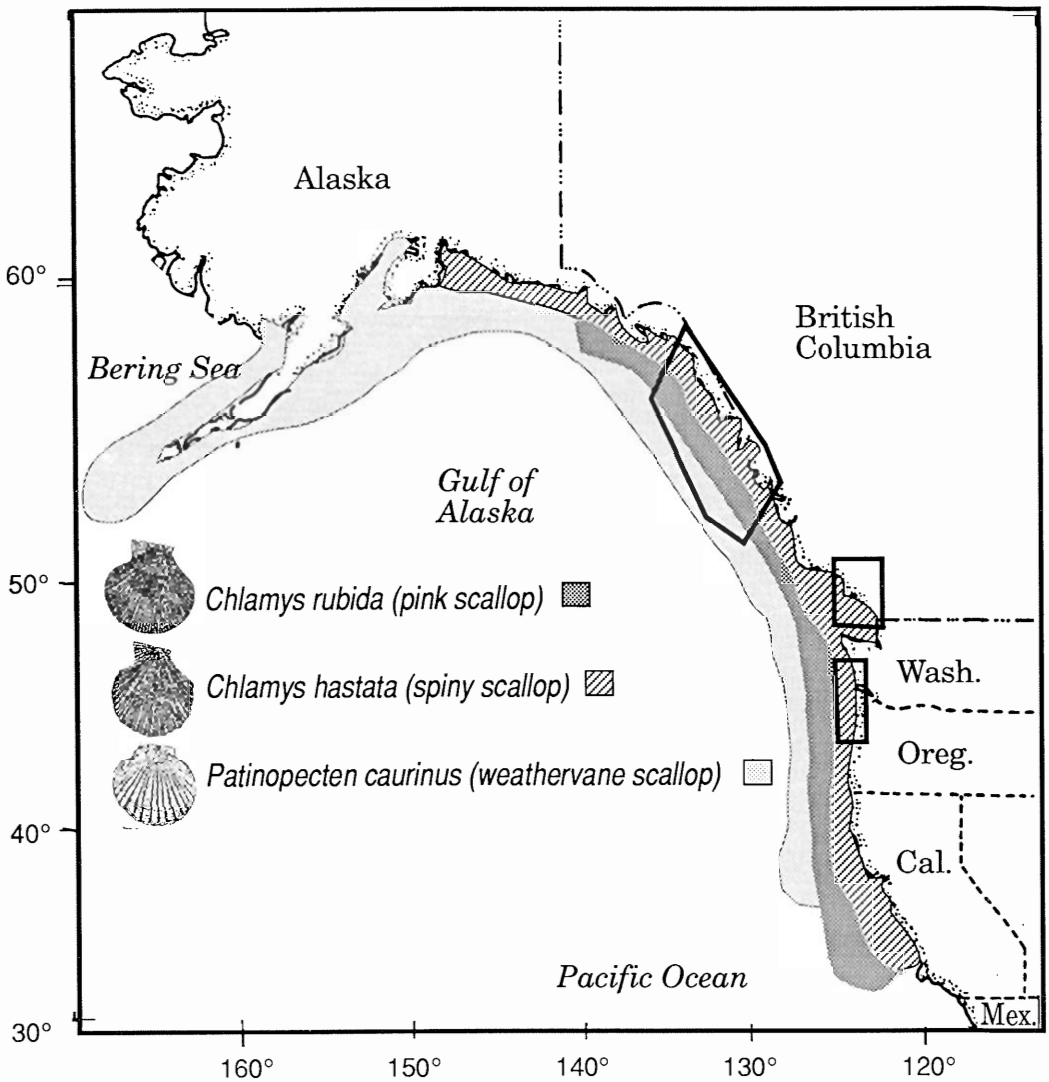

FIG.9. Distribution of Pacific coast scallop species: weathervane scallop, *Patinopecten caurinus*; pink scallop, *Chlamys rubida*; spiny scallop, *Chlamys hastata*. After Bourne 1990).

cenaria, soft clams, *Mya arenaria*, mussels, *Mytilus edulis* and bay scallops, *Argopecten irradians* (State of New York Conservation Department,1969). Wells used a milk separator to clarify his culture water and to collect larvae from cultures for transfer. One of the earliest species he cultured was the bay scallop. It was perhaps the first bivalve cultured in the manner similar to what we think of today as aquaculture (late Joseph Glancy, pers. comm.).

Most scallop culture in the US now utilizes the bay scallop, *A. irradians irradians* or *A. irradians concentricus*. The species is characterized by rapid growth, high fecundity and a high market value (Castagna,1975; Castagna & Duggan, 1971,1972). The hatchery technology is well known and successful manipulation of adult scallops in the hatchery can provide a sexually mature spawning stock throughout the year (Sastry & Blake,1971; Barber & Blake,1981). A number of companies have attempted to culture scallops but have not been economically successful and there

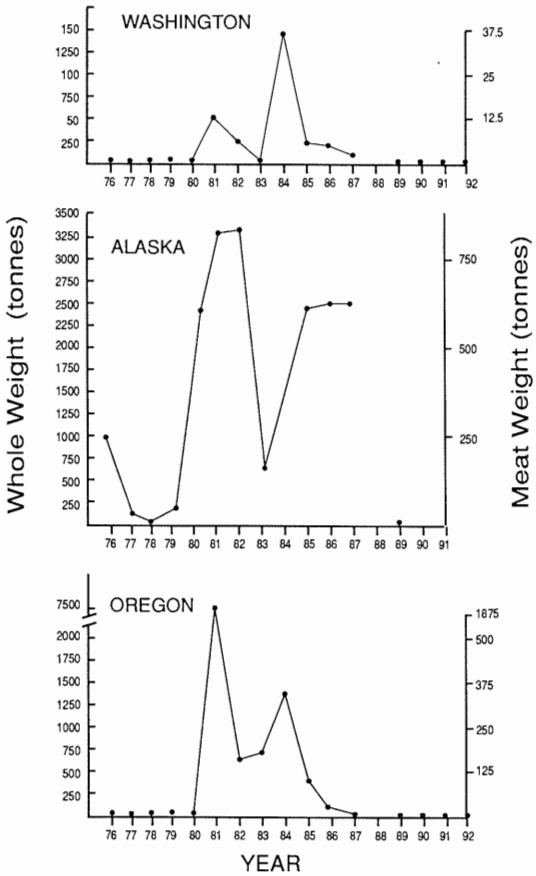

FIG.10. Landed value of weathervane scallops, *Patinopecten caurinus* (Bourne, 1990; NMFS, pers. comm.).

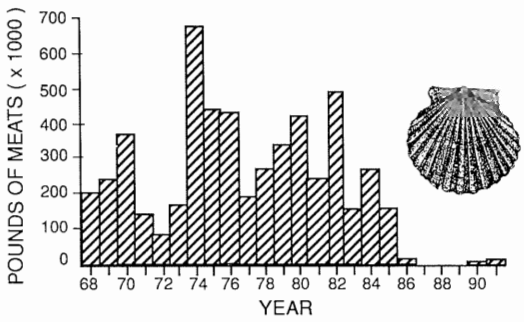

FIG.11. Commercial landings of bay scallops in New York (from Tettelbach & Wenczel,1990).

is no profitable, private aquaculture industry for bay scallops in the US (Rhodes,1990; pers. obs.).

This species has been successfully cultured in China (F. Zhang, K. Chew, pers. comm.) and the product is being imported to the US. Recent unexplained mortalities have been attributed to insufficient genetic diversity and new broodstock has been supplied by Canadian sources (Atlantic Fish Farming, February 27,1993).

A few companies have been involved in enhancement programs, also utilizing bay scallops. Perhaps the most successful is carried out by the Martha's Vineyard Shellfish Group which is a consortium of 5 towns (Chilmark, Gay Head, Oak Bluffs, Tisbury and West Tisbury) on Martha's Vineyard off the coast of Massachusetts. This group, using a number of federal and state grants, built a solar-assisted hatchery to produce *A. irradians irradians* and clams, *Mercenaria mercenaria* (Karney,1978). Their hatchery methods are standard except that the seawater is partially warmed in a passive solar system within the solarium-type building. The post-set scallops are held in an indoor, semi-closed nursery system supplemented with cultured algae until the juveniles are 3–5mm high, then moved out to a small embayment in burlap bags with a brick anchor and a plastic cola bottle inside the bag for a float. Several hundred to a few thousand seed are placed in each bag which is then anchored over the submerged vegetation in the bay. This allows the seed to grow to a size that offers sanctuary from some predators before the bag rots away allowing the juveniles to escape a few at a time and spread into the vegetation (R.C. Karney pers. comm.). Each township has legal jurisdiction over its own shellfish waters, sale of harvesting licenses and control of the harvest. Each township supporting the hatchery buys seed at about cost for replenishment or enhancement of an area. The effect of scallop enhancement has been to add a degree of stability to the harvest in the area that is seeded (Karney,1978).

Another enhancement program was carried out in the Long Island Sound area after heavy mortalities of native scallops caused by a picoplankter, *Aureococcus annophagefferens*. Extensive reseeding of hatchery-reared scallops was initiated in the Peconic Bays by the Long Island Green Seal Committee in 1986 (Tettelbach & Wenczel,1993). In the following two years, seed scallops (*A. irradians)* were purchased from a number of hatcheries and released in selected areas to enhance or replace the natural populations which were lost. The effects of this enhancement effort were not quantified in all areas, but

TABLE 6. Historic number of vessels, number of landings, landed weight of shucked meats, price per pound, exvessel value, landings per vessel, and exvessel value per vessel for the weathervane scallop fishery in Alaska during 1967-1991. All data for 1967-1968, and prices and exvessel values for 1967-1975 and 1979 were taken from Kaiser 1986); all other data were summarized from fish tickets. The 1991 data are preliminary. In years when only one or two vessels participated in a fishery, the harvest statistics are confidential. (from Kruse et al.,1992)

	No. of Vessels	No. of Landings	Landings Wt. (lbs)	Price ($/lb)	Ex-vessel Value ($)	Landings (lbs) per Vessel	Value ($) per Vessel ,
1967	Confidential						
1968	19	125	1,677,268	0.85	1,425,678	88,277	75,036
1969	19	157	1,850,187	0.85	1,572,659	97,378	82,772
1970	7	137	1,440,338	1.00	1,440,338	205,763	205,763
1971	5	60	931,151	1.05	977,709	186,230	195,542
1972	5	65	61,167,034	1.15	1,342,089	233,407	268,418
1973	5	45	1,109,405	1.20	1,331,286	221,881	266,257
1974	3	29	504,438	1.30	655,769	168,146	218,590
1975	4	56	435,672	1.40	609,941	108,918	152,485
1976	Confidential						
1977	Confidential						
1978	0	0	0	-	0	0	0
1979	Confidential						
1980	8	56	632,535	4.32	2,732,551	79,067	341,569
1981	18	101	924,441	4.05	3,743,986	51,358	207,999
1982	13	120	913,996	3.77	3,445,765	70,307	265,059
1983	6	31	194,116	4.88	947,286	32,353	157,881
1984	10	61	389,817	4.47	1,742,482	38,982	174,248
1985	9	54	647,292	3.12	2,019,551	71,921	224,395
1986	9	86	682,622	3.66	2,498,397	75,847	277,600
1987	4	55	583,043	3.38	1,970,685	145,761	492,671
1988	4	47	341,070	3.49	1,190,334	85,268	297,584
1989	7	54	525,598	3.68	1,934,201	75,085	276,314
1990	9	144	1,448,642	3.37	5,016,724	165,405	557,414
1991	6	136	1,136,649	3.72	4,228,334	189,442	704,722
1992	7	120	1,546,231	3.91	6,045,763	220,890	863,680

a number of scientists involved in this experiment initially believed the effects of the seed planting were minimal (Bricelj et al.,1987; Tettelbach & Wenczel,1993). Krause (1992), however, showed about 25% of the scallops in the area were survivors of those released. Subsequent reseeding efforts were further hampered by the shell-boring parasite, *Polydora* sp. and another 'brown tide'. While enhancement efforts are encouraging, the New York bay scallop fishery is precarious.

In the northeast there is some experimental culture of the sea scallop, *Placopecten magellanicus* at the hatchery on Beal Island, Maine. The technology for culturing this species has already been established in Canada; however aquaculture of this species has not been attempted in the US (Culliney,1974; Naidu & Cahill,1986; Beninger, 1987; Mallet,1988). The present study plans to test grow the scallops in near-bottom containers, either bags or cages. Some of these will be placed near salmon pens to see if the effluents will enhance growth rates. Initial studies by Belle (pers. comm.) indicate that increased growth rates can be realized in oysters and sea scallops grown in lantern nets suspended near salmon pens.

On the US Pacific coast, there has been some previous interest in culturing the rock scallop, *Crassadoma gigantea* (Jacobson,1977; Leighton & Phleger,1977,1981; Leighton,1979a,b; Monical, 1980; Cary et al.,1981,1982) and there is an experimental culture program in Washington for this species (Chew, pers. comm.). A project was

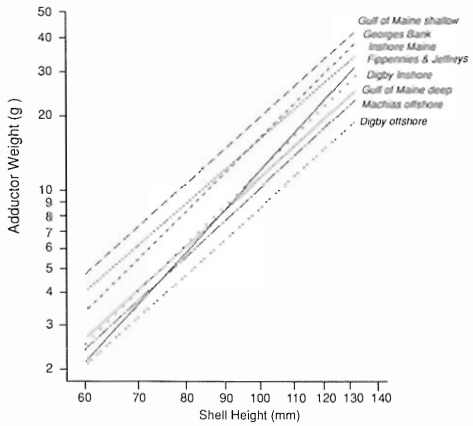

FIG.12. Regression analyses for adductor weight vs. shell height for *Placopecten magellanicus* from various geographic locations (Schick et al. 1987).

initiated in Alaska in 1987 to determine the feasibility of culturing weathervane scallops utilizing natural spat sets. In the Washington state hatchery, after preliminary culture experiments on *Pecten caurinus* and *C. gigantea* (Olsen, 1981, 1983), *C. gigantea* was grown and released in an attempted enhancement program (Olsen,1984); however, the numbers released were insufficient to follow. Efforts have also been made to collect juvenile pink and spiny scallops from natural spat sets; however these species are too small and too slow growing to support an economical culture operation (Bourne, 1990).

Except for small, sporadic releases of *Argopecten* or *Crassadoma* over the years, there are no major scallop enhancement programs in the US. Scallop culture (mainly research) is underway in Maine, Massachusetts, New York and Virginia; however, it can hardly be considered a significant or economically feasible activity.

ACKNOWLEDGEMENTS

We are indebted to Barbara O'Bannon, Robert Morrill, and John Bishop of the National Marine Fisheries Service for landings data and helpful discussions. Thanks also to Gordon Kruse for making Table 6 available. Jan Barter prepared the tables and Jim Rollins drafted the figures.

LITERATURE CITED

ANONYMOUS 1992. Status of fishery resources off the northeastern United States for 1992. NOAA Technical Memorandum NMFS-F/NEC-95: 1–133.

BENINGER, P.G. 1987. A qualitative and quantitative study of the reproductive cycle of the giant scallop, *Placopecten magellanicus*, in the Bay of Fundy (New Brunswick, Canada). Canadian Journal of Zoology 65: 495–498.

BARBER, B.J. & BLAKE, N.J. 1983. Energy storage and utilization in relation to gametogenesis in *A. irradians concentricus* (Say). Journal of Experimental Marine Biology and Ecology 52: 121–134.

BLAKE, N.J. & MOYER, M.A. 1990. The calico scallop, *Argopecten gibbus*, fishery of Cape Canaveral, Florida. Pp. 00–00. In S.E. Shumway, (ed.), 'Scallops: biology, ecology and aquaculture'. (Elsevier: New York).

BOURNE, N. 1990. West coast of North America. Pp.925–939. In S.E. Shumway, (ed.), 'Scallops: biology, ecology and aquaculture'. (Elsevier: New York).

BRICELJ, M., EPP, J. & MALOUF, R. 1987. Interspecific variation in reproductive and somatic growth cycles of bay scallops *Argopecten irradians*. Marine Ecology Progress Series 36: 123–189.

CARY, S.C., LEIGHTON, D.L. & PHLEGER, C.F. 1981. Food and feeding strategies in culture of larval and early juvenile purple-hinge rock scallops, *Hinnites multirugosis* (Gale). Journal of the World Mariculture Society 12: 156–169.

CASTAGNA, M. 1975. Culture of the bay scallop, *Argopecten irradians* in Virginia. Marine Fisheries Review 37: 19–24.

CASTAGNA, M. & DUGGAN, W.P. 1971. Rearing of the bay scallop, *Aequipecten irradians*. Proceedings of the National Shellfisheries Association 61: 80–85.

CASTAGNA, M. & DUGGAN, W.P. 1972. Mariculture experiments with the bay scallop, *Argopecten irradians*, in waters of the seaside of Virginia. Bulletin of the American Malacological Union 37: 21.

CHENEY, D.P. & MUMFORD, T.F. 1986. 'Shellfish and seaweed harvest of Puget Sound'. (University of Washington Press: Seattle).

CULLINEY, L.L. 1974. Larval development of the giant scallop, *Placopecten magellanicus* (Gmelin). Biological Bulletin 147: 321–332.

DORE, I. 1991. 'Shellfish'. (Van Nostrand Reinhold: New York). 240p.

FAO 1992. Aquaculture production 1984–1990. Fishery Information, Data and Statistics Service, Fisheries Department. FAO Fisheries Circular 815: 1–206.

HENNICK, D.P. 1973. Sea scallop, *Patinopecten caurinus*, investigations in Alaska. Final Report July 1, 1969–June 30,1972. Commercial Fisheries Research and Development Act, Project 5–23–R.

INGERSOLL,, E. 1886. The scallop and its fishery. American Naturalist 20: 1001–1006.

JACOBSEN, F.R. 1977. The reproductive cycle of the purple- hinge rock scallop *Hinnites multirugosus* Gale 1928 (Mollusca: Bivalvia). PhD Thesis, San Diego State University, San Diego, CA. 72p.

KAISER, R.J. 1986. Characteristics of the Pacific wethervane scallop [*Pecten (Patinopecten) caurinus* Gould,1850] fishery in Alaska. (Alaska Department of Fish and Game, Division of Commercial Fisheries: Kodiac) 100p.

KARNEY, R.C. 1978. A program for the development of the shellfisheries of five towns on Martha's Vineyard. First Annual Report to the Economic Development Administration, U.S. Dept. Commerce Technical Assistance Grant 01–6–01519.

KRAUSE, M.K. 1992. Use of genetic markers to evaluate the success of transplanted bay scallops. Journal of Shellfish Research 11: 199.

KRUSE, G.H., LARSON, P.R. & MURPHY, M.C. 1992. Proposed interim management measures for commercial scallop fisheries in Alaska. Alaska Department of Fish and Game, Regional Information Report 5J92–08.

LEIGHTON, D.L. 1979a. The rock scallop...a future in mariculture? Sea Frontiers 25: 18–19.

LEIGHTON, D.L. 1979b. A growth profile for the rock scallop *Hinnites multirugosus* held at several depths off La Jolla, California. Marine Biology 51: 229–232.

LEIGHTON, D.L. & PHLEGER, C.F. 1981. The suitability of the purple-hinge rock scallop to marine aquaculture. California Sea Grant College Program Technical Publication T–CSGCP–001: 1–85.

MALLET, A.L. 1988. Larval growth, larval mortality, and metamorphosis success of the giant scallop, *Placopecten magellanicus*. Atelier sur l'elevage du petoncle geant tenu a Gaspe (Quebec) les 30 Novembre et 1 Decembre 1988: 49–51.

MONICAL, J.B.Jr. 1980. Comparative studies on growth of the purple-hinge rock scallop *Hinnites multirugosus* (Gale) in the marine waters of southern California. Proceedings of the National Shellfisheries Association 70: 14–21.

NAIDU, K.S. & CAHILL, F.M. 1986. Culturing giant scallops in Newfoundland waters. Canadian Fisheries and Aquatic Sciences, Manuscript Report 1876: 1–24.

NAIDU, K.S. 1990. Sea Scallop, *Placopecten magellanicus*. Pp. 861–887. In S.E. Shumway, (ed.), 'Scallops: biology, ecology and aquaculture'. (Elsevier: New York).

O'BANNON, B.K. (ed.) 1992a. Fisheries of the United States,1991. NOAA/NMFS Current Fishery Statistics 9100: 1– 113.

O'BANNON, B.K. (ed.) 1992b. Historical Catch Statistics Atlantic and Gulf Coast States 1950–1991. NOAA/NMFS, Current Fishery Statistics 9210: 1–48.

OLSEN, S.J. 1981. New Candidates with aquaculture potential in Washington state: Pinto abalone (*Haliotis kamtschatkana*), weathervane scallop (*Pecten caurinus*), and purple-hinge rock scallop (*Hinnites multirugosus*). Journal of Shellfish Research 1: 133.

OLSEN, S.J. 1983. Abalone and scallop culture in Puget Sound. Journal of Shellfish Research 3: 113.

OLSEN, S.J. 1984. 'Completion report on invertebrate aquaculture shellfish enhancement project 1978–1983'. (Shellfish enhancement project, final report, October 1,1978–March 30,1983. Washington Department of Fisheries: Olympia). 85p.

RHODES, E.W. 1990. Fisheries and aquaculture of the Bay Scallop, *Argopecten irradians,* in eastern United States. In S.E. Shumway, (ed.), 'Scallops: biology, ecology and aquaculture'. (Elsevier: New York).

SASTRY, A.N. & BLAKE, J. 1971. Regulation of gonad development in the bay scallop *Aequipecten irradians* Lamarck. Biological Bulletin 140: 274–283.

SCHICK, D.F., SHUMWAY, S.E. & HUNTER, M. 1988. A comparison of growth rate between shallow water and deep water populations of scallops *Placopecten magellanicus* (Gmelin, 1791) in the Gulf of Maine. Amererican Malacological Bulletin 6: 1–8.

SERCHUK, F.M.,1983. Seasonality in sea scallop shell height-meat weight relationships: review and analysis of temporal and spatial variability and implications for management measures based on meat count. Woods Hole Laboratory Reference Document 83–85: 1–30.

SERCHUK, F.M. & RAK, R.S. 1983. Biological characteristics of offshore Gulf of Maine sea scallop populations: size distributions, shell height-meat relationships and relative fecundity patterns. NMFS/Woods Hole Reference Document 83–07: 1–42.

SHUMWAY, S.E. & SCHICK, D.F. 1987. Variability of growth, meat count and reproductive capacity in *Placopecten magellanicus*: are current management polices sufficiently flexible? ICES C.M. 1987/k.2 Shellfish Committee.

SHUMWAY, S.E. & CEMBELLA, A.D. in press. The impact of toxic algal blooms on scallop culture and fisheries. Reviews in Fisheries Science.

SHUMWAY, S.E. & CEMBELLA, A.D. this memoir. Toxic algal blooms: potential hazards to scallop culture and fisheries.

STATE OF NEW YORK CONCERVATION DEPARTMENT 1969. Early oyster culture investigations by the New York State Conservation Commission 1920–1926.

TETTELBACH, S.T. & WENCZEL, P. In press. Reseeding efforts and the status of bay scallop populations in New York following the occurrence of "brown tide" algal blooms. Journal of Shellfish Research.