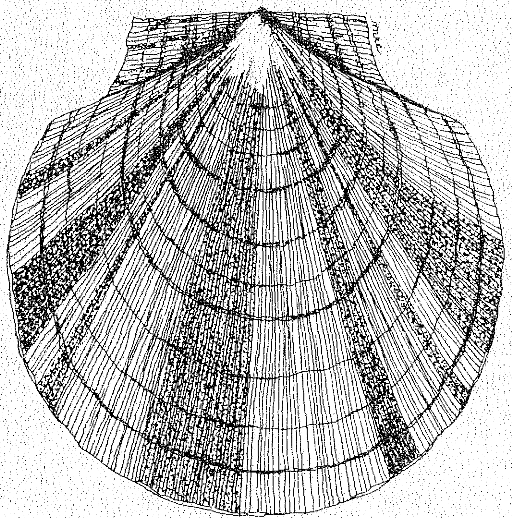

BIOLOGICAL & FISHERIES DATA ON SEA SCALLOP, *Placopecten magellanicus* (Gmelin)

FEBRUARY 1979

Biological and Fisheries Data

on

sea scallop, *Placopecten magellanicus* (Gmelin)

by

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FIGURES

1. IDENTITY

1.1 Nomenclature (taken from Merrill, 1959)

1.1.1 Valid Name

Placopecten magellanicus (Gmelin)

1.1.2 Objective Synonymy

Ostrea grandis Solander, 1776 [nomen nudum]

Ostrea magellanica Gmelin, 1791

Pecten magellanicus (Gmelin), Lamarck, 1819

Pecten tenuicostatus Mighels and Adams, 1841

Pecten fucus Linsley, 1845 [nomen nudum]

Pecten brunneus Stimpson, 1851

Pecten tenuicostatus solidus Verkrüzen, 1881

Pecten clintonius "Say" Verrill, 1884 [non Say]

Pecten tenuicostatus aratus Verrill, 1884

Pecten clintonius tenuicostatus Verrill, 1884

Pecten pleuronectes Jacobs, 1885 [nomen nudum]

Pecten (Pseudamusium) *striatus* "Müller" Dall, 1889 [non Müller]

Pecten (Pseudamusium) *mülleri* "Dall" Verrill, 1897 [non Dall]

1.2 Taxonomy

1.2.1 Affinities

Phylum: Mollusca
  Class: Bivalvia
    Subclass: Pteriomorphia
      Order: Pterioida
        Suborder: Pteriina
          Family: Pectinidae
            Subfamily: Pectininae

Types: "The location of the type specimen of Ostrea magellanica Gmelin is unknown. Gmelin referred to Chemnitz, Conch. Cab. 7, Pl. 62, fig. 597 and this is here selected as the type figure. The locality, Straits of Magellan, given by Gmelin, was in error. The type locality is here designated as Georges Bank, off Massachusetts where over 80% of the commercial catch is obtained." (Merrill, 1959).

Description: Shell resting on right valve, large, 12.5 to 20.0 cm long, subcircular, and compressed. Valves subequal, slightly convex, the right somewhat flatter in form, smoother in sculpture and paler in color. Shell valves moderately thin, lips simple. The valves gaping near the dorsal hinge-line but meeting along the ventral margin with the left (upper) valve slightly overlapping. Radial sculpture apparent in the valves in the form of raised ribs which are more pronounced in the left valve and sometimes imbricated. Concentric sculpture consisting of inconspicuous lamellae or growth lines which at intervals are more prominent because occasionally marginal growth stopped with subsequent thickening of the shell in that area. Color of left valve usually various shades of reddish brown, rarely shades of yellow or lavender; right valve is pale cream to white. Hinge-line simple, straight, edentulous, provided internally with a thin hinge ligament overlying a narrow groove which is separated by a triangular resilium centrally located between the beaks of the valves. Wings of the left valve small and nearly equal; the right valve is asymmetrical because a small shallow sinuation exists at the base of the anterior wing to form the byssal notch. The dorsolateral slope above the notch ridged, pectinidial teeth obsolete in the adult. Inner surface lustrous and smooth unless roughened by secretions laid down in repairing damage caused by boring organisms. Adductor muscle and pallial scars distinct; in some specimens the suspensory gill muscle scars also clearly seen. Area within adductor muscle scar has a pearly luster; area outside the muscle scar, but within the boundary of the pallial line, is of a crystalline structure. Adductor muscle scar almost centrally located, just slightly nearer the dorsal and posterior border; the scar in the left valve much larger (Merrill, 1959).

The juvenile scallop at a length of about 5 mm has some features which are dissimilar from those of the adult. The valves are subcircular, higher than long, the right somewhat flatter. The valves thin, the right especially so. Lips fragile, meeting at the ventral margin, the upper or left valve slightly overlapping. The gaping of the valves below the wing less noticeable than in the adult. Umbo of left valve prominent, overlapping the hinge-line. Sculpture of left valve more pronounced. Radial sculpture present in left valve as fine vermiculated lines within strong ribs; radial sculpture lacking in right valve at this length.

Concentric sculpture strong in left valve, but fine and delicate in right. Shape of hinge and resilium similar to the adult except that the hinge-line is proportionately wider. Wings large, fairly well-developed, the anterior ones well sculptured. Wings nearly equal except that the anterior wing of the right valve is sharply keeled in forming the byssal notch and is separated from the body of the shell by a narrow groove. Pectinidial teeth present along a raised ridge; teeth sometimes lacking or few in number. Inner surface smooth, the muscle scar distinct, the pallial line somewhat less so but with crystalline structure present within its confines. Muscle scar well off center, more so in the right valve. Right valve much thinner and more translucent than left so that the muscle and pallial scars show through it. A layer of prismatic structure can be defined in the thin right valve. The prisms have irregular shapes and are laid down in an uneven concentric pattern. The prismatic layer cannot be seen in lengths much greater than 5 mm and is more apparent in smaller scallops (Merrill, 1959).

Some height-length relationships of some typical sea scallops are as follows (Merrill, 1959):

Height (cm)	Length (cm)	Location
0.5	0.5	Nantucket Shoals (Lat. 40°33'N; Long. 69°28'W)
6.0	5.9	East Georges Bank (Lat. 41°23'N; Long. 66°25'W)
10.2	10.2	East Georges Bank (Lat. 41°23'N; Long. 66°25'W)
13.0	13.3	East Georges Bank (Lat. 41°23'N; Long. 66°25'W)
17.8	18.8	Cape Cod Bay, near Brewster, Massachusetts

The ligament of the sea scallop consists of two layers, the outer extending along the dorsal margin of the valves, and the inner situated between the valves in the umbo region. The outer layer appears fibrous and is somewhat similar to the outer layer of the ligaments of other lamellibranchs. The inner layer consists of three parts, a large central noncalcified structure and two lateral calcified regions which attach the central structure to the valves. The central structure, which consists mainly of a tanned protein complex, is gelatinous. When the valves are closed, the outer layer is subjected to tensile stress and the inner to compression, and the force so derived tends to open the valves (Trueman, 1953a, b). The ligament contains 16 amino acids; glycine comprises about two-thirds of the amino acids on a weight basis (Kahler et al., 1976).

Etymology: Plac - a flat plate; pecten - a comb; magellan - Strait of Magellan; icus - belonging to.

1.2.2 Standard Common Names

Sea scallop, giant sea-scallop, giant scallop, Atlantic deepsea scallop, ocean scallop, smooth scallop.

1.3 Morphology

1.3.1 Shell Morphology

See 1.2.1 and Figure 1.

2. DISTRIBUTION

2.1 Adults

The sea scallop ranges from the north coast of the Gulf of St. Lawrence (Posgay, 1957b) to SSE of Cape Hatteras (Porter, 1974). Scallop populations of sufficient area and density to support a fishery occur from Port au Port, Newfoundland (Lat. 48°30'N) to the Virginia Capes (Lat. 36°50'N) (Posgay, 1957b). The largest concentrations of the scallop are on Georges Bank and the Middle Atlantic shelf; smaller concentrations occur along the coast of Maine, in the Bay of Fundy (particularly off Digby, Nova Scotia), the Gulf of St. Lawrence, on St. Pierre Bank, and in Port au Port Bay, Newfoundland.

North of Cape Cod, the scallop ranges inshore to just below the low tide mark, and in a few small sites in Maine, it occurs intertidally, but elsewhere, it occurs in much deeper water. Usually, scallop populations sufficiently large to support a commerical fishery are found at depths from 40 to 100 m with some records to 200 m (Posgay, in press).

2.2 Eggs and Larvae

The eggs and larvae of the sea scallop are dispersed in the water. Studies of the geographic distribution of sea scallop larvae have never been made, and thus, larval distribution can only be deduced from spatfall locations and circulation patterns. It is believed that the eggs and larvae have the same general geographic distribution as the adults.

3. BIOTIC POTENTIAL, LIFE HISTORY, AND BEHAVIOR

The biotic potential (the maximum intrinsic capacity in a population to increase) of the sea scallop is only partially known. Egg production by individual scallops has never been measured, but it probably totals millions of eggs each season. Growth and physiological mortality rates

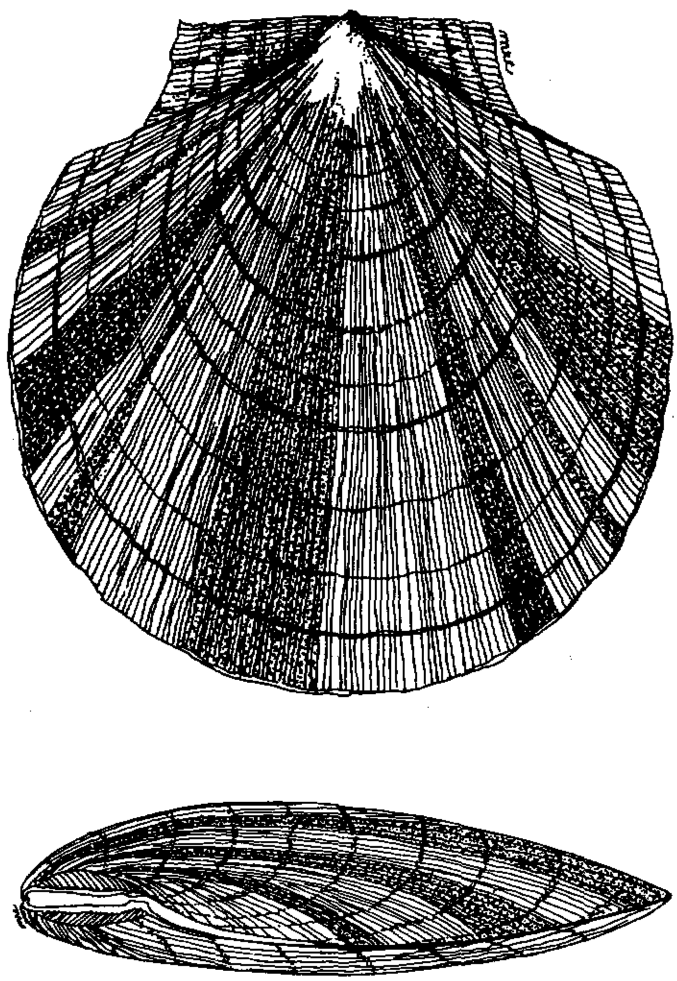

FIGURE 1. Sea scallop (Placopecten magellanicus).

have been measured and are described in this section. Longevity in the scallop has not been examined; nevertheless, a scarcity of empty, full-length scallop shells on the beds suggests that individual scallops have longevity (at least 15 years).

3.1 Reproduction

3.1.1 Sexuality

The sexes are normally separate, but rare instances of hermaphroditism occur: two of about 3,000 sea scallops from Georges Bank (Merrill and Burch, 1960); and 42 of about 3,000 scallops from Port au Port, Newfoundland (Naidu, 1970), contained male and female parts in their gonads.

3.1.2 Maturity

The earliest age and smallest length at which the sea scallop can spawn is known only from observations in Newfoundland. Scallops spawn after their first growth ring is formed at a length of about 2 to 3 cm. A scallop 5.0 cm long was observed spawning on Georges Bank (Posgay and Norman, 1958). Probably, the largest scallops with correspondingly large gonads, however, contribute most to total egg production (Posgay, in press).

3.1.3 Gonads

The size and shape of the gonad is similar in the male and female sea scallop. The gonad is tongue-shaped and occupies most of the body ventral to the foot. It extends dorsally to form a thin layer over the surface of a portion of the digestive gland. When ripe, it is large and plump, but after spawning it becomes much smaller, shriveled, and flaccid. At maturity, the sexual products are easily observed through the gonad covering; the sperm give a whitish appearance to the male gonad; the ova give a bright red appearance to the female gonad (Merrill and Burch, 1960).

The testicular follicles are tightly packed and are covered by the same kind of squamous cell layer that covers the ovarian follicles. Inside the follicle and adjacent to the covering epithelium is a layer of spermatogonial cells up to several cells thick. Progressing inward toward the lumen of the follicle are primary and secondary spermatocytes, followed by spermatids, then mature sperm at or near the center. The tails of the spermatids are usually located in the most central part of the follicle (Merrill and Burch, 1960). Spermatogenesis occurs more rapidly than oogensis; flagellated spermatozoa are about 40-50 microns long (Naidu, 1970).

The ovarian follicles are closely crowded and are packed with mature ova which take the shape of polyhedrons. The lumina of the follicles are tightly filled. Each follicle is lined on the outside by a single layer of squamous epithelium. Inside the follicles, the individual ova are separated by a nongranular intracellular substance sandwiched between and separting the cell membranes. Ova average about 45-50 microns in diameter in fixed material (Naidu, 1970, reported the average ova diameter as 80-90 microns). The germinal vesicles are large and clear, and contain a fine network of chromatin and several conspicuous nucleoli (Merrill and Burch, 1960).

3.1.4 Spawning

Off the coast of North Carolina and Virginia, the sea scallop spawns during July (MacKenzie et al., 1978). In the mid and northern parts of the range, scallops spawn later. In various areas, the following dates for spawning have been reported: Georges Bank, September (Posgay and Norman, 1958); late September and early October (MacKenzie et al., 1978); Cape Cod Bay, late September and early October (Posgay, 1950); Isle of Shoals, New Hampshire, late September (Culliney, 1974); Maine, late August (Drew, 1906), August and September (Welch, 1950); late August to early October (Baird, 1953); Bay of Fundy, August (Stevenson, 1936); late August to early September (Dickie, 1953); and Port au Port Bay, June, September, and October (Naidu, 1970). Probably, spawning ends on Georges Bank in October (MacKenzie et al., 1978).

In New Hampshire, sea scallop spawning was observed at 14°-16°C, and in the laboratory at 10°-15°C (Culliney, 1974). Off the coast of Chincoteague Bay, Virginia, 68% of males and 75% of females had spawned (temperature about 11°C), and off southeastern Long Island, 60% of males and 54% of females had spawned (temperature about 6.5°C) during August 7-16, 1975 (MacKenzie et al., 1978). On Georges Bank, scallop spawning was observed at temperatures between 8° and 11°C (Posgay and Norman, 1958). In Port au Port Bay, Newfoundland, scallops spawned when temperatures ranged between 4.2° and 16.1°C (Naidu, 1970).

On Georges Bank, a bed of sea scallops was once observed spawning over a short time span, most scallops going from completely ripe to completely spent in less than a week (Posgay and Norman, 1958; Posgay, 1976). Probably, scallop spawning is normally much more protracted (Naidu, 1970). Following mass spawning, eggs are fertilized by sperm in the water. After spawning is completed, gonad recovery begins in November and continues through March (Haynes, 1966).

3.2 Pre-Adult Phase

3.2.1 Larval Development

The only available information on development of sea scallop larvae is from laboratory culture experiments by Culliney (1974). Development from the egg, which is 64 microns in diameter when fertilized, to the earliest swimming stage lasted between 30 and 40 hours at 12°C, 32 o/oo. The embryos first became motile at the ciliated gastrula stage, which averaged 69 microns long and 63 microns in diameter. Embryos elongated slightly into a trochophore-like stage, then became typical shelled straight-hinge veligers on the fourth day after spawning. Straight-hinge larvae possess a short apical flagellum. The mean size of the earliest straight-hinge larva was 105 microns long by 82 microns wide. The hinge-line averaged 81 microns long. The ciliated gastrula developed to the straight-hinge stage over a temperature range of 12° to 18°C. The tiny apical flagellum disappeared, it could not be detected by the eighth day. The hinge-line remained visible until about the 13th day when larvae began to exceed 175 microns long x 150 microns wide. During larval development, shell length remained 25-30 microns greater than height. In swimming larvae, the extended velum had a unique "key-hole" outline, which was most pronounced in half-grown veligers. As larvae approached the pediveliger stage, the velum outline tended to become nearly oval.

The shape of the larval shell, standing on edge, revealed a slightly longer taper in the anterior than in the posterior direction. On the 23rd day, typical bivalve veliger eyespots appeared in the larvae that were larger than 230 microns long x 200 microns wide. By this time, the foot had also become prominent, although it was not yet observed extending outside the shell. In addition, many larvae showed a change in swimming behavior. Before the 23rd day, they were well dispersed in the water, although most swam in the upper third of the culture containers. After the 23rd day, increasing numbers of larvae swam in dense swarms, just above the bottom. As they approached the pediveliger stage, larvae often displayed the foot. The most conspicuous feature of the foot was a cluster of long, active cilia at its tip; it also had a well-formed heel or byssal spur. By the 28th day, more than 50% of the larvae possessed the functional foot characteristic of the pediveliger stage. Pediveligers crawled readily for short distances. Most had a gill rudiment. Average measurements of pediveliger larvae were 279 microns long x 242 microns wide with a depth of 127 microns. The hinge of the pediveliger larvae was almost featureless.

3.2.2 Setting Behavior

The only direct observations of setting of sea scallop larvae were of those in laboratory cultures maintained by Culliney (1974). Scallop larvae attach to objects by means of a byssus. The first scallop larvae attached (set) 35 days after egg fertilization. They were reluctant to attach to the bottom and sides of glass culture containers, but attached readily to fragments of sea scallop shells, 3 to 20 mm long, especially to their undersides, where they metamorphosed and became spat. Larvae also attached to small pebbles and glass fragments. In the laboratory, they also attach to glass walls of aquaria (Baird, 1953) and fiberglass walls of tanks (Caddy, 1972a). In nature, sea scallop spat attach to shells of live sea scallops (Naidu, 1970), small shell fragments on the bottom (Caddy, 1968), bryozoa (Baird, 1953; Caddy, 1972a), a red alga (Naidu, 1970), and metal and wooden navigation buoys (Merrill, 1965; Merrill and Posgay, 1967; Naidu, 1970; Merrill and Edwards, 1976). The attachment of larvae to various classes of physical objects suggests a generalized thigmotactic response. Whether the settlement is random or directed is not as yet known.

3.2.3 Post-Setting Behavior and Byssal Attachment

Some observations in laboratory culture of sea scallop spat were made by Culliney (1974). A conspicuous feature of spat setting was the presence of a strong, visible byssus which contrasted with the "invisible" threads produced by pediveligers. Crawling by spat was vigorous and extensive whenever the byssus was broken. At least some spat cast off their velum in large pieces, some of which were nearly whole.

The general features of the early life stages of the sea scallop on the bottom were described by Caddy (1972a). Upon metamorphosis, scallop larvae attach with a byssus to available substrata. When about 1.0 cm long in the year following spatfall, the scallops migrate to the bottom. Juvenile scallops spend up to 75% of their time attached to shells and stones on the bottom. A combination of attachment by means of a byssus and swimming makes for considerable versatility in habitat and behavior. The proportion attached decreases progressively from 75% for scallops that are 2-5 mm long to almost zero for those larger than 12 cm long. The largest scallop observed attached in the laboratory was 14 cm long. Byssal attachment in individual scallops is preceded by exploration of the substratum by the pallial tentacles around the byssal notch. The foot extends and probes the surface for several minutes before being held closely apposed to it for an average of 25 minutes (range, 16 to 45 minutes at 10°C). Upon retraction of the foot, a byssus thread connects its base to the substratum. The thread, initially plastic, hardens rapidly.

3.3 Nutrition

3.3.1 Larvae

Sea scallop larvae feed on plankton. In laboratory culture, larvae have been grown on the phytoflagellate, *Isochrysis galbana* (Culliney, 1974).

3.3.2 Juveniles and Adults

Juvenile and adult sea scallops are filter feeders and utilize plankton and perhaps some organic detritus as food (Posgay, in press). In laboratory culture, scallop spat have been reared on mixtures of *Isochrysis galbana* and *Chrosomonas salina* (Culliney, 1974). In the laboratory, adults have been kept alive on the diatom, *Phaeodactylum tricornutum*, for more than a year (Bourne, 1964).

3.4 Growth

Average values of shell length and meat weight of the sea scallop at ages 3 to 9 are as follows (Posgay, pers. comm.):

Georges Bank

Age(years)	3	4	5	6	7	8	9
Length(cm)	6.2	8.8	10.6	12.0	12.9	13.6	14.1
Weight(gm)	3.8	10.6	18.6	26.2	32.8	38.1	42.2

$$L_{t(mm)} = 152.46 \left[1-e^{-.3374\,(t-1.4544)}\right]$$

$$\ln W_{(gm)} = 2.949 \left(\ln L_{(mm)}\right) - 10.8421$$

Middle Atlantic Shelf

Age(years)	3	4	5	6	7	8	9
Length(cm)	6.5	8.8	10.4	11.7	12.6	13.2	13.8
Weight(gm)	5.1	12.5	21.3	29.9	37.6	44.0	49.3

$$L_{t(mm)} = 151.84\ [1-e^{-.2997\ (t-1.1256)}]$$

$$\ln W_{(gm)} = 3.0431\ (\ln L_{(mm)})-11.0851$$

Some data are available on growth of the juvenile sea scallop on Georges Bank during winter. Juveniles grew from a mean length of 1.0 mm in February 1977, to 1.3 mm in May 1977, an increase of 0.3 mm in three months (Larsen and Lee, 1978). Presumably, growth is much faster during warmer months.

Scallop spat that had set on navigation buoys grew to lengths of about 5 mm in six months, 12 mm in 12 months, and 20 mm in 18 months (Merrill and Posgay, 1967).

3.5 Physiological Mortality Rate

On Georges Bank only, the physiological mortality rate of the sea scallop has been studied: Scallops die during all months; the average instantaneous mortality rate is about 0.10 (Merrill and Posgay, 1964).

3.6 Behavior

3.6.1 Swimming and Possible Migrations

The sea scallop is capable of "swimming". To swim, the valves are first opened wide and then the velum edges are pressed together along the entire periphery except for two small ports that are formed alongside each "ear" or wing. A strong swift contraction of the powerful adductor muscle forces a jet out of each port and propels the scallop through the water with the hinge aft. Each clap of the valves results in about 15 cm of travel (Posgay, 1950). The following observations of sea scallop swimming have been made by SCUBA divers: The mean height reached above bottom during a swim was 0.4 m; ground speeds exceeded 67 cm/sec; and point-to-point swimming distances ranged up to 4 m. Scallops longer than 10.0 cm rarely attempted to swim (Caddy, 1968). More extensive swims have been reliably reported on Georges Bank; small sea scallops have been observed on the water surface where the depth exceeded 46 m (Posgay, 1953).

No evidence exists for long distant movements or seasonal migrations of entire populations of the sea scallop (Baird, 1954; Dickie, 1953, 1955; Posgay, 1963).

4. POPULATION

4.1 Structure

4.1.1 Sex Ratio

The sex ratio of the sea scallop is about 1:1 (MacKenzie et al., 1978).

4.1.2 Length at First Maturity

See section 3.1.2.

4.1.3 Maximum Length

The largest sea scallop ever measured was 23 cm long (Norton, 1931).

4.1.4 Length and Weight Relationship

Regressions of sea scallop adductor muscle meat weight on shell length from various localities are shown in Figures 2 and 3 (Haynes, 1966).

4.2 Abundance

4.2.1 Variations with Depth

In a particular locality, sea scallop abundance varies with depth. For example, on Georges Bank, in a 1975 research cruise survey, scallops were collected at depths ranging from 37 to 100 m; 13% came from 37 to 50 m; 54% from 51 to 75 m; 33% from 76 to 100 m; mean depth for scallops was about 68 m. On the Middle Atlantic shelf, in the same survey, scallops were collected at depths ranging from 31 to 80 m; 24.8% came from 31 to 50 m; 75% from 51 to 75 m; and the remaining 0.2% were from 76 to 80 m; mean depth for scallops was about 55 m (MacKenzie et al., 1978).

4.2.2 Density

Only fragmentary information is available concerning sea scallop population densities. In February 1977, on Georges Bank, densities of scallop spat ranged from 1.7 to 122.8 per m^2 (16 stations were examined), and in May 1977, 2.5 to 62.5 per m^2 (12 stations were examined) (Larsen and Lee, 1978).

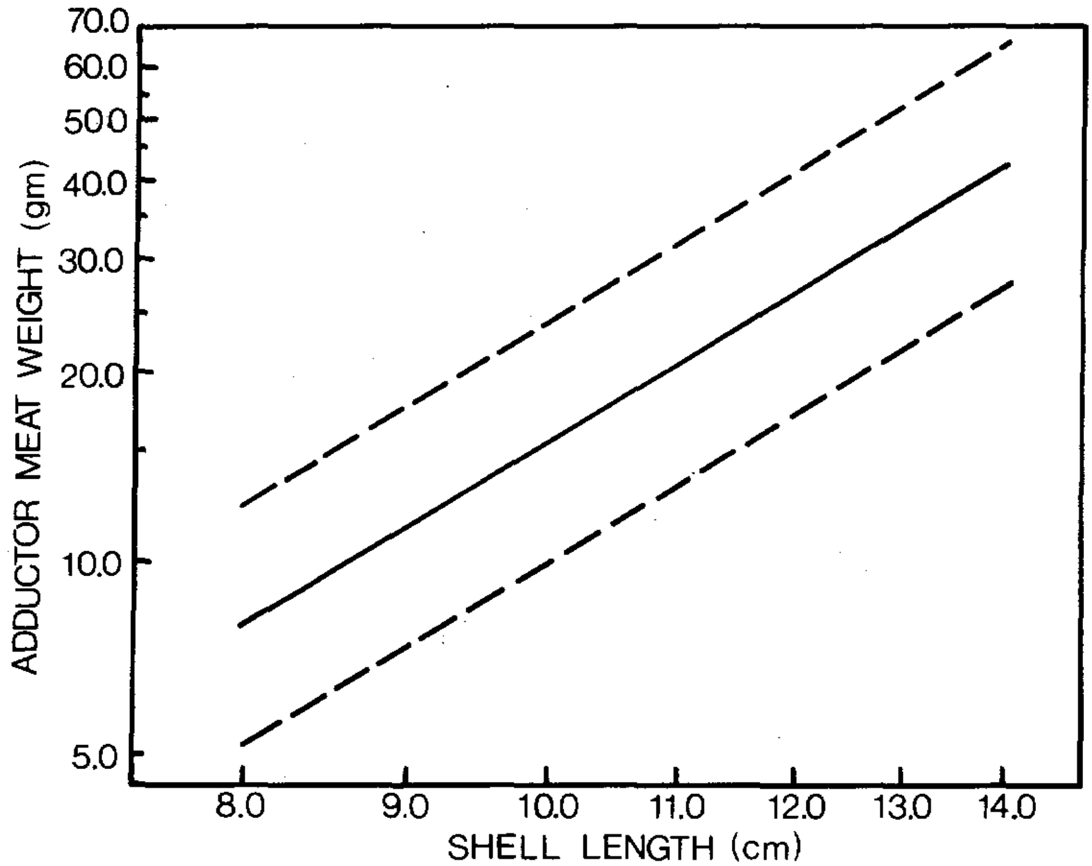

FIGURE 2. Regression line for Georges Bank sea scallops, all seasons and areas combined. The broken lines show the limits within which 95% of the muscle meat weights may be expected to fall (from Haynes, 1966).

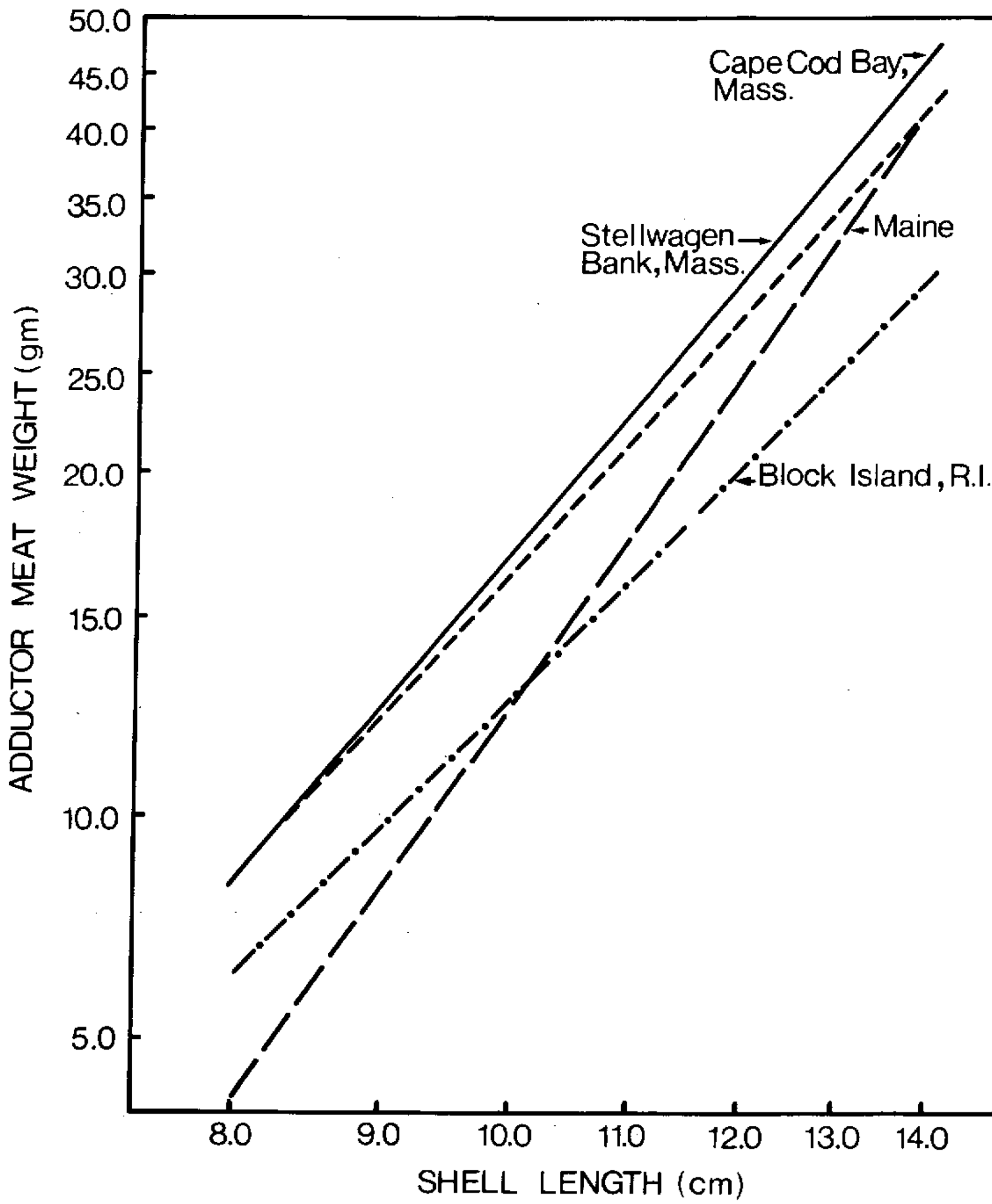

FIGURE 3. Regressions of muscle meat weight on shell length for sea scallops from four areas (from Haynes, 1966).

In 1969, on the northern edge of Georges Bank, in an area of 274 km^2, densities of scallops, nearly all of which were less than 10 cm long, averaged 0.98 per m^2 (Caddy, 1971a). In August 1977, in Northumberland Strait, Gulf of St. Lawrence, densities of scallops of mixed sizes averaged 4.2 per m^2 on sand bottom and 1.4 per m^2 on mud bottom (Caddy, 1968). In July 1968, in Northumberland Strait, densities of scallops of mixed sizes averaged 4.8 per m^2 on sand bottom and less than 0.1 per m^2 on mud bottom (Caddy, 1970).

4.3 Recruitment

The only information available on recruitment of the sea scallop is from reports that describe the results of occasional scallop surveys by United States and Canadian fisheries agencies. The surveys were usually conducted with dredges which had bags made of 5 or 7.5 cm (2 or 3 inch) rings.

Two substantial sets of sea scallop juveniles have been described in recent years. In 1966 and 1967, sets occurred on the northern edge of Georges Bank. In June 1970, the scallops were surveyed by Caddy (1971a); about 270 million scallops were distributed over 274 km^2 of the northern edge. Numbers of young scallops had not been seen on the Bank since 1959-60. In 1972, a widespread scallop set occurred on Georges Bank and the Middle Atlantic shelf. In 1975, the scallops were surveyed by MacKenzie et al. (1978). On the Bank, the 3-year-olds were spread over two-thirds of the northern edge and peak, one-third of the southwest part, and one-third of the South Channel. On the shelf, the 3-year-olds extended from mid-Long Island to the mouth of Chesapeake Bay over nearly the full width of the area normally occupied by scallops. Beyond that, they were also found off the southeastern tip of Long Island and off Albermarle Sound, North Carolina. The largest concentrations on the shelf were found off southeastern Long Island, New Jersey, and Virginia.

4.4 The Population in the Community and the Ecosystem

On Georges Bank, the sea scallop grows on bottoms consisting of sand, gravel, rocks, boulders, and molluscan shells. On the Middle Atlantic shelf, it grows on bottoms consisting of sand and sand-gravel (MacKenzie et al., 1978).

In some areas of Georges Bank, the scallop is associated with the following mollusks: *Lunatia heros*, *Buccinum undatum*, *Colus stimpsoni*, *Neptunea decemcostata*, *Modiolus modiolus*, *Chlamys islandica*, *Astarte islandica*, *Astarte* sp., and *Spisula solidissima* (MacKenzie, unpublished observations).

In some areas of the Middle Atlantic shelf, the scallop is associated with the following mollusks: *Crucibulum striatum*, Lunatia heros, Buccinum undatum, Modiolus modiolus, Venericardia borealis, Astarte subequilatera, Spisula solidissima, Ensis directus, Arctia islandica (Merrill, 1962a); also Busycon carica, Busycon canaliculatum, and Argopecten gibbus (MacKenzie, unpublished observations).

In Chaleur Bay, off the Gulf of St. Lawrence, the scallop is associated with the species listed below. The scallop grounds, at 40-50 m depth, consist of sand overlaid by glacial gravel, 1-10 cm in diameter, which is coated with Lithothamnion. Besides the sea scallop, large epibenthic animals present in low density are: Metridium sp., Cucumaria frondosa, Strongylocentrotus drobachiensis, and the starfish, Leptasterias polaris, Solaster endeca, and Crossaster (Solaster) papposus (Caddy, 1973).

The animals that grow on the sea scallop shell are: boring sponges, sea anemones, branching and encrusting bryozoans, branching hydroids, pelecypods, barnacles, tube worms, other annelids, and simple and colonial ascidians. The species on the shell are those common on any suitable substrate in the vicinity of the scallops. Small scallops, being active, usually collect few animals on their shells, but large scallops, being sedentary, may become heavily fouled (Merrill, 1960, 1961).

Some effects on the sea scallop from the attached hydroid, Hydractinia enchinata, have been reported by Merrill (1967a). The hydroid can grow around the shell margin of the scallop, become established on the internal shell surface, and then interfere with the normal activity of the scallop's mantle, often causing shell deformity. The scallop reacts by producing a new shell edge within the existing shell perimeter and bypasses the hydroid colony. No evidence exists that H. echinata kills the scallop. Apparently, the other fouling animals do not cause similar effects. On Georges Bank and the Middle Atlantic shelf, H. echinata occurs at depths from 29 to 113 m (29 m was the shallowest depth sampled).

On Georges Bank, the bivalve mollusk, Musculus dicors, along with its eggs and offspring, lives in nests on the upper valve of the scallop (Merrill, 1962b; Merrill and Turner, 1963).

The burrowing anemone, Ceriantheopsis americanus, occurs within the sea scallop distribution at least on Georges Bank and the Middle Atlantic shelf.

5. FACTORS THAT LIMIT POPULATION DISTRIBUTION AND SIZES

Environmental resistance (the sum total of all factors that prevent the biotic potential from being realized) is only partially understood in the sea scallop.

5.1 Physical Constraints

The sea scallop dies at temperatures above 20°-24°C (Posgay, 1953; Johannes, 1957; Dickie, 1958); once, in laboratory culture, scallop larvae died at a temperature of 19°C (Culliney, 1974).

Temperature limits the north-south distribution of the sea scallop, and probably the inshore distribution on the Middle Atlantic shelf. In Canada, spawning and larval development of the scallop are prevented or delayed by exceptionally low summer temperatures, leading to insignificant scallop sets (Dickie, 1955; Medcof and Bourne, 1964); on the other hand, mortalities in the scallop can result from exceptionally high summer temperatures (Dickie, 1958; Dickie and Medcof, 1963). At the southern end of the scallop range off Cape Hatteras, North Carolina, the average 20°C isotherm is near shore and extends northward until it is parallel to the 100-fathom (182.9 m) curve. The sea scallop does not range much farther south or east of the Cape because the temperature is too high (Posgay, 1957b). The scallop ranges much closer to shore off Long Island than farther south off the Delmarva Peninsula (MacKenzie et al., 1978), because summer temperatures near shore off the peninsula are probably too high for the scallop.

The sea scallop generally occurs in areas where salinities are oceanic. Low salinity may affect scallop survival only in some shallow-water coastal areas that are affected by fresh-water run-off from land (Johannes, 1957). In laboratory culture, sea scallop larvae remained viable in a salinity of 10.5 o/oo and swam about normally at salinities from 16.9 to 30.0 o/oo within a 42-hour period (Culliney, 1974).

MacKenzie (1977) reported that the sea scallop dies in water which is depleted in oxygen. During the summer of 1976, anoxic and hypoxic bottom water covered a large area of the inner continental shelf off New Jersey. In July and thereafter for a few months, commercial fishermen and personnel on survey cruises by the National Marine Fisheries Service found that all sea scallops and most other biota were dead in the inner side of the distribution zone of the scallop. Approximately 10% of all sea scallops were killed on the shelf off New Jersey.

5.2 Parasites

Medcof (1961) found the flagellate, Hexamita sp., which is common in many mollusks, in a dying sea scallop in an aquarium. Dickie and Medcof (1963) found a ciliate, Trichodina sp., in healthy scallops from Passamaquoddy Bay, Maine, and Hexamita in a dead scallop in an aquarium.

5.3 Predators

The entire assemblage of predators that consume the sea scallop, as larvae, juveniles, and adults, has scarcely been examined. Presumably, 1) predators of larvae exist in the water and on the bottom, and 2) predators consume a great many juvenile scallops, which can be easily bored, cracked open, and swallowed whole. Predators cannot take many adults which are too large. The percentages of sea scallops beginning with the egg, larval, and juvenile stages that attain a commercial length have not been determined anywhere.

Identified predators of juvenile sea scallops include the cod (Gadus morhua), American plaice (Hippoglossoides platessoides), and wolffish (Anarhichas lupus) (Medcof and Bourne, 1964), and the starfish (Asterias vulgaris) (Welch, 1950; Dow, 1962, 1969; Medcof and Bourne, 1964). The juvenile sea scallop, ± 15 mm long, is also preyed upon by, as yet, unidentified gastropods (MacKenzie, unpublished observations). The burrowing anemone, Ceriantheopsis americanus, is suspected as a predator of sea scallop larvae (MacKenzie, personal observations). The anemone is widespread and abundant.

5.4 Combined Mortality Effects in Canada

The possible causes of low abundance and mortality of the sea scallop in Canada as described by Medcof and Bourne (1964) are listed below. Undoubtedly, some causes apply to other areas.

a) Low abundance and natural mortality

1. Low summer temperatures which fail to reach the spawning threshold.

2. Low summer temperatures which delay larval development.

3. Heavy flushing which sweeps larvae out to sea in basins, such as the Bay of Fundy.

4. Intermittant lethal increases in summer temperature, which are caused by wind-induced oscillations in the thermocline position.

5. Predators (see 5.3).

6. Parasites may kill or weaken scallops, but little study has been made of this aspect.

b) Fishing mortality

1. Bottom damage. Dredges can force scallops into soft bottoms, where scallops pack with mud.

2. Damage in dredges. Many small scallops that are discarded probably die when returned to the beds.

3. Boarding and dumping dredges on deck breaks some scallops.

4. Culling and trampling breaks some scallops.

5. Shovelling results in some damage.

6. Air exposure to two or three hours in hot weather can be lethal.

7. Shucking is the only cause of extensive direct fishing mortality. Hydrostatic pressure changes when brought to surface do not harm scallops.

A number of mass mortalities of the sea scallop in the Gulf of St. Lawrence have been described by Dickie and Medcof (1963). Predation by starfish is one cause; in 1950, in a bed off Richibucto, New Brunswick, starfish apparently consumed many scallops; laboratory studies showed that starfish can consume scallops in close confinement. Exposure to lethal high temperatures is another cause. Great increases and decreases in temperature occur on beds at intermediate and shallow depths. They are related to storm activity which changes the position of the thermocline. Starvation, senescence, disease, and weakness during spawning are unlikely mortality causes.

6. EXPLOITATION

6.1 Fishing Equipment

6.1.1 Gear

On Georges Bank and the Middle Atlantic shelf, the standard sea scallop dredge is used for gathering the sea scallop; in the Bay of Fundy and the Gulf of St. Lawrence, the Digby dredge is used; and on the Middle Atlantic shelf, the otter trawl is sometimes used.

The standard dredge consists of a heavy metal frame and a bag of steel rings. The frame is usually 3 to 4 m wide. It is made of 12.5 mm and 44 mm steel plate and is reinforced at the corners and at the central portion. The frame rests on 3 shoes, 9 cm high. The bail, made of 5.7 cm steel rod, is attached to the bottom of the frame and extends forward 2.1-2.8 m ending in an upturned nose. At the top of the frame is the sloping pressure plate, which helps keep the dredge on the bottom. The bottom, sides, and after part of the top of the dredge bag are made of steel rings, which have an inside diameter of 7.6 cm. The rings are connected by steel links. The forward part of the top of the bag is a section of webbing called "twine back" made of 8 mm manila or braided twine. A club at the end of the dredge maintains its shape and is used for dumping (Posgay, 1957a; Bourne, 1964).

The Digby dredge consists of a gang of small dredges, each about 75 cm wide, attached side by side to a straight iron bar. Each small dredge has two similar blades, parallel to one another, and about 20 cm apart. It can rotate on the bar, and, thus, whichever way it lands on the bottom, it can gather scallops. The small dredges consist of steel rings and links and hold about two bushels of material. A wooden club and a length of chain is attached at the end of each dredge to aid in dumping. In the Digby, Nova Scotia area, the dredge has a gang of as many as seven small dredges on a bar up to 5.5 m long (MacPhail, 1954). In the Gulf of St. Lawrence, the dredge has a gang of three or four small dredges on a bar 2.3 to 3 m wide (R. A. Chandler, pers. comm.).

The otter trawl is similar to the one used for catching finfish, but it is reinforced with chaffing twine on the bottom to prevent tearing while being towed.

6.1.2 Vessels

Vessels used for offshore sea scalloping range from 20 to 33.5 m long and are powered by diesel engines which range from 480 to 765 h.p. All vessels are equipped with depth finders, Loran navigating sets, and ship-to-shore radio-telephones. The decks have shucking boxes, a wash tank, and frames necessary for handling the dredges. A vessel carries a captain, a mate or engineer, a cook, and usually eight fishermen. At sea, it will fish 24 hours a day with the watch changing every six hours (Posgay, 1957a; Bourne, 1964; Altobello et al., 1977). In port, the dealer who purchases the scallops usually barrels or boxes them and then stores them in a refrigerator until they are sold, fresh or quick frozen (Posgay, 1957a).

The U. S. vessels rigged for sea scalloping operate from a number of ports, but New Bedford, Massachusetts has the largest concentration of vessels (Posgay, 1957a; Altobello et al., 1977). In the mid-1950's, most New Bedford vessels took about 113 metric tons of scallops worth about $130,000 a year (Posgay, 1957a). In the early 1970's, the annual landings were lower, but values were greater. Most New Bedford vessels took about 2.8 metric tons of scallop meats in eight to ten days at sea. The vessels averaged about 20 trips, landing 56 metric tons of scallops meats that were worth $235,000 a year (Mueller, pers. comm.).

The crew of a New Bedford vessel works under the lay system which stipulates that a predetermined percentage of the gross sea scallop stock remaining after shared expenses are deducted be paid to the crew and the rest to the vessel owner. The shared expenses include bonuses to the engineer, mate, cook, and watchman, and contributions to industrial promotion and advertising funds. A total of 3.5% of the gross stock is contributed to the New Bedford Fishermen's Welfare Fund and New Bedford Fishermen's Pension Fund. The crew's share is 64% and the owner's share is 36% of the remaining gross stock. Ten percent of the owners share is paid to the vessel captain, and expenses for such items as fuel, ice, and water are deducted from the crew's share. What remains of the crew's share is then divided equally among the crew and captain on the trip. The vessel owner is responsible for the gear and maintenance of the vessel (Altobello et al., 1977).

6.2 Fishing Areas

6.2.1 Geographic Range

The sea scallop is fished throughout its range wherever it is abundant.

6.3 Fishing Seasons

The sea scallop is fished throughout the year, except in territorial waters of the state of Maine where it can be taken only between November 1 and April 14.

6.4 Fishing Operations and Results

6.4.1 Effort and Intensity

Most sea scallop vessels pull two standard dredges, using a three:one ratio of warp length to water depth. The duration of tow depends on the scallop density and bottom type. Usually, tows last 25-30 minutes, but sometimes as little as ten minutes. The dredges are brought up alternately to be dumped on deck. After dumping, the crew picks out the scallops and shovels the trash and small scallops overboard. The scallop is shucked with a special knife into plastic or stainless steel buckets; the scallop shells and rims are discarded overboard. The scallop meats (eyes) are washed in seawater, packed in 18 kg (40 pound) bags, and then iced in the hold of the vessel (Posgay, 1957a; Bourne, 1964).

The 1970 fishing effort for the sea scallop per unit area of Georges Bank has been described by Caddy (1973, 1975). A fleet of 80 vessels each towing two dredges, which averaged 3.8 m wide, dragged over an estimated 7,700 km^2 of bottom. Even with some repetitive fishing, a considerable fraction of the 37,000 km^2 of the scallop grounds were dragged over in a year. Fishermen are successful at searching out areas of high scallop abundance.

6.4.2 Selectivity of Dredge

In the Gulf of St. Lawrence and on Georges Bank, the efficiency of the standard sea scallop dredge has been studied by Caddy (1968, 1971b). In the Gulf, the bottom site consisted of sand, and the scallop population was not attached by byssus during the observations. The scallop dredges took a greater percentage of large scallops than small ones from the population, because many small scallops rose from the bottom and swam away from the dredges. On Georges Bank, nearly every scallop was attached by byssus to gravel and could not swim. As a consequence, the dredges took a far greater percentage of small scallops than they had in the Gulf. More than half the scallops smaller than 8.75 cm that entered a dredge, however, passed through the bag - more passed through the interring spaces than through the rings. On the Bank, the overall efficiency of the standard dredge was estimated at 30% for all scallop lengths.

Bourne (1965) made a study to determine whether a change to larger rings in commercial sea scallop dredges would delay the taking of some small scallops that are ordinarily taken and shucked. The scallop meat yield from beds would thereby increase (see 6.4.4). In the test dredge, the ring diameter was increased to 10.2 cm (4 inches) from the usual diameter of 7.6 cm (3 inches). It was anticipated that most 5-year-old scallops about 9.5-10.8 cm long, which are ordinarily taken, would pass through and between the larger rings, and the dredge would collect only the scallops that were 6-years-old, about 10.8-11.8 cm long, and older.

When given trails, the dredge with 10.2 cm rings did not give the desired result, however, because the trash and larger scallops which collected in the dredge largely prevented escapement of the 5-year-old scallops.

6.4.3 Effects of Dredging on Bottom Environment

The effects of sea scallop dredging in the Gulf of St. Lawrence have been reported by Caddy (1973) as follows:

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 rough bottom. Mortalities to scallops with a standard dredge were at least 13 to 17% per tow.

3. Predatory fish and crabs are attracted to dredge tracks and had densities 3 to 30 times greater inside than outside the tracks soon after the dredging.

The probable adverse effects of sea scallop dredging on the environment of commercial finfish populations has not been examined.

The effects of "sanding" scallops during dredging has not been examined. Some scallops, especially small ones, become packed with sand during dredging on sand bottoms. Scallops gathered and passed over by dredges can become sand packed. Fishermen return most small scallops to the bottom. No one knows whether the sand-packed scallops survive.

6.4.4 Dynamics of a Commercially-Exploited Sea Scallop Population

Maximum yield in a fishery is realized when the required amount of fishing effort is expended during the years when a year class has reached its greatest biomass. The parameters which must be measured to calculate maximum yield are: 1) the growth rate, 2) the physiological or natural mortality rate, and 3) the fishing mortality rate (Posgay, 1962).

The growth rate of the sea scallop is shown in 3.4.

On Georges Bank, the physiological mortality rate of the sea scallop is about 0.10 (Merrill and Posgay, 1964). See 3.5.

The fishing mortality rate of the total sea scallop population is difficult to determine precisely because the fishing fleet takes scallops only from areas of greatest abundance. Total instantaneous mortality rate (Z) in areas where scallops are being taken has been estimated from research survey data, by comparing the numbers (N_1) of scallops over the cull length taken in some limited area with the numbers (N_2) taken in the same area at some later date, allowing for growth during the interval. Then $Z = (\ln N_1 - \ln N_2)/\Delta t$. As an illustration, on Georges Bank, 14 unit areas where scallops were being taken were sampled with 80 well-spaced tows in July 1967. The average catch in numbers of scallops longer than 9.5 cm was 35.08 per 10,000 square feet of bottom. The same unit areas were sampled again with 81 tows in September 1968 (Δt is 1.17 years). The average catch in numbers of scallops longer than 11.3 cm, the length to which a 9.5 cm scallop would have grown in the interval, was 11.62 per 10,000 square feet of bottom. Therefore, the estimated Z value for the area was 0.94 at that time (equivalent to an annual mortality rate of 61%). Between 1975 and 1977, for western Georges Bank, the estimated total instantaneous mortality rate was 0.31, and for the Hudson Canyon area, 0.84 (the rates are equivalent to annual mortality rates of 27% and 57%, respectively) (Posgay, pers. comm.).

On Georges Bank, during the late 1960's and early 1970's, the age at which the sea scallop was first taken by fishermen usually varied from ages 3 to 5 (Caddy, 1972b,c; Brown et al., 1972). The biomass of each scallop nearly doubles between ages 3 and 6. Thus, a far greater scallop biomass would be available to the fishermen had the age at first capture been delayed. If the instantaneous fishing mortality rate were 0.7, one-year delays in the taking of separate year classes, 3 to 6, would give increases in total scallop biomass as follows: 3 to 4, 42%; 4 to 5, 21%; 5 to 6, 4%; and 6 to 7, 3%. Beyond year class 7, the scallop biomass declines (Brown et al., 1972). On Georges Bank, the maximum yield per recruit occurs at an age of first capture of about 7 with an instantaneous fishing mortality rate of about 0.7; on Middle Atlantic shelf, it occurs at an age of first capture of about 7 with an instantaneous fishing mortality rate of about 0.4 (Posgay, pers. comm.).

6.4.5 Sea Scallop Landings

In the U. S., in 1930, landings of sea scallops meats totalled about 1 thousand metric tons. In 1950, the total rose to about 9 thousand metric tons, after dropping during World War II to 2-3 thousand metric tons, following a 1939 total of about 4 thousand metric tons. From 1950 to 1964, landings fluctuated between 9-13 thousand metric tons. After 1964, because supplies and effort on the beds decreased, landings dropped sharply, and from 1969 to 1974, they totalled only 2-3 thousand metric tons a year. In 1972, a widespread scallop set occurred, and in the late 1970's, it led to a sharp increase in landings; in 1977, about 10.5 thousand metric tons were landed. See Figure 4.

In Canada, from 1945 to 1950, annual landings of sea scallop meats averaged about 450 metric tons. Landings rose sharply thereafter, and in 1962 totalled more than 6 thousand metric tons (Bourne, 1964). From 1963 to 1975, annual landings fluctuated from nearly 5 thousand to just above 7 thousand metric tons (FAO, 1968, 1975). In 1976, total landings were 8.5 thousand metric tons (ICNAF, 1977).

6.4.6 Relative Change in U. S. and Canadian Fishing Effort

The late 1950's marked the beginning of a major change in relative effort in sea scallop fishing by the United States and Canada. The U. S. scallop fleet became smaller while the Canadian fleet became larger. In 1957, 86% of sea scallops landed along the western Atlantic coast were gathered by U. S. vessels; the remaining 14% by Canadian vessels. In 1962, the relative quantities landed were 64% by U. S. vessels, 36% by Canadian vessels; in 1966, 47% by U. S. vessels, 53% by Canadian vessels (Posgay, 1968); and in 1969, 34% by U. S. vessels, 66% by Canadian vessels. In 1956, the New England scallop fleet had 141 vessels and 1,250 men. By 1971, it had only 43 vessels and 328 men (Altobello et al., 1977). In the mid-1950's, the New Bedford scallop fleet had 70 to 80 vessels (Posgay, 1957a); in 1967, it had 26 to 32 vessels, and in 1973, only 21 vessels (Altobello et al., 1977).

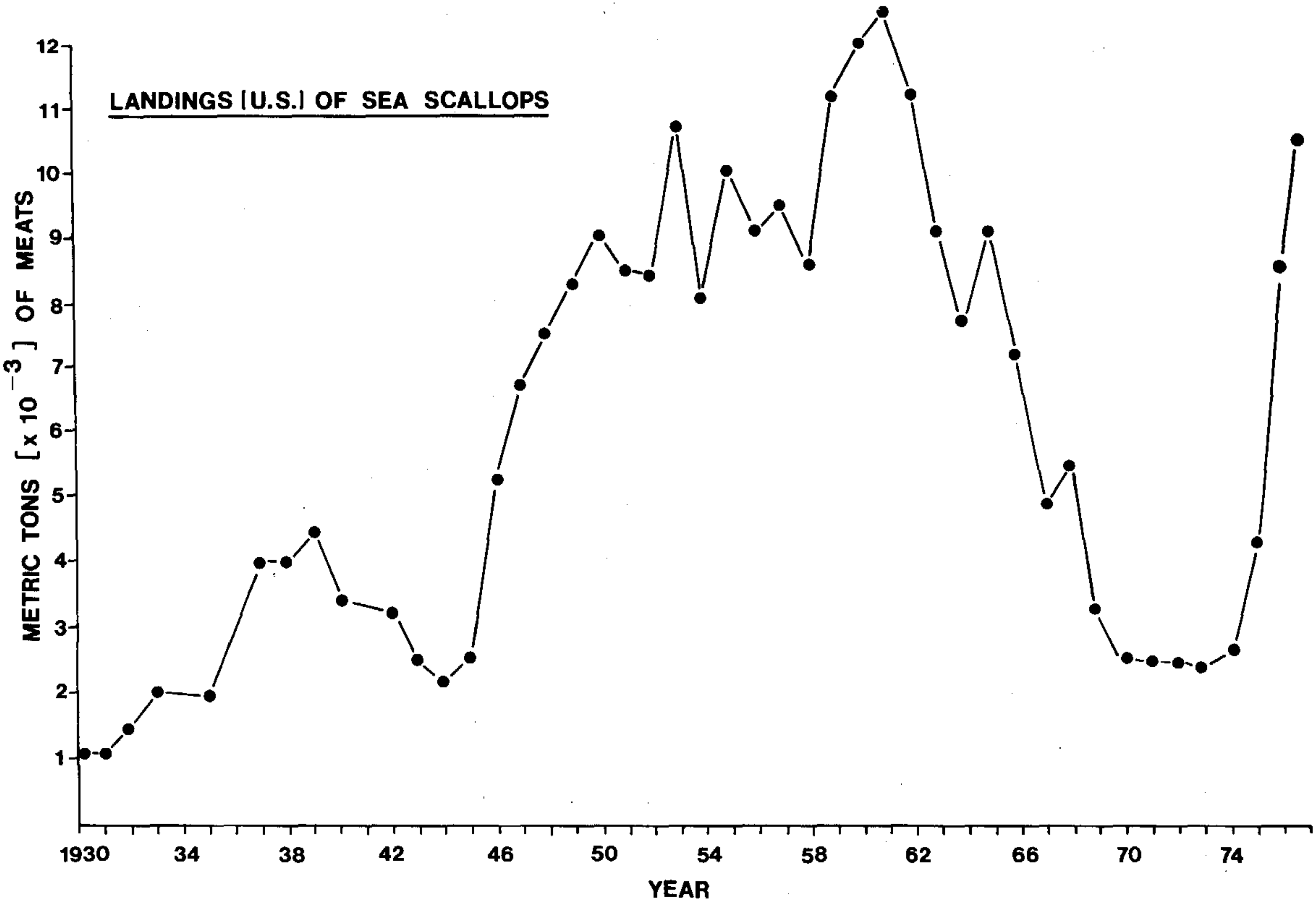

FIGURE 4. Historical landings of sea scallops (meats) by United States fishermen. Sources: Lyles, C. H. (1969). Historical catch statistics (shellfish). U. S. Fish. Wildl. Serv., C.F.S. no. 5007. 116 p.; Fishery Statistics of the United States (1968-1973); Fisheries of the United States (1974-1975); ICNAF (1977); Shellfish Market Review and Outlook. Current Economic Analysis S-40. National Marine Fisheries Service-NOAA. Washington, D. C. (March 1978). 31 p

7. MANAGEMENT TO CONSERVE AND INCREASE SCALLOP ABUNDANCE

7.1 Regulatory Measures

In 1978, no restrictions on sizes or quantities of the sea scallop taken and landed were placed on U. S. fishermen, except in the territorial waters of Maine. The Regional Fishery Management Councils were considering the drawing up of regulations to manage the scallop fishery.

The state of Maine required a license for commercial gathering the sea scallop from its waters. No limit existed on the quantity of scallops which fishermen could take, but only the scallops that had a shell length of 3 or more inches (7.6 cm) could be taken. Regulations also specified areas where scallops could be gathered by dredge and by otter trawl, and they restricted the open scallop season (see 6.3). A license was not required for gathering scallops for recreation, but a person could take only two bushels of scallops in the shell, or four quarts of shucked adductor muscles a day.

7.2 Improvements in the Physical Features of the Environment

None have been made to increase sea scallop abundance.

7.3 Improvements in the Biological Features of the Environment

None have been made to increase sea scallop abundance.

7.4 Artificial Stocking

No artificial stocking of the sea scallop has taken place. Nevertheless, Culliney (1974) listed a number of factors observed in culturing its larvae which led him to speculate that the sea scallop is a potential species for commercial hatchery culture. They were:

1. The fact that the sexes are separate eliminates the possible problem of poor viability that may or may not accompany self-fertilization.

2. Larvae grow rapidly with little mortality and thrive on a diet of the easily cultured phytoflagellate, *Isochrysis galbana*.

3. The natural tendency of pediveligers to settle on small objects can be exploited. Spat are thus easily caught, manipulated, and transported on artificial substrates.

The difficulty of holding sea scallops in sufficiently cool temperatures to allow them to live in culture tanks during the summer has been an obstacle to developing methods for artificial rearing (Posgay, pers. comm.).

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