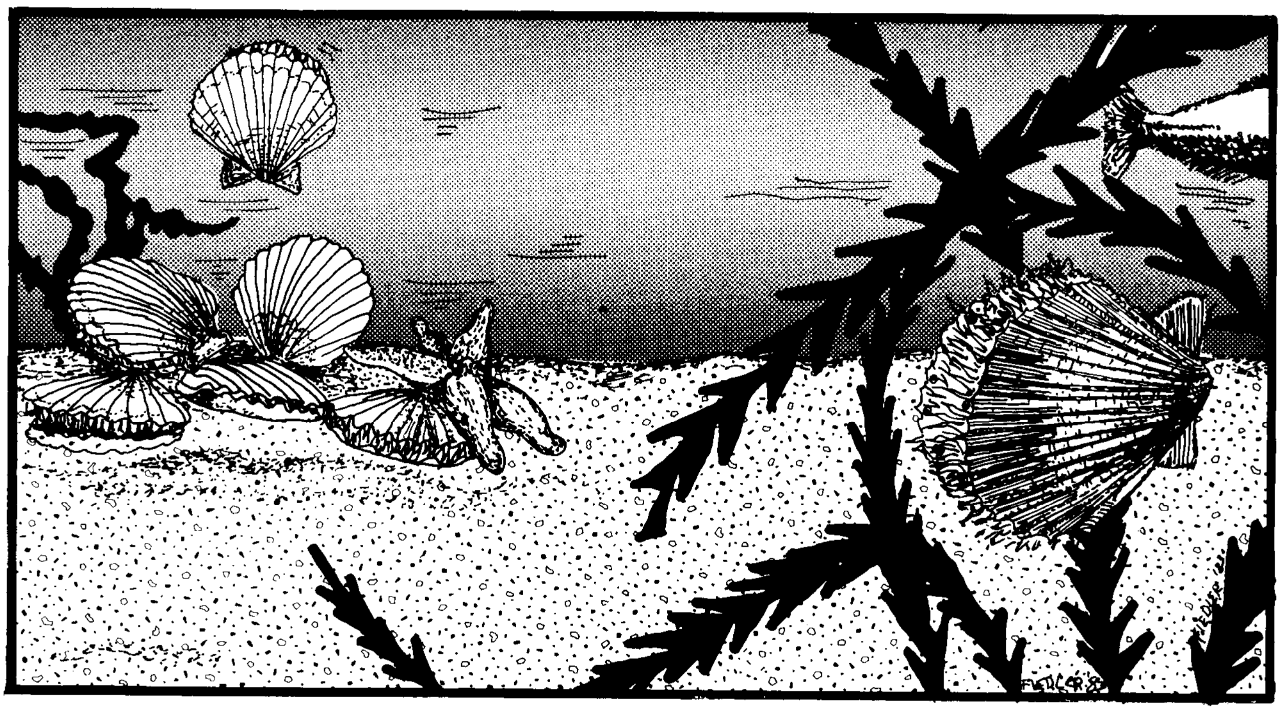
FWS/OBS-82/11.12
October 1983

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic)

BAY SCALLOP



Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

Fish and Wildlife Service
U.S. Department of the Interior

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic)

BAY SCALLOP

by

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Coastal Ecology Group
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Waterways Experiment Station

Performed for
National Coastal Ecosystems Team
Division of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

CONVERSION FACTORS

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (1)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (gm)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (mt)	2205.0	pounds
metric tons (mt)	1.102	short tons
kilocalories (kcal)	3.968	BTU
Celsius degrees	1.8(C°) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
BTU	0.2520	kilocalories
Fahrenheit degrees	0.5556(F° - 32)	Celsius degrees

CONTENTS

PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The orofiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile tias sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to:

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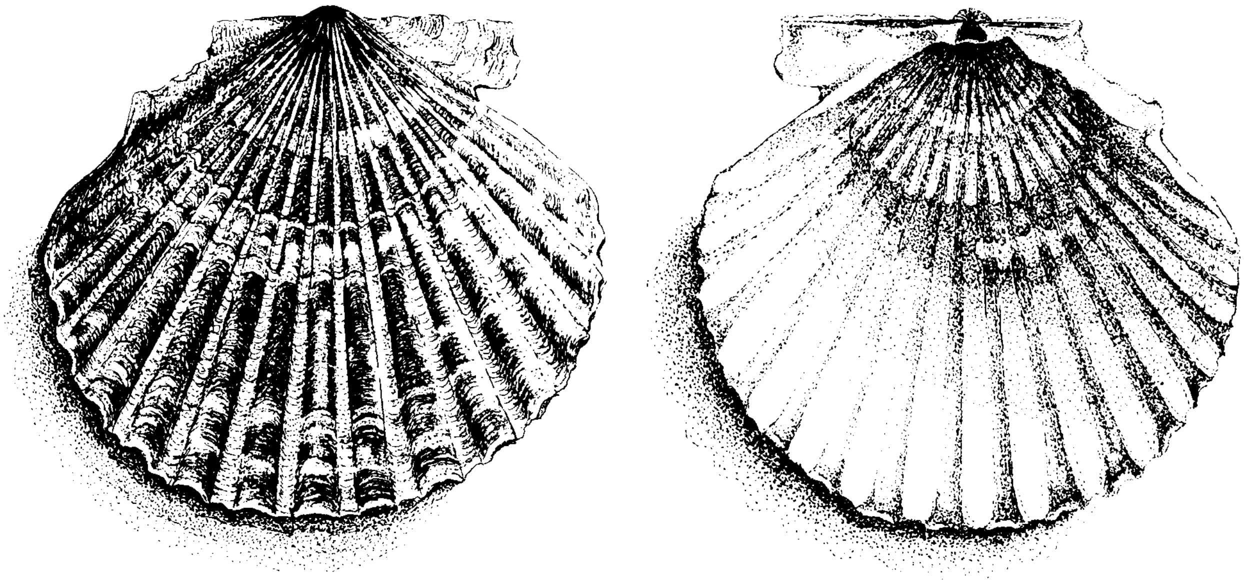

Figure 1. Bay scallop: left, external view of shell; right, internal view of shell.

BAY SCALLOP

NOMENCLATURE/TAXONOMY/RANGE

Scientific name.. . Argopecten irradians
Preferred common name.. .... Bay scallop (Figure 1)
Class.. .... Bivalvia
Order.. ....Anisomyaria
Family.. .... .Pectinidae

Geographic range: North shore of Cape Cod (42°N latitude, 70°W longitude) south to Laguna Madre, Texas (26°N, 97°W) (Waller 1969) (see Figure 2 for a map of the distribution of the bay scallop in the mid-Atlantic region). Three subspecies of Argopecten irradians are generally recognized, intergrading in distribution, with A. i. irradians extending from Cape Cod to New Jersey, A. i. concentricus from New Jersey to the Chandeluer Islands in the Gulf of Mexico, and A. i. amplicostatus from Galveston, -Texas, to Laguna Madre, Texas (Waller 1969).

MORPHOLOGY/IDENTIFICATION AIDS

Distinguishing among the queen scallop (Chlamys opercularis), calico scallop (Argopecten gibbus), and bay scallop is difficult without specimens

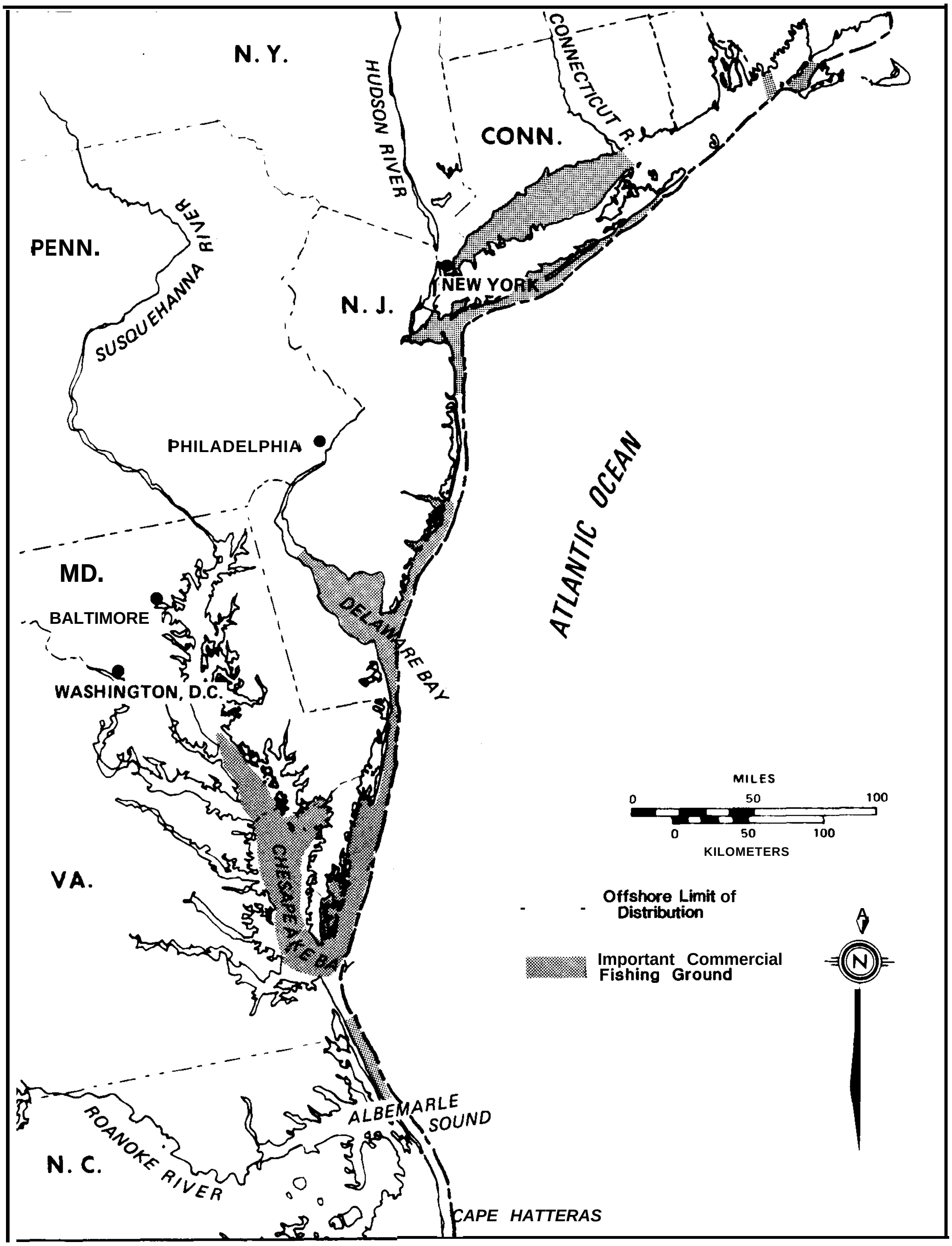

Figure 2. Mid-Atlantic distribution of the bay scallop.

of all three for comparison. The most diagnostic feature for separation is the difference in relative convexity of left and right valves among species. The queen scallop is distinctly left convex ; that is, the left valve is more rounded than the right. The calico scallop valves are slightly left convex or equiconvex. In contrast, the bay scallop is distinctly right convex; that is, the right valve is more rounded than the left (Broom 1976). A list of other qualitative characters, useful when all three species are in hand, and a dichotomous key for species of the genus Argopecten are presented in Broom (1976).

Bay scallop shells are symmetric or nearly so, with a distinct notch on the anterior edge of the hinge. Valves possess 13 to 22 radial ribs (less than 18 on A. i. amplicostatus and more than 14 on A. i. irradians and A. i. concentricus) (Broom 1976). Normal adult size ranges from 55 to 90 mm (2.2 to 3.5 inches) in diameter. Color of the left (top) valve varies considerably, but generally is dark grey, black, or brown, and sometimes with red, orange, or yellow hues; mottling or concentric banding also occurs . Right valves vary from yellow or white to nearly as dark as left valves; additional markings usually are absent, but if present, they are similar to those on the left valve (Waller 1969).

REASON FOR INCLUSION IN SERIES

Bay scallops have been harvested since colonial times, and in recent years (for example, 1976), accounted for up to 946 metric tons (mt) (1,041 tons) of scallop meats (Peters 1978). Of the three commercially exploited scallops of the Atlantic coast, the bay scallop ranks well behind the sea scallop (Placopecten magellanicus) and about equal to the calico scallop in magnitude of catch (Peters 1978). In terms of exvessel price (at the ports), bay scallops are of higher value to fishermen than are sea scallops.

In addition to their economic importance, bay scallops are included in the series because of their vulnerability, the difficulty in managing them, and their importance in the food web. Their distribution is entirely estuarine or near-coastal (less than 4.8 km or 3 mi offshore, and within State territorial waters), making them vulnerable to recreational and industrial development along the shore. Also, bay scallops are short-lived (generally less than 26 months); consequently, exploitable stocks vary considerably from year to year, making management and yield prediction difficult (Peters 1978). Finally, the species is an important link in the estuarine community food web, funneling energy from planktonic and benthic organisms to aquatic and terrestrial predators (Belding 1910).

LIFE HISTORY

Reproductive Physiology/Strategy

Bay scallops are hermaphroditic and generally protandrous (releasing male gametes before female gametes) (Loosanoff and Davis 1963; Peters 1978). A single individual may release both types of gametes in a single spawning period (Peters 1978); but because of protandry, self-fertilization in nature is probably rare (Belding 1910; Gutsell 1930). Bay scallops mature and spawn for the first time at approximately 1 year of age. Although size at age 1 varies because of differences in growth rates among populations, maturity is a function of age, not size (Gutsell 1930; Marshall 1960; Broom 1976). Since the average longevity is only 12 to 16 months, and maximum longevity about 26 months (Belding 1910), few individuals spawn more than once (Peters 1978).

Spawning

In the mid-Atlantic region, bay scallops spawn from mid-April through early September (Chanley and Andrews 1971). Specific spawning times, however, vary considerably across the species range. In Massachusetts (Belding 1910), Connecticut (Cooper and Marshall 1963), Rhode Island (Risser 1901), and Long Island Sound (Hickey 1978), most spawning occurs during June and July, as water temperatures increase. In contrast, populations in North Carolina (Gutsell 1930; Sastry 1966) and Florida (Sastry 1963; Barber and Blake 1983) spawn between August and December, as water temperatures decrease. This apparent latitudinal difference in spawning time may represent different physiological adaptations to environmental conditions among the three recognized subspecies of bay scallops (Sastry 1970a).

Gametogenesis and spawning time of bay scallops are correlated with water temperature and food supply (Turner and Hanks 1960; Sastry 1963, 1966, 1968, 1970a, 1970b; Sastry and Blake 1971; Hickey 1978). A water temperature of at least 15°C (59°F) was necessary for initiation of gametogenesis in overwintering bay scallops, while at least 20°C (68°F) and adequate food supply were necessary for gametogenesis to reach the "germinal vesicle dissolution" stage (Sastry 1968). Temperatures above 20°C and adequate food were necessary for gametes from winter-collected scallops to reach a fertilizable stage. For spring-collected scallops, maturation and spawning occurred with or without food for scallops held at 20°C, 25°C (77°F), and 30°C (86°F), while those held at 10°C (50°F) and 15°C did not mature and spawn (Sastry 1966). Sastry (1970a) stated that variation in reproductive physiology in geographically separated bay scallop populations (Woods Hole, Massachusetts, compared to Beaufort, North Carolina) is probably an adaptive response to differences in water temperature regime and timing of maximum available food supply.

Eggs

Unfertilized bay scallop eggs average 60 millimicrons (mμ)[1] in diameter (Broom 1976), and range from 55 to 65 mμ (Loosanoff and Davis 1963). Eggs are often asymmetrical prior to release into water (Loosanoff and Davis 1963), but rapidly become spherical or nearly so after release (Belding 1910). Yolk granules are numerous and small. Fertilization occurs in the water column or on the bottom, and fertilized eggs are demersal (Belding 1910; Broom 1976). Egg development accelerates as water temperature increases (Broom 1976); however, a critical thermal minimum between 15° and 20°C (59" and 68°F) was reported for successful early cleavages to occur (Sastry 1966). Gastrulation occurred in 9 hr at 24°C (75°F) (Sastry 1965); subsequent stages of embryogenesis are presented in Belding (1910) and Gutsell (1930).

Larvae

At 24°C to 25°C (75°F to 77°F), trochophore larvae first appeared from swimming gastrulae (Belding -1910) after 24 hr, and all surviving eggs had developed into trochophore larvae by 48 hr (Gutsell 1930; Sastry 1965). Gradual transformation to veliger larvae (first appearance of a shell) began shortly after. reaching the trochophore stage and was completed by most larvae in 48 hours (Gutsell 1930; Sastry 1965). Average size of veliger larvae reared at 24°C was 101 mμ (Sastry 1965). The veliger larvae began feeding activity by using their ciliated velum. By the third day of the veliger stage, average shell size

[1] 1 mμ = 1 nanometer or 10^{-9}m.

was 122 mμ, and the straight-hinged veliger shell began to develop curved umbones characteristic of the pediveliger stage. The veliger stage lasted about 10 days;; by this time the foot was fully developed (pediveliger stage), and metamorphosis to the juvenile stage occurred. Average shell length of juveniles at settlement was 190 mμ, gills had developed, and the velum was completely absorbed (Sastry 1965).

Total time between egg fertilization and settlement is about 14 days (Loosanoff and Davis 1963; Sastry 1965), but ranges from 10 to 19 days (Castagna and Duggan 1971), depending not only on water temperature but also food supply. Unfed larvae will not metamorphose (Broom 1976). Detailed observations on larval development of bay scallops are given in Belding (1910) and Gutsell (1930).

Juveniles

Characteristics of the juvenile stage are settlement and appearance of the dissonconch shell, a thin, fragile, postveliger structure, completely separated from the thicker, veliger shell (Sastry 1965). Upon settlement to a suitable substrate, the juvenile scallop attaches by a fine thread called the byssus, which is secreted by a special gland in the foot (Belding 1910; Broom 1976). If the attachment surface is suspended off the bottom (e.g., a blade of seagrass), the juvenile will remain attached until it reaches 20 to 30 mm (0.8 to 1.2 inches) in length, at which time it drops to the bottom (Castagna 1975). Very young scallops (< 10 mm or 0.4 inches) apparently cannot tolerate highly silted substrates (Castagna 1975); thus, attaching to epibenthic surfaces until reaching 20 to 30 mm and then dropping to the bottom probably improves their survival rate (Castagna 1975).

Juvenile bay scallops use a variety of substrates as settlement/attachment locations, including stones, seaweeds (Ingersoll 1886), oyster shells, rope, and filamentous algae (Marshall 1960). Beds of eelgrass (Zostera marina) and other seagrasses are apparently preferred as settlement locations (Thayer and Stuart 1974), though scallops are able to settle and survive in areas lacking seagrasses (Marshall 1947, 1960). Kirby-Smith (1972) found that young bay scallops grew faster in slow currents compared to fast currents; and since seagrass beds tend to slow normal water currents (Castagna 1975), availability of these plants may enhance growth rates.

Upon settlement, juveniles climb and crawl using the foot, byssal threads, and tentacles until the swimming powers of the adult develop. The foot is also used for turning over, should the young scallop accidently land on its left valve (characteristically, all bay scallops rest and feed on their right valve) (Belding 1910; Gutsell 1930).

Juvenile bay scallops tend to vary more in coloration than adults, and range from nearly pure white to dark grey or brown, with some predominantly red individuals present. Lightly colored young scallops darken as they age, while darker juveniles change little in color (Belding 1910).

Adults

The adult stage is characterized by the radial ridges and furrows often observed on scallop shells. Once the ridges appear, they do not increase in number as the scallop grows (Belding 1910). Another distinguishing characteristic of adults is a concentric ridge on the shell (vs. radial ridges). It is caused by slow growth during the first winter of life, and is analogous to an annulus on a fish scale. This shell character is often used by law enforcement personnel to determine whether illegal (subadult) scallops have been commercially harvested (Peters 1978).

Even though adult scallops retain the ability to attach by byssal threads (Castagna 1975; Peters 1978), they are seldom found attached in nature (Castagna 1975) . Adult scallops prefer quiet waters, protected from high winds, storms, and tides (Belding 1910). Preferred depths range from 0.3 to 10 m (1 to 33 it), though occurrence to 18 m (59 ft) has been reported (Belding 1910; Broom 1976). Scallops are often most abundant on tidal flats with only 0.3 to 0.6 m (1 to 2 ft) of water at low tide.

Adult bay scallops are effective swimmers at all sizes (Castagna 1975). The mechanism for swimming is pulsed expulsion of water from the mantle cavity (called "clapping" in much of the literature). Alternation of expelled water out the anterior and posterior gapes of the shell results in a swimming motion that appears zigzag. Alternate expulsion is apparently voluntary, as bay scallops can also move sideways by using only one end of the shell for water release (Belding 1910; Gutsell 1930). Voluntary movement of bay scallops is used to escape unfavorable environmental conditions or predators (Belding 1910; Gutsell 1930; Moore and Marshall 1967). Using tagged scallops from the Niantic River Estuary, Connecticut, Moore and Marshall (1967) found that summer movements of bay scallops were 0.8 m (2.6 ft) or less from release points over the maximum observation period of 6 days. Successive movements by individuals were not directional, but pooled movements of released groups were slightly but significantly directional. Directionality, however, may have resulted from tidal influence on otherwise random individual movements (Moore and Marshall 1967). Belding (1910) also noted that much of the scallop movement observed was directional only under the influence of tidal currents. Though the possibility of long-range migrations by bay scallops was noted in Belding (1910), no such evidence for extensive migrations has been presented (Baird 1966; Moore and Marshall 1967).

The average life span of bay scallops ranges from 12 to 24 months in waters south of Maryland (Gutsell 1930; Sastry 1961; Castagna 1975), and from 20 to 26 months in waters north of Maryland (Belding 1910; Marshall 1960; Russel 1971; Robert 1978). Maximum reported life span was 26 months (Belding 1910) to 30 months (Robert 1978) for populations north of Connecticut.

GROWTH CHARACTERISTICS

Growth rates of bay scallops seem to depend on water temperature, current velocity, food availability, and possibly scallop density. Growth rates in shell diameter reported in early literature varied from 3.8 to 8 mm (0.1 to 0.3 inches) per month, with most of this growth occurring during the 4 or 5 warmest months of the year (Risser 1901; Belding 1910; Gutsell 1928). Belding (1910) found that growth of Massachusetts bay scallops ranged from 3.8 to 4.5 mm (0.1 to 0.2 inches) per month over 3 years of study. Growth rate was highest in May, August, September, and October, and only about half as fast in June and July, when these populations spawned. Gutsell (1928) reported that North Carolina scallops may begin to grow as early as February, even though water temperatures may be as low as 3°C (37°F). Growth ceased after October, even though water temperatures were still above 20°C (68°F). In North Carolina, spawning occurs in September and October, and this cessation of growth occurred immediately thereafter.

Water currents were demonstrated to affect growth of scallops. Kirby-Smith (19.72) reported that scallops held at 27°C (81°F) over 21 days showed no growth at a current velocity of 12.4 cm/s (0.4 ft/s); those exposed to 3 to 4 cm/s (0.10 to 0.13 ft/s) grew an average of 0.5 mm (0.02 inch); exposure to 0.75 and 0.21 cm/s (0.02 and 0.007 ft/s) produced the highest growth rate of 4 mm (0.16 inches) (5.7 mm or 0.22 inches/month). Scallop growth in standing water was not investigated. Kirby-Smith (1972) demonstrated that phytoplan kton removal by scallops was most efficient at the slower current speeds, and this may account for the observed growth patterns.

Kirby-Smith and Barber (1974) found that the optimum combination of temperature and food particle density for growth was 1.2 µg/l of chlorophyll a at 22°C (72°F). Growth was lower at higher temperatures (e.g., 28°C or 82°F), even with higher food particle density (2.4 µg/l chlorophyll a). The relationship between growth and food particle density was:

$$V = Vm (S - a)/(C - a) + (S - a)$$

where V = growth rate, Vm = maximum growth rate (saturation), S = optimal food particle concentration, C = value of S at Vm/2, and a = value of S when V = 0. Using this equation, there is a different value of S for each temperature (Kirby-Smith and Barber 1974).

Duggan (1973) found that bay scallops from Virginia waters held in cages at the surface, 1 m (3.3 ft) below the surface, 2 m (6.6 ft) above the bottom, and 1 m above the bottom, showed no significant difference in growth rate over 5 months. Observed growth ranged from 41.5 to 45 mm (1.6 to 1.8 inches) over the 5 months. Effects of scallop density on growth were also investigated. up to a size of 27 to 28 mm (1.06 to 1 .10 inches), growth was not significantly different at scallop densities of 1075, 806, 537, and 269/m² (100, 75, 50, and 25/ft², respectively) ; above this size, growth decreased with increasing density. At termination of the experiment (4 months), average size ranged from 40 mm (1 .6 inches) at the highest density to 49 mm (1.9 inches) at the lowest density (Duggan 1973).

Growth rates over 3 months, mean size at age, and mean weight at age were consistently lower for North Carolina bay scallops experimentally infected with female pea crabs (Pinnotheres maculatus, an internal, commensal parasite of bay scallops), compared to uninfected scallops (Kruczynski 1972). Evidence indicated that parasitism by the pea crab, though not directly fatal to the scallop, affected the ability of bay scallops to grow (Sastry 1961; Kruczynski 1972).

Cooper and Marshall (1963) investigated the condition of bay scallops in relation to the environment in four separate populations of the Niantic River, Connecticut. Environments of the four populations were generally similar except for tidal current; two populations were in relatively current-free areas, and two were in areas with strong tidal currents. The formula for calculating bay scallop condition was:

$$K = V/L^N$$

where K = condition, V = muscle volume, L = shell height, and N = the slope of the regression of log(V) to log(L). Condition increased with age, except during and after spawning in June and July, when condition decreased in all four populations. Condition was highest in populations located in slow-current environments, even though the highest densities of scallops occurred at one of the two strong-current environments. The relationship between condition and age for all four populations combined, applicable to scallops of age 7 to 20 months, was (Cooper and Marshall 1963) :

$$\log(K) = 0.06197(t) - 0.06203$$

where t = time in months.

ECOLOGICAL ROLE

Food Habits

Investigations by Davis and Marshall (1961) indicated that the primary food of bay scallops was benthic diatoms. Characteristically, planktonic forms of algae were present in very low densities in stomachs compared to benthic forms. Also, benthic-oriented bacteria and miscellaneous or unidentifiable detritus were found in bay scallop stomachs, further indicating the importance of benthically derived food sources (Davis and Marshall 1961).

In the laboratory, larval bay scallops were successfully reared on suspensions of either green algae (*Chlorella* spp.), or a combination of naked flagellates (*Isochrysis galbana* and *Monochrysis lutheri*) (Loosanoff and Davis 1963; Sastry 1965). Growth was better on the flagellate diet (Loosanoff and Davis 1963). Both larval and adult bay scallops were reared and maintained successfully on either flagellates (*M. lutheri* and *Dunaliella tertiolecta*) or diatoms (*Phaeodactylum tricornutum*) (Castagna and Duggan 1971).

Feeding Behavior

Bay scallops are filter-feeders, pumping water through the mantle cavity and straining food particles on the gill cilia (Broom 1976). Observations by Kirby-Smith (1970) indicated that pumping was continuous; however, the investigator suggested that rate and duration of feeding may be modified according to food particle densities. Filtration rate appeared to be related to body size; assuming that the relationship can be described by $F = KW^b$, where F = filtration rate, W = body weight and K and b are constants, Kirby-Smith (1970) obtained a value of -0.58 for b. Filtration rates for scallop size classes of 38 to 44 mm (1.49 to 1.73 inches), 47 to 48 mm (1.85 to 1.89 inches), 54 to 56 mm (2.13 to 2.20 inches), and 64 to 65 mm (2.52 to 2.56 inches) were reported at 0.99, 0.93, 0.79, and 0.71 l/h r/g wet weight, respectively (Chipman and Hopkins 1954).

Normal feeding position of adults is resting on the bottom on the right valve, with a shell gape of approximately 20° (Belding 1910). Water movement through the body is from anterior to posterior. When the scallop occasionally lands on its left valve, it quickly flips over using its foot and water expulsion (Belding 1910). In coarse sand substrates, shallow burrowing may be used during feeding, with the right valve buried in the sand and the left valve exposed to the water (Belding 1910).

Predators

In shallow water areas, where bay scallops are often abundant, the most important predators are probably the green crab (*Carcinides maenes*) (Marshall 1960) and the blue crab (*Callinectes sapidus*) (Castagna 1975). In water deeper than 2 m (6.6 ft), principal predators are the asteroid starfish *Asterias* spp. and *Marthasterias* spp. (Gutsell 1930; Marshall 1960). Starfish attack the scallop by attaching tube feet to both valves and pulling in opposite directions until the adductor muscles of the scallop fatigue (Belding 1910). Another predator is the oyster drill (*Urosalpinx cinerea*) (Marshall 1960). Gutsell (1930), however, noted that the total mortality from oyster drill predation was insignificantly low, because of the long time period the drill needs to bore and consume its prey (at least 8 days total, Belding 1910), and the ability of bay scallops to respond quickly to tactile stimuli and escape predators (Belding 1910; Gutsell 1930). Lastly, the herring gull (Larus argentatus) (Gutsell 1930) and probably other gulls and terns (Family Laridae) are important predators of bay scallops. Because of the shallow water habitats frequented by bay scallops, predation by sight-feeding birds is effective. A commonly observed feeding behavior of gulls is to grab the scallop with their bill, fly up over the beaches or roads, and drop the scallop to break the shell (Gutsell 1930).

Competitors

No evidence is available on interspecific competition involving bay scallops. There is some evidence of intraspecific competition. Density studies by Duggan (1973) indicated that very high scallop densities (on the order of $1075/m^2$ or $100/ft^2$) decreased growth and increased mortality compared to lower densities ($269/m^2$ or $25/ft^2$). Even the lowest densities tested by Duggan (1973), however, were considerably higher than densities in natural populations studied by Cooper and Marshall (1963) and Thayer and Stuart (1974).

Parasites

The pea crab is an internal commensal parasite of bay scallops (Cheng 1967), and the gastropod Odostomia seminuda has been reported as an ectoparasite (Cheng 1967). Kruczynski (1972) reported that bay scallops infected with pea crabs grew slower and were consistently lower in mean dry weight than uninfected scallops. Incidence of infection with pea crabs ranged from 48 in fall to 10% in summer in Bogue Sound, North Carolina. The percentage of infected bay scallops in Alligator Harbor, Florida, ranged from 13% to 36% seasonally (Sastry and Menzel 1962).

THE FISHERY

Commercial Fisheries

All bay scallop landings come from areas within 4.8 km (3 mi) of the coast, and most from inside the contiguous coastline (inland waters). Published information about the distribution of landings along mid-Atlantic States is not available, but Gusey (1976, 1981) indicated that the most important commercial fishing grounds for bay scallops are the south shore of Cape Cod, Long Island Sound, Sandy Hook Bay (New Jersey), Great Egg Harbor (New Jersey), Delaware Bay, nearshore Delmarva Peninsula, and all of Chesapeake Bay proper (see also Figure 2).

Modern bay scallop fisheries use small dredges, approximately 1 m (3 ft) wide, towed by small powerboats. In shallow water areas, dip nets, rakes, and hand-gathering are also used (Peters 1978). Most harvesting occurs in water less than 6 m (20 ft) deep (Gutsell 1928, 1930; Marshall 1960). In most mid-Atlantic States, the scallop fishing seasons are from autumn through spring, usually October to April (Marshall 1960; Broom 1976).

Although the current 5-year average of U. S. bay scallop landings (1977-81) was 585 mt (643.5 tons), landings have fallen steadily from 946 mt (1041 tons) in 1976 to 437 mt (481 tons) and 302 mt (332 tons) in 1980 and 1981, respectively. The dollar values of the 1980 and 1981 landings were $3,894,000 and $2,427,000, respectively (National Marine Fisheries Service 1978-1982).

Since bay scallops are short-lived, landings respond quickly to fluctuations in year-class strength. Thayer and Stuart (1974) provided evidence that the dredging method used for harvesting scallops may account for the decline of landings in dredged areas. In areas where beds of eelgrass or other seagrasses are fundamental to the presence and survival of bay scallop populations (including nearly all exploited scallop beds), dredging alters the eelgrass and therefore may cause poor harvests for several years after an initial scallop dredging. Eelgrass requires several years to recover to a density suitable for use by young bay scallops. Thayer and Stuart (1974) reported that hand-raking,. another method of bay scallop harvest, did not significantly alter eelgrass beds, and although less efficient in catch per unit effort, appeared to be a better method for sustaining a long-term yield of bay scallops from a given eelgrass bed.

Recreational Fisheries

The recreational bay scallop catch from Massachusetts waters increased steadily (except for 1977) from 5,660 bushels in 1975 to 21,647 bushels in 1980, then dropped off to only 8,762 bushels in 1981. The recreational catch represents from 4.5% to 14.8% of the total Massachusetts bay scallop landings in any one year (the remainder taken commercially). Inshore waters around the Massachusetts towns of Brewster, Chatham, Falmouth, Nantucket, Dennis, and Bourne accounted for the majority of recreational landings each year (Commonwealth of Massachusetts Shellfisheries Statistics 1982[2]).

Population Dynamics

Age and size composition. Only two age classes are usually represented in bay scallop populations because of their short life span. Annual catches therefore vary almost directly with fluctuation in year-class strength. Age at first capture is approximately 1 year, and few 2-year-old scallops appear in scallop landings or natural populations (Broom 1976). In North Carolina populations, two size modes occurred: at 0 to 15 mm (0 to 0.6 inches) and 35 to 49 mm (1.4 to 1.9 inches) in March, at 0 to 5 mm (0 to 0.2 inches) and 55 to 70 mm (2.2 to 2.8 inches) in August, and at 0 to 10 mm (0 to 0.4 inches) and 65 to 75 mm (2.6 to 2.9 inches) in November (Gutsell 1930). Large numbers of scallops in the 0- to 5-mm class appeared in August, and increased steadily through November, reflecting the August-October spawning season in North Carolina (Gutsell 1930; Broom 1976).

Density. Cooper and Marshall (1963) found that densities of bay scallops at four locations In the Niantic River, Connecticut, ranged from 3 to $5/m^2$ (0.3 to $0.5/ft^2$) in a slackwater environment, 11 to $25/m^2$ (1 .O to $2.3/ft^2$) in intermediate currents, to 65 to $75/m^2$ (6.0 to $7.0/ft^2$) in high currents . For North Carolina bay scallop populations, Thayer and Stuart (1974) reported densities of $24.8/m^2$ ($2.3/ft^2$) and $19.5/m^2$ ($1.8/ft^2$) in two separate areas . Densities in natural populations observed by cooper and Marshall (1963) and Thayer and Stuart (1974) were much lower than those tested by Duggan (1973) for effects of density on scallop growth. Therefore, densities in most natural populations are probably not high enough to cause a decrease in growth rate.

In the populations studied by Thayer and Stuart (1974), average scallop density was reduced from $24.8/m^2$ ($2.3/ft^2$) to $16.7/m^2$ ($1.6/ft^2$) in one population by 6 man-hours of hand raking. In a second population, average density dropped from $19.5/m^2$ ($1.8/ft^2$) to $3.0/m^2$ ($0.3/ft^2$) after 6 man-hours of raking and 2 man-hours of dredging. These data indicated that scallop harvest by dredging,

[2] No published document; tabulated catch data received from Frank Germano, Assistant Marine Fisheries Biologist for the Commonwealth of Massachusetts.

even under light fishing pressure, quickly depleted exploitable scallops in an area (Thayer and Stuart 1974).

Mortality. Average monthly mortality of 10-mm (0.4-inch) bay scallops maintained in trays (but otherwise under natural conditions) from November 1969 to November 1970 was 7% or lower, except during the August-to-September interval, when mortality was 13% (Castagna and Duggan 1971). In depth experiments with bay scallops, Duggan (1973) found that total mortality over 4 months was 4% at 2 m (6.6 ft) off the bottom, 8% at 1 m (3.3 ft) below the surface, 16.5% at the surface, and 29.0% at 1 m above the bottom. The higher mortality at 1 m from the bottom was probably caused by heavy siltation of holding cages at that depth; many times scallops were completely buried in silt. In density tests, total mortality was similar for scallops up to 27 to 28 mm (1.06 to 1.10 inches), regardless of density; above that size, mortality increased with increasing density. Total mortality over 4 months ranged from 3.2% at the lowest test density of 269/m² (25/ft²) to 35.0% at the highest test density of 1075/m² (100/ft²) (Duggan 1973).

Aquacultural potential. Studies by Kirby-Smith (1972), Kirby-Smith and Barber (1974), Castagna (1975), and Epifanio (1976) provided information on aquacultural potential and requirements for bay scallops. These studies identified the control of water temperature (particularly in relation to gonad development and spawning), salinity, food supply, water currents, scallop density, and predators as most important for successful rearing of bay scallops. Castagna (1975) provided the most comprehensive review in terms of aquacultural potential.

Introduction potential. Robert (1978) discussed the potential for introduction of bay scallops into Maritime waters north of the Gulf of St. Lawrence. Several limiting factors to successful introduction were noted: (1) very cold (<2°C or <36°F), ice-covered waters for a minimum of 4 months; (2) high number and intensity of spring freshets, frequently reducing salinity below the minimum requirement of 14 ppt; (3) limited food supply at the appropriate time for settling juveniles; and (4) eelgrass beds occurring on silt substrates, and perhaps less suitable than those on sand and mud substrates further south. Other factors of importance to bay scallop survival and growth, such as appropriate depths, water currents, and protection from storms, were considered to be at least marginally acceptable in Maritime waters. Robert (1978) recommended that if scallops were introduced, seed stock should be gathered from waters nearest in environmental conditions to Maritime waters.

ENVIRONMENTAL REQUIREMENTS

Temperature

Castagna (1975) reported that survival and development of eggs were best at water temperatures above 20°C (68°F). Optimum temperatures for development appeared to be 26° to 28°C (79° to 82°F). Belding (1910) stated that Massachusetts bay scallops need a temperature over 7.2°C (45°F) for growth, and growth rate was closely tied to temperature and food supply. Marshall (1960) found that adult bay scallops tolerated exposure to air temperatures as low as -6.6°C (20°F) for 2 hr. Below this temperature, tolerance time decreased.

Probably the most significant information on the effects of temperature on bay scallops is that contained in a series of studies by Sastry (1963, 1966, 1968, 1970a, 1970b), and by Sastry and Blake (1971) on relationships between temperature, food, gonad development, and spawning. Overwintering scallops in a "resting reproductive state" could not survive direct exposure to 25°C (77°F) or 30°C (86°F). They survived at 25°C if an acclimation period of 30 days at 15°C (59°F) or 20°C (68°F) and adequate food were provided. Gametogenesis was stimulated in all overwintering scallops held at 15°C and 20°C, with or without food; but the most advanced stage of gametogenesis (dissolution of germinal vesicle) was achieved only by scallops held at 20°C with adequate food. After dissolution of the germinal vesicle, temperatures greater than 20°C were necessary for gametes to attain a fertilizable stage (Sastry 1966, 1968). Scallops collected in spring and early summer, in a "reproductive development" stage, matured and spawned rapidly when held in the laboratory at 20°C, 25°C, or 30°C, even without food. Spring-collected scallops held at 10°C (50°F) and 15°C (59°F) did not mature and spawn. Also, tolerance of changes in water temperature was lowest for ripe scallops, and much higher for "reproductive development" stage individuals (Sastry 1966). Sastry (1970b) and Sastry and Blake (1971) concluded that both food and temperature were important factors determining initiation and overall rate of gonadal development, readiness to spawn, and spawning time, and therefore may account for geographic differences in spawning activities observed over the species range (Sastry 1970a).

Salinity

Because of the estuarine habitat, bay scallops are frequently exposed to changes in salinity, especially when salinity is reduced from freshwater runoffs (Duggan 1975). Castagna (1975) reported that the minimum salinity required for eggs to develop to the straight-hinged veliger larval stage was 22.5 ppt. In general, the minimum sdinitv requirement determining overall distribution patterns of settling juveniles and adults is about 14 ppt (Belding 1910; Gutsell 1930; Sastry 1961; Castagna and Chanley 1973). Bay scallops have occasionally been found at salinities as low as 10 ppt (Gutsell 1930), but whether this was the prevailing salinity at the collection site was not indicated. Vernberg et al. (1963) reported that exposure to 12-15 ppt caused gill cilia to cease beating.

Transfer of scallops from 28 ppt to 21 ppt, 14 ppt, and 7 ppt salinity was conducted by Sastry (1961). No observable change in behavior was noted for scallops moved to 21 ppt and 14 ppt; however, transfer to 7 ppt induced scallops to close their valves tightly for an extended period. After an apparent period of acclimation, the valves slowly opened, but tentacles were not extended and water was not actively circulated through the scallop body. Sastry (1961) did not report whether any transferred scallops attempted movement. Test specimens were able to tolerate 2 hr of exposure to 7 ppt, and after transfer back to 28 ppt, resumed normal water filtration. Sastry (1961) also reported that direct transfers from 28 ppt to distilled water for up to 2 hr did not affect scallop survival.

Duggan (1975) investigated the effects of gradual reductions in salinity on bay scallops, since under natural conditions, reductions are more gradual than in the situations tested by Sastry (1961). Salinity in test aquaria was reduced from 26 ppt to 6 ppt over 4 hr. Behavior of control and experimental specimens was observed and classified into one of four activity modes, ranging from "normal activity" to "no activity." At 10° to 15°C (50° to 59°F), all experimental animals showed "reduced activity" as salinity reached 22 ppt, and "no activity" when 16 ppt was reached. At 20° to 25°C (68° to 77°F), "reduced activity" occurred between 22 ppt and 18 ppt, and all test animals showed "no activity" when salinity reached 12 to 13 ppt. Initial response of the test animals to introduction of freshwater was a higher than normal clapping rate (the swimming movement of scallops). One-half of the scallops of one test group was transferred at the end of the 4-hr experiment directly into 26 ppt, while the other half was transferred after 15.5 total hr at 6 ppt. Both groups survived and resumed normal filtration activity upon transfer to 26 ppt (Duggan 1975). This evidence suggested that short periods of exposure to low salinities, such as from heavy runoff, probably does not affect survival of bay scallops.

Temperature-Salinity Interaction

Bay scallop embryos require a narrow range of temperature-salinity combinations for proper development. The optimum combination for normal development was reported at 20°C (68°F) or 25°C (77°F) (test temperatures at 5°C increments) and 25 ppt salinity. Salinities above or below 25 ppt significantly affected normal embryonic development. No embryos developed normally at 10 ppt or 15 ppt salinity, or at water temperatures of 10°C (50°F) or 35°C (95°F) (Tettelbach and Rhodes 1981).

Bay scallop larvae could not tolerate 10-ppt salinity or 35°C; at least some larvae survived at all other test temperatures and salinities. Maximum larval survival occurred at 20°C and 25 ppt salinity. Minimum requirements for larval growth were 25° to 30°C (77° to 86°F) and 20- to 35-ppt salinity. Larval growth was maximized at 25°C and 25 ppt salinity (Tettelbach and Rhodes 1981). Tettelbach and Rhodes (1981) also gave multiple regression equations for predicting larval survival through 5 days, larval survival through 8 days (settlement), larval growth through 5 days, and larval growth through 8 days, from temperature and salinity of the rearing environment.

Water Currents

Water currents seem to influence food availability, waste removal, growth rate, larval movements, and distribution of juvenile settlements (Broom 1976; Robert 1978). Kirby-Smith (1972) found that scallops grew best in water currents less than 1 cm/s (0.03 ft/s); maximum growth occurred at 0.21 cm/s (0.007 ft/s). Scallop growth ceased at a water velocity of 12 cm/s (0.4 ft/s). Adductor muscle (the edible portion of scallops) quality was higher at slow currents compared to fast currents. Food availability was interrelated with current and growth, and growth decreased if adequate food (given as 1.2 µg/l chlorophyll a) was not available, even at the slowest current speeds. Cooper and Marshall (1963) reported that although the densest of four scallop beds studied was in an area with the highest current velocity, scallops in slower currents had the higher condition factors.

Water currents probably influence the directional movements and distribution patterns of planktonic life stages of the bay scallop (Moore and Marshall 1967; Merrill and Tubiash 1970). However, once bay scallops reach the adult stage, water currents play a lesser role in influencing movement, though they may cause apparent directionality of movement in otherwise random individual scallop movements (Moore and Marshall 1967; Broom 1976).

Turbidity

Stone and Palmer (1973) demonstrated that bay scallops exposed to 1000 ppm turbidity (clay particles) for several weeks showed a 19% reduction in dry weight compared to control animals. At 500 ppm, filtering rates of bay scallops decreased 35% compared to controls. Stone and Palmer (1973) suggested that long-term exposure to levels of turbidity greater than 500 ppm may interfere with normal growth and reproductive processes of bay scallops.

Substrate

The availability of appropriate substrates for settlement, attachment, and feeding activity is essential. Beds of eelgrass and other seagrasses growing on sand substrates are preferred (Belding 1910). Soft mud and silt substrates are harmful to the survival of settling juveniles, but only if juveniles do not first attach directly to seagrass for a short period of growth before dropping to the bottom (Castagna 1975). Extremely thick seagrass beds, with no open spaces, cut off water circulation entirely and are detrimental to settling juvenile scallops (Belding 1910).

Oxygen Requirements

Resting requirements of oxygen for adult bay scallops averaged 70 ml/kg/hr at 20°C (68°F), a value comparable to that of other temperate bivalves possessing strong swimming powers (Van Dam 1954). Rate of oxygen uptake was independent of dissolved oxygen concentration down to a level of 1.5 ppm. Percentage of available dissolved oxygen removed by scallops ranged from 0.5% to 13% (Van Dam 1954).

Heavy Metals

Ninety-six hour LC_{50} values for juvenile bay scallops exposed to silver, mercury, and cadmium were 33 ppb, 89 ppb, and 1480 ppb, respectively (Nelson et al. 1976). Scallops surviving after 96 hr of exposure to 940 ppb cadmium and 22 ppb silver had significant uptake ,of these metals in all body tissues. Exposure to LC_{25} and LC, concentrations of cadmium caused higher oxygen consumption compared to control animals. Juvenile scallops exposed to LC_{25} concentrations of silver also had higher oxygen consumption, but those exposed to LC_5 concentrations did not exhibit this reaction (Nelson et al. 1976).

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal aquatic species. They are prepared to assist in environmental impact assessment. The bay scallop (Argopecten irradians) is a commercially and ecologically important scallop of estuarine and inshore environments, from Cape Cod, Massachusetts, to Laguna Madre, Texas. They occur at depths from 0.3 to 18 m but are most common in waters less than 2 m deep. They spawn at 1 year of age from April through December, later in southern populations. Water temperature and food supply are important factors for proper gonad development and spawning. Larvae are planktonic, and juveniles settle and attach by byssal threads to suitable substrates; seagrass beds are preferred for settlement. Bay scallops are filter feeders, consuming primarily benthic diatoms. Temperature, salinity, water currents, and availability of suitable attachment/settlement substrates are the most important environmental requirements of bay scallops. They require a minimum water temperature of 20°C for spawning, and a minimum of 14 ppt salinity, grow best in currents less than 1 cm/s, and prefer eelgrass to other seagrasses for settlement and attachment during early life stages.

17. Document Analysis a. Descriptors

Scallops
Feeding
Shellfish
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Bay scallop
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Spawning

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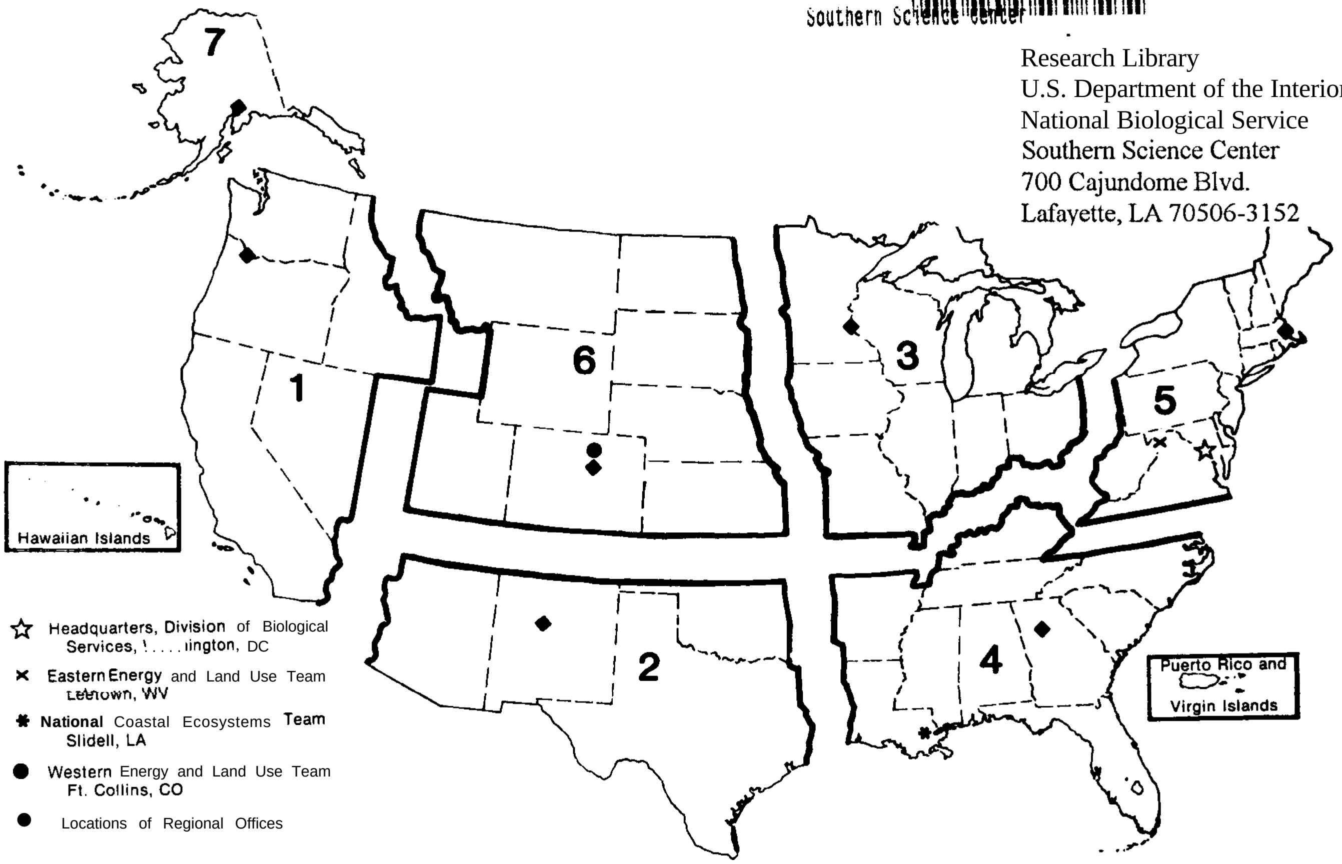

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