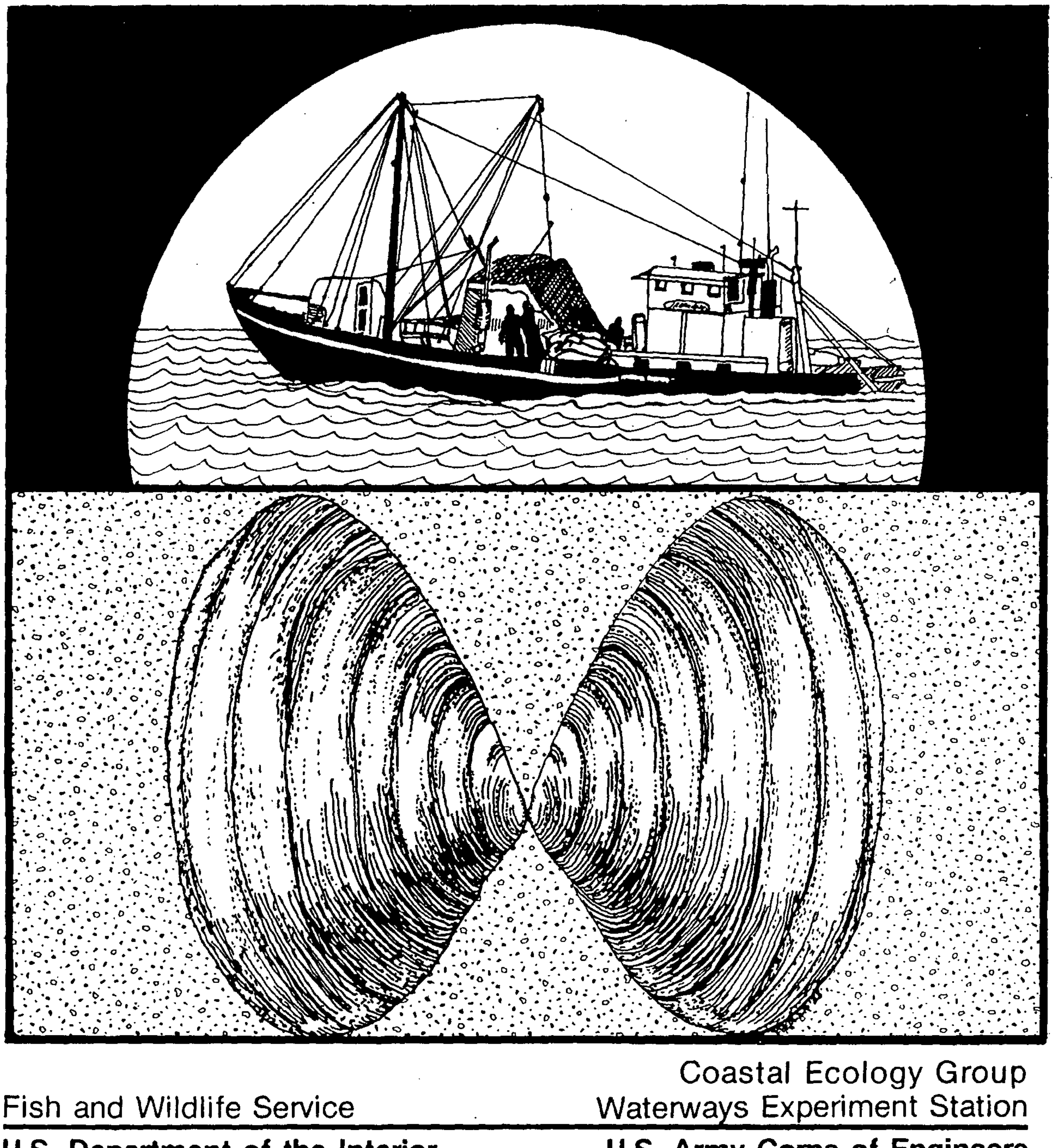
FWS/OBS-82/11.13
October 1983
TR EL-82-4

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

SURF CLAM



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

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

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

SURF CLAM

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 (l)	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

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 profiles 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 has 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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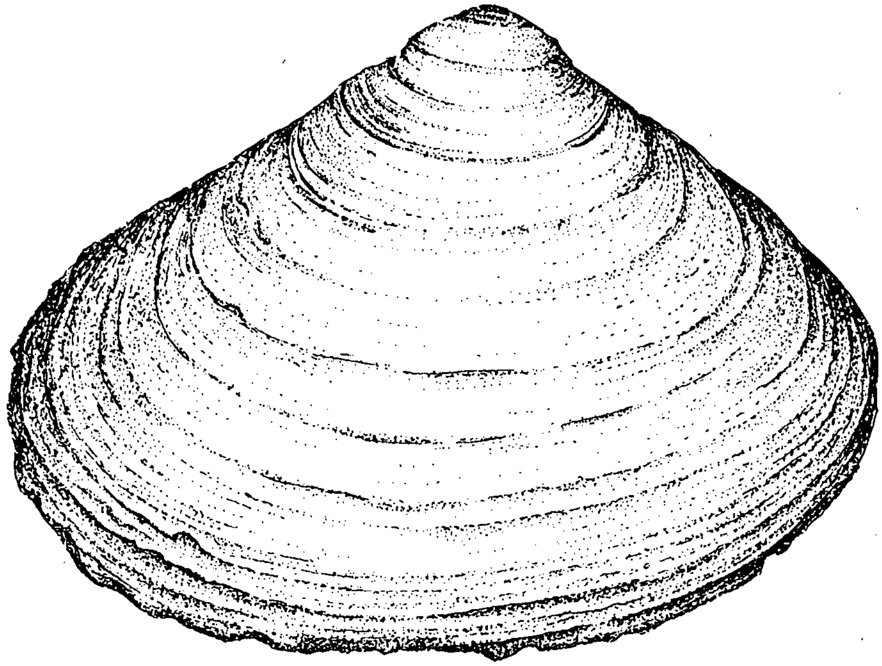

Figure 1. Surf clam.

SURF CLAM

NOMENCLATURE/TAXONOMY/RANGE

Scientific name......<u>Spisula solidissima</u>
Preferred common name.........Surf clam (Figure 1)
Other common names....Bar clam (Canada), hen clam (Maine), sea clam (Massachusetts), beach clam, skimmer clam (Ropes 1980)
Class........................Bivalvia
Order......................Veneroida
Family......................Mactridae

Geographic range: Gulf of Maine south to Cape Hatteras, North Carolina (Wigley and Emery 1968) (see Figure 2 for the distribution of the surf clam in the mid-Atlantic region). A much broader latitudinal range, from the southern Gulf of St. Lawrence to the northern Gulf of Mexico, was given in Merrill and Ropes (1969), Ropes et al. (1969), and Ropes (1980). Evidence that the populations south of Cape Hatteras are actually a distinct subspecies of S. solidissima, S. s. ravaenelli, is presented in Merrill and Webster (1964) and Jacobsen and Old (1966). Surf clams are predominantly oceanic, most common in turbulent waters just beyond the breaker zone (Ropes 1980). Encroachment into estuarine zones is probably limited by salinity requirements.

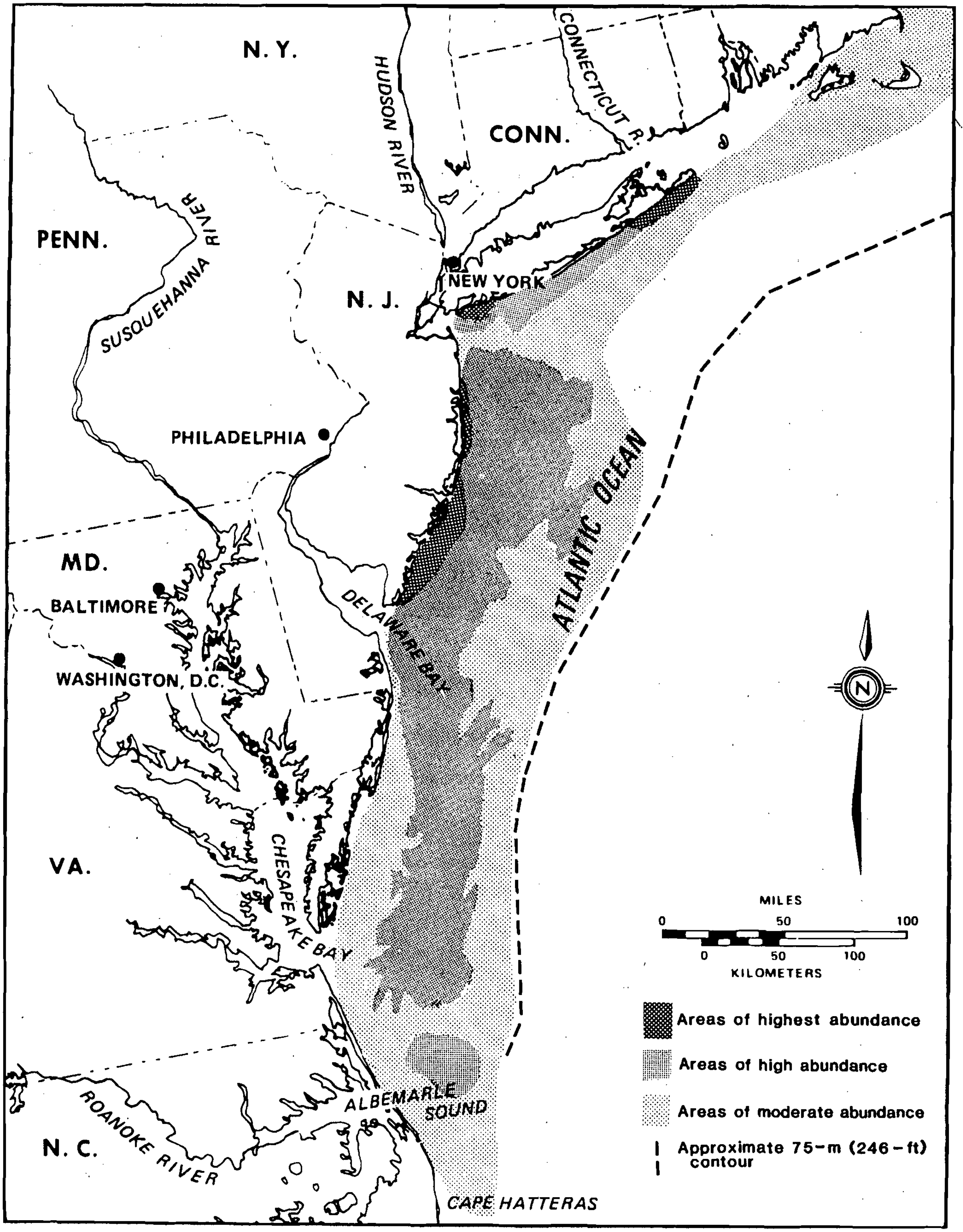

Figure 2. Mid-Atlantic distribution of the surf clam, with areas of relative abundance indicated.

MORPHOLOGY/IDENTIFICATION AIDS

Shells oval to trigonal, concentrically striated or ridged, otherwise with no external sculpture; gape slight when shell closed; ligament spisuloid; complete complement of lateral teeth; pallial sinus shallow and not larger than adductor muscle scar (Chamberlin 1954). Detailed family and generic morphological characteristics and anatomical drawings are given in Ropes (1980).

REASON FOR INCLUSION IN SERIES

The surf clam commercial fishery has grown from a small bait fishery during the years prior to World War II (Ropes et al. 1969) to one contributing 71.8% of all clam meats used in the United States between 1970 and 1974 (Ropes 1982). Per capita consumption of surf clam meat doubled between 1947 and 1974 (Ropes 1982). Within the mid-Atlantic region, the surf clam is a particularly important commercial clam species because of its wide distribution and abundance in the region, and because most vessels in the fishery are located in New York, New Jersey, Delaware, Maryland, and Virginia (Ropes 1982).

LIFE HISTORY

Reproductive Physiology/Strategy

Surf clams are heterosexual (Ropes 1980), though hermaphroditism has been reported (Ropes 1968a). Male and female surf clams are identical in external appearance, and histological sectioning and examination of gonads is the only sure way to determine surf clam gender (Ropes et al. 1969). Male and female surf clams reach full sexual maturity during their second year, even though ripe gonads and some spawning activity may occur in 1-year-old clams (Ropes 1979). Smallest reported shell length at maturity was 45 mm (1.8 inches) (Ropes 1980). No observations on fecundity of surf clams are available.

Spawning

Surf clam populations from New Jersey coastal waters exhibited two annual spawnings in 1962, 1963, and 1964 (Ropes 1968b). These occurred from mid-July to early August and from mid-October to early November. In 1965, a single spawning period from mid-September to mid-October was observed. The spawning season is probably earlier south of New Jersey, since juvenile clams have been found in North Carolina waters in April, May, and June (Williams and Porter 1971). Little is known concerning the spawning season of surf clam populations north of New York.

Within a bed of clams, spawning is probably a synchronous, annual event (Ropes 1968b). Water temperature is an important factor influencing initiation and time of spawning (Ropes 1980), and may also influence rate of gonadal ripening and number of major spawning periods per year (Ropes 1968b). After eggs and sperm are broadcast, fertilization occurs in the water column above the spawning bed of clams (Murawski and Serchuk 1981; Ropes 1980).

Eggs

Surf clam eggs are spherical and average 1.42 mm (0.06 inch) in diameter across the vitelline membrane; the inner germinal vesicle averages 0.79 mm (0.03 inch) in diameter (Allen 1953). Several layers lie between the invisible, outer, jellylike layer and the germinal vesicle (Ropes 1980). Longo (1973) reviewed the literature on embryogenesis of fertilized surf clam eggs.

Little is known concerning the effects of water temperatures on development rate of surf clam eggs. Fertilized eggs held at an average water temperature of 21.7°C (71°F) (range 18.3° to 24.9°C or 65° to 77°F) in the laboratory completed first cleavage by 70 min after fertilization (Costello et al. 1957). Trochophore larvae began appearing 9 hr after fertilization (Costello et al. 1957; Ropes 1980). Fertilized eggs reached the veliger larvae stage in 72 hr at 14°C (57°F), and in 28 hr at 22°C (72°F) (Loosanoff and Davis 1963).

Larvae

Pyramid-shaped, planktonic trochophore larvae began developing from swimming gastrulae 9 hr after fertilization at a water temperature of 21.7°C (71°F) (Costello et al. 1957; Ropes 1980). Veliger larvae (first appearance of bivalved shell) formed by 19 to 20 hr after fertilization, and a ciliated velum also appeared at this time (Ropes 1980). The velum is used for propulsion of the larvae until the juvenile or "settlement" phase is reached. One day after fertilization, veliger larvae averaged 89 microns (µ) long and 71 µ high (Ropes 1980). Other reported values for the size of veliger larvae at 1 day were (length by height) 95 µ by 80 µ (Sullivan 1948) and 80 µ by 65 µ (Loosanoff et al. 1966).

Pediveliger larvae, a transitional, "swimming-crawling" larval stage with development of a foot for burrowing (Carriker 1951), were first observed 18 days after fertilization at 21.7°C (71°F); by 21 days, nearly all veliger larvae had developed through the brief pediveliger stage and metamorphosed into juvenile clams (complete absorption of velum, settlement to the substrate, and beginning of sedentary life stage) (Ropes 1980). At 14°C (57°F) and 22°C (72°F), metamorphosis to juveniles was first observed after 35 and 19 days, respectively. Larvae reared at the lower temperature were significantly smaller than larvae reared at 22°C (72°F) (Loosanoff and Davis 1963).

Detailed descriptions of the anatomical development of surf clam larvae from the trochophore larval stage through the juvenile stage are provided by Ropes (1980). A key for identifying larvae of 23 clam species inhabiting the Middle Atlantic Bight and suggestions for general taxonomic separation are given in Chanley and Andrews (1971). Additional information on species separation is available in Loosanoff and Davis (1963) and Loosanoff et al. (1966).

Water currents in areas where planktonic surf clam larvae live are important in determining eventual patterns of distribution and settlement for developing juveniles (Ropes et al. 1969; Ropes 1980). Dispersal and redistribution of surf clams to other areas, through swimming and crawling activities and water currents, occur primarily during the larval stages. Specific information, however, on the interaction of water currents and larval settlement patterns is unavailable (Ropes 1980).

Juveniles

Juvenile surf clams, with a well-developed foot for burrowing and fully absorbed velum, were present 18 days after fertilization at 21.7°C (71°F). By 21 days, all clam larvae had metamorphosed into juveniles; average size was 303 µ long by 267 µ high (Ropes 1980). Other reported values were (length by height) 270 µ by 245 µ (Sullivan 1948) and 263 µ by 245 µ (Loosanoff et al. 1966). The juvenile stage lasts from first settlement in the substrate until sexual maturity, which may occur during the second (age 1^+) or third (age 2^+) summer of life.

The extent of juvenile surf clam movement by a locomotion called "leaping" (a push with the foot against the substrate) was investigated by Ropes and Merrill (1973). A young surf clam, disturbed from its burrow by the investigators or a predator, usually reburrowed in the same spot. Leaping was infrequent, and was usually caused by repeated disturbance of the clam in its burrow. Stimuli reported for leaping in a closely related mactrid, *Mactra corallina*, were (1) proximity to a predator, (2) inability to burrow in the substrate of settlement, and (3) exposure to air (Ansell 1969). Ropes and Merrill (1973) concluded that surf clam leaping was exceptional and infrequent, and probably insignificant in determining their overall settlement and distribution patterns. Voluntary leaping (i.e., with no disturbance) was never observed.

Adults

Adult surf clams spend most of their lives burrowed in medium to coarse sand and gravel substrates. Since siphons are about as long as the adult clam, burial depth may be well below the substrate surface (Ropes 1980). Papillae fringing the siphonal openings (Morse 1919) may aid in preventing sand grains from being drawn into the siphon during respiration and feeding (Ropes and Merrill 1973). Abundance of adults in suitable substrates ranges from loose, fairly evenly distributed aggregations (Olsen 1970) to localized or patchy, dense beds, occasionally with individuals close enough in the substrate for shells to touch (Wilbur 1964; Flowers 1973; Ropes 1980).

Surf clams were a dominant species collected in surveys of inshore benthic fauna from southwestern Long Island, New York (Steimle and Stone 1973), and Little Egg Harbor, New Jersey (Garlo and Hondo 1973). Most surf clam beds of the Middle Atlantic Bight are located from the beach zone to a depth of 43.9 m (144 ft) off Long Island, out to 59.7 m (196 ft) off New Jersey, from 10.1 m to 65.5 m (33 ft to 215 ft) off the Delmarva Peninsula, and from 8.2 m to 58.8 m (27 ft to 193 ft) off Virginia and North Carolina (Ropes 1979). Inshore distribution of surf clams, particularly in estuarine zones, is probably limited by salinity requirements (Ropes 1980) (see ENVIRONMENTAL REQUIREMENTS -- *Salinity* section).

Adult surf clams rarely voluntarily vacate their burrows, and under natural stimuli alone, may live their entire lives in a single burrow. Studies by Armstrong (1965), Ropes and Merrill (1970), and Ropes and Merrill (1973) reported little or no voluntary movement of marked clams under natural conditions. Oceanic storms and water currents generated over the ocean floor may displace surf clams a considerable distance (Yancey and Welch 1968), but survivors of the displacement not washed onto the beach probably burrow at or near the site where they settle after a storm (Ropes and Merrill 1973).

Determinations of surf clam longevity have been made from individual specimens. Three records of the oldest surf clams are 17-year-old specimens averaging 163 mm (6.41 inches) long (Westman and Bidwell 1946), 20-year-old specimens averaging 147 mm (5.79 inches) (Loesch and Ropes 1977), and 25-year-old specimens averaging 164 mm (6.46 inches) (Jones et al. 1978). The greatest shell length ever reported for surf clams was a 226-mm (8.9-inch) specimen collected offshore of Point Pleasant, New Jersey, at a depth of 21.3 m (70 ft). This individual was in a commercial sample of 10, averaging 193 mm (7.6 inches) and ranging from 178 to 226 mm (7.0 to 8.9 inches) in length (Ropes and Ward 1977).

GROWTH CHARACTERISTICS

Growth Rates

In laboratory experiments conducted at 21.7°C (71°F), length-by-height measurements of veliger larvae shells at daily ages were 1 day, 89 μ by 71 μ; 2 days, 89 μ by 76 μ; 7 days, 94 μ by 79 μ; 17 days, 213 μ by 194 μ; and 18 days (beginning of pediveliger stage), 245 μ by 230 μ (Ropes 1980).

A unique situation for studying surf clam growth occurred in a discrete, newly settled clam bed discovered in Chincoteague Inlet, Virginia, on 1 October 1964 (Ropes et al. 1969). Age 0^+ clams from this bed averaged 21.1 mm (0.8 inch) in shell length on 28 October 1964. Subsequent samples indicated average shell lengths of 42.4 mm (1.7 inches) on 7 July 1965 (age 1^+), 68.6 mm (2.7 inches) on 18 July 1966 (age 2^+), and 90.5 mm (3.6 inches) on 7 August 1967 (age 3^+). During the winter of 1967-68, heavy losses to predation and storm-related mortality reduced this population below levels necessary for sampling. Projection of the data collected, however, indicated an average shell length of 110 mm (4.3 inches) at age 4^+.

Prior to 1975, most determinations of age and growth of adult surf clams were made by counting and measuring radii of concentric "rings" or "ridges" commonly observed on the external surface of shells (e.g., Belding 1910; Kerswill 1944; Westman and Bidwell 1946). Growth data from these and other studies using the external aging method were summarized by Ropes (1980). Age and growth techniques were refined by National Marine Fisheries Service investigators beginning in 1975. Shells cut along a line from the umbo to the ventral edge and polished revealed distinctive marks related to the external ridges (Ropes 1980). Greater accuracy in measuring age and growth was achieved because the marks were better defined than the external ridges. Since development of this technique, studies by Chang et al. (1976) and Jones et al. (1978) reported age-size relationships using cut and polished shells (Table 1). These data indicate that surf clams sampled from the Ocean City area grew faster and lived longer than those collected from Barnegat Bay and Point Pleasant areas. But Ropes (1980) noted that these differences may be a function of depth of the clam bed and its location with respect to shore (i.e., inshore vs. offshore). Both Chang et al. (1976) and Jones et al. (1978) found that surf clams sampled from relatively deepwater, offshore areas (18.3 to 28.0 m or 60 ft to 92 ft deep) grew faster and lived longer than those sampled from relatively shallow-water, inshore sites (11.6 m to 15.0 m or 38 ft to 49 ft). The influence, however, of exploitation differences among these populations was not considered.

The most recently developed technique for aging surf clams is thin-sectioning of the chondrophore (located in the hinge of the clam) (Ropes and O'Brien 1979). Marks on the sectioned chondrophore correspond to those on the cut and polished shell. This method was apparently simpler to use and data on growth easier to collect compared to the valve-cutting technique (Ropes and O'Brien 1979).

Length-Weight Relationships

Shell length (L in mm) to drained-meat weight (W in g) relationships for surf clam populations of the Middle Atlantic Bight were determined by Murawski and Serchuk (1981), and are presented below for the following areas: (1) southern New England, (2) New Jersey, (3) Delmarva Peninsula, (4) North Carolina, and (5) all areas combined.

(1) $\ln(W) = -7.973 + 2.578 \ln(L)$

(2) $\ln(W) = -9.206 + 2.825 \ln(L)$

(3) $\ln(W) = -9.106 + 2.767 \ln(L)$

Table 1. Surf clam shell length (mm) at age (yr) for three mid-Atlantic locations, determined by the cut-and-polished-shell technique.

Age (yr)	Shell length (mm) Point Pleasant, New Jersey[a]	Barnegat Bay, New Jersey[b]	Ocean City, Maryland[b]
1	38	34	39
2	62	56	57
3	79	73	94
4	88	88	113
5	94	102	126
6	97	109	136
7	102	---	143
8	106	---	148
9	108	---	152
10	109	---	156
11	110	---	159
12	---	---	161
13	---	---	163

[a]Jones et al. 1978.
[b]Chang et al. 1976.

$$(4) \quad \ln(W) = -7.058 + 2.303 \ln(L)$$
$$(5) \quad \ln(W) = -9.194 + 2.805 \ln(L)$$

Similar relationships for shell length to shell height, shell width, shell weight, total clam weight, and chondrophore length were given in Chang et al. (1976).

Age-Length/Age-Weight Relationships

Von-Bertalanffy growth equations for (1) age (t in yr) to shell length (L in mm), (2) age to total live weight (W in g), and (3) age to drained-meat weight (W in g) were determined for Middle Atlantic Bight surf clams (Chang et al. 1976) as follows:

$$(1) \quad L = 174.8(1-e(\exp -0.19(t+0.81)))$$
$$(2) \quad W = 762.7(1-e(\exp -0.11(t-3.13)))$$
$$(3) \quad W = 263.2(1-e(\exp -0.14(t-2.05)))$$

where values in parentheses with "exp" represent the exponent of e, the base of natural logarithms.

THE FISHERY

Commercial Fisheries

Compared to information available on life history and environmental requirements of surf clams, information on fishery operations, stock assessment, and trend prediction is extensive and detailed. Summaries of fishery operations for 1972 (Ropes et al. 1975a), 1973 (Ropes et al. 1975b), and the period 1965 to 1974 (Ropes 1982) are available. Summaries of the geographical distribution of landings, relative abundance of exploitable and recruiting stocks, fishery operations through 1982, and predicted trends in the fishery are available in Ropes (1979) and Murawski and Serchuk (1979, 1981, 1982). The reader is referred to these seven studies for detailed information on surf clam fisheries and population dynamics. For the scope and purpose of this profile, only major aspects and trends of the fishery are included.

Earliest methods of harvesting surf clams were by hand-operated rakes or simply by gathering clams from beaches after storms (Parker 1971). During the 1920's, scraper-type dredges towed behind power-boats were used, but were relatively inefficient and broke many clams. In the mid-1940's, the water-jet dredge was developed. This innovation increased fishing efficiency, decreased clam breakage, and was instrumental in developing the modern-day surf clam fishery (Ropes 1980).

The present surf clam fishery uses a "knife-scraper" dredge with a water-jet system mounted ahead of the scraper. These dredges are larger and heavier than those used in the 1940's. The knife may be as wide as 3 m (10 ft), and the water-jet hose as large as 20 cm (7.8 inches) in diameter. Special vessel construction is now necessary to tow these dredges effectively. The addition of stern ramps and conveyor systems to clam fishing boats constructed or converted after 1970 has further increased fishing efficiency (Ropes 1980).

The commercial fishery for surf clams has developed from one during World War II, when surf clams supplied 3.2% of the U. S. landings of clam meats, to an extensive fishery by the late 1950's. Between 1970 and 1974, surf clams provided 71.8% of all clam meats used in the United States. Per capita consumption of surf clams in the United States has doubled from 0.122 kg (0.268 lb) in 1947 to 0.267 kg (0.589 lb) in 1974.

Ropes (1982) summarized monthly landings and trends of the surf clam fishery for five States in the Middle Atlantic Bight, from 1965 to 1974. Over this 9-year period, landings at New York, Maryland, and Delaware ports remained relatively stable and low compared to those at New Jersey and Virginia ports. Landings at New Jersey ports declined gradually from 1965 to 1970, then more rapidly from 1970 to 1974. Despite the decline, New Jersey ports remained the most important for total clam landings through 1972. Landings at Virginia ports began to increase sharply in 1970 as fishermen shifted their efforts southward. By 1974, Virginia landings had surpassed New Jersey landings, and these two States accounted for more than 80% of all surf clam landings (Ropes 1982).

Clam stocks and harvests from New Jersey waters continued to decline after 1974, but some signs of at least temporary rebuilding of fishable stocks were evident in 1981 trawl surveys (Murawski and Serchuk 1981). In contrast to the New Jersey fishery, fisheries off Virginia (including the Delmarva Peninsula) have increased in importance to the overall fishery. Commercial fisheries apparently continue to shift the concentration of effort southward, since northern stocks remain at relatively low levels (Murawski and Serchuk 1981).

Table 2 summarizes total U. S. landings of surf clams between 1965 and 1981. Percentage of the total catch outside State territorial waters (greater than 4.8 km or 3 mi offshore) is also given in Table 2 (data from Murawski and Serchuk 1982, and National Marine Fisheries Service 1978-1982). Total U. S. landings in 1974 and 1975 were 96.1 million lb (43.6 thousand metric tons (mt)) and 87.0 million lb (39.5 thousand mt) of shucked meats, respectively. In

Table 2. Total U.S. commercial landings of surf clams (in thousands of lb of meats), U.S. commercial landings from the Fishery Conservation Zone (4.8 to 321.9 km or 3 to 200 mi offshore), and the percentage of the total landings taken in the Fishery Conservation Zone.

Year	Total landings (thousands of lb)	Landings outside 3 mi offshore (thousands of lb)	Percent of landings[a] outside 3 mi
1965	44,088	33,000	74.9
1966	45,113	32,400	71.8
1967	45,054	24,700	54.8
1968	40,552	20,000	49.3
1969	49,575	15,900	32.1
1970	67,318	14,100	20.9
1971	52,535	50,053	95.3
1972	63,371	55,272	87.1
1973	82,370	72,579	88.1
1974	96,110	74,430	77.4
1975	86,956	44,270	50.9
1976	49,133	42,558	86.6
1977	51,036	42,968	84.2
1978	39,237	31,393	80.0
1979	34,912	29,070	83.3
1980	37,737	34,718	92.0
1981	46,100	37,340	81.0
1982	------	27,635[b]	----

[a]Proration for 1972-81 based on data presented in Fisheries of the United States (National Marine Fisheries Service 1978-1982). Earlier data from Murawski and Serchuk (1982).
[b]Only preliminary data available for 1982.

1976, total landings dropped to 49.1 million lb (22.3 thousand mt). The major reason for the large decline between 1975 and 1976 was the collapse of the New Jersey fishery, due to large areas of ocean-bottom water with low levels (<2.0 ppm) of dissolved oxygen during the spring and summer of 1976 (see ENVIRONMENTAL REQUIREMENTS -- Dissolved Oxygen section). Total landings dropped even further by 1979, to 34.9 million lb (15.9 thousand mt), but increased again in 1980 and 1981 to 37.7 million lb (17.1 thousand mt) and 46.1 million lb (20.9 thousand mt), respectively.

For landings in 1981, 58% came from Delmarva Peninsula fishing areas, while 41% came from northern New Jersey areas. Only 1% of the catch was taken from southern New Jersey, which in the 1960's and early 1970's had been one of the more important clam fishing grounds (Murawski and Serchuk 1981). Part of the apparent rebound of the surf clam fishery in 1980 and 1981 was due to improved resource conditions in the northern New Jersey areas.

Except for 1975, greater than 75% of all surf clam landings between 1971 and 1981 came from areas greater than 4.8 km (3 mi) offshore (Table 2). In 1980 and 1981, 92% and 81%, respectively, of the total landings came from the U. S. Fishery Conservation Zone (4.8 to 321.9 km or 3 to 200 mi offshore). These offshore areas are apparently increasing in importance, as easier-to-fish but overexploited inshore populations remain depleted (Murawski and Serchuk 1981).

After passage of the Fishery Conservation and Management Act of 1976, a Fishery Management Plan (FMP) was developed for surf clam stocks in the U. S. Fishery Conservation Zone. At the time this FMP was developed, surf clam stocks were at a relatively low level compared to historical stocks. Intensive fishing during the 1960's and early 1970's and the oxygen depletion dieoff in New Jersey waters in 1976 reduced exploitable surf clam stocks. To achieve the catch goals in the FMP, various regulatory mechanisms have been implemented, including annual and quarterly landings quotas, weekly effort restrictions, a moratorium on new vessel construction, closure of specific areas to protect young clams (future recruitment), and most recently (26 July 1981) a minimum clam size of 14 cm (5.5 inches) (Murawski and Serchuk 1981). Since its adoption, the minimum size limit has resulted in the further decline of catch per unit effort, thus indicating the importance of 10- to 13-cm (3.9- to 5.1-inch) clams to the fishery prior to size regulation (Murawski and Serchuk 1981).

The most recent assessments of the abundances of fishable and recruiting surf clam stocks indicate that the relatively strong 1976 year class has helped restore northern New Jersey fishing grounds. The bulk of the 1976 cohort still remains below exploitable size (14 cm or 5.5 inches), but is predicted to enter the fishery in substantial numbers by mid-1983. Harvestable biomass in southern New Jersey waters has also increased from low levels in the late 1970's, but is still well below that which was available to fishermen in the late 1960's (Murawski and Serchuk 1981). The Delmarva Peninsula has maintained fairly stable levels of harvestable biomass since it became an important fishing ground in the mid-1970's. However, most of the 1981 landings prior to July 1981 (adoption of the size limit) came from the relatively strong 1977 year class in the Delmarva area, and adoption of the minimum size limit curtailed full exploitation of this year class until at least 1984 (Murawski and Serchuk 1981).

Population Dynamics

Sex ratios. A 4-year study of the reproductive cycle of surf clams off the New Jersey coast, between 1962 and 1965, indicated that sex ratios in clam beds did not deviate significantly from a 1:1 ratio (Ropes 1968b). Data from National Marine Fisheries Service (NMFS) surveys during 1965 and miscellaneous sources also indicated no significant deviation from a 1:1 sex ratio in the populations sampled (Ropes 1980).

Age composition. According to all of the clam age data from Ropes (1980), the age classes (determined by both external and shell-sectioning aging techniques) present in samples from various mid-Atlantic areas were as follows: offshore Virginia, 1 to 19 (Loesch and Ropes 1977); inshore Chincoteague Inlet, Virginia, 1 to 3 (Ropes et al. 1969); offshore Ocean City, Maryland, 1 to 13 (Chang et al. 1976); inshore Barnegat Bay, New Jersey, 1 to 6 (Chang et al. 1976); inshore Point Pleasant, New Jersey, 1 to 11 (Jones et al. 1978); offshore Point Pleasant, New Jersey, 1 to 25

(Jones et al. 1978); offshore central New Jersey, 1 to 12 (Ropes 1980); and offshore Long Island, New York, 1 to 17 (Westman and Bidwell 1946). These age class data support the hypothesis that individuals from offshore, deepwater clam beds live longer than those from inshore, shallow water beds. Differences in age class structure among populations, however, may be because of varying degrees of exploitation in inshore and offshore beds.

Recruitment and production. Relative abundance (mean number per tow) of recruiting surf clams (less than 14.0 cm or 5.5 inches) in National Marine Fisheries Service bottom trawl surveys from 1965 to 1978 is summarized in Table 3 (data from Murawski and Serchuk 1982). Exceptionally high abundances in surveys beginning in December 1978 off northern New Jersey and Delmarva Peninsula indicated relatively strong year classes in 1976 and 1977 in those areas. Young clams from the 1976 and 1977 year classes were predicted to enter the fishery by 1982 (prior to establishment of a minimum size limit) (Murawski and Serchuk 1979). However, with the adoption of the 14-cm (5.5-inch) minimum size limit in July 1981, these year classes will probably not be recruited to the fishery until 1983 or 1984 (Murawski and Serchuk 1981).

In three unexploited surf clam beds in the Gulf of St. Lawrence, off Buctouche, New Brunswick, density of surf clams averaged $1.06/m^2$ ($0.10/ft^2$) and ranged from 0.68 to $1.25/m^2$ (0.06 to $0.12/ft^2$). Total estimated standing crop in these three beds, which collectively covered 2.6 km^2 (1.0 mi^2), was 2.8 million clams (Caddy and Billard 1976). Three models for predicting yield based on varying fishing mortality rate (F) and age of first capture were tested by using data from these unexploited beds. To develop and test these models, natural mortality rate (M) was assumed equal to 0.2 (estimated with catch curves from diving expeditions), and recruitment was assumed constant at 500,000 age 1 clams per year to an initial population size of 2.8 million clams. Values for variables in the three yield models were (1) age at first capture 5 years (approximately 8.0 cm or 3.1 inches) and F=0.5, (2) age at first capture 3 years (approximately 4.0 cm or 1.6 inches) and F=0.5, and (3) age at first capture 3 years and F=0.25 (Caddy and Billard 1976).

For all three models, catch rates declined steadily from the first year of fishing through the eighth year. Long-term yield per recruit was 40% higher for model (1) compared to model (2). Model (1) approximated an optimum sustained yield per recruit. Initial catch under model (2) was half that of the other models, but long-term catch under model (2) was intermediate to models (1) and (3). Although model (1) appeared to be near optimum for long-term sustained yield, model (3) was predicted to have the highest catch per unit effort (kg per diver hour); and model (1) would require twice the fishing effort of model (3) to achieve the long-term predicted yield (Caddy and Billard 1976). Caddy and Billard (1976) also noted that fishing mortality rates higher than 0.5 or age of first capture greater than 5 years significantly decreased yield per recruit compared to the three models tested (this was apparently determined in preliminary model testing).

ECOLOGICAL ROLE

Food Habits

In laboratory-reared surf clam larvae, yolk material was fully absorbed and algal cells began appearing in some stomachs at 1 day

Table 3. Relative abundance (mean number per standardized 5-min tow) of recruiting (less than 14.0 cm or 5.5 inches) surf clams from National Marine Fisheries Service surveys, 1965-82, in the Fishery Conservation Zone offshore of northern New Jersey, southern New Jersey, Delmarva Peninsula, and Virginia-North Carolina (data from Murawski and Serchuk 1982).

Cruise period	Northern New Jersey	Southern New Jersey	Delmarva Peninsula	Virginia-N. Carolina
May 1965	15.4	78.1	15.8	2.9
Oct 1965	6.2	33.3	10.8	11.8[a]
Aug 1966	5.4	14.6	10.7	16.3[a]
Jun 1969	3.9	5.5	8.0	78.7
Aug 1970	4.8	2.7	4.7	0.7[a]
Jun 1974	2.7	2.2	6.7	12.7
Apr 1976	2.4	0.6	7.3	1.1
Jan 1977	1.4	1.2	2.7	----
Jan 1978	1.5	3.9	4.9	1.1
Dec 1978	43.9	4.5	616.4	----
Jan 1980	27.5	2.5	58.1	86.1[a]
Aug 1980	50.7	2.9	39.4	----
Aug 1981	31.1	0.6	156.9	18.0[a]
Aug 1982	101.5	3.6	102.5	1.2[a]

[a]Only a small portion of the total Virginia-North Carolina offshore area was surveyed.

of age (veliger larvae) (Ropes 1980). Larval surf clams fed on algal cells throughout the remainder of the stage (Ropes 1980). Loosanoff and Davis (1950, 1963) successfully reared larval surf clams on mixed plankton cultures and discussed conditions necessary for raising larval surf clams in relation to food. Laster and Strittmater (1968) noted that maltase activity in developing larval surf clams increased tenfold in the early veliger stage, coincidental with development of the esophagus, stomach, intestine, and digestive gland.

Stomachs of adult surf clams from New Jersey coastal waters contained a variety of diatom genera and species, but only Amphipora constricta and Tintinnus spp. were identified from the contents (Leidy 1878). Difficulties in identification were caused by change in diatom structure after entry into the surf clam's digestive tract.

Stephens and Schinske (1961) observed that the amino acids glycine, glutamic acid, tyrosine, methionine, phenylalinine, and arginine were successfully removed from food items ingested by surf clams, and appeared to be of nutritional value. Food consumed and assimilated by surf clams probably depends on geographic location and depth of the bed, seasonal variation in availability of food items and feeding activity, and annual or long-term fluctuations in diversity and abundance of food organisms.

Feeding Behavior

Like many bivalves, surf clams are planktivorous, siphon feeders. Feeding activity of surf clams is intimately associated with the overall process of siphoning water for respiration and excretion (Ropes 1980). Feeding surf clams burrow deep enough in the substrate so that the end of the incurrent siphon barely protrudes above the bottom (Ropes and Merrill 1976). Some sand grains and other unwanted material may be ingested under these circumstances, but the action of papillae fringing the siphon may reduce such occurrences (Morse 1919; Jacobsen 1972). Surf clams in the breaker zones of coastal oceanic habitats close their siphons when breaking waves with suspended sand pass by, reopening the siphon quickly after the wave passes (Jacobsen 1972). Food particles trapped on the mucus-coated inner siphonal surfaces move unidirectionally with the mucus toward the gut of the clam (Kellog 1915). Morphology and responses of the incurrent siphonal valve and adductor muscles of surf clams, used to clean debris from the siphonal cavity, were described by Prior (1974). The crystalline style in the digestive tract stirs the stomach contents and aids in producing and excreting enzymes for digestion (Ropes 1980). Studies have been conducted on the enzymes and enzymatic processes in the surf clam gut (Lavine 1946; Patton and Quinn 1973; Shallenberger et al. 1974, 1975; Lindley and Shallenberger 1976, 1977) and on the neurophysiological mechanisms of gut movements (Nystrom 1976; Smucker and Nystrom 1970, 1972).

Predators

Little is known concerning the predators of planktonic surf clam larvae or newly settled juveniles. Some information on predators of other young mactrid clams in European waters is available (e.g., Hunt 1925; Birkett and Wood 1959; Thorson 1966; Muus 1966, 1973; Christensen 1970; Masse 1975), but its relevance and applicability to Atlantic coast surf clam populations are unknown.

The most important predators on adult surf clams are two moon snail species, Lunatia heros and Polinices duplicatus. A characteristic countersunk hole drilled by the snail's radula is usually located near the hinge or umbo of the shell. Low temperatures and salinities apparently reduce predation rates of these snails (Hanks 1952). In laboratory experiments P. duplicatus ceased feeding at 5°C (41°F) or lower and 6 ppt salinity, while L. heros reduced feeding at 2°C (35.6°F) or lower and ceased feeding below 10 ppt salinity. Lunatia heros may be a size-selective predator on surf clams, since Franz (1977) found that most surf clams selected by snails off Long Island were less than 80 mm (3.1 inches) in shell length. This selection, however, may also be related to seasonal or geographic availability of clam size classes to predators.

Another invertebrate predator of the surf clam is the boring snail, Urosalpinx cinerea. In laboratory experiments this snail was unable to bore successfully in running seawater, but was much more effective at boring surf clam shells in standing seawater (Pratt 1974).

Predatory fish reported to consume surf clams are haddock (Melanogrammus aeglefinus) (Clapp 1912; Clarke 1954) and cod (Gadus morhua) (Bigelow and Schroeder 1953; Clarke 1954). Much of this apparent predation may result from scavenging on the soft bodies of fractured surf clam shells which result from major oceanic storms. Recreational cod and haddock fishermen believe that surf clam soft bodies are one of the best baits for several days after a major oceanic storm, but are only fair baits at other times.

Competitors

Little is known concerning competitive interactions between surf clams and other benthic organisms. If competition occurs, it probably involves availability of space at the appropriate depth in the substrate and availability of usable food organisms in the water column just above the seabed (Ropes 1980).

Some evidence exists for intraspecific competition in dense, inshore surf clam beds, including roughened shell surfaces and edges, older shell deposits raised one on top of another like shingles, and blunted posterior ends of shells (Ropes 1980). These features are generally unique to dense populations and may indicate disruption in growth patterns through some competition among clams for space or food (Ropes 1980). In laboratory experiments, localized, physical stimulation of the mantle edge of some mollusks produced large areas of shell regeneration, indicating that proximity of individual clams in dense beds may account for the irregularities in shell growth observed in such beds (Wilbur 1964).

ENVIRONMENTAL REQUIREMENTS

Temperature

Surf clam larvae tolerated a water temperature range from 14°C to 30°C (57°F to 86°F) (Loosanoff and Davis 1963). Optimum temperature for larval development was 22°C (72°F) (Loosanoff and Davis 1963). Juvenile surf clams survived higher temperatures than adults, but became inactive at 4°C (39°F) or lower (Saila and Pratt 1973). Survival of spawning adults and their fertilized eggs was significantly affected at water temperatures of 30°C (86°F) or higher (Loosanoff and Davis 1963). Adult surf clams were unable to establish pedal anchorage at water temperatures greater than 30°C (86°F) (Savage 1976). Lethally low water temperatures for adult surf clams are probably never reached in their oceanic habitat, but low air temperatures (less than 0°C or 32°F) may freeze exposed gill tissue in live clams temporarily washed up onto the beach during storms (Ropes 1980).

In laboratory experiments, the burrowing rate of surf clams increased as water temperature increased to 20°C (68°F), but decreased above this temperature (Savage 1976). Some clams failed to begin digging activities at water temperatures below 2°C (36°F), and others began digging but could not accomplish complete burial at that temperature. Temperature shocks induced by a 14°C (25°F) increase in water temperature, with a starting temperature of 4°C (39°F), did not significantly affect burrowing. A temperature increase of 22°C (40°F) produced gaping, lethargy, and eventually death (Ropes 1980). Water temperature is also important for initiation and rate of gonadal development (Loosanoff and Davis 1963), and for initiation and timing of spawning (Ropes 1968b).

Salinity

Minimum salinities for larval and adult surf clam survival were 16 ppt and 12.5 ppt, respectively (Castagna and Chanley 1973). Adult surf clams tolerated salinities from 14 ppt to 52 ppt (concentrated seawater) (Theede 1965). Encroachment of surf clams into estuarine areas is probably limited by salinity (Ropes 1980).

Dissolved Oxygen

Several instances of severe depletion of dissolved oxygen in the bottom waters of the ocean (equivalent to the hypolimnion in freshwater), along the New Jersey and Long Island coasts, have produced surf clam mortalities. A major event of this type occurred in the spring and summer of 1976. Anoxic water developed over clam beds between Cape May, New Jersey, and Long Island's south shore, out to a depth of 75 m (246 ft), because of the combined effects of meteorological and hydrographic conditions, organic loading from human waste dump sites, and an unusually large bloom and die-off of the dinoflagellate Ceratium tripos (Steimle and Sindermann 1978). The kill area was estimated at 6,750 km^2 (2,605 mi^2), and the loss of meat weights was estimated at 147 thousand mt (162 thousand tons), representing 62% of the New Jersey surf clam resource (Steimle and Sindermann 1978; Ropes 1980). Dissolved oxygen isopleths measured during the kill period indicated an area of approximately 278 km^2 (107 mi^2) (approximately 12.8 km or 8 mi southeast of Barnegat Inlet, New Jersey) where hypolimnetic waters contained no measurable dissolved oxygen. A total area of approximately 9,722 km^2 (3,752 mi^2) contained 1.0 ppm dissolved oxygen or less in the hypolimnion. Nearly the entire area along the New Jersey coast, from the shoreward limit of the hypolimnion to a depth of 75 m (246 ft), contained 2.0 ppm or less dissolved oxygen (Steimle and Sindermann 1978). Other important commercial shellfish, such as ocean quahogs (Artica islandica) and sea scallops (Placopecten magellanicus) were also affected, as well as some finfish populations.

All available evidence indicated that the specific events that caused development of anoxic bottom waters in 1976 were (1) an unusually warm winter, with highest river runoff in February rather than April, thus allowing early development of dense dinoflagellate populations; (2) earlier than normal thermal stratification, sealing off organically rich, oxygen-demanding water (from dead and dying dinoflagellates) early in the spring; (3) additional organic loading from human waste dump sites off New Jersey and Long Island; (4) limited water mass movement for an extended period (4-6 weeks), due to a persistent southerly flow of air; and (5) abnormally low cyclonic storm activity over the same 4- to 6-week period. Any one of these events probably would not have caused oxygen depletion to the extent observed, but together they devastated New Jersey and Long Island surf clam populations (Steimle and Sindermann 1978).

Little specific information is available concerning the long-term or short-term dissolved oxygen requirements of surf clams. However, since part of the estimated kill zone in 1976 was between the 1.0-ppm and 2.0-ppm dissolved oxygen isopleths, a lower lethal limit of 2.0 ppm can be assumed until more detailed information on oxygen requirements is collected. Prior to 1976, other less extensive oxygen depletion events and associated surf clam mortalities had been observed (Ogren 1969; Ogren and Chess 1969; Young 1973). In addition to causing mortality, low dissolved oxygen concentrations (values not given) were reported to depress burrowing activities of surf clams (Savage 1976) and may be a stimulus for surf clams to vacate their burrows (Ropes 1980).

Other Environmental Factors

Though specific studies are lacking, water currents are thought to be important in influencing distribution of planktonic, larval stages of the surf clam, and in the development of new surf clam beds (Ropes 1980). Major water current patterns over weeks or months may also influence availability of dissolved oxygen in the oceanic hypolimnion, and in combination with other abiotic and biotic events, may influence surf clam mortality rates (see ENVIRONMENTAL REQUIREMENTS -- Dissolved Oxygen section).

Hydraulic water-jet dredges used by commercial fishermen to harvest clams apparently do not stimulate uncaptured individuals to actively leave the area, since these fishermen may repeatedly dredge the same areas for weeks or months (hotspots), and continually take clams in commercially usable numbers (Ropes and Merrill 1973). These same water-jet dredges, however, may affect survival of uncaptured clams by increasing exposure to snail predators. Also, uncaptured surf clams are prone to injury from the water-jets because their shells gape slightly at the siphon end. The water-jets force the shells open, expose the soft bodies to predation, and disrupt normal respiration, feeding, and excretion (Ropes 1980). Surf clams in general are less hardy than hard clams (Mercenaria mercenaria), which can close their shells tightly (Ropes 1980). MacKenzie (1982) concluded that hydraulic dredges used in commercial fisheries for ocean quahogs (a closely related mactrid) off New Jersey did not significantly affect abundance of invertebrates in areas of dredging.

Pollutants

Two major classes of pollutants have been documented to affect surf clam populations or exploitation of those populations: (1) human refuse, sewage, and sludge (oceanic dump sites), and (2) metals.

Zoellner (1977) reviewed water quality problems related to molluskan shellfish and the effectiveness of current discharge control laws. Although natural phenomena, dredging, and chemical contamination were all noted as having significant impacts on shellfish populations, he considered domestic waste discharge to have the greatest negative impact on sanitary conditions in and around shellfish beds. Positive fecal coliform counts were reported in 70% of surf clam samples taken offshore of Delaware Bay in 1966 and 1967 (Buelow 1968). Areas in the New York Bight contaminated with human fecal coliforms were contiguous with sewage and sludge disposal sites, and extended northeastward 11 km (6.8 mi) and southward 37 km (23.0 mi) from Hudson River Estuary dumping sites (Babinchak et al. 1977). Pearce (1972) concluded that "normal benthic communities" in the New York Bight had been significantly altered by solid waste disposal in the bight. In most areas of solid waste dumping, surf clams were a dominant bivalve in an otherwise low-diversity, high-dominance assemblage (Pearce 1972). This general degradation of community diversity was also noted by O'Connor (1976). Commercial size surf clams were rare in a 1,550-km^2 (598-mi^2) area surrounding dump sites off New Jersey, even though surf clams were common outside the immediate areas of dumping.

The continual leaching of contaminants from oceanic dump sites into the water and sediments and the uptake by sedentary oceanic fauna such as the surf clam have forced closure of various important clam-harvesting areas of the Middle Atlantic Bight over the past two decades. Most areas closed during this period were between Delaware Bay and the southeast end of Long Island (Verber 1976; Babinchak et al. 1977; Ritchie 1977). An approximate total area of 1,580 km^2 (610 mi^2) of the Middle Atlantic Bight was and remains closed because of contaminants in clam bodies from dump sites (Ropes 1980). A further effect of dump sites is the contribution to biological oxygen demand in the oceanic bottom waters (see ENVIRONMENTAL REQUIREMENTS -- Dissolved Oxygen section), thereby increasing surf clam mortalities due to natural periodic depletions of oxygen in bottom waters of the ocean (Steimle and Sindermann 1978).

Studies have delineated lethal concentrations of certain heavy metals and determined sublethal concentrations contained in natural populations of surf clams. In laboratory studies, 96-hr LC_{50} values for silver were (1) between 50 ppb and 100 ppb for juveniles, and (2) greater than 100 ppb for adults (Thurberg et al. 1975). Sublethal effects (observed for larvae at 50 ppb and juveniles at 10 ppb) appeared as increases in metabolic oxygen requirement and rhythmic valve movement, both indicators of higher respiration and filtration rates. Silver accumulated rapidly in gills and other body tissues of test specimens, and silver concentrations in gill tissues were four times as high as concentrations in other body tissues (Thurberg et al. 1975).

Elevated concentrations of iron and copper (Lear et al. 1973) and chromium and nickel (Buelow 1968) were found in surf clams collected near sewage' and acid waste dump sites offshore of Delaware Bay. Recently, the Environmental Protection Agency estimated that an area of 3,600 km^2 (1,389 mi^2) off Maryland and Delaware had several potentially toxic metals in sediments and organisms. Though surf clams were not analyzed, two closely related species from the area, ocean quahogs and sea scallops, contained elevated concentrations of vanadium in their body tissues (Lear and Pesch 1975).

Relatively high concentrations of cadmium, copper, nickel, vanadium, chromium, and zinc were found in surf clams from Delaware Bay (Reynolds 1979), though sample sizes were too small to test statistically. Mean arsenic levels in Middle Atlantic Bight surf clams ranged from 1.46 ppm to 2.66 ppm, a range exceeding allowable levels (1.14 ppm) recommended by the Australian National Health and Medical Research Council (Wenzloff et al. 1979) (no levels recommended by Environmental Protection Agency).

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15. Supplementary Notes

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16. Abstract (Limit: 200 words)

The surf clam (Spisula solidissima) is a dominant clam species in the mid-Atlantic region, and contributed 71.8% of all clam meats consumed in the United States between 1970 and 1974; total landings in 1981 were 20.9 thousand metric tons (46.1 million lb). Surf clams live in the coastal zone from the Gulf of Maine to Cape Hatteras, North Carolina; they are most common in the breaker zone, but occur to depths of 70 m (230 ft). They reach sexual maturity in 2 years and spawn in the mid-Atlantic region from mid-July through mid-October, often with two spawning peaks per year. Larval stages are planktonic; upon settlement, they metamorphose into juvenile clams. Adults live buried in sandy or gravel substrates, with siphons extended above the bottom for feeding and respiration. Surf clams may live up to 25 years and reach a size of 225 mm (8.9 inches). Larvae tolerate water temperatures of 14° to 30° C (57° to 86° F), and salinities as low as 16 ppt. Adults tolerate 0° to 28° C (32° to 82° F) and 12.5 ppt salinity or higher. Depletion of dissolved oxygen in ocean bottom waters was the major cause for large-scale surf clam mortalities off New York and New Jersey over the last two decades. Sewage, sludge, and heavy metals often cause accumulation of toxic materials in surf clam meats and force closure of beds to fishing to prevent human consumption of these toxic materials.

17. Document Analysis a. Descriptors

Coastal Zone
Clams
Distribution
Feeding
Growth

b. Identifiers/Open-Ended Terms

Surf clam
Spisula solidissima
Substrate requirements
Depth distribution
Temperature requirements

c. COSATI Field/Group

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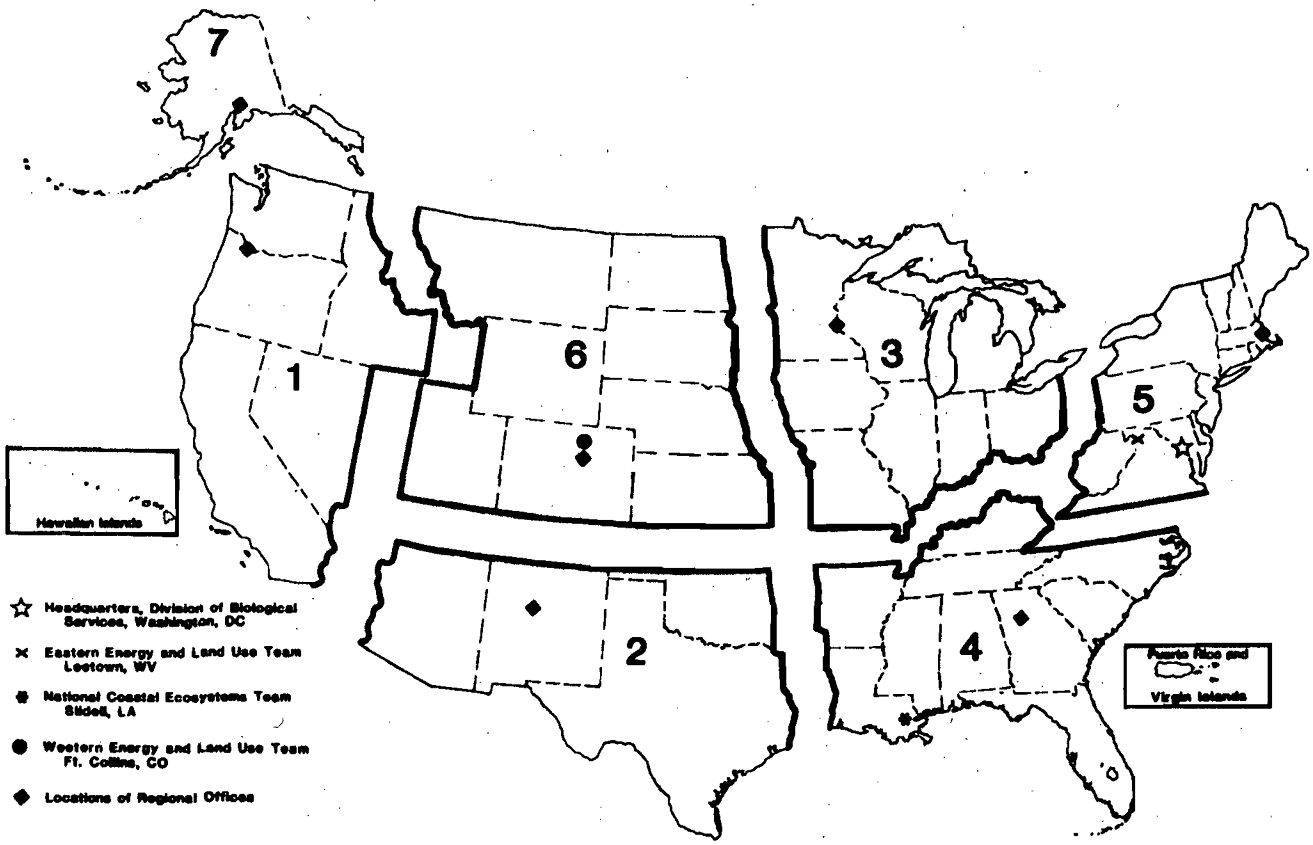

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