BIOLOGICAL & FISHERIES DATA
ON
SURF CLAM , *Spisula solidissima* (Dillwyn)

FEBRUARY 1980

Biological and Fisheries Data on the Atlantic Surf Clam,
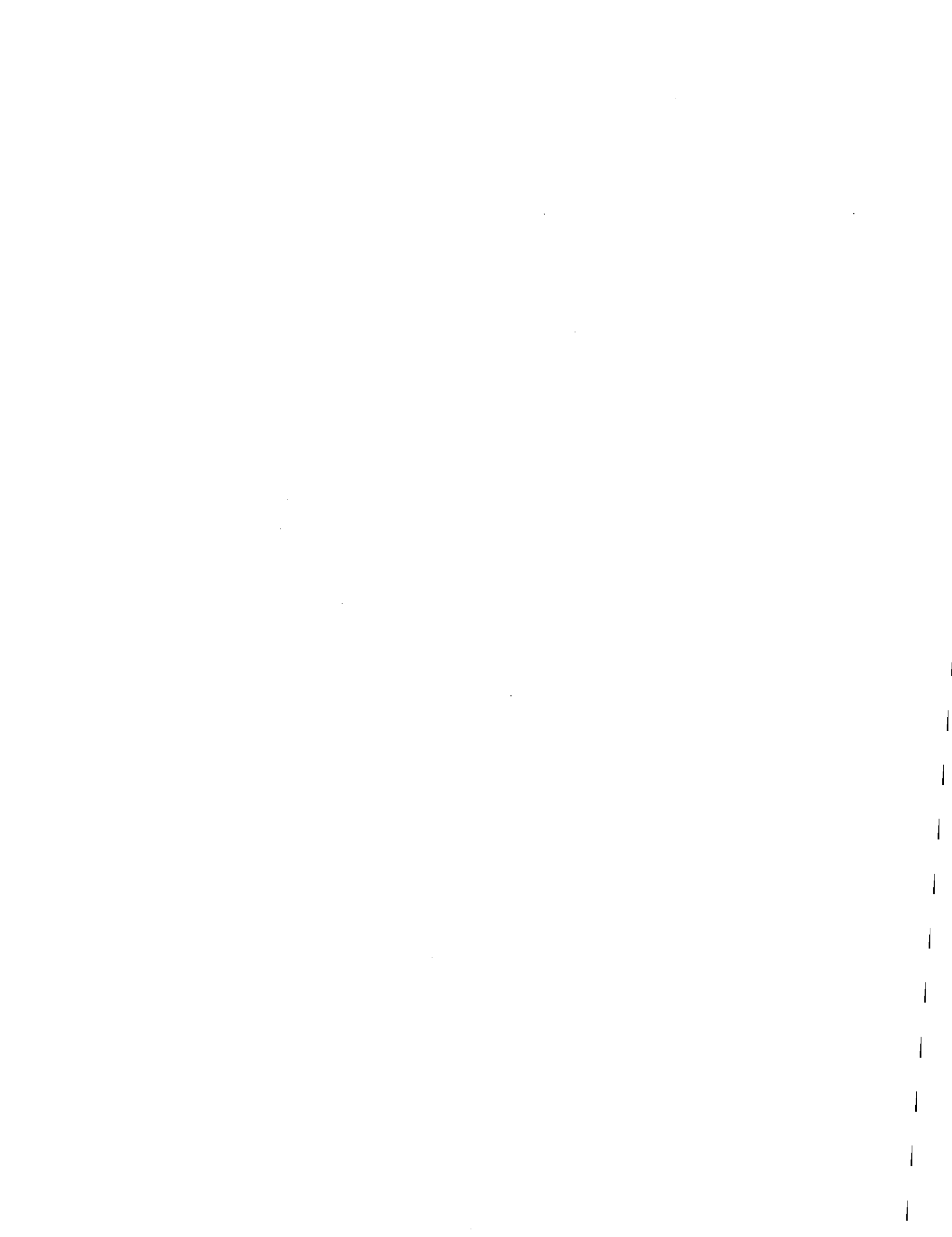
Spisula solidissima (Dillwyn)

by

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SYMBOLS USED

bu	=	bushels
cal	=	calorie
C	=	Celsius
dm	=	decimeter (0.1m)
g	=	gram
hr	=	hour
kg	=	Kilogram (10^3gm)
km	=	Kilometer (10^3m)
L	=	length
M	=	natural mortality rate
m	=	meter
min	=	minute
mm	=	millimeters
mt	=	metric tons
ppb	=	parts per billion
ppm	=	parts per million
ppt	=	parts per thousand
t	=	time
W	=	weight
X^2	=	chi-square
%	=	percent
0/00	=	per thousand
u	=	micron (10^{-3}mm)

1. IDENTITY

   1.1 <u>Nomenclature</u>

   1.1.1 Valid Name

   <u>Spisula</u> <u>solidissima</u> (Dillwyn 1817)

   1.1.2 Objective Synonymy (from Whiteaves (1901))

   <u>Spisula</u> <u>solidissima</u> Dillwyn 1817

   <u>Mactra</u> <u>similis</u> Say 1882

   <u>Mactra</u> <u>gigantea</u> Lamarck 1830

   <u>Mactra</u> <u>solidissima</u> Gould 1841

   <u>Mactra</u> <u>ponderosa</u> Phillippi 1844

   <u>Hemimactra</u> <u>solidissima</u> Conrad 1868

   <u>Spisula</u> (<u>Hemimactra</u>) <u>solidissima</u> Dall 1895

   1.2 <u>Taxonomy</u>

   1.2.1 Affinities

Class--	Bivalvia Linnaeus 1758
Subclass--	Heterodonta Neumayr 1884
Order--	Veneroida H. and A. Adams 1858
Superfamily--	Mactracea Lamarck 1809
Family--	Mactridae Lamarck 1809
Subfamily--	Mactrinae Lamarck 1809
Genus--	<u>Spisula</u> Gray 1837
Species--	<u>solidissima</u> Dillwyn 1817

A. External and internal shell structures and dimensions of common shell measurements.

a. umbo - earliest shell growth
b. paired cardinal teeth
c. chondrophore (holds the resilium, a wedge-shaped elastic portion of the hinge)
d. lateral teeth
e. foot retractor muscle scar
f. adductor muscle scar
g. pallial line
h. pallial sinus
i. external hinge ligament

B. Anatomy of the soft body after removal of the left valve, mantle and mantle edge.

a. kidney
b. foot retractor muscle
c. adductor muscle
d. gills
e. cut mantle edge
f. foot
g. palps
h. infrabranchial chamber
i. epibranchial chamber
j. incurrent siphon
k. excurrent siphon

C. Anatomy of the soft body after removal of the gills and palps.

a. intestine
b. heart
c. pericardial chamber
d. genital papilla (exaggerated)
e. rectum
f. anus
g. mantle edge
h. digestive diverticula which overlaps i.
i. gonad

D. Anatomy of the soft body after cutting into the soft body.

a. crystalline style and sac
b. stomach
c. mouth

FIGURE 1. Shell structures and anatomy of the surf clam, _Spisula solidissima_.

1.2.2 Taxonomic Status

The family Mactridae includes clams with a glossy periostracum covering the smooth or concentrically sculptured outer surfaces. The valves gape slightly. The pallial line has a sinus (Figure 1). The siphons are united to their tips. Records date from the Upper Cretaceous to the present. Subfamily characteristics are subequilaterally-shaped shells with a well developed hinge bearing two somewhat joined cardinal teeth in the right valve. The siphons are wholly retractile within the shells. Generic features are shells trigonal or ovate in shape, but not gaping, and the shell surfaces concentrically striated. A lunule and escutcheon are delimited, but the hinge ligament and resilium are not separated by a shelly lamella. The pallial sinus is oval. Records date from the Tertiary period and Mactridae have a cosmopolitan distribution (Moore and Pitrat 1969).

1.2.3 Subspecies

Taxonomic literature is equivocal about the existence of a subspecies of Spisula on the continental shelf of the northwestern Atlantic. Abbott (1974) states in a recent manual on marine mollusks of the Americas that S. raveneli may be a synonym for the subspecies S. s. similis. Earlier malacologists used several species names (Mactra similis, M. raveneli, and S. raveneli and S. s. similis) for surf clams some considered "submature" or "pathologic" forms, because of their small size, irregularities in growth and shell shape, and other morphological shell features (Dall 1894; Henderson and Bartsch 1914; Jacot 1919; Johnson 1934). These have usually been reported inhabiting littoral zone locations, such as Rockaway Beach, Long Island, New York; Cape May, New Jersey, and Chincoteague Island, Virginia. In recognition of differences in the maximum size of surf clams throughout their geographic range, Merrill and Webster (1964) thought the small variety found south of Cape Hatteras, North Carolina, should be "known by the varietal or subspecific name raveneli."

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Jacobson and Old (1966) provided supportive evidence listing subspecies synonyms for S. solidissima and S. raveneli and locating the respective distributions of the two species north and south of Cape Hatteras.

1.2.4 Standard Common Names, Vernacular Names

Several common names are in use within local geographic areas along the northwestern Atlantic coast: bar clam in Canada; hen clam in Maine; sea clam, surf clam, beach clam, or skimmer in the middle Atlantic states of New York through Virginia.

1.3 Morphology

1.3.1 External Morphology (Shell)

Shells oval to trigonal; gape slight; no external sculpture; ligament spisuloid; lateral teeth complement is complete; granular scuplturing or cross striations on some or all contact surfaces of the lateral teeth, if apparent at all; the shallow pallial sinus is not larger than the posterior adductor muscle scar (Chamberlin 1954).

1.3.2 Cytomorphology

None available.

1.3.3 Protein Specificity

None available.

2. DISTRIBUTION

2.1 Total Area

Wigley and Emery (1968) charted and discussed the general geographic distribution of surf clams from Cape Hatteras, North Carolina, on Georges Bank, and throughout the Gulf of Maine. A more detailed latitudinal range for the species from the southern Gulf of St. Lawrence to the northern Gulf of Mexico is reported by Merrill and Ropes (1969) and Ropes et al. (1969). In the northern latitudes it is commonly abundant in the turbulent waters of oceanic beaches, just beyond the breaker zone. It has occasionally been found to depths of 128 m on Georges Bank and to 61 m on the Middle Atlantic continental shelf. Abundant concentrations, sought after

commercially, are in near shore to 55 m depths. A generally
smaller surf clam (S. ravaeneli, cf. Sec. 1.2.3) inhabits the
waters south of Cape Hatteras. These have been found at inshore,
shallow water depths, but their occurrence offshore is largely
unknown. S. polynyma, another species which could be confused
with S. solidissima, was found distributed northward from
off Long Island, New York, in deeper and colder waters by
Chamberlin and Sterns (1963). In a discussion of the distribution
of Spisula species in the continental shelf of eastern North
America, Merrill and Ropes (1969) believe that mixing of known
species (S. solidissima, S. raveneli, and S. polynyma is unlikely
in the Middle Atlantic Bight fishery.

2.2 Differential Distribution

The species is predominantly oceanic, but settlement can occur
at entrances of estuaries in relatively high-salinity water
(Carriker 1951, 1959; Castagna and Chanley 1966; Maurer et
al. 1974).

The depth range of surf clams has been delineated in the Middle
Atlantic Bight from several sources (June and Reintjes 1957;
Merrill and Webster 1964; Merrill and Ropes 1969, 1971;
Ropes and Merrill 1971, 1976; Franz 1976a, 1976b; Haskin and
Merrill 1973; Loesch and Ropes 1977) in a recent review by
Ropes (1979a). Off Long Island, New York, they occur from the
beach zone to 43.9 m; off New Jersey, from the beach zone to
57.9 m; off Delmarva Peninsula (the coastal portions of
Delaware, Maryland, and Virginia), from 10.1 to 65.5 m; and off
Virginia-North Carolina, from 8.2 to 58.8 m (Figure 2).
Concentrations were greatest at less than 18.3 m depths
off Delmarva Peninsula and Virginia-North Carolina.

Several studies provide detailed evidence of surf clam distribution
at specific locations in their range:

Emery et al. (1965) photographed surf clam shells off Long
Island during a sampling program to delineate the geology and
biology of the sea floor on the continental shelf and slope
off the northeastern United States.

From collections of benthic invertebrates of the continental
shelf off North Carolina, Cerame-Vivas and Gray (1966) found
surf clams in the Virginian and Carolinian biotic provinces,
but not the Tropical province. The marine climates in the
three provinces were discussed.

Dexter (1968) reported finding surf clams in subtidal locations
at Cape Ann, Massachusetts. They were present in sandy
habitats of Ipswich Bay, the north branch of the Annisquam River,

The table embedded in the figure:

AREA	MIN. DEPTH	DEPTH RANGE		MAX. DEPTH
		PRIMARY CONCENTRATION	SECONDARY CONCENTRATION	
Long Island	10.7	<18.3 m	18.4-36.6	43.9
New Jersey	9.1	<18.3 m	18.4-36.6	57.9
Delmarva P.	10.1	18.4-36.6	<18.3 m	65.5
Virginia-NC	8.2	18.4-36.6	<18.3 m	58.8

SURF CLAMS

■ Very high
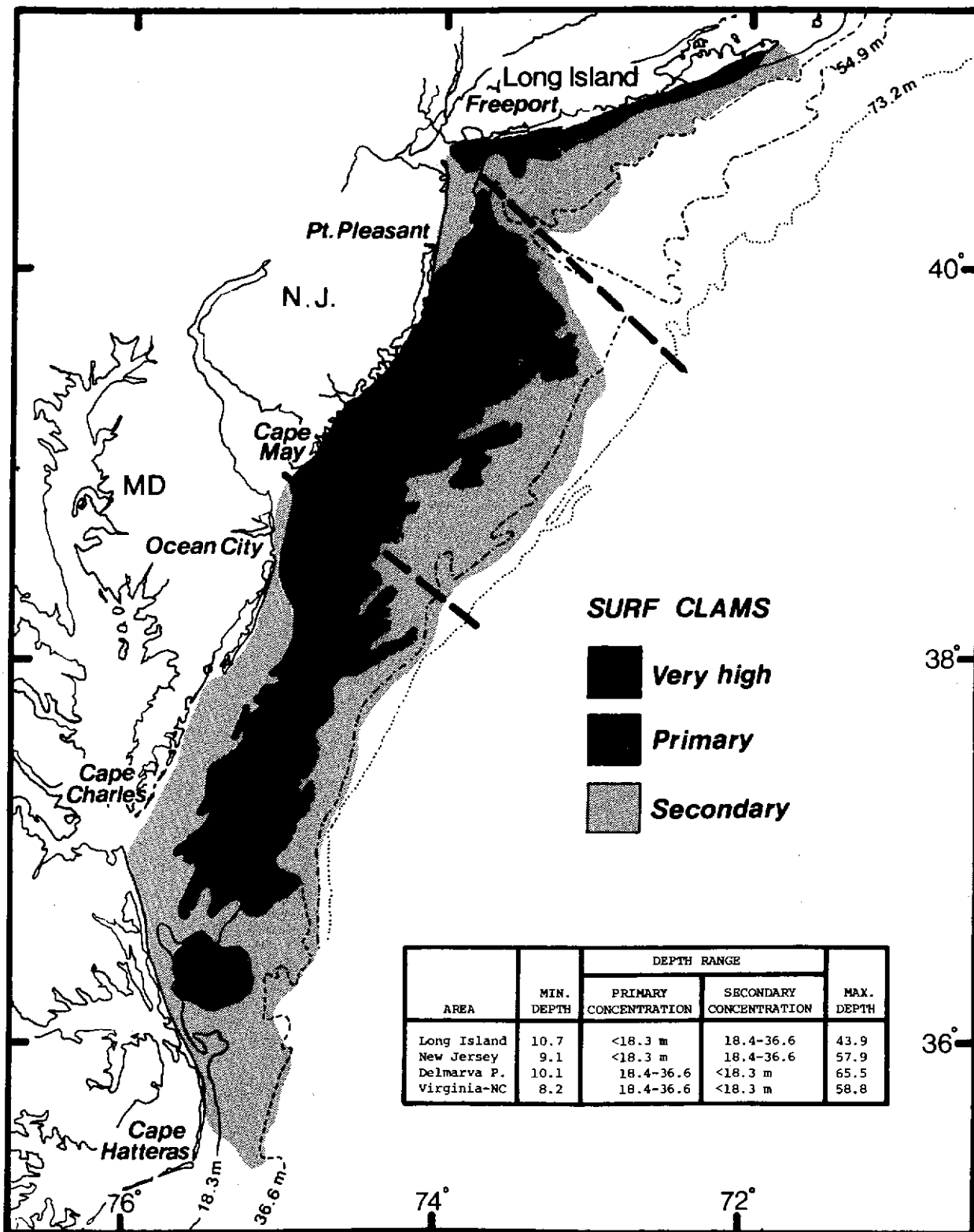
■ Primary

▨ Secondary

FIGURE 2. The distribution of surf clams, Spisula solidissima, in the Middle Atlantic Bight. The categories of concentrations (very high = 5 bu or more; primary = < 5 to 1 bu; secondary = < 1 bu. Meter depths shown correspond to 10 fathoms increments. An occurrence at a minimum or maximum depth may represent only a single clam (Adapted from Ropes, 1979a).

Little River, and Gloucester Harbor, but were absent in the muddy bottom of the south branch of the Annisquam River.

Olsen (1970) studied the ecology of surf clams in shallow water beds on Coanicut Island and Easton Beach, Rhode Island, in 1969. Surf clams were evenly distributed in small aggregations of well sorted sand and gravel sediments. The population at Coanicut Island was dominated by clams 130 and 150 mm in length, but size was highly variable within an aggregation. Hydrographic forces concentrated the larvae in shallow water along the beach. Two explanations were proposed for the numerical dominance of clams larger than 130 mm: (1) the population was stable; and (2) the dominant size class represented 1 to 6 successful sets occurring 6 to 12 years ago. At Easton Beach, hydrographic forces also concentrated the larvae and location of sets. Clams from overcrowded beds, a condition that impeded growth, washed onto the beach.

Caddy (1970) recorded the occurrence of surf clams in scallop-dredge hauls from the Bay of Fundy, Canada. Dead shells and occasional live individuals were found in tows on sand bottom at depths of 55 m and shallower off the Nova Scotia coast.

Wigley and Theroux (1970) reported intact shells and fragments of surf clams from sea-bottom photographs and macrobenthic collections from the continental shelf off Massachusetts.

Flowers (1973) designed a study to determine patch-distribution characteristics of surf clams in the Harbor of Refuge, Point Judith, Rhode Island. Patch pattern was density-dependent, with patches of high density tending toward "complete aggregation", but medium and low densities were randomly distributed discrete patches.

Steimle and Stone (1973) conducted a qualitative and quantitative survey of the inshore benthic fauna off southwestern Long Island, New York. The surf clam was one of the dominant organisms encountered and was among organisms classified as a medium sand assemblage. The mean number of organisms collected from the medium sand sediment ranged from 49 animals/m^2 to 2,030 animals/m^2. The total number of species generally increased with depth from 11 to 54.

Garlo and Hondo (1973) reported on a benthic invertebrate sampling program in the vicinity of a proposed nuclear-generating site off New Jersey. The surf clam was the dominant species in and near the site in samples taken in 1972 with a Ponar bottom grab and a clam dredge. The sampling program was continued throughout 1973 by Garlo et al. (1974). Again the surf clam was a dominant species and densities of newly settled spat were high.

Merrill and Edwards (1975) observed mollusks among the
fouling organisms attached to navigational buoys. Surf clams
were not one of the nine pelecypods found on the buoys, but
they were in samples taken from the sea floor at the
buoy site.

Pearce et al. (1976) compared the distribution and abundance
of benthic organisms sampled during 1973 and 1974 in the
New York Bight area. The fauna in coastal and inshore shoal
waters were characterized by the bivalves, Tellina agilis
and Spisula solidissima, and the sand dollar, Echinarachnius
parma. These were considered typical of high-energy coastal
marine environments.

Franz (1976a) conducted an intensive survey of the Long
Island, New York, inshore population of surf clams in 1974.
Selected locations were resampled in 1975. His summary
follows:

> "East of Shinnecock Inlet adult clams occurred at
> densities between 0.5 and 3.0 bushels per dredge
> haul. West of Shinnecock adults declined gradually,
> reaching a minimum west of Jones Inlet to East
> Rockaway Inlet. Abundances increased precipitously
> off Rockaway Beach.

> "Highest densities of juveniles occurred at 0.5 mi
> and decreased rapidly farther offshore. Juveniles
> were more abundant at the west end of Long Island,
> particularly inshore at 0.5 mi. Higher densities
> of juveniles here may result from accumulation of
> larvae produced farther east and transported westward
> via longshore currents. The convergence of tidal
> and longshore currents may effectively "trap"
> larvae off western Long Island.

> "Clam stocks off eastern Long Island probably are
> older than 9 years and are mostly composed of 1-3
> age classes. Clam stocks off the Rockaways
> appear younger. The commercial fishery is apparently
> dependent on massive settlements of larvae occurring
> irregularly and infrequently."

Franz (1976b) analyzed benthic molluscan assemblages in
relation to sediment gradients in Northeastern Long Island
Sound, Connecticut, in 1973. The surf clam was among 52
mollusks encountered. They were at stations designated
as low-diversity, high-energy habitats and in areas of

severe tidal surge. Sediments were fine to coarse sand, with silt/clay levels less than 5%.

2.3 Determinants of Distribution

Determinants of distribution for S. solidissima are poorly known. Henderson (1929) reported a high maximum lethal temperature of 37°C for large surf clams. A lethal temperature limit of 30°C was found by Schlieper et al. (1967) in recent investigations of S. solida, a related mactrid species in Europe. The clam was also the least heat-resistant species tested and was described as a cold stenotherm inhabiting coarse sands at 15-30 m depths in the North Sea. Saila and Pratt (1973) gave 26 to 28°C as an upper lethal temperature limit for adult surf clams, and noted that younger clams can survive higher temperatures, but became inactive at 4°C. Savage (1976) observed an inability of surf clams to establish pedal anchorage at temperatures over 30°C and thought a condition like the critical thermal maximum had been reached.

In experiments on the freezing resistance of gill tissue, survival of S. solida, as indicated by gill cilia activity, was the lowest of seven North Sea species tested at 30°/00 salinity and -10°C (Theede 1965). A narrow, low cellular osmotic freezing resistance range at salinities between 14 and 52°/00 was found for the clam, "but its resistance against concentrated seawater was relatively higher than would be expected because of its low freezing resistance." Such low temperature conditions would probably never be encountered by S. solidissima in their relatively deep water, oceanic habitat. Those living in the beach zone may be marginally affected, especially if they are washed onto the air-exposed beach.

Dupal and Webb (1974) reported an increase in alanine concentration of surf clam gill tissues held under increased salinity conditions. Metabolic pathways for this accumulation appeared similar to those described for invertebrate faculative anaerobiosis.

Castagna and Chanley (1973) reported minimum salinities of 12.5 and 16°/00 for adult and larval surf clam survival, respectively.

Loosanoff and Davis (1963) found surf clam larval development was best at 22°C, rather than lower (14°C) and higher (30°C) values. Since the larval period may last for 19 days at 22°C, movement of larvae by water currents has an

important influence on surf clam distribution. Specific studies on the effects of environmental currents distributing surf clam larvae are unavailable, mostly because of difficulties experienced in identification of the larvae in plankton collections. Sandine et al. (1973) sampled zooplankton during September 1972 - January 1973 at and near a proposed nuclear generating site off New Jersey. The available evidence suggested that surf clam larvae were probably in the samples, but in the enumeration of meroplanktonic forms was categorized only as bivalve larvae. Bivalve larvae were very numerous in November samples, although a change in the type of sample net used may have influenced results. The conditions necessary for successful settlement of larvae and survival thereafter are largely unknown. Merrill and Ropes (1977) discussed the conditions affecting bivalve larval development and formation of shellfish beds, such as bottom substrata, reproductive and feeding biology, water quality, and causes of mortality.

Some experimental results are available on the effects of heavy-metal exposure on surf clams. Thurberg et al. (1975) exposed larval, juvenile, and adult clams to silver. During 96-hr exposures, larvae survived concentrations up to and including 50 ppb, levels between 50 and 100 ppb caused juvenile deaths, and concentrations greater than 100 ppb were lethal to adults. Silver-induced increases in oxygen consumption occurred for each life stage. Silver increased rhythmic valve movement, an activity closely related to respiration and filtration. These findings have been summarized by Calabrese et al. (1977).

Oceanic clams have been affected by man's waste-disposal practices. The U.S. Department of Health investigated ocean waste-disposal in the New York Bight and off Delaware Bay in 1966 and 1967 (Buelow 1968). Positive coliform values were reported in seven of ten surf clam samples taken off Delaware Bay, all clam samples were high in chromium, and four were high in nickel. In a report on the effects of solid waste disposal on benthic communities in the New York Bight, Pearce (1972) found normal populations were decidedly affected. Surf clams were a dominant bivalve out of the dump site areas and along the northern New Jersey coast in medium to coarse sand. They were part of a low diversity, high dominance fauna characteristic of high energy, wave swept, coastal environments. South and east of the disposal areas, the animal community was diverse and little affected by solid waste disposal activities. The impoverished fauna in the dump areas was

believed due to toxins in the sediments and water.
O'Connor (1976) discussed the effects of contaminants
on the biota of the New York Bight. He noted the general
degradation of benthic invertebrate assemblages and the
rarity of commercial-size surf clams in about 1,550 Km^2
of the bottom surrounding the Apex dump sites. Lear
et al. (1973) reported concentrations of iron and copper
in surf clams collected near sewage and acid waste dumpsites
off the mouth of Delaware Bay. More recently the Environmental
Protection Agency investigated the effects of ocean-disposal
activities off Delaware and Maryland (Lear and Pesch 1975).
An affected area of at least 3,600 sq km was found containing
potentially toxic metals in the bottom sediments and organisms.
Although values for surf clams were not in the report,
elevated concentrations of vanadium were found in ocean
quahogs (Artica islandica) and sea scallops (Placopecten
magellanicus) and evidence is given for mortalities of
ocean quahogs in areas of accumulated waste metals.
Reynolds (1979) reported on trace metal monitoring at the
Delaware ocean disposal sites. Sea scallops and ocean
quahogs were the principal bivalves analyzed, since they
occurred most often in the samples. Cadmium, copper, nickel,
vanadium, chromium, and zinc levels were given for surf
clams taken incidentally in 1975 samples, but the significance
was not discussed because too few were available for analyses.
Grieg and Jones (1976) identified six metals in the tissues
of surf clams from several locations to develop baseline
data, but did not comment on the significance of the values
obtained. A special symposium focused scientific attention
on the Middle Atlantic continental shelf and New York Bight
(Gross 1976). Sources of contamination and effects on the
ecosystem, fish and shellfish, and man were examined in
detail. Apart from the obvious necessity of closing some
areas for public health reasons, the continued flow of
contaminants is having probable effects on all life-history
stages of marine organisms, causing mortalities, abnormalities,
and other physiological disturbances. The known problems
had probable impact in evaluating two proposed alternate
sewage sludge dump sites in the New York Bight. Potential
commercial shellfish resources, including the surf clam,
distributed in and near the proposed dump areas, did not
favor selecting either site (Gunnerson and Swanson 1975;
Swanson 1976). Wenzloff et al. (1979) reported concentrations
of silver, arsenic, cadmium, copper, chromium, mercury,
nickel, lead, and zinc in tissues of surf clams collected
during an extensive mid-Atlantic coast survey in 1974.
Silver, arsenic, and zinc concentrations decreased significantly

in the southern latitudes, but no statistically significant
trends were found for other metals in surf clams. Mean
arsenic levels of 1.46 to 2.63 ppm exceeded the Australian
National Health and Medical Research Council's recommended
concentration (1.14 ppm). Except for arsenic, the concentrations
of other metals did not exceed existing levels recommended
by agencies responsible for establishing action limits.
The investigators believe that large areas of the mid-Atlantic
coast may be affected by heavy metals, but that consumers
of surf clams need not be unduly concerned at this time.

Despite the concern for fishery resources, loss of clam-harvesting
areas has resulted from sizeable closures in the ocean.
A closure in May 1970 of a 380-sq-km circular area in the
approaches to New York Harbor contained active dump sites
(Verber 1976). By April 1974, an additional 450 sq km
was closed by extending lines form the periphery of the
former closed area to the Long Island, New York, and New
Jersey shores. Off the mouth of Delaware Bay, dumping resulted
in closure to shellfishing of a 380-sq-km area in May 1970.
All dumping at this site was prohibited after May 1973,
but a new site was located offshore. The former site was
reopened for shellfishing in January 1975. The new offshore
site was not immediately closed to shellfishing, but by
December 1976 a warning notice to harvesters created two
closed areas totaling 486 sq km. Similar action has been
taken within the jurisdictional limits (ca. 4.8 km) of
the New Jersey shore. Babinchak et al (1977) delimited
a fecal coliform contaminated area in the New York Bight
contiguous with the sewage sludge disposal site and
extending northeastward 11 km and southward in the Hudson
Shelf Valley 37 km. Almost 40% (ca. 267 sq km) of that
state's total area has been closed to surf clamming because
of nearshore ocean outfall contamination (Ritchie 1977).
Ocean-area closures, then, have removed about 1,580 sq km
from shellfish harvesting in the Middle Atlantic Bight.

A major impact occurred on surf clams in 1976. Anoxic water
developed over the beds from the combined effects of
meteriological and hydrographic conditions, organic loading
of coastal waters, and a massive bloom and die off of the
dinoflagellate Ceratium tripos (Steimle and Sindermann 1978;
Ropes et al. in press). A loss of 147 thousand mt of surf
clam meats was estimated in an intense kill area of
6,750 sq km and at depths from nearshore to 36.6 m. This
was about 62% of the New Jersey resource. It was supposed
that surf clams reacted like the European mactrid, Spisula
solida, when it was experimentally subjected to oxygen-deficient
water treated to create a hydrogen sulfide condition (Theede

et al. 1969). Its survival was seriously affected and it
was the least resistant species tested. Low oxygen conditions
seriously affected surf clam burrowing by slowing the
rate of activity (Savage 1976). The loss had an important
effect on commercial landings of surf clams. Ocean quahogs
Arctica islandica and sea scallops Placopecten magellanicus
were marginally affected because they were mostly distributed
outside the area of low oxygen concentrations.

Garlo et al. (1979) reported on the impact of hypoxic conditions
in the vicinity of Little Egg Inlet, New Jersey, in the
summer of 1976. Although the surf zone was hypoxic by
mid-July, no mortalities of megabenthos were observed and
the surf clam was the most abundant species collected.
In September samples, mortalities of surf clams ranged
from 0 to 100% and averaged 7%. Most of the dead surf clams
were at locations of low density and at depths greater
than 9 m.

Mortalities of marine organisms off the New Jersey coast
have occurred in the recent past before 1976 (Ogren and
Chess 1969; Ogren 1969; Young 1973). Low oxygen levels and
mortalities of surf clams were recorded in the two earliest
reports.

Zoellner (1977) reviewed water quality problems related to
molluscan shellfish and effectiveness of present-day laws.
The study focused on the specific needs of molluscs for
survival and propagation. Natural phenomenon, dredging,
chemical contamination, and other water quality problems
affect shellfish, but domestic waste discharge was considered
to have the greatest negative impact on the sanitary condition
of growing areas. Overcoming problems in implementing
existing laws was recommended.

2.4 Hybridization

Hybridization has not been reported, but may be possible under
laboratory conditions for at least the three species of
Spisula (S. solidissima, S. polynyma, and S. raveneli)
found along the northwestern Atlantic coast.

3. BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality

The sexes are separate (dioecious) and hermaphroditism

is a rare anomaly (Ropes 1968a).

3.1.2 Maturity

Surf clams mature at an early age. They can contain
ripe gonads and spawn one year after setting, but
reach full sexual maturity during the second year
(Ropes, 1979b). Although the smallest fully mature
clam can be 45 mm long, growth to a size larger than
other clams of the same age is important in early
development of sexuality.

3.1.3 Spawning

In a bed of clams, spawning is probably a synchronous,
annual event (Ropes 1968b). Thermal stimulation
seems to be an important factor in initiating the
spawning act but subtle nervous and hormonal conditions
may have important interrelationships. Stickney (1963)
described an egg reservoir in the gonad of surf clams
and noted the faster response of surf clams to spawning
stimuli than soft clams (Mya arenaria).

Hormones and enzymes have been reported in the
eggs, sperm, and gonadal tissues. Hagerman (1956)
found that estradiol added in vitro had no effect
on the metabolism of surf clam ovaries, but Hagerman
et al. (1957) found appreciable amounts of an estrogenic
material in the ovaries. Eble (1969; 1970; 1971)
reported high levels of glycogen in gonadal alveolar
epithelium and sex cells of male and female surf
clams. Enzyme systems of the testes and ovary were
examined and related to the reproductive stages
of gonadal development.

3.1.4 Fertilization

Fertilization occurs after gametes unite externally in the
water over the beds. The gametes have been used by
numerous investigators studying physiological
responses and cleavage activities (Allen 1953;
Rebhun 1959; Schecter 1956 are a few of the many
available references of research on surf clams using
the light microscope). Longo (1973) reviewed the
extensive literature on ultrastructural research of
the events during fertilization for the surf clam,
the mussel (Mytilus edulis), the sea urchin (Arbacia
punctulata), and the rabbit (Oryctolagus cuniculus).

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Sperm incorporation into the egg and associated
events, male pronucleus development, morphogenesis
of the male pronucleus following its formation,
development of the sperm aster, migration of the
pronuclei, fate of the sperm mitochondria, fate
of the sperm flagellum, fate of the perinuclear
structures of the spermatozoon, morphogenesis
of the maternal chromatin, germinal vesicle breakdown
and formation of the first meiotic apparatus, formation
of the first and second polar bodies, development
of the female pronucleus, and pronuclear association
were discussed in more detail than can be presented
herein.

3.1.5 Fecundity

No observations on fecundity are known.

3.1.6 Spawning Seasons

The gonads of more than 1,500 clams were collected
from offshore New Jersey during 1962-1965 and
histological preparations were studied to determine
the annual frequency and duration of spawning
(Ropes 1968b). In 1962, 1963, and 1964, two annual
spawnings occurred. The first (major) spawning was
in mid-July to early August and the second (minor)
spawning was in mid-October to early November. In
1965, however, only a single spawning was observed
during mid-September to mid-October.

From records taken daily at a lightship near the
New Jersey sample area, bottom-water temperatures
seemed to influence the spawning cycle according
to Ropes (1968b). During the first six months of
1962-1964, a gradual warming trend of bottom water
coincided with a gradual ripening of the clam gonads.
In 1965, when only one reproductive cycle and
spawning was observed, temperatures were generally
lower than in the previous years when two annual
spawnings occurred. Ropes (1968b) reviewed the literature
on spawning of surf clams.

Observations on juvenile surf clam settlement
suggest the spawning season will be earlier at more southern
latitudes than off New Jersey. Williams and Porter
(1971) studied the meroplankton in North Carolina
estuaries. From 3 to 21 postmetamorphal surf clams
are listed in a table for the months of April, May,

and June in 1963 and 1964 at shell lengths of 1.1
to 2.5 mm.

3.1.7 Eggs

The unfertilized eggs have a diameter of 56μ,
measuring from the inside of the vitelline membrane;
the germinal vesicle is about 31μ in diameter and
is somewhat eccentric (Allen 1953). The spherical
eggs are composed of several layers. An outermost
"jelly layer," about 2μ thick, is usually invisible
in unstained living eggs.

3.2 Larval History

The following describes larval development to the juvenile
stage under experimental laboratory conditions. An average
water temperature of 21.7°C (range 18.3-24.9°C) was maintained
during all stages of the culture.

Soon after egg fertilization, an inner, tough and very visible
vitelline membrane elevates from the plasma membrane surrounding
the dense cytoplasm to form a clear perivitelline space;
the germinal vesicle around the nucleus dissolves and leaves
in its place a light central area (Figure 3A); and the
transparent nucleolus within the nucleus disappears leaving
the opaque nucleolinus. This latter structure begins its
spindle-forming role at this time (Allen 1951; 1953).

Cellular changes after sperm penetration proceed fairly
rapidly and the earliest stages have been timed, photographed,
and described in Schecter (1941) and Allen (1953). Both the
first and second polar bodies extrude at the plane of the
first cleavage as preliminary steps in the division of the
egg. These events take place within 70 minutes after
fertilization.

Thereafter, the cleavage stages rapidly succeed one another.
Each stage was recognized at 70, 90, 110, and 120 minutes,
respectively (Table 1), and photographed (Figures 3B-3E).

An unequal division of the eggs into blastomeres differing
greatly in size is most evident after each of the early
cleavages. Subsequent spiral-type cleavages are rapid
and difficult to follow. Swimming gastrulae, found
5¼ hours after fertilization (Figure 3F), are formed by
epiboly. During epiboly, small ectodermal cells proliferate
by rapid division over the larger, yolk-filled endodermal
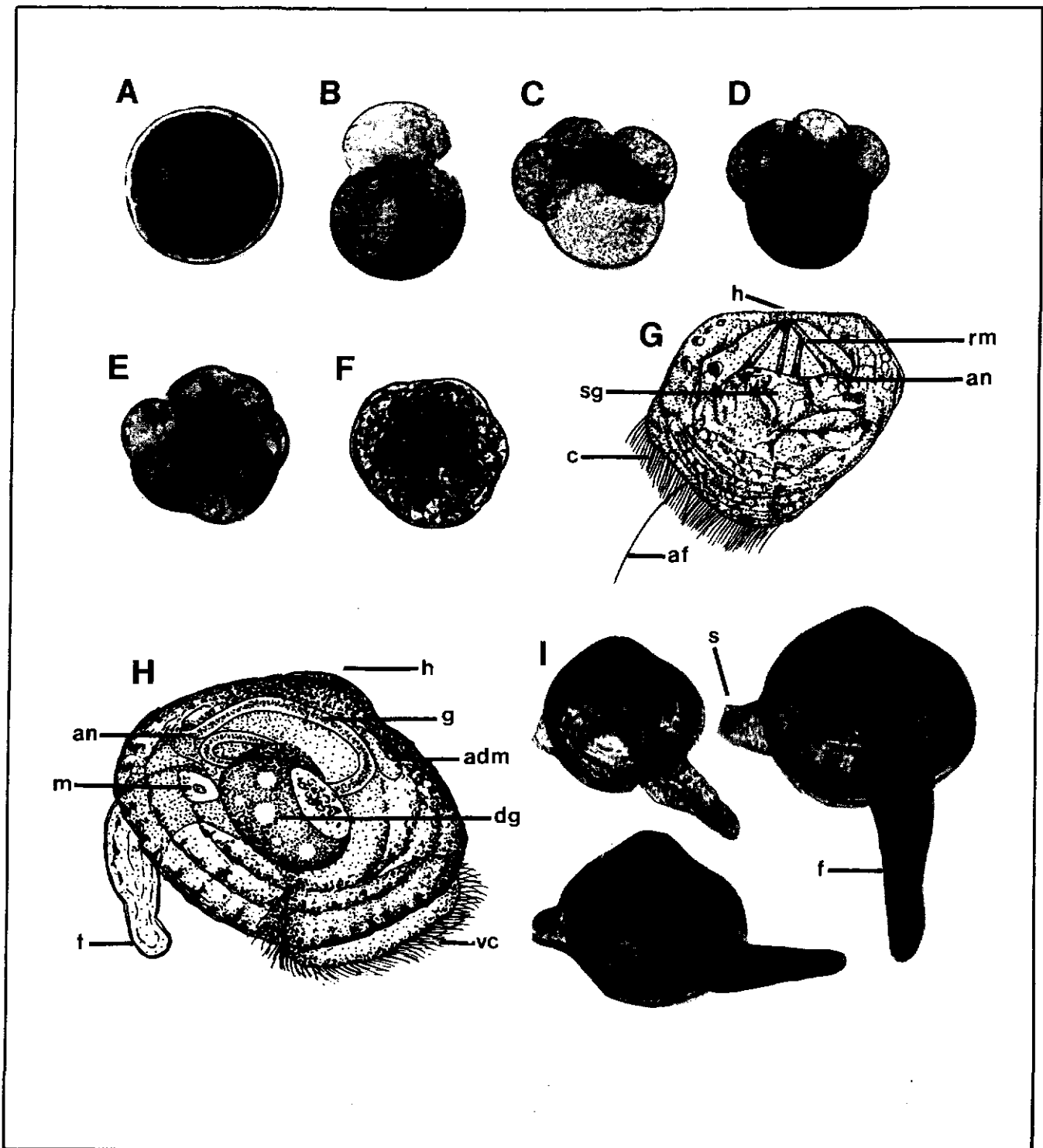
FIGURE 3. Stages in the early development of a surf clam, Spisula solidissima: (A) Fertilized egg; (B) First cleavage; (C) Second cleavage; (D) Third cleavage; (E) Many celled; (F) Gastrula; (G) A D-shaped or straight-hinged veliger, showing h.-hinge, rm.-retractor muscle, an.-anus, sg.-stomach and gut, vc.-vellum fringed with cilia, and af.-apical flagellum; (H) A prediveliger, showing h.-hinge, g.-gut, adm.-anterior adductor muscle, dg.-digestive gland, vc.-velum fringed with cilia, pam.-posterior adductor muscle, an.-anus, m.-mesoderm, and f.-foot; and (I) Fully metamorphosed juveniles, showing f.-foot, and s.-siphons.

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Table 1. Elapsed time after fertilization for the appearance of developmental stages of surf clam, Spisula solidissima, larvae held at an average temperature of 21.7°C. In part from Costello et al. (1957).

Stage of Development	Time
First cleavage	70 minutes
Second cleavage	90 minutes
Third cleavage	110 minutes
Many-celled	120 minutes
Swimming gastrula	5¼ hours
Trochophore	9 hours
Straight-hinge veliger	19-20 hours
Pediveliger and Juvenile	18-21 days

cells, but an opening is left into the archenteron called the blastopore (Costello et al. 1957; Wada 1957).

Trochophore larvae, which were not photographed, occurred 9 hours after fertilization. Costello et al. (1957) described trochophores as having a pyramidal shape. The expanded base of the trochophore is the later site of velum formation. Young veliger larvae, formed by 19-20 hours, had bivalved shells and a straight-hinge line, hence the name D-shaped or straight-hinge veliger (Figure 3G). During active movements and feeding, the larvae extended a well developed velum with cilia and apical flagellum beyond the shell margin. Retractor muscles immediately ventrad to the hinge were conspicuous when the velum was everted. These muscles appeared to be in a cavity above the prominent and centrally located stomach. A rudimentary intestine was present off the stomach at the anterior end, but a mouth was not clearly recognized. The stomach sometimes contained algal cells. Cilia fringed the velum when it was exposed, and a long apical flagellum was prominent. Both the cilia and flagellum actively propelled the larvae during locomotor activities which usually turned them in a counterclockwise direction. The retractor muscles quickly drew the velum and soft body parts into the shell and after closing the shell the larvae sank toward the bottom.

Anatomical structures of the soft body of larvae only 48-hours old and older were partly obscured by the shell, but growth was often obvious as a rim of new shell deposited along the ventral margin.

Shell measurements at stages of larval development and metamorphosis were made for comparison with similar data in the literature (Table 2). Veliger larvae seen one day after fertilization had an average shell length of 89μ, a shell height of 71μ, and a hinge line of 55μ. These are measurements about midway between the values reported by Sullivan (1948) and Loosanoff et al. (1966). Additional shell growth was slight 7 days after fertilization, but 10 days later the larvae averaged 213 x 194μ. A pediveliger was first seen on the 18th day and its measurements (245 x 230μ) were larger than most reported by Loosanoff et al. (1966), although they saw some both larger and smaller (Fig. 3H). An even larger pediveliger (261 x 239μ) was seen 21 days after fertilization, and most larvae had metamorphosed into crawling juvenile clams (303 x 267μ) (Figure 3I). The metamorphosed clams were larger than

Table 2. Larval shell measurements during the development of surf clams, Spisula solidissima, and comparison with measurements in the literature.

Number of larvae measured	Time in days	Average shell measurements, length x height x hinge line (in microns)	Literature reference of shell measurements (L = length, H = height, in microns)
11	1	89 x 71 x 55	85L, Loosanoff and Davis (1963); 80L x 65H, Loosanoff et al. (1966); 95L x 80H, Sullivan (1948).
11	2	89 x 76 x 54	
15	7	94 x 79 x 54	
10	17	213 x 194[a]	
1	18[b]	245 x 230	160L x 165H was the smallest pediveliger seen by Loosanoff et al. (1966).
1	21[c]	261 x 239	Most were 215L, and a few 260L were still swimming.
6	21[d]	303 x 267	270L x 245H, Sullivan (1948); most were 230-250L. Average from graph, 263L x 245H, Loosanoff et al. (1966).

[a]Umbones obscured hinge line.

[b]First appearance of a pediveliger, velum used mostly for locomotion.

[c]Pediveligers few in culture.

[d]Footed clams most numerous in culture.

those reported by Sullivan (1948) and Loosanoff et al. (1966).

Direct evidence about the type of larval development by Spisula solidissima in the natural environment and throughout its distributional range is not available. From a review by Mileikovski (1971), most of the marine bottom invertebrates have a pelagic development and the numbers of species having such development increases near the equator and in shallow-shelf waters. These general criteria apply to the surf clam. Based on the types of pelagic development proposed by Thorson (1950), surf clam larvae are probably planktotrophic, (live in the floating plankton), since the yolk material in laboratory-reared larvae was indistinguishable after 24 hours of their early life and some of the D-shaped larvae had algal cells in the stomach. During the remaining 95% of their larval life, the larvae fed on algal cells. An enzyme for digesting algal cells is probably present early in the larval life of the clam, equipping it for a planktonic existence. Laster and Strittmatter (1968) found a tenfold increase in maltase activity in developing surf clam larvae. It coincided with the appearance of the esophagus, stomach, intestine, and digestive gland. This would be at the D-shaped stage. Larvae of a European mactrid, S. subtruncata, were obtained in plankton samples and raised to an identifiable size by Jorgensen (1946).

The problem of species identification of larval bivalves collected in plankton samples, commented on by Loosanoff and Davis (1963) and Loosanoff et al. (1951; 1966), has resulted in the development of techniques for rearing larvae under laboratory conditions. In general, the youngest and smallest larval forms lack distinctive shell and body structures for clear separation. For this reason investigators have reared larvae collected in plankton samples to larger sizes before claiming species identity (Jorgensen 1946; Landers 1954). This technique can result in greater accuracy, but is time consuming and requires additional facilities. More recently several species of bivalve larvae, including S. solidissima, have been reared from known parents, examined microscopically during development for distinctive features, systematically measured, and the observations compared between species (Loosanoff and Davis 1963; Loosanoff et al. 1966; and Chanley and Andrews 1971). The latter investigators provided a key for the identification of 23 species inhabiting the Middle Atlantic Bight and made recommendations for identifying larval bivalves.

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Cable and Landers (1974) reported on results of egg and embryo development of surf clams in synthetic seawater which were comparable to natural seawater. Rhodes et al. (1975) summarized information on the availability, maintenance, conditioning, and spawning of adult surf clams used in rearing the embryos and larvae and observation on the growth of juveniles.

3.3 Adult History

3.3.1 Longevity

Age determinations of surf clams by counting the number of growth rings on the shell have been attempted by several investigators (Kerswill 1944, at Prince Edward Island, Canada; Caddy and Billard 1976, at Buctouche, Canada; Belding 1910, at Cape Cod, Massachusetts; Westman and Bidwell 1946, at Long Island, New York; Welch 1963, off Point Pleasant, New Jersey; Chang et al. 1976, off Barnegat Inlet, New Jersey, and Ocean City, Maryland; Ropes et al. 1969, at Chincoteague Inlet, Virginia; Loesch and Ropes 1977, off Virginia; Jones et al. 1978, off Virginia and New Jersey). Three records of the oldest surf clam are a mean length of 163 mm at age 17 (Westman and Bidwell 1946); 147 mm at age 20 (Loesch and Ropes 1977); and 164 mm at age 25 (Jones et al. 1978). Although the latter reported a maximum age of 30 years for some, no shell length values were given. As seen in section 3.3.6 below, a much larger surf clam has been reported. Since growth is generally slower at ages older than 10 years, longevity may be greater than 17 years.

An estimate of longevity was computed using the 226 mm maximum length and the von Bertalanffy age/length relationship computed by Chang et al. (1976), as follows:

$$L_t = 174.8 \ (1-e^{-0.19(t+0.81)})$$

$$t = \frac{1}{K} \log_e \frac{L_\infty}{L_\infty - L_t} + t_0$$

$$t = \frac{1}{0.19} \log_e \frac{174.8}{174.8 - 226} + (-0.81)$$

$$t = Age_\infty = 26 \ \text{years}$$

3.3.2 Hardiness

No data are available on hardiness of surf clams. Commercial plants that process the meats of this clam, however, usually complete their operations within a 24-hour period after landing the catch, and many hold it in refrigerated rooms until processing can be started. The clam is prone to injury by the water jets of the dredges used to harvest them, since it gapes slightly at the siphon end. The removal of surf clams from their burrows adversely affects survival, because an elastic resilium in the hinge constantly forces the shells open, contributing to an eventual fatigue of opposing muscles. The valves gape open exposing the soft body to disication in air and to predators in the marine environment and normal body functions, such as respiration, feeding, and elimination of waste metabolites, are disrupted in either situation. Surf clams would rate low on a scale of hardiness compared to hard clams, *Mercenaria mercenaria*, which close their shells tightly.

3.3.3 Competitors

A variety of benthic organisms occur in the beds with surf clams. It is not known how these may compete, but most would utilize space in the bottom, form a smothering mat over it, or utilize the available foods.

Survey samples have occasionally taken large numbers of surf clams per tow from inshore beds. Clams in these samples frequently exhibit a roughened shell surface: older shell deposits appear raised over new in a shingle-like fashion; some have a decidedly blunted posterior end. These shell irregularities suggest that normal growth was somehow interrupted. A smaller size at their maximum age than offshore clams is discussed later (in section 4.1.2.2). The physical closeness of clams in a dense bed conceivably results in marginal food intake per clam and slower growth, but there may also be actual contact between adjacent shells. Wilbur (1964) discussed experimental observations that localized stimulation of mantle cells resulted in a large area of shell regeneration in some molluscs. Thus,

repeated irritating contacts and injury of the
delicate shell producing mantle edge seem possible
from movements of surf clams in their burrows at
locations of high densities. Irregular and slower
shell growth of some inshore clams may, then, be
visible effects of competition within the species.

3.3.4 Predators

Moon snails, Lunatia heros and Polinices duplicatus,
were recognized by early biologists as predators
of surf clams (Leidy 1878; Belding 1910). The
characteristic countersunk hole bored by the snail's
radula is usually found near the hinge and apex of the
shell. Under experimental conditions, low temperature
and salinity affected feeding of both species
(Hanks 1952). Polinices ceased at 5^0C or lower and
6^0/OO salinity; Lunatia had a reduced rate of feeding
at 2^0C and ceased at salinities of 10^0/OO or lower.
The latter species was considered a predator able to
feed throughout the annual temperature range of
New England and in the oceanic waters where surf clams
are abundant. Extensive windrows of small dead
surf clams were found on the exposed beach at
Wallops Island, Virginia, and 50% were bored
(Ropes et al. 1969). Edwards (1974) reported a food
list for Polinices which included surf clams and
a preference for larger prey and certain species tested
(Mytilus and Mya). Off Long Island, New York,
Franz (1977) found that Lunatia tends to select clams
less than 80 mm in shell length. In laboratory
experiments, Pratt (1974) found that the boring snail,
Urosalpinx cinerea, when confined with surf clams
in running seawater made some contacts, but drilled
no holes; many more contacts were made in standing
water and holes were drilled in some shells.
Carriker (1977) observed that the snails, Urosalpinx
cinerea, bored to the same average depth in the
calcitic shells of Crassostrea virginica and the
aragonitic shells of Spisula solidissima and Anomia
simplex. Wells et al. (1961) reported 17 species
of pelecypods in the stomach contents of the sea-star,
Astropecten articulatus, from off Ocracoke Inlet,
North Carolina, but surf clams were not included;
Porter (1972) also examined the stomach contents
of this species, with the same results for surf clams.
Tagatz (1968) found three mactrid species other than
the surf clam in the stomachs of blue crabs,

Callinectes sapidus, from Florida. These latter
observations suggest that starfish and crabs are
potential predators of surf clams.

Fish can be predators of surf clams. Surf clam
shells have been found in the stomachs of haddock,
Melanogrammus aeglefinus (Clapp 1912; Clarke 1954),
and cod, Gadus callarias (Bigelow and Schroeder 1953;
Clarke 1954).

Several European studies report a variety of invertebrate
predators of mactrid species. Hunt (1925) found
three species of starfish and the moon snail, Natica,
had Mactra sp in their stomachs. Birkett and Wood
(1959) reported that the siphons of the European mactrid,
Mactra stultorum, were regenerated after the plaice,
Pleuronectes platessa, had nipped off a portion.
They also observed mortalities of M. stultorum by
Natica, Asterias, and Astropecten. Partially pierced
holes from snail boring on some clams were believed
due to regeneration of the shell. Thorson (1966)
observed that a turbellarian, Discocelides longi,
ate an average of 3 and 2.6 S. elliptica 1-2 mm
long per day in laboratory culture dishes. The
sea urchin, Echinocardium cordatum, included
S. subtruncata about 1 mm long in its diet and may
consume 224 young spat in four weeks during the period
when these small sizes are most available. The moon
snail, Natica alderi, and brittle star, Ophiura
texturata, also prey upon spat of S. subtruncata.
The omnivorous hermit crab, Pagurus bernhardus, was
observed to eat 51 (85%) of the young Spisula-spat
in 2 sq dm of sand. Muus (1966; 1973) showed an
intense set of S. subtruncata (ca 8,500/sq m)
occurring in June to August rapidly disappeared
within two months. Predation was believed the main
cause of the disappearance. The starfish, Astropecten
irregularis, feeds on S. subtruncata and Christensen
(1970) elaborated on its feeding biology. Three
Spisula species were found in the stomachs: 422
S. subtruncata, 67 S. solida, and 39 S. elliptica
were the maximum number of each found in a single
stomach. It was estimated that a medium-sized
Astropecten may destroy 30,000 S. subtruncata-spat
annually. Masse (1975) reported on S. subtruncata
being eaten by Astropecten aranciacus. Fretter and

Graham (1962) reviewed the literature on the feeding mechanisms of gastropods and included many of the mactrid prey species given above. Birkett (1973) determined the energy transfer through a food chain centered around Mactra stultorum on the Dogger Bank. Although the energy consumed by Mactra during the first and second summers of life were high, fish predation of Mactra, expressed as an energy rate (g cal/g live wt/day), was highest during the first summer of the clam's life. Asteroid starfish predation of the clam was highest during the second summer of the clam's life, closely followed by predation from Natica. Mileikovsky (1974) discussed predation of pelagic larvae and early juveniles of marine bottom invertebrates by adult benthic invertebrates and their passing alive through their predators, but no real significance of this phenomenon for recruitment of a species in the benthos was given. Nielson (1975) observed predation of bivalves by the whelk, Buccinum undatum, but found that S. truncata and S. elliptica leaped away when attacked.

There are, then, various known predators of mactrid species, and although relatively few have been identified for S. solidissima, the effects of predation on survival of newly settled juvenile spat may be very significant.

3.3.5   Diseases

Protistan organisms, larval trematodes, larval cestodes, and tumors are among known parasites and diseases of marine commercial clams (Sindermann and Rosenfield 1967). Some of these organisms have been reported as parasites of Spisula solidissima. Kudo (1966) listed the thigmotrich, Sphenophyra dosinae, found on the gills; Humes and Cressey (1960) reported the cyclopoid copepod, Myocheres major, was found in surf clams form Rhode Island; and Cake (1973) found the phyllobothrid plerocercoid cestode of the genus Echeneribothrium free in the stomach and digestive diverticula of surf clams from Florida. Heavy infections of an immature anisakid nematode, tentatively identified as Paranisakiopsis pectinis, were in surf clams from off Maryland and Virginia and these contained large numbers of the sporocysts of a haplosporidian hyperparasite, Urosporidium spisula, which colored the nematodes a dark brown (Perkins et al. 1975; 1977). Lichtenfels et al. (1976) reported an

immature nematode resembling Paranisakiopsis
Yamaguti, 1941, was found in the surf clam, the whelk,
Busycon canaliculata, and the moon snail, Lunatia
heros. A similar larval nematode has been collected
from scallops from off North Carolina and Florida.
Lichtenfels et al. (1977) reported additional
information on the identity of the nematode found
in the surf clam, whelk, and moon snail. They
believe the nematode is identical to Paranisakis
pectinis found in scallops from off North Carolina,
but know it has characteristics like Sulcascaris
sulcatus, a species infecting marine turtles.
Experiments to confirm this are in progress. Payne
et al. (1977) reported the results of samples examined
monthly from August 1976 to March 1977 for the nematode
in surf clams. Large clams off Virginia were more
heavily infected than clams off New Jersey.
Lichtenfels et al. (1978) identified the anisakid
nematode found in surf clams (Spisula solidissima),
calico scallop (Argopecten gibbus), Atlantic bay
scallop (Argopecten irridians), and whelk (Busycon
canaliculata) to the genus Sulcascaris. He states that
Sulcascaris sulcata is the only known species of
this nematode genus to parasitize the green (Chelonia
mydas) and loggerhead (Caretta caretta) turtle.
These turtles occur in the area where the nematode
parasitizes the molluscs. An anatomical description
of the nematode is included. Kern (in preparation)
found the larval nematode in 13% of 1,293 clams
examined; the hyperparasite was present in 96% of
the worms. Nematode prevalence increased from 2%
in clams from off New Jersey and Maryland to 32%
in clams from off Virginia. It was mostly in the
visceral mass, but was also in the foot, adductor
muscles, and mantle tissues. An unidentified trematode,
mentioned by Yancey and Welch (1968) was found by
Ropes (1968b) as the cause of distended surf clam gonads,
sometimes when uninfected gonads were in a shrunken
and spent condition.

Several other parasites have been reported for mactrid
species related to S. solidissima: Nicoll (1906a;
1906b) reported the trematode Himasthla leptosoma
in Mactra stultorum; Sindermann (1970) included the
spores of the gregarine, Nematopsis schneideri, found
in the gills of Mactra solida by Leger (1903)
and Leger and Duboscq (1913); Gallien (1949) reported
Proboscidosaccus enigmaticus (of uncertain taxonomic

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position) in S. solida from France; Humes and Cressey
(1958) reported the copepod Conchyliruus torosus in
Mactra gallbrato from Pointe-Noire, Congo; Sindermann
and Rosenfield (1967), and Sindermann (1970) included the
copepod Mytilicola mactrae as a parasite of the
Japanese Mactra veneriformis found by Hoshina and
Kuwabara (1959); Cheng (1967) listed Ancistrum
japonica, a ciliate, in Mactra sulcataria and
M. veneriformis; Chun and Kim (1969) reported
encysted metacercariae of the trematode genus
Echinostoma in Korean Mactra sulcataria; and Humes
and Stock (1973) listed the copepod Paranthesis sp
in Mactra sulcataria from Japan and Herrmannella
rostrata in Mactra stultorum from France.

A few commensal and symbiotic organisms have been
found in mactrid species. The commensal nemertean,
Malacobdella grossa, has been found in Mactra
sachalinensis from Japan by Takahura (1897); in
Mactra stultorum from Europe (Coe 1943); in Mactra
secta (Cheng 1967); and in the siphonal plates of
Tresus nuttallii (Stout 1970-1971); but was not found
in S. solidissima by Ropes and Merrill (1967).
The pea crab, Pinnotheres pisum, has been found in
association with Mactra stultorum (Dalgliesh 1934),
and Christensen (1968) found soft-shelled specimens
in Spisula solida from Denmark and the first crab
stage in the same clam species off the west coast
of Sweden.

Toxins and organisms pathogenic to man have been found
in surf clams. Buelow (1968) showed positive results
for total coliforms in surf clams from the New York
Bight disposal area. Since survival of enteric
organisms in marine muds has been reported, surf clams
in and near the sump site may be contaminated
with pathogenic bacteria and viruses from sewage
sludge. The pathogen, Vibrio parahaemolyticus, was
found in 1 of 100 samples of the bar clam, S. solidissima,
and none in 74 samples of processed meats from the
Canadian Atlantic coast by Varga and Hirtle (1975).
Paralytic shellfish poisoning (PSP) of humans in
Canada resulting from eating surf clams containing
toxins of the dinoflagellate Gonyaulax tamarensis
has been reported by Medcof et al. (1974) and Bond and
Medcof (1957). Medcof et al. (1947) found that surf
clams retained the PSP toxin longer than any other

mollusk tested and may retain it from one year to the next. Prakash et al. (1971) presented the available information on the paralytic shellfish poisoning problem in Canada. Bar clams (Spisula solidissima) were not considered a serious hazard, although they are sometimes very toxic in the Bay of Fundy. The toxin was highest in the gills and digestive gland relative to the adductor muscles, siphons, and other parts of the clam. The toxin was eliminated slowly by the clams and may remain in some from year to year. Blogaslawski and Stewart (1978) examined the anatomical localization of the toxin and developed methods of exposing toxin-bearing clams to ozone. Rapid detoxification was exhibited in all tissues after 2 weeks exposure.

Leibovitz et al. (1976) reported finding a pedunculated tumor on the foot of a surf clam. After an examination of histologically prepared tissues, the tumor was interpreted as a polypoid myoma. An earlier reference of a foot lesion in a surf clam was included.

Goldberg (1978) observed significant mortalities of surf clams exposed to gas-supersaturated seawater. Gas-laden tissue blisters formed in the siphons and membranous tissue blisters and abnormal shell depositions were observed. The relevance of air supersaturation to the bivalve culturist was discussed.

3.3.6 Greatest Size

A shell length of 226 mm is the greatest size reported for a surf clam to date (Ropes and Ward 1977). It was among clams measured by NMFS personnel gathering catch data at the Point Pleasant, New Jersey, port and from the commercial clam vessel, HAROLD F. SNOW, on August 1, 1974. The vessel operated at $73^O54.5'$ W Long. and $39^O48.5'$ N Lat. east of Barnegat Inlet in 21.3 m of water and caught 290 bu of clams. The 226 mm clam was in a sample of 10 averaging 193.3 mm; the smallest in that sample was 178 mm.

3.4 Nutrition and Growth

3.4.1 Feeding

Feeding is intimately related with the currents of

water drawn in through and expelled from the siphons
for respiratory and excretory purposes, since the water
may carry food particles eventually ingested by
the clam. Open siphons of surf calms have been seen
at or in a depression slightly below the sand-water
interface (Ropes and Merrill 1966) and thus unwanted
particles of sand or other debris may sometimes be
washed into the clam. Morse (1919) and Jacobson (1972)
described in detail the siphonal structure and behavior
of surf clams during pumping activities. They
observed the number and action of papillae fringing the
siphons and two stout papillae (one is bifurcated)
in the branchial (incurrent) siphon. Jacobson (1972)
described the closing action of the siphonal openings
of a clam in its burrow when a wave flowed past.
This was considered a defensive mechanism to prevent
the ingestion of sand. Belding (1910) included
a brief account of the feeding habits of surf clams,
which was expanded upon by Kellogg (1915). He
described the directional flow of food particles and
other materials trapped in the mucous-covered
surfaces of the soft body parts, such as the gills,
palps, visceral mass, and mantle. Cable (1973)
observed a valvular membrane in the exhalent siphon
of surf clams. Prior (1974) elaborated on the morphology
and responses of the incurrent siphonal valve and
adductor muscles which coordinate to clean debris
trapped in the siphonal cavity.

The crystalline style of surf clams is a prominent
structure that, in addition to mechanical stirring
in the stomach, functions enzymatically to aid digestion
and assimilation of ingested foods. Lavine (1946)
demonstrated a cellulolytic property; Patton and Quinn
(1973) found a lipase which was more versatile on primary
wax esters and menthol esters than hog pancreatic
lipase, and Shallenberger et al. (1974) reported
larinaranace activity. Shallenberger (1975) studied
the carbohydrases of the style that lyse cellulose and
initiate hydrolysis of the carbohydrate reserves--laminaran
and starch--to sugars. Powders prepared from the
styles appeared to be stable and may have scientific,
technological, and industrial uses. Lindley and
Shallenberger (1976;1977) purified, characterized,
and tested two hydrolase enzymes from surf clam styles
as steps in determining potential use in dissolving
entrapped polysaccharides in filter mats used in

the production of beer.

Neurophysiological studies have been conducted on
the gut movements in surf clams. Nystrom (1967)
demonstrated tonic and phasic spontaneous contractions
of longitudinal, nonstriated muscles in the cardiac
(rectal) segment of the intestine; Smucker and Nystrom
(1970) were unable to demonstrate an extrinsic
(outside) innervation of the gut posterior to the
stomach or the cardiac and esophagus segments as well.
The control of gut motility was described as an
interaction of components within the neural plexus
and associated muscles (Smucker and Nystrom 1970; 1972).

3.4.2 Food

Leidy (1878) made observations on the contents of the
digestive tract of surf clams from a New Jersey beach.
He was surprised "at the number of different genera
and species of diatoms found" but mentioned only
Amphiprora constricta and a suspected ciliated
infusorian, Tintinnus, in the brief remarks. He
observed changes in the diatoms due to digestion
and the lack of contents before they passed from the
rectum. Belding (1910) included diatoms as the
food of surf clams. Loosanoff and Davis (1950; 1963)
used mixed plankton cultures to feed larval surf
clams and discussed various conditions for raising
larval bivalves related to food. Stephens and
Schinske (1961) observed the removal of amino acids,
such as glycine, glutamic acid, tyrosine, methionine,
phenylalanine, and arginine, by surf clams, although
the nutritive significance was considered speculative.

3.5 Behavior

3.5.1 Local Movements

The surf clam is considered a sedentary, infaunal,
and benthic creature which spends most of its life
buried in the sea floor substrata (Ropes and Merrill
1973). Due to its relatively short siphon, it is
generally believed that it burrows to a depth about
equal to its shell length. A diver found surf clams
with the uppermost portion of the shell about 1/2-in
(12.7mm) below the surface (Ropes and Merrill, 1966).

They described the burrowing action of surf clams in aquaria and natural situations.

Edwards and Emery (1968) reported an observation of a large surf clam leaping about 18 in (457 mm) off the bottom during dives in the research submersible ALVIN. It landed 2 or 3 ft (609-914mm) away from its starting point.

Several factors, such as the size of the clam, temperature, and shock, influence the speed of burrowing by surf clams, Spisula solidissima, in laboratory experiments and are significant with respect to bed formation in the natural environment (Ropes in preparation). Small clams burrowed more actively than large clams by making fewer digging cycles. Under cold temperature conditions $(1.8^{o}C)$, some clams failed to begin digging activities, while others were inhibited in beginning and completing burial. Mechanical shock induced digging at temperatures of $4^{o}C$. Burrowing activities of clams acclimated to a $14^{o}C$ increase were only slightly affected, but a $22^{o}C$ rise in temperature from $4^{o}C$ caused gaping, lethargy, and eventual death. The seasonal warming trend in the spring significantly increased burrowing activities, but the subsequent increase in temperature during the summer had little effect. Based on these experiments, the greatest disruption of surf clams would be expected during the cold months of the year, and small clams are probably most affected by surf zone currents because of their lower weight in water.

Hunter and Grant (1962) tested the ligament of surf clams in relation to mode of life. An opening moment was determined (mean of 608.89 mm/ml) and was about 3.5 times more powerful than the ligament of soft clams, Mya arenaria. The mechanical differences were said to reflect the modes of life of the two species. The opening moment of the hinge ligament in a surf clam functions to actively maintain a burrow, which is often relatively unstable sand substratum. A relationship between the action of the hinge ligament and hardiness has been discussed (cf. section 3.3.2). Kahler (1976) also reported on the form, function, chemical analysis, and mechanical properties of the ligament of surf clams.

Locomotion by postmetamorphal surf clams is a
remarkably active behavior. The foot can be
extended beyond the valve margins to a length almost
equal to the shell height and is used to pull the
young clam over the bottom or is probed into the
bottom substratum (Figure 31). In laboratory
cultures, the clams can move actively over the
glass bottom of a beaker, sometimes pulling with them
other clams and shells. The end of the foot is
ciliated and may have a means of physical adhesion
to such surfaces as smooth as glass. Attachment
by a byssus thread has not been demonstrated for
juvenile surf clams, but has been found for a
Japanese relative, S. sachalinensis (Hayashi and
Terai 1964). Yonge (1962) reviewed the primitive
significance of the byssus for bivalves and noted
its absence in adults of the superfamily Mactracea,
which includes the surf clam.

3.5.2 Schooling

Not a behavior of clams.

3.5.3 Stimuli

Several neurophysiological investigations described
nerve pathways affected by stimuli. Kennedy (1960)
found the pallial nerves of surf clams contained a
single afferent nerve fiber. It responded to
illumination and apparently mediated the "shadow"
response of siphon retraction. The clams were
more responsive to decreases in intensity than sudden
increases in illumination. Mellon (1965) examined
nerual pathways controlling reflex withdrawal of the
siphons in surf clams. The pathways were among the
fastest in the relevant nerve trunks and he was able to
account for symmetrical siphonal withdrawal. Mellon
and Prior (1970) studied the fast portion of the
posterior adductor muscle of surf clams and found
Type I motor neurons. Prior (1972a) found local
reflexes which mediate localized siphonal contractions
in response to tactile stimulation. Prior (1972b)
studied the behavioral sequence involving local reflexes,
siphon retraction, and valve adduction. Discrimination
between low and medium stimulus intensities was
observed. Mellon (1972) studied the electrophysiology
of touch sensitive neurons in surf clams. He found

stomata of first-order tactile neurons are located
in the central nervous system and elaborated on their
form and function. Prior and Lipton (1977) studied
the ultrastructure of peripheral neurons and associated
non-neural structures in surf clams. Synaptic
topography was described and anatomical correlates
of previous physiological observations were provided.
Prior et al. (1979) observed an evasive jump response
of surf clams by touching the siphons with the tube
feet of a starfish (Asterias forbesi). Small clams
(2.0-5.0cm) were most responsive, medium clams
(5.4-11.5cm) were moderately responsive, and large
clams (12.0-18.0cm) were unresponsive. They considered
small clams were more susceptible to predation than
large clams because of shorter siphons which permit
only shallow burrowing. The neural basis for the
evasive jump response was investigated.

Temperature has been used to hasten gonadal development
in surf clams. Clams moved from the natural environment
during the late fall, winter, and early spring, to
warm-water laboratory conditions, stimulated
gonadal development to a ripe condition (Loosanoff
and Davis 1963). Sapwning was induced by thermal and
chemical stimulation, although thermal stimulation
alone was sufficient on several occasions. Normal
larvae for culture purposes "out-of-season" were
produced on many occasions. The influence of
temperature as a stimulus in the natural environment
was recognized in studies of gonadal development
(Ropes 1968b). Gametogenesis proceeded to a ripe
gonad condition during warming trends in the spring
and early summer. Spawning coincided with abrupt
increases in bottom-water temperature.

Temperature also influenced burrowing activities
in surf clams. Burrowing rate was stimulated by
increasing temperature to about $20^{o}C$, but was
depressed by higher temperatures (Savage 1976).

Low dissolved oxygen can be a stimulus. During the
summer of 1976, low oxygen in the bottom water off
New Jersey was a stimulus prompting some surf clams
to vacate their burrows (Ropes et al. in preparation).
Scuba diver observations and catches of dead and
dying clams in otter trawl samples were evidence for
this unusual behavior. Low oxygen conditions severely

depressed burrowing activities of surf clams (Savage 1976).

4. POPULATION

4.1 Structure

4.1.1 Sex Ratio

Data for determining the sex ratio of surf clams were from two sources: (1) the study of the reproductive cycle of the clam off New Jersey during 1962-1965 (Ropes 1968b); and (2) random collections of gonads taken during survey cruises in 1965 and other miscellaneous sources. The latter samples were prepared for microscopic examination in the same manner as was done in the study of the reproductive cycle above (Table 3). In a chi-square test to determine if the samples were from a population having a 1:1 sex ratio, X^2 values of 2.2218 and 0.4902 obtained for the two respective sources of data were non significant at the 5% level. Therefore, the hypothesis was accepted that the samples were drawn from a population in which the sex ratio 1:1.

4.1.2 Age Composition

Age-size relationships for surf clams have been derived by several means of observing shell growth and for widely separated geographic areas and years (Table 4). Age was determined from "rings" or "ridges" seen on the external shell surfaces by Belding (1910) at Cape Cod, Massachusetts; Kerswill (1944) at Prince Edward Island, Canada; Westman and Bidwell (1946) at Long Island, New York; Welch (1963) at Central New Jersey; and Caddy and Billard (1976) at Buctouche, Canada. In refined analyses of Westman and Bidwell's (1946) and Welch's (1963) data, Loesch and Ropes (1977) reported that the latter were used in approximating surf clam growth in part of the fishery off Virginia.

In 1975, NMFS investigators developed methods to more clearly observe marks deposited in the shells of surf clams. The shells were cut from the umbo to ventral margin and the cut surfaces were polished. This procedure exposed marks that were related to

Table 3. The number of surf clams, *Spisula solidissima*, by sex.

Year	Number of samples	Number of Male	Female	Totals
A. Samples taken during a study of the reproductive cycle (Ropes 1968b).				
1962	8	74	98	172
1963	20	244	246	490
1964	20	240	244	484
1965	14	170	198	368
Totals	62	728	786	1,514
B. Random samples from survey cruises and miscellaneous sources.				
1965S	19	78	93	171
1965F	23	101	87	188
Misc	8	43	57	100
Totals	50	222	237	459

S = spring; F = fall

TABLE 4. Mean shell length (mm) at external (ext.) or internal (int.) growth marks and measurements of yearly growth of surf clams, _Spisula solidissima_, from various geographic locations and years.

Source	Location, Type of Bed, & Number of clams	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV
Belding (1910)	Monomoy Point; inshore; not given; (ext.)	25.4	40.6	81.3	91.4	101.6	108.0	114.3																		
Kerswill (1944)	P.E.I., Canada; offshore; 100; (ext.)	15.9	34.9	57.2	76.2	92.1	101.6	111.1	117.5	120.7	123.8	127.0														
Westman & Bidwell (1946)	Long Island, N.Y.; offshore; ca. 100; (ext.)	34.0	60.0	79.0	92.0	103.0	112.0	120.0	127.0	133.0	138.0	143.0	147.0	151.0	155.9	158.0	161.0	163.0								
Welch (1963)	Central New Jersey; offshore; 10; (ext.)	45.7	78.7	99.1	116.8	124.5	132.1	137.2	139.7	142.2	143.2	144.8	147.3													
Caddy & Billard 1976	Buctouche, Canada; inshore; 155; (ext.)	15.0	31.0	49.0	65.0	81.0	96.0	109.0	119.0	128.0	134.0	139.0	143.0	145.0	149.0	150.0	151.0									
Loesch & Ropes (1977)	Offshore Virginia; Welch's data used.	47.2	79.2	100.8	115.8	125.7	132.6	137.4	140.5	142.7	144.3	145.3	145.8	146.3	146.6	146.8	147.1	147.1	147.1	147.3						
NMFS 1975 Chang et al (1976)	Barnegat, N.J.; inshore; 39; (int.)	34.0	56.0	73.0	88.0	102.0	109.0																			
NMFS 1975 Chang et al (1976)	Ocean City, Md.; offshore; 36; (int.)	39.0	57.0	94.0	113.0	126.0	136.0	143.0	148.0	152.0	156.0	159.0	161.0	163.0												
Jones et al (1978)	Pt. Pleasant, N.J.; inshore; 54; (int.)	38.0	62.0	79.0	88.0	94.0	97.0	102.0	106.0	108.0	109.0	110.0														
Jones et al (1978)	Pt. Pleasant, N.J.; offshore; 30; (int.)	29.0	55.0	81.0	99.0	112.0	122.0	130.0	135.0	140.0	144.0	147.0	148.0	149.0	151.0	152.0	153.0	153.0	155.0	156.0	157.0	160.0	161.0	162.0	164.0	164.0
NMFS 1965-67 Ropes et al (1969)	Chincoteague Inlet, Va.; inshore; annula shell measurements; 846.	44.2	68.6	90.5																						

"rings" on the external valve surface of the cut and uncut shells. The method appeared to be more accurate than simply examining the external valve surface, because some internal marks were found but corresponding "rings" on the external surface were poorly defined. Chang et al. (1976) reported age-size relationships from data compiled using this technique on surf clams from inshore and offshore locations (Table 4). Later, Jones et al. (1978) reported on a study of aging inshore and offshore surf clams using the same technique.

Three mean yearly increments of surf clam growth have been derived from measurements of the shell lengths of a discrete settlement discovered in Chincoteague Inlet, Virginia, on October 1, 1964. A total of 366 clams from Wallops Island Beach averaged 21.1 mm in shell length on October 28, 1964. Thereafter, 311 clams from this beach averaged 42.4 mm on July 7, 1965; 405 averaged 68.6 mm on July 18, 1966; and 75 averaged 90.5 mm on August 7, 1967 (Table 4). After January 29, 1968, clams were unavailable from this source, due to heavy losses from predation and storms. Ropes, Chamberlin and Merrill (1969) reported on these data and included a projected size at 4 years of 110 mm.

Ropes and O'Brien (1979c) reported on a method of thin-sectioning the chondrophore in the hinge of surf clams to expose growth marks. Correspondence was found between marks in the chondrophore and valve. They believe the techniques of preparing study specimens were simple and that growth increments were more easily observed and measured than in sectioned valves. They discussed the problem of assigning a year's growth to each observed growth mark.

4.1.2.1 Age composition of landings

Analyses are in progress summarizing age-size relationships of surf clams landed by area and years. The results are too preliminary to report at this time. As indicated by the size composition of landings (cf sec. 4.1.3.1), large and probably old clams were fished from offshore Point Pleasant, N.J., and Ocean City, Md., during 1965-74, but off Virginia, the fishery concentrated on much smaller clams from a settlement found in 1969 (cf sec. 5.2.1).

4.1.2.2 Variations with depth

Mean length at age, determined by the method of cutting shells, provides observations on 39 clams from an inshore Barnegat, New Jersey, location and 36 clams from an offshore Ocean City, Maryland, location (Table 4). The depth at these respective locations was 11.6 m and 18.3 m. Although these are not wide differences in depth, the age-size relationship of the oldest clams at the Barnegat site was 5 years and 109 mm and at the Ocean City site was 12 years and 163 mm. Growth at 5 years by the Ocean City clams exceeded the Barnegat clams by 27 mm.

Jones et al. (1978) provided similar observations of variation in growth of surf clams with depth (Table 4). For two sites east of Point Pleasant, New Jersey, 54 clams were collected from an inshore location 1.8 km from shore and at a 15-m depth, and 30 clams from an offshore location 17.5 km from shore and at 28m. The age-size relationship for the oldest clams at the inshore site was 11 years and a mean of 110 mm, and at the off-shore site was 25 years and a mean of 164 mm. Growth of the offshore clams at 11 years exceeded the inshore clams by 37 mm.

4.1.2.3 Age-length and age-weight relationships

Chang et al. (1976) determined the relationships

between age and length, total weight and drained meat weight for the Middle Atlantic Bight surf clam. The respective equations are:

Age and shell length (mm) -- $L_t = 174.8 \ (1-e^{-0.19(t+0.81)})$

Age and total weight (g) -- $W_t = 762.7 \ (1-e^{-0.11(t-3.13)})$

Age and drained weight (g)-- $W_t = 263.2 \ (1-e^{-0.14(t-2.05)})$

Caddy and Billard (1976) determined the age-length relationship for the surf clam at Buctouche, Canada, as:

Age and shell length (cm) -- $L_t = 17.0656 \ (1-e^{-0.1553(t-0.628)})$

Ropes (1979a) included a generalized age-length graph in a discussion about aging surf clams (Fig. 4).
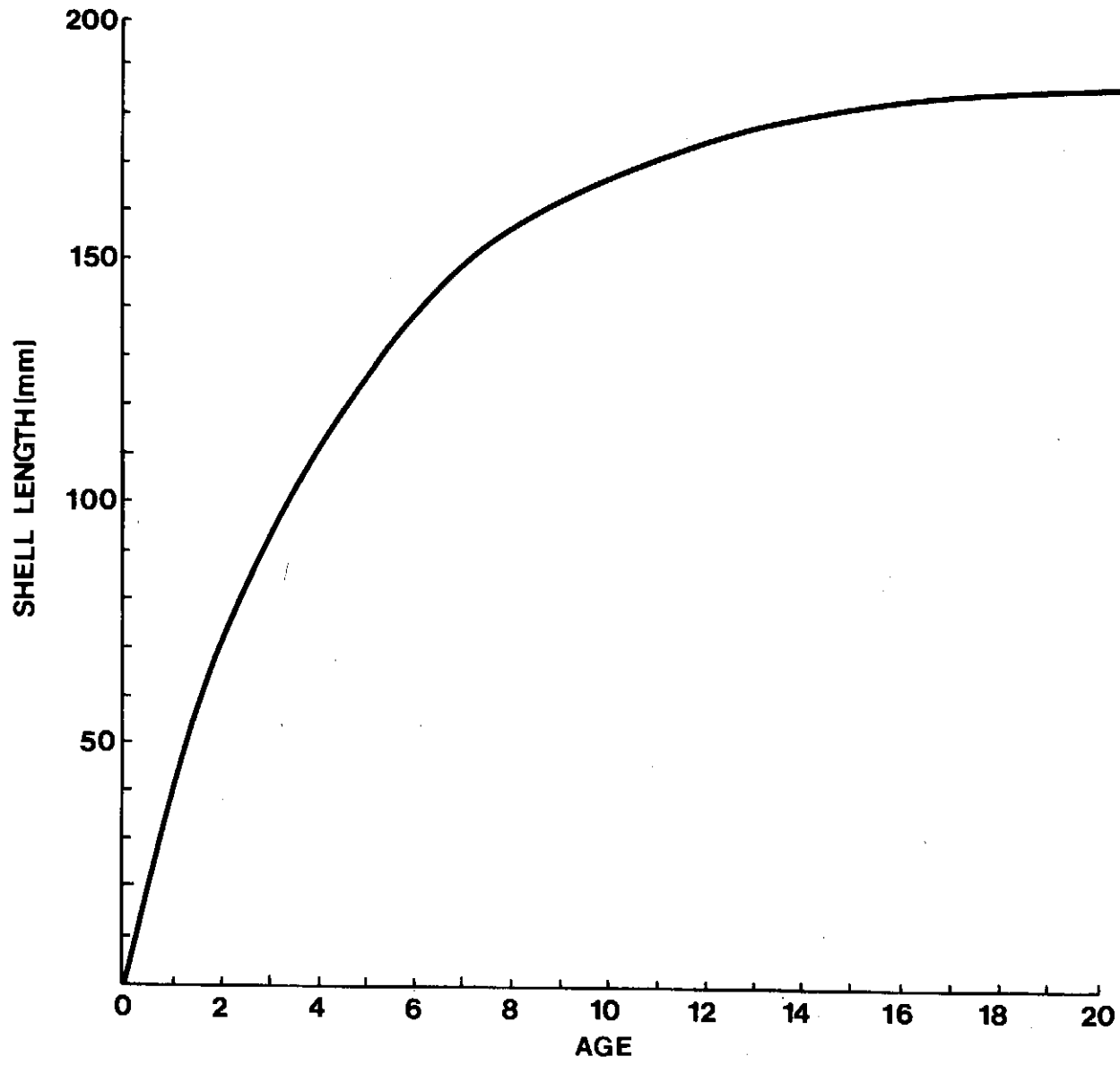
FIGURE 4. General age and growth relationship for surf clams, _Spisula solidissima_. (From Ropes, 1979a).

4.1.3 Size Composition

4.1.3.1 Size composition of landings

Measurements of surf clams have been taken
during interviews of vessel captains landing
their catches in 1965-74 (Groutage and Barker
1967a,b; Yancey 1968, 1970; Barker and
Ropes, Merrill, and Ward 1975; Ropes and Ward
1977). Mean shell lengths and range of
sizes have been derived from these measurements
(Table 5). Mean clam size at the Point
Pleasant, New Jersey, port was consistently
large and increased from 151 mm after 1965.
The size of the clams was considered typical
for the offshore resource. At Cape May -
Wildwood, New Jersey, catches from both an
inshore and offshore resource were landed.
The sizes from the inshore resource were small
(ca. 130 mm); those from the offshore
resource were large (ca. 155 mm). Landings
at Ocean City, Maryland, were from the offshore
resource and large clams (ca. 155 mm).
At Virginia ports, clams of a small mean size
(ca. 133 mm) were landed, but these were
from a recent settlement that were harvested
before they reached the more typical large
offshore size. Shell lengths range from about
100 to 200 mm in most commercial landings,
although smaller and larger individuals are
sometimes taken.

4.1.3.2 Variations with depth

Ropes et al. (1972) report surf
clam catch by depth and distance from shore.
The data were from 370 interviews of vessel
captains at Cape May - Wildwood, New Jersey,
in 1972. Clams from beds at 8.2, 10.1,
22.1, and 23.6 m depths and 3.0, 4.6,
27.8, and 29.9 km from shore averaged
113.3, 127.1, 155.5, and 163.4 mm in shell
length, respectively. For those samples shell
length clearly increased directly with depth
and distance from shore. The smaller clams
at the nearshore and shoal locations were
considered inshore stocks in opposition

Table 5. The mean shell lengths and (range of) sizes of surf clams, _Spisula solidissima_, measured in samples during NMFS interviews of vessel landings, 1965-74.

| | | New Jersey | | | |
| | | Cape May - Wildwood | | Maryland | Virginia |
Year	Pt. Pleasant	Inshore	Offshore	Ocean City	Cape Charles
1965	151(120-180)		139(105-180)		
1966	151(105-189)		130(100-160)		
1967	149(110-185)		141(095-178)		
1968	153(109-184)		147(111-195)		
1969	155(116-203)	131	157(109-187)		
1970	157(126-171)	128	160(113-173)	141(095-200)	
1971	157(110-184)	129	159(098-190)	151(100-198)	
1972	158(110-185)	127	158(087-191)	159(104-194)	133(106-160)
1973				161(107-198)	135(086-170)
1974	186(145-226)			160(106-192)	132(097-188)

to offshore stocks of larger clams further from shore and in deeper water. The larger size, faster growth, and greater age (cf. section 4.1.2.2) of offshore than inshore clams suggests that conditions for growth are more optimum offshore.

4.1.3.3 Size at first harvest

Prior to the development of mechanical processing equipment in the early 1970's, the fishery attempted to exclude catching clams less than 125 mm in shell length. Some smaller clams occurred in the catches and were usually rejected during the shucking operations by hand methods. At the present time there are no restrictions on gear to limit the catching of small clams (cf. sec. 6.1). Size at first harvest can be less than 100 mm and some as small as 87 mm have been measured (cf. 4.1.3.1).

4.1.3.4 Size at maturity

Cf. sec. 3.1.2

4.1.3.5 Maximum size

Cf. sec. 3.3.6

4.1.3.6 Length and weight relationships

Chang et al. (1976) determined the relationships between surf clam shell length (L) and total weight, dry shell weight, and drained meat weight for the Middle Atlantic Bight. The respective relationships are:

$$\ln W_t = -10.3188 + 3.21034 \ln L$$

$$\ln W_t = -8.25149 + 2.7168 \ln L$$

$$\ln W_t = -8.97583 + 2.766297 \ln L$$

Relationships were also developed between shell length vs. shell height, width, chondrophore

length, and shell cross-section, and
chondrophore and shell cross-section
measurements. These latter were derived from
measurements of annular rings exposed by
cutting the clam shells (cf. sec. 4.1.1).

Caddy and Billard (1976) determined the
relationship between shell length and drained
meat weight for surf clams from Buctouche,
Canada, as follows:

$$W_t = 0.1063(L)^{2.5996}$$

Murawski and Serchuk (1979) determined the
relationship between shell length and
drained meat weight for surf clams from
commercial samples off Delmarva Peninsula,
as follows:

$$\log_{10} W = -3.5876 + 2.6224 \log_{10} L$$

4.2 Abundance and Density

4.2.1 Estimation of Population Size

Caddy and Billard (1976) estimated the production of
bar clams in an unexploited population at Buctouche,
New Brunswick, Canada. Production estimates were
based on an estimated virgin biomass of 58.8 mt
of drained meat. From their analyses, a prediction
was that small local populations can probably
sustain full-time harvesting by 1 or 2 fishermen
using diving gear.

4.2.2 Changes in Relative Abundance

Serchuk et al. (1978) reported trends in research
survey relative abundance indices for surf clams in
the major offshore fishing areas of the Middle Atlantic
during the 1965 through 1977 period. The survey indices
were compared with annual landings in each area (Figures
5A-D). Recruitment in these areas is reported in
section 4.3.3.

In northern New Jersey, relatively high abundance
indices in 1965-1967 steadily declined to low levels
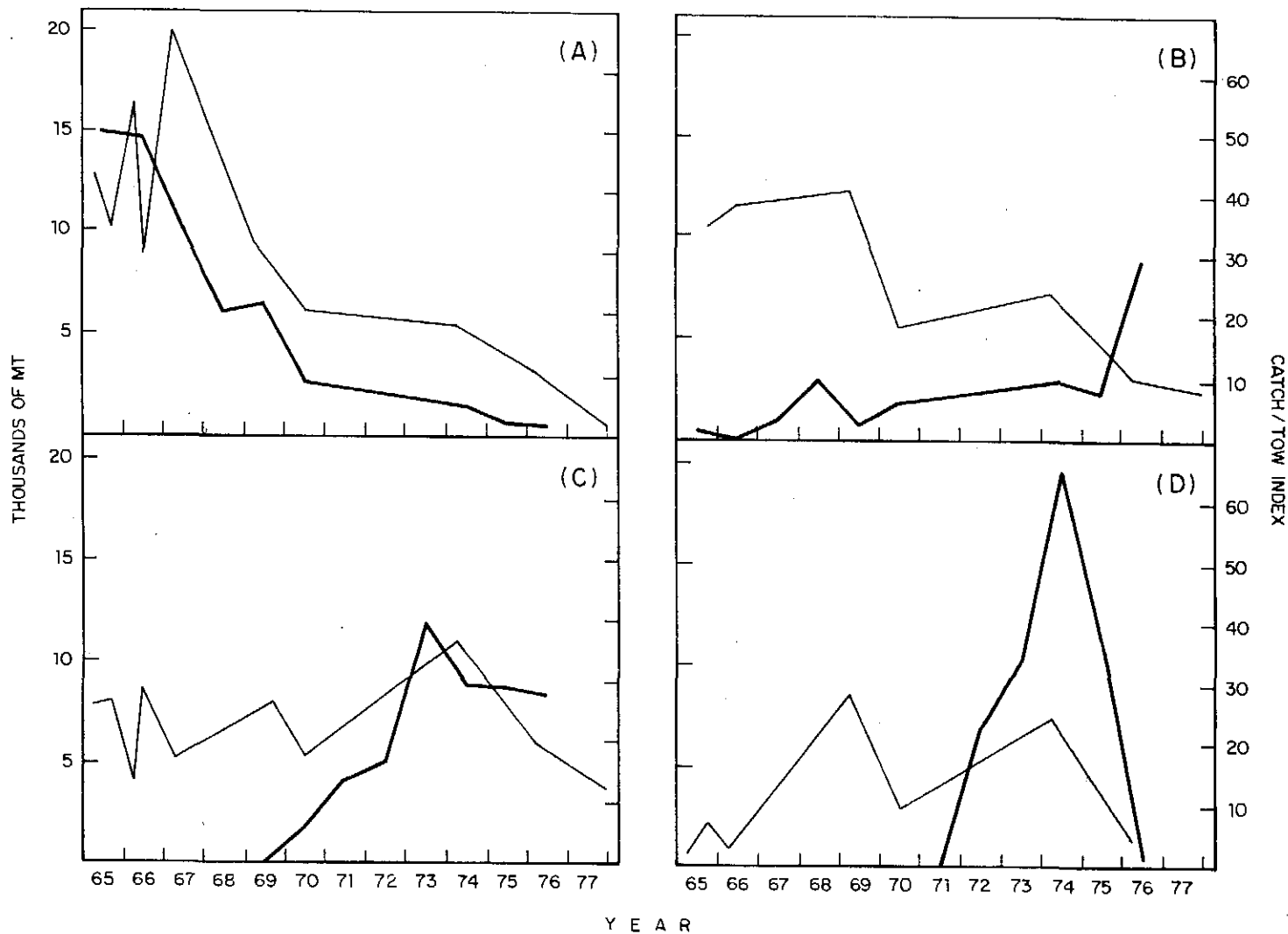by the mid-1970's (Figure 5A). Correspondingly,

FIGURE 5. Estimated annual landings of surf clam (<u>Spisula solidissima</u>) meats in metric tons (solid lines) and catch per tow indices in mean number of clams (broken lines) from the offshore Fishery Conservation Zone and: (A) northern New Jersey, (B) southern New Jersey, (C) Delmarva, and (D) Virginia - North Carolina. (Adapted from Serchuk et al. 1979).

landings declined by 96% between 1965 and 1976. A massive clam kill in 1976 reduced survey indices to a low of 2.7 clams per tow by 1977. The estimated loss was almost 62% of New Jersey's surf clam biomass (cf. section 2.3).

In southern New Jersey, high survey indices in 1965-1969 stabilized at slightly lower levels during 1970-1974 (Figure 5B). Annual landings in the same 10-year period were moderate, averaging 1,588 mt of meats. Thereafter, landings of 2,268 to 8,845 mt meats in 1975 and 1976 reflected an increase in fishing effort and survey indices declined.

Off Delmarva, surf clam abundance indices during 1965 to 1976 were the most stable of any area surveyed, ranging from 13.8 to 36.9 and averaging 24.1 clams per tow (Figure 5C). Annual landings from offshore beds increased after 1972 and averaged 8,525 mt of meats. The moderately high abundance indices recorded for the area were in part (cf. section 4.3.3) considered an indication that a stable fishery might result at annual harvest levels of about 8,100 mt of meats. A 50% decline in the 1977 survey indices from 1976, however, suggested that the 8,100 mt level may be too high.

Off Virginia - North Carolina, abundance indices were the most variable of any area surveyed (Figure 5D). The indices increased ten-fold in 1969 from relatively low levels in 1965 and 1966, declined sharply in 1970, increased sharply in 1974, and decreased to a low level in 1976. Annual landings from the area were insignificant before 1972, but increased to 19,777 mt of meats by 1974. Landings decreased sharply in 1975 and the negligible amount landed in 1976 indicated the collapse of the fishery.

Murawski and Serchuk (1979) analyzed the 1976 to 1978 research survey relative abundance indices for surf clams in the major offshore fishing areas of the Middle Atlantic. Off northern New Jersey, indices for commercial-sized clams ($\geq$ 12 cm shell length) remained relatively low and no apparent trend was observed in the indices for off southern New Jersey. Off Delmarva, all relative abundance indices declined between 1976 and 1977 and those for commercial-sized clams remained low throughout a December 1978 survey. In effect, then, no significant increase was observed in the commercially exploited biomass for any of the survey areas. Most (92% and about 13,000 mt of meats) of the 1978 landings of surf clams were from the Delmarva area, nearly all of the rest (8% and about 1,100 mt of meats) was from off New Jersey, and a small amount (0.2% and about 270 mt of meats) was from off Virginia-North Carolina.

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4.3 Natality and Recruitment

4.3.1 Reproductive Rate

Unknown

4.3.1.1 Annual egg production rates

Unknown

4.3.1.2 Egg and larval survival rates

Unknown

4.3.2 Factors Affecting Reproduction

4.3.2.1 Density-dependent factors

Unknown

4.3.2.2 Physical factors

4.3.2.2.1 Temperature

Temperature was not clearly reported as a
stimulus for spawning of surf clams by Ropes
(1968b). Some spawning was observed before
abrupt temperature increases were observed
and when bottom values were 12°C or less.
The gradual gonadal development to ripeness
before spawning, accompanied by the probable
production of neurosecretory products, were
thought of as important conditions influencing
spawning. Nevertheless, a minimum temperature
threshold eliciting the spawning response is
likely, although not clearly known. Under
laboratory conditions, spawning of ripe clams
can usually be easily induced by a simple rapid
increase in temperature. Instances of spontaneous
spawning by individuals held under constant temper-
ature conditions, however, have been observed.

In the laboratory, Loosanoff and Davis (1963)
induced spawning of surf clams at temperatures
of 18-25°C, but at 30°C and above, the survival
of clams and eggs were unfavorably affected.

Loosanoff and Davis (1963) reported on larval
development of surf clams at two temperatures
and a salinity of 27 ppt. At 14°C, ferti-
lized eggs reached the straight-hinge stage

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after 72 hr; at 22°C the same stage was
reached after only 28 hr. Metamorphosis
was first observed after 35 and 19 days at
the two respective temperatures. Development
was not only slower at the colder temperature
but the larvae were smaller than those
raised at 22°C.

4.3.2.2.2 Water movements

It is suspected that ocean water currents
transport surf clam larvae, since they have
relatively weak self-locomotory abilities.
Bumpus (1965, 1973) and Bumpus and Lauzier
(1965) described the residual surface and
bottom drift of water currents along the
continental shelf of the Middle Atlantic Bight.
They reported a coastal current flows
predominantly southwesterly and southward,
with reversals expected between April and
September in years when river runoff is
abnormally low (Bumpus 1969).

4.3.2.2.3 Anoxic factors

Cf. section 2.3.

4.3.3 Recruitment

Serchuk et al. (1979) reported trends in research
survey relative abundance indices for recruiting
surf clams (9.0-11.9 cm shell length) in the major
offshore fishing areas of the Middle Atlantic during
1965-1977; Murawski and Serchuk (1979) provided
similar indices for surveys during 1976-1978 (Table 6).
Off northern New Jersey, recruitment was low in
1965 to January 1978, but in the December 1978
survey, the index was 27.8 clams per tow, a 28-fold
increase over the low January 1978 value. Off
southern New Jersey, recruitment indices in 1965
and 1966 were only slightly higher than off northern
New Jersey, but declined thereafter through 1976.
Only a slight increase was observed in the 1977 and
two 1978 survey values. Off Delmarva, recruitment
values were low, but relatively steady, throughout
1965 to January 1978. In the December 1978 survey, the

Table 6. Relative abundance (mean number per tow) of recruiting
          (9.0-11.9 cm in shell length) surf clams, Spisula solidissima,
          for NMFS surveys during 1965-1978 in the offshore Fishery
          Conservation Zone from northern New Jersey, southern New
          Jersey, Delmarva, and Virginia-North Carolina. (Data
          from Serchuk et al. 1979; Murawski and Serchuk 1979).

Cruise Period	Northern New Jersey	Southern New Jersey	Delmarva	Virginia- N. Carolina
1965-Spring	3.1	5.9	4.6	1.1
1965-Autumn	1.6	7.6	4.3	2.9
1966-Spring	4.4	ND	2.3	1.0
1966-Summer	2.8	2.4	4.2	ND
1967-Spring	3.5	0.0*	0.8	ND
1969-Spring	1.2	1.7	2.0	5.6
1970-Summer	1.1	0.8	1.2	1.0**
1974-Spring	0.8	0.8	4.6	3.1
1976-Spring	1.0	0.2	3.5	0.2
1977-Winter	0.9	0.8	1.5	ND
1978-Jan.	0.9	1.6	2.6	ND
1978-Dec.	27.8	2.0	394.2	ND

  * Only 5 stations
 ** Only 11 stations
ND No data

recruitment index was 394.2 clams per tow, the largest
value recorded to date for an offshore area. The
small clams were distributed in a 1,300 km^2 area
at 9 to 27 m depths off Ocean City, Maryland and in
7,560 km^2 area at 27 to 46 m depths off Chincoteague
to Cape Charles, Virginia. Off Virginia - North
Carolina, recruitment indices were low in six surveys,
but the index recorded in 1969 was an indication of
an earlier important settlement. Ropes (1979a)
reported that 76% of the clams caught during the 1969
survey ranged from 61 to 99 mm and by 1974, 73%
ranged from 121 to 149 mm. Clams landed at Virginia
ports in 1972 to 1974 averaged 132 to 135 mm and
were from the settlement found in 1969. The fishery
relied heavily on clams from this settlement,
harvesting them at unprecedented rates (Ropes
and Ward 1977). The fishery was most active for
about four years and then collapsed (cf section
4.3.3). For the small clams found off New Jersey
and Delmarva in late 1978, Murawski and Serchuk
(1979) predicted probable recruitment to the fishery
in 1981 to 1982 and they discussed the need to
monitor natural mortality of the pre-recruits to
assess their impact on harvestable resource abundance.

4.4 Mortality and Morbidity

4.4.1 Mortality Rates

A natural mortality rate (M) for surf clams was assumed to be 0.2 by Caddy and Billard (1976), Chang et al. (1976) and Murawski and Serchuk (1979) used 0.25.

4.4.2 Factors Causing or Affecting Mortality

The predators and parasites of surf clams and conditions determining or having possible influence on distribution have been reviewed (cf. sections 2.3, 3.3.4, and 3.3.5), but their effects on mortality of the larval, juvenile, and adult forms in the ocean are largely unknown or only suspected. Mortalities of large numbers of surf clams washed ashore on beaches have been the subject for newspaper articles and other reports (Barnes 1910; Jacot 1920; Sieling 1960; Smithsonian 1970). Newspaper reports are most common for such occurrences on New Jersey beaches. Prodigious numbers of clams have been photographed and estimated. Often severe storm conditions are implicated as the cause of the mortalities. Although not entirely unimportant, the phenomenon occurs with unpredictable frequency and involves small local segments of the total resource. The clams often inhabit the shoal turbulent surf zone that cannot be fished by the dredges in the fishery. These unpredictable mortalities result from equally unpredictable settlements of the clams and are similar to fluctuations reported for settlements of other bivalve species in the littoral zone by Coe (1953; 1956). He found "no satisfactory indication of long-term periodic or rhythmical cycles" for the fluctuations.

The direct effects of fishing mortality are obvious and the size of the surf clam biomass and harvestable population have noticeably declined (cf. section 4.2.2). Less obvious effects may be damages to clam habitats from the high water pressures of the dredge manifold. Furthermore, mortalities of clams exposed to the gear, but not harvested, may be high, since the hydraulic action of the dredge can cause misalignment of the clam's hinge, damage to the valves, intrusion of sand in and around the soft body, and severance of the posterior adductor muscle.

4.5 Dynamics of Population (as a whole)

As indicated in section 4.2.1, surf clam populations in some survey areas declined between 1965 and 1978. Although 23,000 mt of meats was a first approximation of the maximum sustainable yield (MSY), based on the average of the commercial catch from 1960-1976, a quota of 14,000 mt was the optimum yield from the Fishery Conservation Zone recommended by the Mid-Atlantic Fishery Management Council (FMP 1977) (cf. section 6.1). The quota was adopted in response to excessive fishing mortality and adverse environmental conditions. During the first full year of operating under the quota system, landings of 14,240 mt in 1978 were a 27% decline from 19,050 mt in 1977 (FMP, No. 2, 1979).

5. EXPLOITATION

5.1 Fishing Equipment

5.1.1 Gear

The earliest methods of harvesting surf clams were by hand-operated rakes or tongs and sometimes by simply gathering clams washed ashore after storms (Parker 1971). Scraper-type dredges towed behind power boats were used during the 1920's, but these were relatively inefficient and broke many clams. During the mid-1940's, scraper-type dredges were designed with a hydraulic jetting system mounted ahead of the knife. Water was pumped through the jets to loosen the bottom sediments. This innovation reduced clam breakage, increased the area fished by the dredge, and was instrumental in establishing the modern-day U.S. ocean clam fisheries. The dredges were initially small and light in weight compared with the present-day dredges (Figure 6). The knife was about 30.5 cm wide and water was supplied to the jet manifold by 6.35 cm diameter canvas fire hose. Now the knife may be 152-305 cm wide and the water is supplied through 15.2-20.3 cm diameter, specially constructed, rubber hose. The large size and weight of the dredge requires powerful vessels, some of which have been specially designed and built for ocean clam fishing (Ropes 1972b). A large dredge, stern ramp, and conveyor system for moving the catch to cages in the hold are usually incorporated in vessels built or converted for surf clamming since 1970. These innovations have greatly increased fishing efficiency (cf. section 5.4.1).
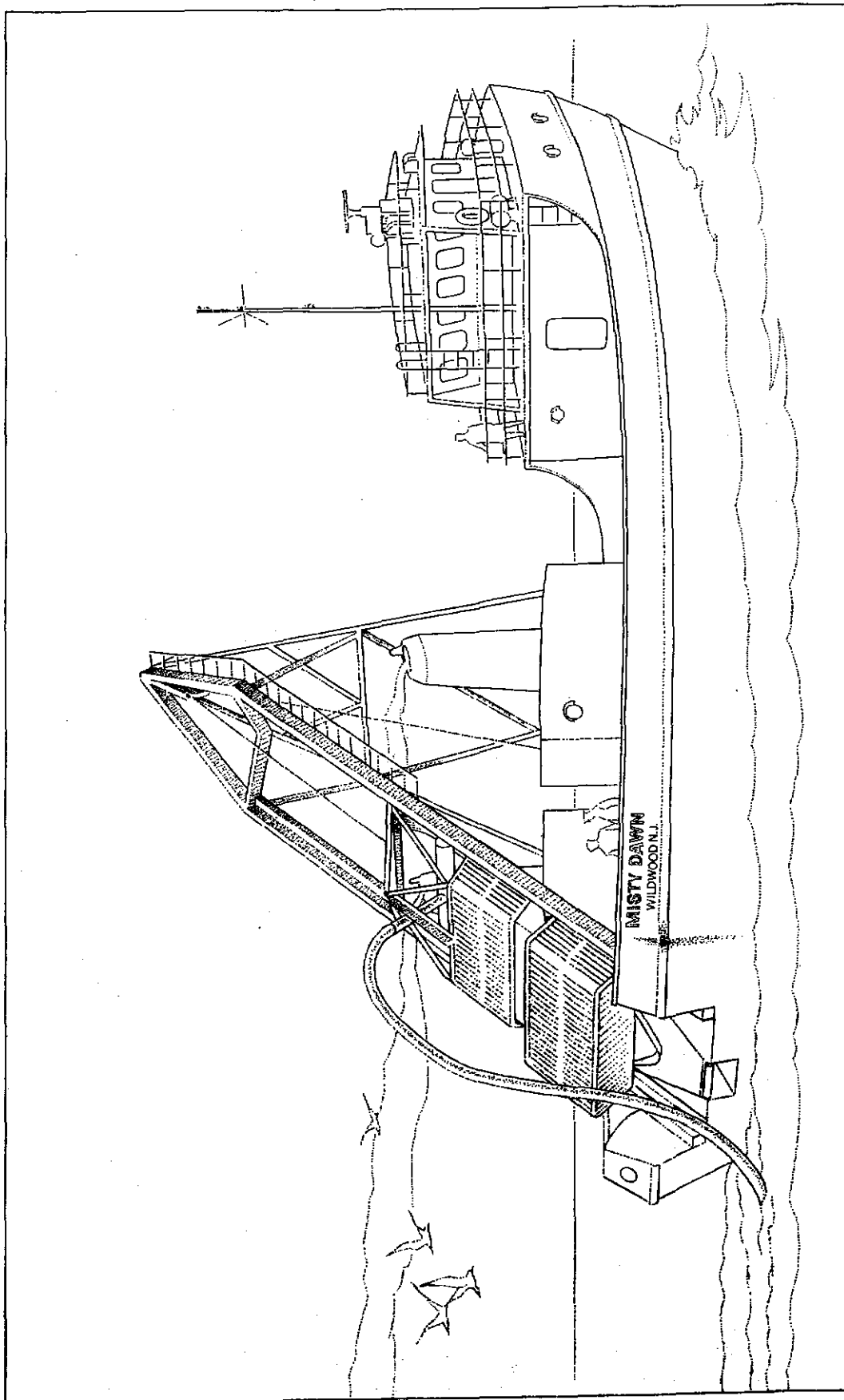
FIGURE 6. A modern commercial surf clam vessel rigged with the dredge on a stern ramp.

5.2 Fishing Areas

5.2.1 Geographic Range

The first organized fishery for surf clams began
on Cape Cod in the 1870's, and earlier records
indicate the clam was a known source of food
(Yancey and Welch 1968). The fishery in the New
England region, however, has remained a marginal
operation through 1977 (Ropes 1979a). Annual production
has been low (< 0.09 metric tons). The rocky bottom
topography of the New England coast and expense of
modern dredge equipment to operate on small,
localized beds have been factors limiting the fishery.

The discovery of the principles of the hydraulic
clam dredge and processing technology to remove sand
from the meats during the mid-1940's in industry shops
on Long Island, New York, were necessary for an expansion
of the fishery throughout most of the range of the
clam in the Middle Atlantic Bight. This expansion
was within the 3-decade period 1945-74 and has been
reviewed by Ropes (1979a).

The modern-day fishery for surf clams began on
beds off Long Island, New York, from East Rockaway
to Fire Island Inlets and from nearshore to about
18.3-m depths. These beds have been fished continuously
at relatively low levels of production to the present
time. Landings are made at Freeport, the principal
New York port.

Industry explorations located beds of surf clams
off the New Jersey coast in 1949 and the fishery
greatly expanded its operations. Interview records
from fishermen and federal survey results begun
in the mid-1960's located the beds at depths nearshore
to about 40 m. Most of the landings until about
1969 were from depths greater than 18.3 m and of
large clams considered an offshore resource. These
beds were very important in establishing the fishery
as a major industry in the Middle Atlantic Bight.
High densities of clams smaller in shell length
than those offshore, and considered an inshore
resource, were found in beds from the surf zone to
about 18.3-m depths off Cape May to Absecon Inlet.
These were heavily harvested in the early and mid-1970's.

Ports at Point Pleasant, Barnegat, Atlantic City,
and Cape May - Wildwood receive landings and many
of the major processing plants operate in the state.

Industry explorations in 1949 also located beds of
surf clams off Delaware and Maryland. Interview records
from fishermen and federal survey results located
beds mostly at depths of 18.4 to 36.6 m. The
earliest landings of surf clams on Delmarva.
Peninsula were at Ocean City, Maryland, which continues
to be a major port. Catches made since 1950 to
about 1970 were from shoal depths of the resource,
but research surveys indicated significant unfished
beds were at deeper depths to the east and off the
southern portion of the Peninsula (Ropes and Merrill,
1976). These beds were a basis for expansion of
the fishery after 1967.

Ports from Chincoteague to Little Creek, Virginia, were
developed for surf clam landings in the late 1960's
to early 1970's. Some vessels from these ports
fished the resource off southern Delmarva Peninsula,
but more from the Cape Charles area began an intensive
exploitation of beds to the east of Virginia and
Currituck Beaches at 13- to 31-m depths. The clams
were from a bountiful settlement identified
in a 1969 survey and, although small in shell size,
resulted in unprecedented amounts landed for a
4-year period (1972-75). Beds further south have
been fished, but production is generally low.

Surf clams were not reported by Cummins (1966)
in catches of a nonhydraulic dredge during shallow-
water (ca. 7-10m) explorations for hard clams off
the southeastern coast of the United States.
In a description of an offshore North Carolina fishery
for the southern quahog, Mercenaria campechiensis,
Porter and Chestnut (1962) reported explorations
with a hydraulic clam dredge conducted by the North
Carolina Department of Conservation and Development
in 1953 and 1958. Samples were taken at about 9
to 27 m depths from Bear Inlet to Oregon Inlet, but the
occurrence of surf clams in the catches was not
mentioned. Their observations on commercial and other
experimental dredging in the area also excluded
catching surf clams. In the mid-1970's, industry

vessels explored for surf clams south of Cape
Hatteras, but returned to their northern ports because
a fishable resource was not found. Porter and Wolfe
(1971) include living S. solidissima in a table of
mollusc species collected from calico scallop
grounds in Onslow Bay off the southern coast of
North Carolina and well south of Cape Hatteras,
but no information was given about station location
or numbers caught. In an atlas of the occurrence
of North Carolina marine and estuarine molluscs,
Porter (1974) mentions holdings of S. solidissima
at the Institute of Marine Science, University of
North Carolina, from N.E. of Cape Hatteras. The
existence of S. solidissima south of Cape Hatteras,
then, may be marginal at best and of little commercial
significance.

5.2.2 Depth Range

Cf. sec. 2.2

5.2.3 Condition of the Grounds

As indicated in the management plan for the surf clam
fishery (FMP 1977) and in a review by Serchuk et al.
(1979) intense fishing has severely reduced stocks
in the offshore New Jersey to Virginia beds. Levels
of abundance of harvestable clams and pre-recruits
were particularly low in 1977 and forecasts for
the immediate future production were poor.

Specific studies on the effects of hydraulic clam
dredges on the condition of the grounds are not
available. However, the washing action of the
hydraulic system may physically, chemically, and
biologically disturb the bottom composition,
detrimentally altering conditions for future
settlement of clam larvae and their subsequent
survival. Clams are found in the catch with
adductor muscles severed, shells broken, and sand
packed into the mantle cavity. Such injuries may
cause mortalities of clams not harvested by the
dredges, adding decaying meats to the bed environment
or attracting predators.

5.3 Fishing Seasons

The generally sedentary, nonmigratory nature of surf clams after settlement to the bottom and establishment of beds allows fishing operations throughout the year. Unlike oysters, no prohibition of fishing during the spawning season has been established.

5.4 Fishing Operations and Results

5.4.1 Effort and Intensity

Fishing operations are mostly on a day-trip basis during daylight hours. At a fishing location, the dredge, hose, and polypropylene tow line are put overboard, the pump for the hydraulic system started, and the dredge lowered to the bottom with the main winch cable. After allowing slack in the cable, the tow line tightens to begin the tow over the bottom for 10 to 30 min, depending upon the catch of clams, shells, and other bottom materials. At the end of a tow the dredge is winched onboard and opened to release the catch (Ropes 1967; Yancey and Welch 1968). On older vessels the catch is dumped on deck for sorting into 1-bu quantities held in sacks; on more modern vessels the dredge lands on a stern-ramp, the catch is dumped into a bin and moved by conveyor belts to cages of 20 to 32-bu amounts stored in the hold. Annual average daily effort varies somewhat from port to port, but ranges from 6 to 10 hr of actual fishing time (Ropes in preparation).

From interviews with vessel captains during 1965-1974, annual average catch-per-hour values at some ports have declined (Ropes in preparation). In 1965, a high of 307 kg of meats was recorded for the Point Pleasant, New Jersey, port, but reached a low of 143 kg in 1972 (Figure 7). At Cape May - Wildwood, New Jersey, a high of 699 kg was recorded for vessels fishing inshore beds in 1965, declining to a low of 308 kg in 1972; on offshore beds highs of 262 kg were recorded in 1967 and 1971 and a low of 193 kg in 1970. A high catch of 409 kg was recorded for Ocean City, Maryland, in 1970 and a low of 147 kg in 1974. Average catch-per-hour values of 910-1,242 kg for
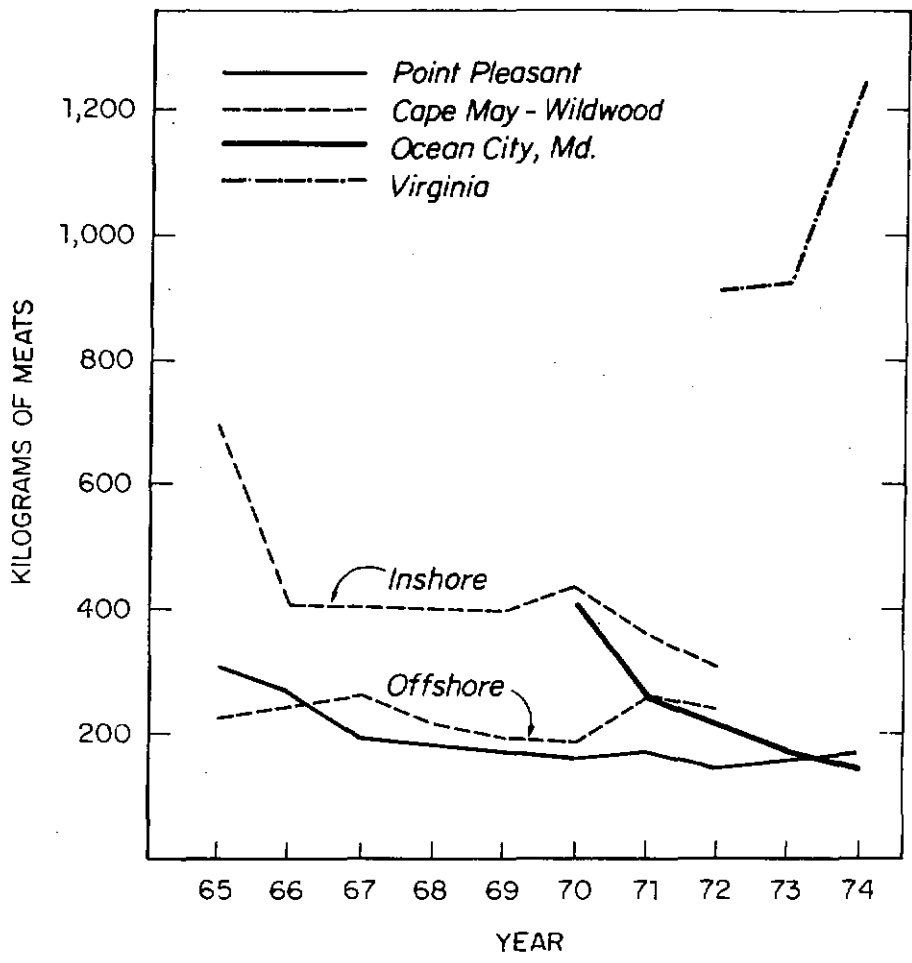
FIGURE 7. The annual mean catch per hour of surf clams,
Spisula solidissima, fishing from Point Pleasant and Cape
May - Wildwood, N.J., Ocean City, Md., and Virginia ports
in 1965-1974.

the Virginia fleet in 1972 to 1974 were the highest
recorded for any fleet. The much higher values for
the Virginia fleet resulted from the entry of larger
more efficient vessels into the fishery (cf section
5.1.1).

5.4.2 Selectivity

Specific studies are unavailable on the efficiency of
clam capture by dredges. Also, see cf. section
4.1.3.3.

5.4.3 Catches

(cf section 4.2.1 and Figures 5 A-D).

6. PROTECTION AND MANAGEMENT

6.1 Regulatory Measures

During the United Nations Conference on the Law of the
Sea, the Convention on the Continental Shelf of April
29, 1958, defined the natural resources of the shelf and
identified coastal states for exploration and exploitation.
The natural resources were living, sedentary organisms
"which, at the harvestable stage, either are immobile on or
under the seabed or are unable to move except in constant
physical contact with the seabed or the subsoil"
(Young, 1961). Public Law 88-308 on May 20, 1964, enacted
prohibitions for foreign fishing on such organisms and on
June 23, 1971, the surf clam, Spisula solidissima, was listed
among other creatures protected by the act (Federal
Register 1971).

On March 10, 1977, the Mid-Atlantic Fishery Management
Council accepted a plan developed by state, federal, and
industry representatives to rebuild the surf clam (Spisula
solidissima) resource and protect the ocean quahog
(Arctica islandica) populations in the United States
Fishery Conservation Zone (FMP 1977). As stated in the plan:

> "Other than the Fishery Conservation and Management
> Act of 1976 (P.L. 94-265), no institutions have
> management authority over surf clams and ocean quahogs
> throughout their ranges.

> "No treaties or international agreements exist
> relative to surf clams or ocean quahogs.

> "The most important federal law relative to the surf clam
> and ocean quahog fisheries is the Fishery Conservation
> and Management Act of 1976. This plan was produced
> pursuant to that statute.

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"The Water Pollution Control Act, as amended, is
important in maintaining the habitat of surf clams
and quahogs.

"Federal law provides for financial assistance for
commercial fisheries. Part 251, Title 50, Code of
Federal Regulations sets forth this program
as operated by the National Marine Fisheries Service.
On July 12, 1977, the National Marine Fisheries
Service issued a final rulemaking establishing
conditional fisheries status for the surf clam
fishery. This means that financial assistance
in that fishery will be limited to that which does
not significantly increase harvesting capacity.

"The States of New York and New Jersey have regulations
which cover clams in general and, therefore, relate
to sea clams in their inshore waters but these
are principally concerned with the prohibition of
taking clams from polluted waters and time and location
limitations on fishing to help enforce these regulations.
In 1975, New Jersey enacted regulations to specifically
control the inshore harvest of surf clams. These
regulations are now in effect and are designed to
control the size and total number of clams harvested
from their waters while protecting the economic
viability of the individual vessels. These regulations
were modified and updated in 1976.

"No local or other applicable laws, regulations, and
policies relating to the surf clam and ocean quahog
fisheries relative to the Fishery Conservation Zone
are known to exist. New Jersey levies a tax on
surf clams landed at ports within that State."

Pursuant to the Fishery Management Plan prepared by the
Middle Atlantic Regional Management Council, specific
restrictions and penalties have been implemented by the
Secretary of Commerce relative to:

1. Annual catch quotas

2. Closed areas

3. A moritorium on vessel entries into the fishery

4. Reports and records of catch

5. Vessel licensing and identification

6. Enforcement

On August 9, 1979, an amendment of the management plan for
surf clams and ocean quahogs was approved by the Mid-Atlantic
Fishery Management Council (FMP No. 2 1979). It updates current
data on the fisheries and extends the plan through calendar year
1981, with provisions for vessel restrictions and catch quotas
from the New England and Mid-Atlantic areas.

6.2 Control or Alteration of Physical Features

Artificial reefs have been constructed or are proposed
on the northwestern United States continental shelf
(Anon. 1972). These are shown on navigational charts
as fish havens and, although primarily installed to
benefit fish, the effect on clams and other benthic
organisms is largely unknown. They do cover potential
bottom for beds of clams and constitute hazards to
fishermen dragging nets or dredges in their vicinity.

Deposits on the continental shelf off the northwestern
United States have been inventoried as a future source
of large quantities of sand and gravel for beach restoration
and stabilization (Schlee 1968; Pearce 1979). These
deposits form the substrata for surf clam beds and removal
may constitute a major detrimental environmental impact.
At this time, little is known of the effects of large-scale
operations to alter physical features of the ocean bottom.

6.3 Control or Alteration of Chemical Features

Cf. section 2.3.

6.4 Control or Alteration of Biological Features

Cf. section 2.3.

6.5 Artificial Stocking

Surf clams have been reared successfully through the larval
stages to setting by several investigators, but usually
for purposes other than providing clams for artificial
stocking (cf. section 3.2). Rhodes and Goldberg (1978)

maintained surf clams after setting under controlled
conditions to observe the effects of substrata and density
on growth. Their techniques have possible application in
artificial stocking projects, but attempts to do this have
not been reported. The fate of releasing small surf clams
in the natural environment, then, is largely unknown.

7. ACKNOWLEDGEMENTS

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