Subtidal Clam Populations: Distribution, Abundance, and Ecology

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osu sea grant

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PART I General Introduction

I. A. History of Oregon's commercial and recreational bay clam fisheries

DANIL R. HANCOCK
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Bay clam species of commercial use in Oregon consist of the gaper or horseneck clam (*Tresus capax*), the cockle (*Clinocardium nuttalli*), the littleneck (*Venerupis staminea*), and to lesser extents, the soft-shell clam (*Mya arenaria*) and the butter clam (*Saxidomus giganteus*). All are marketed for restaurant, fresh food and bait use.

Bay clam production history from 1941 to 1975 is shown in Figure I.A.1.-1. World War II restrictions on night digging effected a decrease in production in 1942, while relaxed restrictions allowed increased production to a maximum 306,000 lbs. (139 metric tons) in 1945. Since that year, there has been a general downward trend, reportedly a result of increased oyster culture and decreased digging effort (Cleaver, 1951; Marriage, 1954). However, the present authors believe that the reduced production following 1945 was more likely a consequence of clam population reduction and poor market conditions. In 1948, because of reduced stocks of gaper clams, the digging of these clams was prohibited to all users from January 1 to June 30 (Cleaver, 1951; Marriage, 1954). This seasonal closure of the clam beds continued until 1960, when the restriction was lifted for personal use diggers only, but with a reduced bag limit (Snow, Wagner and Sims, 1962). Production never again reached the 1945 peak.

Coos, Tillamook and Yaquina Bays constitute the major commercial bay clam production areas in Oregon, contributing approximately 40, 25 and 20% respectively to the state's annual bay clam harvest (Marriage, 1954). Clam harvest in Coos Bay is comprised of nearly all gaper clams, in Tillamook of primarily cockles, and in Yaquina of gapers and cockles. Gaper clam harvests in Oregon have contributed as much as 60% to the total bay clam production (Cleaver, 1951; Marriage, 1954; Smith, 1956). Nonetheless, sporadic spatset and seasonal and bag restrictions have caused respectively

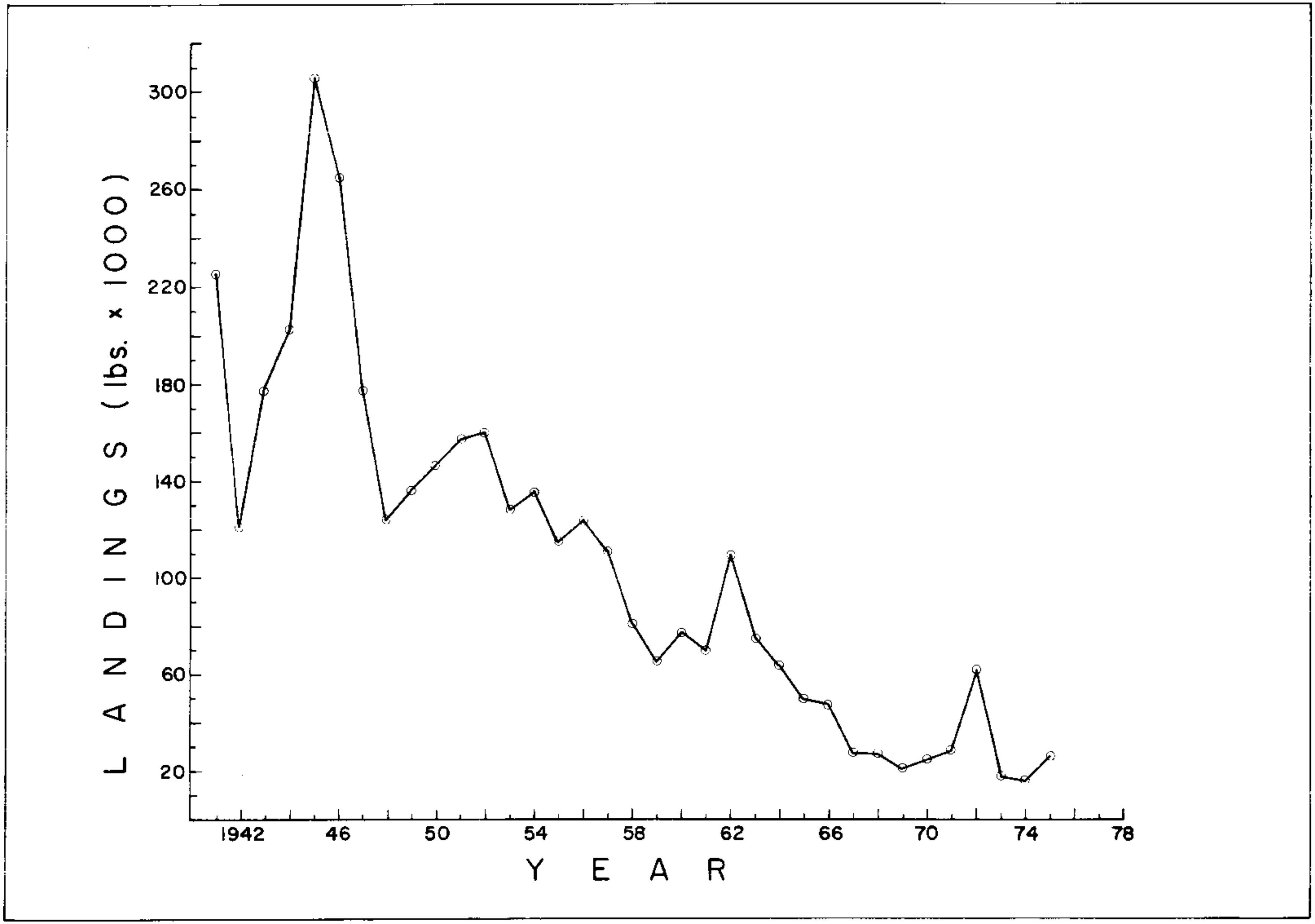

Figure I.A.1.-1. Commercial bay clam landings in Oregon, 1941-1975.

unstable population stocks and harvest production.

Prior to 1961, clam digging was done by hand in the intertidal regions of bays. In 1961 in Coos Bay, two divers used mechanical equipment to collect subtidal gaper clams (Snow, Wagner, Demory, 1964), but no information about the amount of their harvest is available. Permits to mechanically harvest clams from subtidal areas in Coos Bay were issued in 1967-68 and 1969, but market conditions held the harvest to a minimum (Snow, Gaumer, Demory, Neilson, Osis, Phibbs and Gibson, 1970).

The harvest of bay clams for non-commercial or personal use has not been as thoroughly monitored as that for commercial use. Nonetheless, Cleaver (1951) and Marriage (1954) showed that the non-commercial take of bay clams far exceeded commercial production. A series of more recent surveys of Oregon's bays by the ODFW (Gaumer, Demory, Osis, 1973-74; Gaumer, Demory, Osis, and Walters, 1974) showed similar results and generally that recreational clam harvests comprise 90% or more of the total take from tidal flats.

I. B. Scope of research

GAIL (BREED) WILLEKE
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The purpose of this study was to determine the distribution, abundance and species composition of Oregon bay clams, to understand the relationship between subtidal and intertidal clam populations, their biology, and to evaluate the potential effect on intertidal populations of a subtidal commercial clam fishery in Oregon.

A concerted effort was undertaken by the Oregon Department of Fish and Wildlife to determine the location, abundance and density, and species composition of bay clams in ten Oregon bays. The surveys included both subtidal and intertidal populations.

As the distributional surveys neared completion, interest in the results, as well as a worldwide increase in demand for clams, prompted the development of a 181 metric ton pilot harvesting program in Yaquina Bay. This continuing program was initiated in 1976 under a permit system and is being closely monitored by the Oregon Department of Fish and Wildlife (ODFW). Information on harvesting rates, suitable equipment, population resilience under harvest pressure, and environmental impacts is being gathered.

Although four major species of hardshell clams (gaper, littleneck, cockle, and butter) frequently co-occur, the distribution data indicated that the fishery would be dominated by *T. capax*. Prior to forming a subtidal management strategy, studies of the biology of the gaper clam were desirable to understand the impact of the proposed subtidal fishery on the existing intertidal commercial and recreational fisheries and on the estuarine ecosystem as a whole. The role played by the subtidal populations of *T. capax* in the ecology of the intertidal populations of *T. capax* was therefore of fundamental interest in this study. Consequently, studies were undertaken by the Oregon State University School of Oceanography and the Oregon Department of Fish and Wildlife to provide information about growth rates, conditions necessary for spatset, and reproductive cycles of *T. capax* populations from different locations in Yaquina Bay.

Although several other commercially important species of planktonic fish and shrimp are known to enter the bay during the winter, the contribution of the *T. capax* populations to the winter planktonic food supply was an important consideration of this study. Utilization of data obtained during the course of this study, along with information on age specific fecundity and the age of sexual maturity, would allow estimates of the amount of this contribution to be calculated using a method recently described by Barnes and Barnes (1977).

While few studies are ever complete, we have attempted to identify those areas of *Tresus* biology which would increase our abilities to make sound decisions relating to the management of subtidal clam fisheries.

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PART II Studies of the Distribution of Clams in Oregon's Estuaries and their Commercial Potential

II. A. Studies of the distribution of clams and other biological and physical features

THOMAS F. GAUMER
GREGORY P. ROBART

II.A.1. SAMPLING PROCEDURES

Intertidal and subtidal surveys were conducted on 10 of Oregon's principal clam-producing estuaries (Figure II.A.1.-1), using techniques developed by the Oregon Department of Fish and Wildlife (Osis and Gaumer, 1973). Surveys were generally conducted between April and October.

Intertidal Sampling Techniques

Oregon's estuaries contain two basic types of tideflats: (1) broad expanses of intertidal areas containing several hundred acres each, and (2) narrow shore-bordering strips sometimes several miles long. Some estuaries have a combination of these two types of tideflats while others might have one or the other. The type of tideflat governed the procedure used to lay out the transects. On broad tideflats, permanent landmarks such as navigational markers or a compass course were used to orient the transect lines. This type of survey design generally took a spoke-wheel appearance using an established marker as the focal point. The shoreward ends of the transects were 274.3 m apart. Samples were taken every 91.4 m along the transect lines. An all-terrain vehicle (ATV) was used in laying out transects and sampling stations. Distances were measured by using an odometer wheel.

Where no convenient landmarks were found, a base line was established along one shore of the estuary. From this base line transects were laid out perpendicular to the shore baseline. Transect lines and survey stations along transect lines were each set 91.4 m apart.

At each sampling station, the presence and abundance of clams and shrimp, substrate type and vegetation were recorded. The following methods were used to document presence and abundance of clams at a given sample station: (1) the general area of the station was visually surveyed and a sample plot containing $9.3/m^2$ was marked out. Clam

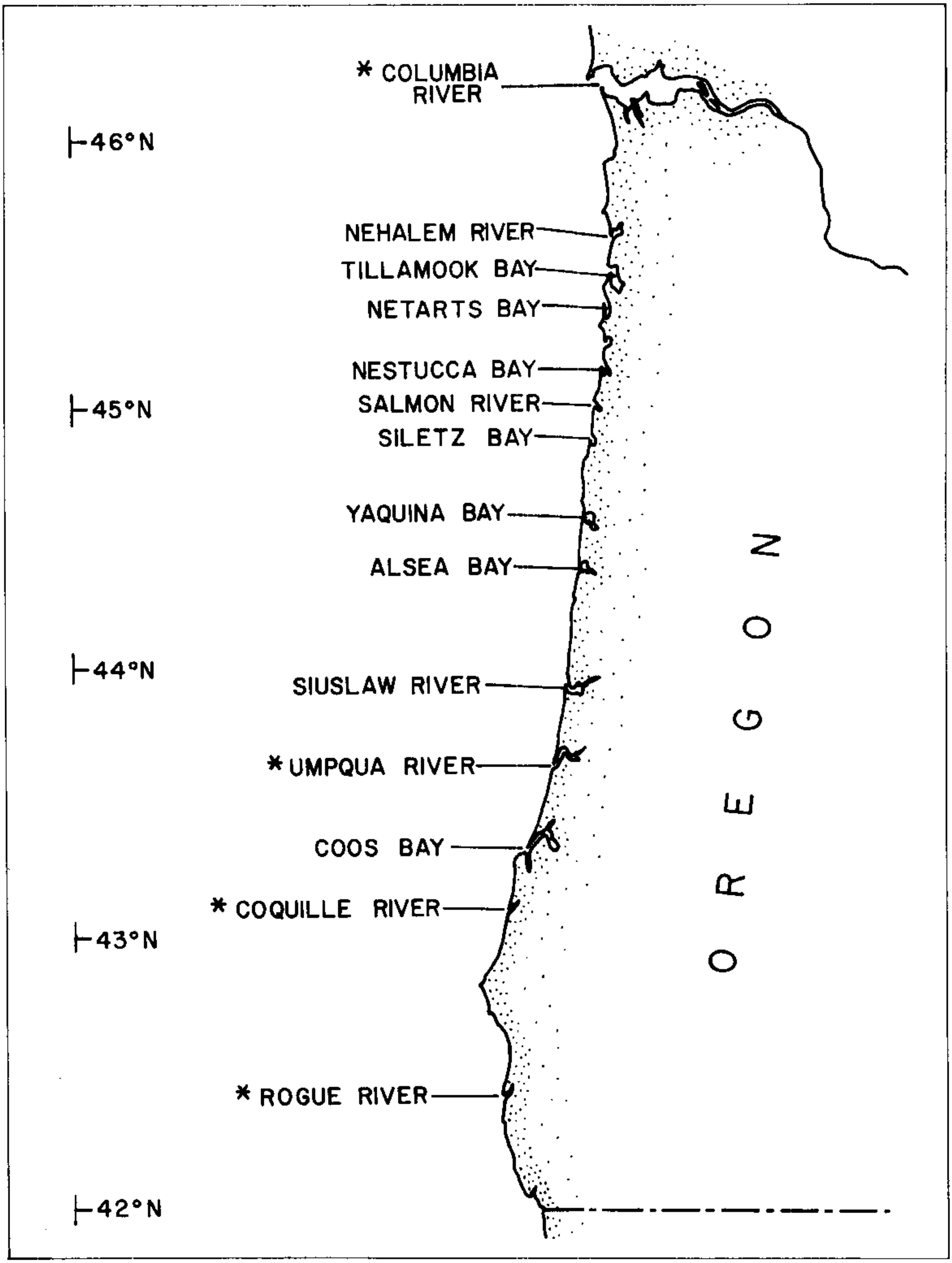

Figure II.A.1.-1. A map of coastal Oregon showing estuaries surveyed by the Oregon Department of Fish and Wildlife (*not included in this study).

and shrimp species could be identified by the shape of siphon or burrow hole; these were classified and counted. The main shortcomings of this procedure were that only adult clams were detected and eelgrass obscured some siphon holes. (2) Once the holes were identified, the sample plot was raked for surface-dwelling clams (primarily cockles). (3) Finally a 0.09 m^2 section of substrate from within the sample plot was removed by shovel. Each sample was about 36 cm deep. All removed clams were identified and counted.

Subtidal Sampling Techniques

Surveys started at the lower reaches of each estuary and extended up-bay until all major clam beds had been surveyed.

Using a well-defined geographical landmark as a starting point, 610 m sections of the bay were plotted on a map for survey. Within these sections, transects were established parallel to shore, generally at 45.7 m intervals. The transect line was a 610 m polypropylene rope weighted at 3 m intervals with 142 gm gill-net lead weights and with sampling station markers every 30.5 m.

At each sampling station two SCUBA divers recorded information on water depth, maximum number of clams per square foot, vegetation and substrate.

Clams were located visually and by pounding, raking or digging. The tips of gaper and piddock clam siphons were usually easily seen. On heavy shell bottom, pounding the surface generally exposed the presence of gaper clams. Cockle and littleneck clams were usually found on top of the substrate or by raking the surface. Digging located littleneck and butter clams. Vegetation and shrimp concentrations were subjectively enumerated. For this report, shrimp and vegetation distributions were classified as sparse or dense.

II.A.2. RESULTS

Surveys on the distribution and abundance of clams, shrimps and vegetation were completed in Tillamook, Netarts, Nestucca, Salmon, Siletz, Yaquina and Alsea bays (Table II.A.2.-2). Surveys were conducted but not completed in Nehalem, Siuslaw and Coos bays.

During our surveys we examined more than 518,160 m of transect line and collected biological and physical data from 9,216 sample stations. A total of 17 species of bivalves, two species of shrimps and four genera of vegetation were recorded during the surveys (Table II.A.2.-1).

Nehalem Bay

Only subtidal surveys were completed in Nehalem Bay. A total of 4,877 m of transect line was surveyed and 160 observations made. Substrate material was generally sand, and sand mixed with shell (Figure II.A.2.-1). Several areas at the mouth of the bay contained massive outcroppings of rock; extensive areas of unstable sand bordered the west side of the main lower bay channel.

The principal clam species observed in the bay were gaper and littleneck. The distributions of gaper, littleneck, cockle and butter clams are shown in Figures II.A.2.-2 to II.A.2.-3. No shrimps were observed in the subtidal survey.

Eelgrass (*Zostera marina*) was the principal species of vegetation observed in the bay (Figure II.A.2.-4). Several unidentified species of green, brown and red algae were noted in the channel near the mouth (Figures II.A.2.-5 to II.A.2.-7).

Tillamook Bay

Intertidal and subtidal surveys for Tillamook Bay were completed in 1977. A total of 118,140 m of transect line were surveyed and 2,096 observations recorded.

Much of the substrate in the Garibaldi area of Tillamook Bay consisted of gravel and rock with some shell and sand. This area supports some of the heaviest concentrations of intertidal and subtidal bay clams in Oregon's estuaries. The mid- and up-bay portions of the estuary were primarily of mud or combinations of mud and sand (Figure II.A.2.-8).

Eleven species of clams were observed. Of the recreationally or commercially important clams, gapers and cockles were the principal species observed in the lower bay while the softshell was the most prevalent clam species in the upper bay. The distributions of gaper, butter, cockle, native littleneck, irus, softshell, Baltic, bentnose, California softshell and piddock clams were charted (Figures IIA.2.-9 to II.A.2.-17). Ghost and mud shrimps also inhabited much of the tideflats (Figure II.A.2.-18).

Eelgrass and species of green and brown algae covered extensive areas of the tideflats and channels of Tillamook Bay (Figures II.A.2.-19 to II.A.2.-22). A number of the major clam-producing areas occurred in the

Species Name	Common Name	Other Local Names
Bivalves:		
Adula falcata	pea pod borer	
Clinocardium nuttallii	cockle clam	basket cockle, cockerel
Cryptomya californica	California softshell	false softshell
Macoma balthica	Baltic clam	
M. irus	irus clam	
M. nasuta	bentnose clam	
M. secta	sand clam	
Mya arenaria	softshell clam	mud clam, bay clam
Ostrea lurida	native oyster	
Petricola sp.		
Saxidomus giganteus	butter clam	beefsteak, Coney Island, giant Oregon clam, quahog, Washington clam
Solen sicarius	jackknife clam	
Tellina bodegensis	Bodega tellin clam	
Tresus capax	gaper clam	horseneck clam, horse clam, blue clam, blue-neck clam, Empire clam
Venerupis philippinarium	Manila littleneck clam	steamer, butter clam
V. staminea	native littleneck clam	steamer, butter clam
Zirfaea pilsbryi	piddock clam	rock oyster
Shrimps:		
Callianassa californiensis	ghost shrimp	sand shrimp
Upogebia pugettensis	mud shrimp	
Vegetation:		
Enteromorpha sp.	green algae	
Fucus sp.	rockweed	
Ulva sp.	sea lettuce	
Zostera marina	eelgrass	

Table II.A.2.-1. Taxonomic list of species observed.

	Nehalem	Tillamook	Netarts	Nestucca	Salmon	Siletz	Yaquina	Alsea	Siuslaw	Coos
Complete		x	x	x	x	x	x	x		
Incomplete	x								x	x
Total Observations	160	2096	1336	330	151	372	2906	827	461	579
Butter clam	1	17	35	0	0	0	4	0	0	30
Cockle clam	1	476	449	0	0	0	442	12	0	171
Gaper clam	24	486	165	0	0	0	739	49	14	229
N. littleneck	17	98	61	0	0	0	38	5	3	78
M. littleneck	0	0	18	0	0	0	0	0	0	0
Softshell clam	0	619	55	125	27	197	256	238	107	3
Irus clam	0	146	4	8	0	0	42	13	62	90
Baltic clam	0	425	33	130	42	155	4	102	101	0
Bentnose clam	0	139	52	0	0	4	96	58	0	40
Bodega tellin	0	0	4	0	0	0	27	0	0	4
Jackknife clam	0	0	0	0	0	0	0	0	0	1
Piddock clam	0	5	30	0	0	0	64	2	5	15
Sand clam	0	1	0	0	0	0	0	0	0	0
Calif. softshell	0	132	25	27	1	0	1	0	1	3
Pea pod borer	0	0	0	0	0	0	3	0	0	0
N. oyster	0	18	0	0	0	0	18	0	0	0
Shrimps	0	771	512	129	33	284	480	399	109	0
Mud	32	742	476	113	69	201	1489	349	113	55
Sand	160	2034	1308	288	126	366	2369	787	318	746
Gravel	60	411	90	48	18	21	299	56	24	33
Shell	61	608	209	3	0	2	765	161	37	294
Rock	55	191	102	39	6	19	187	30	8	20
Bedrock	3	78	9	3	2	2	68	12	11	34
Enteromorpha	0	63	96	32	41	15	38	135	74	0
Fucus	0	83	5	30	3	6	209	3	3	0
Ulva	13	308	109	76	31	31	6	23	41	45
Eelgrass	16	580	461	87	32	129	464	308	99	54
Green algae	0	7	15	0	0	0	0	0	1	1
Brown algae	40	98	136	1	0	0	107	19	4	115
Red algae	6	19	14	0	0	0	0	0	0	1

Table II.A.2.-2. Number of transect points where observed sediment type and bivalve and vegetation species occurred.

eelgrass beds. This was especially evident on the Bay Ocean sand spit and on the tideflats adjacent to the mouth of Kilchis River.

Netarts Bay

Subtidal surveys of Netarts Bay were completed in 1975; intertidal surveys were finished in 1977. The surveys included 1336 observations along 79,120 m of transect line. Many of the tideflats surveyed consisted of a combination of sand and mud. The down-bay channel areas were primarily rock, gravel and sand; the up-bay channels were covered with sand and shell sediments (Figure II.A.2.-23). Sand and sand mixed with mud covered most of the tideflats.

Gaper, butter, cockle, native littleneck, Manila littleneck, softshell, irus, Baltic, bentnose, Bodega tellin, California softshell, and piddock clams were widely scattered over much of the bay (Figures II.A.2.-24 to II.A.2.-34). Mud and ghost shrimps were also widely distributed over the tideflats (Figure II.A.2.-35).

Vegetation, predominantly eelgrass, covered extensive areas of the channels and tideflat (Figures II.A.2.-36 to II.A.2.-40). Few clams were observed in the vegetation due to the deneseness of the plants and the difficulty of locating clams in this type of environment.

Nestucca Bay

Subtidal and intertidal surveys of Nestucca Bay were completed in 1977. We made 330 observations along 44,022 m of transect line. The tideflats consisted primarily of sand and sand mixed with mud (Figure II.A.2.-41). Subtidally, massive boulders and rock outcroppings were predominant at the mouth of the bay, grading into a substrate of gravel and sand up-bay. The western side of the channel was primarily composed of soft shifting sand.

Figures II.A.2.-42 to II.A.2.-43 indicate the distribution of softshell, Baltic and irus clams in the bay. The softshell clam was the principal species observed. No clams were observed in the subtidal survey although there appeared to be suitable habitat in the channel near the mouth of the bay. Mud and ghost shrimps were also widely scattered over the tideflats (Figure II.A.2.-44).

Eelgrass was the most common vegetation observed and occurred over much of the tideflat of the Little Nestucca Estuary (Figures II.A.2.-45 to II.A.2.-47). Patches of eelgrass and sea lettuce occurred in the subtidal channels.

Salmon River Estuary

Intertidal surveys of the Salmon River estuary were completed in 1976. One hundred fifty-one observations were made along 10,187 m of transect. Most of the substrate consisted of mud, sand, or mud mixed with sand (Figure II.A.2.-48). Rock and gravel covered much of the northern tideflat near the mouth of the bay.

Sparse populations of softshell and Baltic clams were observed throughout the survey area (Figures II.A.2.-49 and II.A.2.-50). Mud and ghost shrimps were widely distributed over much of the interidal areas of the bay (Figure II.A.2.-51).

Sparse vegetation was scattered throughout most of the survey area (Figures II.A.2.-52 and II.A.2.-53). Eelgrass was especially prevalent along the north shore of the bay.

Siletz Bay

Intertidal and subtidal surveys were completed for the Siletz Estuary. A total of 572 observations were made along 38,717 m of transect. Tideflats of the upper bay consisted mainly of soft mud and mud mixed with sand. The lower bay tideflats consisted primarily of sand (Figure II.A.2.-54). Rock, gravel and sand were prevalent in the channel. This material appeared to be suitable clam habitat but strong currents might preclude clam larvae from settling on or surviving in this area.

The softshell clam was the main species observed (Figure II.A.2.-55). Baltic clams also inhabited the intertidal tideflats (Figure II.A.2.-56). No clams were observed in the subtidal survey. Ghost and mud shrimps were extremely dense throughout much of the intertidal area (Figure II.A.2.-57).

The up-bay tideflats were uniformly covered with eelgrass (Figure II.A.2.-58). Green and brown algae occurred in lesser densities in the mid-and down-bay portions of the estuary (Figures II.A.2.-59 to II.A.2.-61).

Yaquina Bay

Distribution surveys for Yaquina Bay were completed in 1975. During these surveys we made 2,906 observations along 117,561 m of transect line.

Sand mixed with gravel and shell was predominant in the lower bay channel (Figure II.A.2.-62). This material gradually changed to a pure sand or sand mixed with mud up-bay. The tideflats were of a sand, mud or mud-sand composition.

Ten species of bivalves were identified in the bay (Figures II.A.2.-63 to II.A.2.-71); cockle, gaper and softshell clams being prevalent. The intertidal areas generally contained clams in densities of less than $10.8/m^2$. Subtidally, clams were considerably more dense with extensive areas containing clams in excess of $54.0/m^2$. Several areas had concentrations of more than $108.0/m^2$.

Ghost and mud shrimps were observed on all the tideflats surveyed from below the 101 highway bridge up-river to just below the town of Toledo (Figure II.A.2.-72).

Eelgrass was scattered over most of the tideflats from the mouth of the bay up to near Toledo (Figure II.A.2.-73). Densities were greatest on the down-bay tideflats. *Enteromorpha* sp. and brown algae including *Fucus* sp. were widely scattered over most of the tideflats (Figures II.A.2.-74 to II.A.2.-75).

Alsea Bay

Intertidal and subtidal distribution surveys were completed on Alsea Bay in 1975. Surveys were made along 36,332 m of transect line and included 827 observations. Much of the substrate of the lower bay consisted of unstable, shifting sand (Figure II.A.2.-76). Sand with scattered shell was common in the mid-bay subtidal area while mud and sand were predominant in the up-bay intertidal area.

Figures II.A.2.-77 to II.A.2.-79 show the distribution of gaper, cockle and littleneck clams. The softshell and California softshell clams were the principal species found and are combined in Figure II.A.2.-80. In the intertidal areas densities of small clams (less than 25.4 mm long) were greater than $108.0/m^2$ in many of the samples; densities were generally less than $21.6/m^2$ for larger clams. Mud and ghost shrimps were widely scattered over most of the tideflats (Figure II.A.2.-81). Most sample stations contained dense shrimp populations.

Eelgrass was the principal species of vegetation observed in the channels and tideflats (Figure II.A.2.-82). Green and brown algae were widely scattered throughout the bay (Figures II.A.2.-83 and II.A.2.-84).

Siuslaw Bay

Subtidal and intertidal surveys of Siuslaw Bay are incomplete. To date, we have made 461 observations along 30,126 m of transect line.

Much of the substrate material of the lower bay channel consisted of sand with patches of rock, gravel and shell. The up-bay tideflats were primarily of combinations of sand and mud (Figure II.A.2.-85).

Small populations of gaper, native littleneck and piddock clams inhabited the lower bay channel; softshell, Baltic and irus clams were recorded for the up-bay tideflats (Figures II.A.2.-86 to II.A.2.-90). Mud and ghost shrimps were observed at most of the intertidal sampling stations (Figure II.A.2.-91).

Vegetation covered much of the up-bay tideflats (Figures II.A.2.-92 to II.A.2.-93). Eelgrass was the principal species observed.

Lower Coos Bay and South Slough

To date, only the subtidal clam beds of South Slough have been completely surveyed. Intertidal and subtidal surveys on the remainder of the bay are only partially completed. Sand and a combination of sand mixed with shell comprised much of the substrate material throughout the channel areas (Figure II.A.2.-94). A rock shelf covered much of the bottom across and immediately down-bay from the Charleston boat basin.

During the surveys we made 579 observations along 17,648 m of transect line. Figures II.A.2.-95 to II.A.2.-99 show the subtidal distributions of gaper, butter, cockle, littleneck and piddock clams. The concentrations of cockle and gaper clams throughout the Charleston ship channel were of particular interest, since we had previously thought that clams had been removed by maintenance dredging. No mud or ghost shrimps were observed in the surveyed subtidal areas.

Vegetation in the South Slough channel consisted of eelgrass, and green, brown and red algae (Figures II.A.2.-100 to II.A.2.-102). Sparse vegetation was recorded in the channel across and down-bay from Empire.

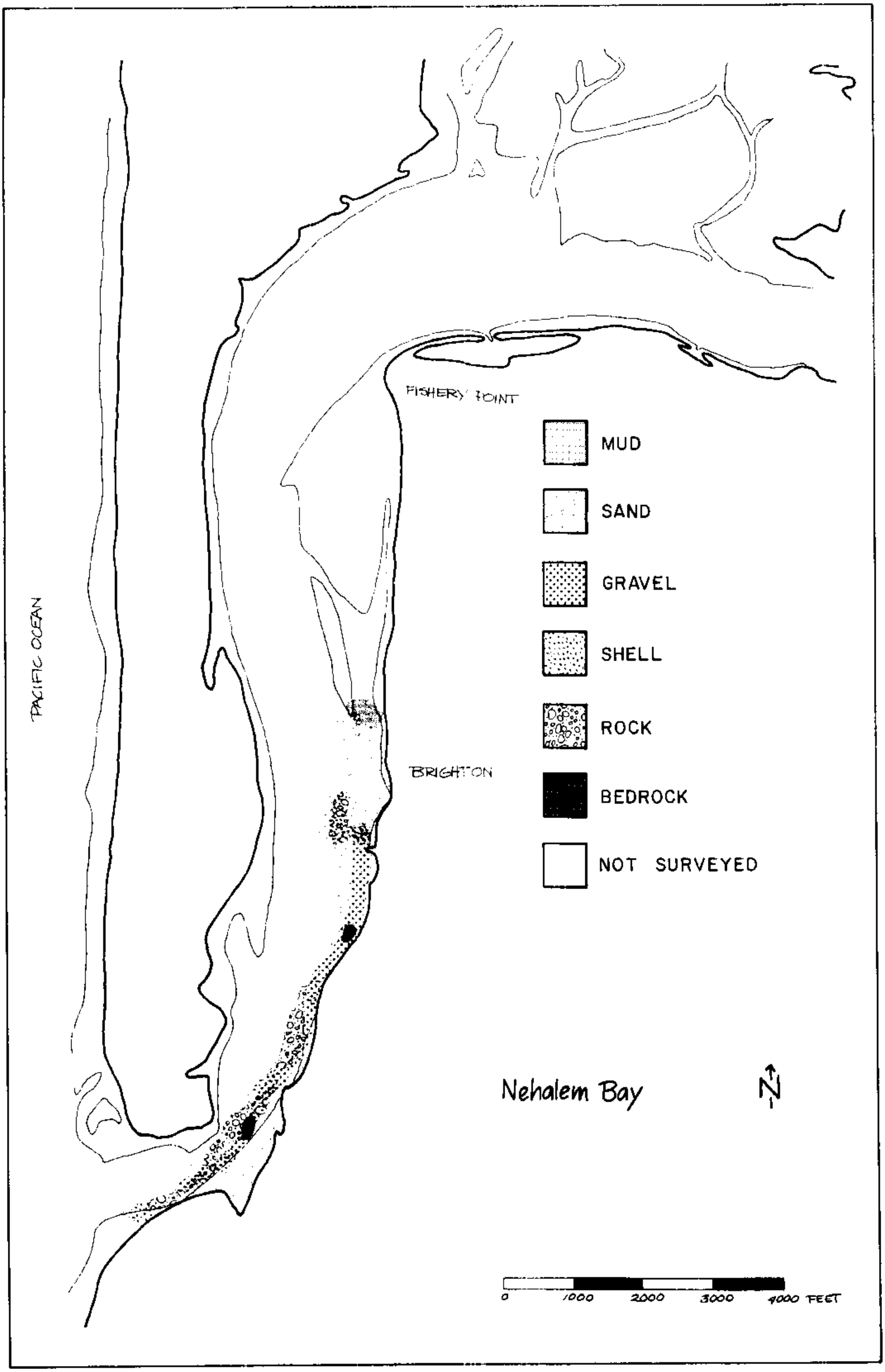

Figure II.A.2.-1. Distribution of substrate materials in Nehalem Bay Oregon.

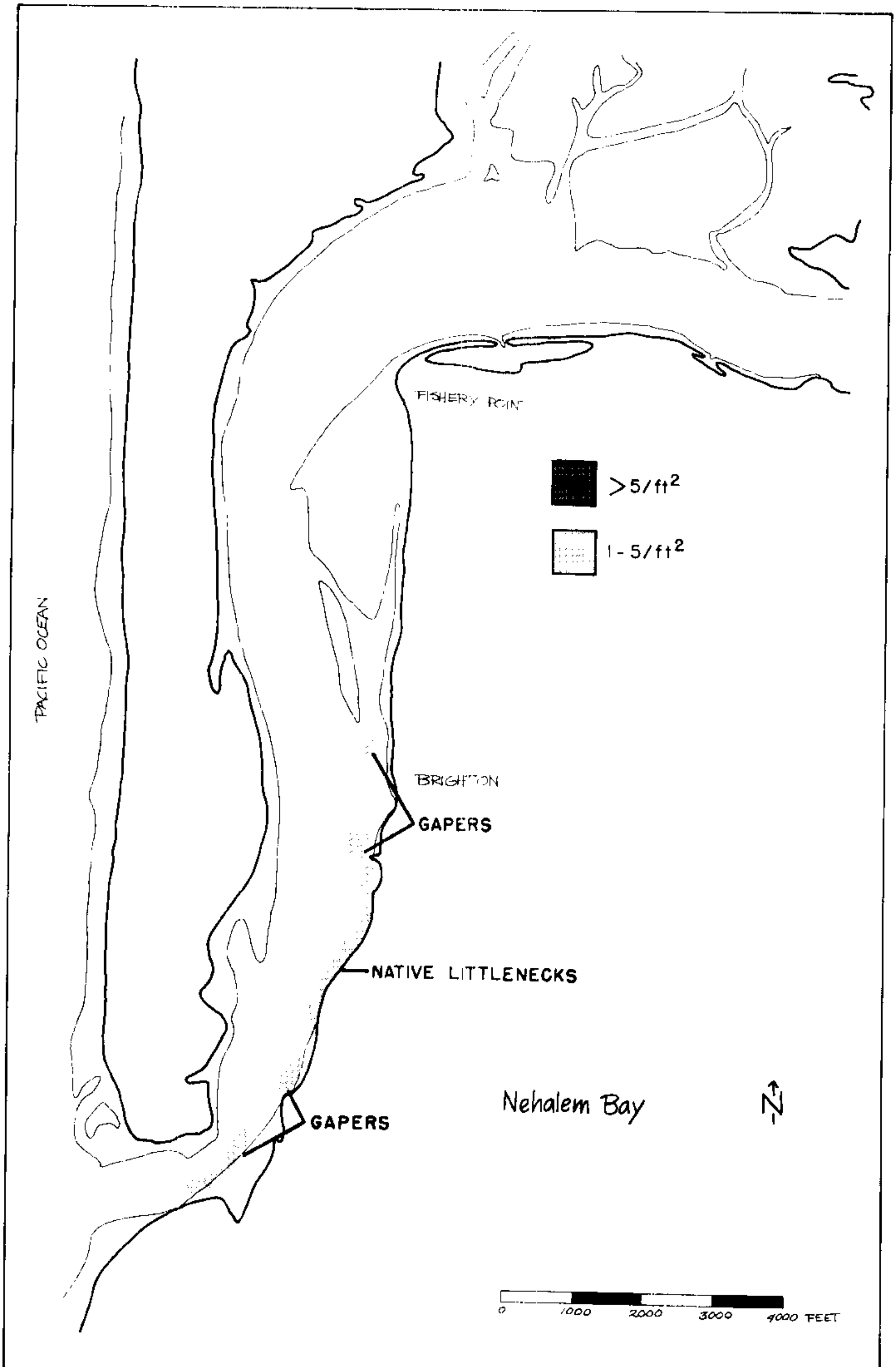

Figure II.A.2.-2. Distribution of gaper clams (*Tresus capax*) in Nehalem Bay, Oregon.

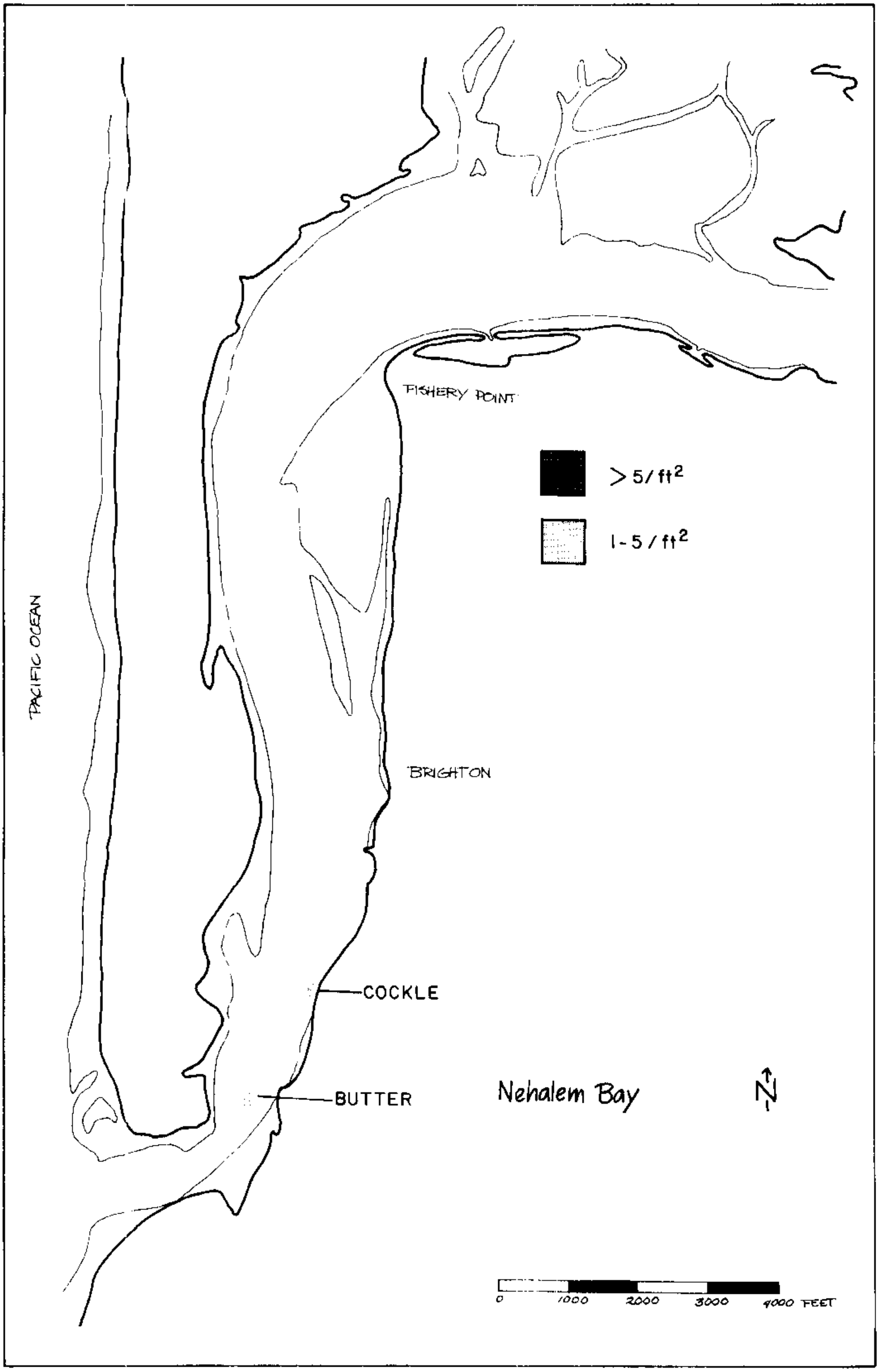

Figure II.A.2.-3. Distribution of cockle clams (*Clinocardium nuttallii*) and butter clams (*Saxidomus giganteus*) in Nehalem Bay, Oregon. (See Fig. II.A.2.-1. for areas not surveyed.)

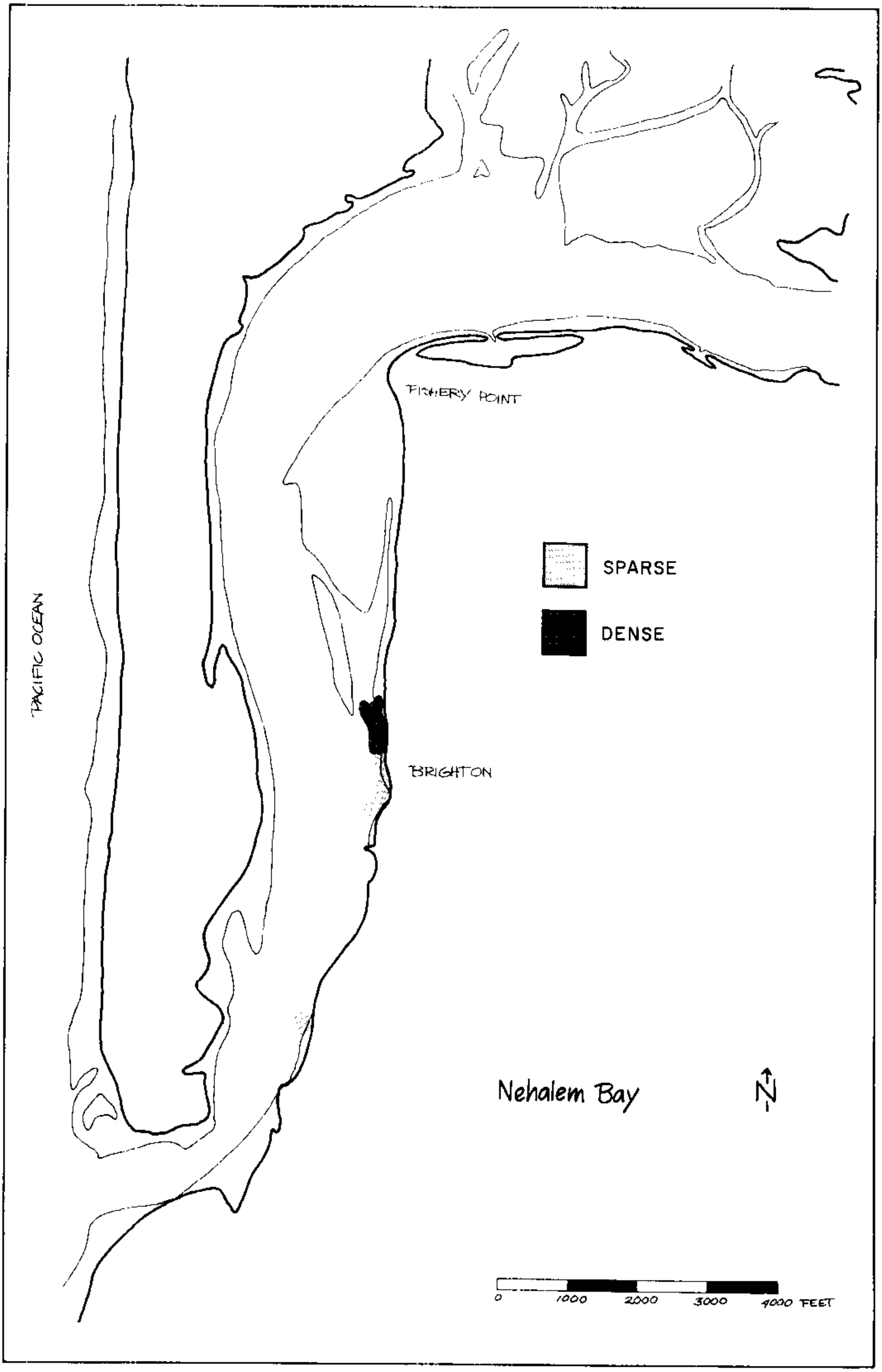

Figure II.A.2.-4. Distribution of eelgrass (*Zostera marina*) in Nehalem Bay, Oregon. (See Fig. II.A.2.-1 for areas not surveyed.)

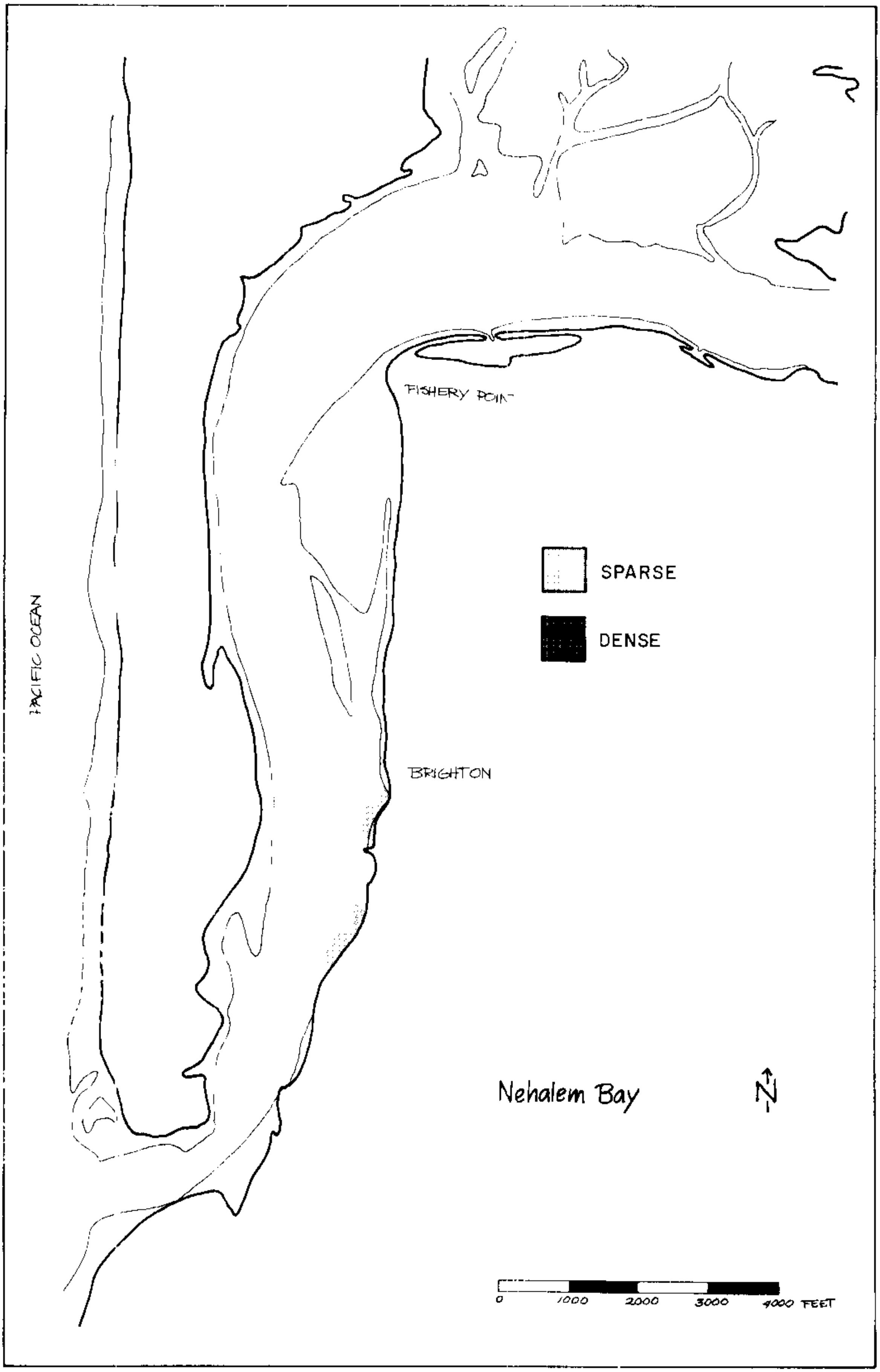

Figure II.A.2.-5. Distribution of sea lettuce (*Ulva* sp.) in Nehalem Bay, Oregon. (See Fig. II.A.2.-1 for areas not surveyed.)

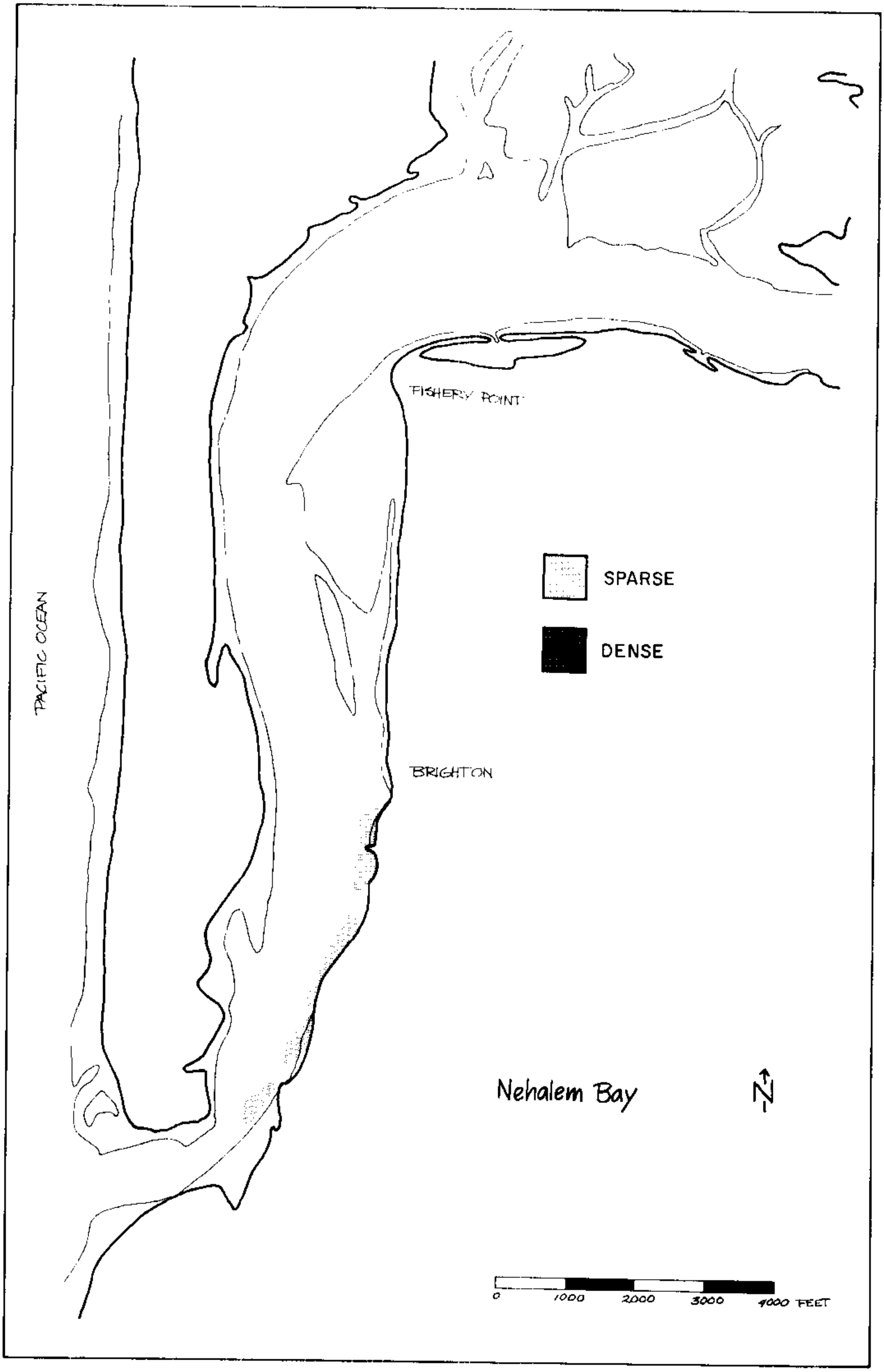

Figure II.A.2.-6. Distribution of unidentified brown algae in Nehalem Bay, Oregon. (See Fig. II.A.2.-1 for areas not surveyed.)

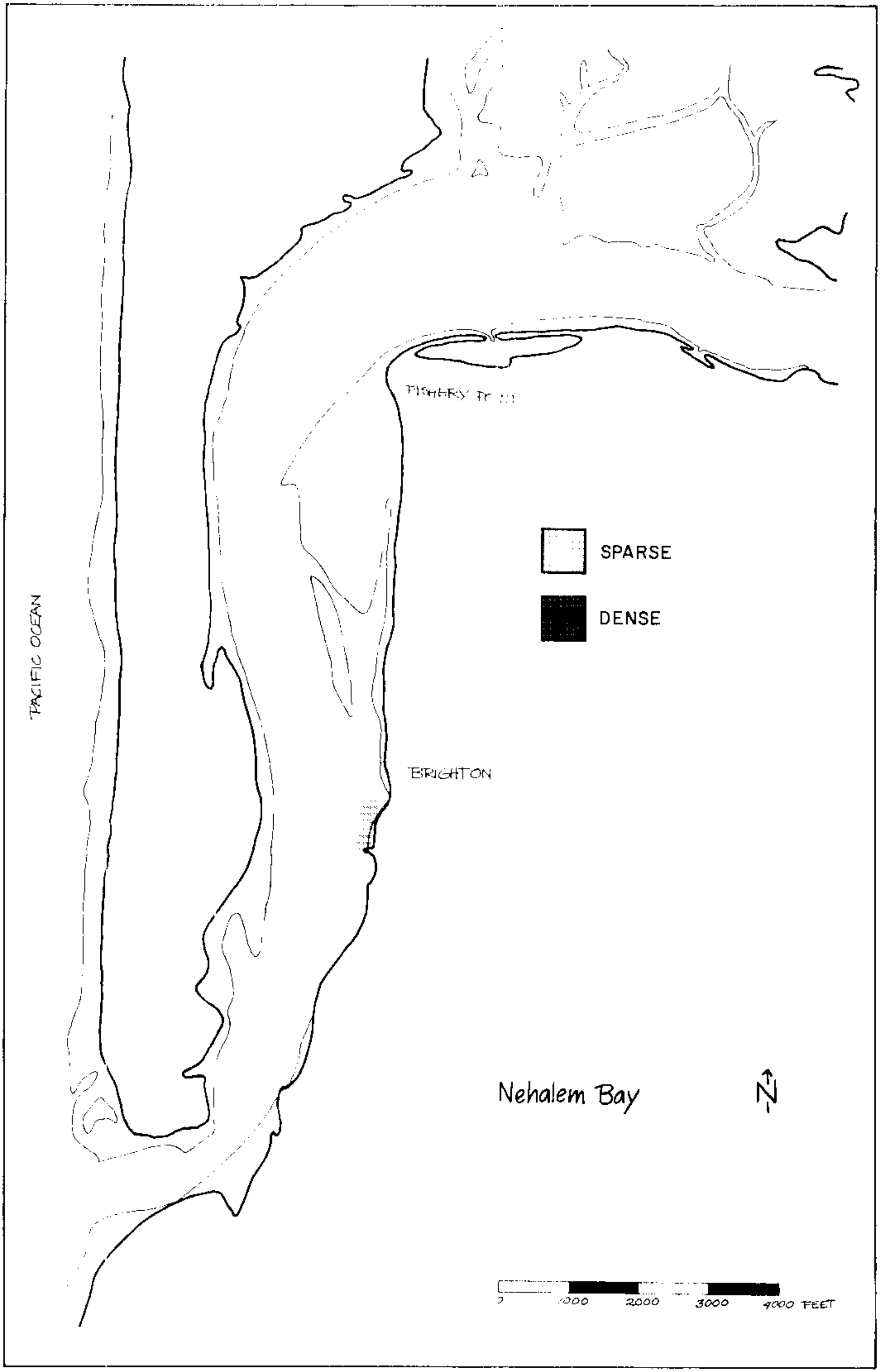

Figure II.A.2.-7. Distribution of unidentified red algae in Nehalem Bay, Oregon. (See Fig. II.A.2.-1 for areas not surveyed.)

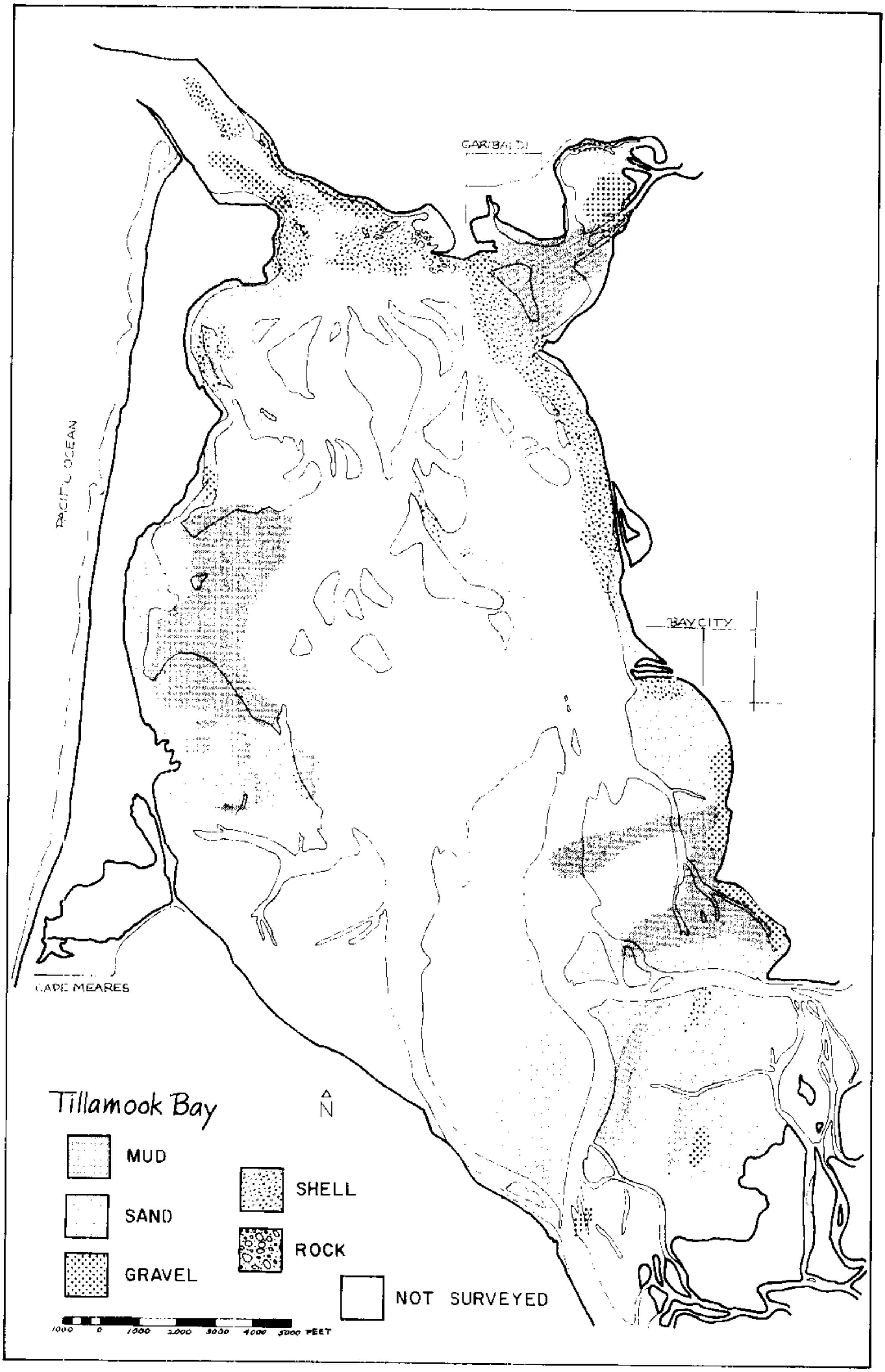

Figure II.A.2.-8. Distribution of substrate materials in Tillamook Bay, Oregon.

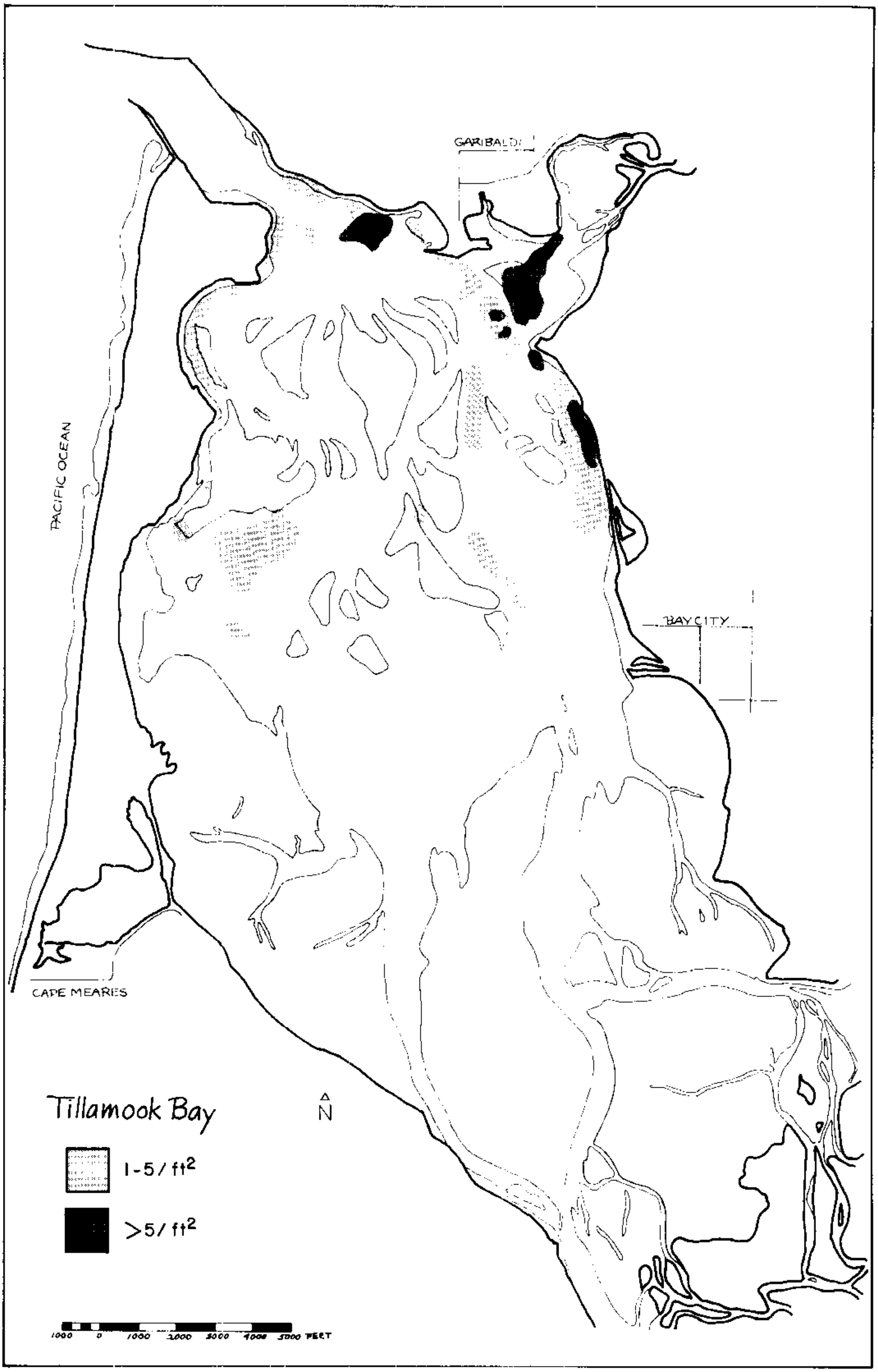

Figure II.A.2.-9. Distribution of gaper clams (*Tresus capax*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

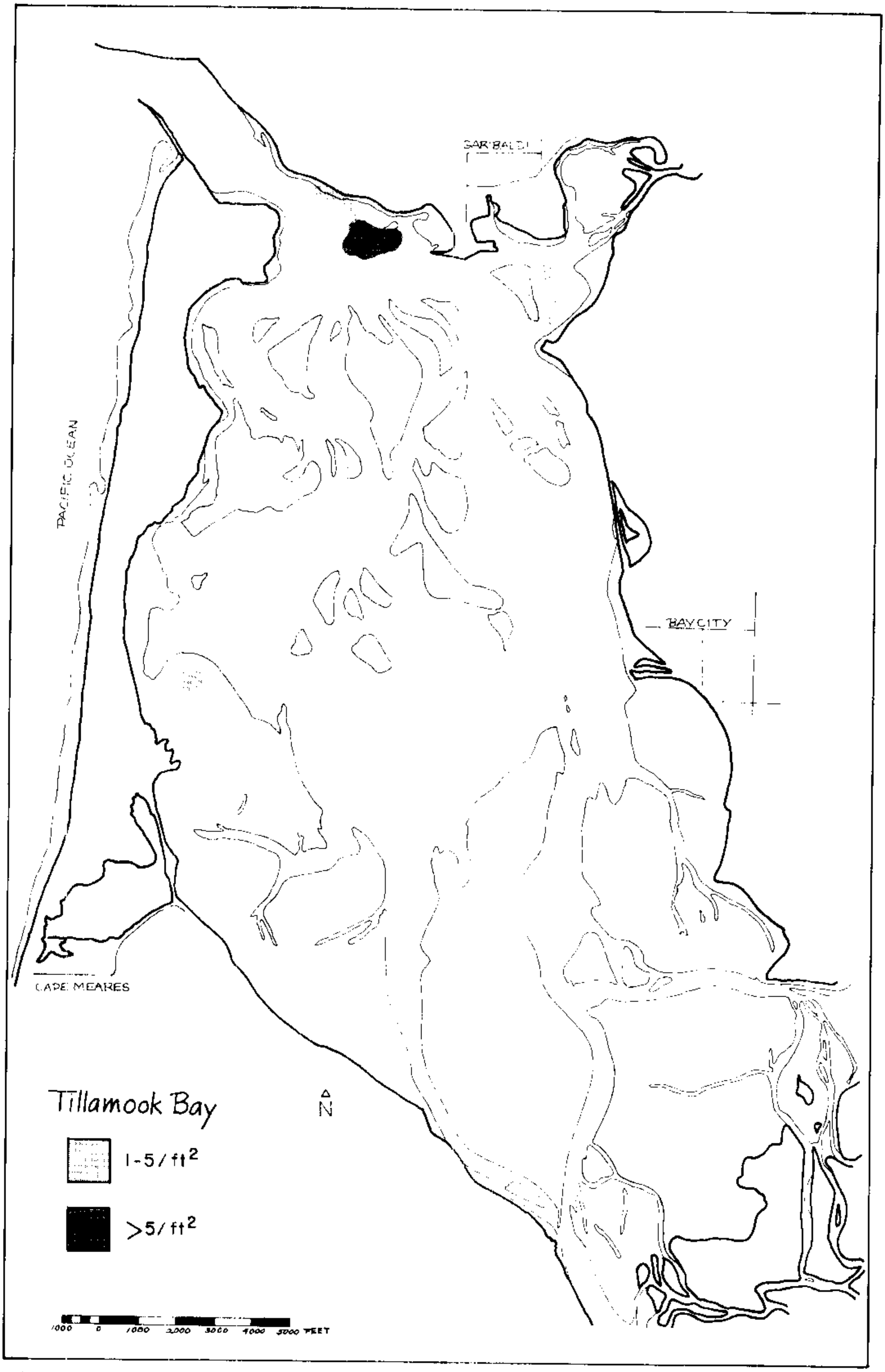

Figure II.A.2.-10. Distribution of butter clams (*Saxidomus giganteus*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

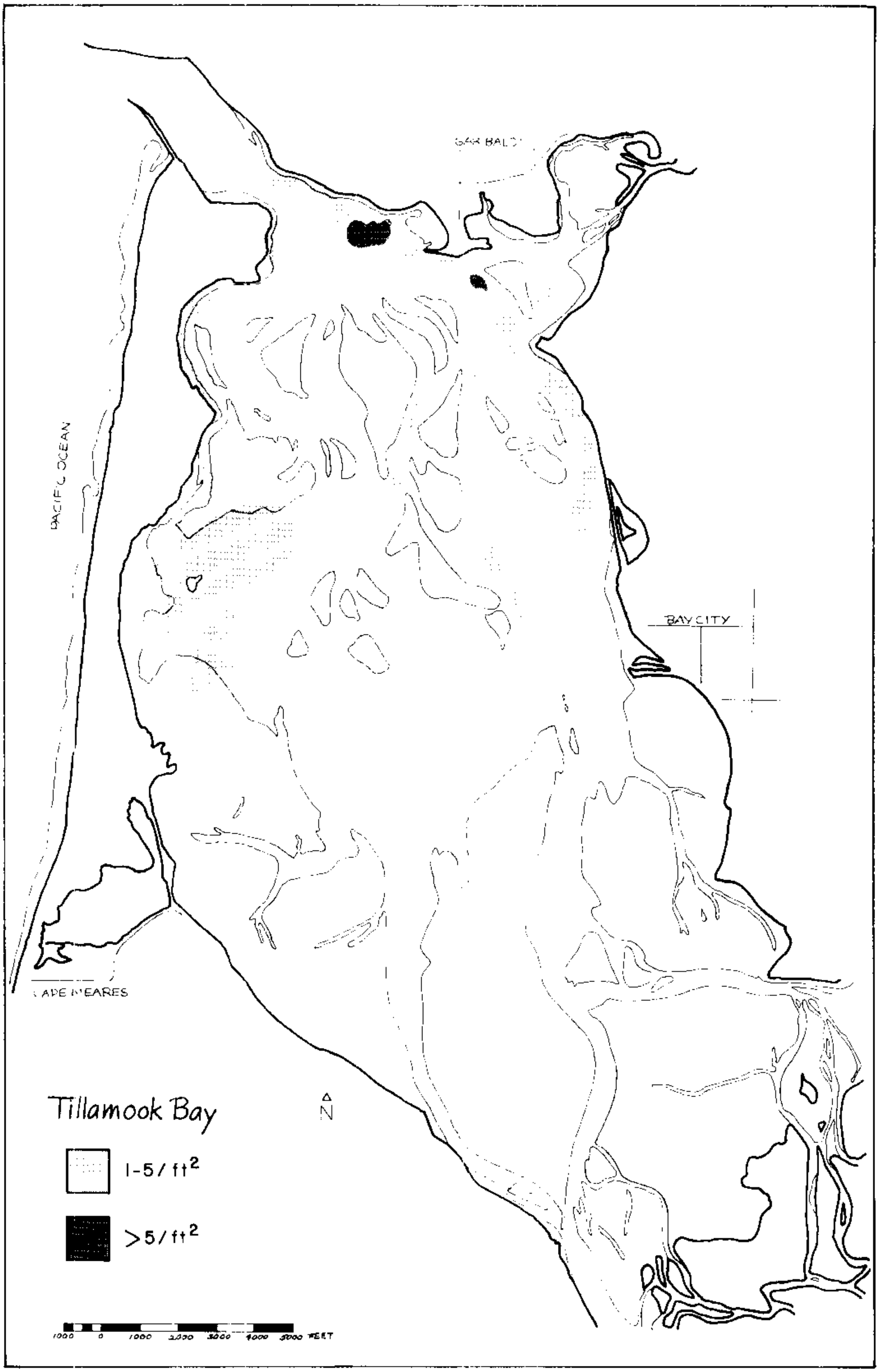

Figure II.A.2.-11. Distribution of cockle clams (*Clinocardium nuttallii*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

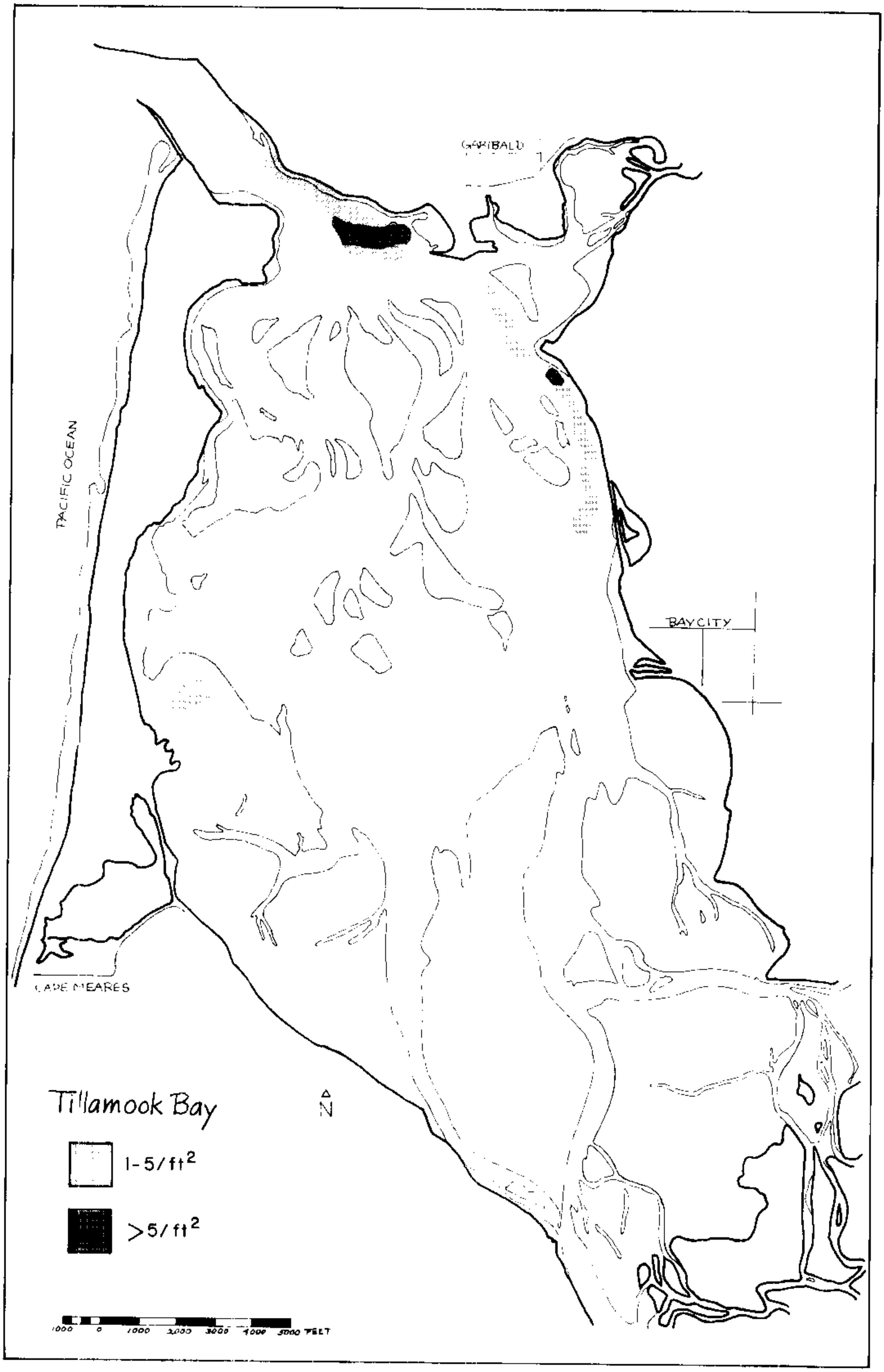

Figure II.A.2.-12. Distribution of native littleneck clams (*Venerupis staminea*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

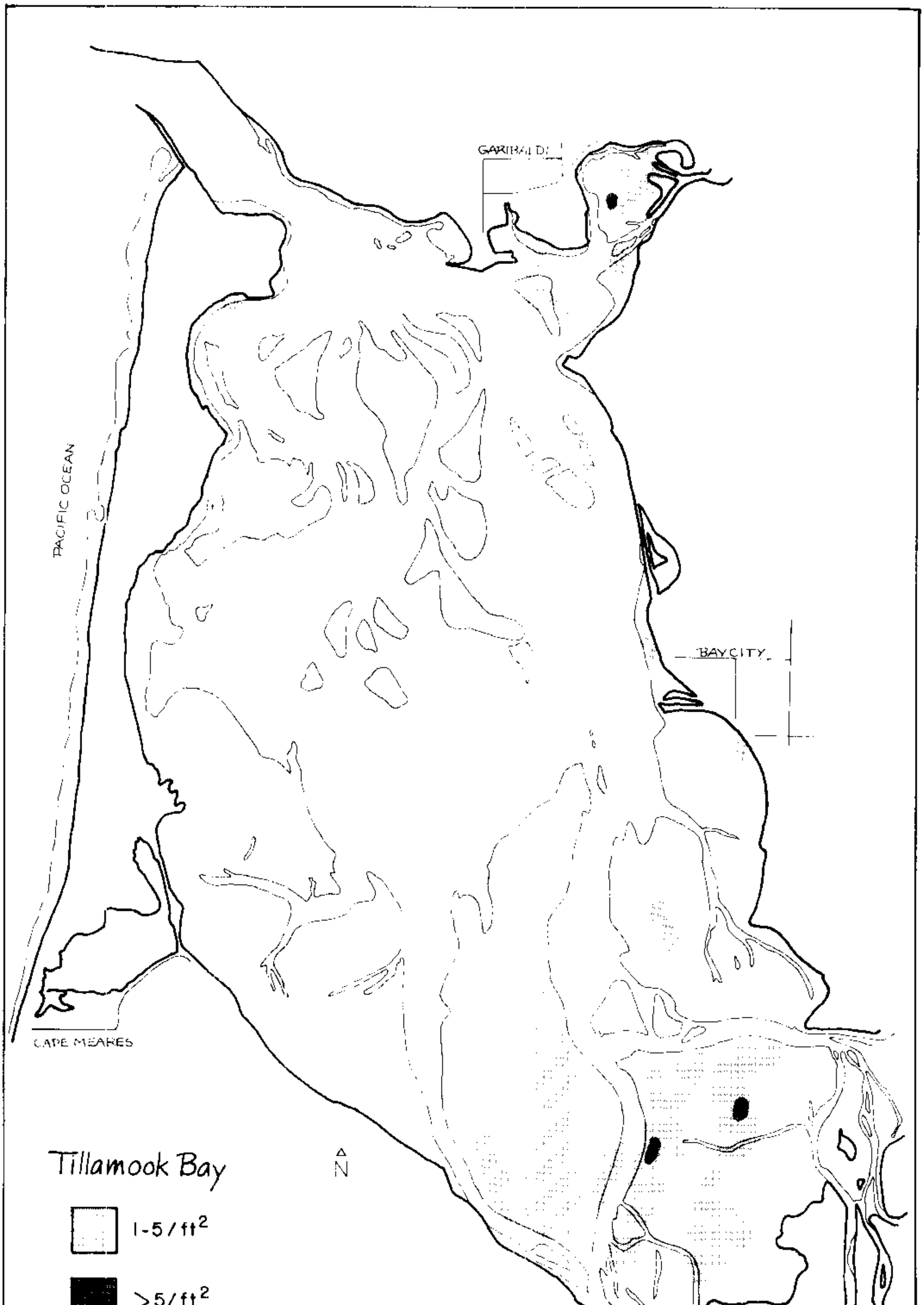

Figure II A.2.-13. Distribution of irus clams (*Macoma irus*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

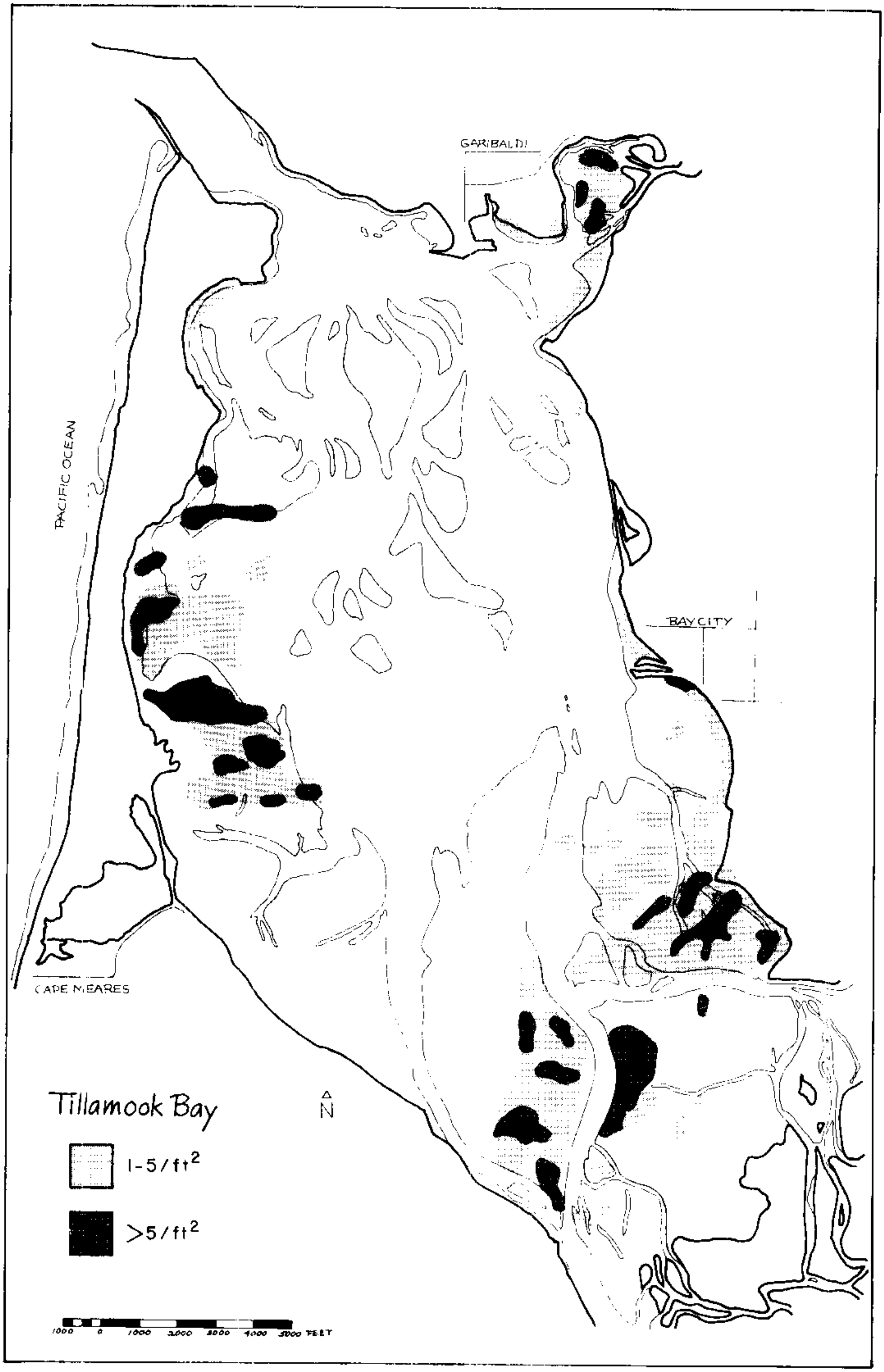

Figure II.A.2.-14. Distribution of softshell clams (*Mya arenaria*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

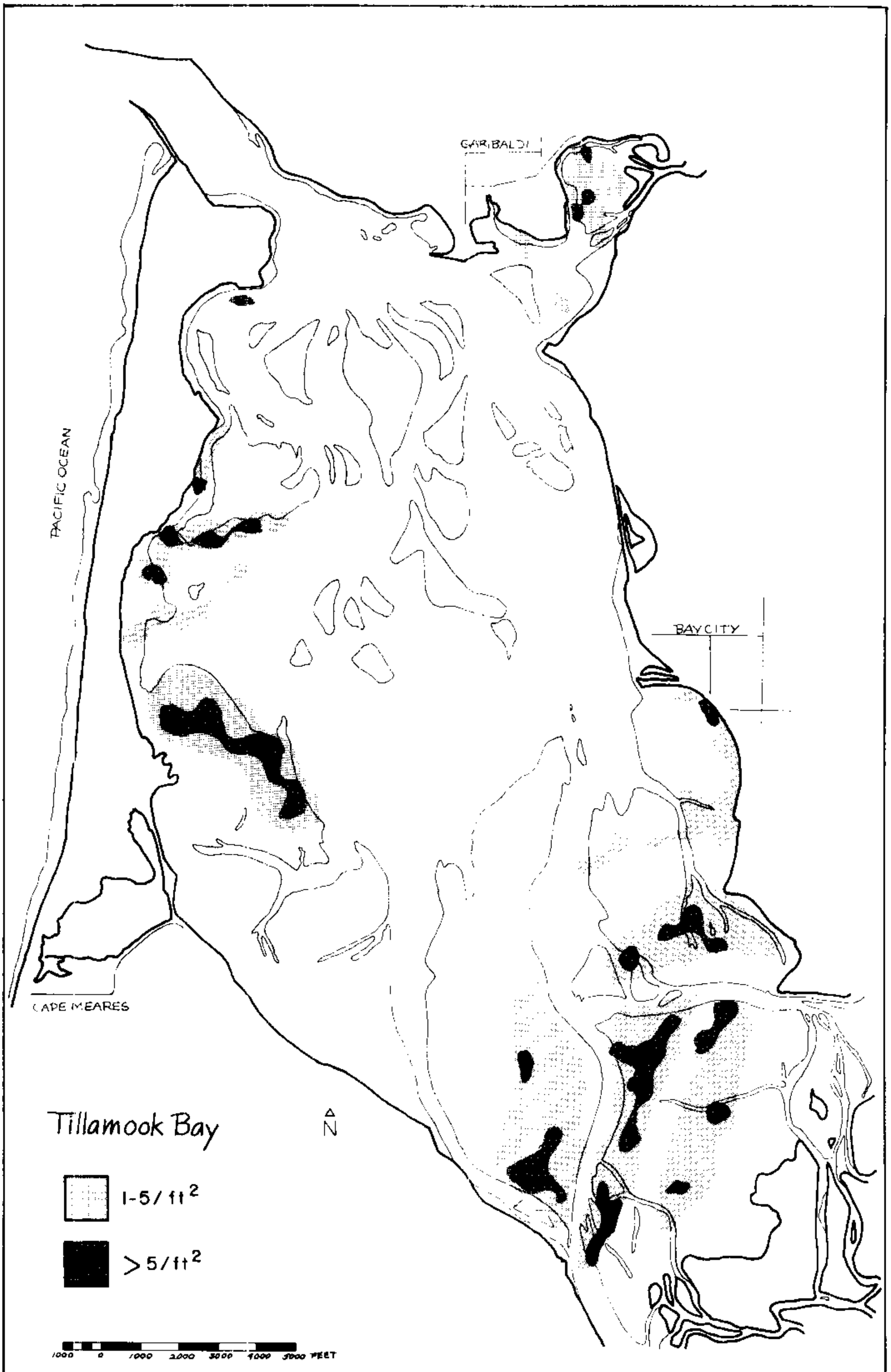

Figure II.A.2.-15. Distribution of Baltic clams (*Macoma balthica*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

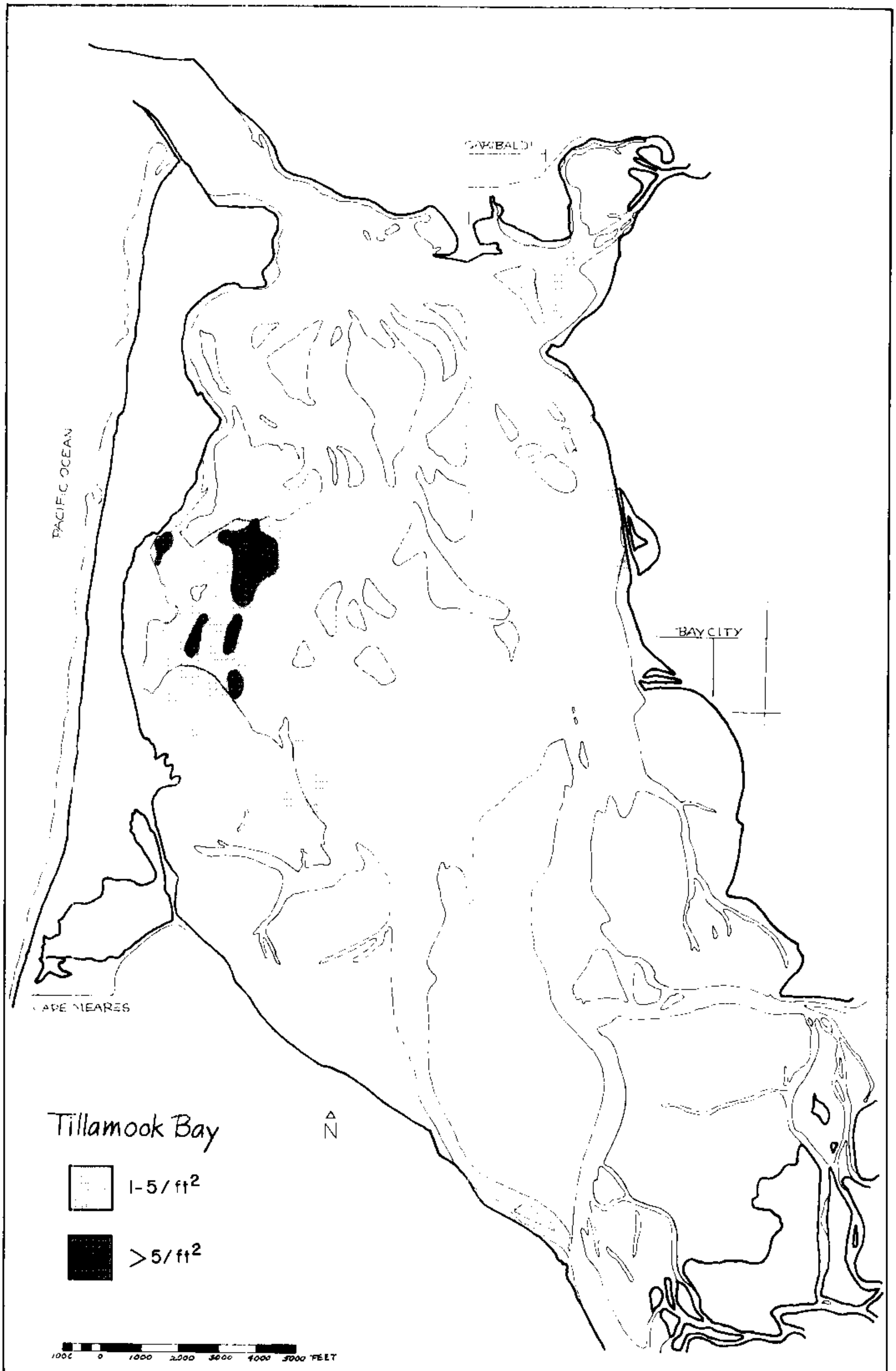

Figure II.A.2.-16. Distribution of bentnose clams (*Macoma nasuta*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

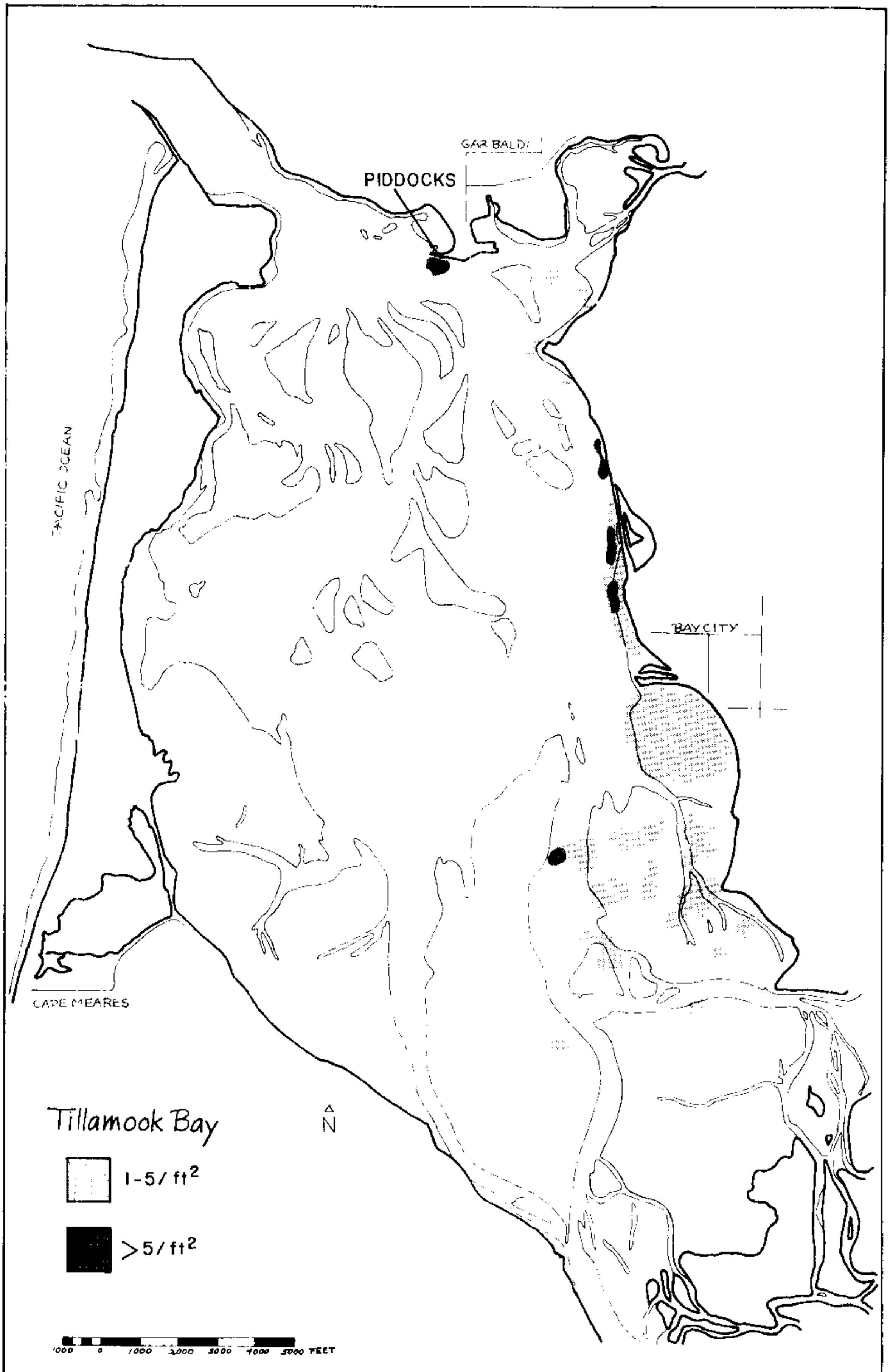

Figure II.A.2.-17. Distribution of California softshell clams (*Cryptomya californica*) and piddock clams (*Zirfaea pilsbryi*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

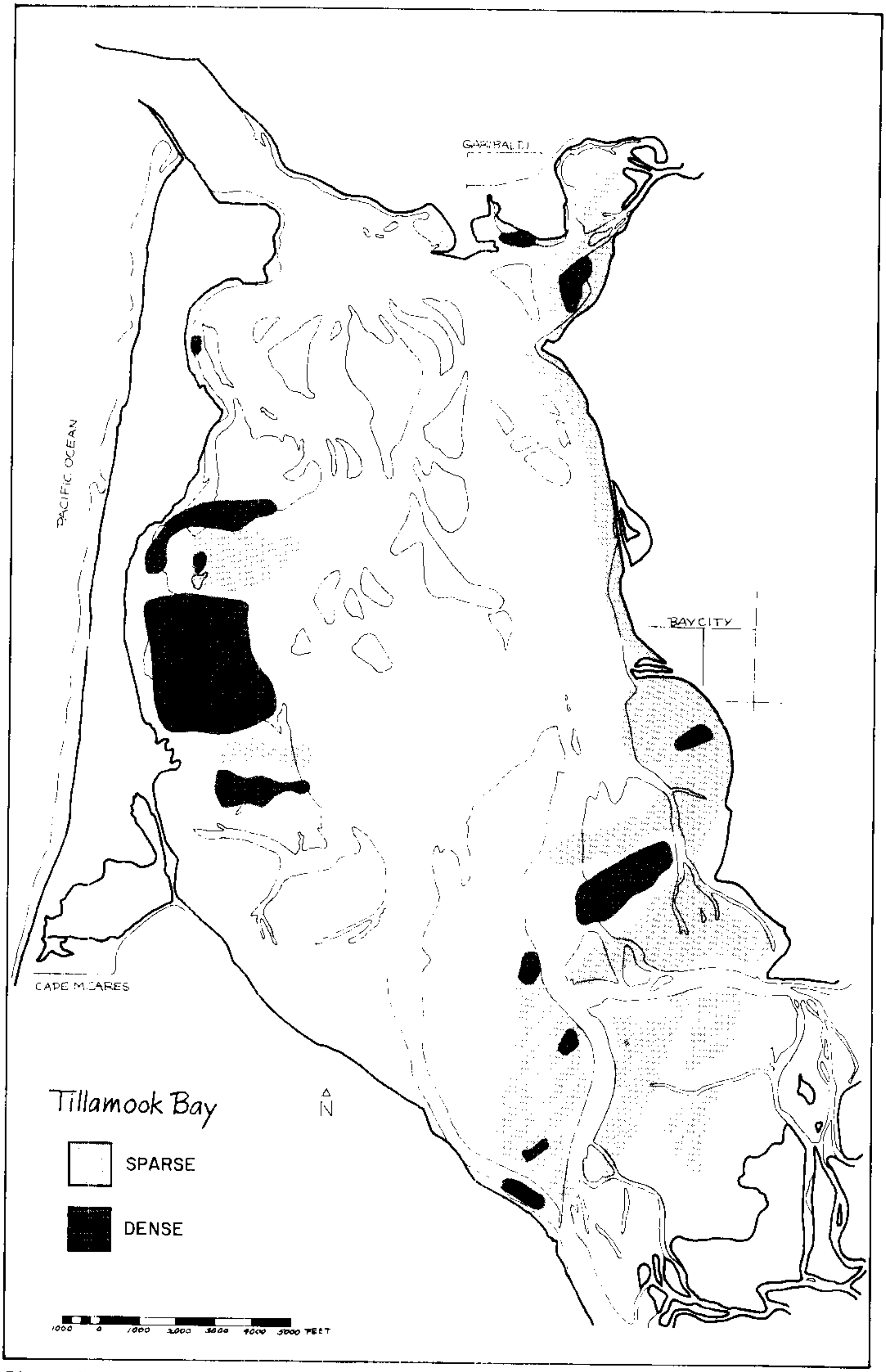

Figure II.A.2.-18. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

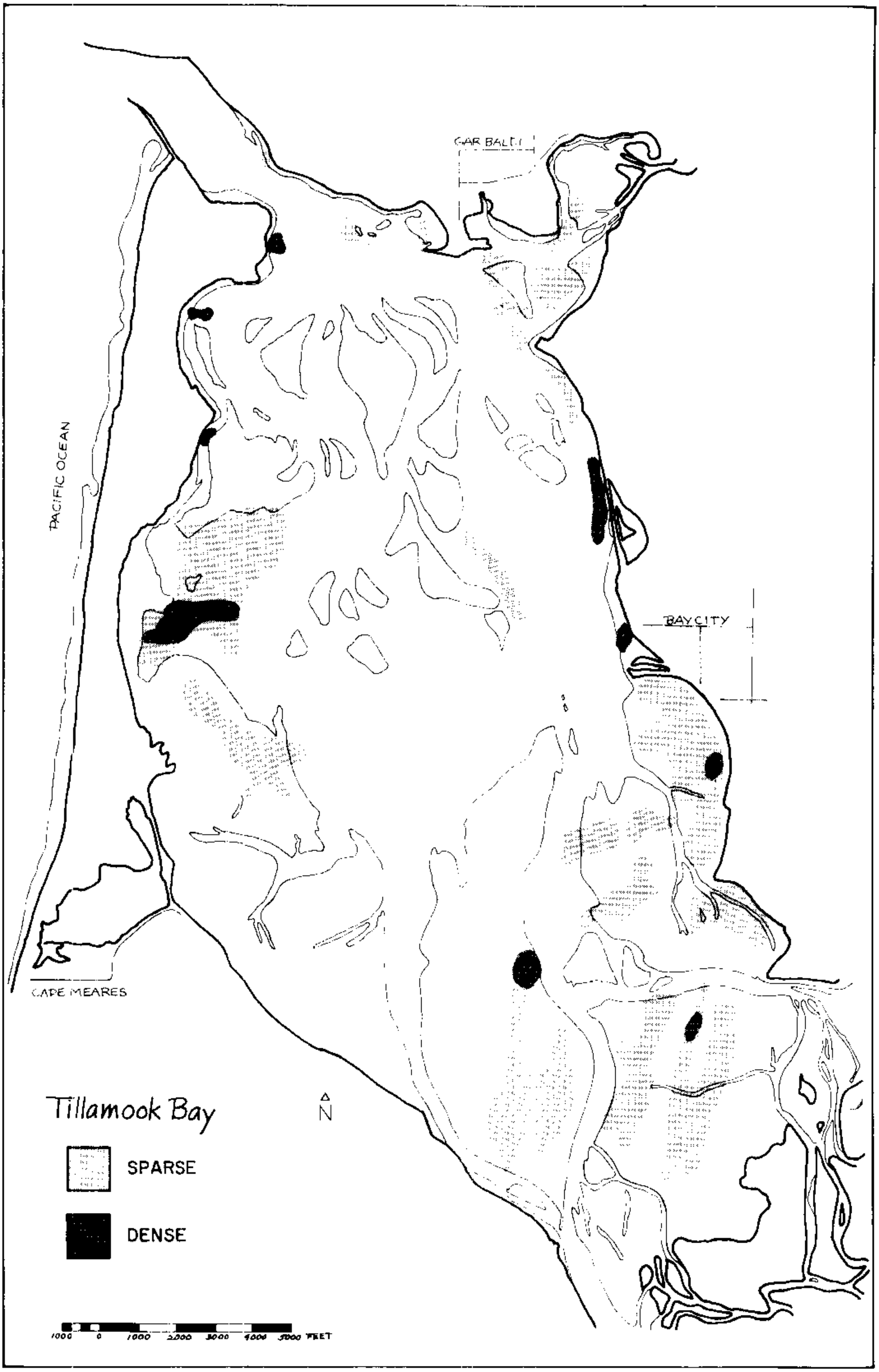

Figure II.A.2.-19. Distribution of eelgrass (*Zostera marina*) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

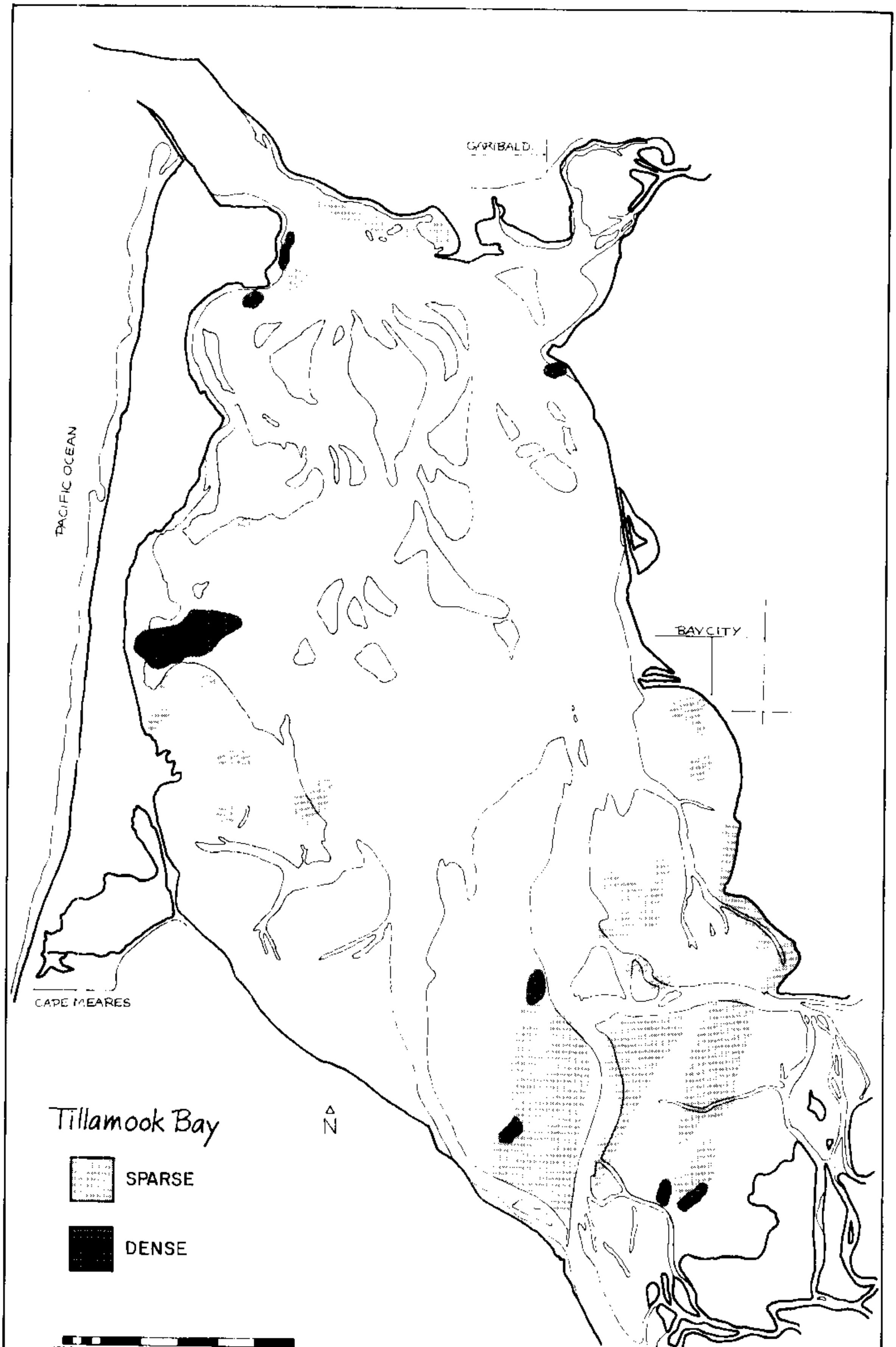

Figure II.A.2.-20. Distribution of sea lettuce (*Ulva* sp.) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

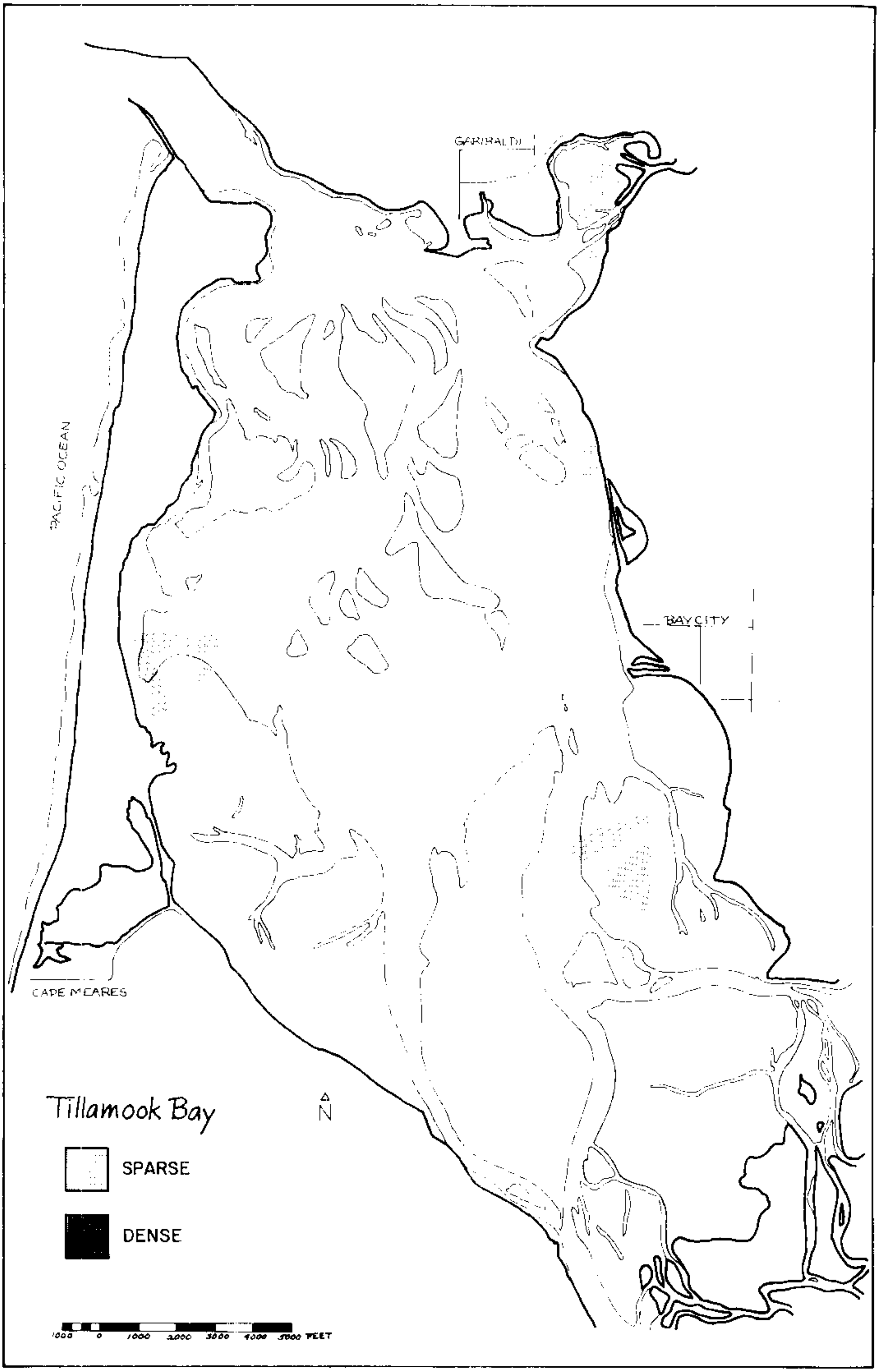

Figure II.A.2.-21. Distribution of the green alga *Enteromorpha* sp. in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

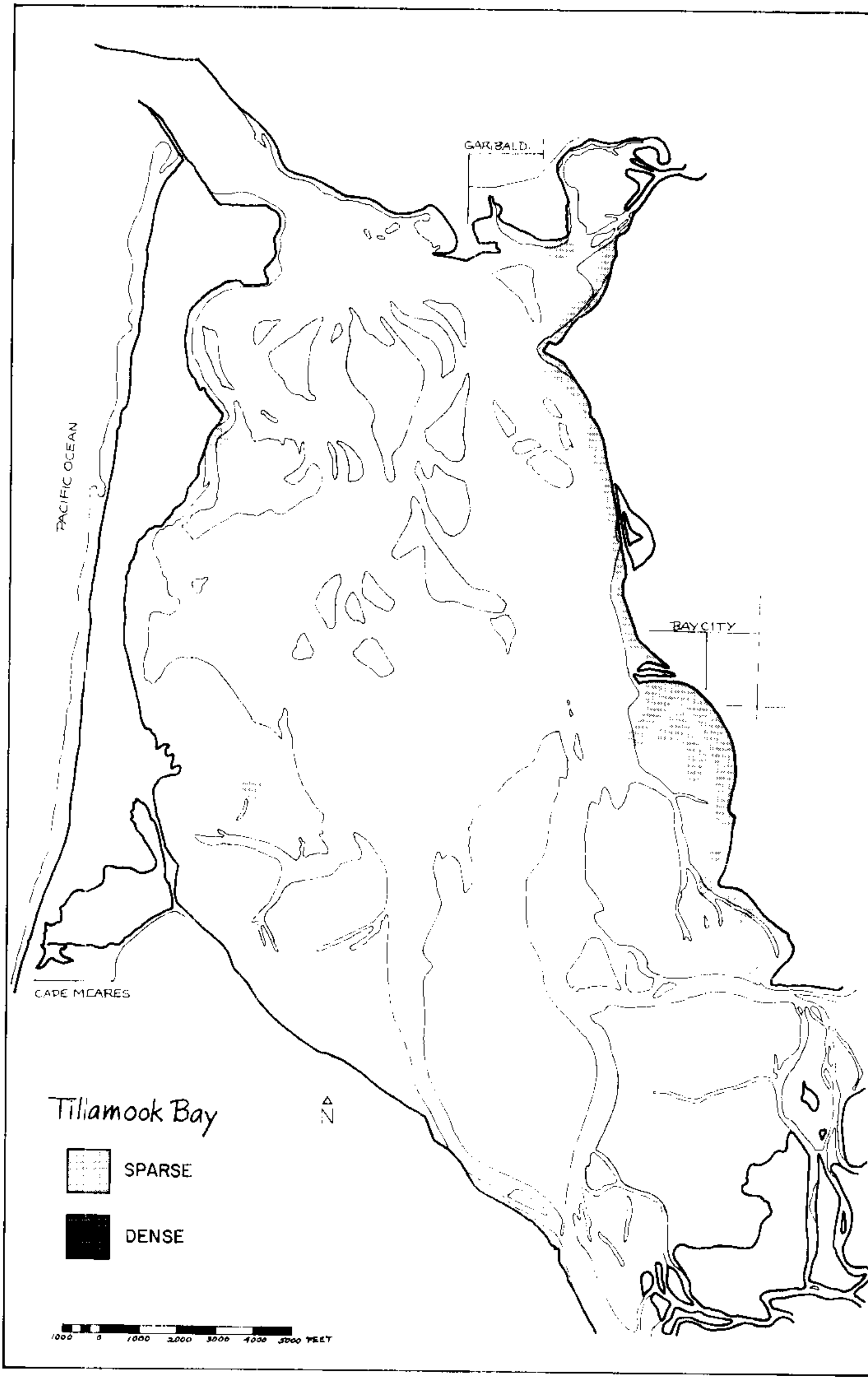

Figure II.A.2.-22. Distribution of the rockweed (*Fucus* sp.) in Tillamook Bay, Oregon. (See Fig. II.A.2.-8 for areas not surveyed.)

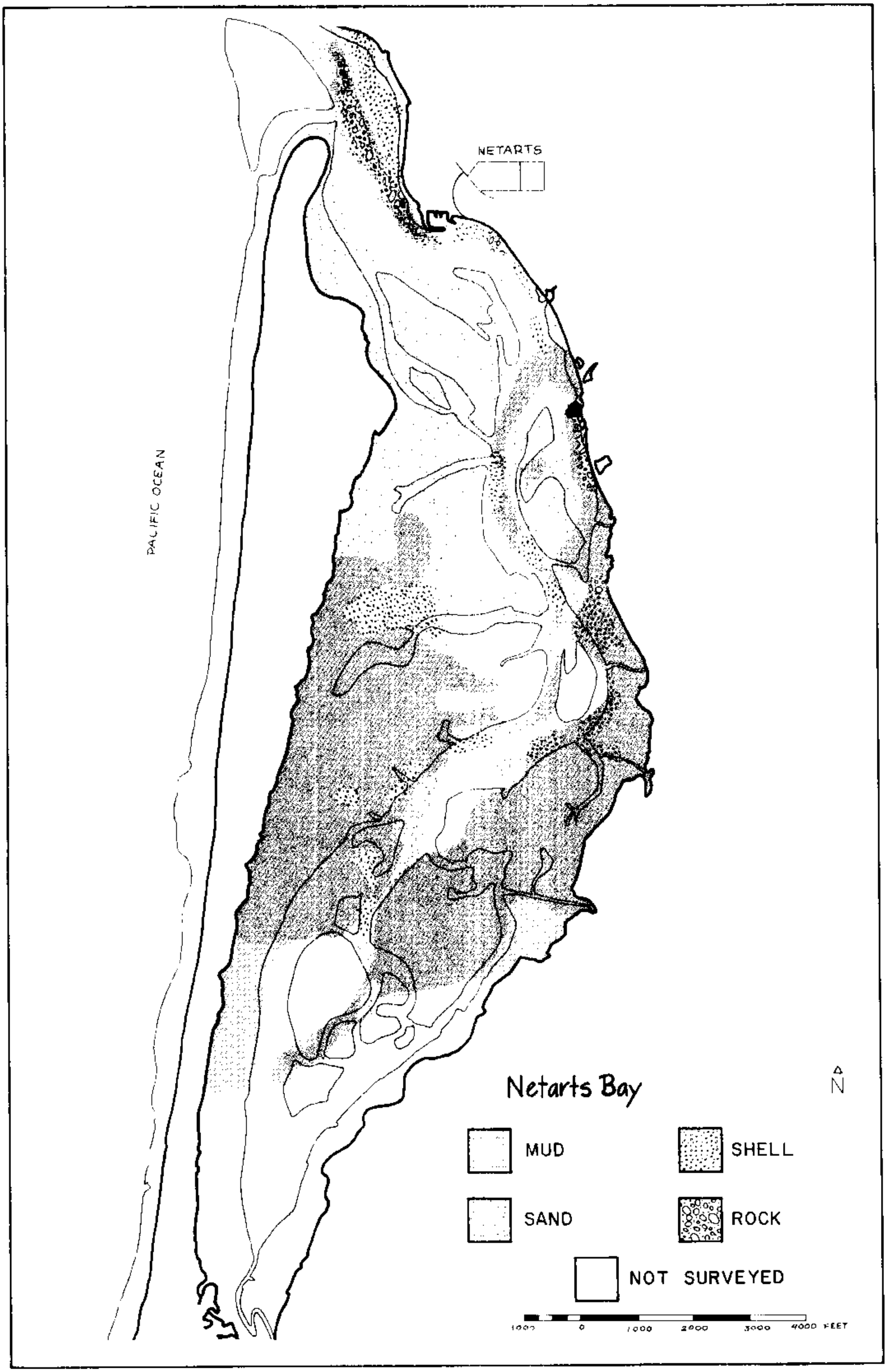

Figure II.A.2.-23. Distribution of substrate materials in Netarts Bay, Oregon.

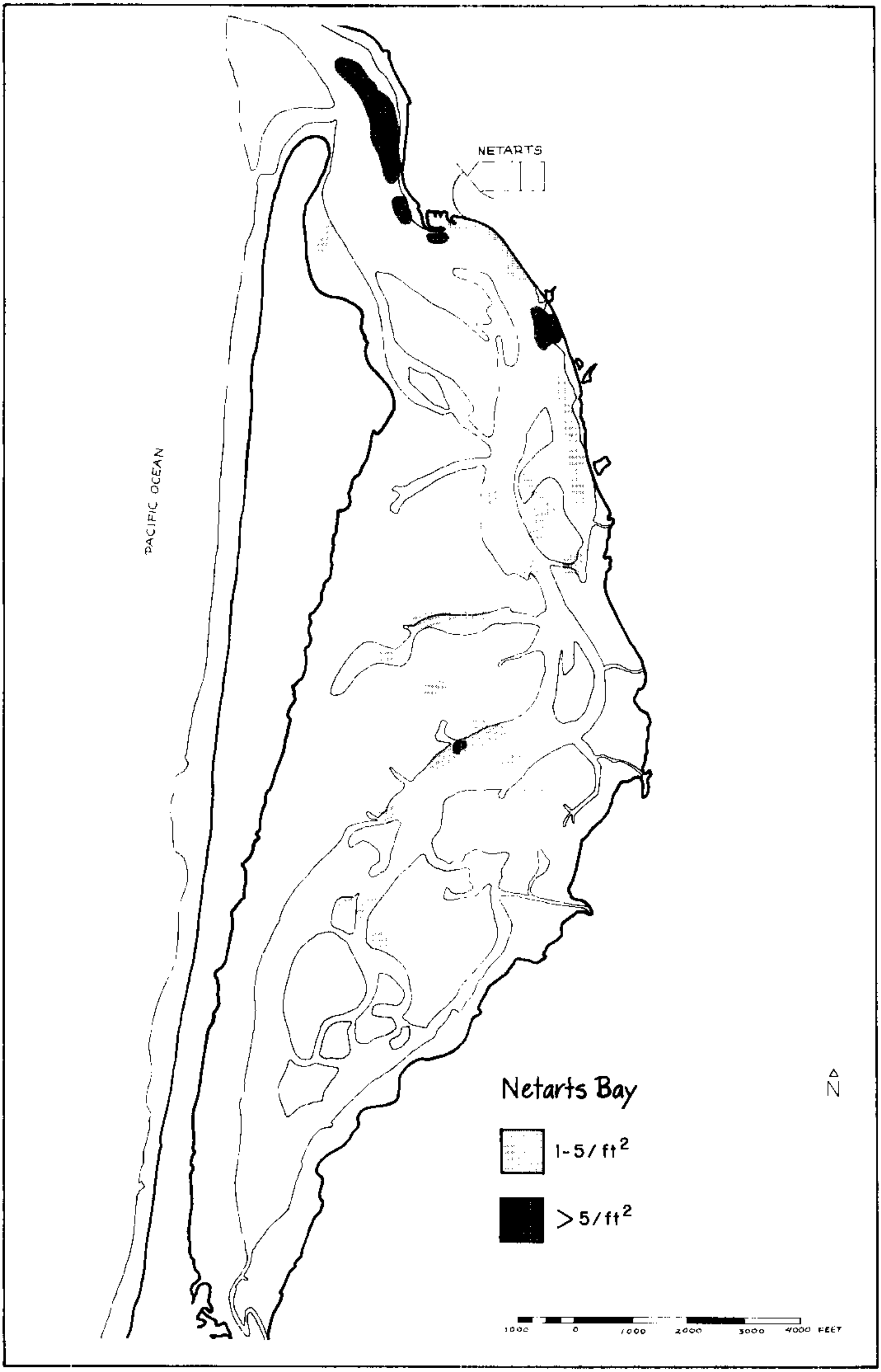

Figure II.A.2.-24. Distribution of gaper clams (*Tresus capax*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

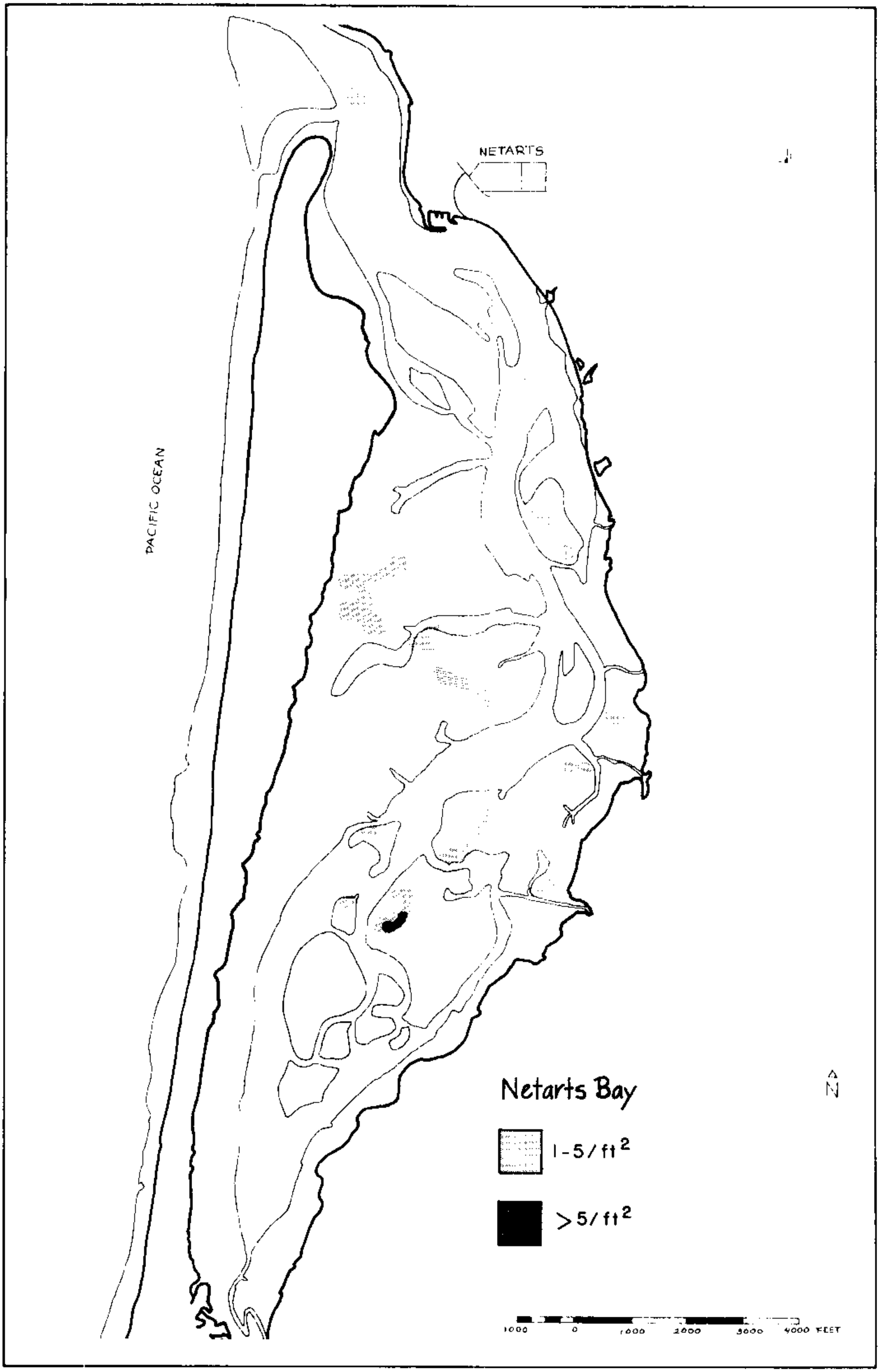

Figure II.A.2.-25. Distribution of butter clams (*Saxidomus giganteus*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

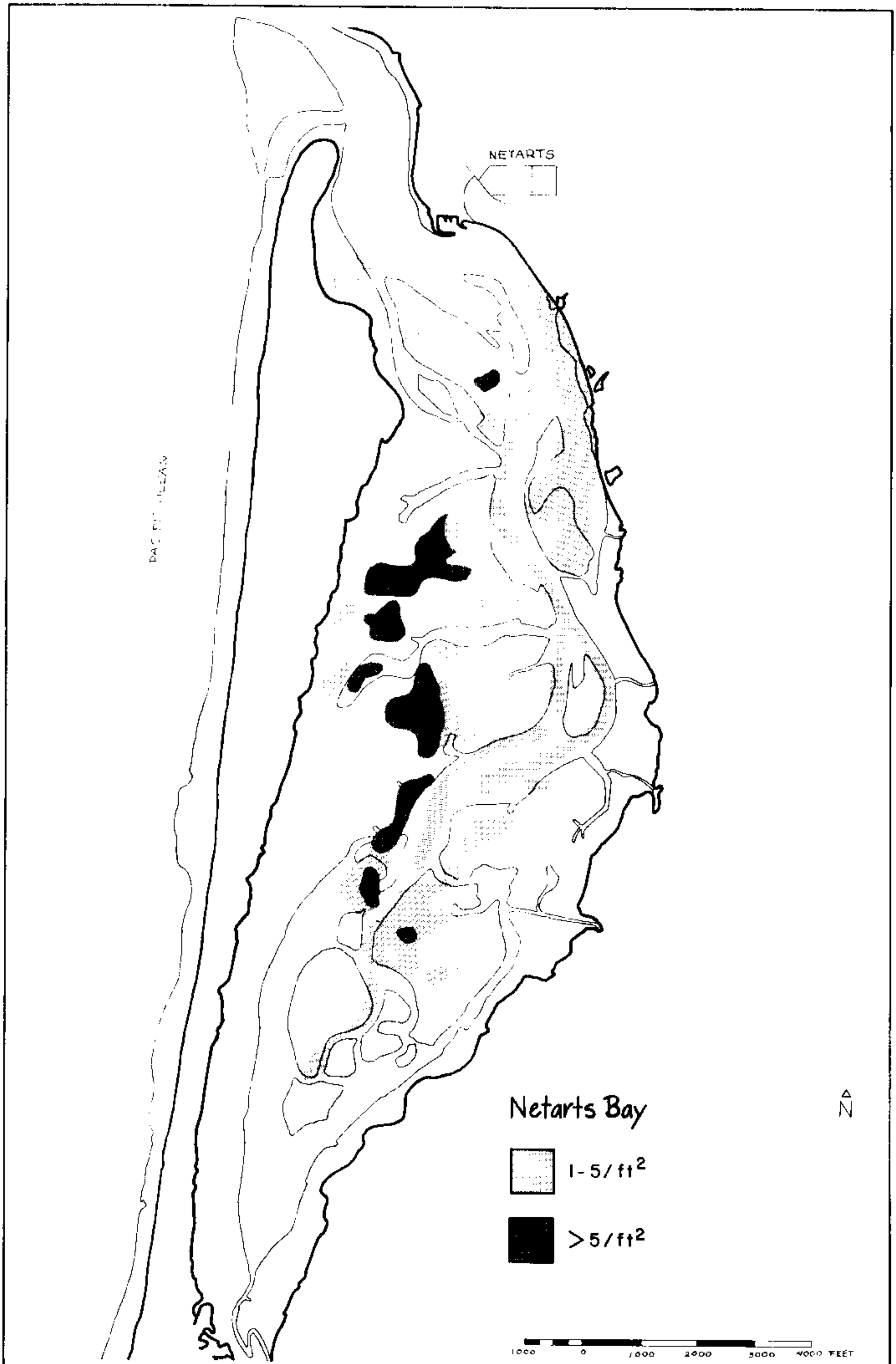

Figure II.A.2.-26. Distribution of cockle clams (*Clinocardium nuttallii*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

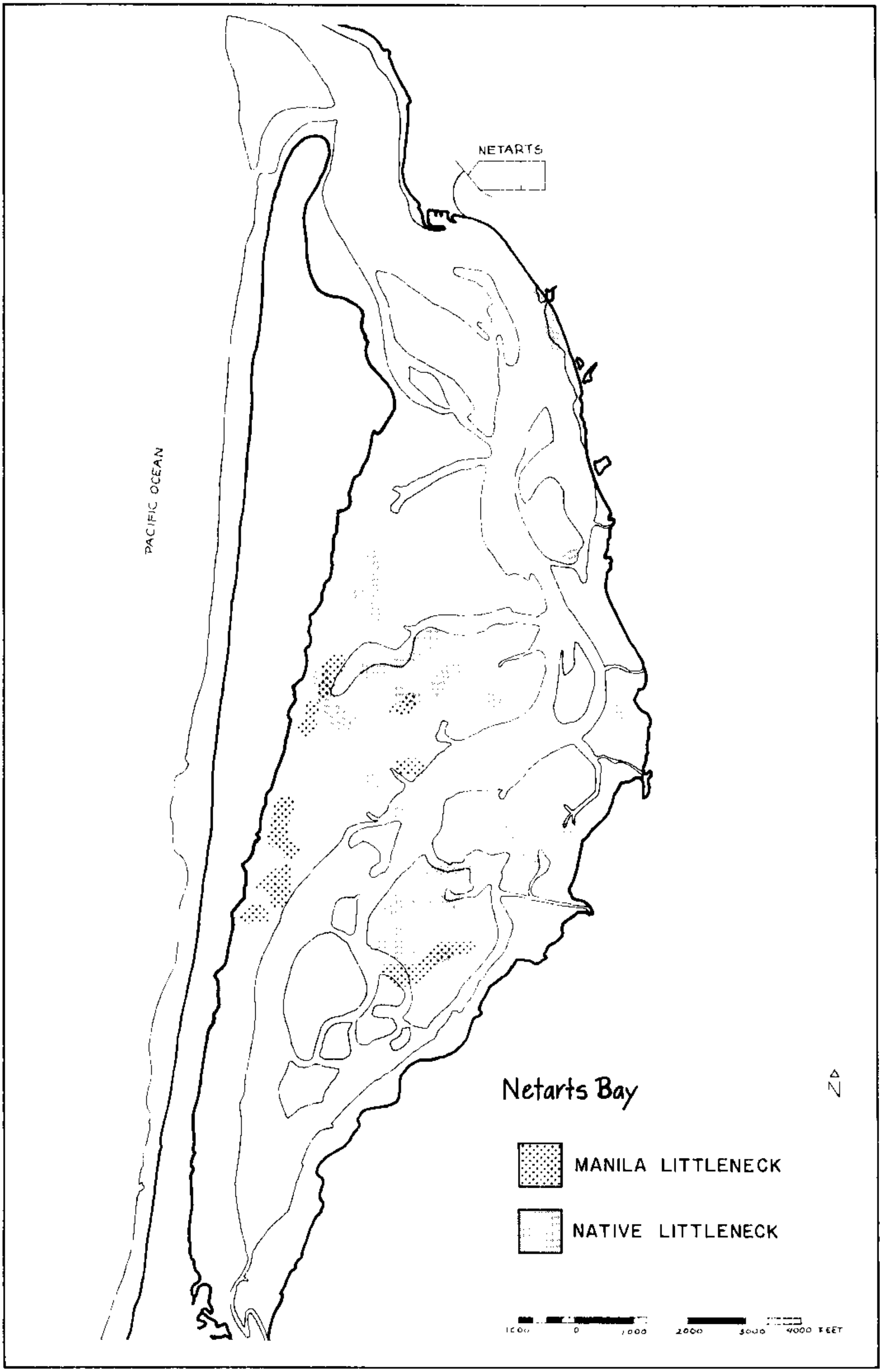

Figure II.A.2.-27. Distribution of Manila littleneck clams (*Venerupis philippinarium*) and native littleneck clams (*V. staminea*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

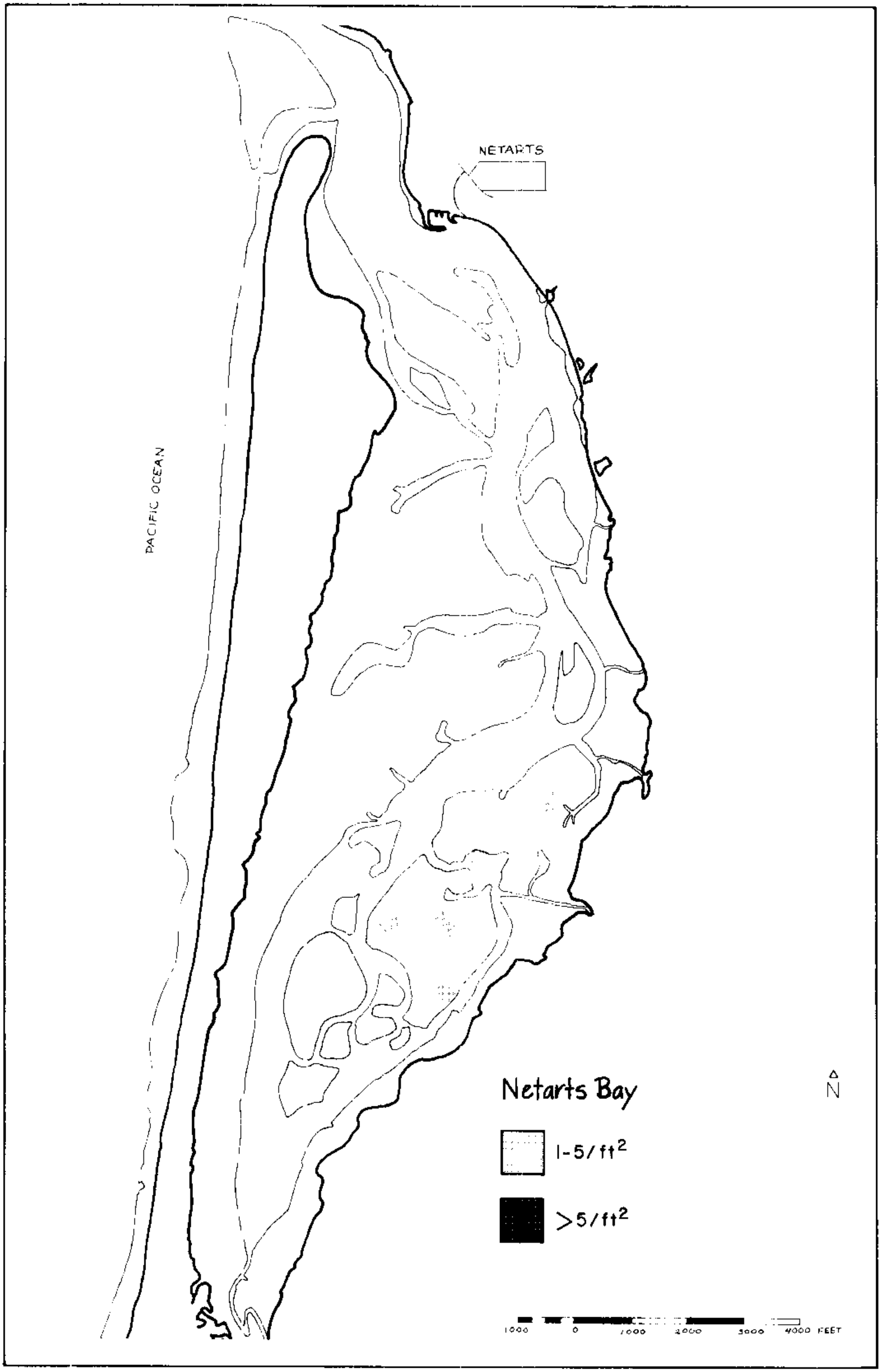

Figure II.A.2.-28. Distribution of irus clams (*Macoma irus*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

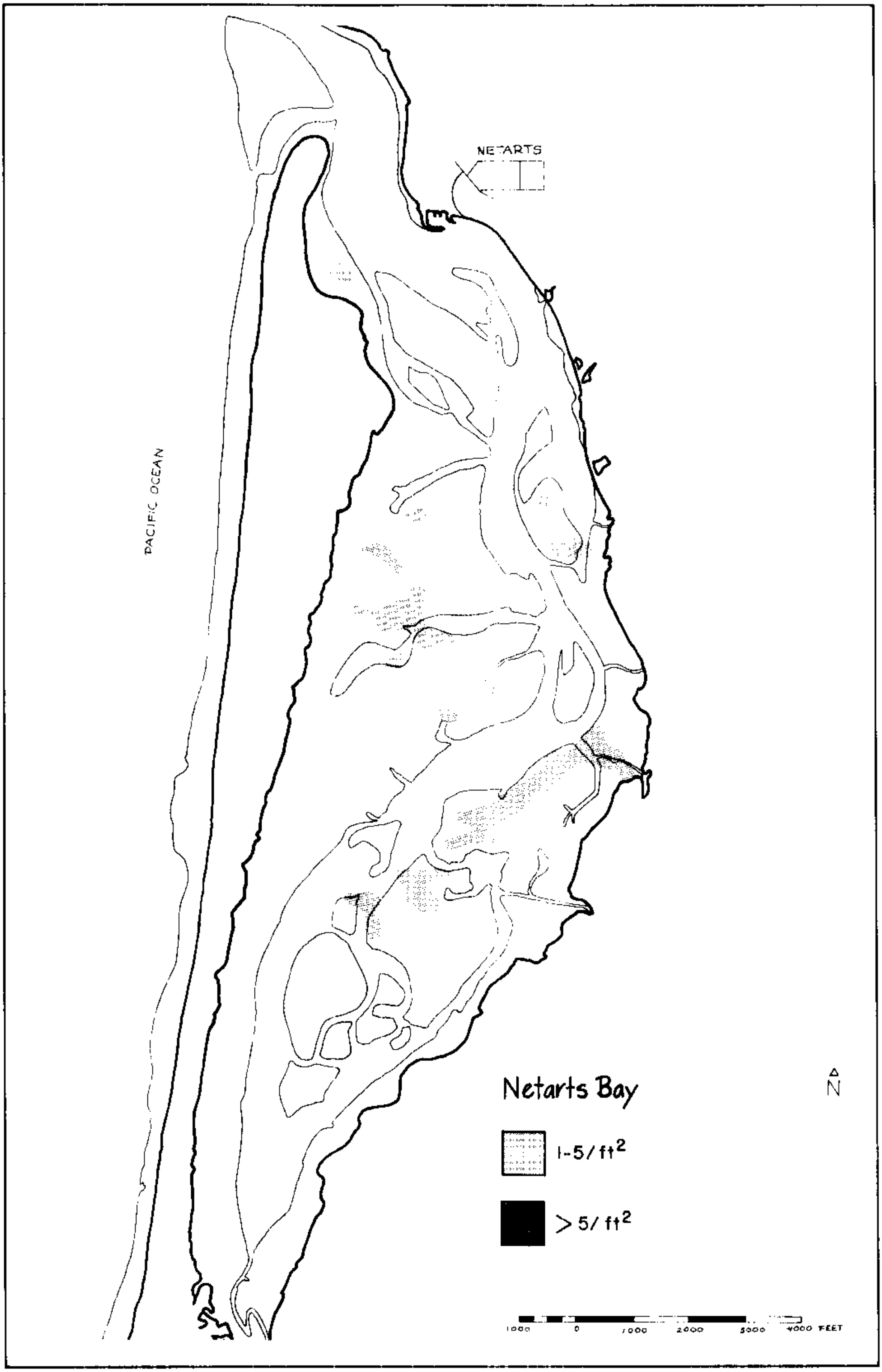

Figure II.A.2.-29. Distribution of softshell clams (*Mya arenaria*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

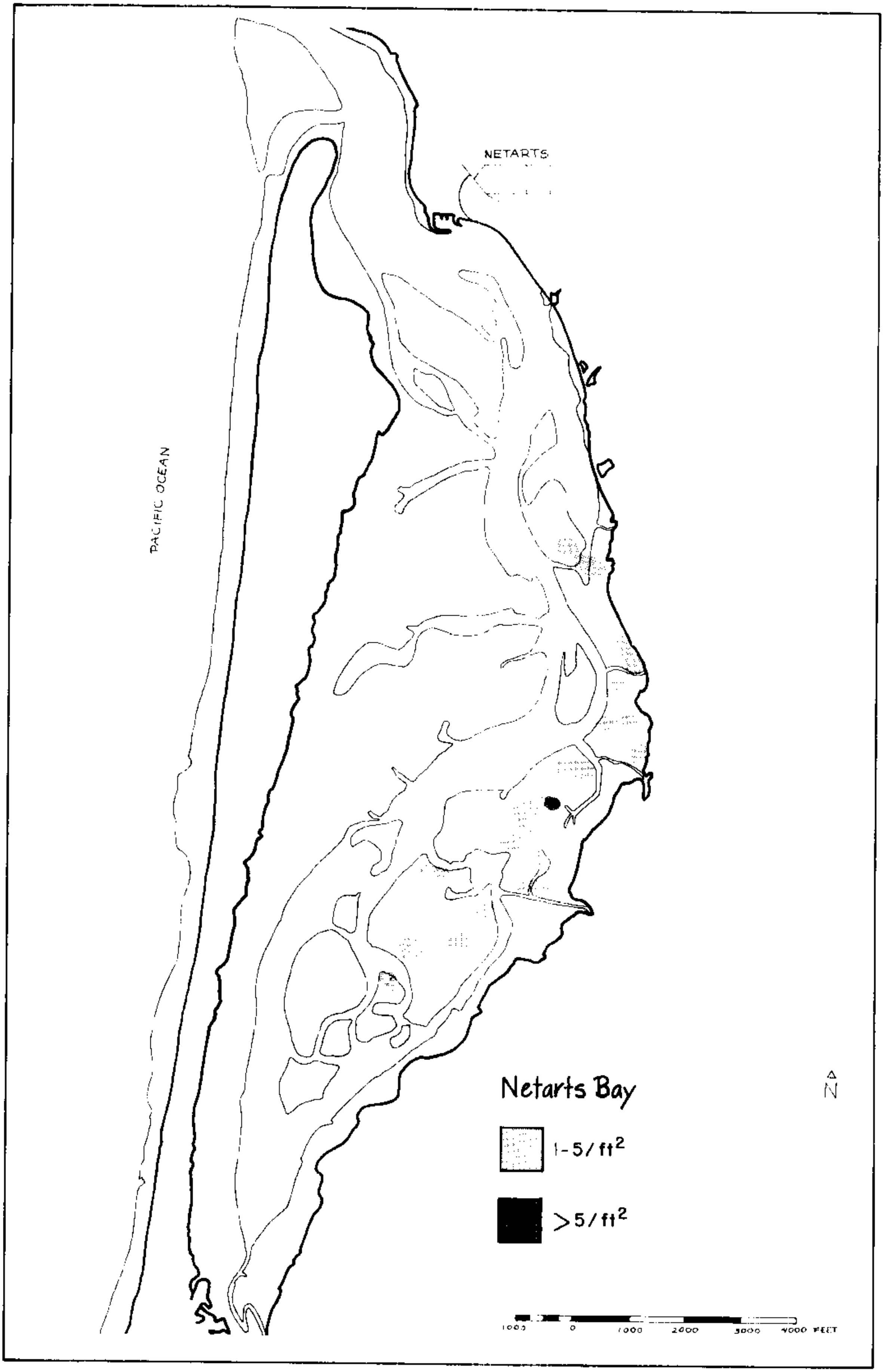

Figure II.A.2.-30. Distribution of Baltic clams (*Macoma balthica*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

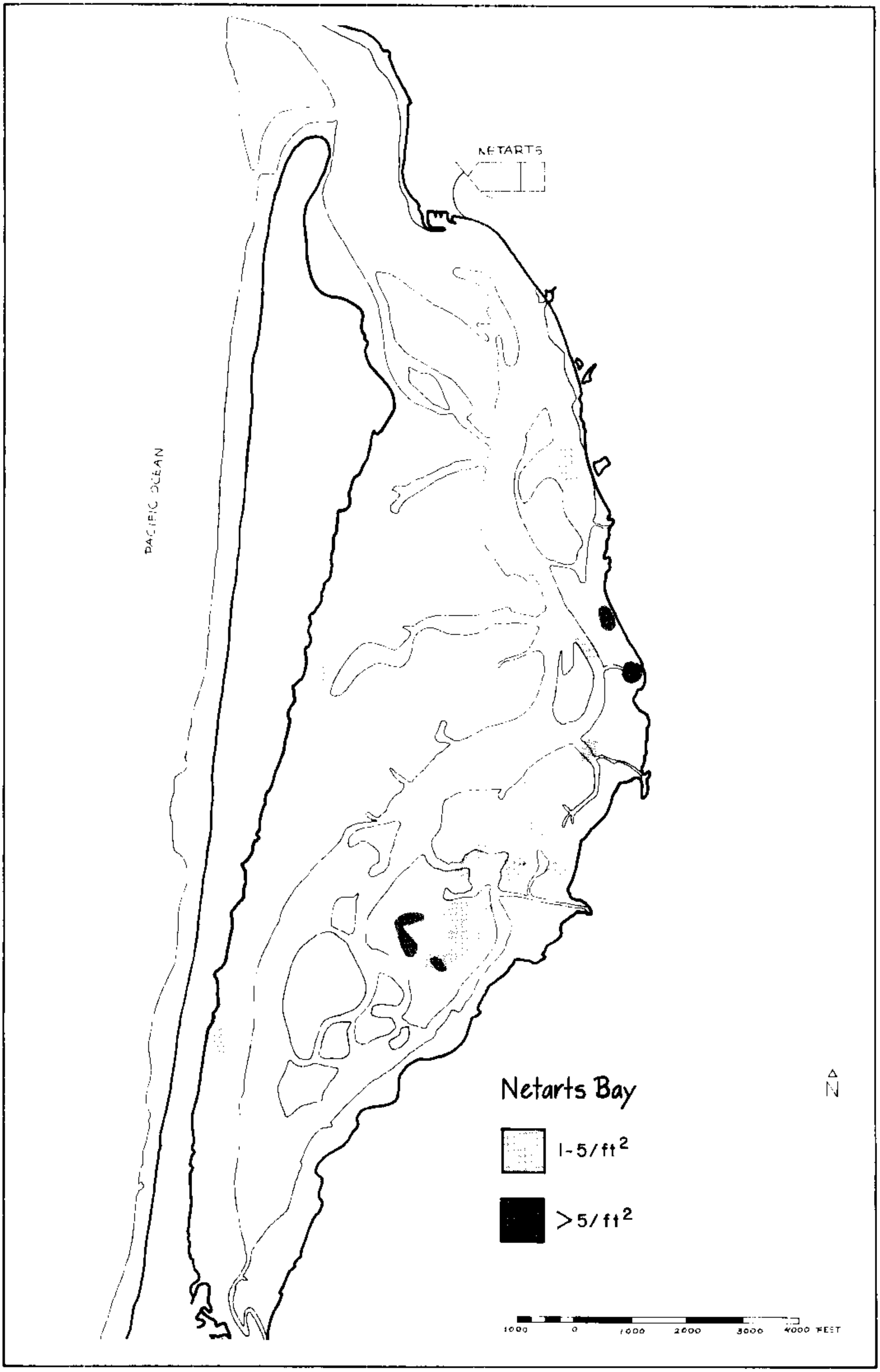

Figure II.A.2.-31. Distribution of bentnose clams (*Macoma nasuta*) in Neatarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

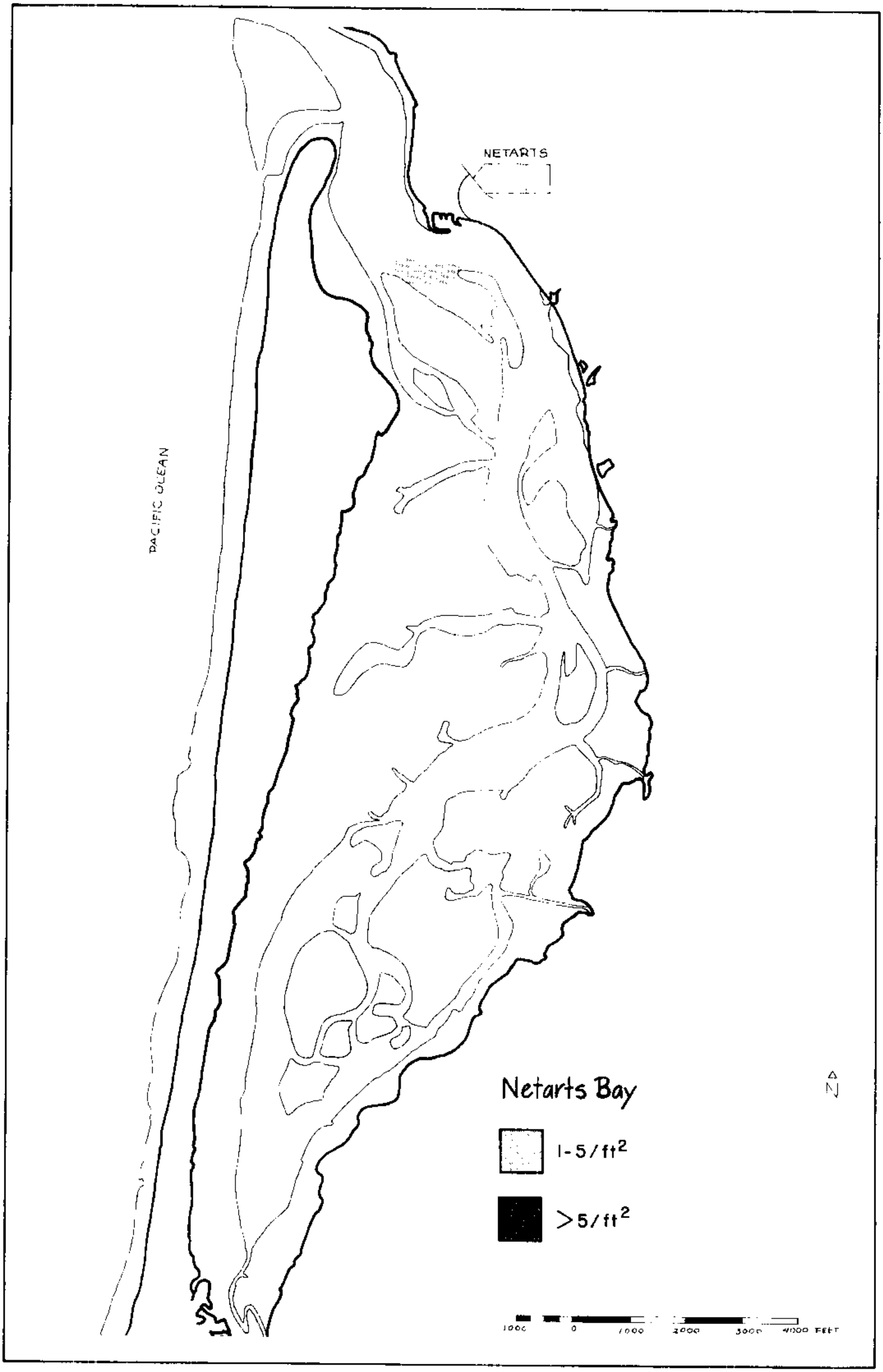

Figure II.A.2.-32. Distribution of Bodega tellin clams (*Tellina bodegensis*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

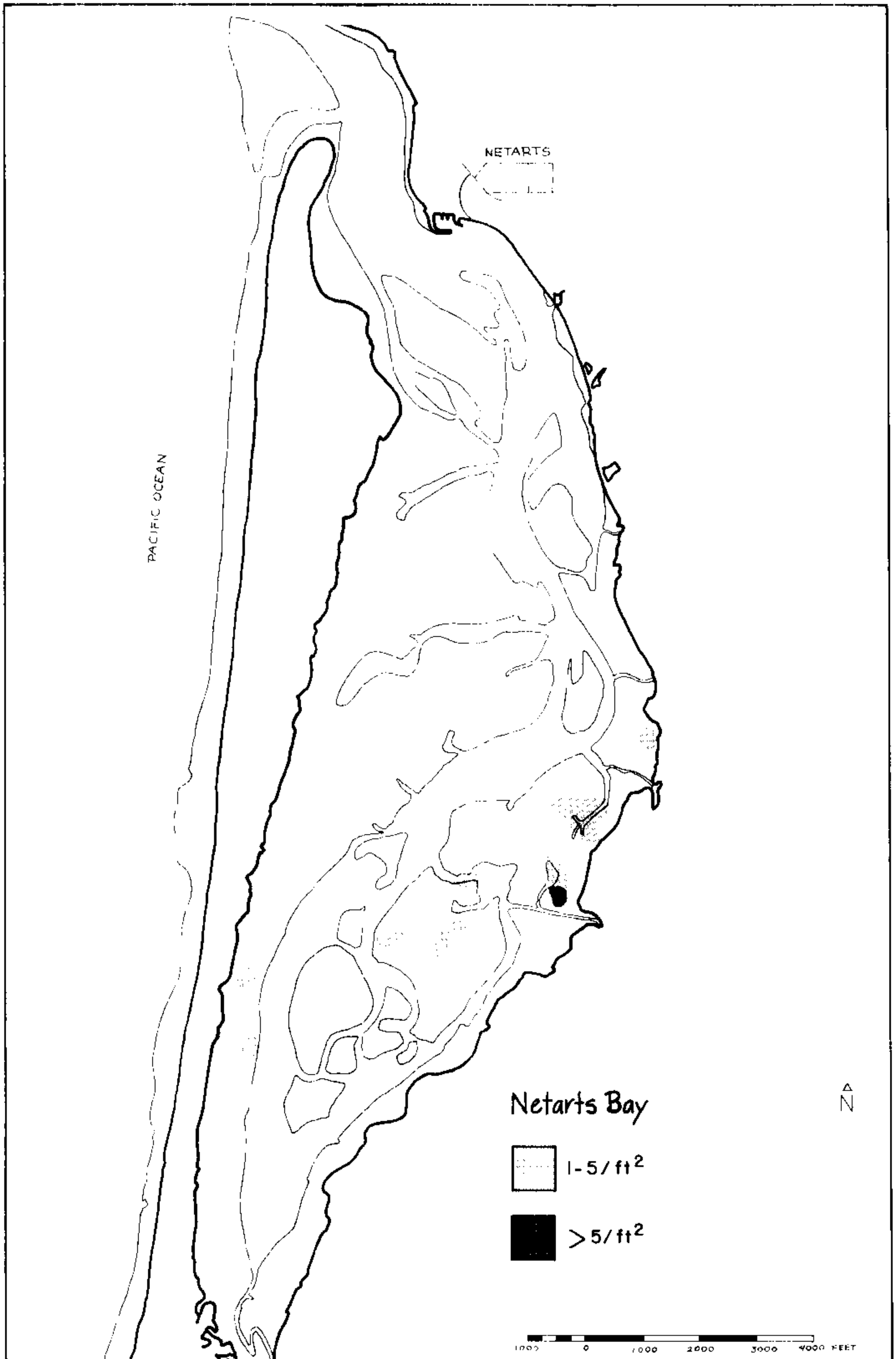

Figure II.A.2.-33. Distribution of California softshell clams (*Cryptomya californica*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

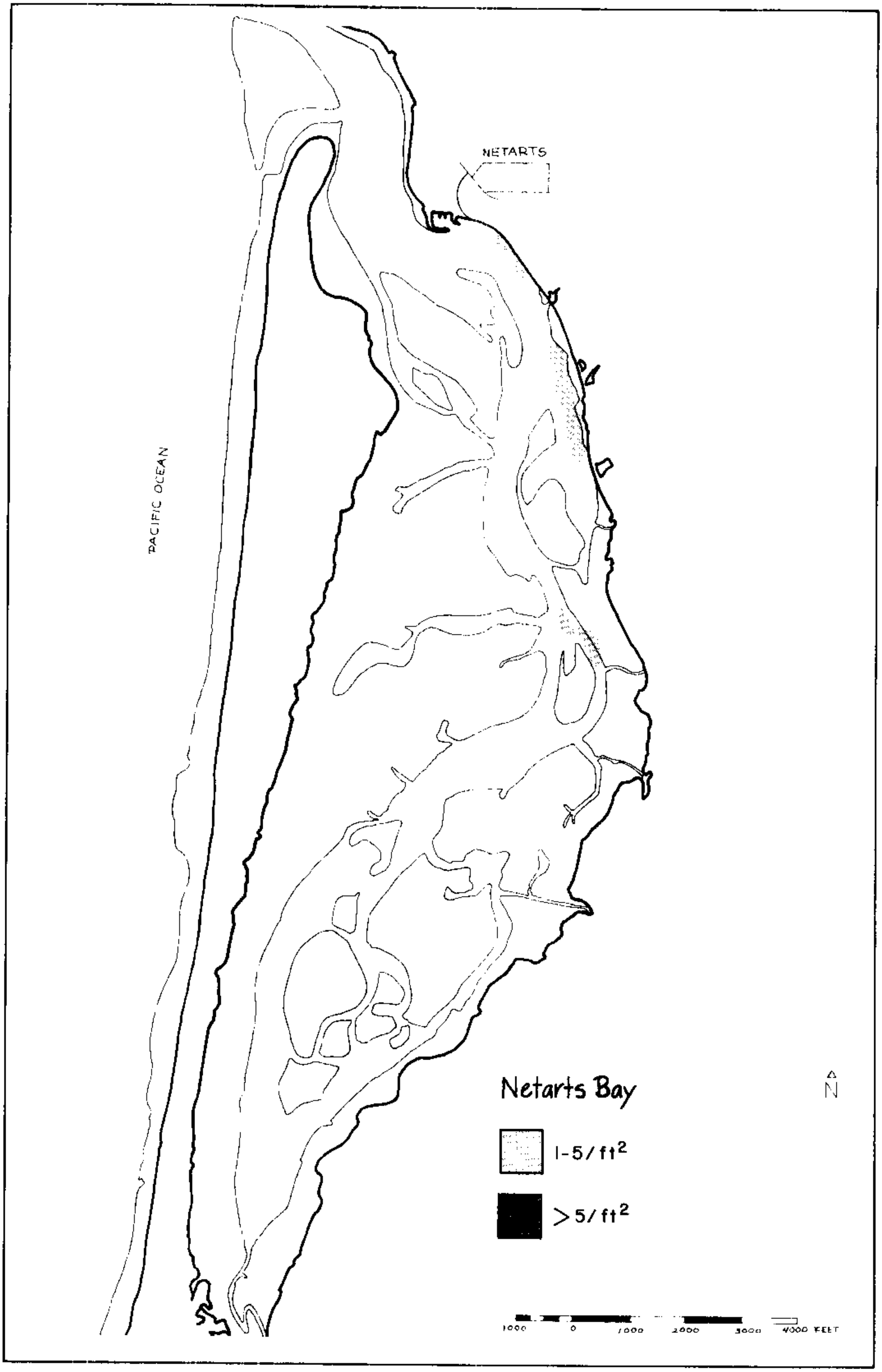

Figure II.A.2.-34. Distribution of piddock clams (*Zirfaea pilsbryi*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

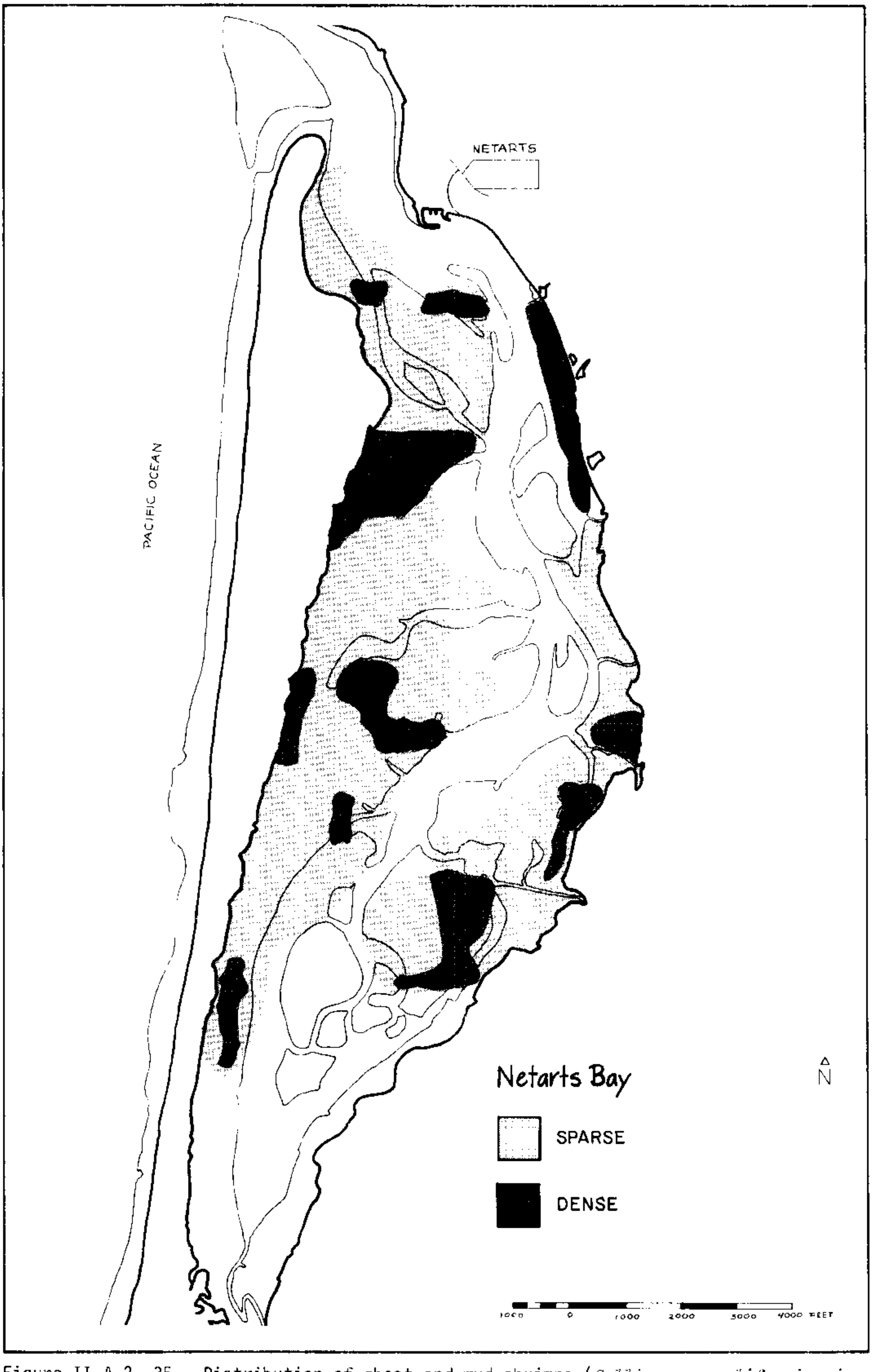

Figure II.A.2.-35. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

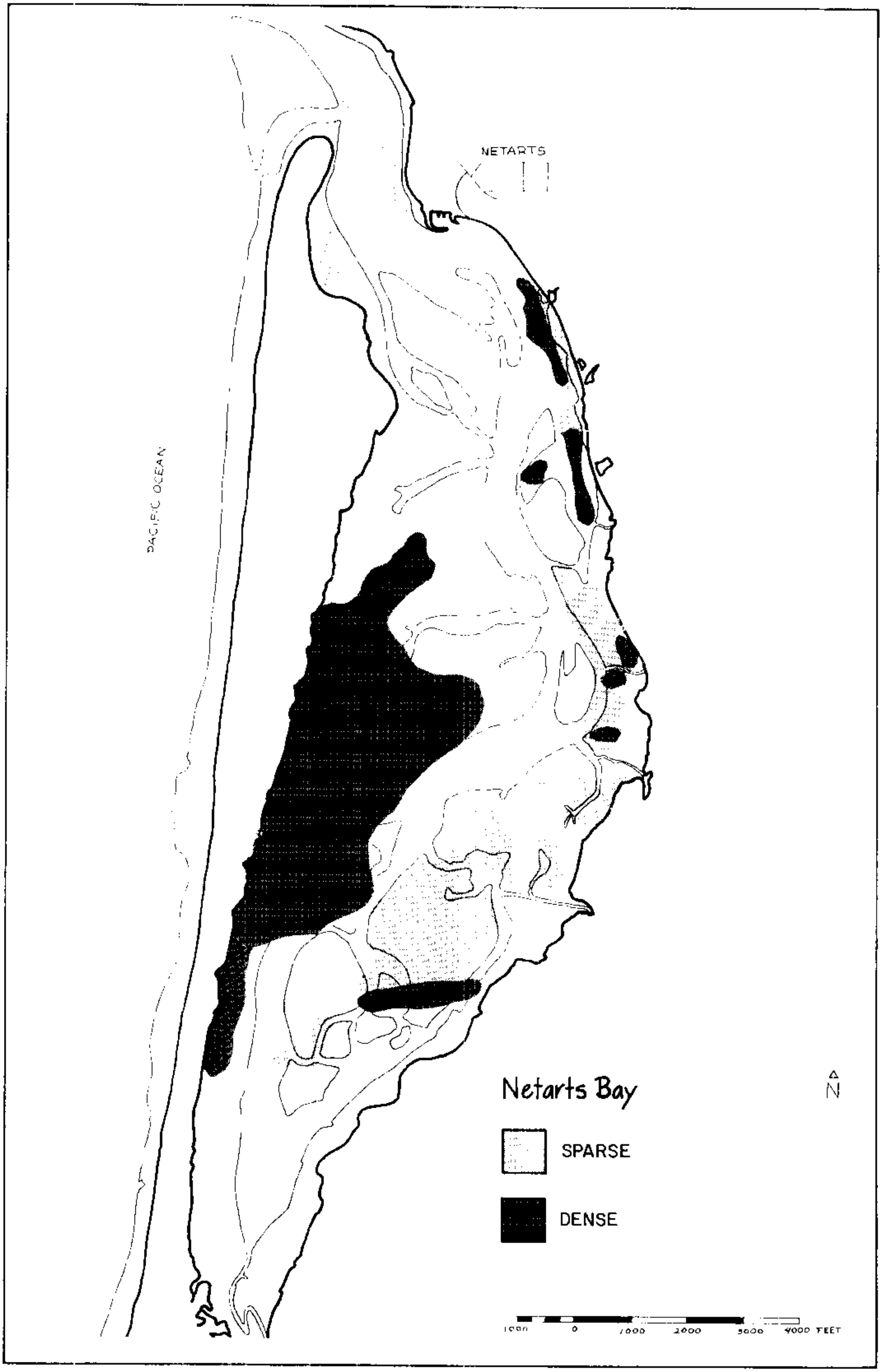

Figure II.A.2.-36. Distribution of eelgrass (*Zostera marina*) in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

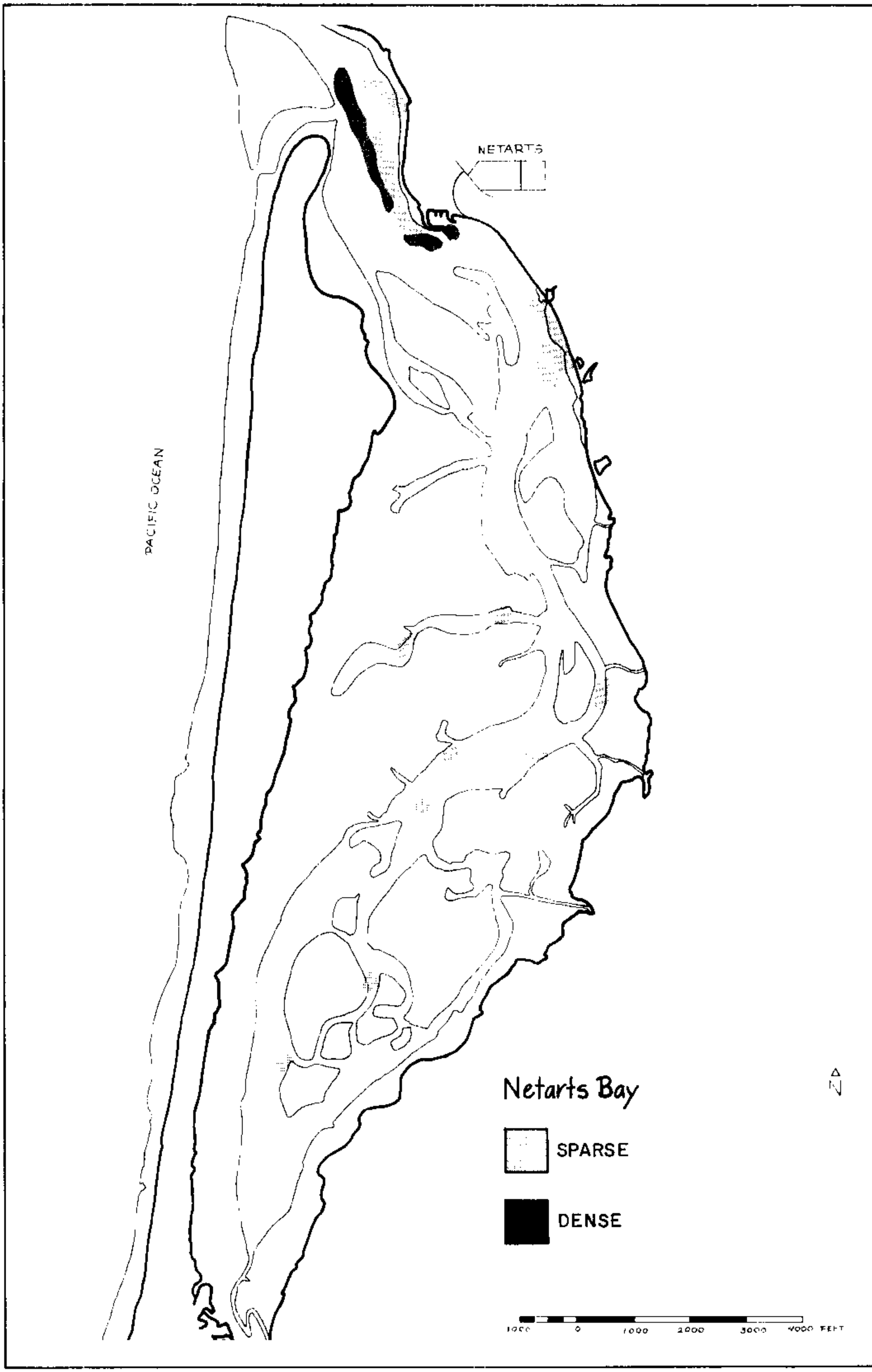

Figure II.A.2.-37. Distribution of sea lettuce (*Ulva* sp.) and other green algae in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

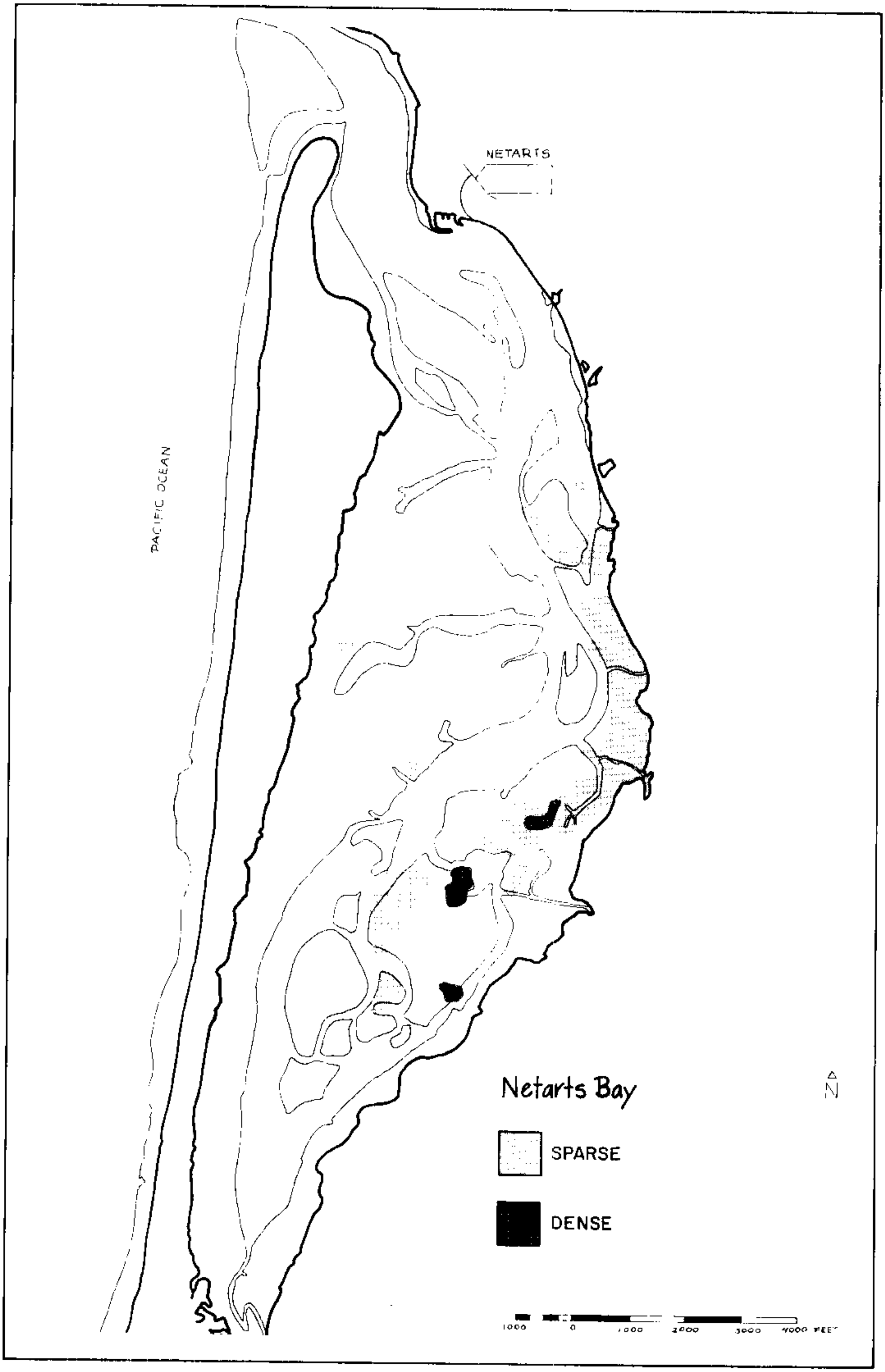

Figure II.A.2.-38. Distribution of green alga *Enteromorpha* sp. in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

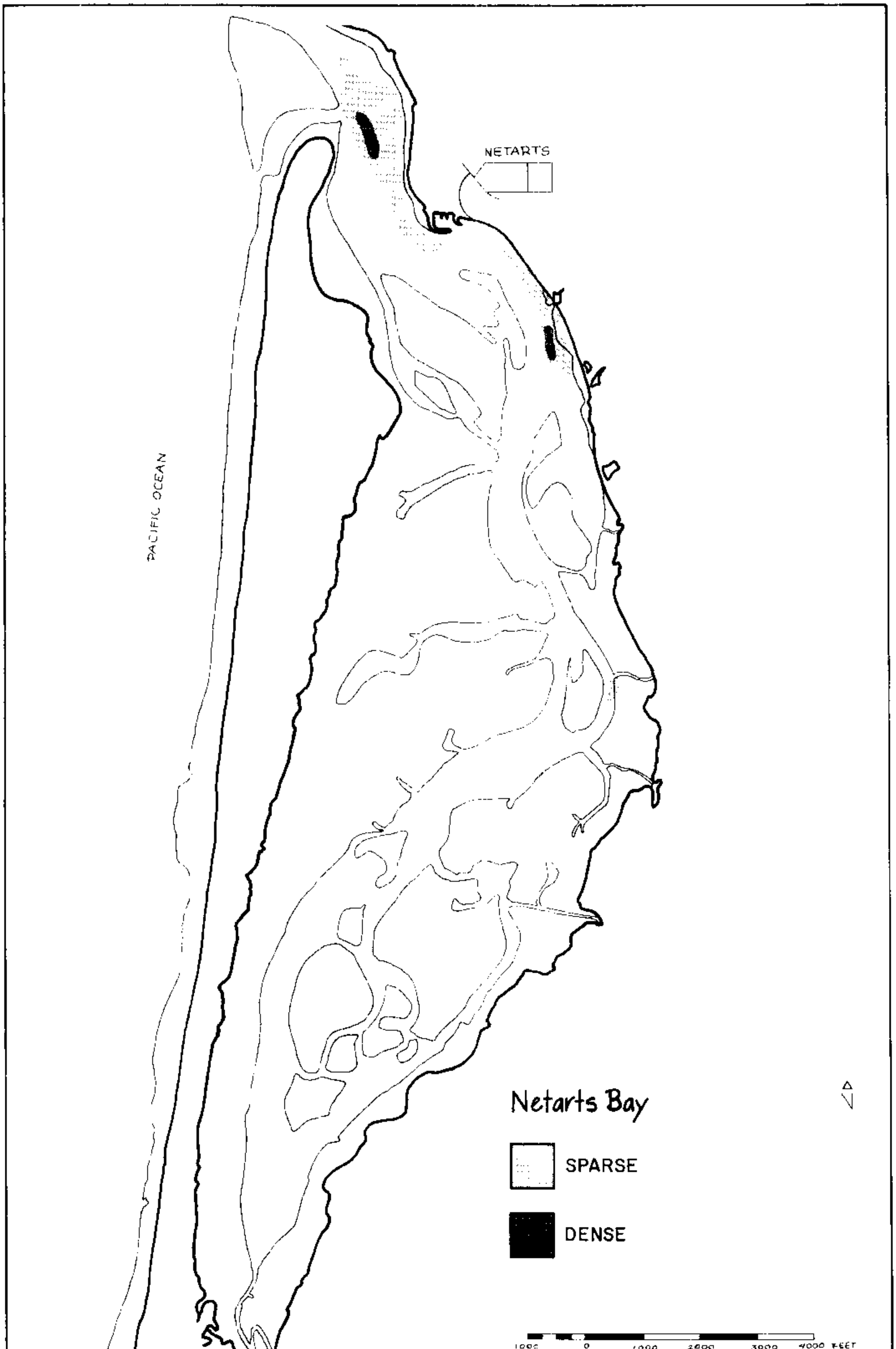

Figure II.A.2.-39. Distribution of unidentified brown algae in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

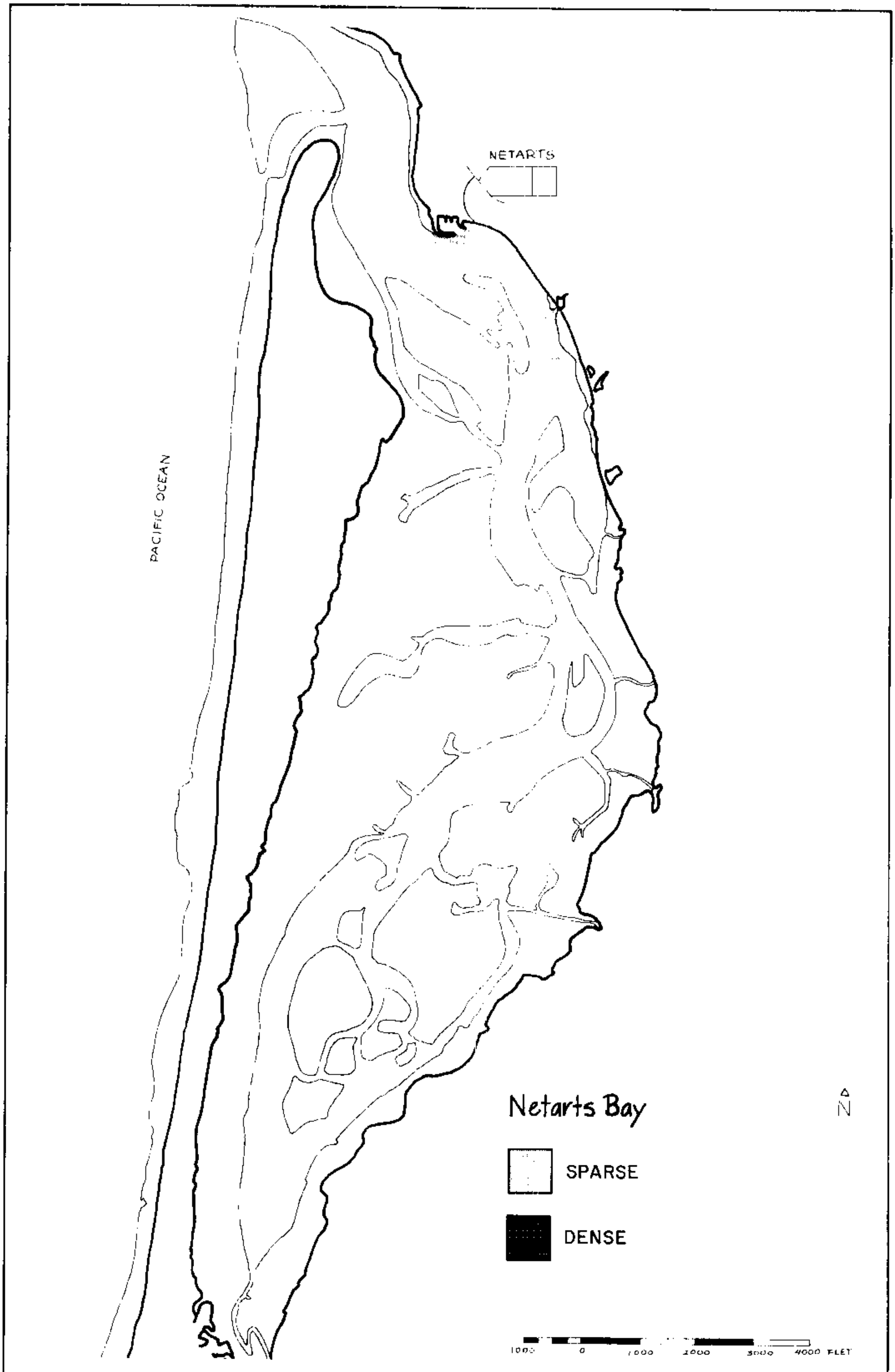

Figure II.A.2.-40. Distribution of unidentified red algae in Netarts Bay, Oregon. (See Fig. II.A.2.-23 for areas not surveyed.)

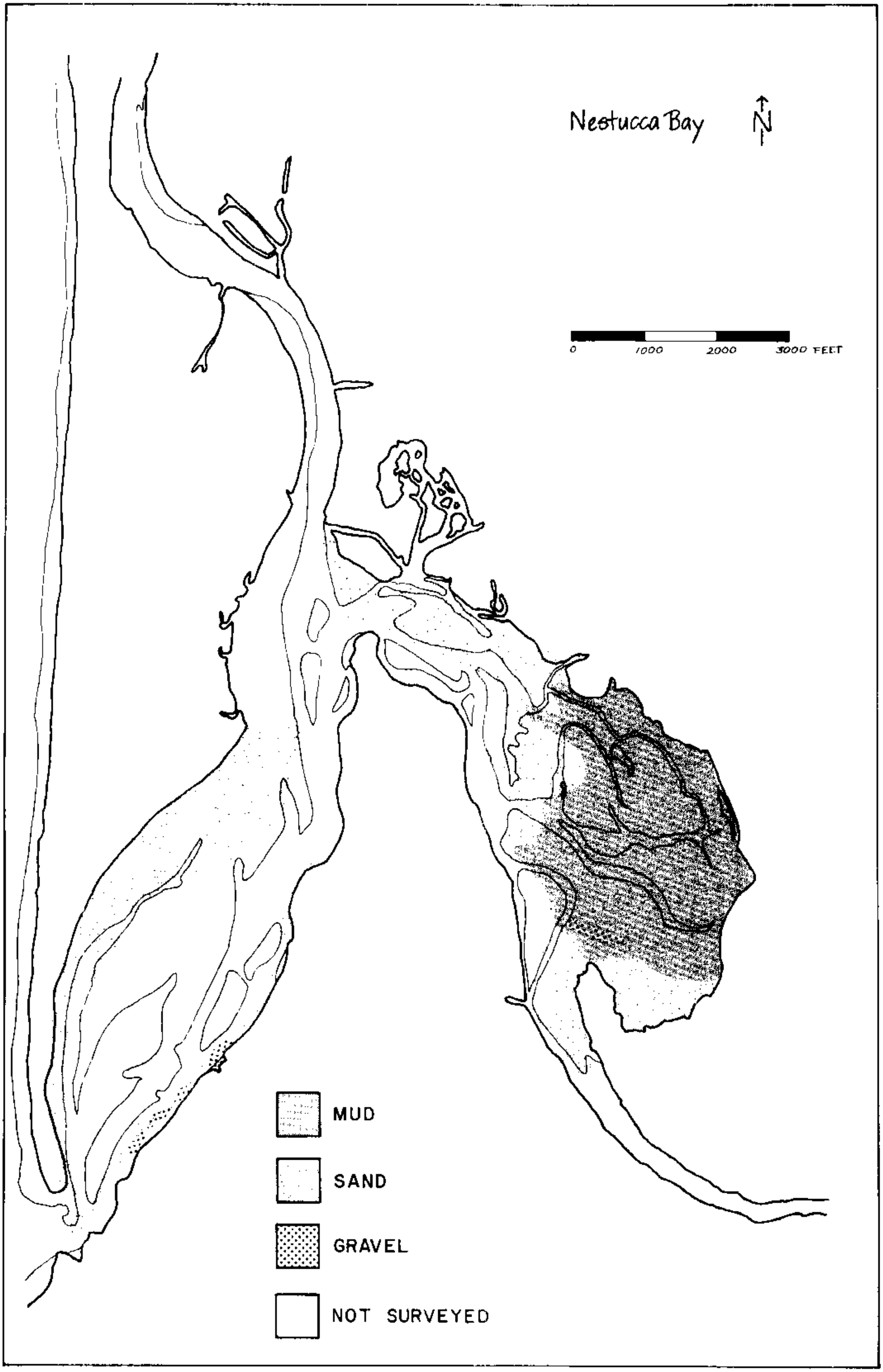

Figure II.A.2.-41. Distribution of substrate materials in Nestucca Bay, Oregon.

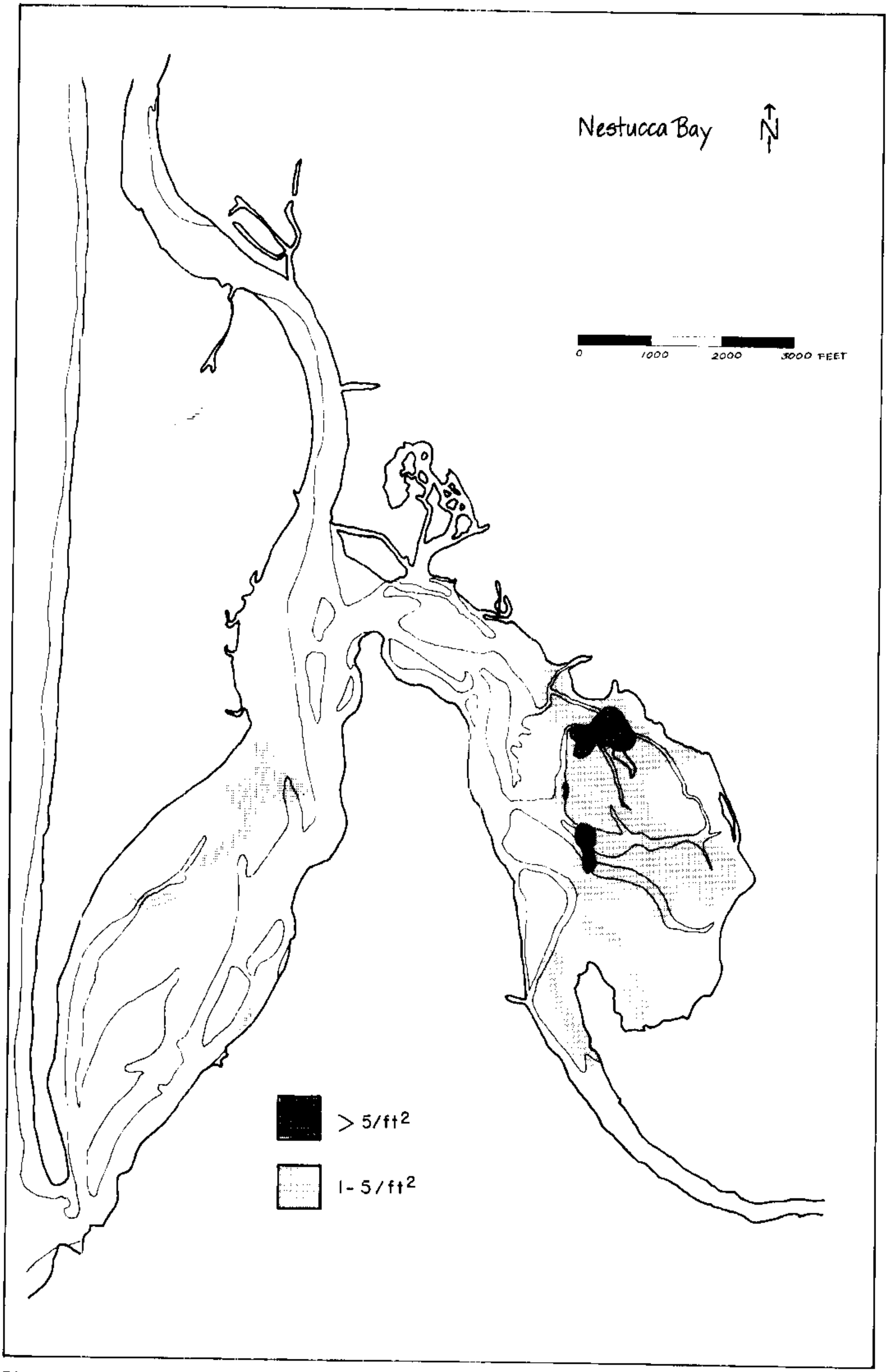

Figure II.A.2.-42. Distribution of softshell clams (*Mya arenaria*) in Nestucca Bay, Oregon. (See Fig. II.A.2.-41 for areas not surveyed.)

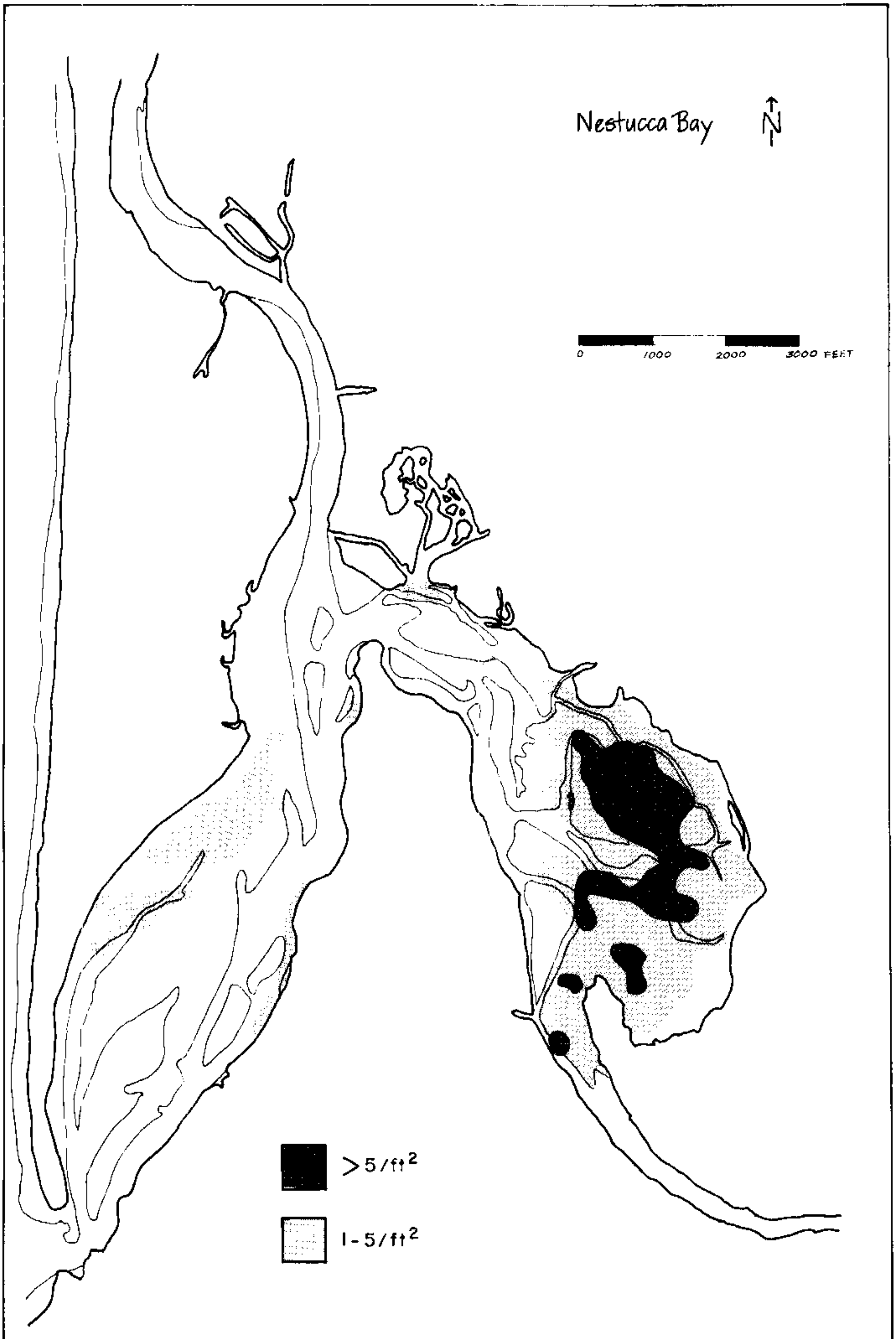

Figure II.A.2.-43. Distribution of Baltic clams (*Macoma balthica*) and irus clams (*M. irus*) in Nestucca Bay, Oregon. (See Fig. II.A.2.-41 for areas not surveyed.)

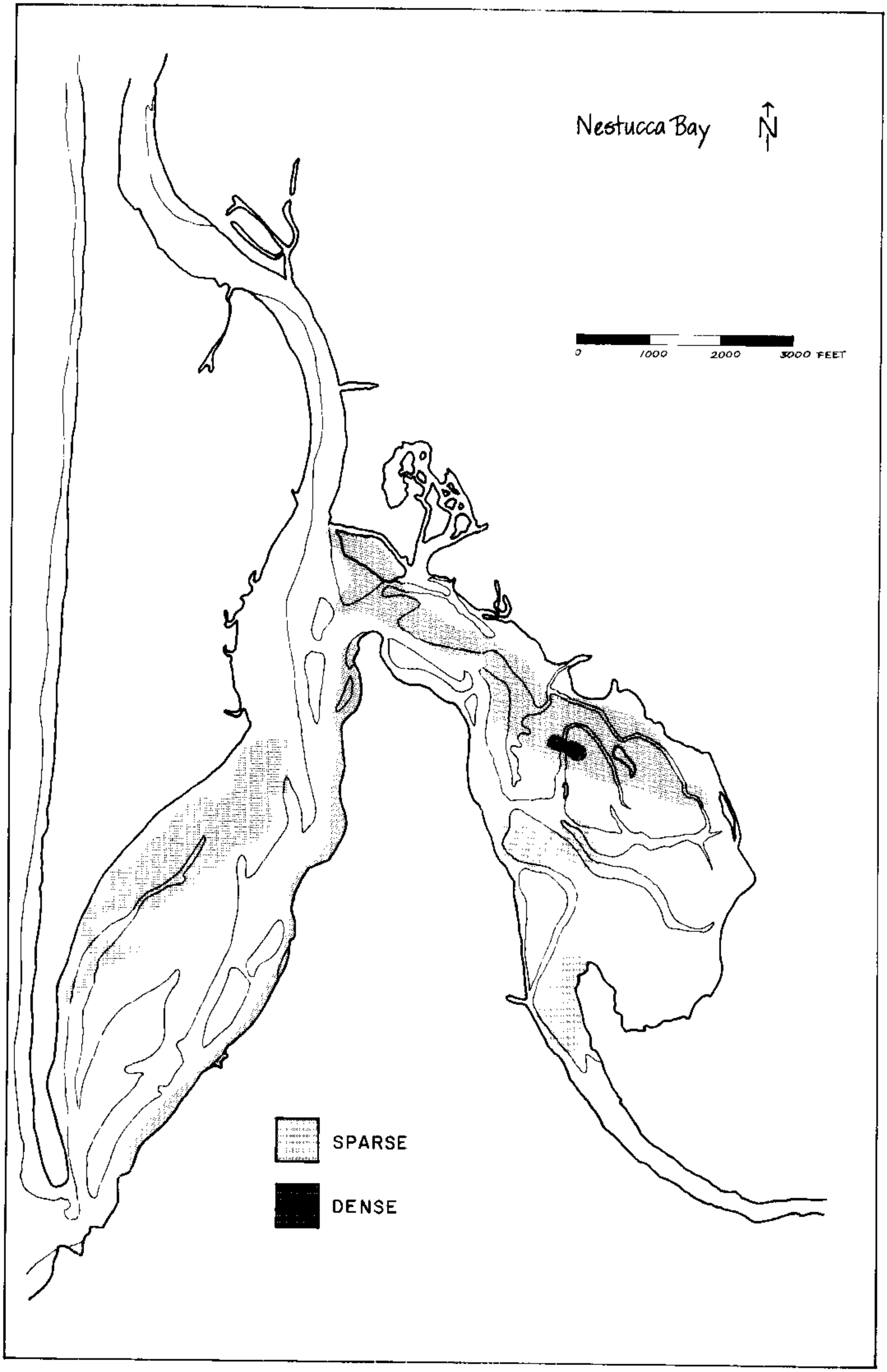

Figure II.A.2.-44. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in Nestucca Bay, Oregon. (See Fig. II.A.2.-41 for areas not surveyed.)

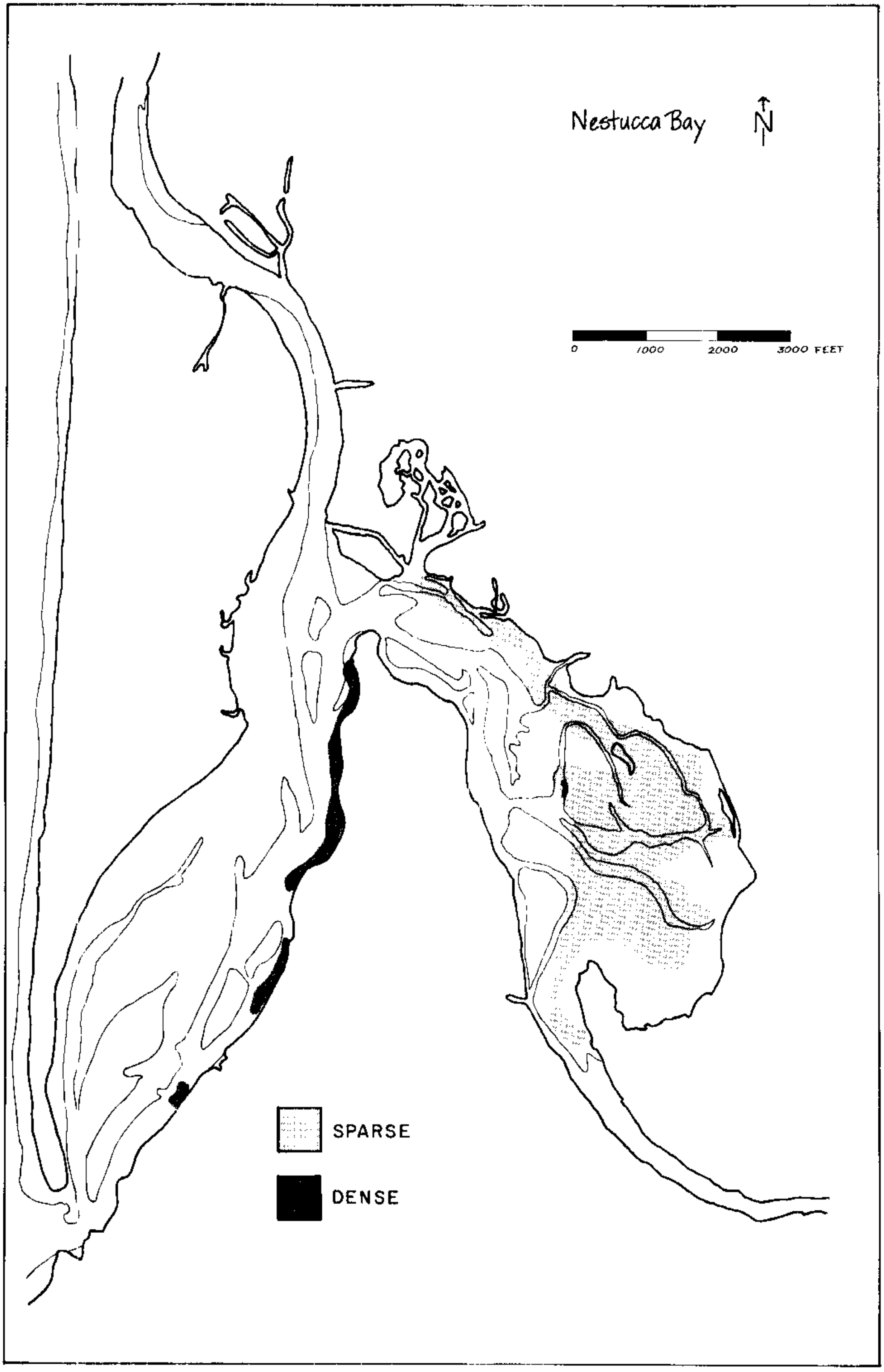

Figure II.A.2.-45. Distribution of eelgrass (*Zostera marina*) in Nestucca Bay, Oregon. (See Fig. II.A.2.-41 for areas not surveyed.)

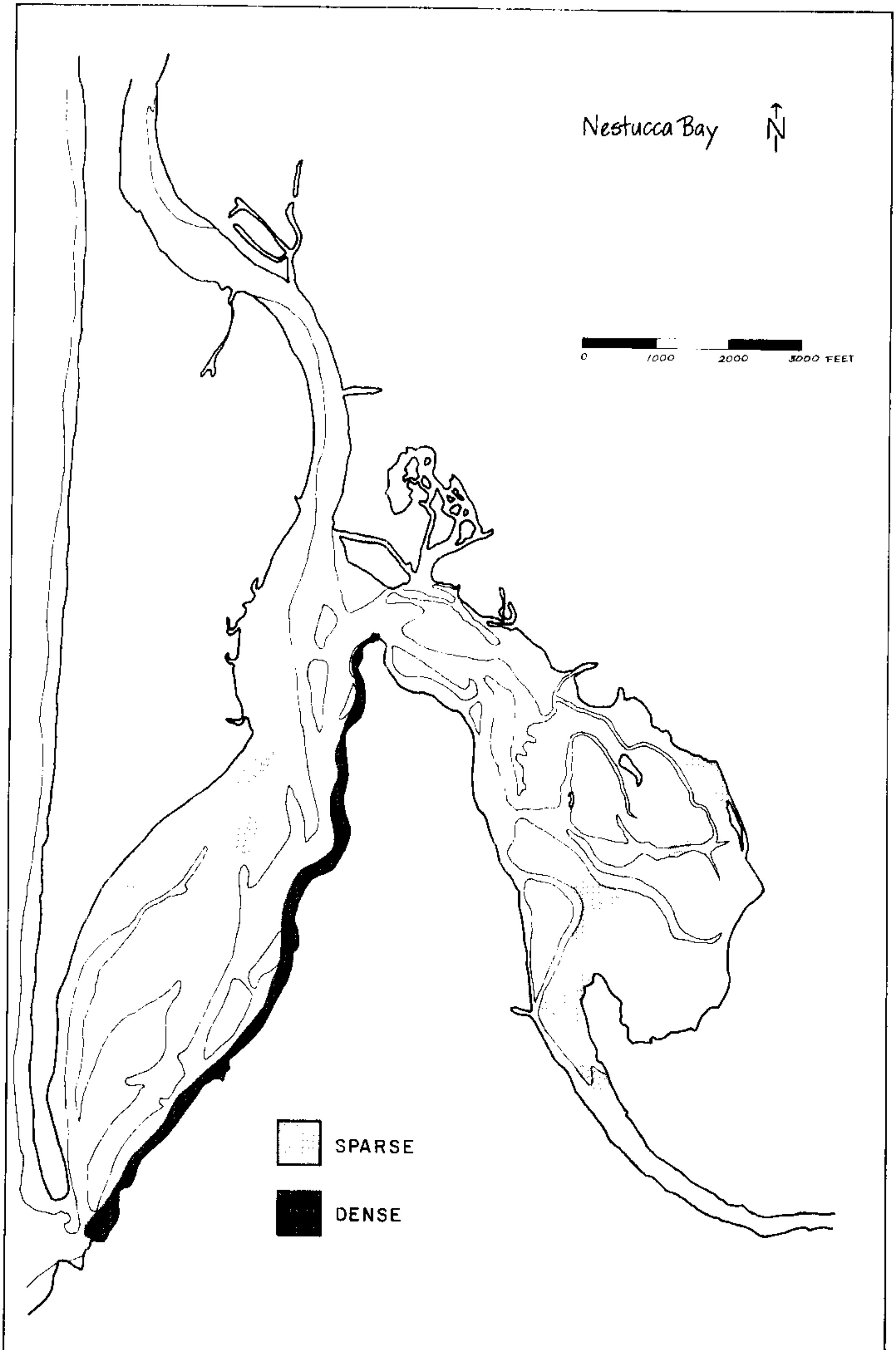

Figure II.A.2.-46. Distribution of sea lettuce (*Ulva* sp.) and *Entermorpha* in Nestucca Bay, Oregon. (See Fig. II.A.2.-41 for areas not surveyed.)

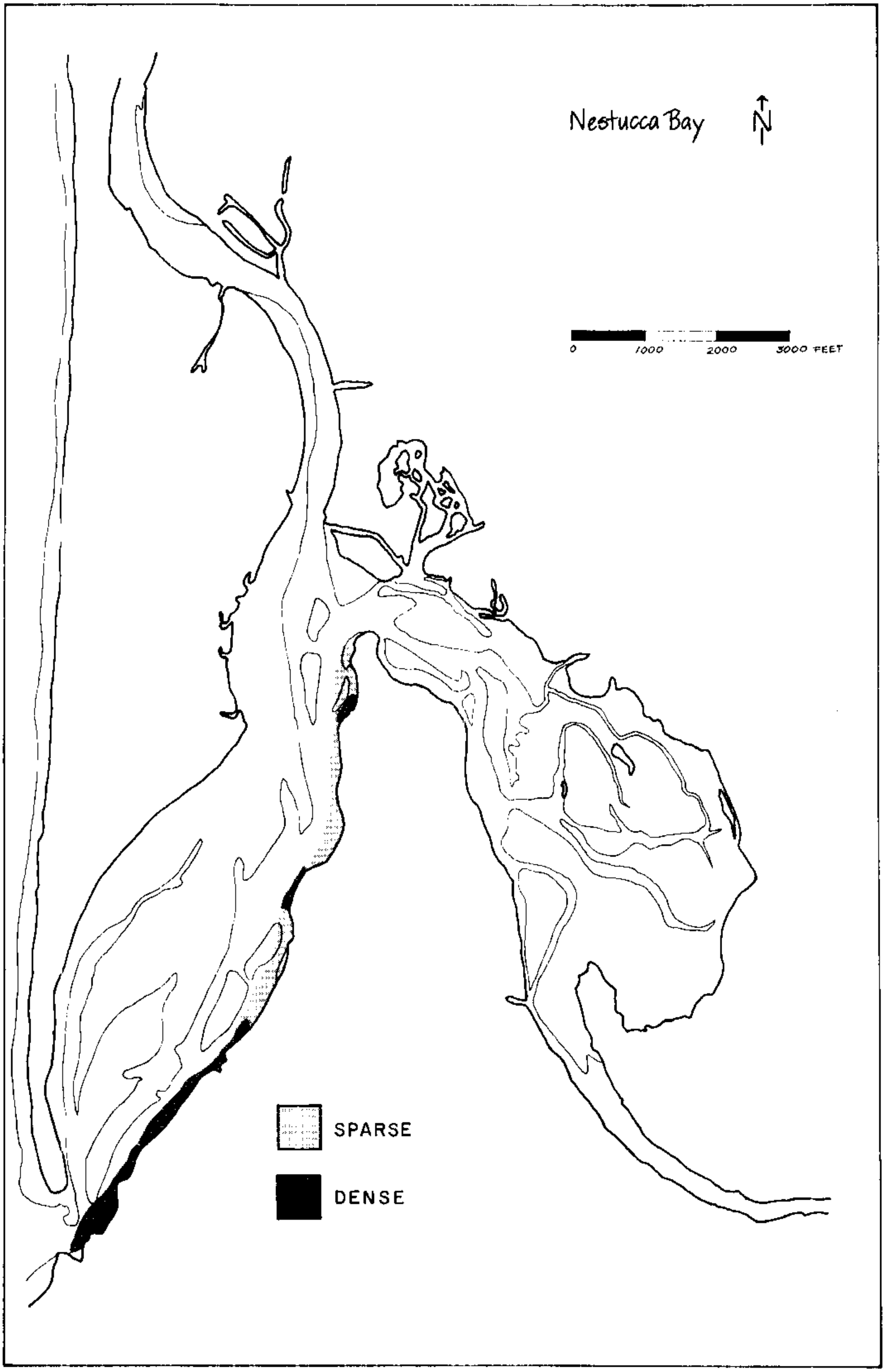

Figure II.A.2.-47. Distribution of rockweed (*Fucus* sp.) in Nestucca Bay, Oregon. (See Fig. II.A.2.-41 for areas not surveyed.)

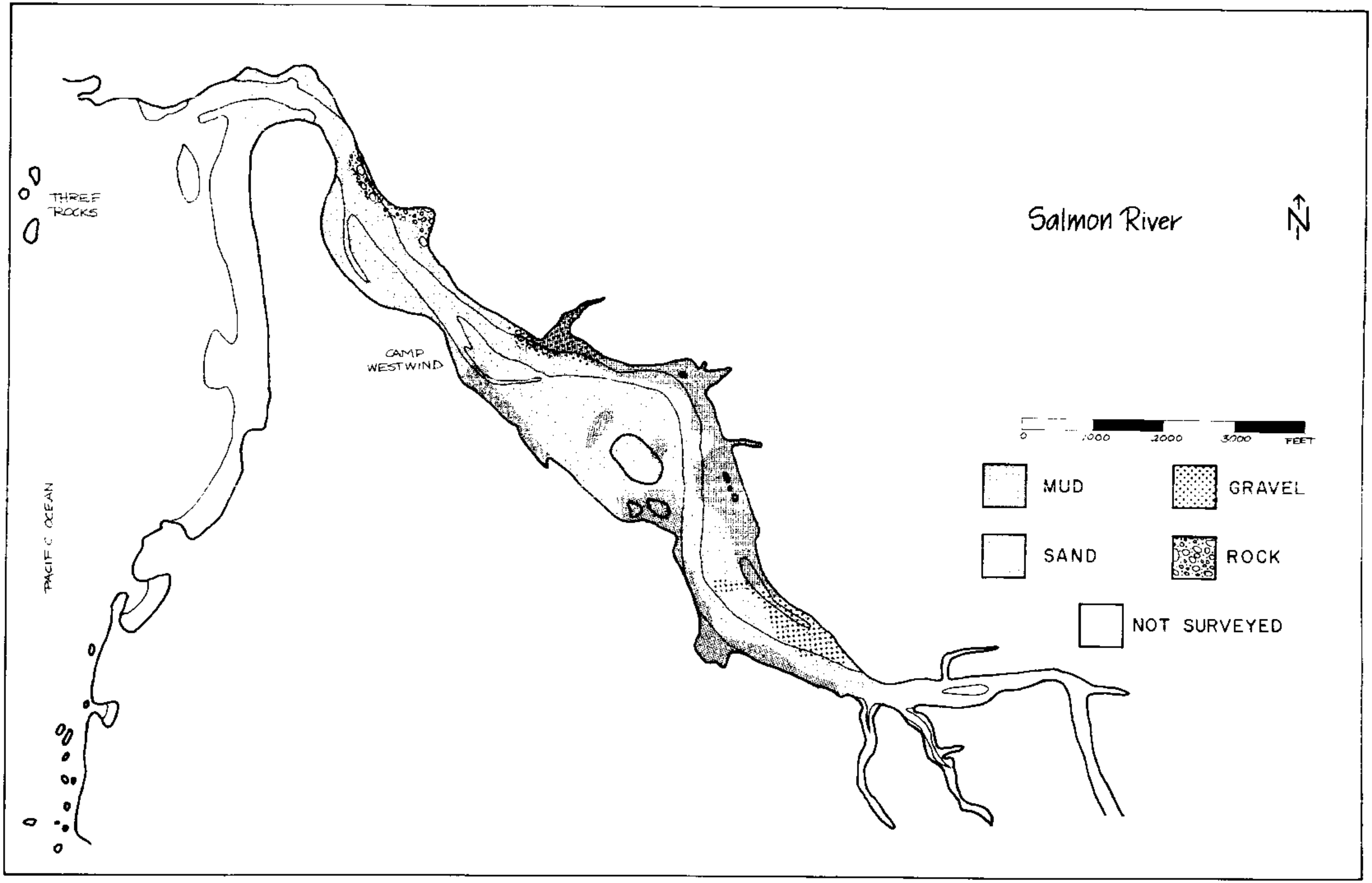

Figure II.A.2.-48. Distribution of substrate materials in the Salmon River, Oregon.

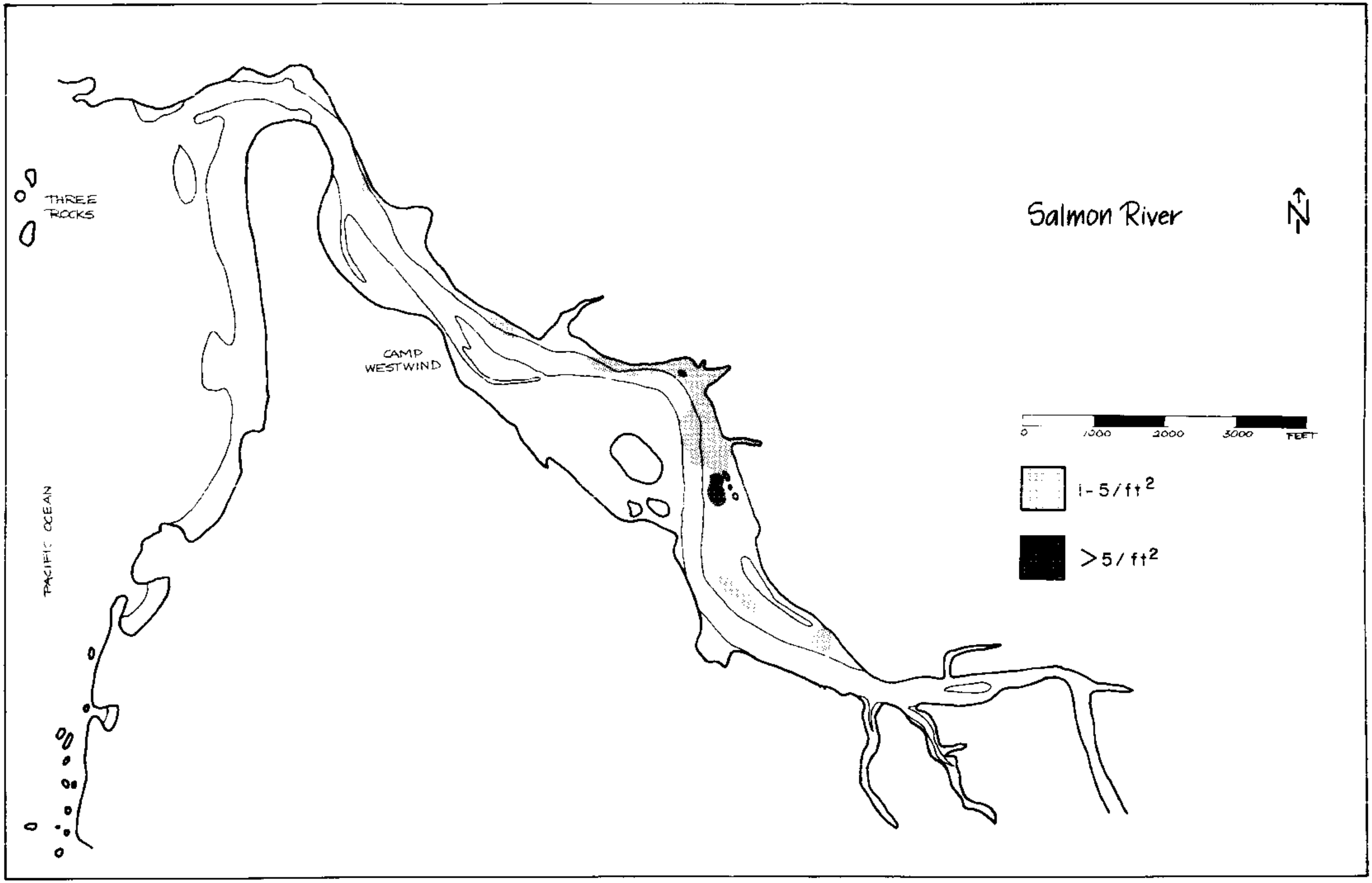

Figure II.A.2.-49. Distribution of softshell clams (*Mya arenaria*) in the Salmon River, Oregon. (See Fig. II.A.2.-48 for areas not surveyed.)

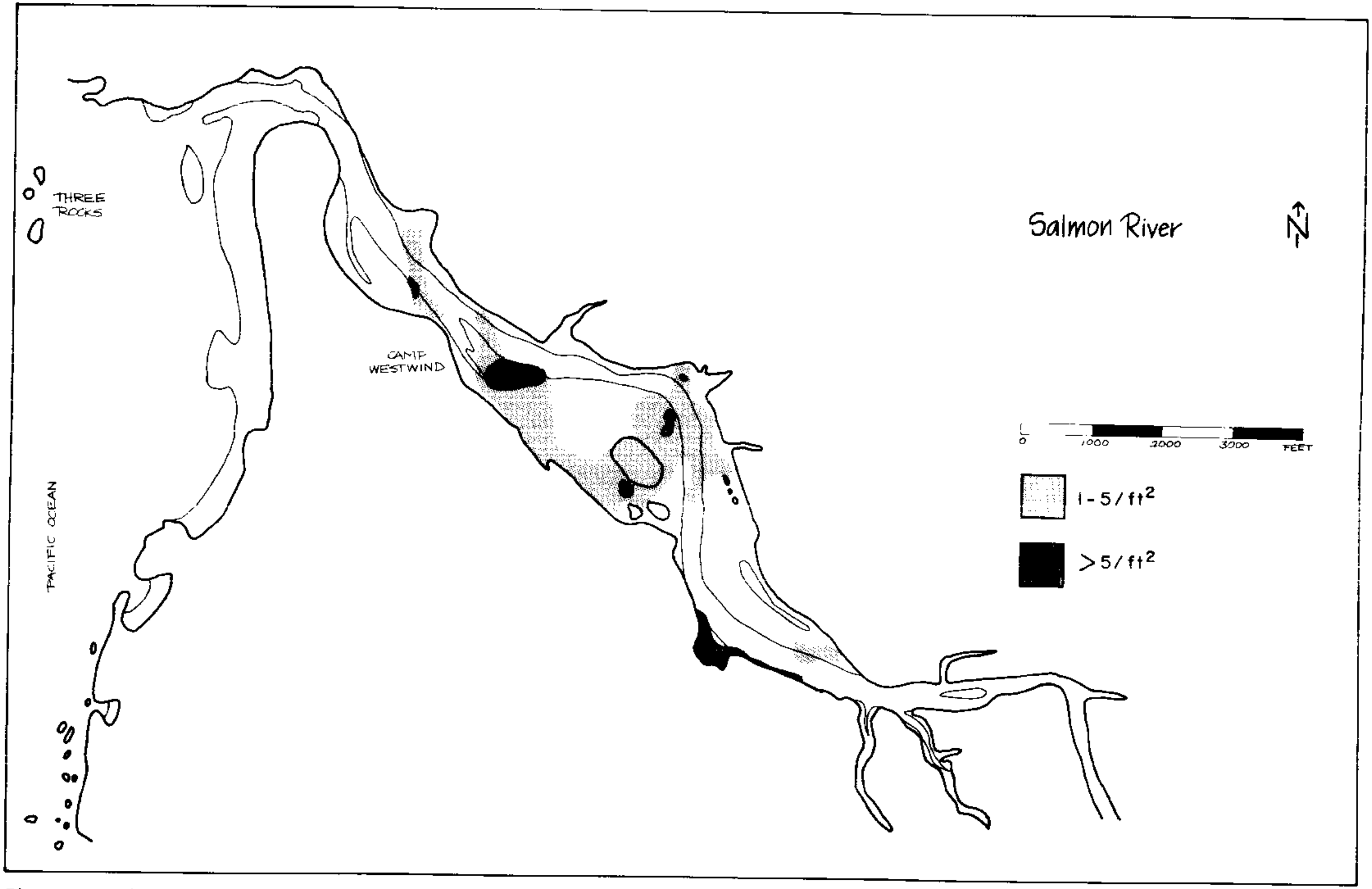

Figure II.A.2.-50. Distribution of Baltic clams (*Macoma balthica*) in the Salmon River, Oregon. (See Fig. II.A.2.-48 for areas not surveyed.)

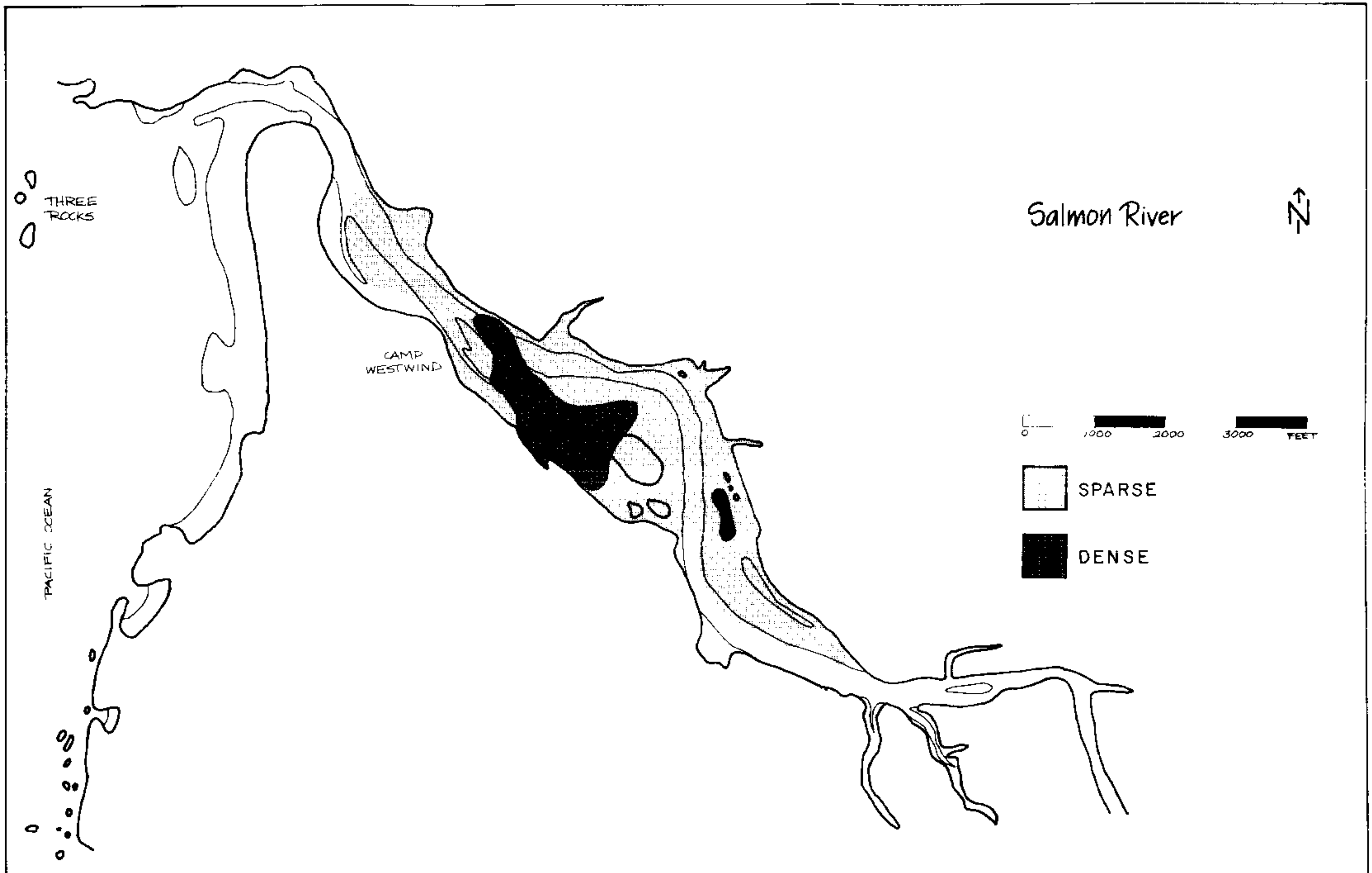

Figure II.A.2.-51. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in the Salmon River, Oregon. (See Fig. II.A.2.-48 for areas not surveyed.)

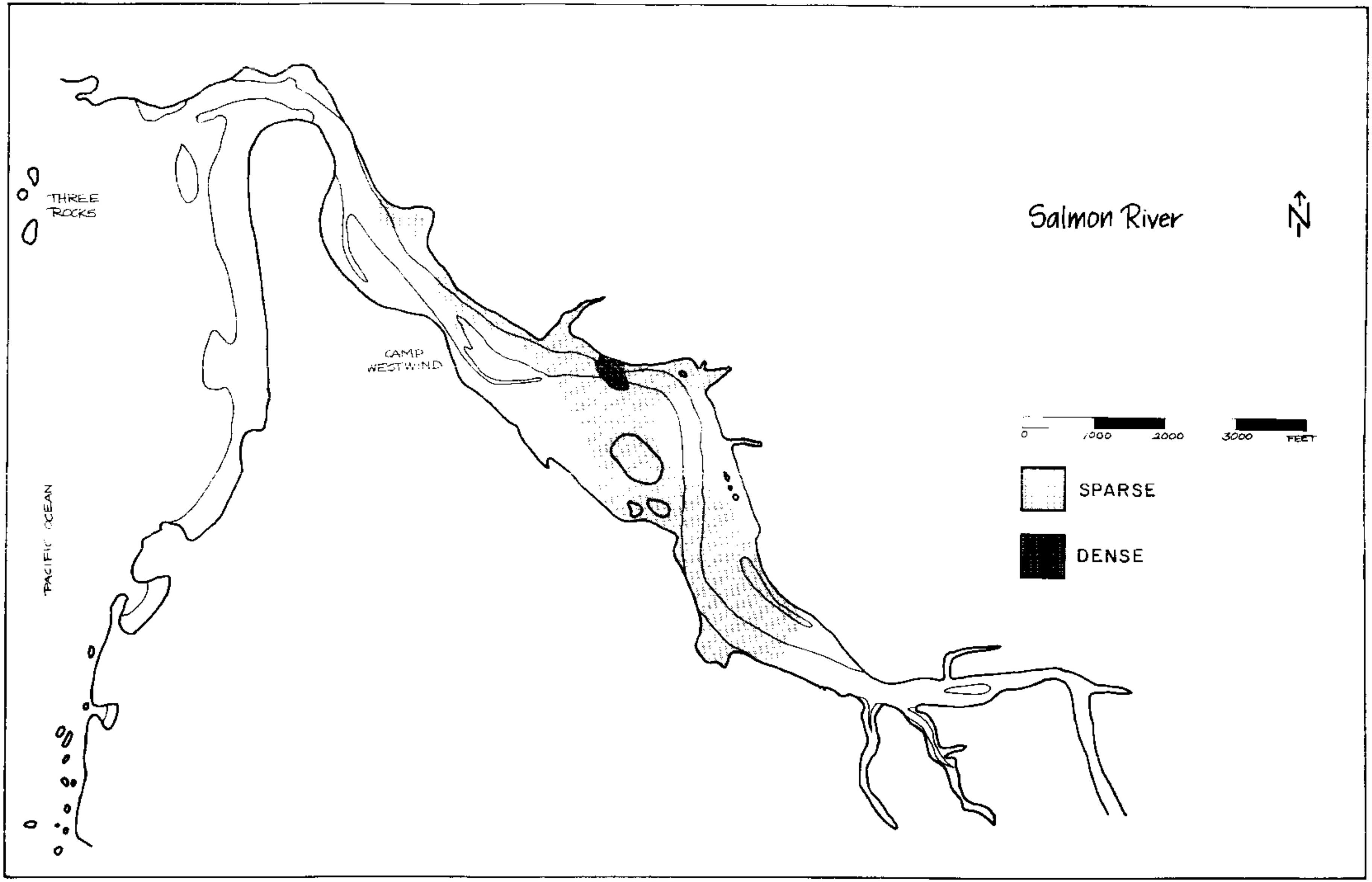

Figure II.A.2.-52. Distribution of eelgrass (*Zostera marina*) in the Salmon River, Oregon. (See Fig. II.A.2.-48 for areas not surveyed.)

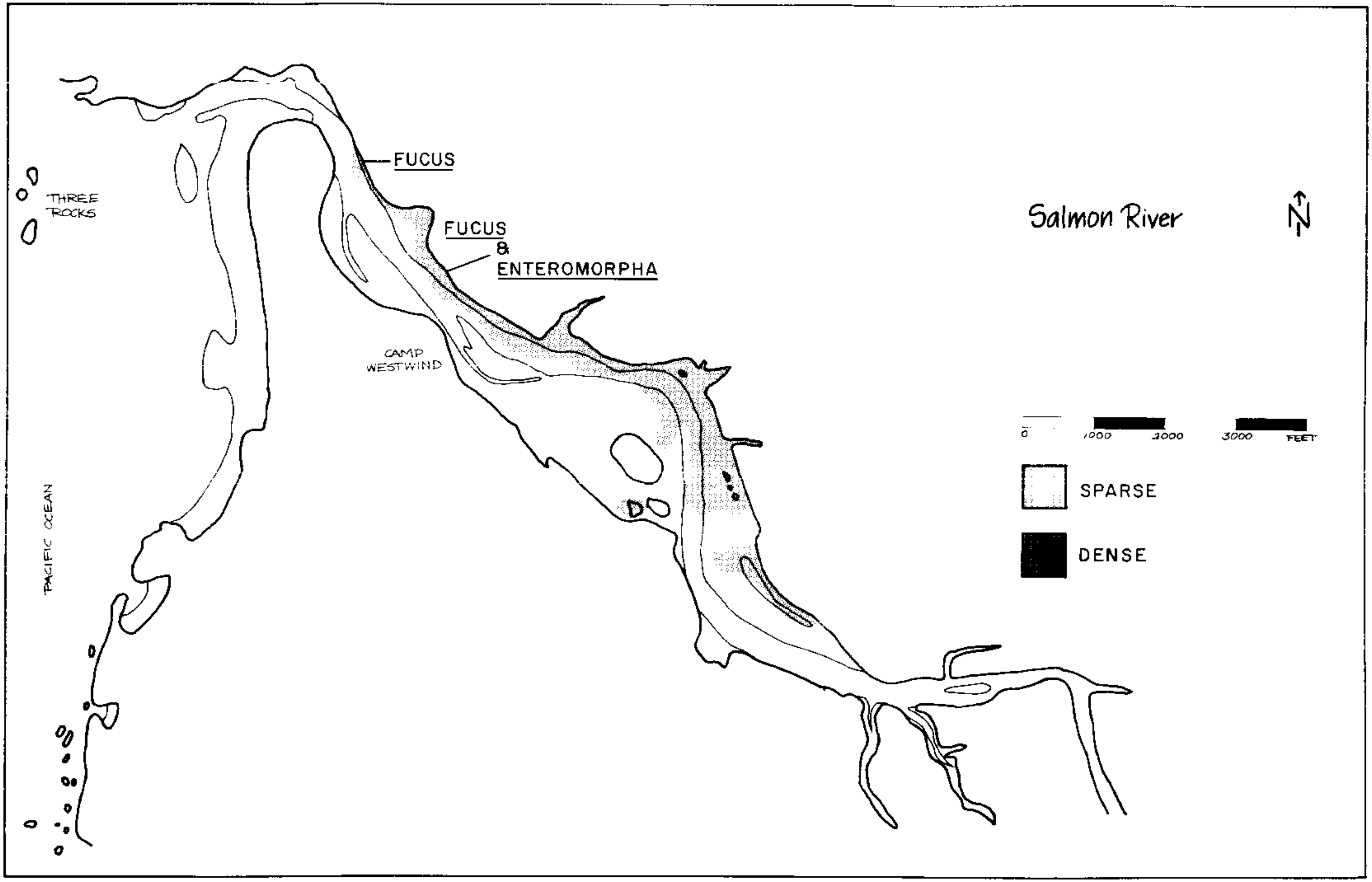

Figure II.A.2.-53. Distribution of sea lettuce (*Ulva* sp.) in the Salmon River, Oregon. (See Fig. II.A.2.-48 for areas not surveyed.)

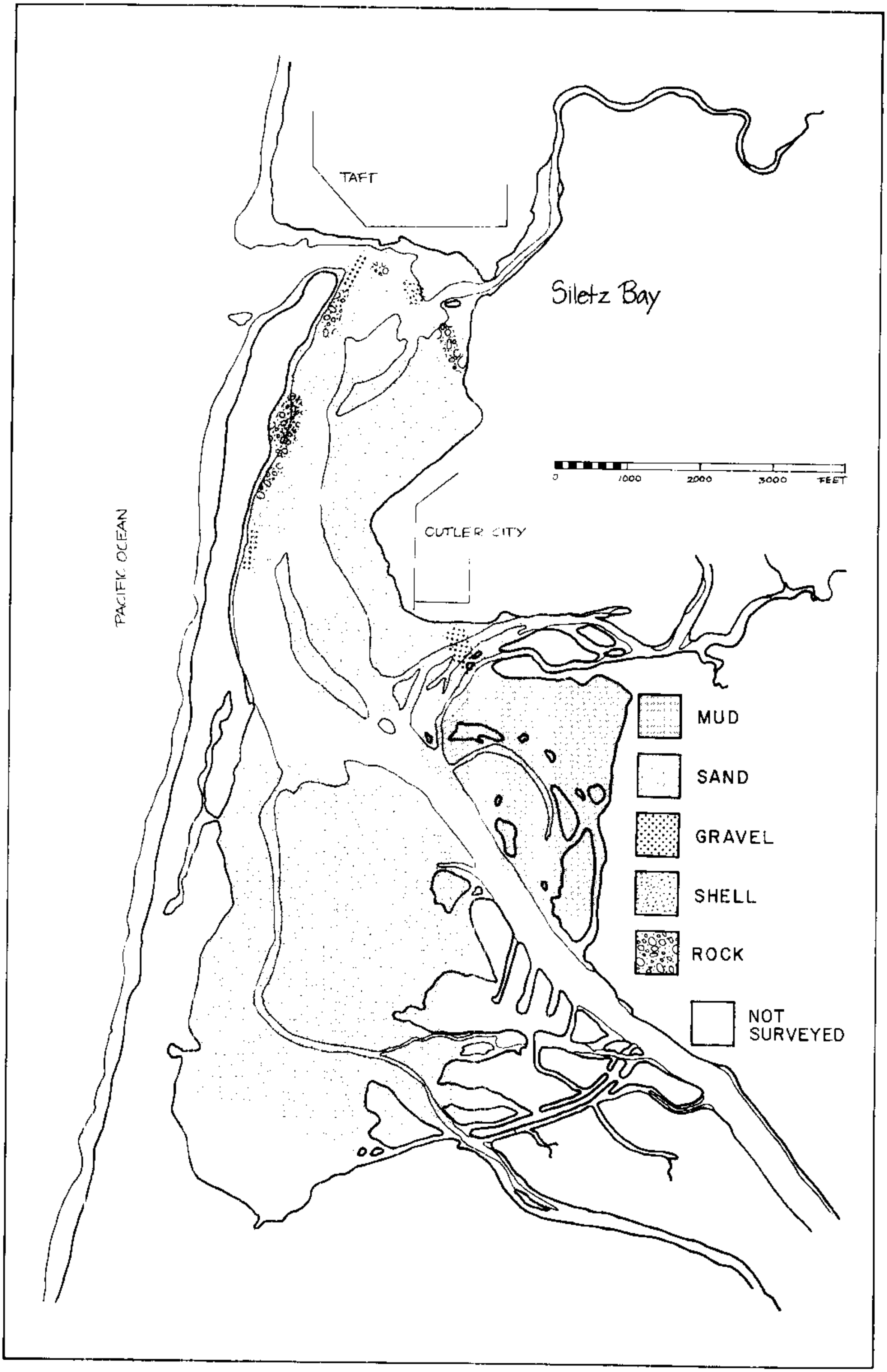

Figure II.A.2.-54. Distribution of substrate materials in Siletz Bay, Oregon.

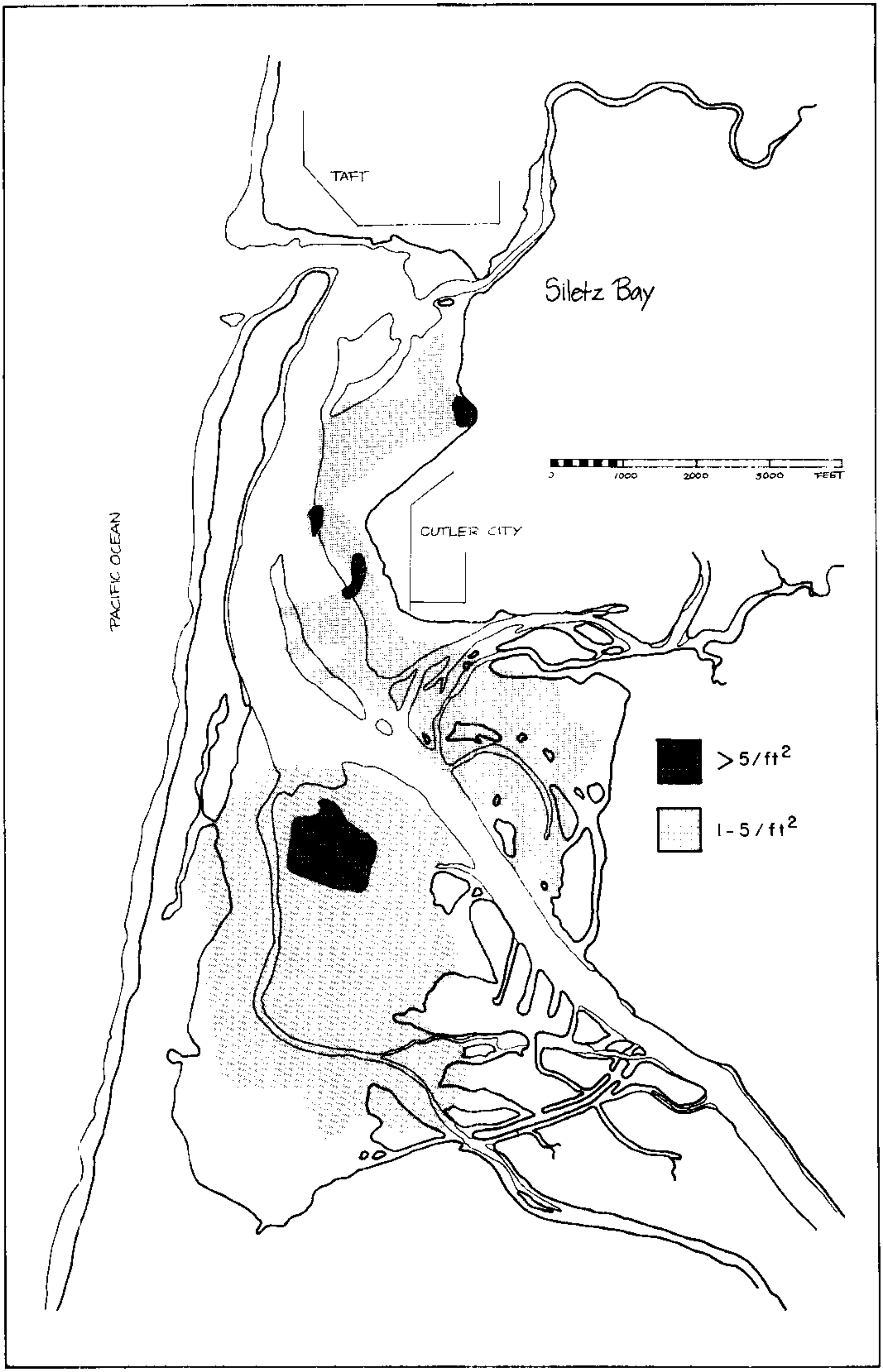

Figure II.A.2.-55. Distribution of softshell clams (*Mya arenaria*) in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

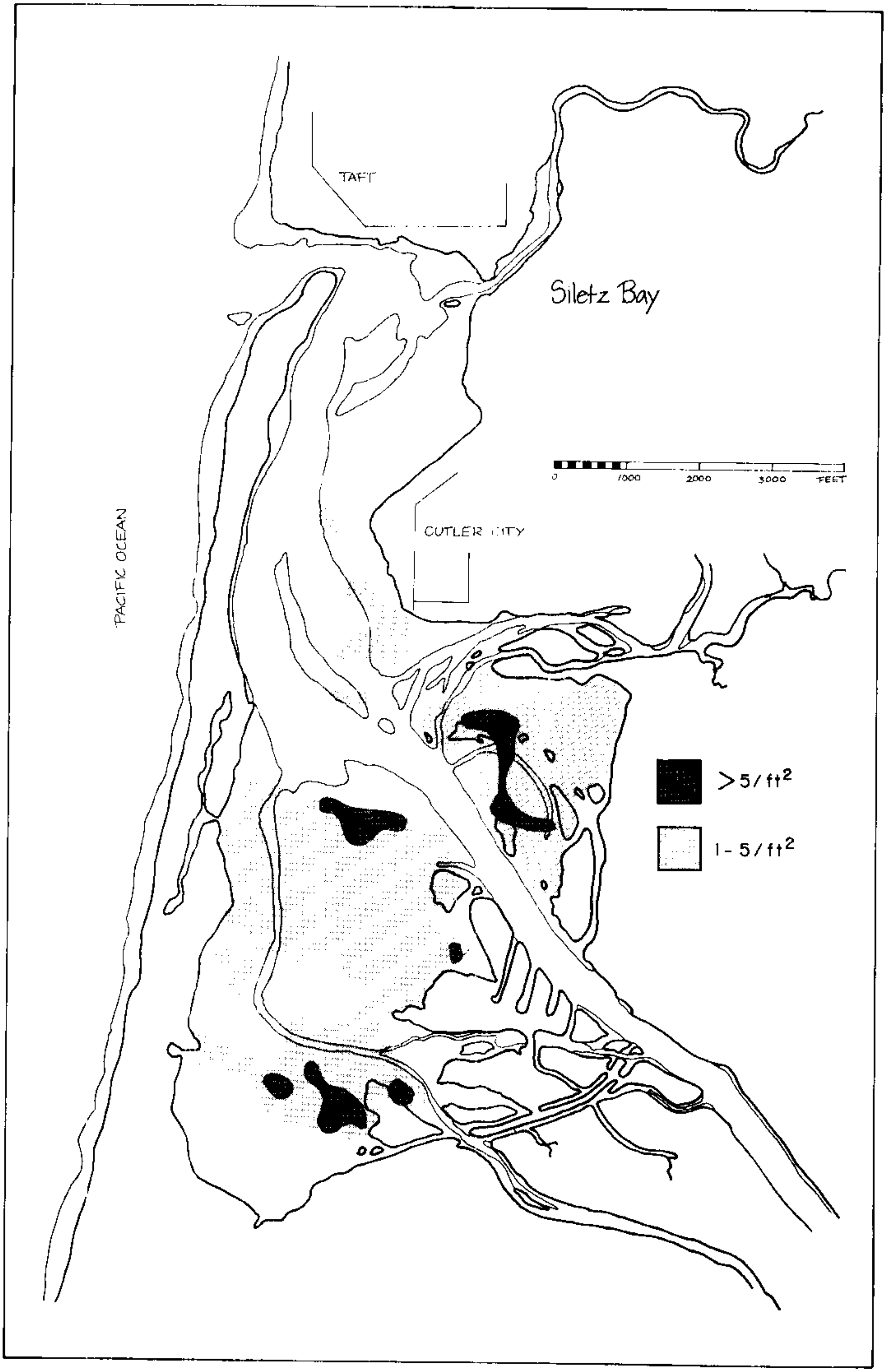

Figure II.A.2.-56. Distribution of Baltic clams (*Macoma balthica*) in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

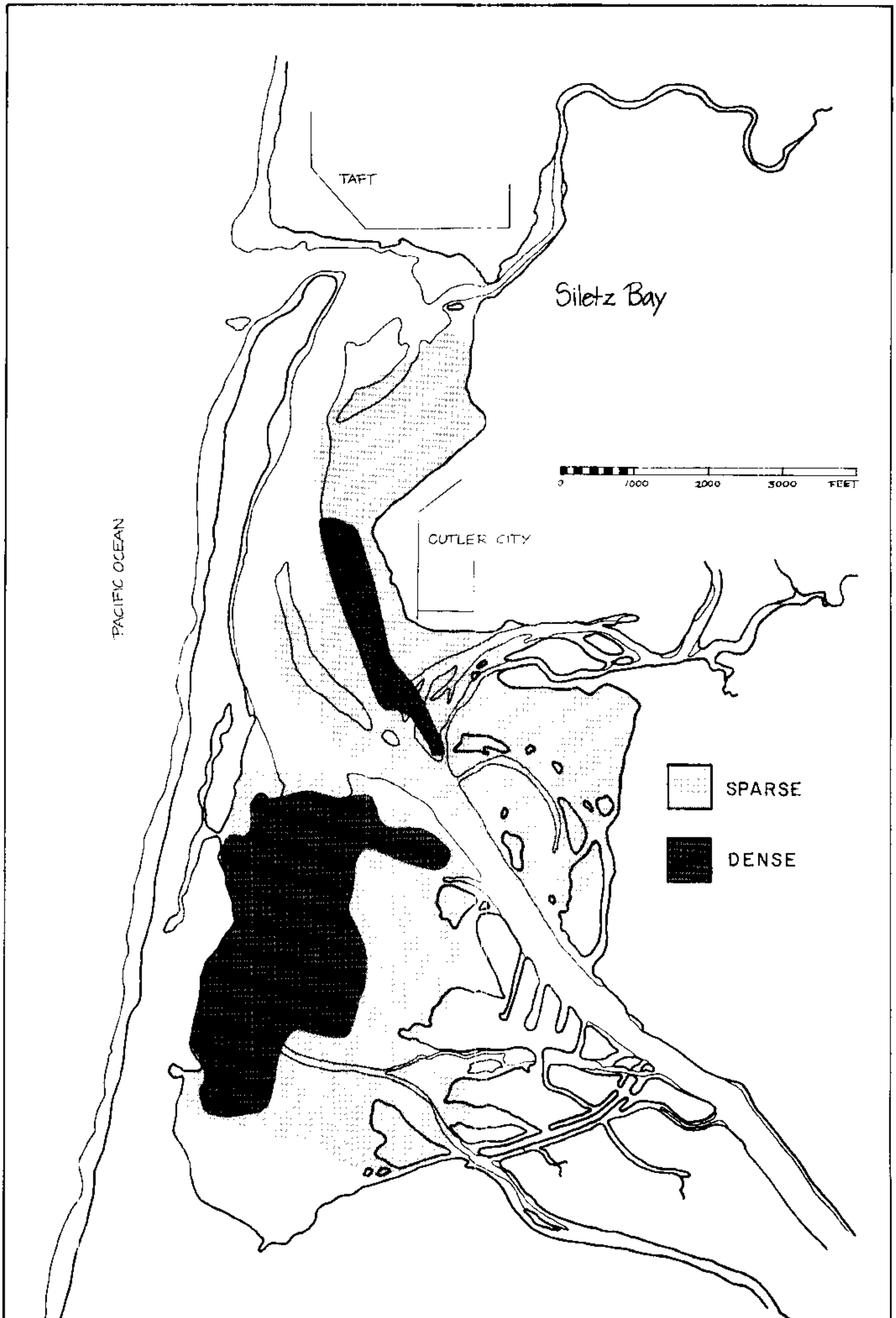

Figure II.A.2.-57. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

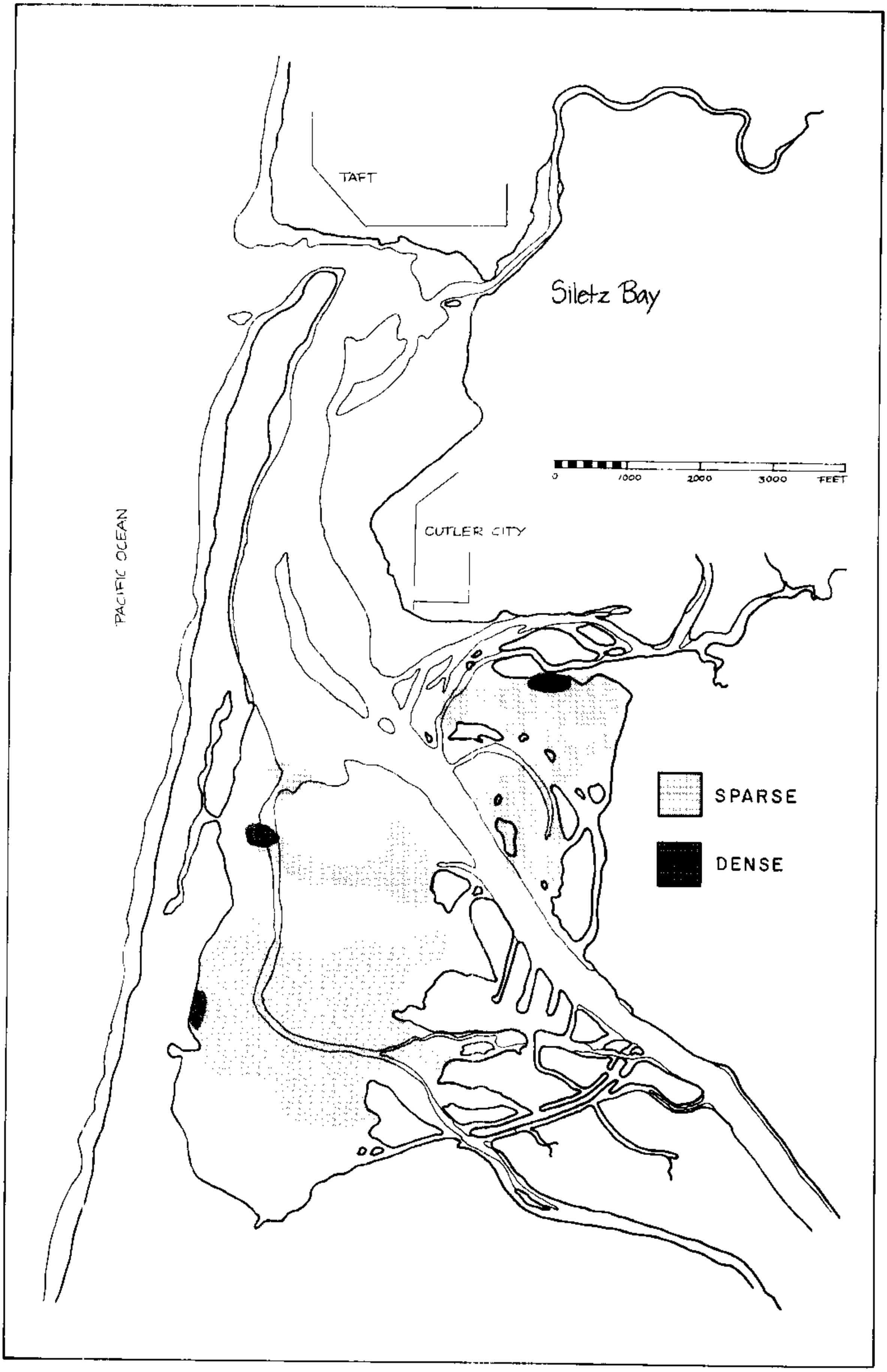

Figure II.A.2.-58. Distribution of eelgrass (*Zostera marina*) in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

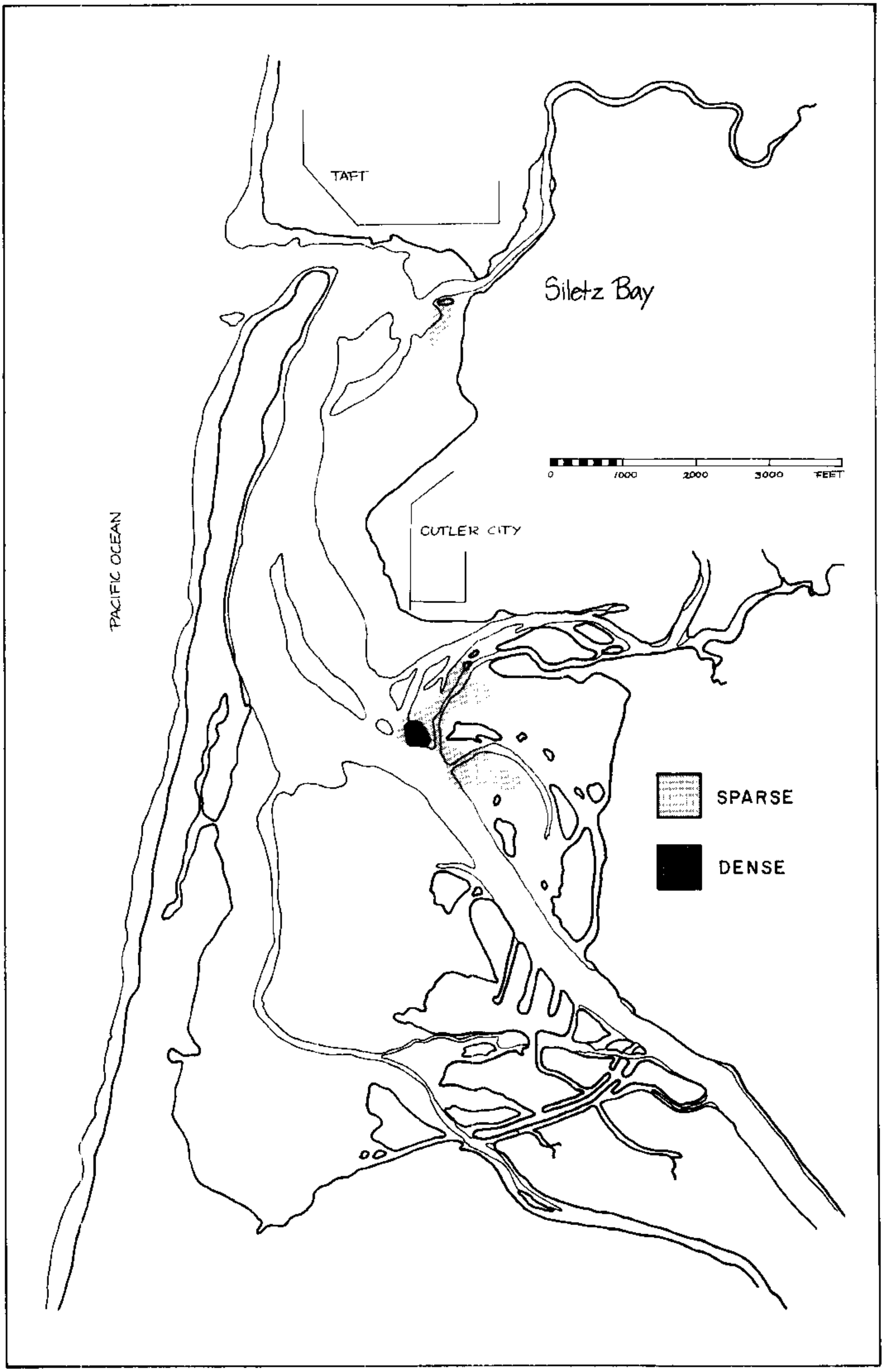

Figure II.A.2.-59. Distribution of sea lettuce (*Ulva* sp.) in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

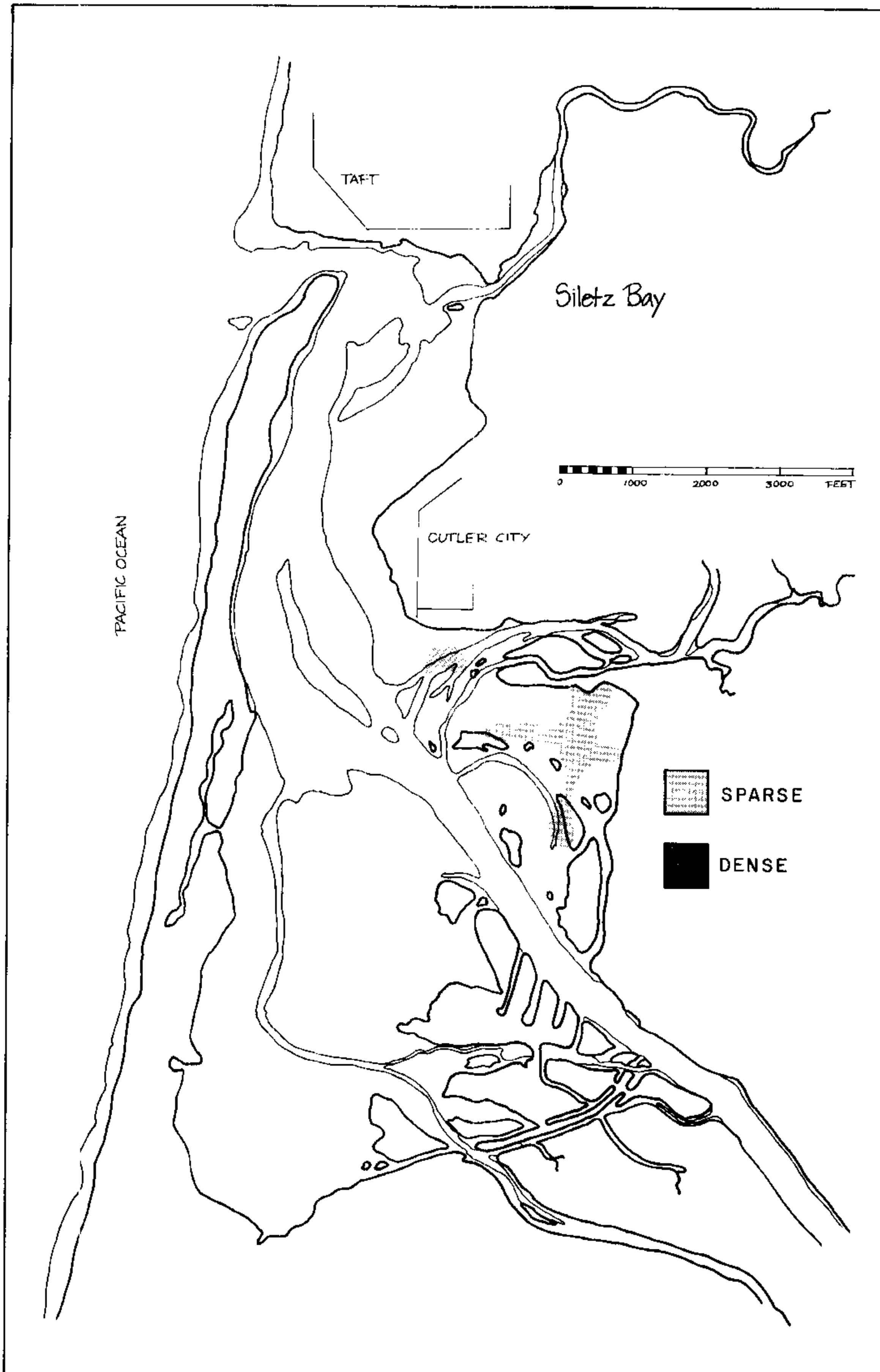

Figure II.A.2.-60. Distribution of the green alga *Enteromorpha* sp. in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

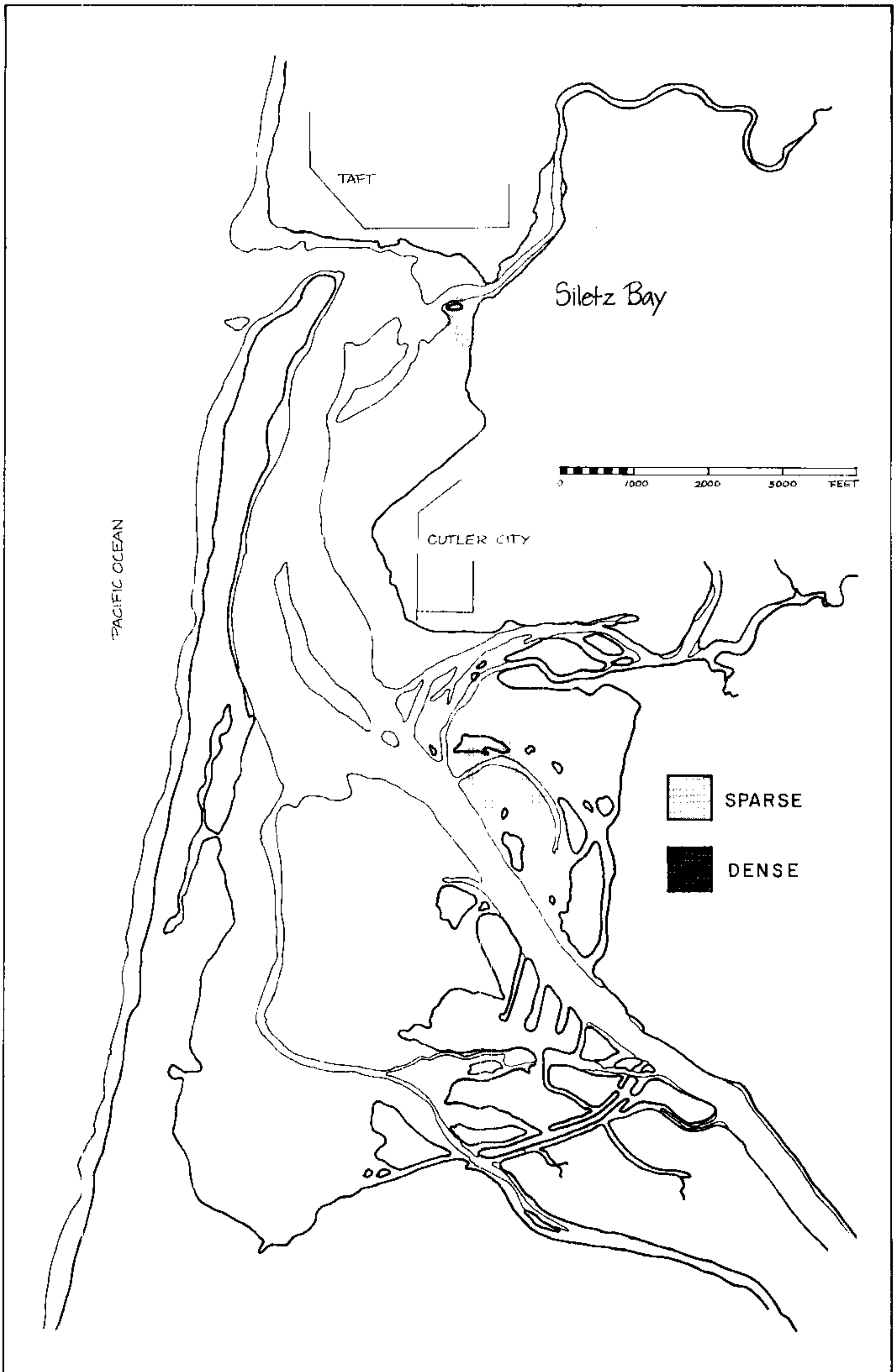

Figure II.A.2.-61. Distribution of rockweed (*Fucus* sp.) in Siletz Bay, Oregon. (See Fig. II.A.2.-54 for areas not surveyed.)

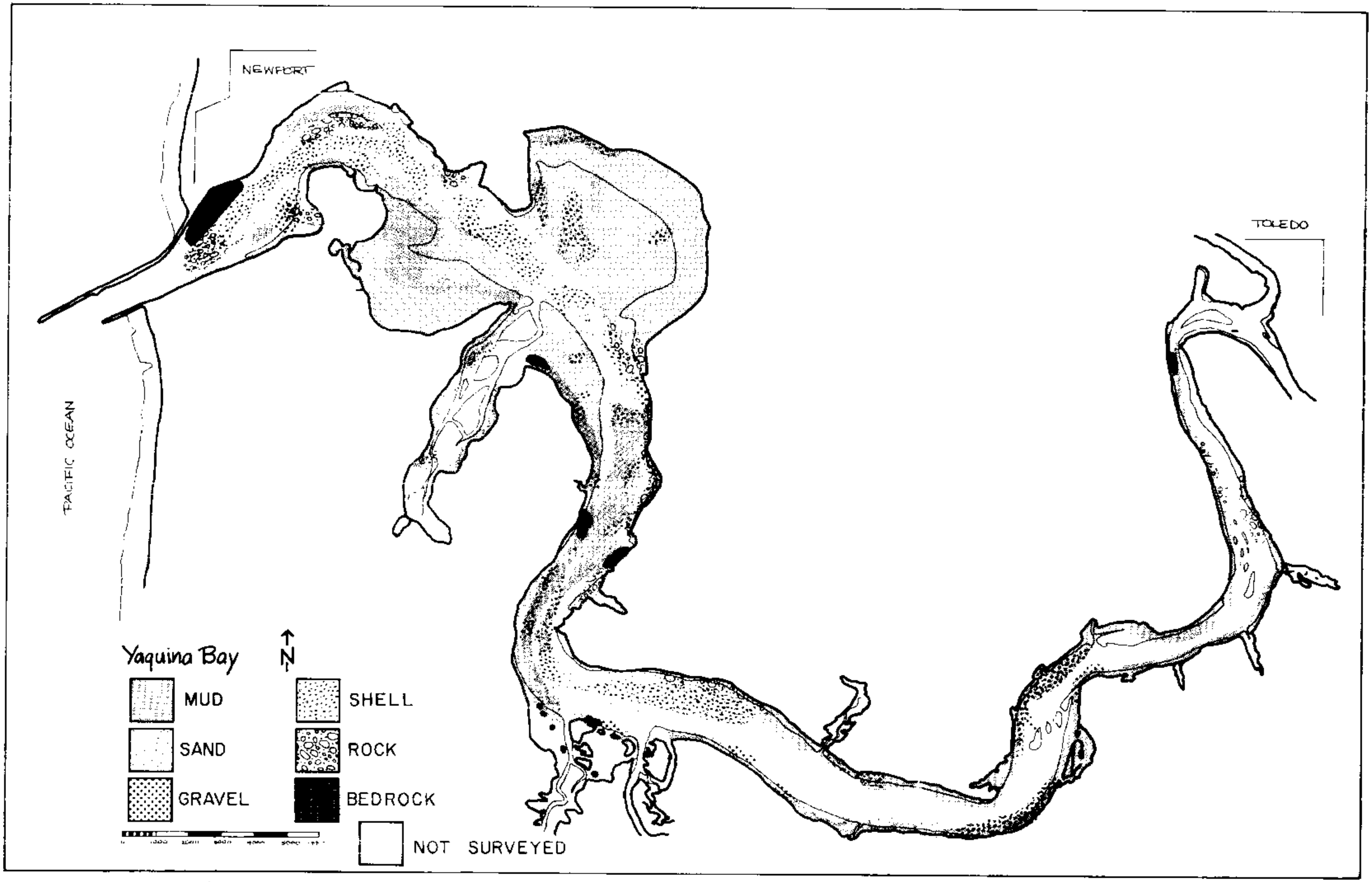

Figure II.A.2.-62. Distribution of substrate materials in Yaquina Bay, Oregon.

Figure II.A.2.-63. Distribution of gaper clams (*Tresus capax*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

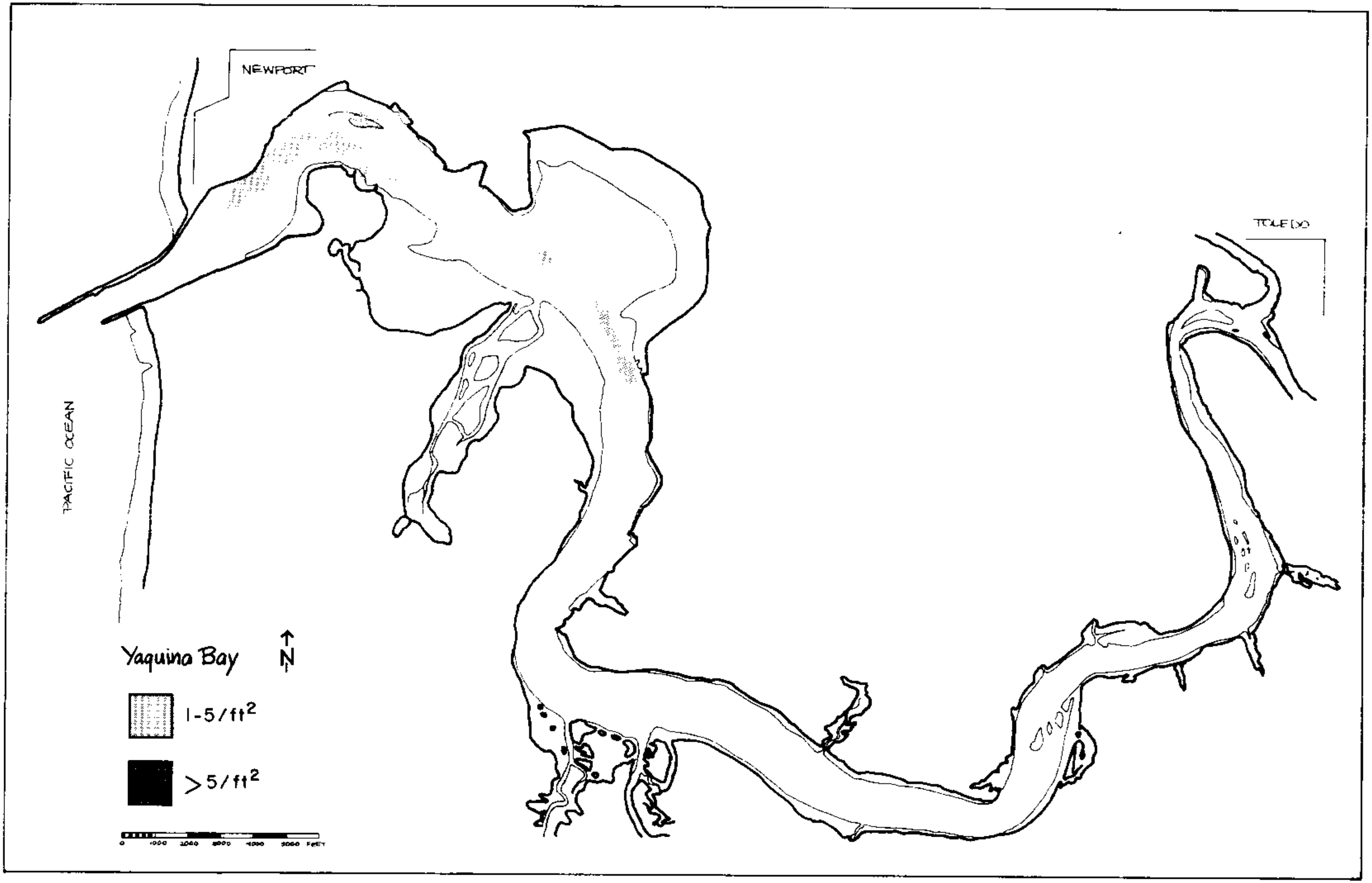

Figure II.A.2.-64. Distribution of butter clams (*Saxidomus giganteus*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

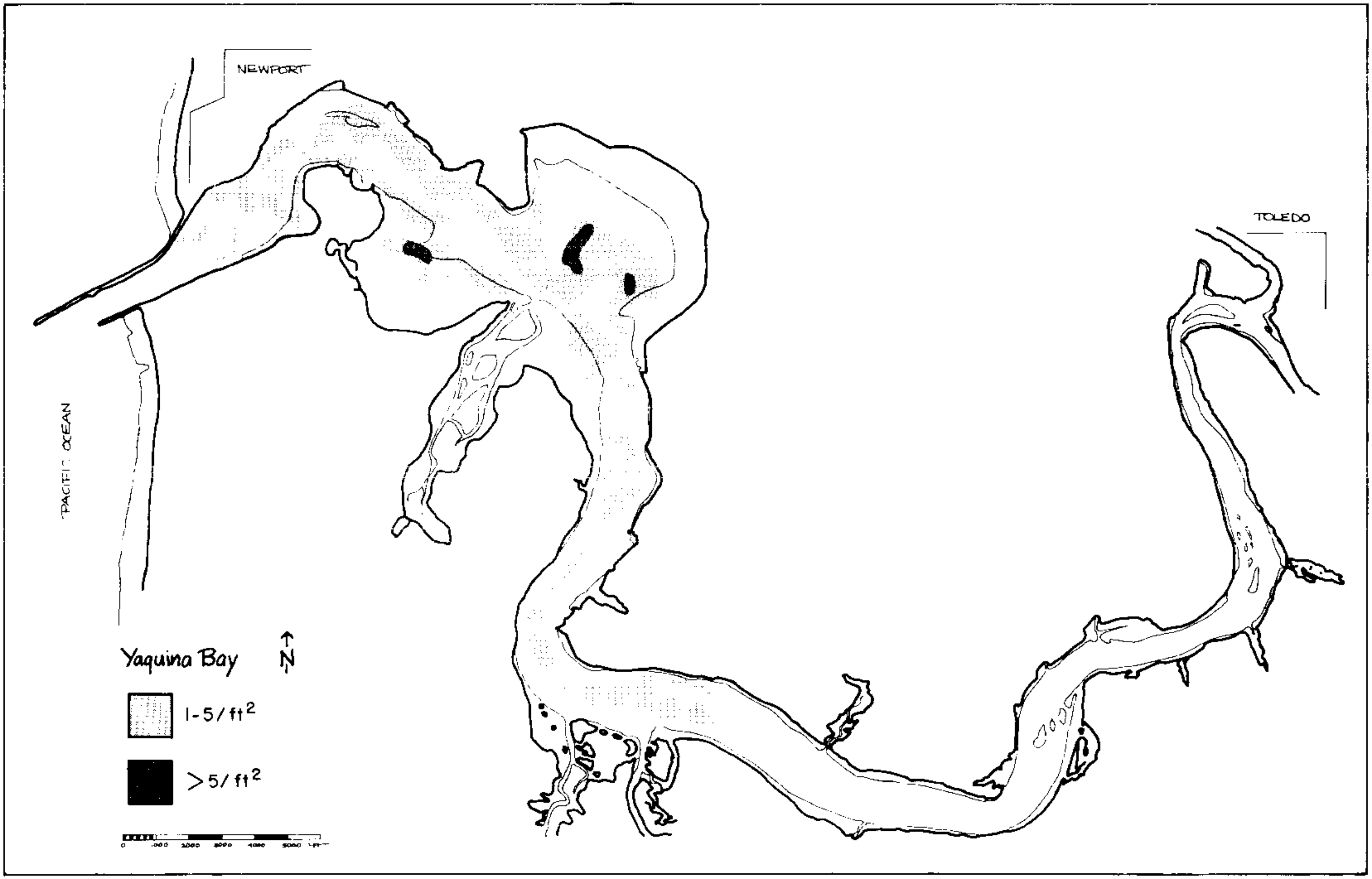

Figure II.A.2.-65. Distribution of cockle clams (*Clinocardium nuttallii*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

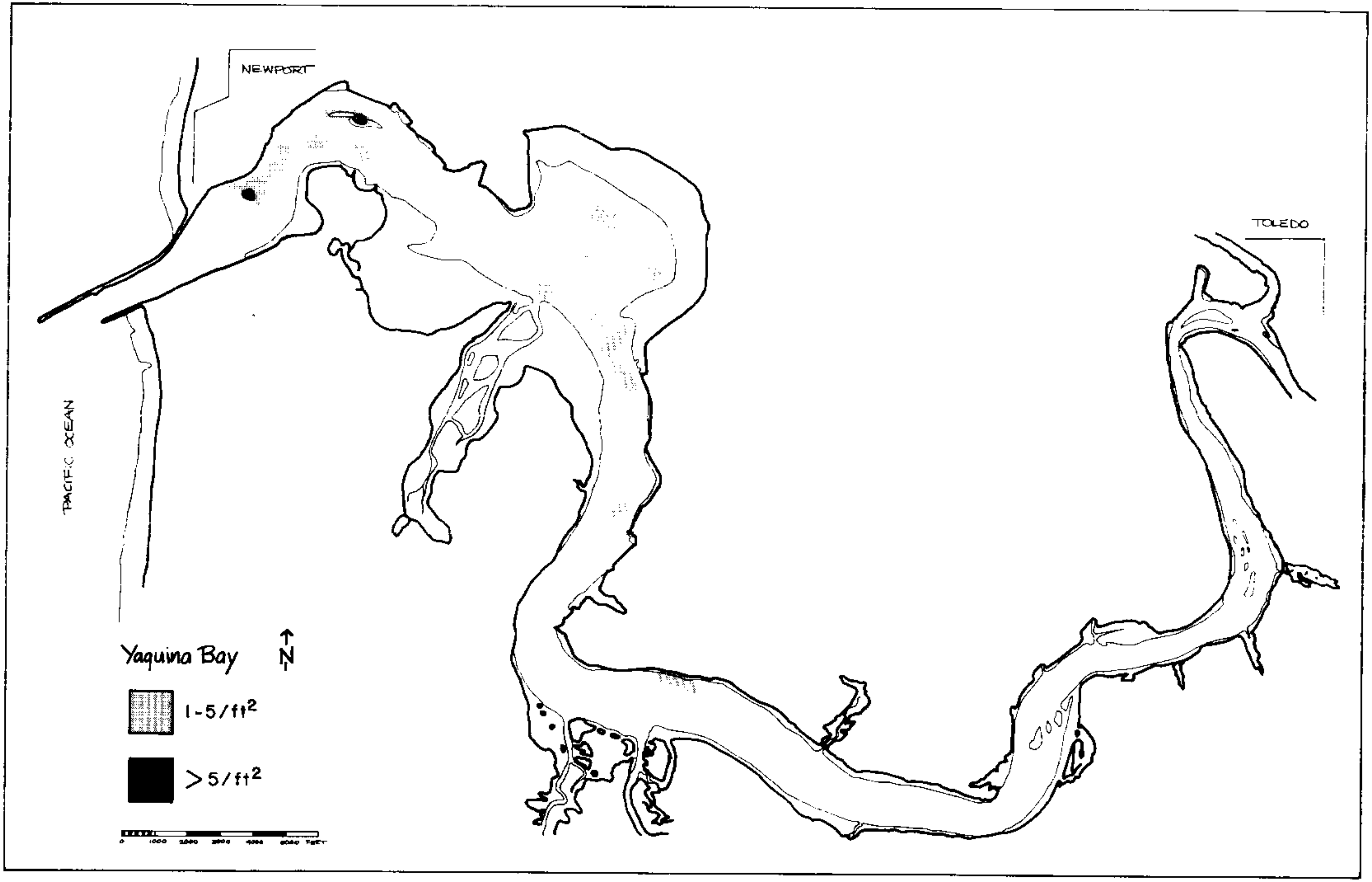

Figure II.A.2.-66. Distribution of native littleneck clams (*Venerupis staminea*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

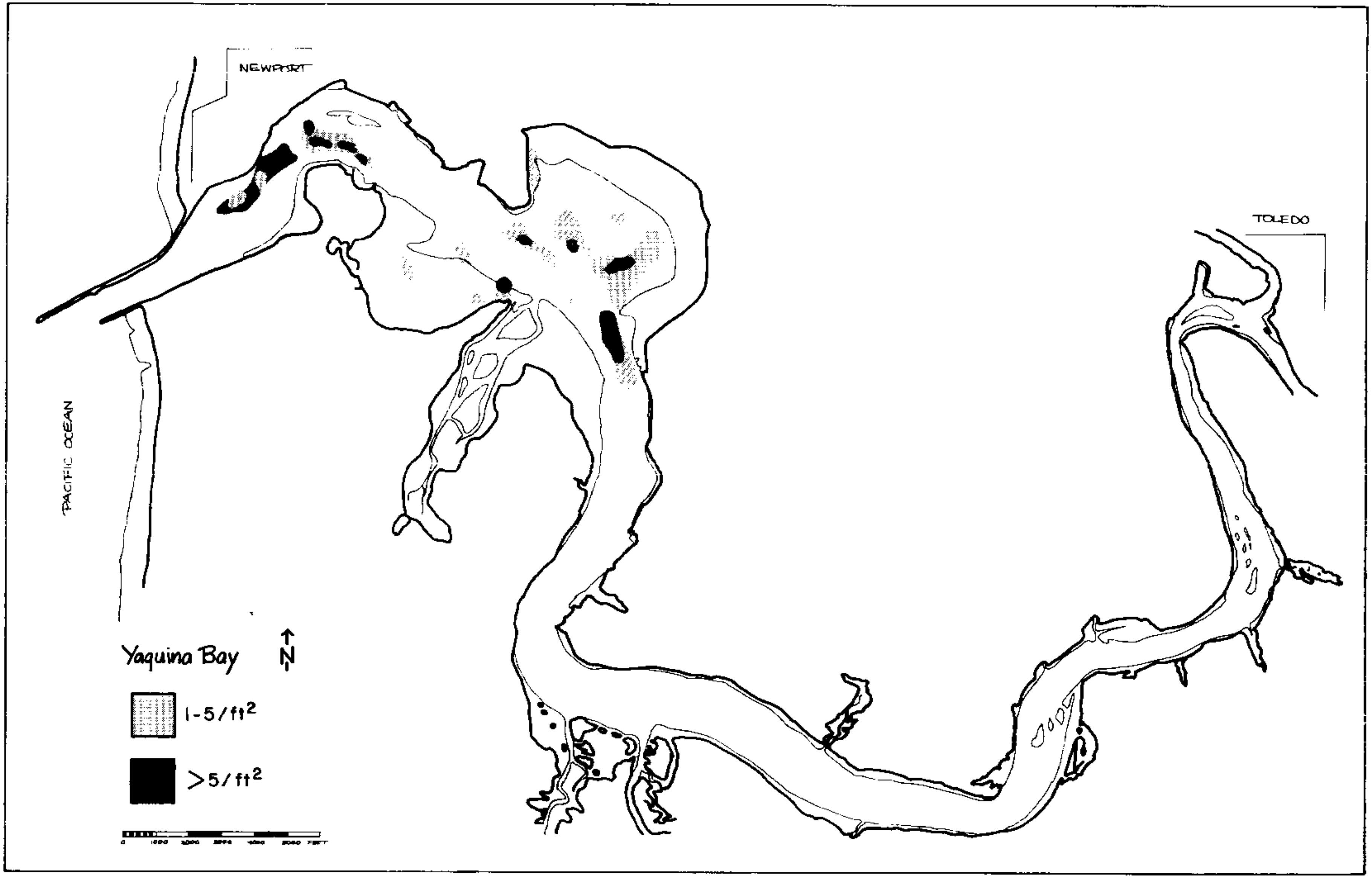

Figure II.A.2.-67. Distribution of irus clams (*Macoma irus*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

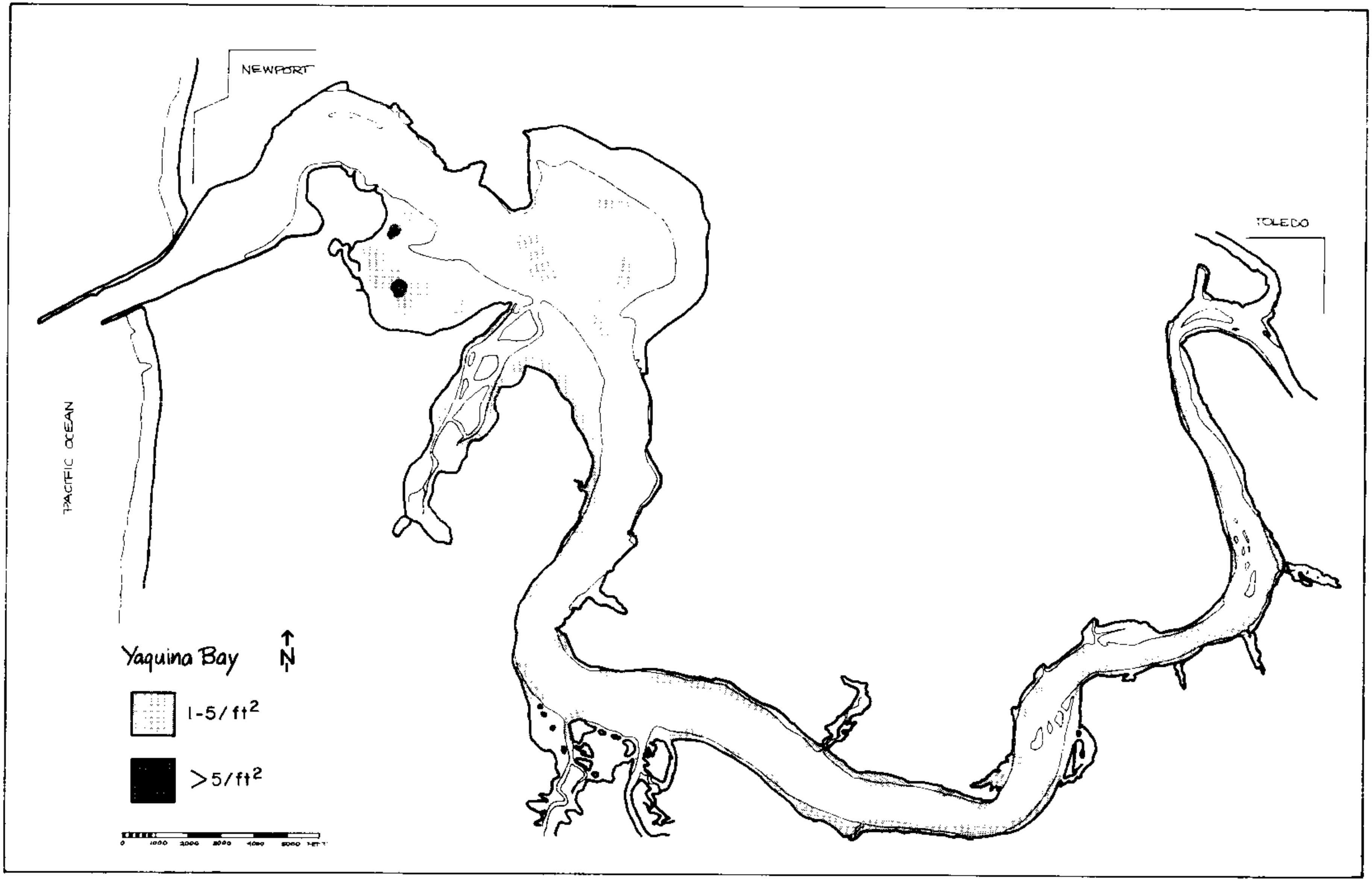

Figure II.A.2.-68. Distribution of softshell clams (*Mya arenaria*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

Figure II.A.2.-69. Distribution of bentnose clams (*Macoma nasuta*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

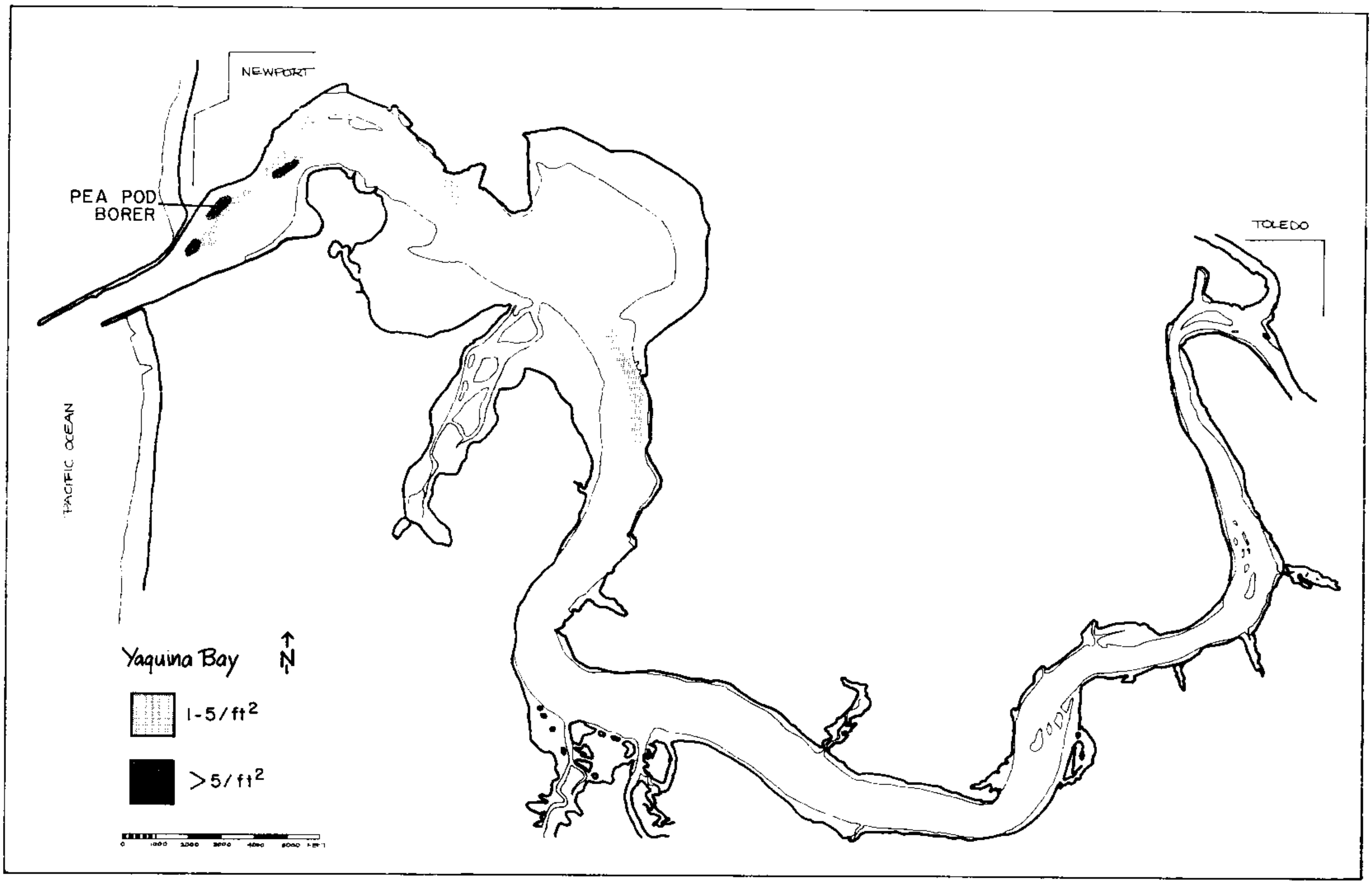

Figure II.A.2.-70. Distribution of piddock clams (*Zirfaea pilsbryi*) and the pea pod borer (*Adula falcata*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

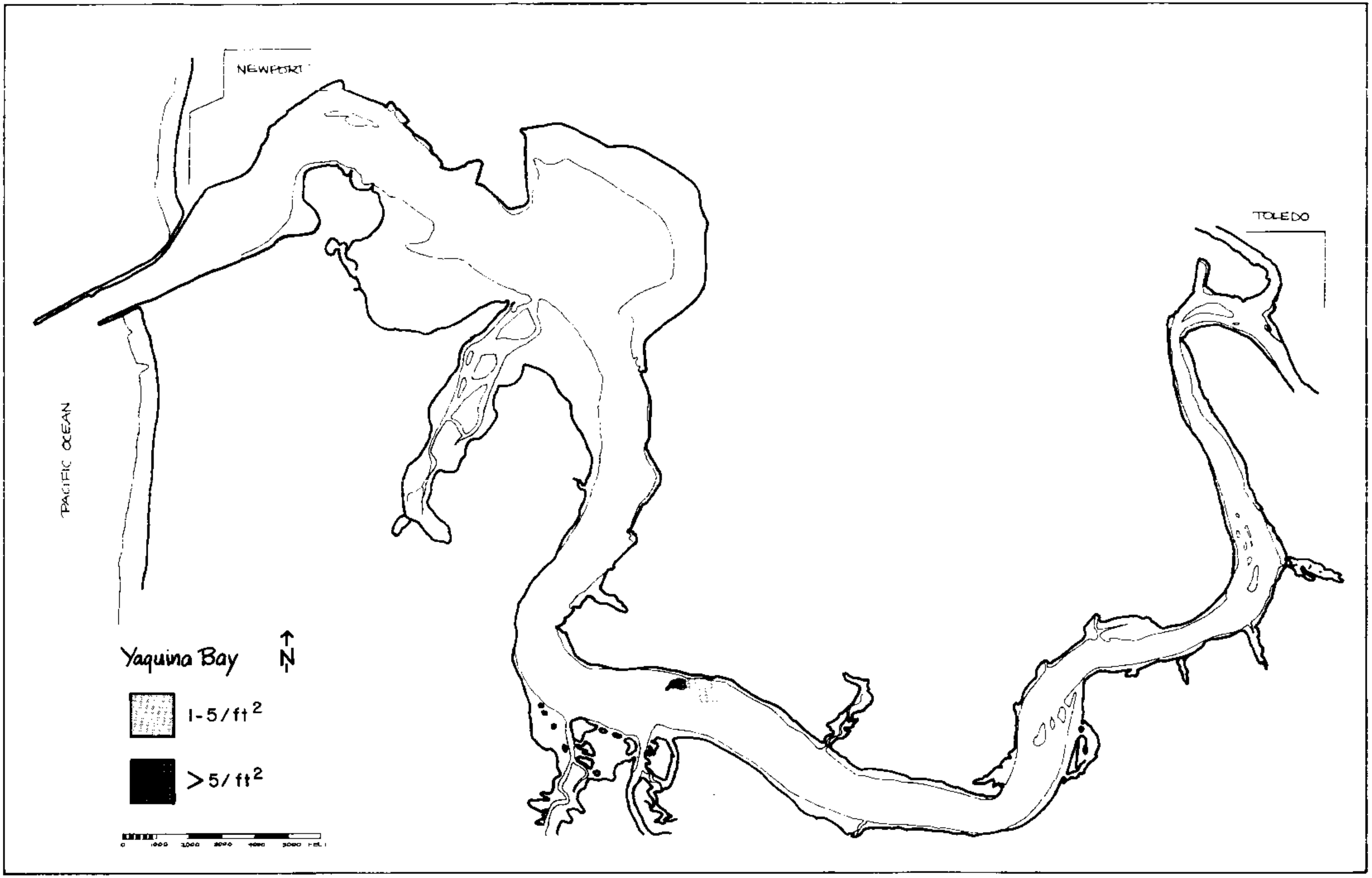

Figure II.A.2.-71. Distribution of native oysters (*Ostrea lurida*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

Figure II.A.2.-72. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

Figure II.A.2.-73. Distribution of eelgrass (*Zostera marina*) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

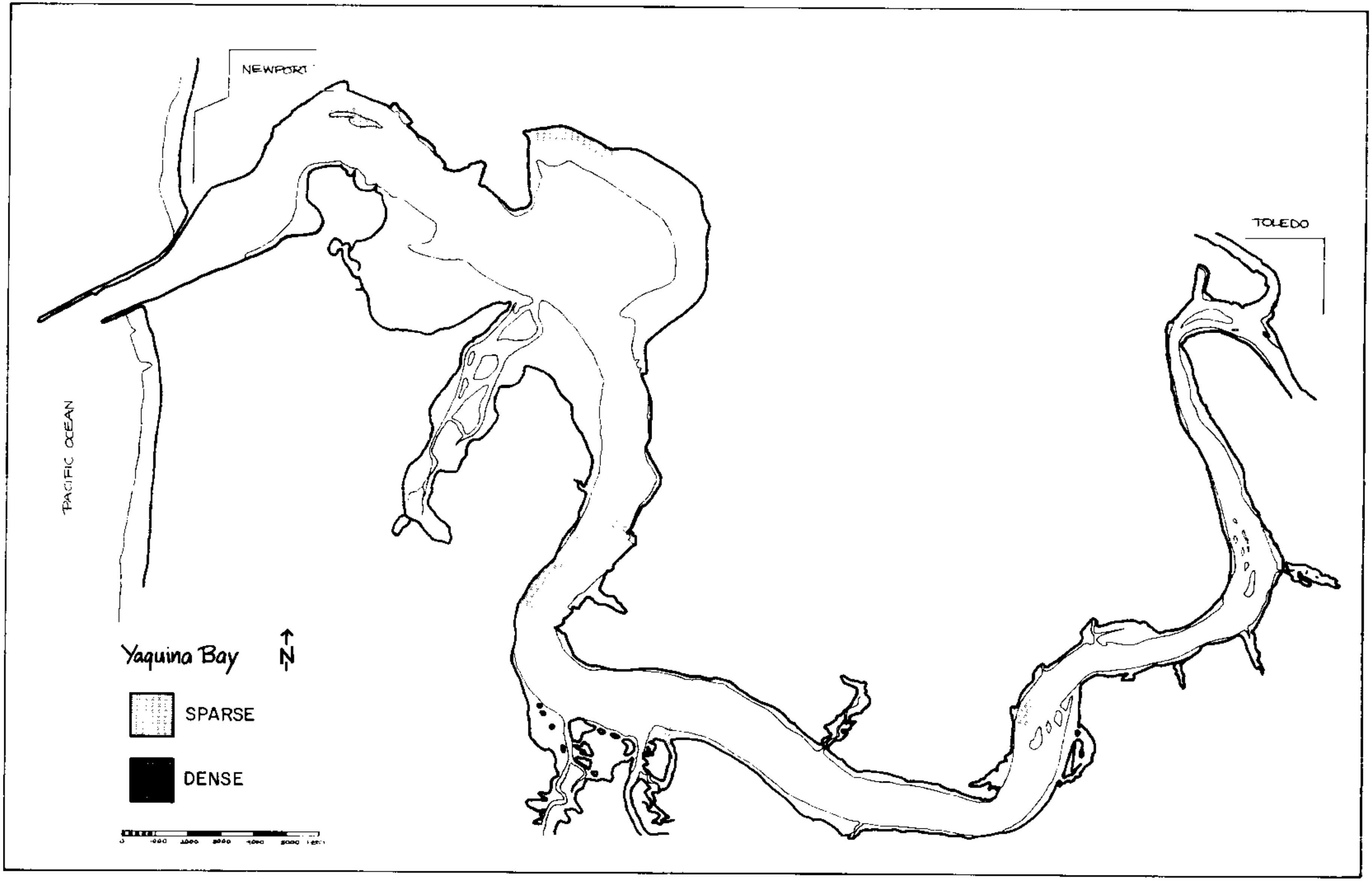

Figure II.A.2.-74. Distribution of the green alga *Enteromorpha* sp. in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

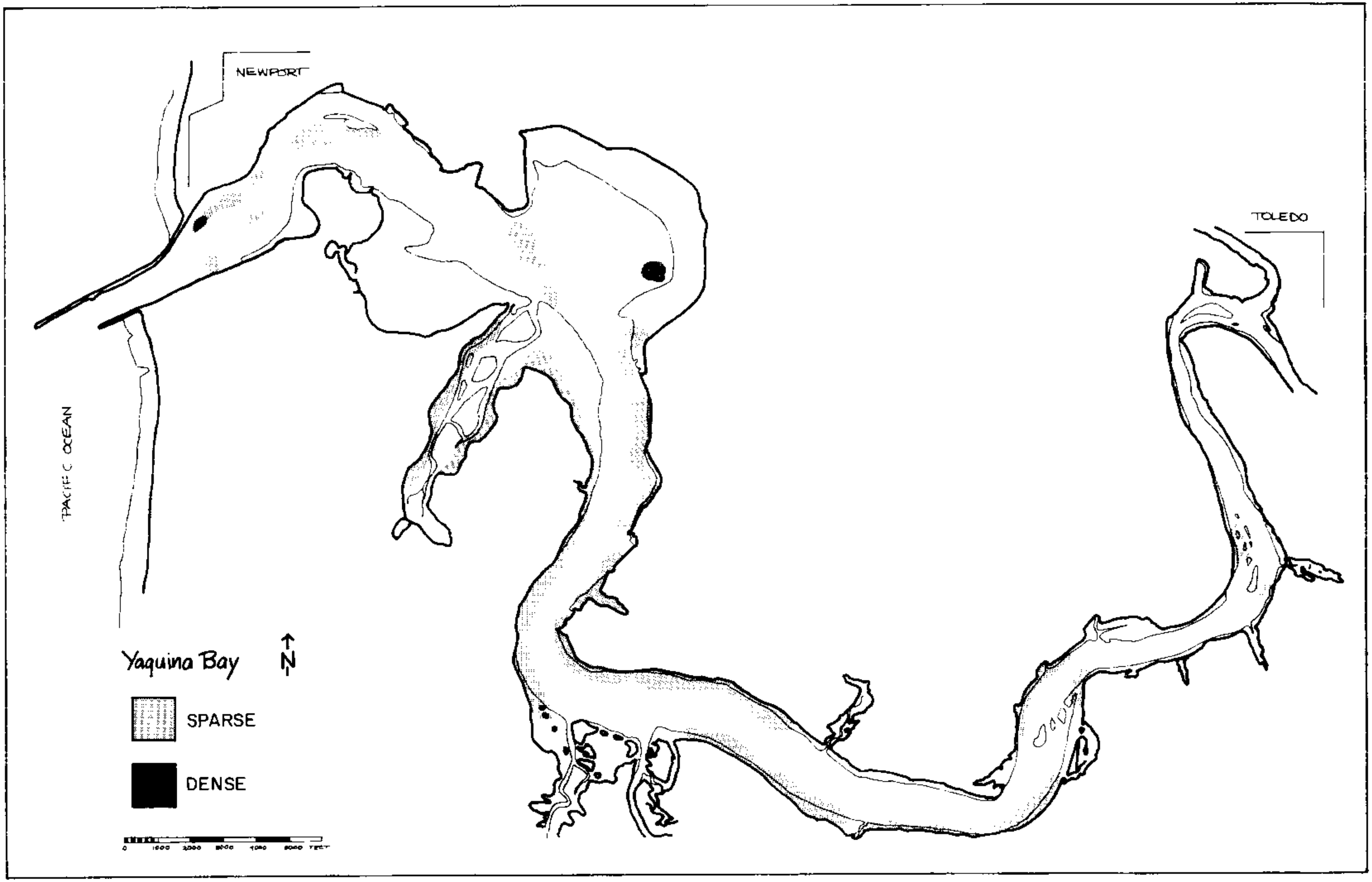

Figure II.A.2.-75. Distribution of rockweed (*Fucus* sp.) in Yaquina Bay, Oregon. (See Fig. II.A.2.-62 for areas not surveyed.)

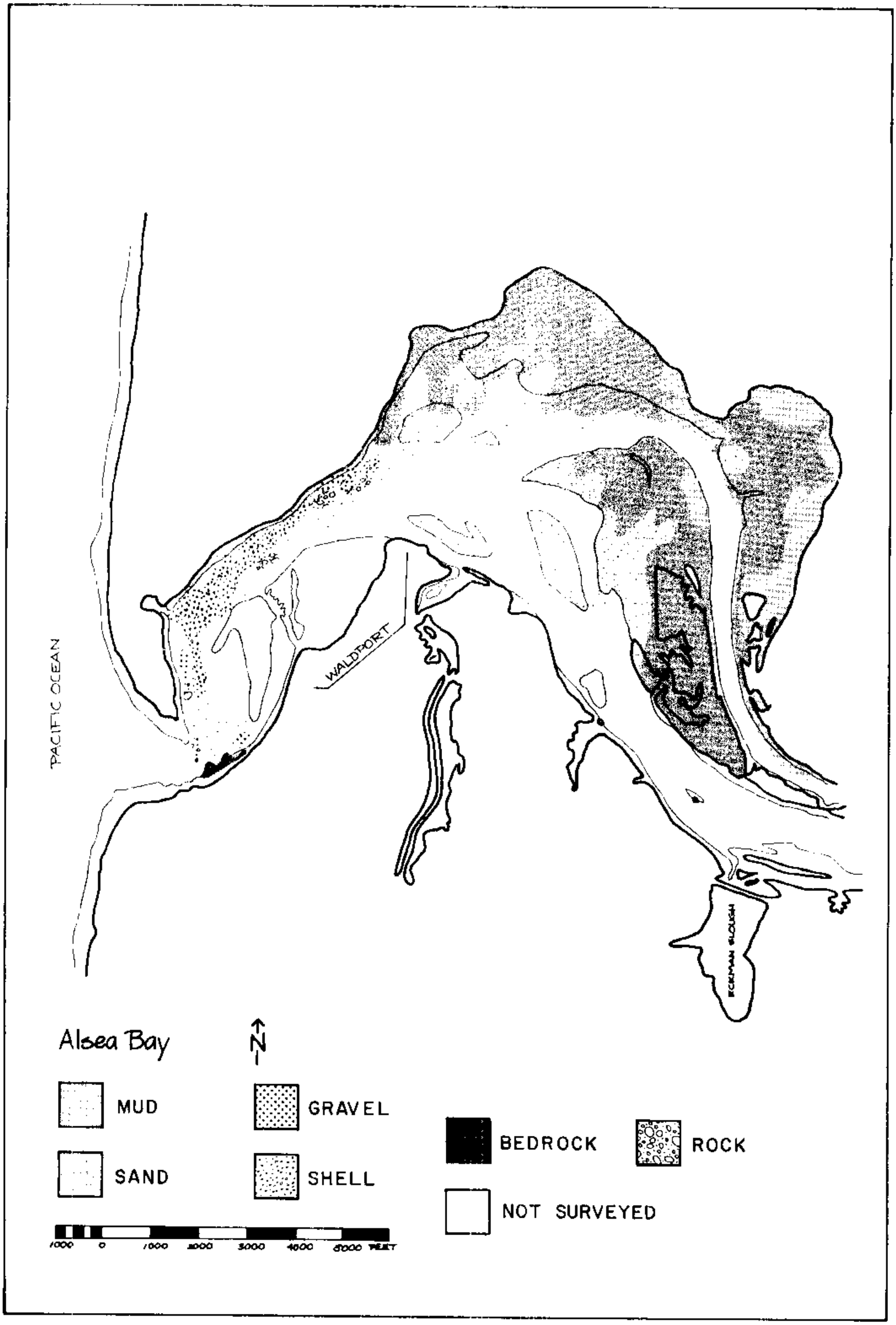

Figure II.A.2.-76. Distribution of substrate materials in Alsea Bay, Oregon.

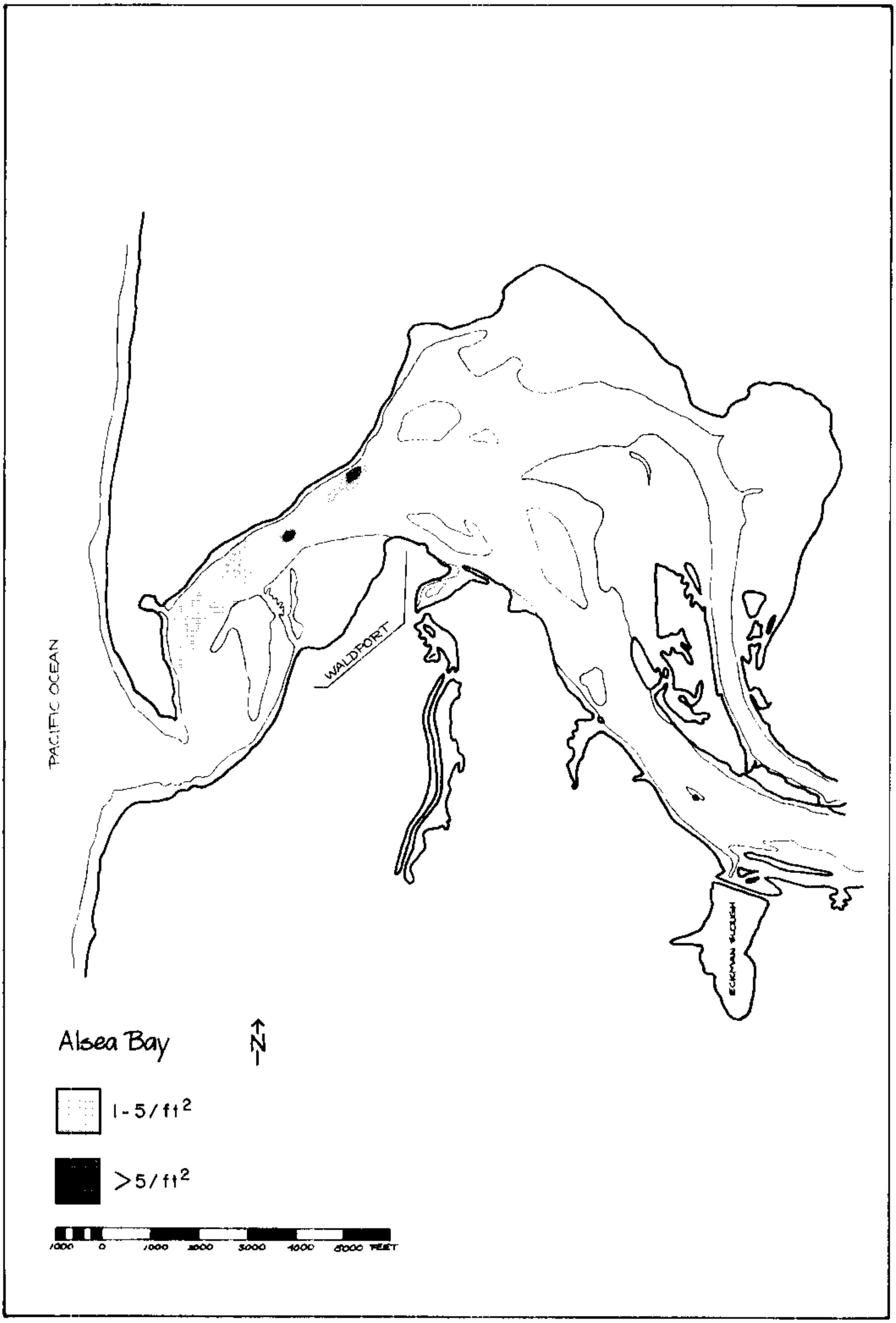

Figure II.A.2.-77. Distribution of gaper clams (*Tresus capax*) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

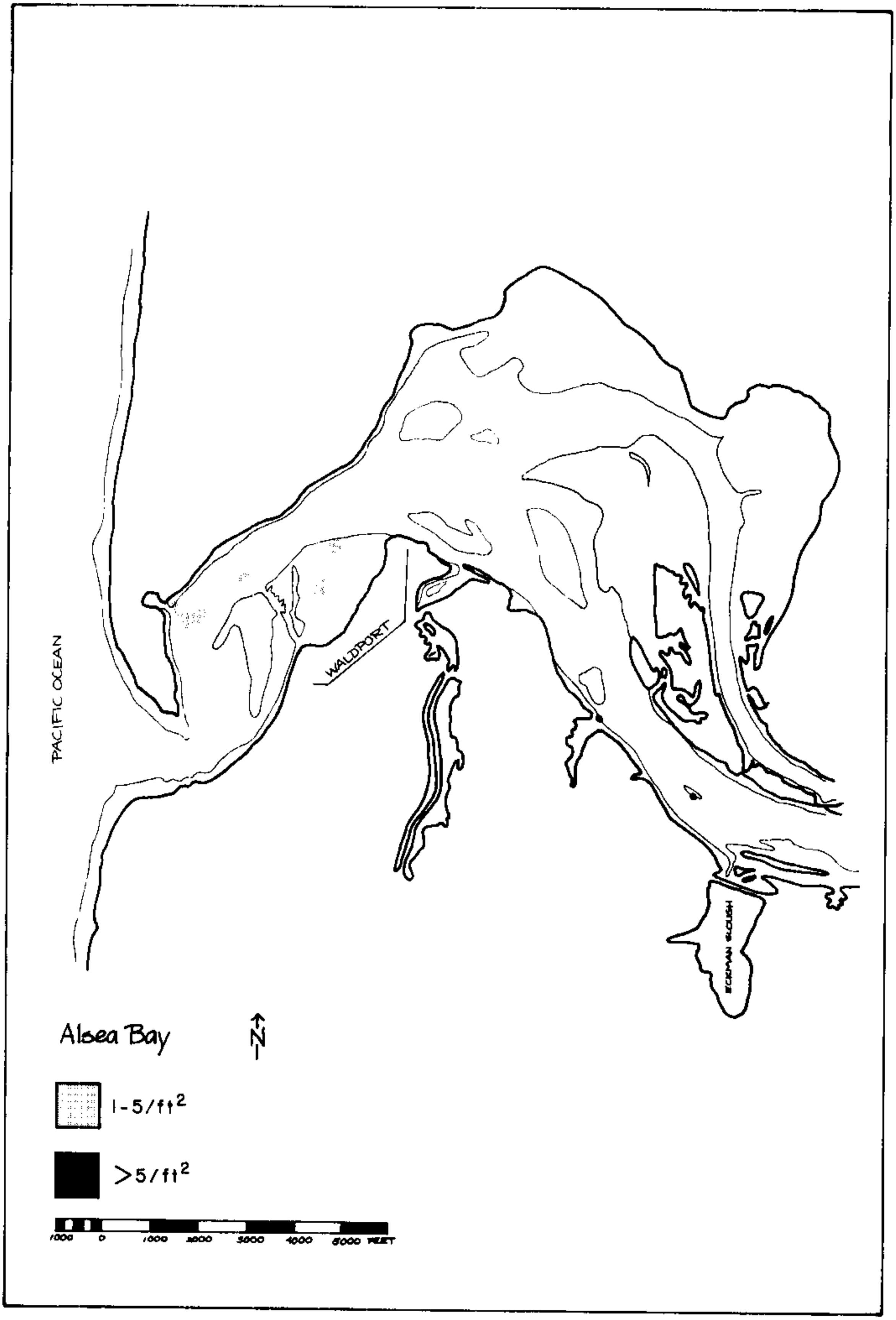

Figure II.A.2.-78. Distribution of cockle clams (*Clinocardium nuttallii*) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

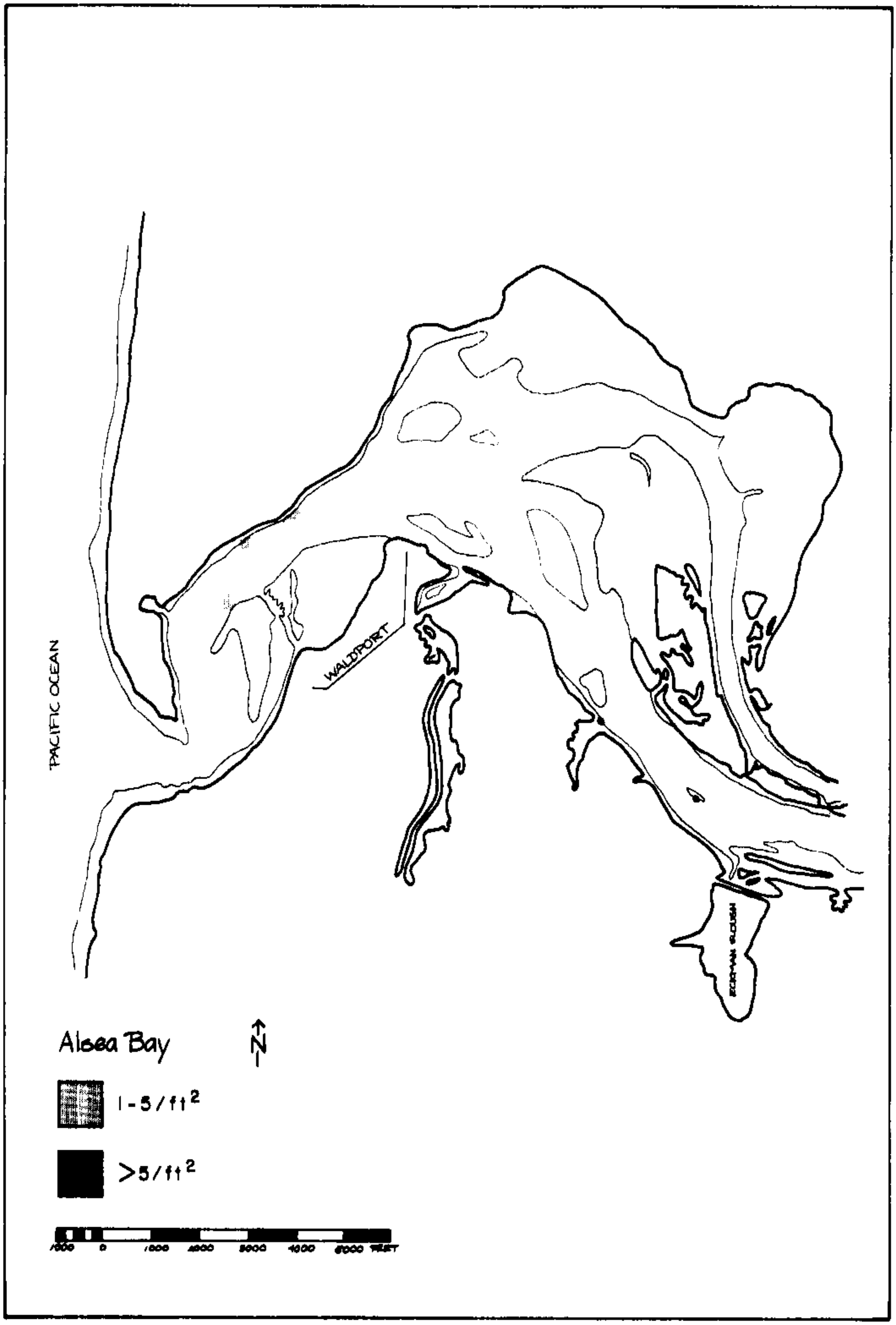

Figure II.A.2.-79. Distribution of native littleneck clams (*Venerupis staminea*) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

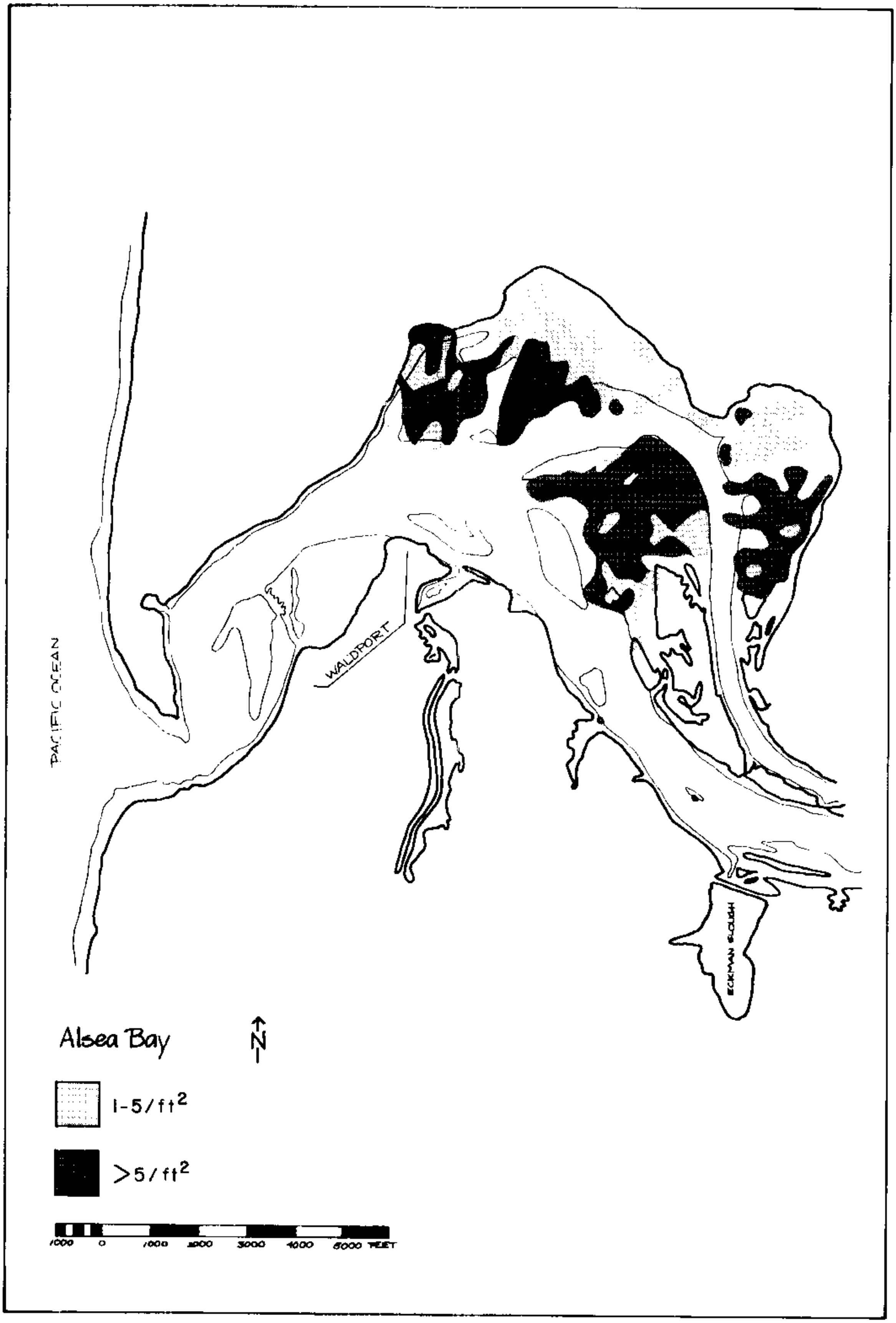

Figure II.A.2.-80. Distribution of softshell clams (*Mya arenaria*) and California softshells (*Cryptomya californica*) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

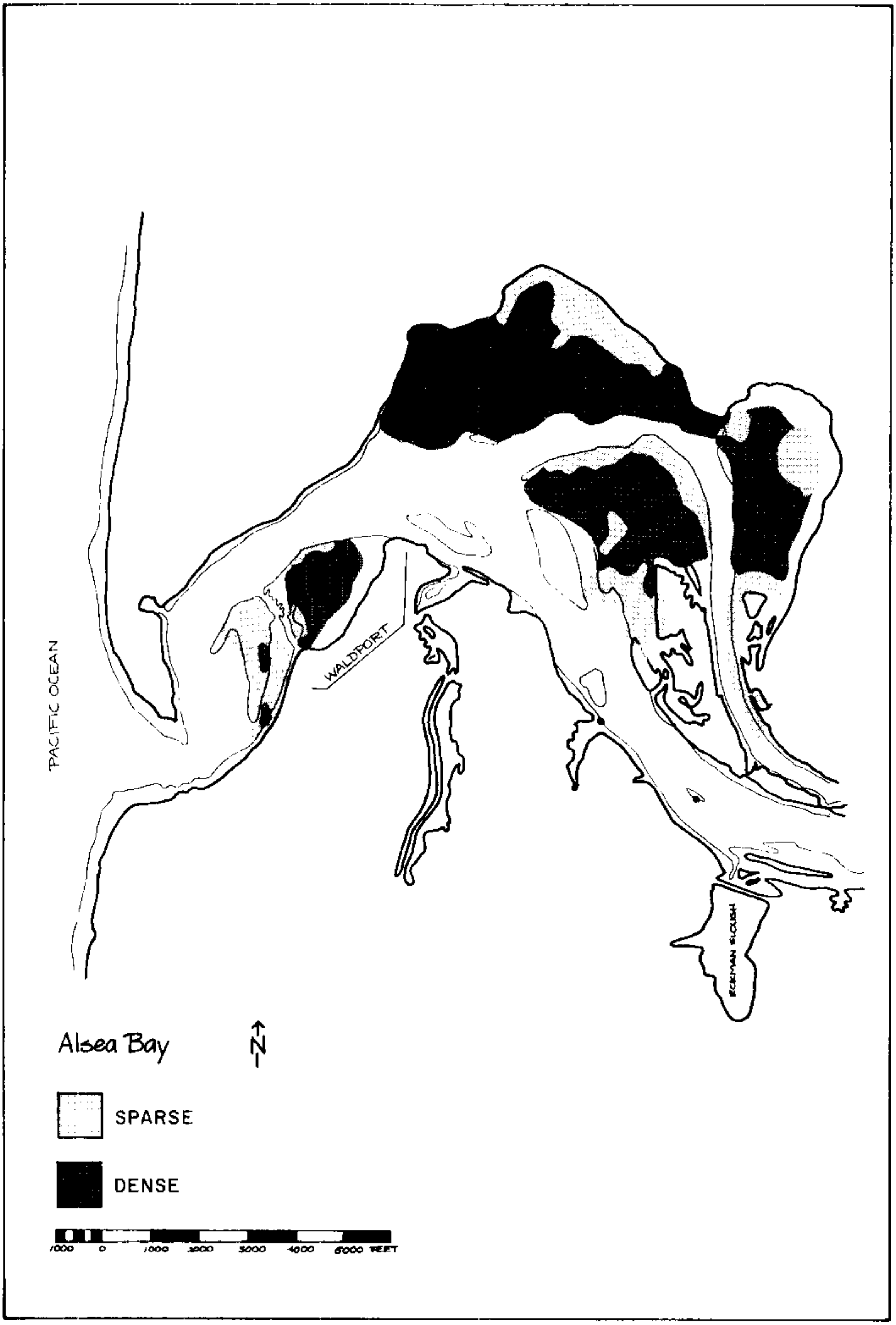

Figure II.A.2.-81. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

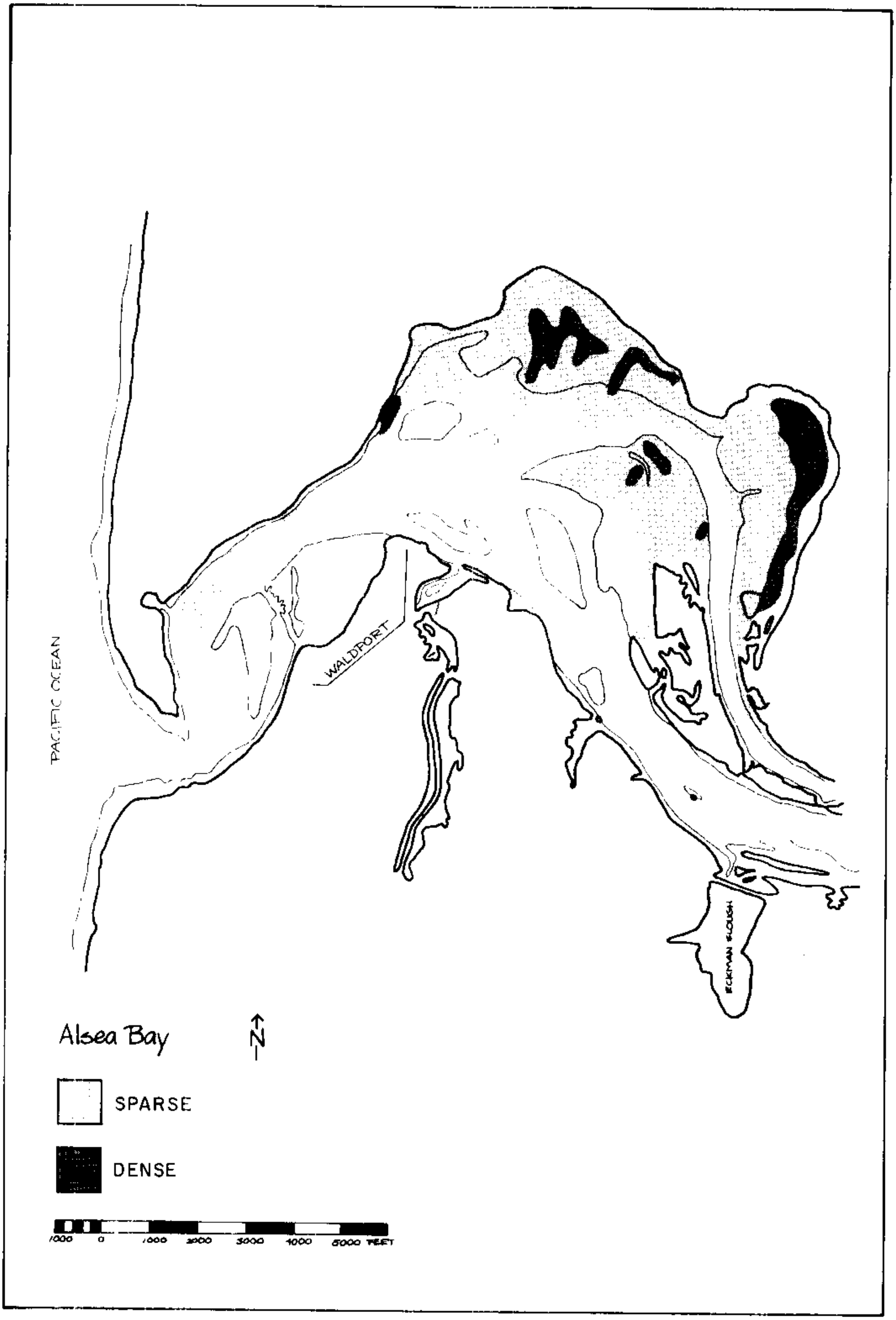

Figure II.A.2.-82. Distribution of eelgrass (*Zostera marina*) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

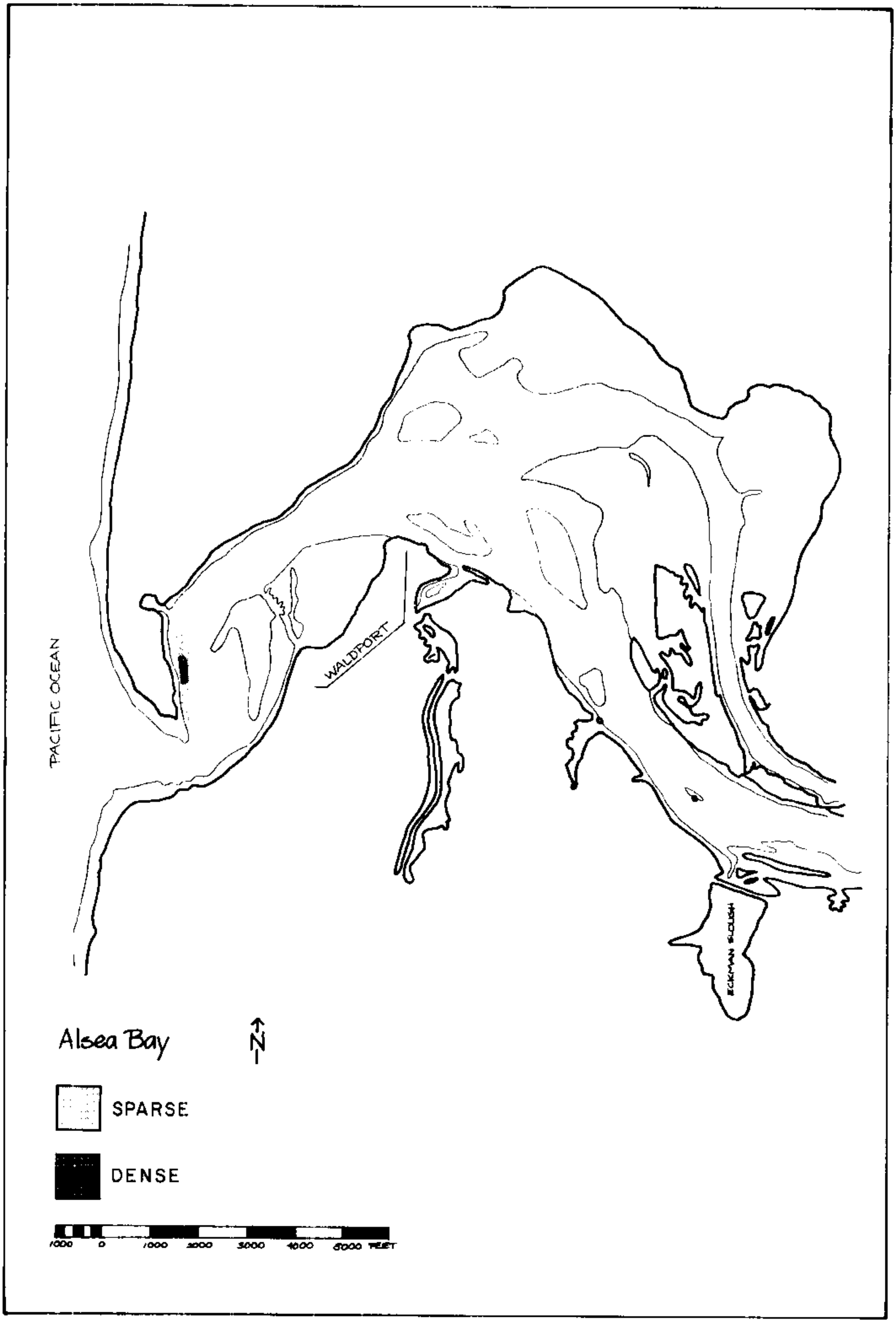

Figure II.A.2.-83. Distribution of sea lettuce (*Ulva* sp.) in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

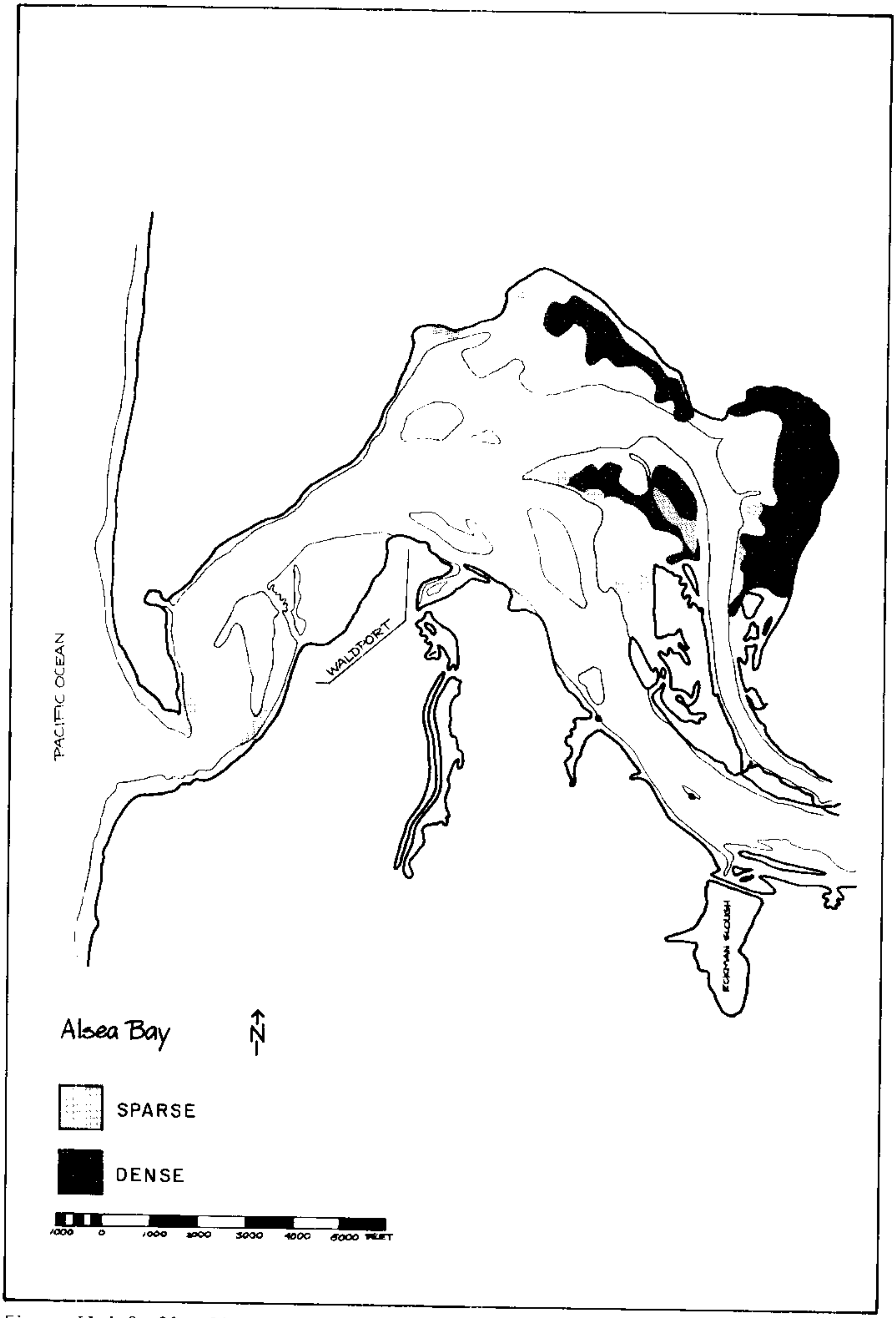

Figure II.A.2.-84. Distribution of unidentified brown algae in Alsea Bay, Oregon. (See Fig. II.A.2.-76 for areas not surveyed.)

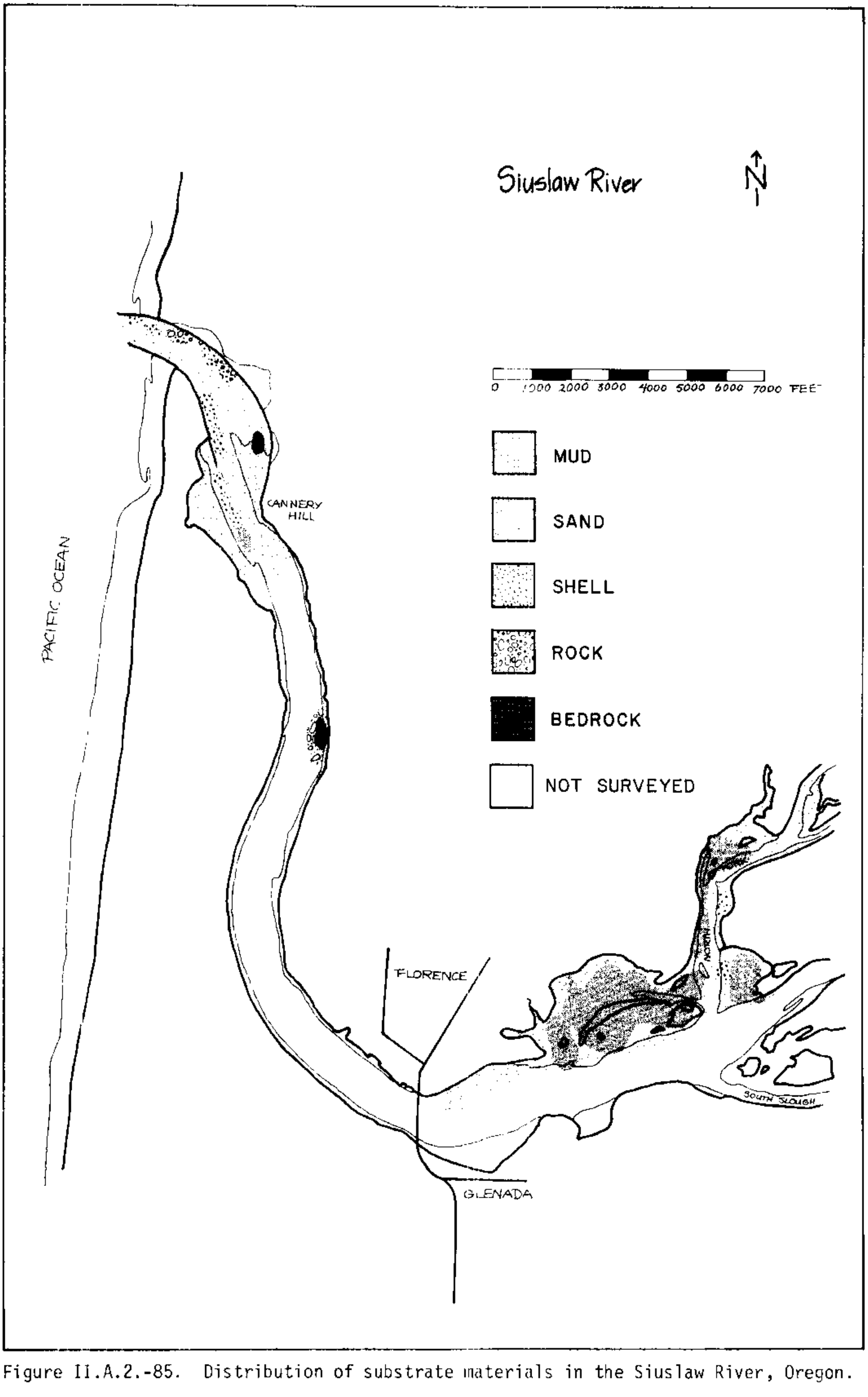

Figure II.A.2.-85. Distribution of substrate materials in the Siuslaw River, Oregon.

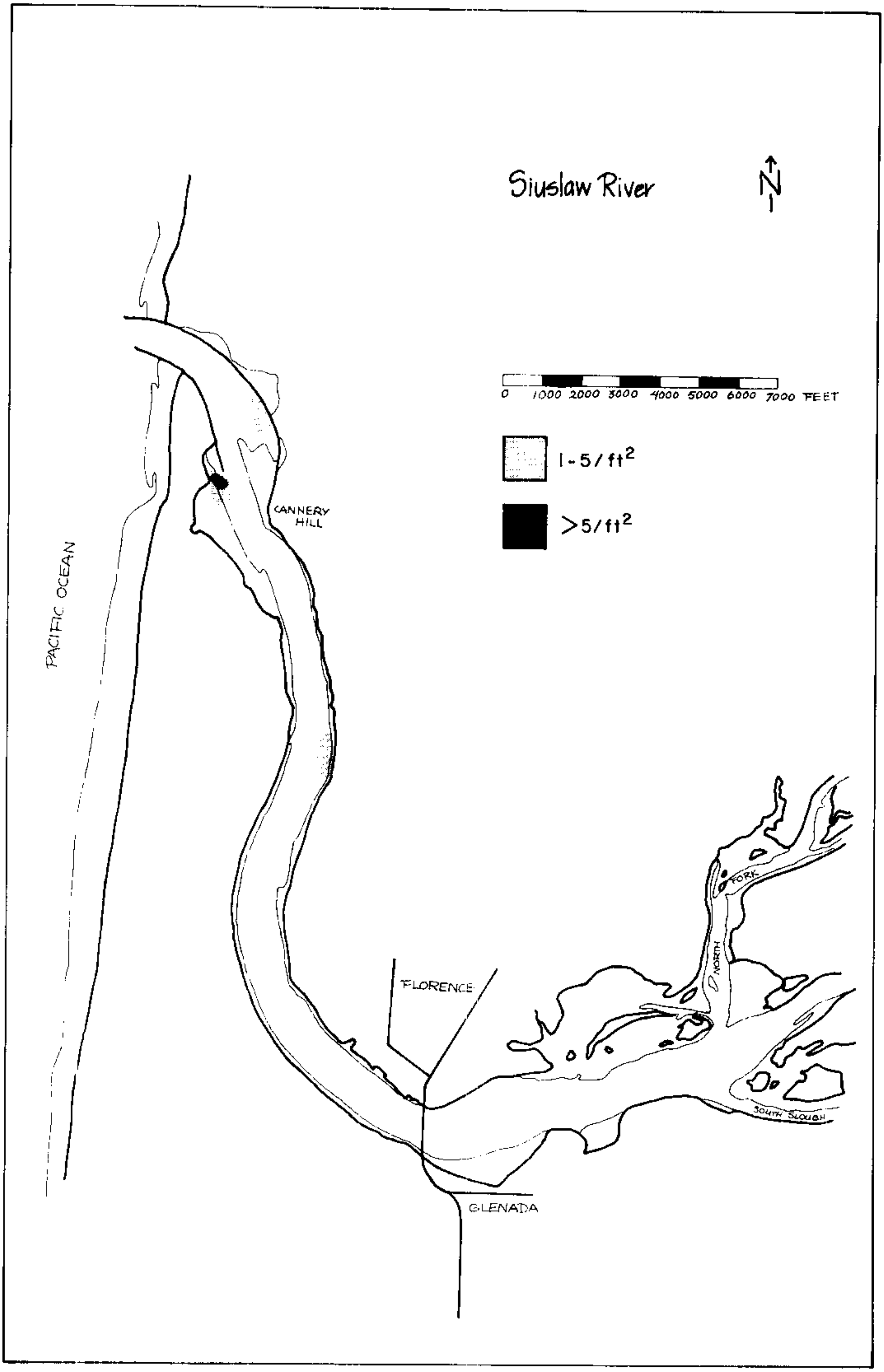

Figure II.A.2.-86. Distribution of gaper clams (*Tresus capax*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

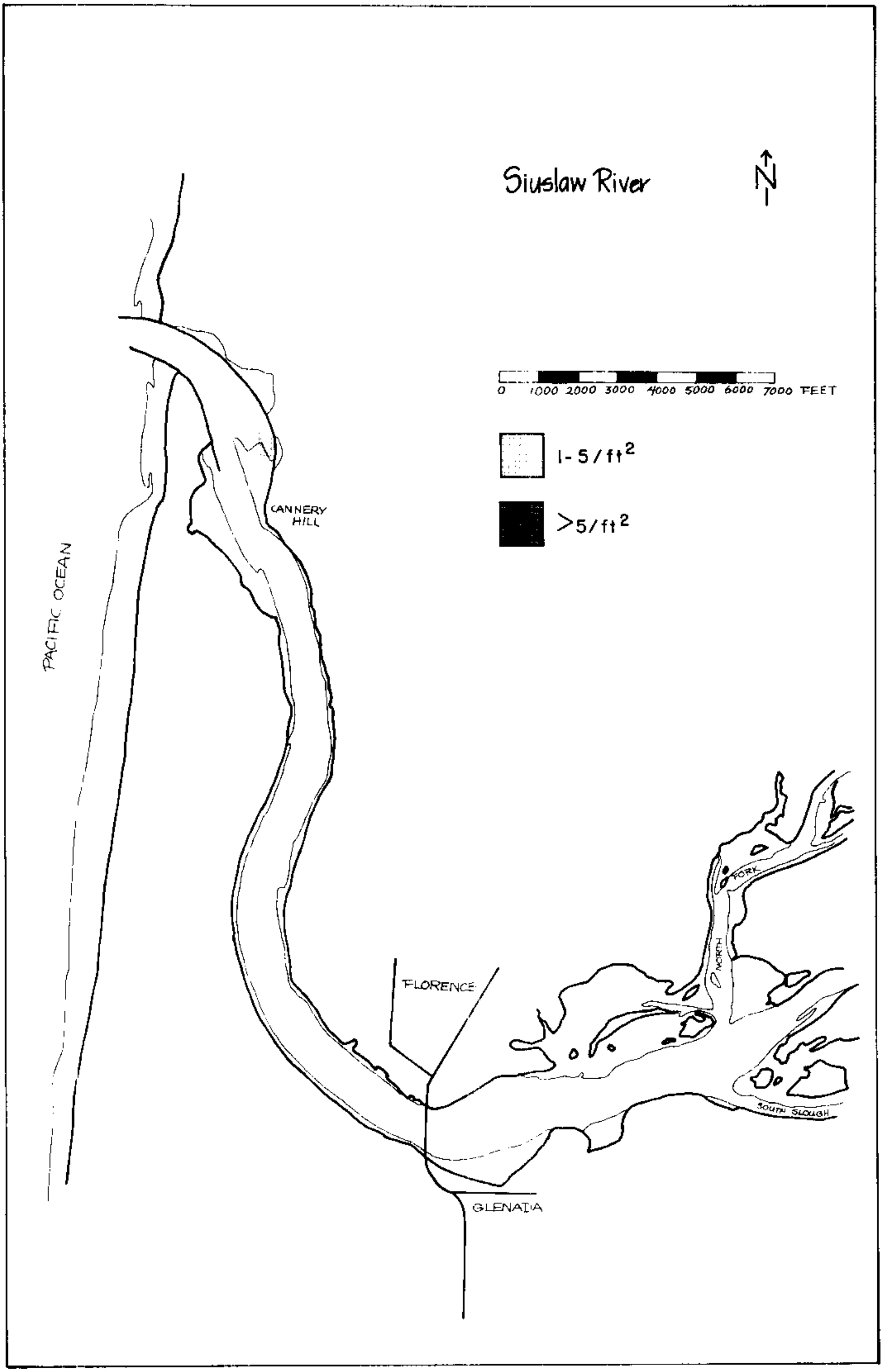

Figure II.A.2.-87. Distribution of native littleneck clams (*Venerupis staminea*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

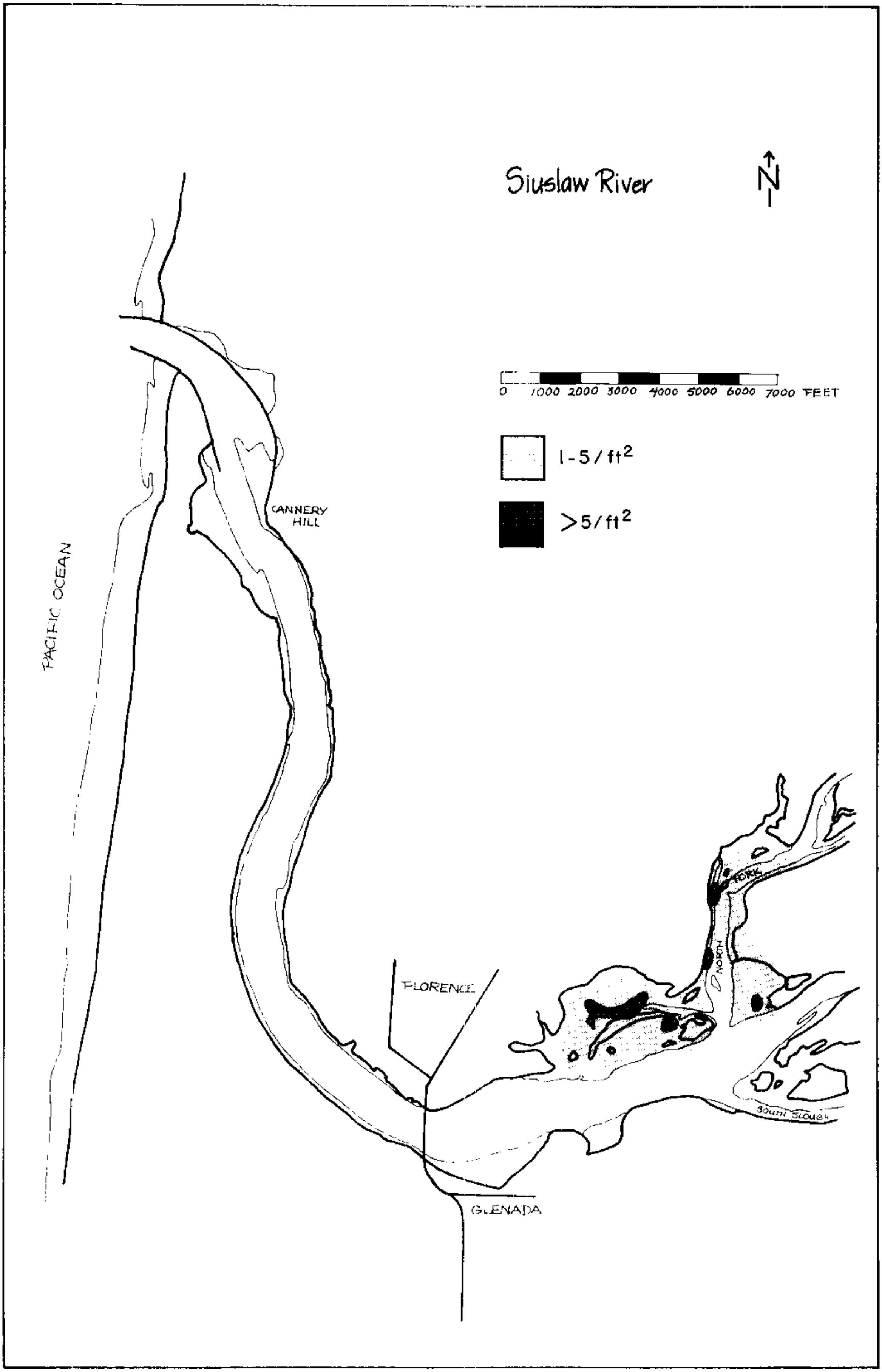

Figure II.A.2.-88. Distribution of softshell clams (*Mya arenaria*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

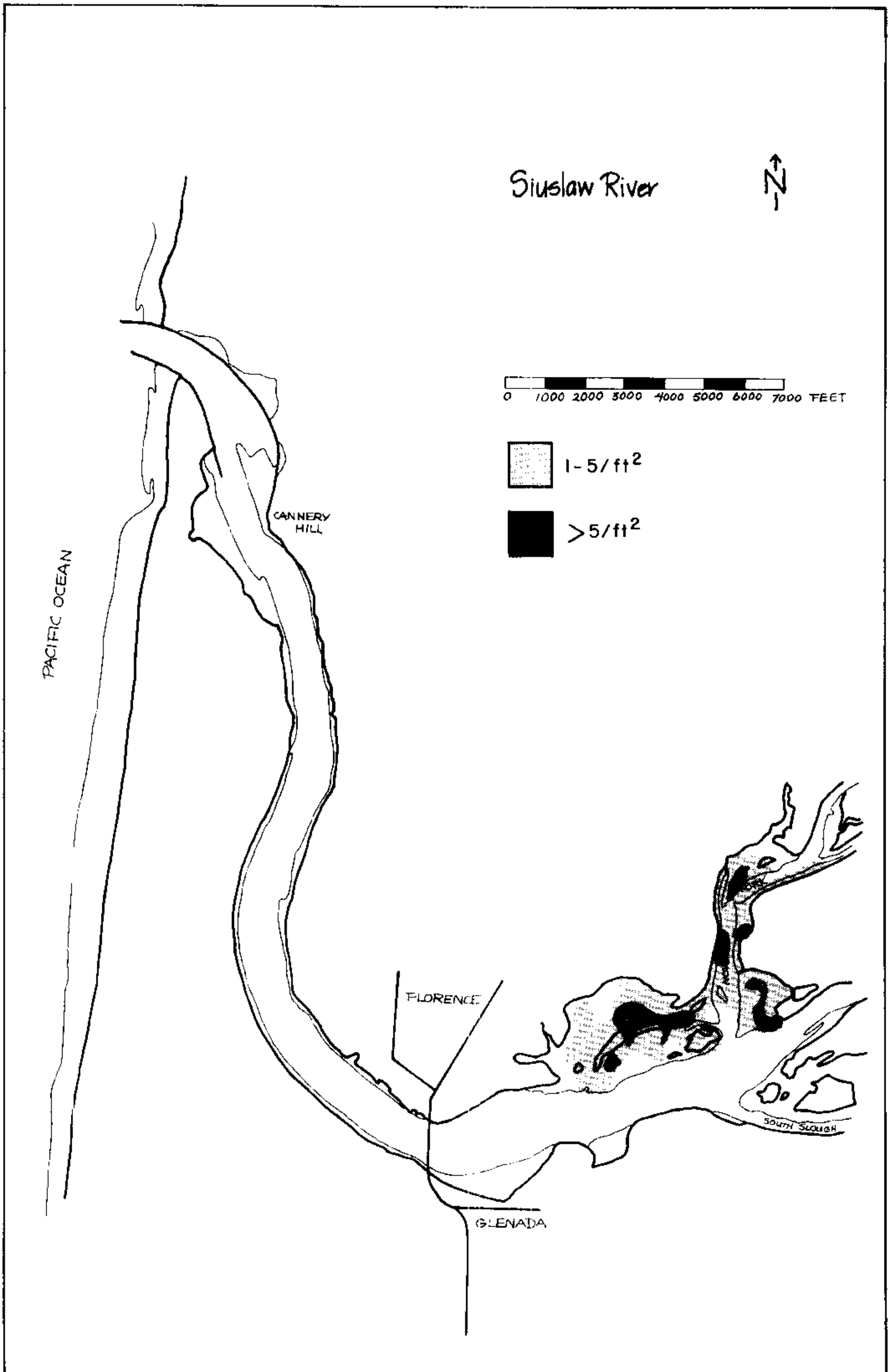

Figure II.A.2.-89. Distribution of Baltic and irus clams (*Macoma bathica* and *M. irus*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

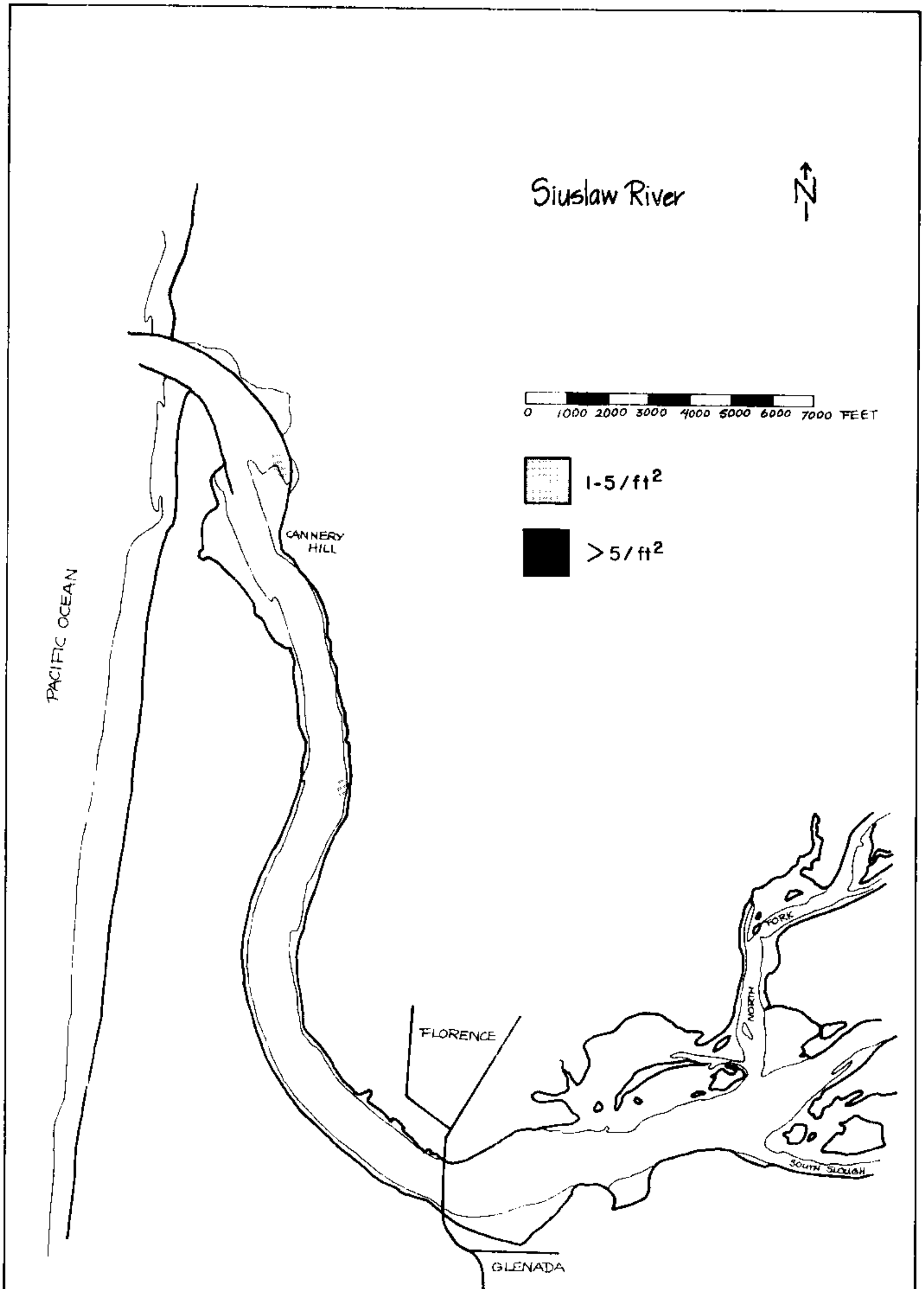

Figure II.A.2.-90. Distribution of piddock clams (*Zirfaca pilsbryi*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

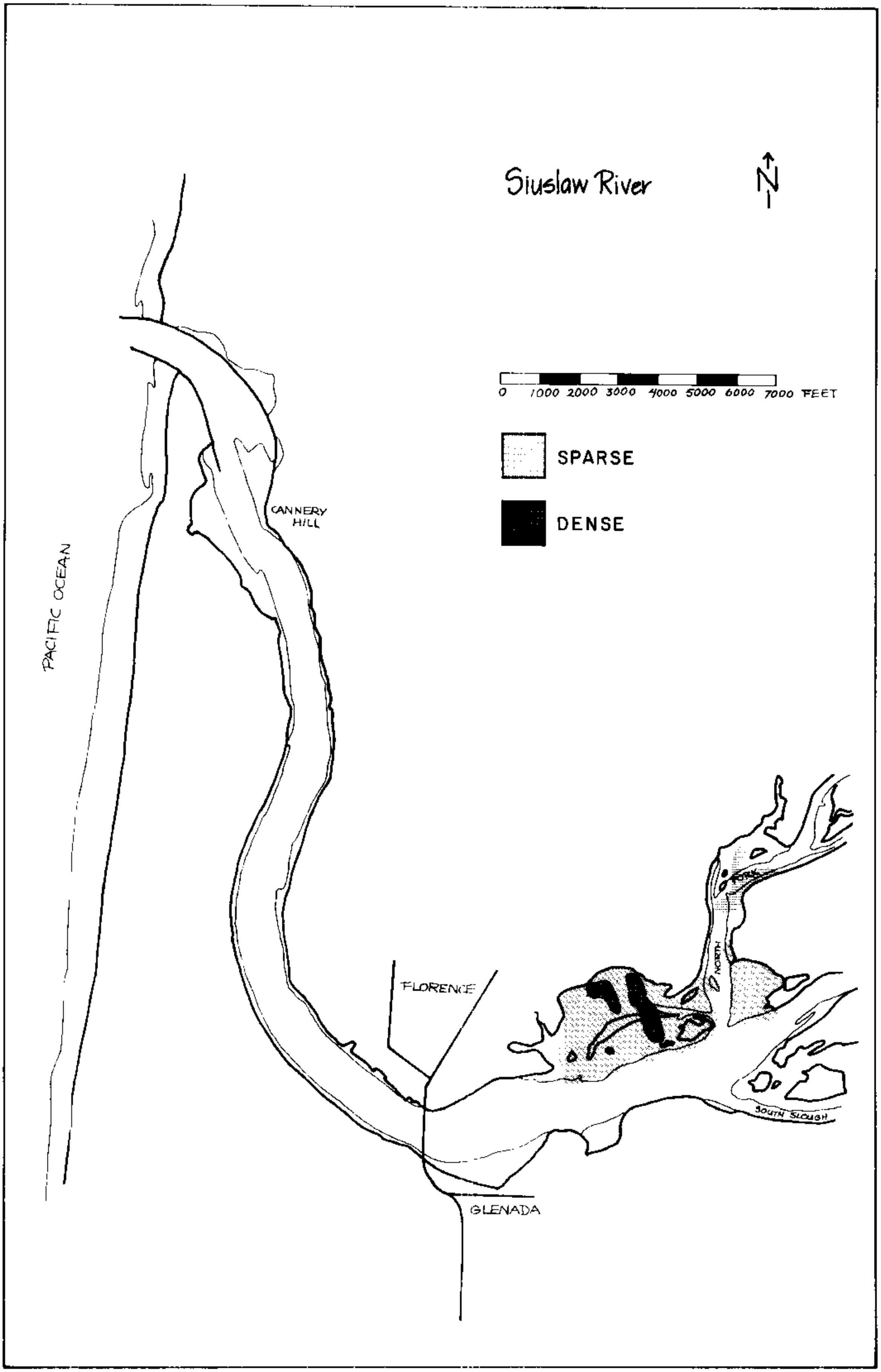

Figure II.A.2.-91. Distribution of ghost and mud shrimps (*Callianassa californiensis* and *Upogebia pugettensis*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

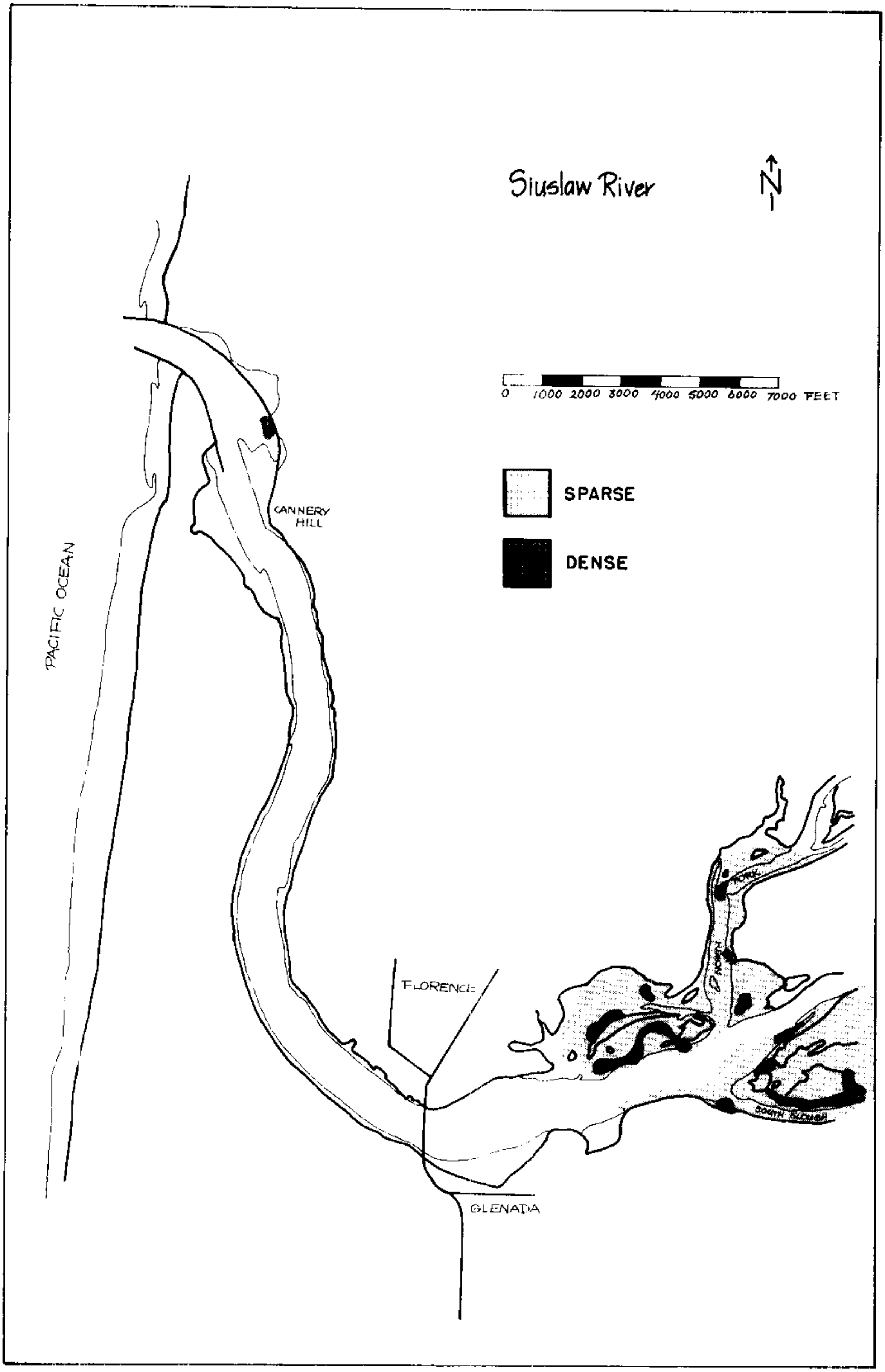

Figure II.A.2.-92. Distribution of eelgrass (*Zostera marina*) in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

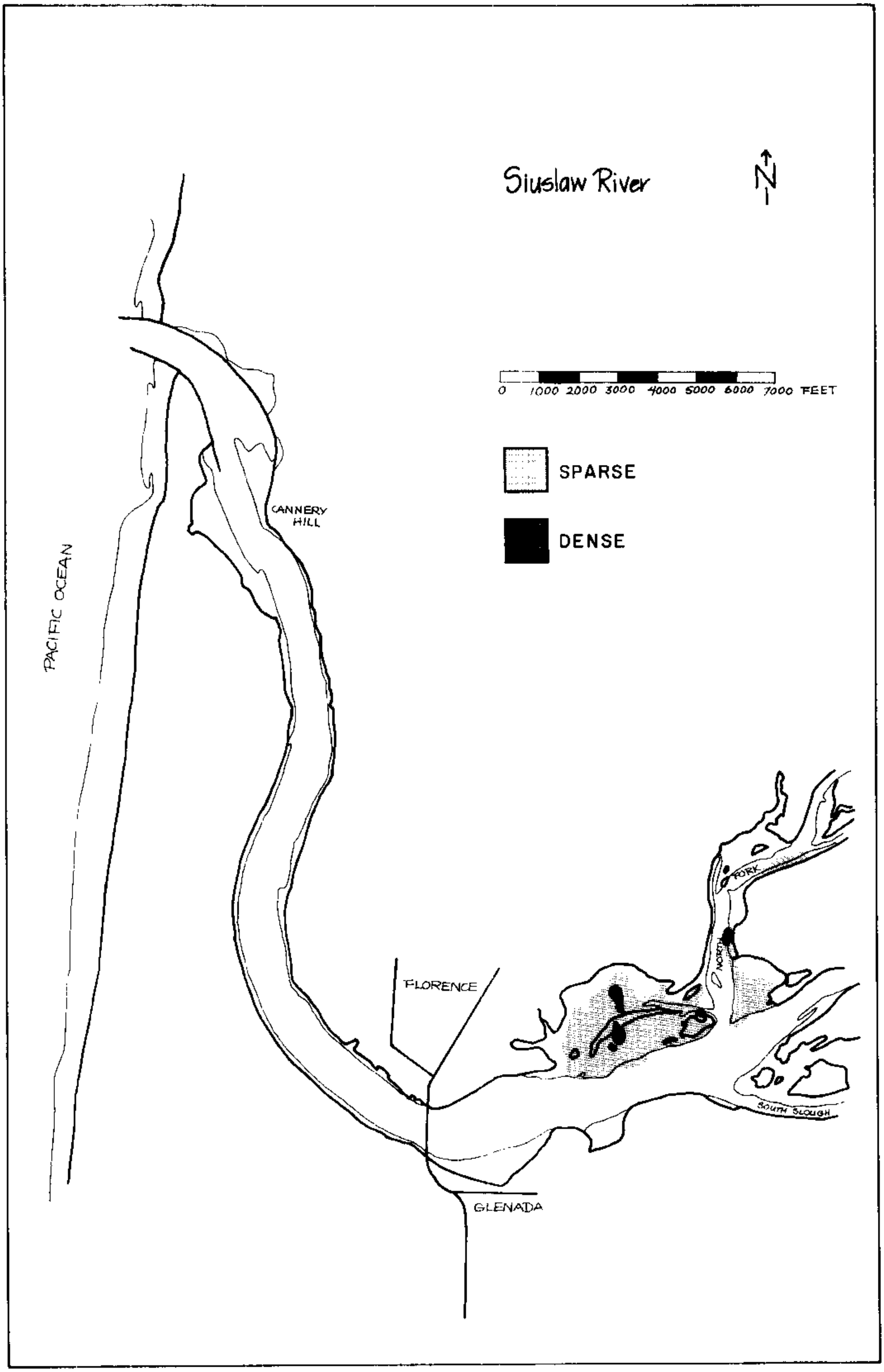

Figure II.A.2.-93. Distribution of the green alga *Enteromorpha* sp. in the Siuslaw River, Oregon. (See Fig. II.A.2.-85 for areas not surveyed.)

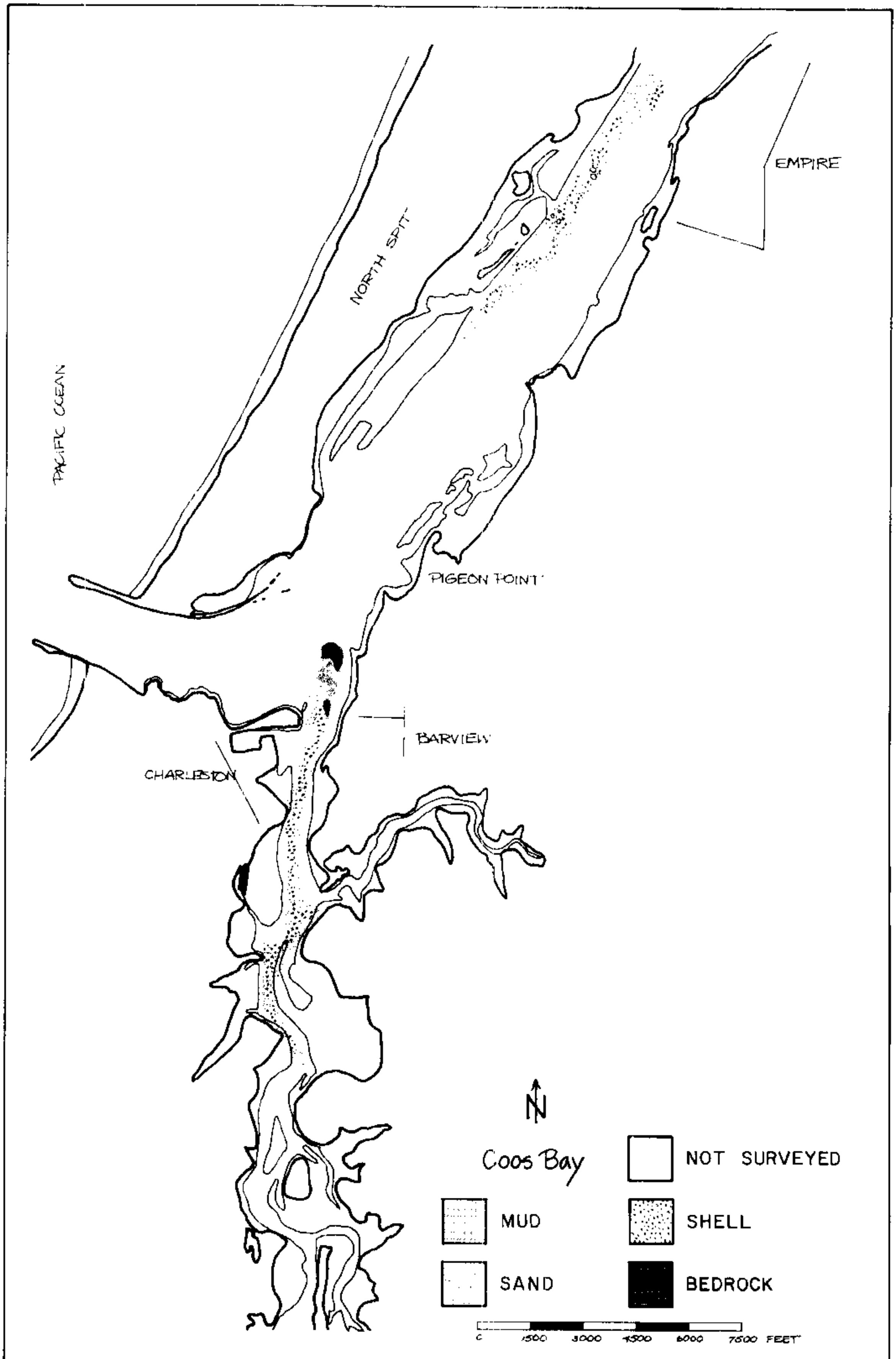

Figure II.A.2.-94. Distribution of substrate materials in lower Coos Bay and South Slough, Oregon.

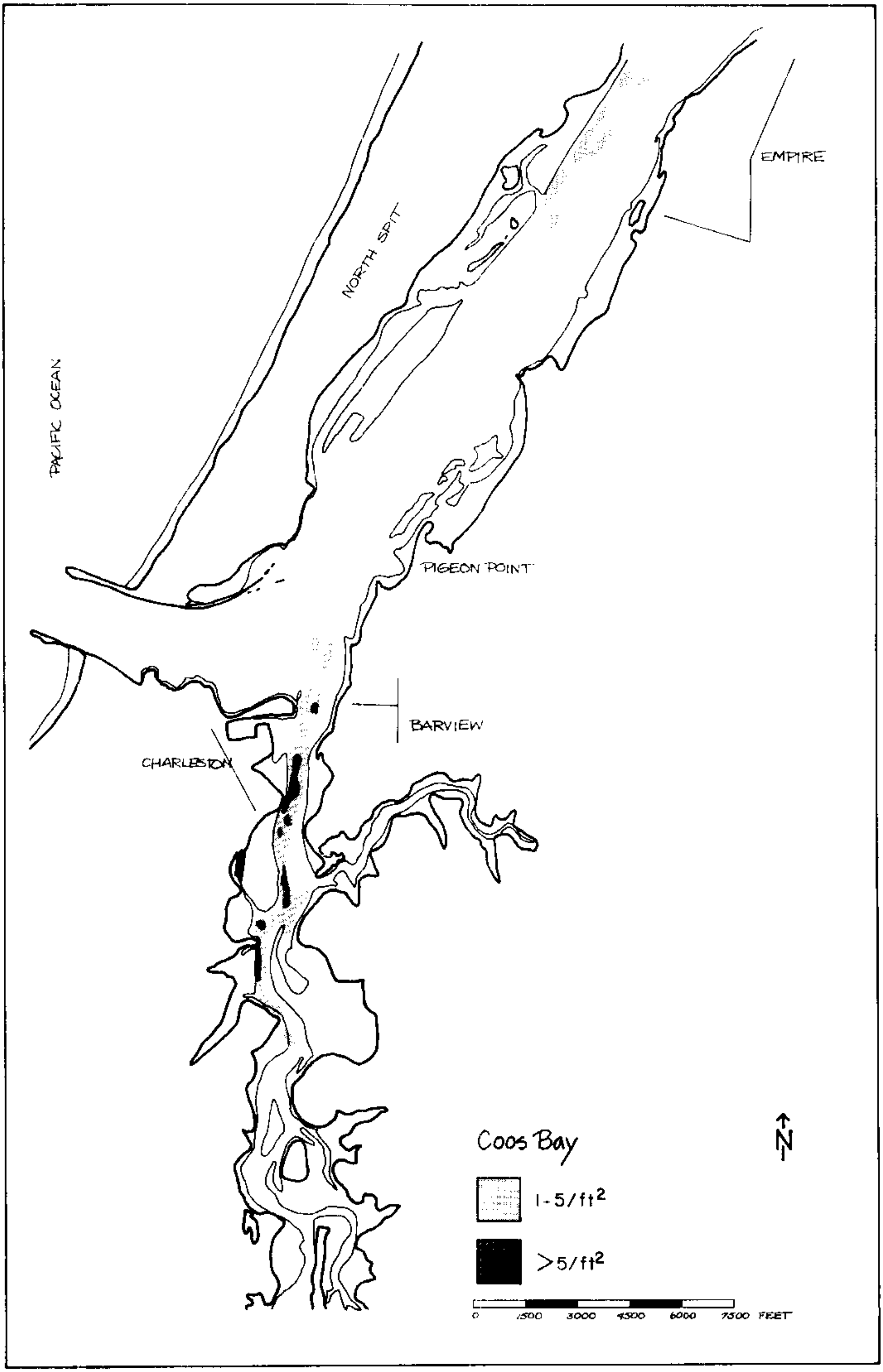

Figure II.A.2.-95. Distribution of gaper clams (*Tresus capax*) in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

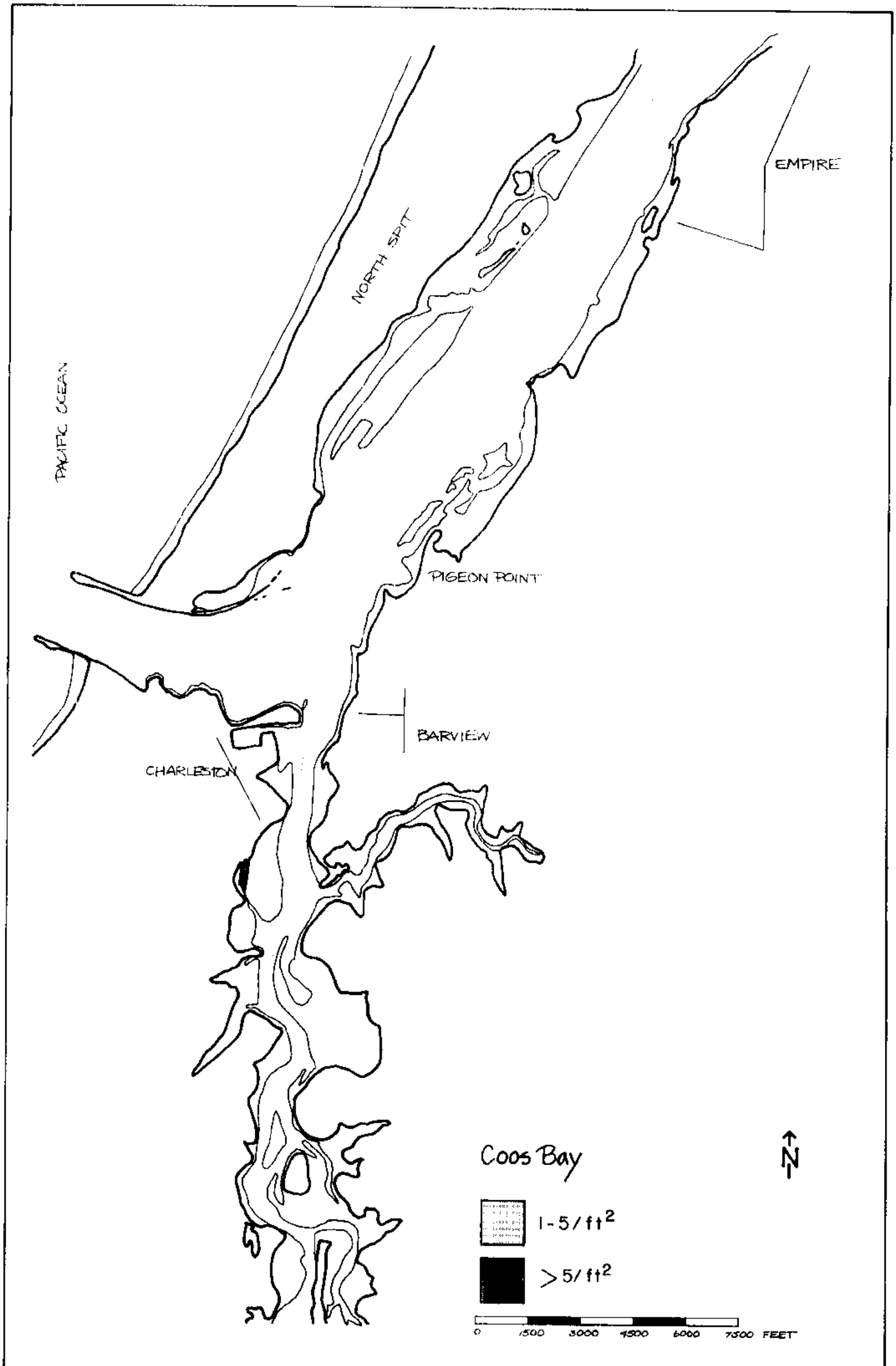

Figure II.A.2.-96. Distribution of butter clams (*Saxidomus giganteus*) in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

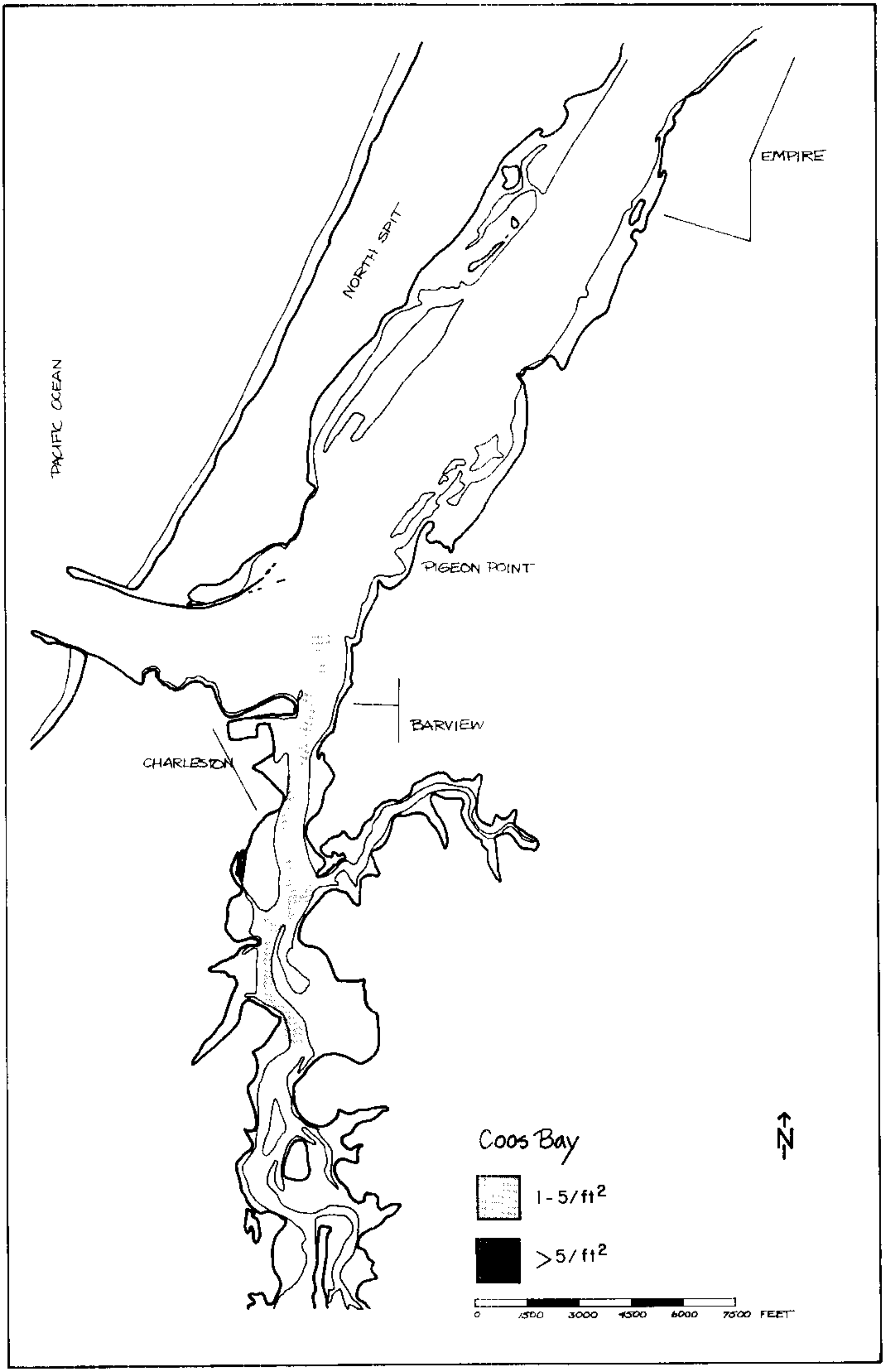

Figure II.A.2.-97. Distribution of cockle clams (*Clinocardium nuttallii*) in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

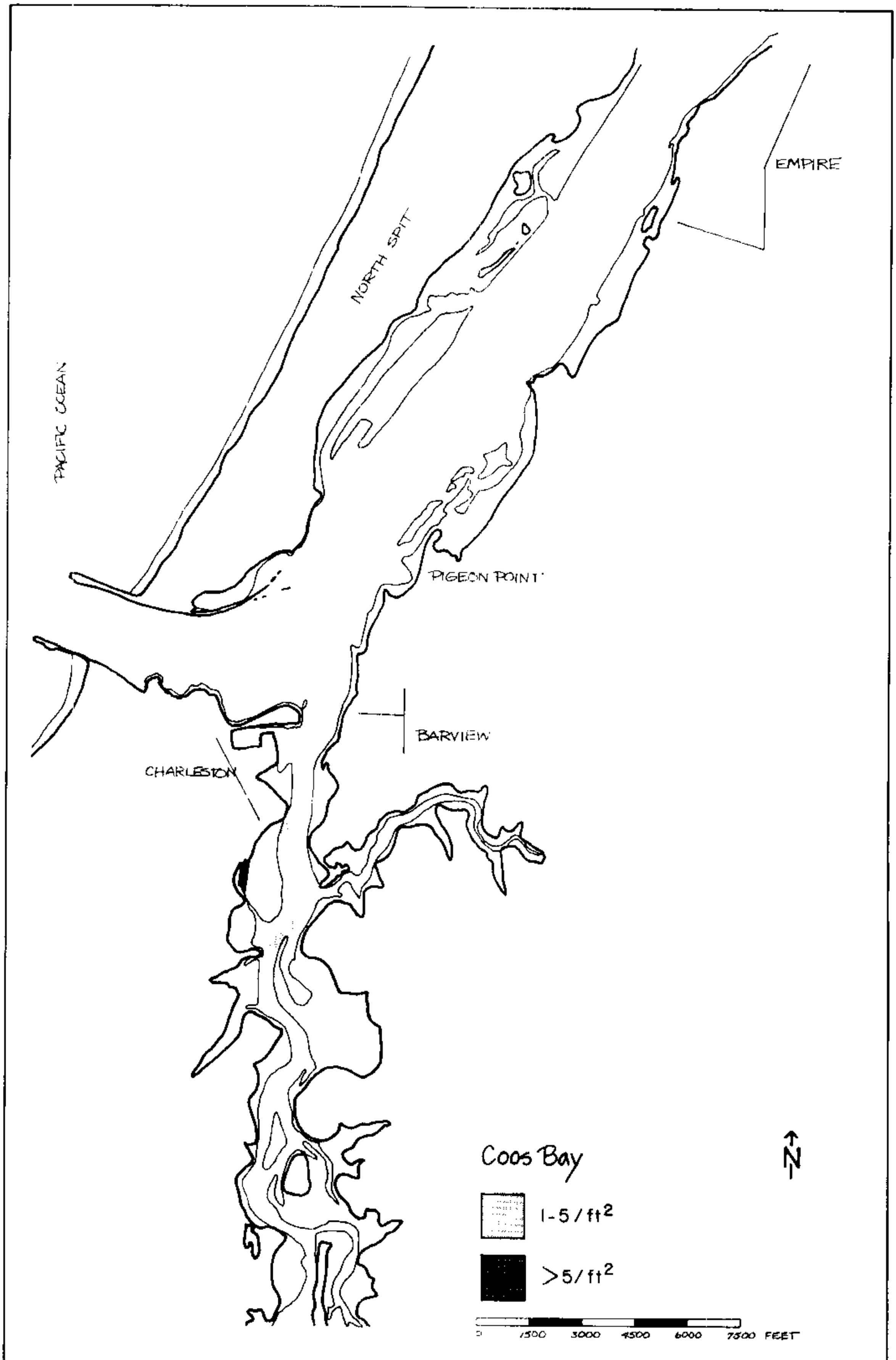

Figure II.A.2.-98. Distribution of native littleneck clams (*Venerupis staminea*) in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

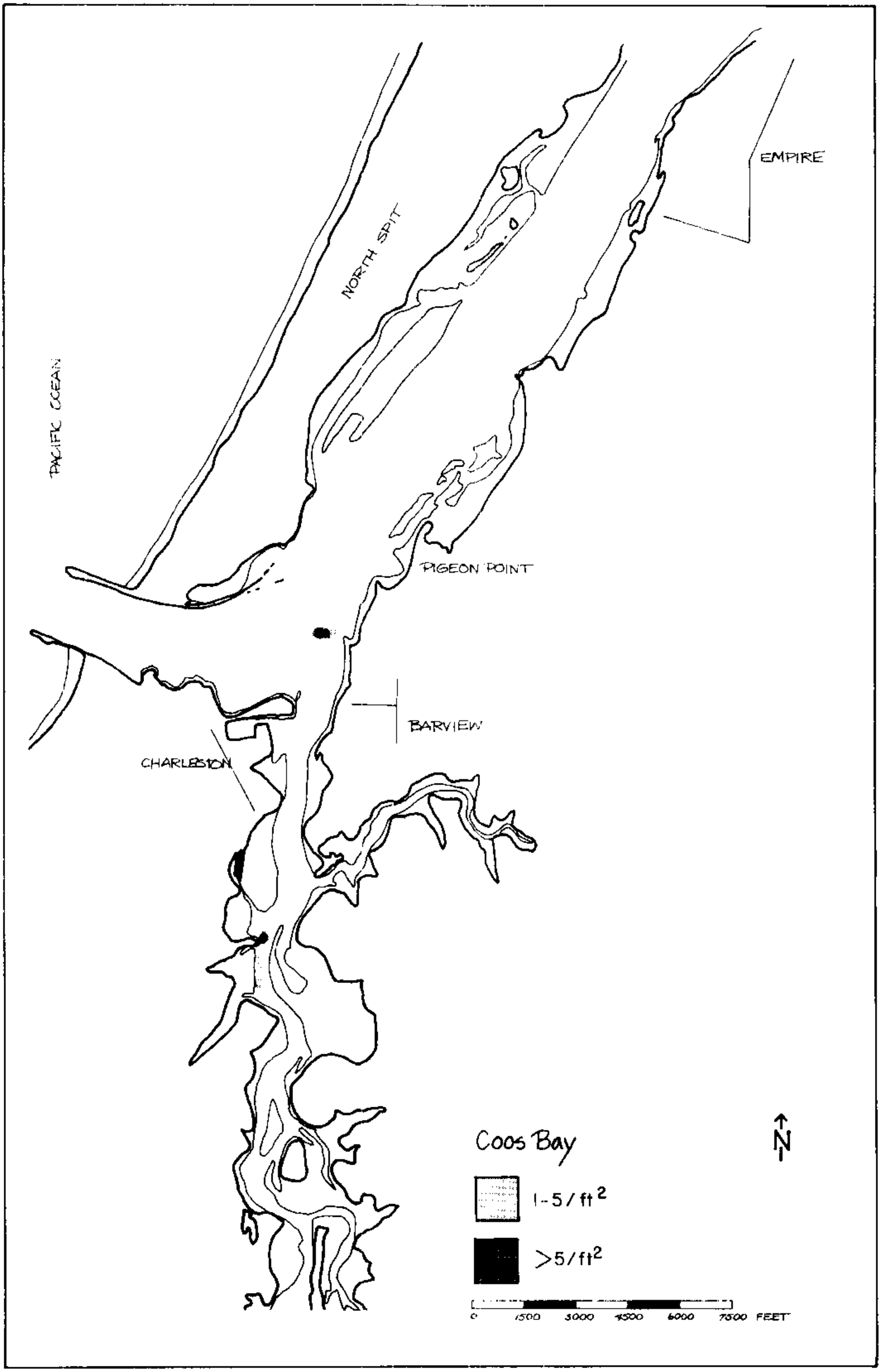

Figure II.A.2.-99. Distribution of piddock clams (*Zirfaea pilsbryi*) in lower Coos Bay and South Slough, Oregon . (See Fig. II.A.2.-94 for areas not surveyed.)

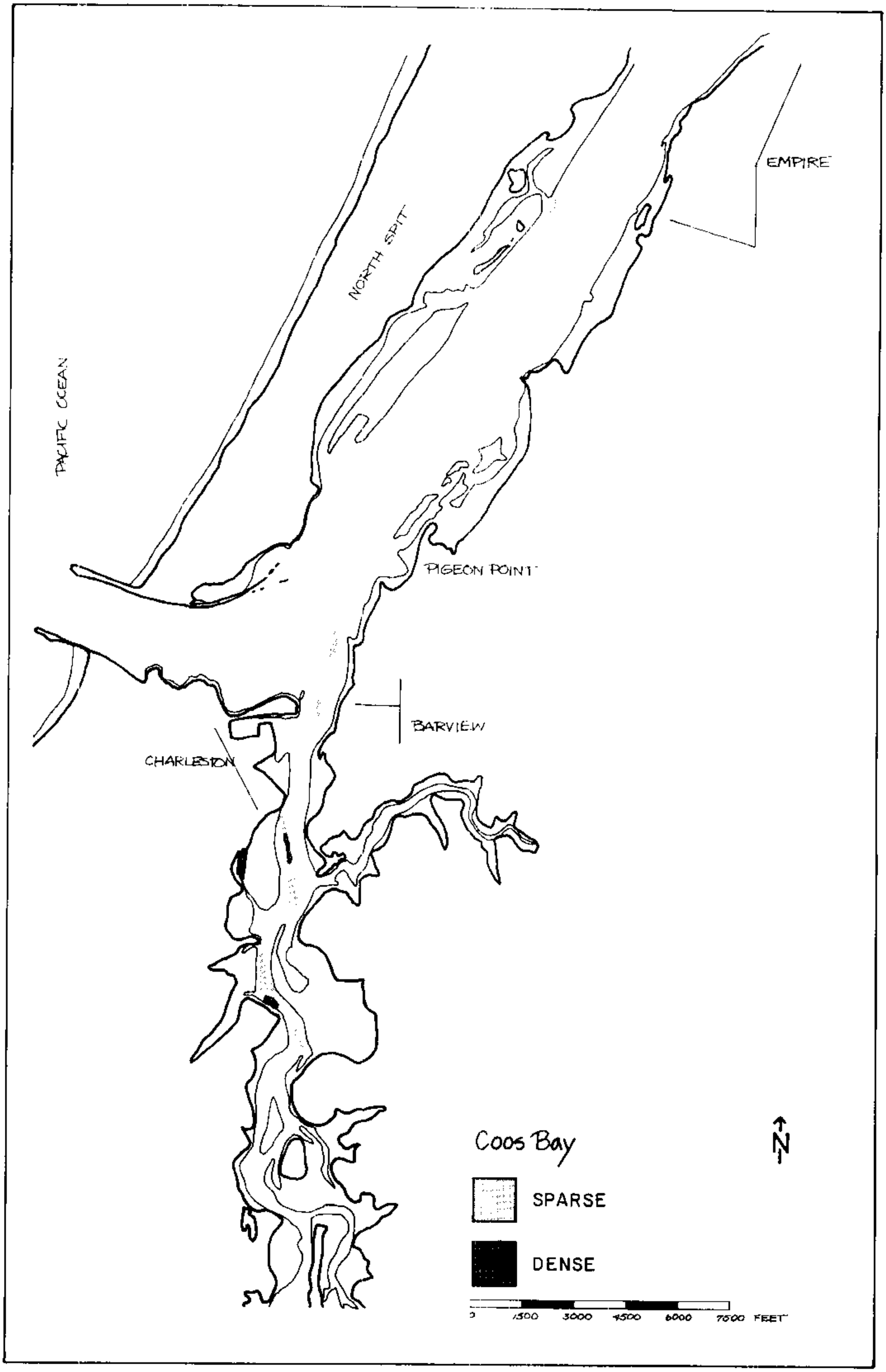

Figure II.A.2.-100. Distribution of eelgrass (*Zostera marina*) in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

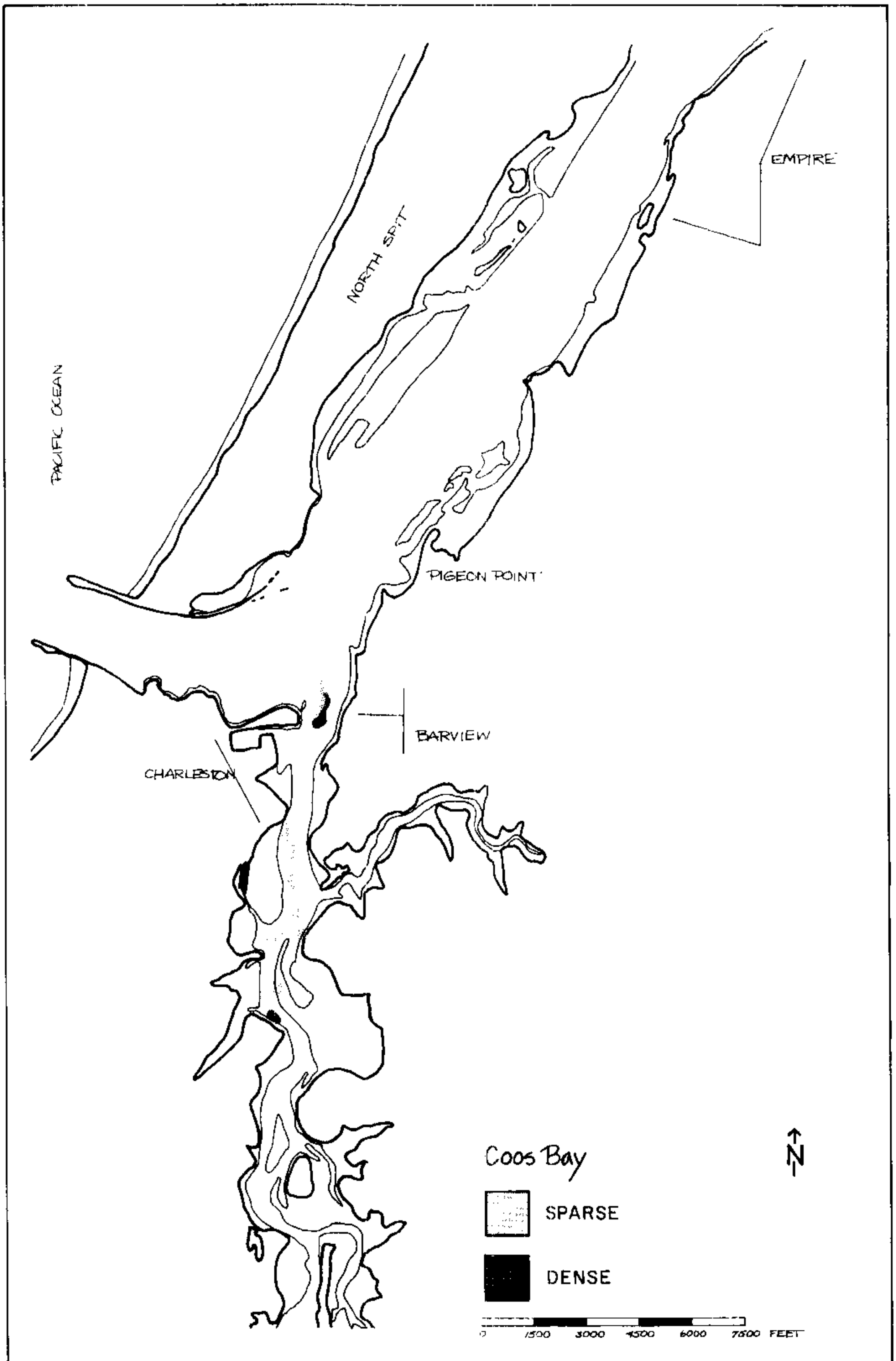

Figure II.A.2.-101. Distribution of unidentified green and red algae in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

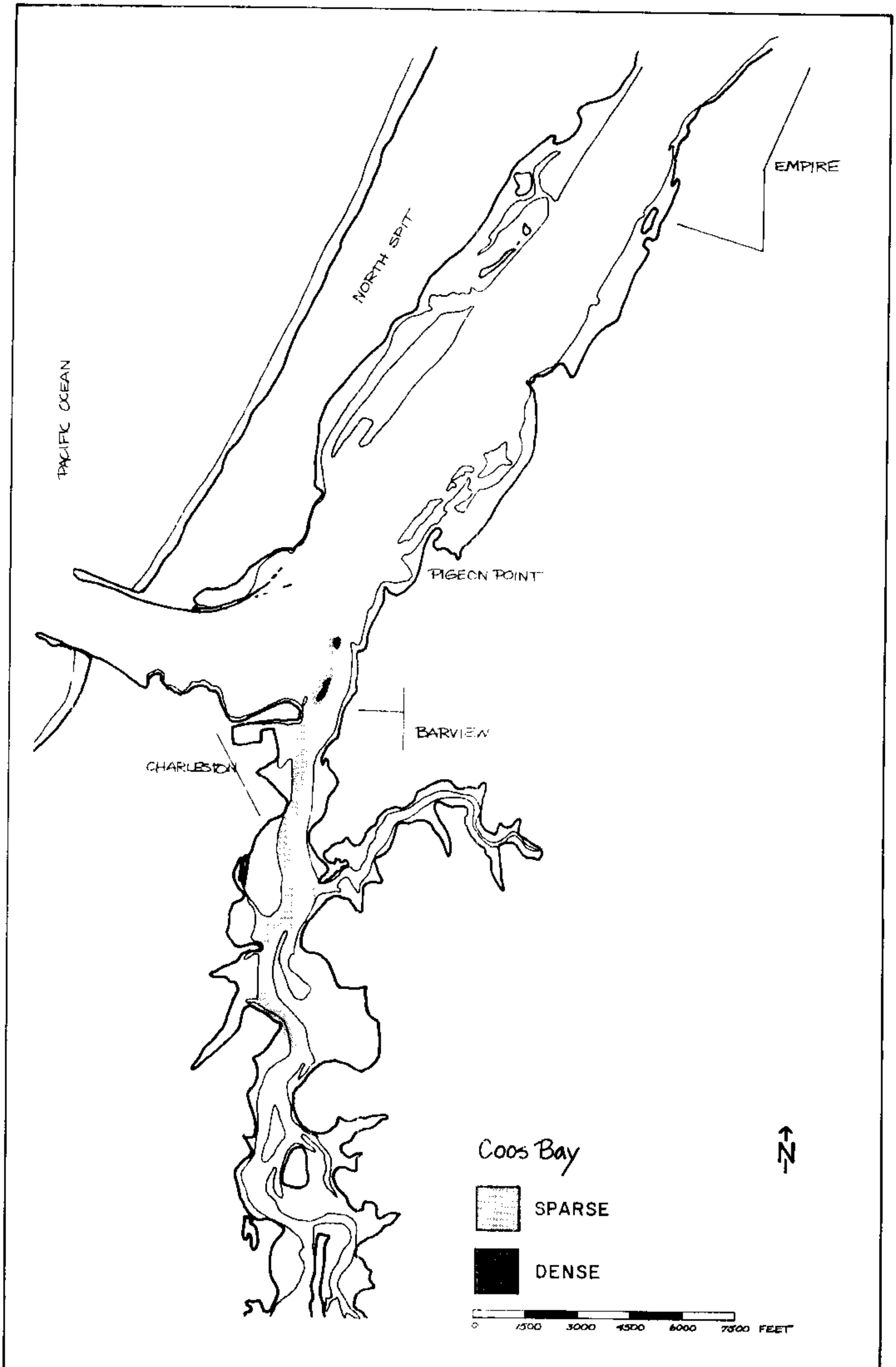

Figure II.A.2.-102. Distribution of unidentified brown algae in lower Coos Bay and South Slough, Oregon. (See Fig. II.A.2.-94 for areas not surveyed.)

II.A.3. DISCUSSION

Our surveys revealed several interesting facts about the distribution and abundance of clams, shrimps and vegetation in Oregon's estuaries. The subtidal surveys produced new information on the location of clam beds having commerical harvest potential in Tillamook, Yaquina and Coos bays. Stocks of clams in the other surveyed estuaries were either too scattered or sparsely populated to support a commercial fishery.

Nestucca and Siletz estuaries contained no subtidal clams although suitable clam habitat appeared to occur in each bay. Strong water currents, lack of adequate spawning stock or other unmeasured environmental parameters have apparently precluded successful spawning or survival of set in these bays.

Evidence that vegetation, especially eelgrass, is important to the occurrence of clams was observed in several estuaries. Gaper clams were frequently encountered among the eelgrass beds whereas adjacent non-vegetated areas contained few or no gapers.

Ghost and mud shrimps had a negative relationship with the abundance of bay clams. Few clams were observed among dense concentrations of shrimps. Unstable substrate conditions caused by the burrowing shrimps may preclude establishment of clams in these areas.

II. B. Gaper clam aging studies

THOMAS F. GAUMER
GREGORY P. ROBART

II.B.1. INTRODUCTION

One of the basic requirements for managing clam resources is an understanding of the age structure for each species. Aging techniques used in this study depended on the fact that growth of the gaper clam is usually greatly reduced during winter months when an annular ring is formed (Orton, 1923; Stevenson and Dickie, 1954; Wilbur and Owen, 1964).

II.B.2. METHODS

Gaper clams were collected subtidally adjacent to Pigeon Point in Coos Bay during October 1976. A total of 135 clams were used to test five methods of determining the ages of gaper clams. The right and left valves of each clam were also measured separately to determine differences in size and age. After aging, analysis of variance tests were performed to determine significant differences, if any, between aging techniques. The five methods used to age the gaper clams were as follows:

Aging Technique 1: Shell Annuli

The annular rings on the exterior surface of the valves were identified and counted (Figure II.B.2.-1).

Aging Technique 2: Cartilage Annuli

The two valves were separated and the cartilage removed from the chondrophore, or ligament pit. Caution was required when removing the cartilage because the tip of the oldest portion often breaks off during removal. Annular rings were counted on the cartilage where: (1) the cartilage attaches to the chondrophore; or (2) the left and right sections of the cartilage separate. For the smaller clams, it was necessary to use a 10x magnifying glass to accurately count the annuli.

Aging Technique 3: Chondrophore Annuli

The valves were separated and the cartilage removed from the chondrophore. The annular rings in the chondrophore, appearing as light purplish bands between the cream colored background of the chondrophore, were counted.

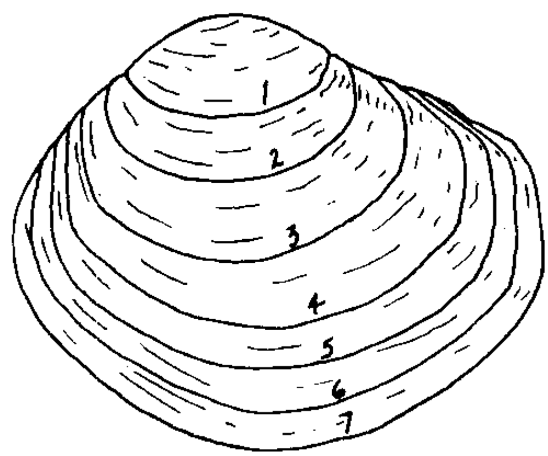

Fig. II.B.2.-1. Exterior annual rings on the shell of the gaper clam (*Tresus capax*).

Source	SS	df	MSS	F	F.05
Between clam ages	13465.35	134	100.49	904.5	1.00
Between aging techniques	5.20	8	0.65	5.85	1.94
Residual	119.10	1072	0.11		

$0 \leq [Pr\ (F \geq 5.85)/H_0\ \text{true}] \leq .05$

Table II.B.3.-1. Two-way analysis of variance of clam aging techniques.

Aging Technique 4: Chondrophore Annuli with High Intensity Light

The chondrophore was removed intact from the separated valve. Once removed, a high intensity light was held or mounted behind the chondrophore exposing the annular rings as bright white lines against a darker background.

Aging Technique 5: Chondrophore Cross-Section

Each valve was cross-sectioned from the umbo to the outer margin of the shell with either a hacksaw or a pair of wire cutters. Following removal of the cartilage, the annular rings of either the chondrophore or the valve were then counted.

II.B.3. RESULTS

The results of the five aging techniques were not identical. The null hypothesis that the five techniques would yield identical results was rejected at the 5% significance level (Table II.B.3.-1).

Aging technique No. 1, counting the annular rings on the exterior of the valve, accounted for the greatest variance in identifying growth checks with 29% disagreement between readings; the cartilage annuli method had 26% disagreement; chondrophore method, 18%; cross-section technique, 16%; while method No. 4 accounted for the least disagreement, 11%. Comparison of our aging techniques against known aged clams was not made.

Analysis of differences in apparent age between the left and right valves showed the greatest variance (34%) with the chondrophore cross-section techinque. Counting the exterior annular rings had almost the same amount of variance, 33%, as the cross-sectioning technique. The aging technique utilizing the chondrophre and the high intensity light varied 8% between right and left valves. There was only 2% variance between the left and right chondrophore aging technique without the high intensity back-up light.

II.B.4. DISCUSSION

Each technique had certain advantages and disadvantages:

Aging Technique 1: Shell Annuli

The annular rings on the exterior of the valves were more pronounced along the posterior edge and easier to identify. The annular rings in the middle portion of the valve showed better on the more recently formed part of the valve. It was often necessary to scrape off the periostracum to locate the annular ring. Two distinct advantages of this method over the others were: (1) examination for age was rapid; and (2) the clams did not have to be sacrificed to determine age. This method is complicated by the occasional presence of false checks resembling annular rings but caused by circumstances other than the reduced growth in winter. Such complications are reflected in the high variance (33%). Further complications are caused by the abrasion of the older part of the shell including the first few annular rings. It was often necessary to compare known zero-age shells to the shell in question to help determine where the first annulus occurred. Reduced growth in older clams made it difficult to identify the later annuli because they are spaced too closely for reliable determination of age.

Aging Technique 2: Cartilage Annuli

Removal of intact cartilage was difficult especially in the larger clams. Determination of the first annulus was also difficult as the older portion of the cartilage was always compressed and folded over. Only on a few occasions was it possible to count the annular rings on the cartilage at the separation between the left and right sections. Generally, the cartilage was cracked and had an irregular surface which damaged the annular rings.

Aging Technique 3: Chondrophore Annuli

Locating the first annular ring of the chondrophore was difficult especially in older clams, because the first ring was often over grown by later portions of the shell. The disturbance checks on the chondrophore were generally much easier to recognize than the disturbance checks on the exterior of the valves. Disturbance checks in the chondrophore appeared as a fine indistinct band whereas an annulus was considerably more prominent. This technique was much more accurate using dry samples rather than fresh, wet samples.

Aging Technique 4: Chondrophore Annuli with High Intensity Light

This method was most accurate of the five methods analyzed. There was very little doubt as to whether a ring was an annular ring or a disturbance check. Consequently, we used this method to age all gaper clams during the study. The main disadvantage was the animals had to be killed.

Aging Technique 5: Chondrophore Cross-Section

The greatest problem with this method was obtaining a uniform, smooth break along the valve at the umbo. If the separation did not begin exactly at the umbo, the first annular ring was missed and the age underestimated by one year. Therefore, it was easier to count the annuli in the chondrophore than those in the valve itself. The annular rings in the cross-section of the valve were very indistinct and not nearly so identifiable as those in the chondrophore. Cross-sectioning did not work well for smaller or younger clams which have less distinct annular rings than older clams.

II. C. Surveys of clam beds with commercial potential

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II.C.1. INTRODUCTION

During the clam distribution surveys, subtidal clam beds containing prospective commercial quantities of clams were located in Tillamook, Yaquina and Coos bays. To assess the magnitude and extent of these subtidal stocks of clams, a sampling program was developed. A suction pump patterned after one developed by the Washington Department of Fisheries (Goodwin, 1973) was employed to evaluate similar clam stocks. Those areas having clams in densities greater than 21.6 m^2 were categorized as having commercial clam harvesting potential.

II.C.2. METHODS

Three areas in Tillamook Bay, four areas in Yaquina Bay and a single area in Coos Bay (Figures II.C.2.-1, II.C.2.-2 and II.C.2.-3) were selected for study. Sampling schemes were generally similar for each area (Gaumer and Lukas, 1975; Gaumer and Halstead, 1976). A sampling grid was designed for each area with sampling intensity proportional to the number of clams observed in the area during the distribution study. Samples were collected by SCUBA divers using a suction pump powered by a 9 h.p. gasoline engine capable of discharging water at 73,826 kgs/m^2. The outlet hose, when connected to a 15.2 cm diameter suction tube, created a venturi water lift.

Each sample station was excavated to a depth of approximately 30.5 to 45.7 cms or until the dredge operator was confident all clams had been removed. Sample station area was a 0.2/m^2 of surface. The dredge was fitted with a collection basket covered with 1.3 cm mesh vinyl covered hardware cloth. The retained dredge material was sorted in the boat. In the laboratory, length measurements (to the nearest lower mm) were recorded from all clams except the cockle where height (rib length) was used. Live wet weight (to the nearest gram) was recorded. All butter, cockle, gaper and littleneck clams were aged when possible. Aging techniques included counting exterior growth rings on the butter, cockle and littleneck clams, and annuli in the chondrophore of the gaper clams. Biomass estimates were calculated for each area by determining the mean weight of the clams by age and expanding by the population estimates for each age.

Substrate materials were assessed and recorded at each sample station by the pump operator. Sediment categories were bedrock, rock, gravel, sand, mud, shell or debris.

The clam bed in Tillamook Bay was divided into three units with Area 1-A (off Hobsonville Point) surveyed in 1974, Area 1-B (off Larson Cove) in 1975 and 1-C (off Garibaldi) in 1976 (Figure II.C.2.-1). Area 4 of

Yaquina Bay was surveyed in 1974 and Areas 1, 2 and 3 in 1975 (Figure II.C.2.-2). A portion of Area 2 in Yaquina Bay was resurveyed in 1976 and 1977 to obtain information on recruitment and natural mortality. The Pigeon Point area of Coos Bay was surveyed in 1975 (Figure II.C.2.-3).

II.C.3. RESULTS AND DISCUSSION

A total of 159.8 ha of clam beds having commercial clam potential were surveyed during the study. We estimated that 214.7 million clams inhabited the eight areas (Table II.C.3.-1). Gaper and irus clams (*Macoma irus*) were the principal species, comprising 83.3% of the total estimated clams. Total clam densities ranged from 627.4 clams/m^2 in Area 2 of Yaquina Bay to 16.5 clams/m^2 in Area 4 of Yaquina Bay (Table II.C.3.-2). Maximum densities encountered in Tillamook and Coos bays exceeded 135 clams/m^2. Biomass estimates showed that approximately 9,335.8 mt of gaper, cockle, littleneck and butter clams occurred in Tillamook, Yaquina and Coos bays (Table II.C.3.-3). Of this total, approximately 7,367.3 t were of a commercially desirable size. The confidence limits at the 95% confidence level were $\pm$13.3% for the biomass of these clams.

Tillamook Bay

Our surveys showed that the subtidal clam resources in Tillamook Bay have a definite potential for the development of a commercial clam fishery. Population estimates revealed that approximately 39.6 million clams inhabited the 46.1 ha area between Garibaldi and Larson Cove (Table II.C.3.-1). Gaper, cockle, littleneck, butter and irus clams were the main species recorded, providing 7.2, 8.3 and 10.6 million clams, respectively, of the total. Figures II.C.3.-1 to II.C.3.-5 show the distribution and abundance of the commercially important species in Tillamook Bay. Figure II.C.3.-6 shows the incidental clam species.

Mean density of clams in Tillamook Bay ranged from 135.7 clams/m^2 in Area 1-C to 57.4 clams/m^2 in Area 1-A (Table II.C.3.-2). All commercially important clams (gaper, cockle, littleneck, butter, irus and softshell) occurred in excess of 4.8 clams/m^2 and averaged 15.1/m^2.

Biomass estimates showed that 2,596.9 t of gaper, cockle, littleneck and butter clams occurred in the survey area (Table II.C.3.-3). Of this total, approximately 2,411.5 t (92.9%) were of a commercially desirable size. (Minimum desirable commercial sizes were arbitrarily established for the gaper, cockle, littleneck and butter clams at 100 mm, 50 mm, 40 mm and 65 mm, respectively.) Of the 2,596.9 t, 1,109.5 t (42.7%) were gaper clams and 796.6 t (30.7%) were cockle clams. The confidence limits at the 95% confidence level ranged from $\pm$17.2% for cockles to $\pm$29.2% for butter clams (Table II.C.3.-3).

Year-class composition data indicated that gaper clams adjacent to Hobsonville Point (Area 1-A) were primarily of the 1967 year-class (Figure II.C.3.-7), whereas gapers upstream and adjacent to Larson Cove (Area 1-B) were mainly of the 1970 and 1971 year-classes (Figure II.C.3.-8). Our surveys off Garibaldi (Area 1-C) showed an exceptionally strong recruitment from the 1975 year-class (Figure II.C.3.-9). The 1966 year-class was also prominent in the channel adjacent to Garibaldi. No 1969 or 1971 year-class gaper clams were observed off Garibaldi indicating sporadic survival of gaper set. Total year-class failures have been also observed for *Protothaca staminea* (Paul and Feder, 1973; Paul et al., 1976), and *Saxidomus giganteus* (Quayle and Bourne, 1972).

Cockle and littleneck clams exhibited strong recruitment from the 1969 through 1973 year-classes in Areas 1-A and 1-B (Figures II.C.3.-7 and II.C. 3.-8); the 1974 year-class was prominent in Area 1-C (Figure II.C.3.-9).

The 1966 year-class was the principal age group of butter clams in Area 1-C (Figure II.C.3.-9). Indistinct annular growth rings precluded aging butter clams in Areas 1-A and 1-B.

Mean lengths for cockle, gaper, littleneck and butter clams collected in Area 1-A were 56.3, 96.6, 36.5 and 73.7 mm, respectively (Figure II.C.3.-10). Mean lengths for these same species from Area 1-B were 59.1, 98.5, 38.4 and 90.1 mm, respectively (Figure II.C.3.-11), and 59.2, 65.0, 36.5 and 68.8 mm, respectively, from Area 1-C (Figure II.C.3.-12).

Yaquina Bay

An estimated 148.7 million clams inhabited the 90.4 ha surveyed in Yaquina Bay. Of this total, 25.0 million, 93.2 million, 23.1 million and 7.3 million clams occurred in areas 1, 2, 3 and 4, respectively (Table II.C.3.-1). Gaper and irus clams were the main species observed and contributed 139.4 million clams (93.7%) to the total. Figures II.C.3.-13 to II.C.3.-17 show the relative distribution and abundance of the commercially important species of clams in the four survey areas. Figure II.C.3.-18 shows the same information for the incidental clams in the bay.

Mean clam densities ranged from 16.5 clams/m^2 in Area 4 to 627.4 clams/m^2 in Area 2 (Table II.C.3.-2). The exceptionally high values of clam densities in Yaquina Bay are partially the result of extremely strong recruitment from the 1975 year-class of gaper clams. Several of our samples had more than 2,153/m^2 gaper set.

Biomass estimates revealed that approximately 5,889 t of gaper, cockle, littleneck and butter clams occupied the survey area (Table II.C.3.-3). Of this total, approximately 4,188.2 t (71.1%) were of a commercially desirable size; 5,660.5 t (96.1%) were gaper clams. Due to the small number of cockle, littleneck and butter clams encountered in Areas 1, 2 and 3, we combined their totals for biomass estimation. The confidence limits at the 95% confidence level ranged from $\pm$24.4% for gapers to $\pm$41.7% for cockle clams (Table II.C.3.-3).

Year-class composition data for gaper clams for Areas 1, 2, 3 and 4 are shown in Figure II.C.3.-19. Strong recruitment for the 1975 year-class is indicated for Areas 1, 2 and 3. Area 4 was surveyed in 1974 prior to the spawning and setting of the 1975 year-class. Mean age of gaper clams increased up-bay, ranging from 0.9 years in Area 1 to 7.2 years in Area 4.

Due to the scarcity of butter, cockle and littleneck clams sampled in Areas 1, 2 and 3, we combined these clams, by species, to show their age composition (Figure II.C.3.-20). Figure II.C.3.-20 also shows the year-class compositon of gaper clams. Recruitment from the 1975 year-class was especially strong for gaper and cockle clams; the 1974 year-class was predominant for butter and littleneck clams. Figure II.C.3.-21 shows the year-class composition for cockle, gaper and littleneck clams in Area 4. We were unable to age butter clams from Area 4 due to indistinct shell annulation. Year-class composition of each species from Area 4 was considerably different than that for the down-bay clams, older clams being predominant up-bay.

Length-frequency data showed that gaper clams in Areas 1, 2, 3 and 4 had a mean size of 41.1, 36.9, 47.6 and 109.7 mm, respectively (Figure II.C.3.-22). The high value for Area 4 reflects the lack of set in that area.

Length-frequencies for cockle, gaper, littleneck and butter clams from areas 1, 2 and 3 were combined and are shown in Figure II.C.3.-23. Mean sizes for these four species were 19.6, 39.2, 24.7 and 29.5 mm, respectively; these same species averaged 59.7, 109.2, 53.8 and 86.8 mm in size, respectively, in Area 4 (Figure II.C.3.-24).

Year-class composition of gaper clams in Area 2 during 1975, 1976 and 1977 is shown in Figure II.C.3.-25. Gaper clams of the 1975 year-class were prominent each year and survival continued high through 1977. In 1976, the oldest gaper clams collected were of the 1963 year-class. The oldest gapers sampled in 1975 and 1977 were of the 1966 year-class.

Figure II.C.3.-26 shows the size composition of gaper clams in Area 2 for 1975, 1976 and 1977. Size composition was slightly bimodal, reflecting the abundance of 1975 year-class clams and clams of older age groups.

Natural mortality was estimated using a technique utilized by Gruffydd (1974). A catch curve of ages was plotted against the natural logarithm of mean abundance of age-classes from samples taken in Yaquina Bay each year from 1975-1978. Since abundance of age-class varies from year to year in a given location, the effect of uneven recruitment can be largely avoided by plotting the natural log of abundance of age-class against age.

An age-specific population depletion rate was difficult to ascertain from the age composition within individual sample years. When the mean of all yearly samples was utilized, however, an estimate of natural mortality was calculated.

The regression line in Figure II.C.3.-27 was fitted mathematically and assumes that gaper clams are fully recruited into the catchable population at age 0 and that the age-specific natural mortality rate is constant on sampled years. The total mortality coefficient was calculated from the expression:

$$-Z = \log_e \frac{N_t + 1}{N_t},$$

where N = number of clams for each age-class, and

t = time in years

No clams were found in the samples greater than 13 years old. A mean annual mortality rate of 0.488, corresponding to the slope of the regression line, was calculated for gaper clams in Area 2 of Yaquina Bay by this procedure.

Coos Bay

A 19.4 ha section of Coos Bay, proposed by the U.S. Army Corps of Engineers as a dumping site for dredge spoils, was surveyed between Pigeon Point and Empire. We estimated that 26.4 million clams inhabited the area. Of this total, 16.0 million (60.0%) were irus clams and 5.6 million (21.4%) were gaper clams (Table II.C.3.-1). Figures II.C.3.-28 to II.C.3.-32 show the relative distribution and abundance of the commercially important species of clams in the area. Figure II.C.3.-33 shows the distribution and abundance of the incidental clams in the survey area.

Total clam densities averaged 136.0/m^2 in the surveyed area (Table II.C.3.-2). Irus and gaper clams average 82.5/m^2 and 29.1/m^2, respectively.

We estimated that over 849.9 t of gaper, cockle, littleneck and butter clams populated the surveyed area. Of this total, approximately 767.6 t (90.3%) were of a commercially desirable size (Table II.C.3.-3). The confidence limits at the 95% confidence level ranged from $\pm$44.8% for gapers to $\pm$99.0% for cockle clams.

Year-class compositions of cockle, gaper, littleneck and butter clams are shown in Figure II.C.3.-34. As in Yaquina Bay, gaper clam recruitment was especially strong for the 1975 year-class, indicating excellent coastwide recruitment in 1975. Unlike Yaquina Bay, littleneck and butter clams were primarily of the older age groups.

Mean lengths of cockle, gaper, littleneck and butter clams were 33.4, 65.7, 56.3 and 89.6 mm, respectively (Figure II.C.3-35). Mean sizes were nearly twice as large for each species as those found for Yaquina Bay clams.

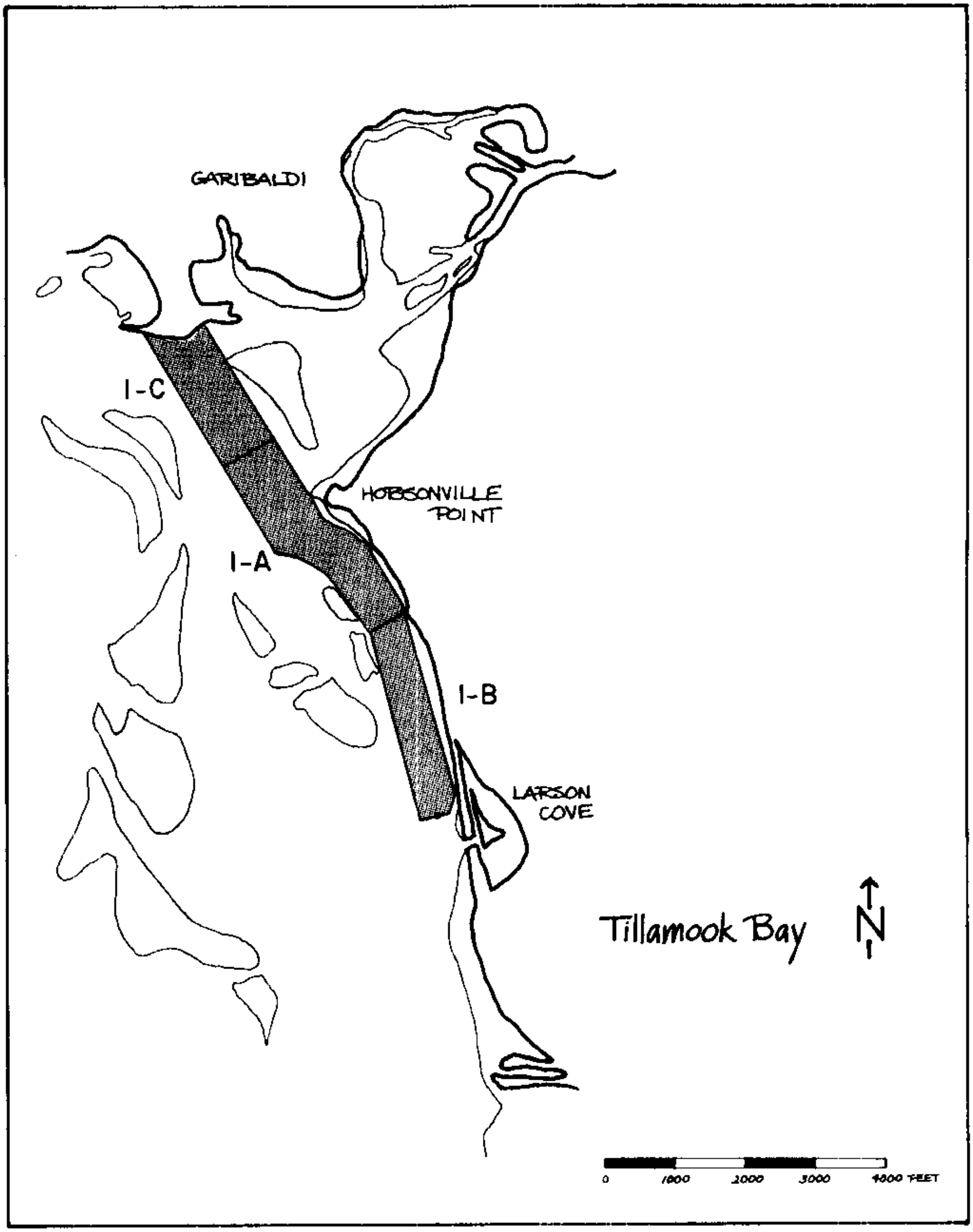

Figure II.C.2.-1. Location of Areas 1A, 1B, and 1C surveyed for commercial potential in Tillamook Bay, Oregon.

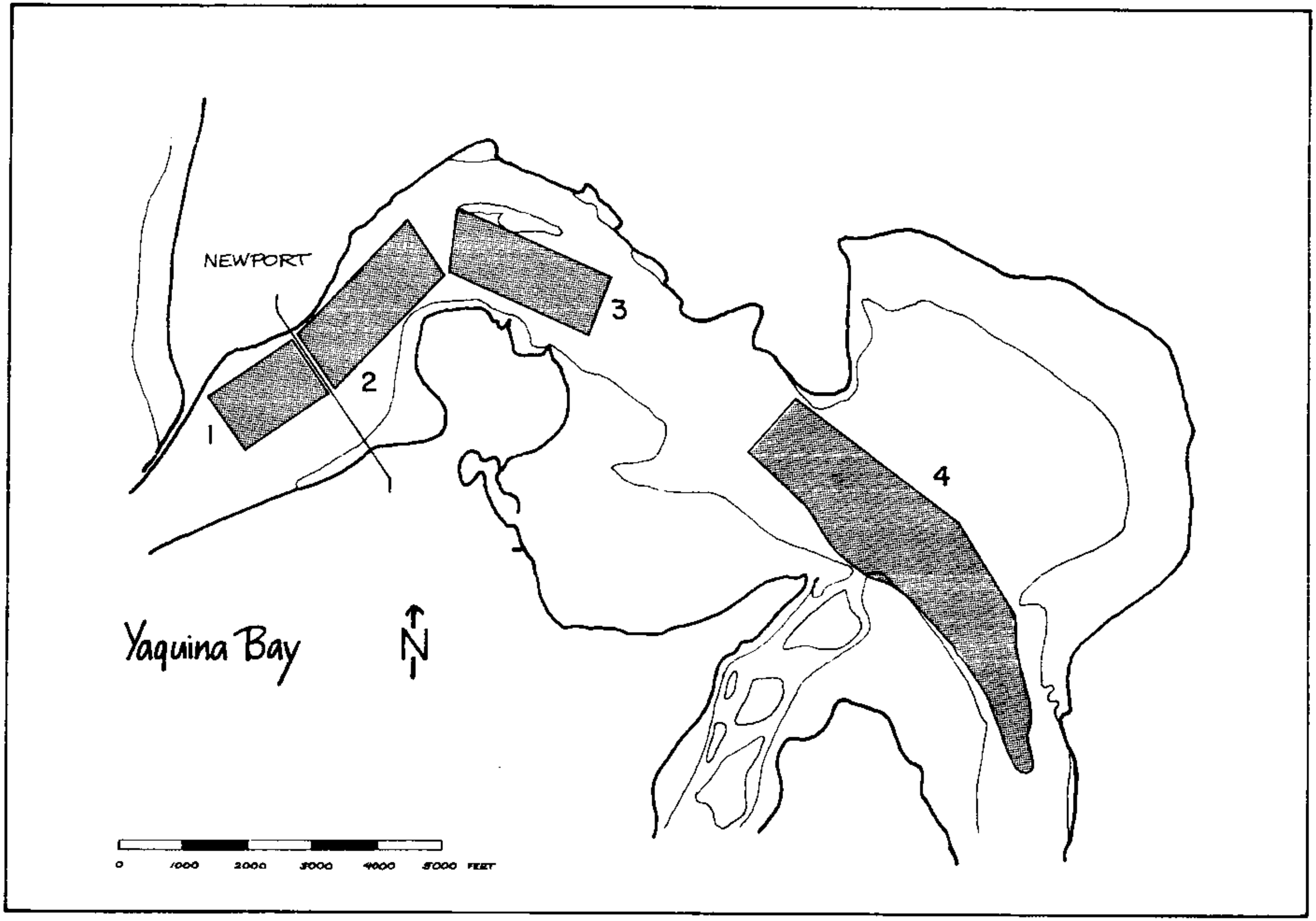

Figure II.C.2.-2. Location of Areas 1, 2, 3 and 4 surveyed for commercial potential in Yaquina Bay, Oregon.

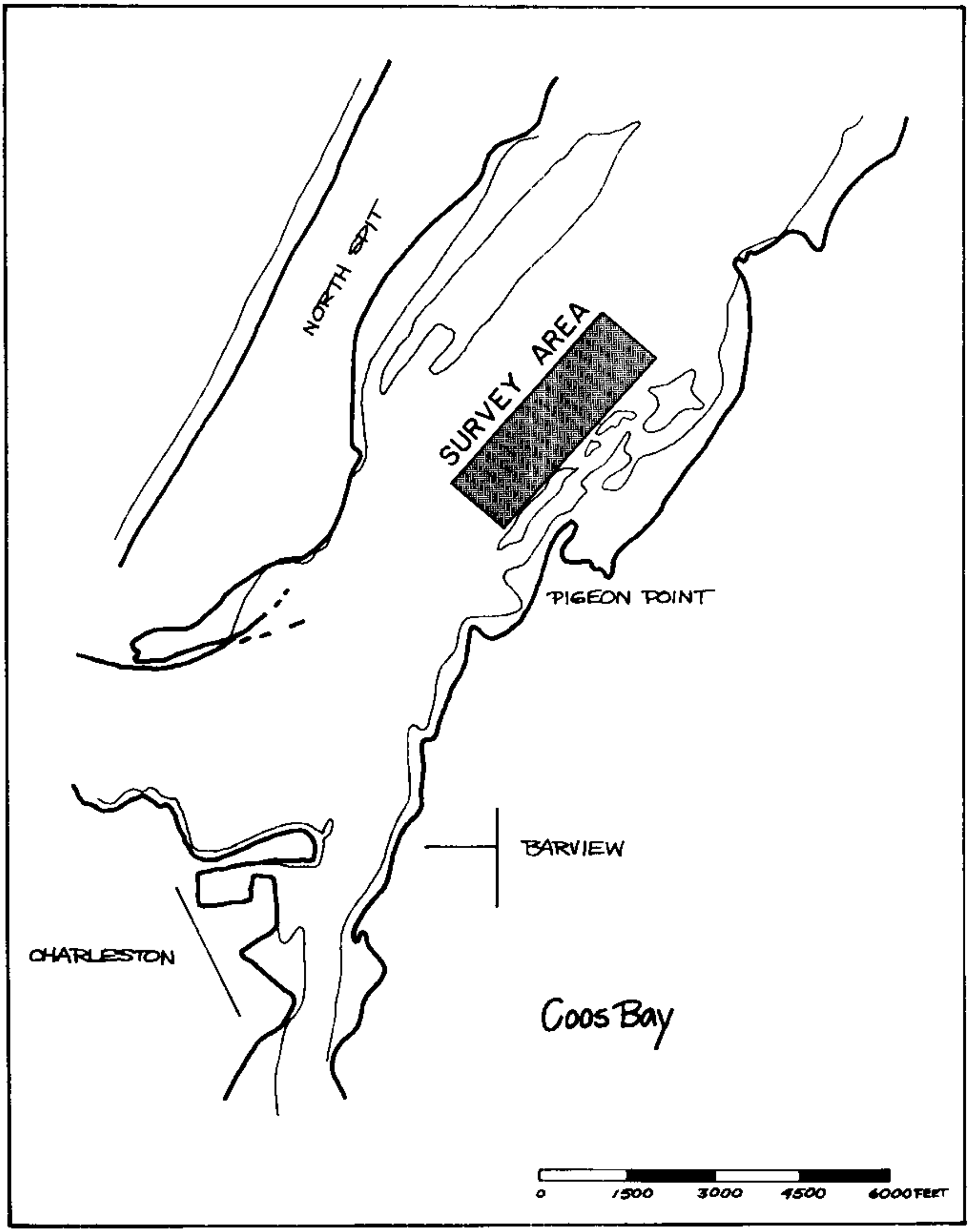

Figure II.C.2.-3. Location of a study area surveyed for commercial potential in lower Coos Bay, Oregon.

Bay	Area No.	Hectares	Year Sampled	Population Estimates (Thousands of clams) Gaper	Cockle	Littleneck	Butter	Irus	Bentnose	Softshell	Piddock	Cryptomya	Rock	Jackknife	Bodega	Total
Tillamook	1-A	21.4	1974	1,766	2,850	3,127	1,825	1,682	9	1,026	0	0	0	0	0	12,285
Tillamook	1-B	10.7	1975	912	1,638	1,463	1,013	2,600	50	763	0	0	0	0	0	8,439
Tillamook	1-C	13.9	1976	4,484	3,798	2,601	782	6,367	0	846	0	0	0	0	0	18,878
Subtotal		46.0		7,162	8,286	7,191	3,620	10,649	59	2,635	0	0	0	0	0	39,602
Yaquina	1	8.2	1975	19,224	81	147	261	4,612	0	0	634	0	0	0	16	24,975
Yaquina	2	14.3	1975	68,253	315	568	989	20,863	0	0	2,147	0	0	0	105	93,240
Yaquina	3	14.4	1975	13,608	462	168	567	7,854	168	0	0	0	0	42	273	23,142
Yaquina	4	57.5	1974	2,461	375	529	654	2,480	486	215	0	0	0	112	0	7,312
Subtotal		94.4		103,546	1,233	1,412	2,471	35,809	654	215	2,781	0	0	154	394	148,669
Coos	Pigeon Point	19.4	1975	5,649	202	843	809	16,019	2,647	0	0	67	101	0	101	26,438
Total !!		159.8		116,357	9,721	9,446	6,900	62,477	3,360	2,850	2,781	67	101	154	495	214,709
Percentage				54.2	4.5	4.4	3.2	29.1	1.6	1.3	1.3	<0.1	<0.1	<0.1	0.2	100

Table II.C.3.-1. Summary of population estimates of subtidal clams, Tillamook, Yaquina and Coos bays, 1974-1976.

Bay	Area	Size of Area (m^2)	Clam Species and Densities ($clams/m^2$) Gaper	Cockle	Littleneck	Butter	Irus	Bentnose	Softshell	Piddock	Cryptomya	Rock	Jackknife	Bodega	Total ($Clams/m^2$)
Tillamook	1-A	214,000	8.3	13.3	14.6	8.5	7.9	<0.1	4.8	0.0	0.0	0.0	0.0	0.0	57.4
Tillamook	1-B	107,000	8.5	15.3	13.7	9.5	24.3	0.5	7.1	0.0	0.0	0.0	0.0	0.0	78.9
Tillamook	1-C	139,000	32.3	27.3	18.7	5.6	45.7	0.0	6.1	0.0	0.0	0.0	0.0	0.0	135.7
Yaquina	1	82,000	234.4	1.0	1.8	3.2	56.4	0.0	0.0	7.8	0.0	0.0	0.0	0.2	304.8
Yaquina	2	143,000	459.2	2.2	3.8	6.7	140.4	0.0	0.0	14.4	0.0	0.0	0.0	0.7	627.4
Yaquina	3	144,000	87.2	3.0	1.1	3.6	50.3	1.1	0.0	0.0	0.0	0.0	0.3	1.7	148.3
Yaquina	4	575,000	4.3	0.6	1.4	1.8	7.0	0.6	0.6	0.0	0.0	0.0	0.2	0.0	16.5
Coos	Pigeon Point	194,000	29.1	1.0	4.3	4.2	82.5	13.6	0.0	0.0	0.3	0.5	0.0	0.5	136.0

Table II.C.3.-2. Summary of clam densities of subtidal clam stocks, Tillamook, Yaquina and Coos bays, 1974-1976.

Clam Type	Area No.	Biomass Pounds	Estimates Metric Tons	Pounds of Clams of Commercial Size	95% Confidence Interval for Biomass (±%)
Tillamook Bay					
Gaper	1-A	826,300	374.8	785,700	37.2%
Gaper	1-B	381,900	173.0	347,900	38.9
Gaper	1-C	1,238,900	561.7	1,122,900	34.7
Total		2,447,100	1,109.5	2,256,500	20.8
Cockle	1-A	527,500	239.4	507,300	22.8
Cockle	1-B	357,500	162.[illegible]	349,500	37.4
Cockle	1-C	871,100	395	789,000	29.2
Total		1,756,100	796.6	1,645,800	17.2
Littleneck	1-A	143,000	64.8	119,600	35.3
Littleneck	1-B	68,100	30.9	59,900	42.9
Littleneck	1-C	137,300	62.3	126,900	69.3
Total		348,400	158.0	306,400	26.5
Butter	1-A	619,500	281.0	584,600	41.6
Butter	1-B	343,800	155.9	324,500	47.4
Butter	1-C	211,500	95.9	199,600	72.8
Total		1,174,800	532.8	1,108,700	29.2
Grand Total (Tillamook Bay)		5,726,400	2,596.9	5,317,400	±4.5%
Yaquina Bay					
Gaper	1	2,359,600	1,070.1	545,700	66.1
Gaper	2	6,058,300	2,747.5	4,270,800	48.1
Gaper	3	2,058,500	1,353.5	2,921,400	40.7
Gaper	4	1,078,800	489.4	1,049,800	27.0
Total		12,481,200	5,660.5	8,787,700	24.4
Cockle	1,2,3	22,100	10.0	20,100	89.0
Cockle	4	78,200	35.4	76,000	46.8
Total		100,300	45.4	96,100	41.7
Littleneck	1,2,3	20,200	9.2	17,500	63.8
Littleneck	4	74,600	33.9	70,500	36.2
Total		94,800	43.[illegible]	88,000	32.3
Butter	1,2,3	62,100	28.3	41,500	75.8
Butter	4	246,300	111.7	221,700	40.7
Total		308,400	140.0	263,200	36.6
Grand Total (Yaquina Bay)		12,984,700	5,889.0	9,235,000	±24.1
Coos Bay					
Gaper	Pigeon Pt.	1,530,800	694.2	1,355,700	44.8
Cockle	"	23,000	10.5	19,300	99.0
Littleneck	"	71,600	32.6	69,800	49.7
Butter	"	248,200	112.6	247,700	58.2
Total		1,873,600	849.9	1,692,500	34.7
Grand Total (Coos Bay)		1,873,600	849.9	1,692.500	±34.7

Table II.C.3.-3. Summary of biomass estimates of commercially imporatant clams in Tillamook, Yaquina and Coos bays.

Clam Type	Area No.	Biomass Pounds	Estimates Metric Tons	Pounds of Clams of Commercial Size	95% Confidence Interval for Biomass (±%)
Grand Total (All Bays Combined)					
Gaper		16,459,100	7,464.2	12,399,900	18.6
Cockle		1,879,400	852.5	1,761,200	19.0
Littleneck		514,800	233.7	464,200	20.8
Butter		1,731,400	785.4	1,619,600	22.6
Total		20,584,700	9,335.8	16,244,900	±13.3%

Table II.C.3.-3. continued.

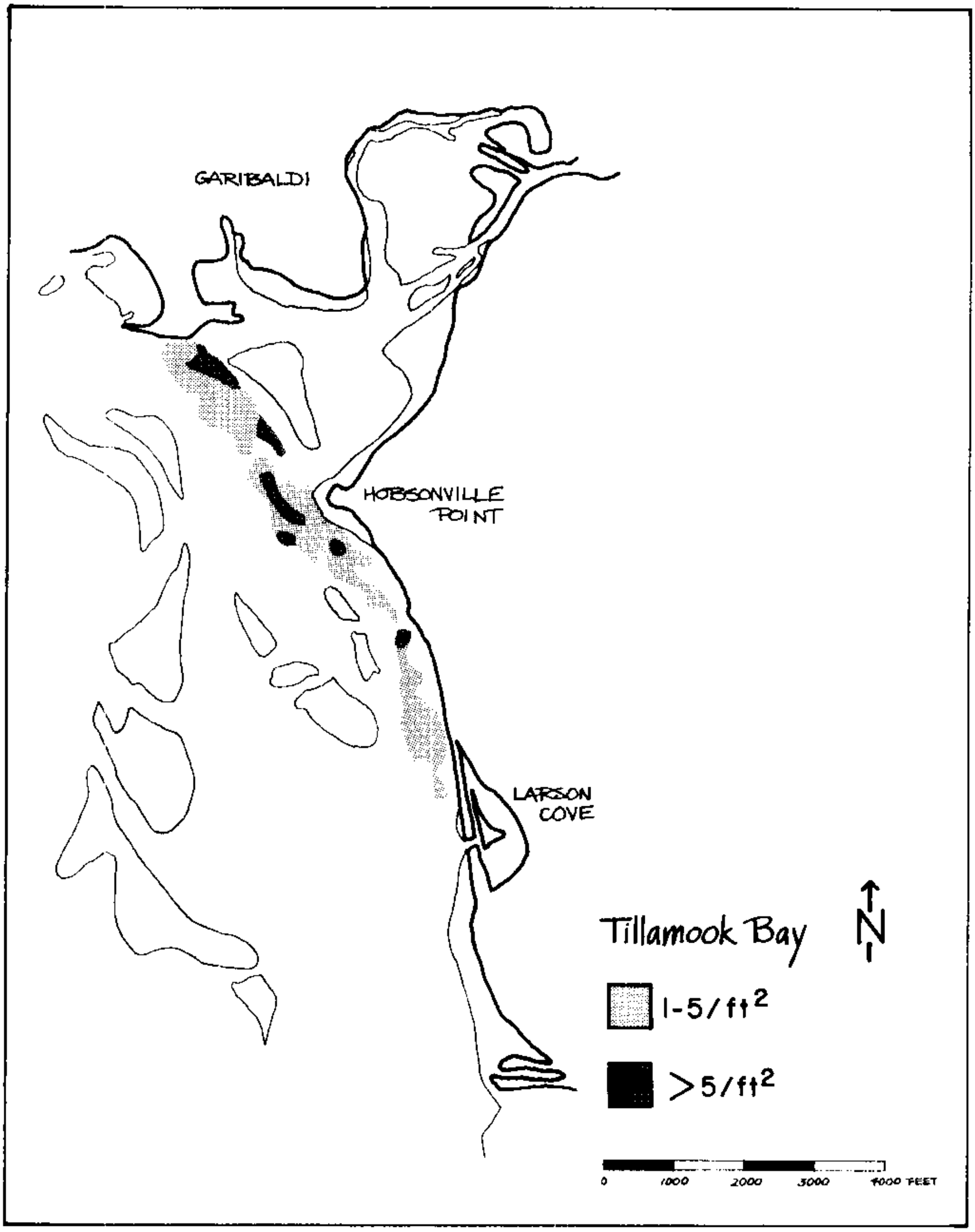

Figure I?.C.3.-1. Distribution and density of gaper clams (*Tresus capax*) in Areas 1A-C, Tillamook Bay, Oregon.

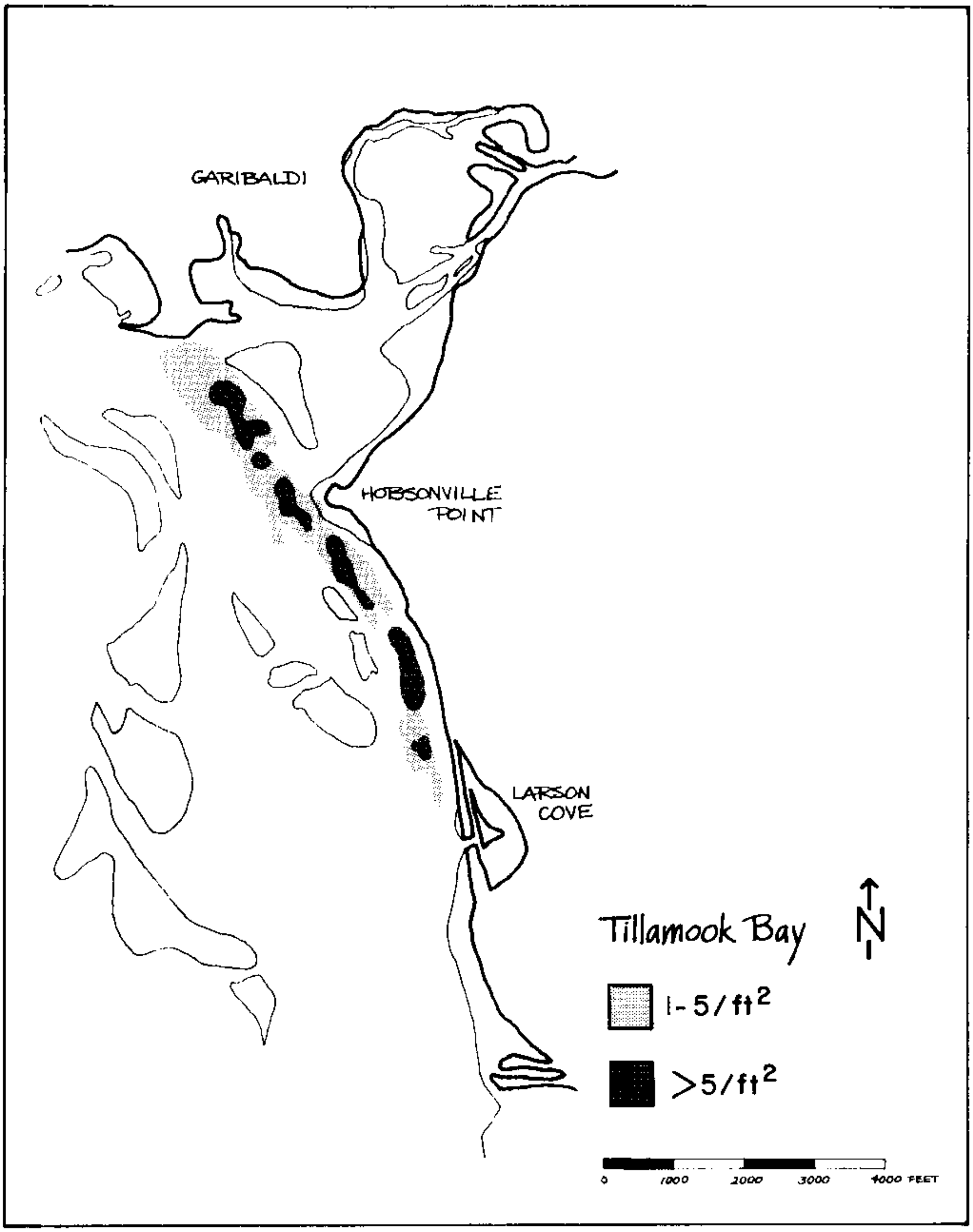

Figure II.C.3.-2. Distribution and density of cockle clams (*Clinocardium nuttallii*) in Areas 1A-C, Tillamook Bay, Oregon.

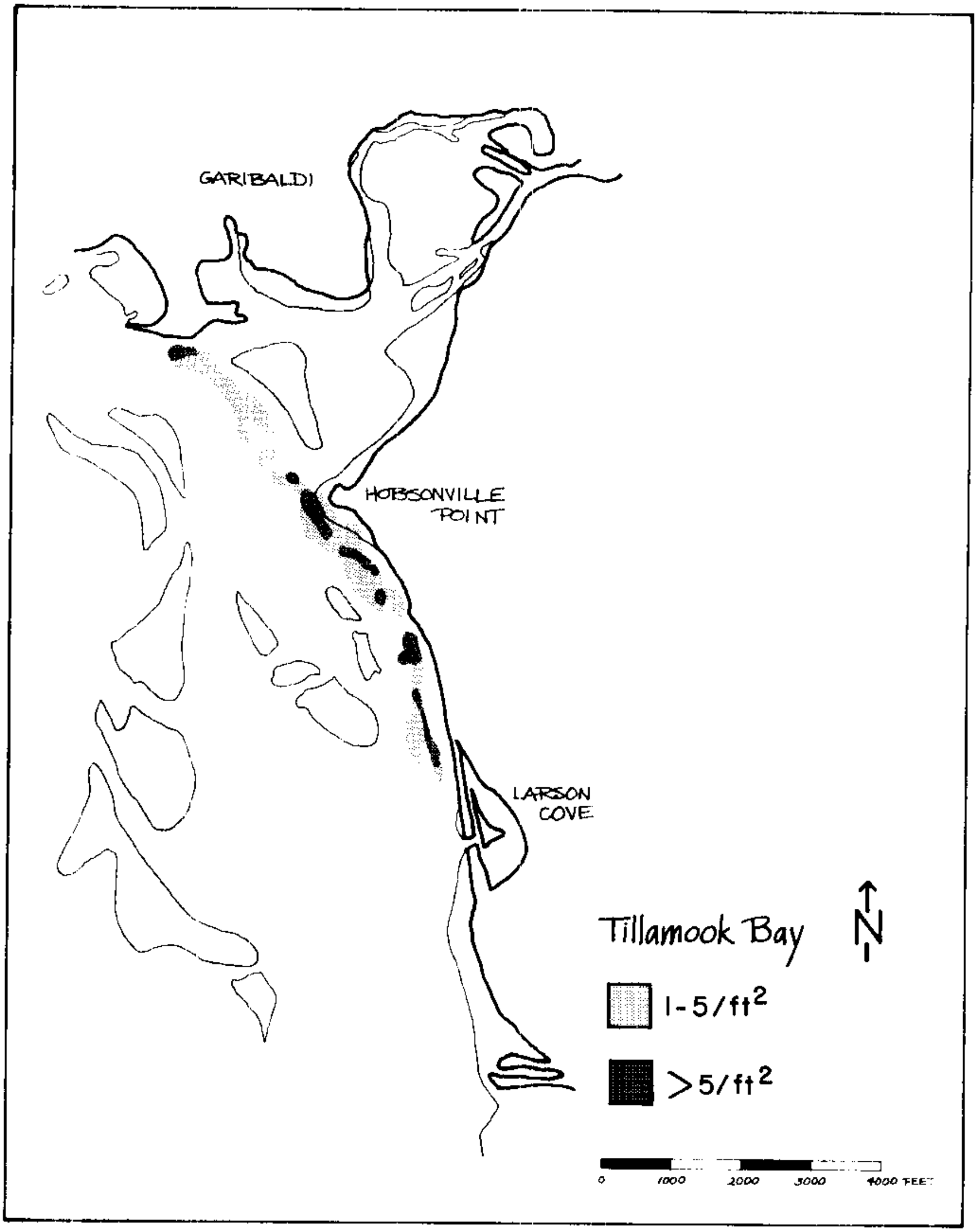

Figure II.C.3.-3. Distribution and density of butter clams (*Saxidomus giganteus*) in Areas 1A-C, Tillamook Bay, Oregon.

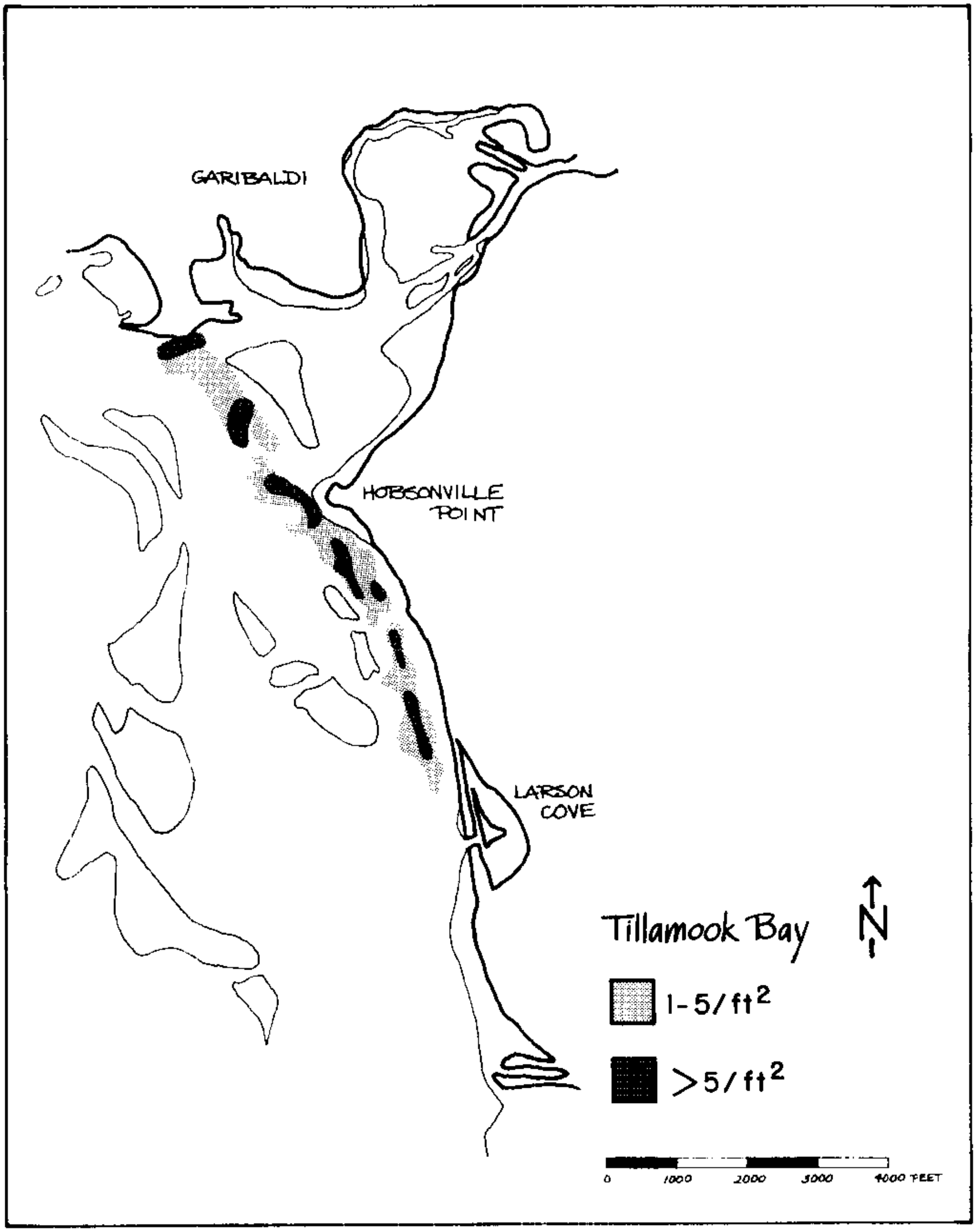

Figure II.C.3.-4. Distribution and density of native littleneck clams (*Venerupis staminea*) in Areas 1A-C, Tillamook Bay, Oregon.

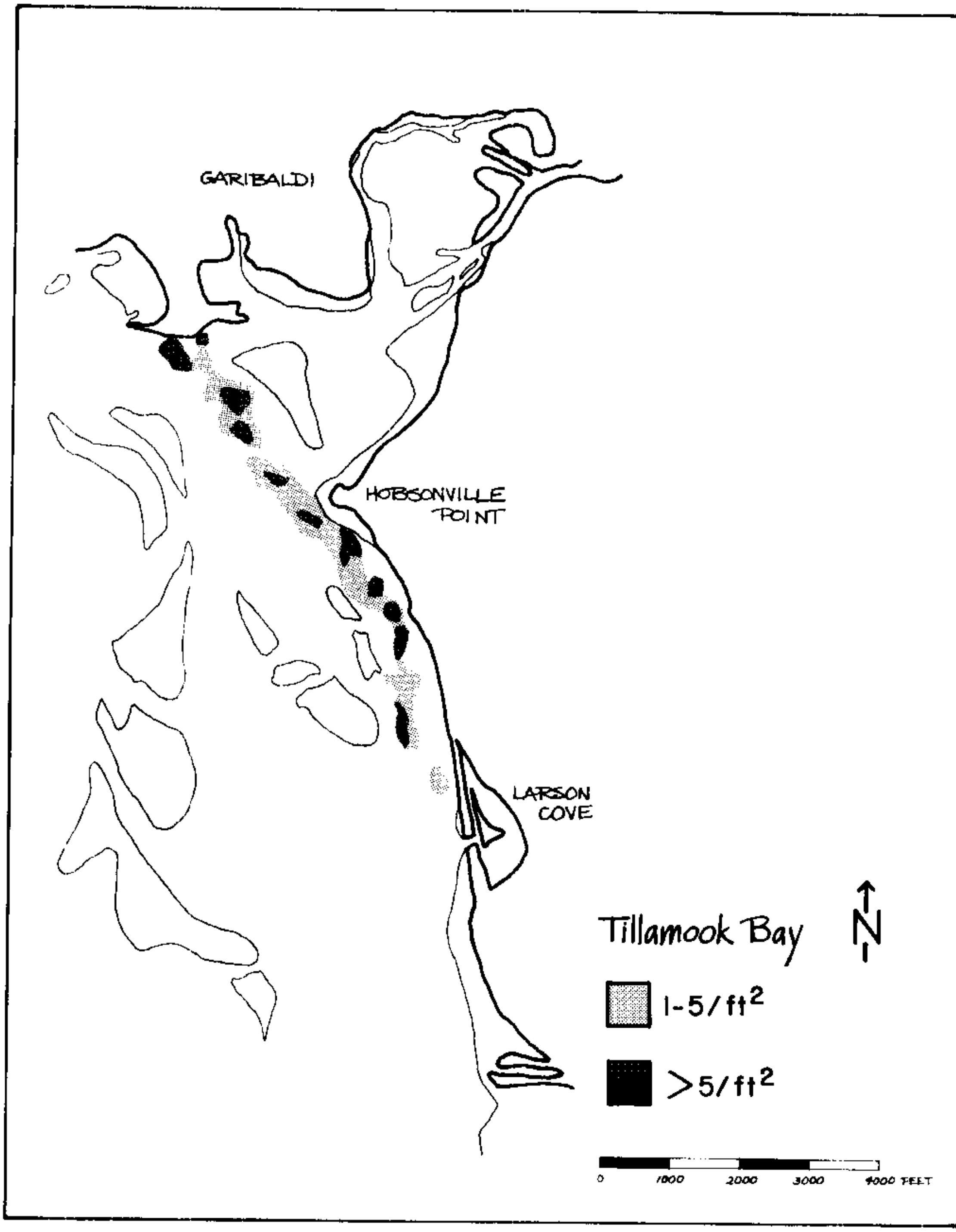

Figure II.C.3.-5. Distribution and density of irus clams (*Macoma irus*) in Areas 1A-C, Tillamook Bay, Oregon.

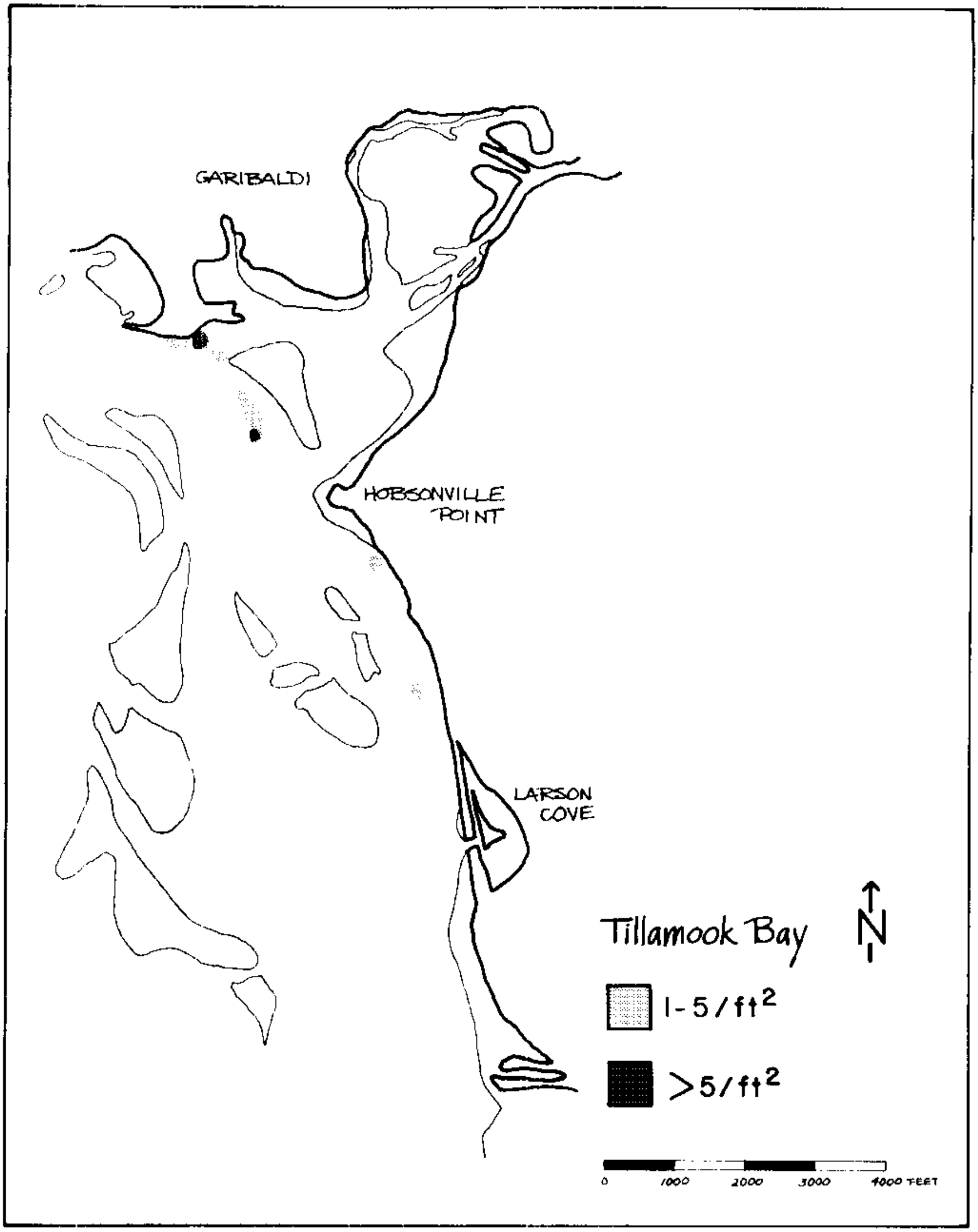

Figure II.C.3.-6. Distribution and density of bentnose clams (*Macoma nasuta*) and California softshell clams (*Cryptomya californica*) in Areas 1A-C, Tillamook Bay, Oregon.

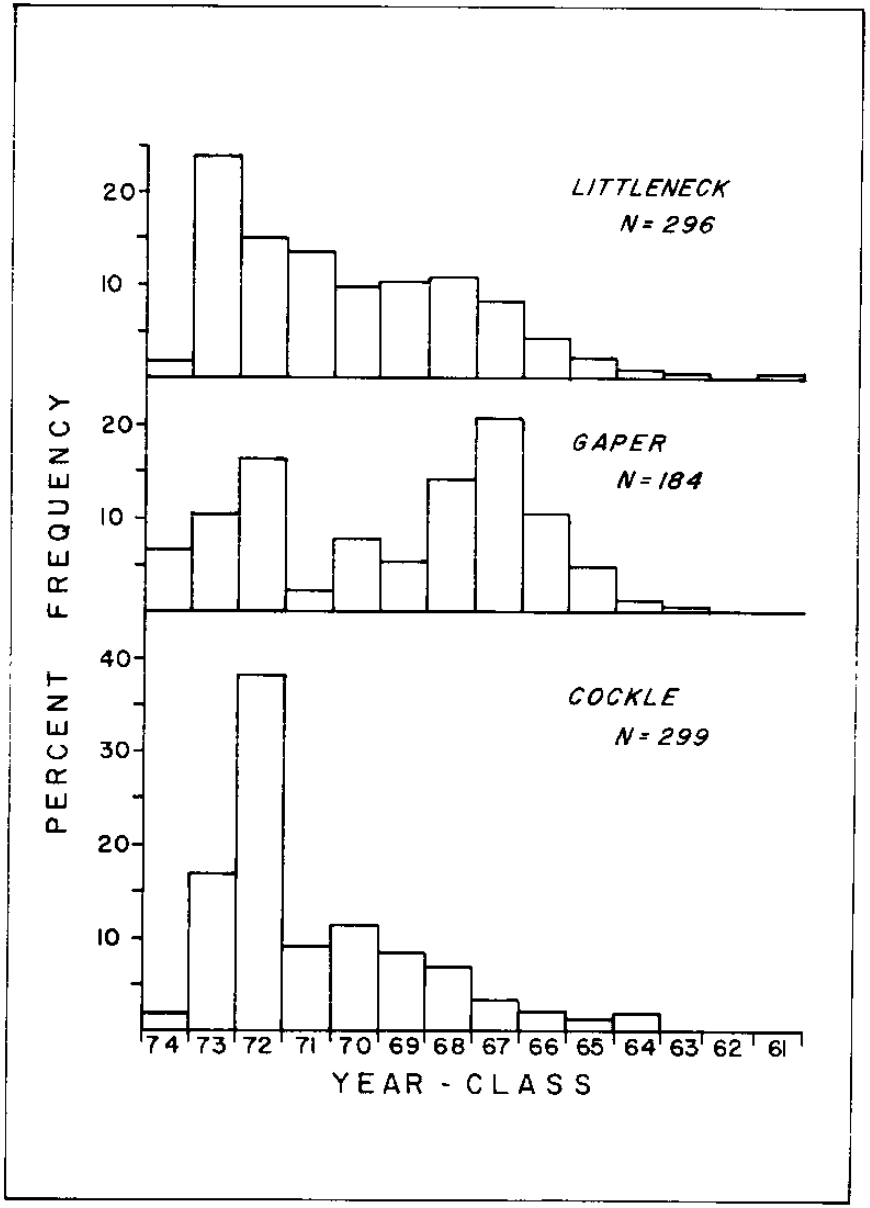

Figure II.C.3.-7. Year class composition of subtidal clams collected from Area 1A, Tillamook Bay, Oregon, 1974.

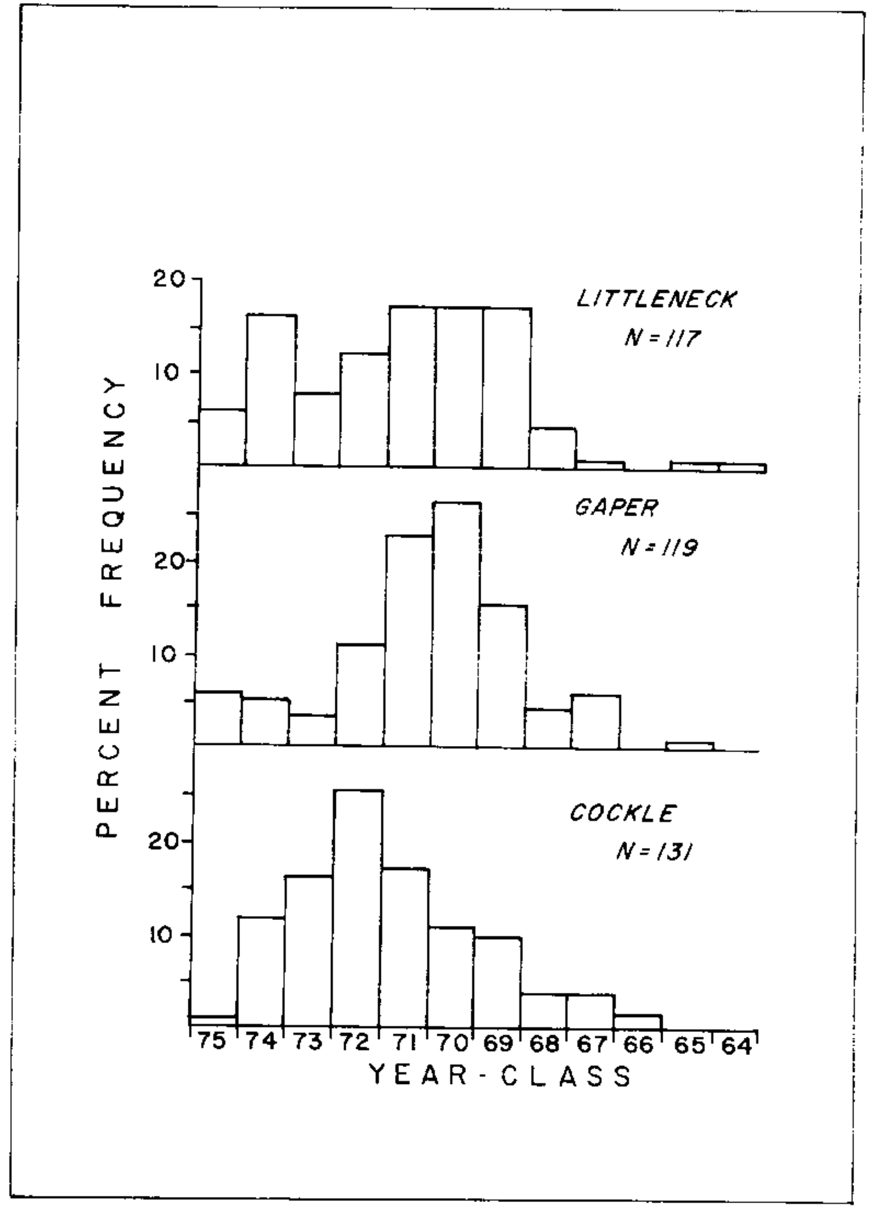

Figure II.C.3.-8. Year-class composition of subtidal clams collected from Area 1B, Tillamook Bay, Oregon, 1974.

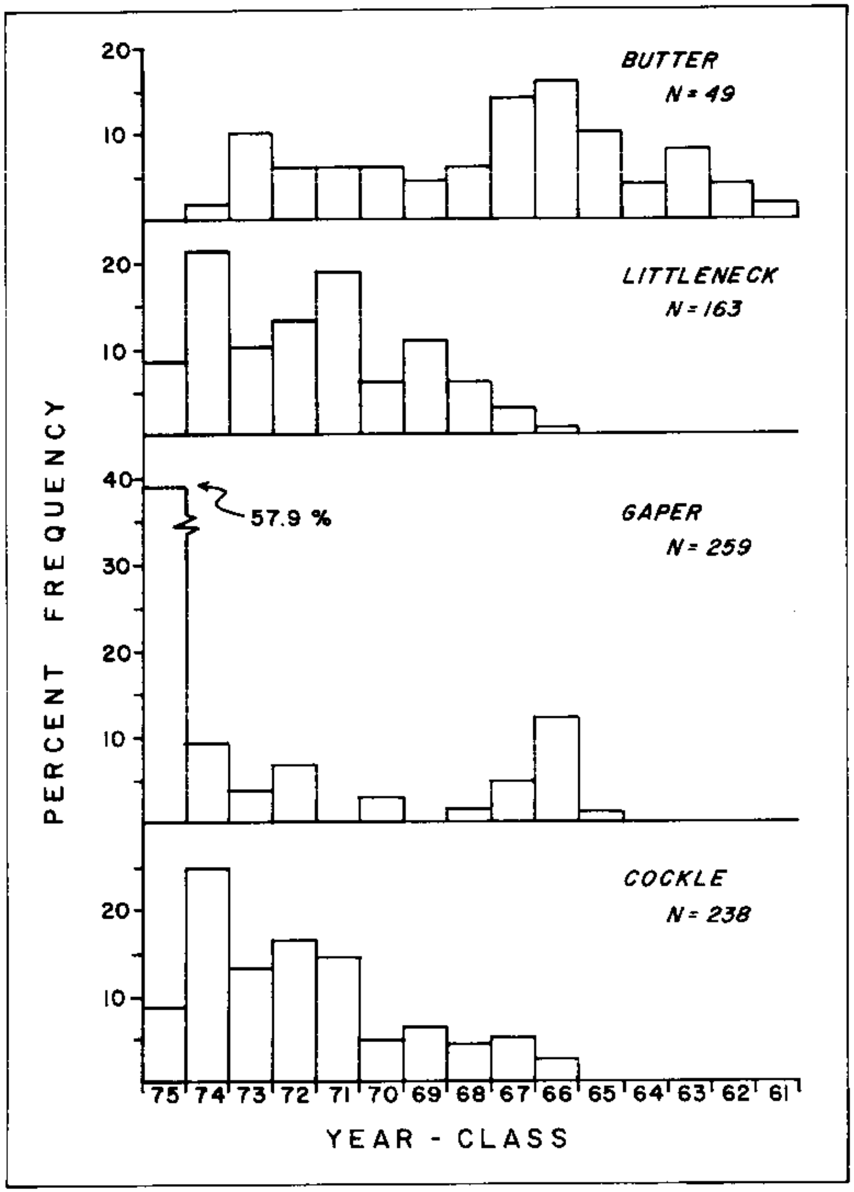

Figure II.C.3.-9. Year-class composition of subtidal clams collected from Area 1C, Tillamook Bay, Oregon, 1976.

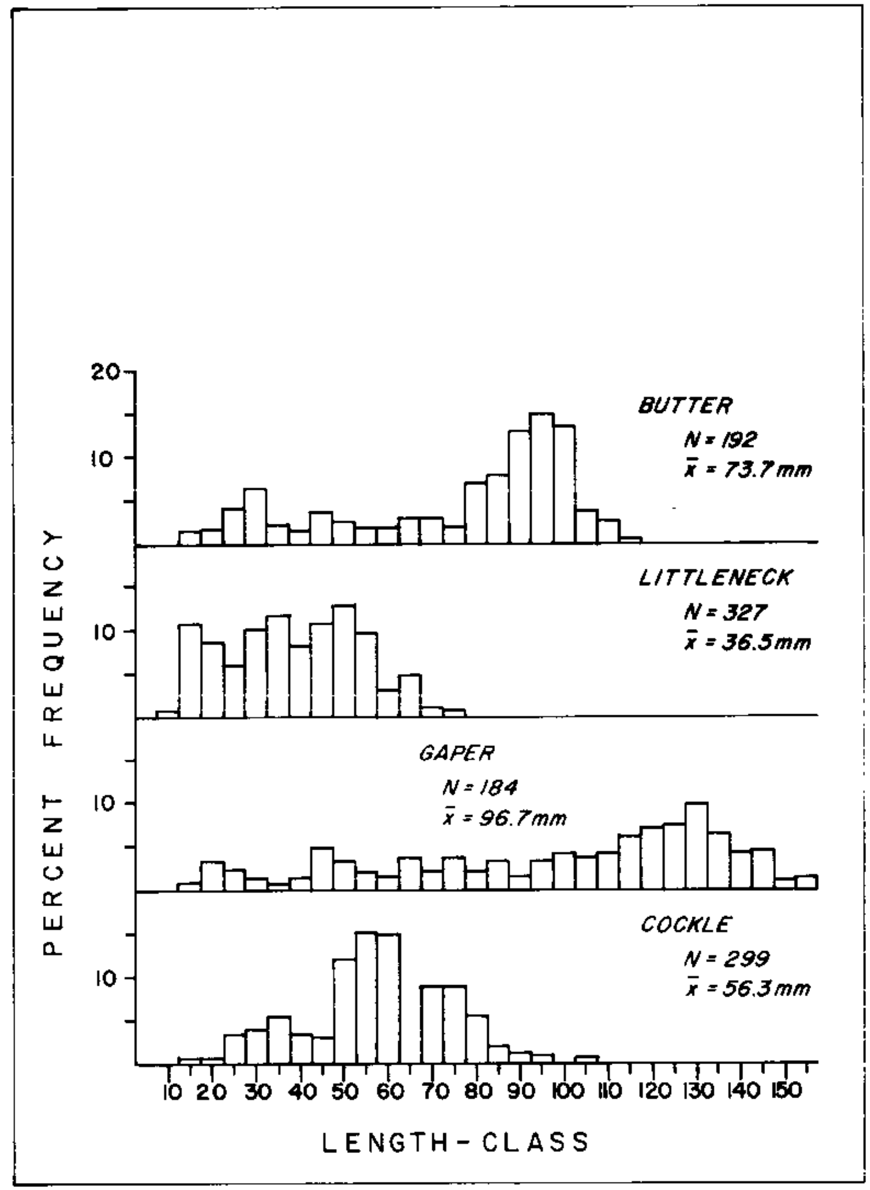

Figure II.C.3.-10. Length-class composition of subtidal clams collected from Area 1A, Tillamook Bay, Oregon, 1974.

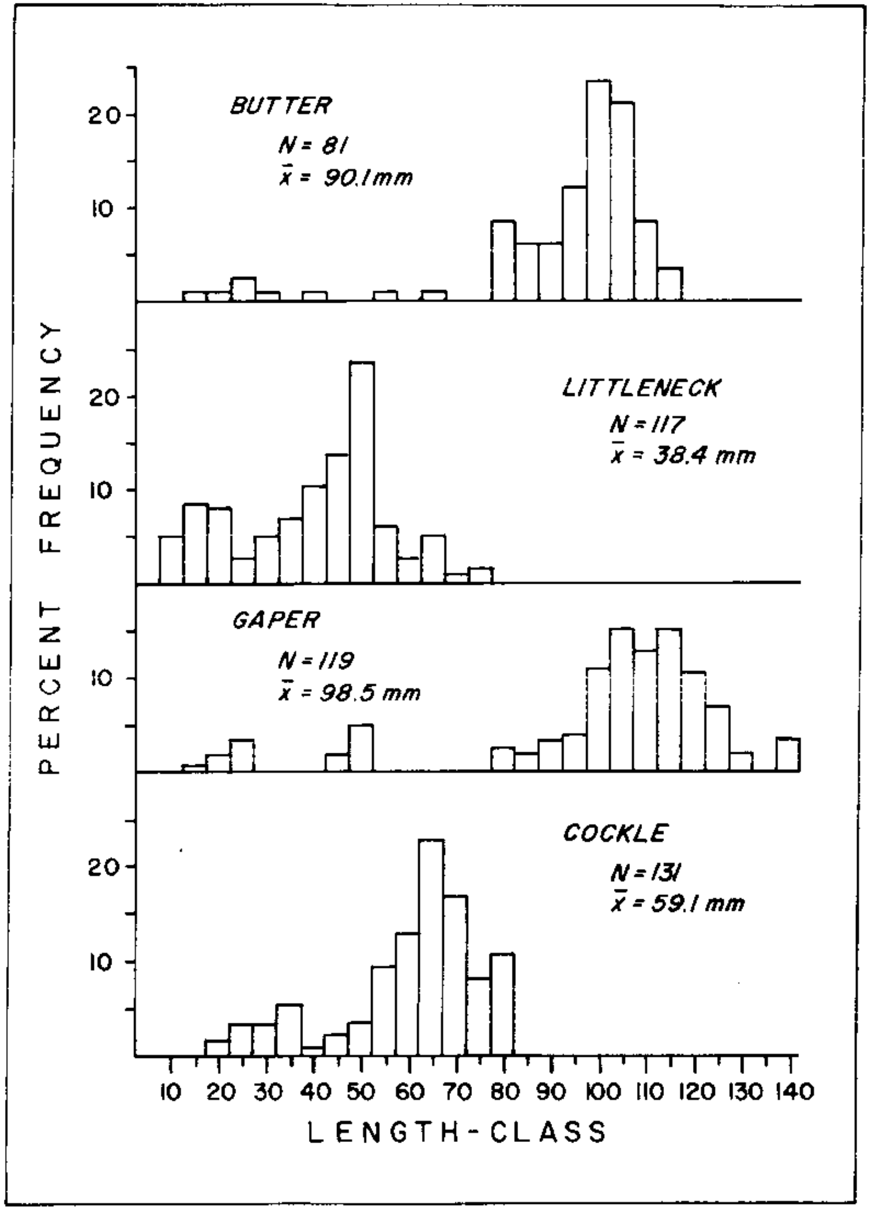

Figure II.C.3.-11. Length class composition of subtidal clams collected from Area 1B, Tillamook Bay, Oregon, 1975.

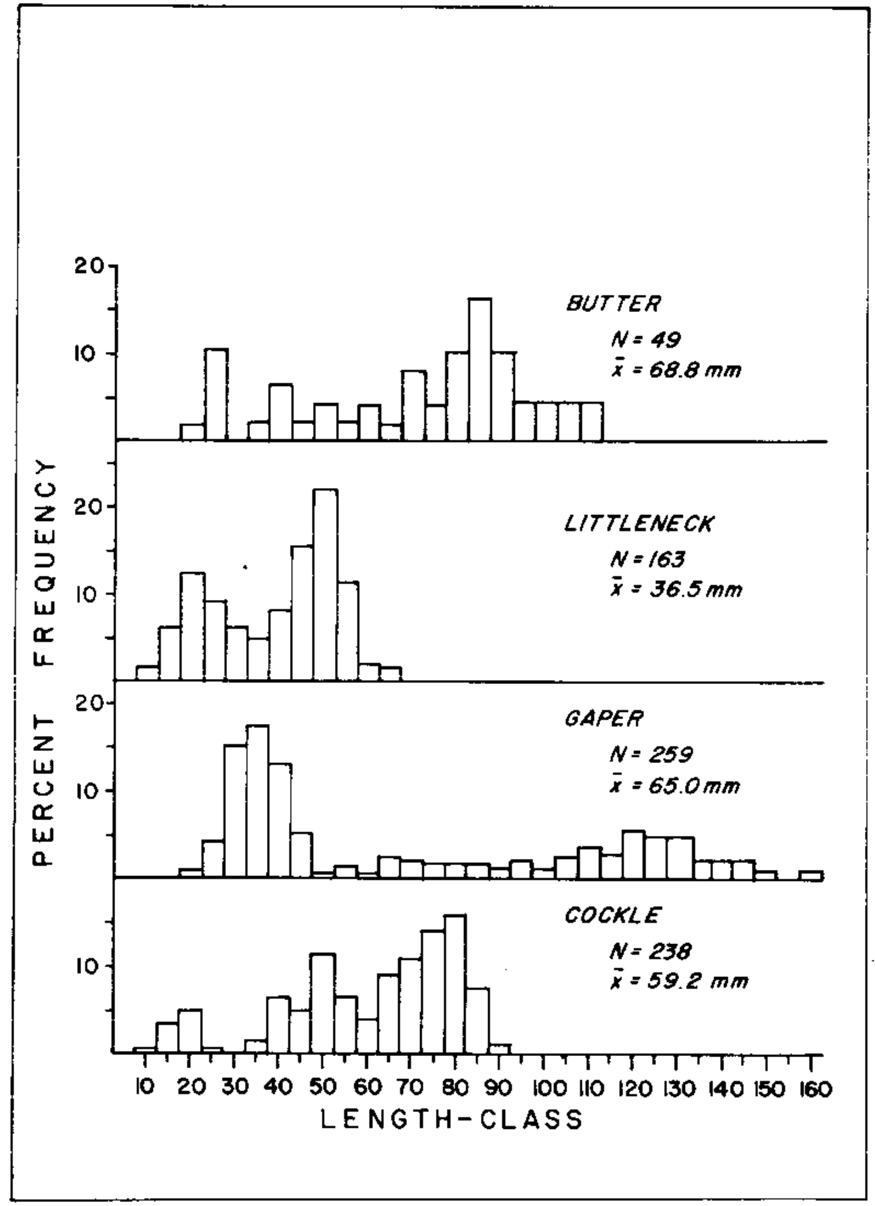

Figure II.C.3.-12. Length-class composition of subtidal clams collected from Area 1C, Tillamook Bay, Oregon, 1976.

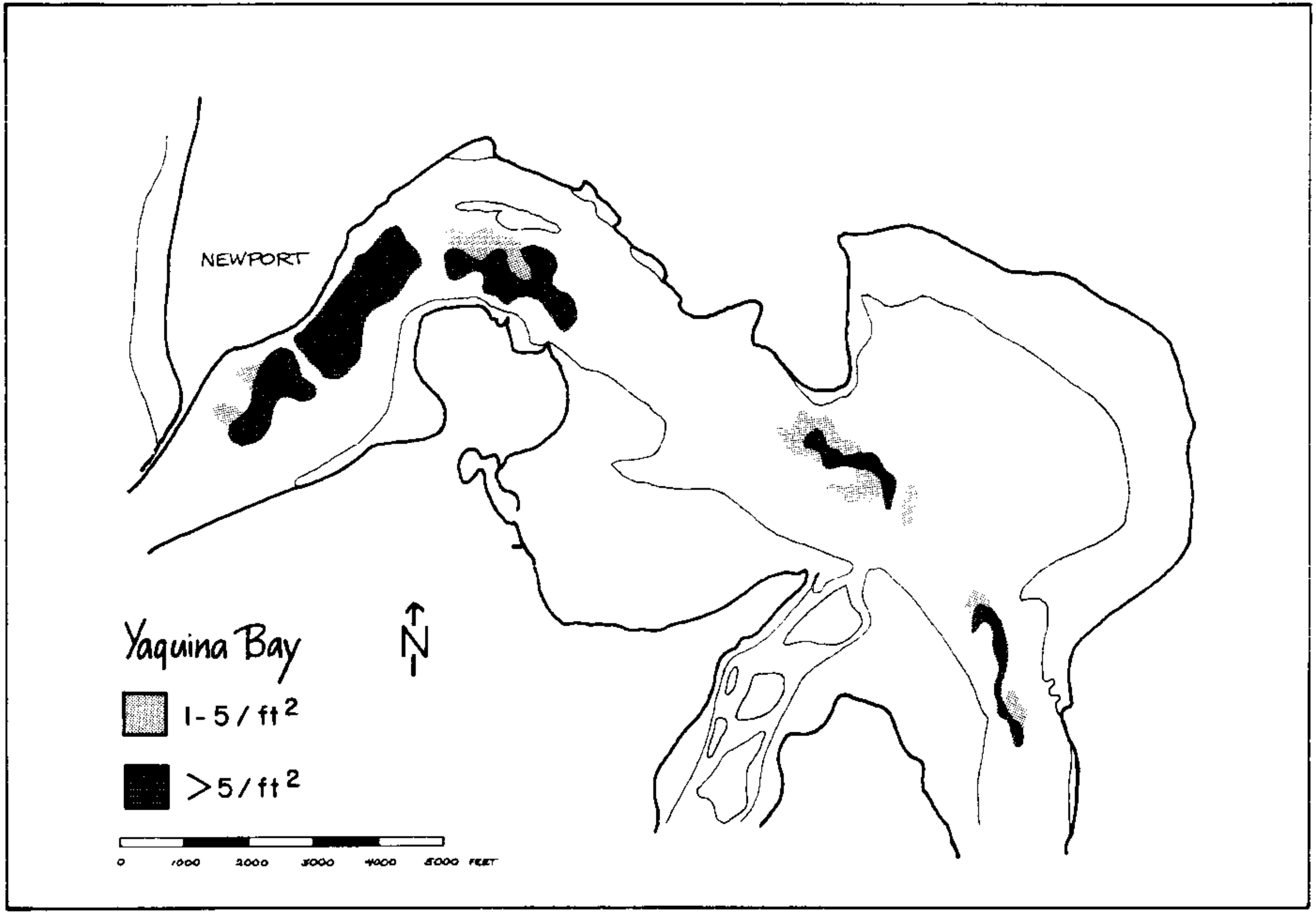

Figure II.C.3.-13. Distribution and density of gaper clams (*Tresus capax*) in Areas 1-4, Yaquina Bay, Oregon.

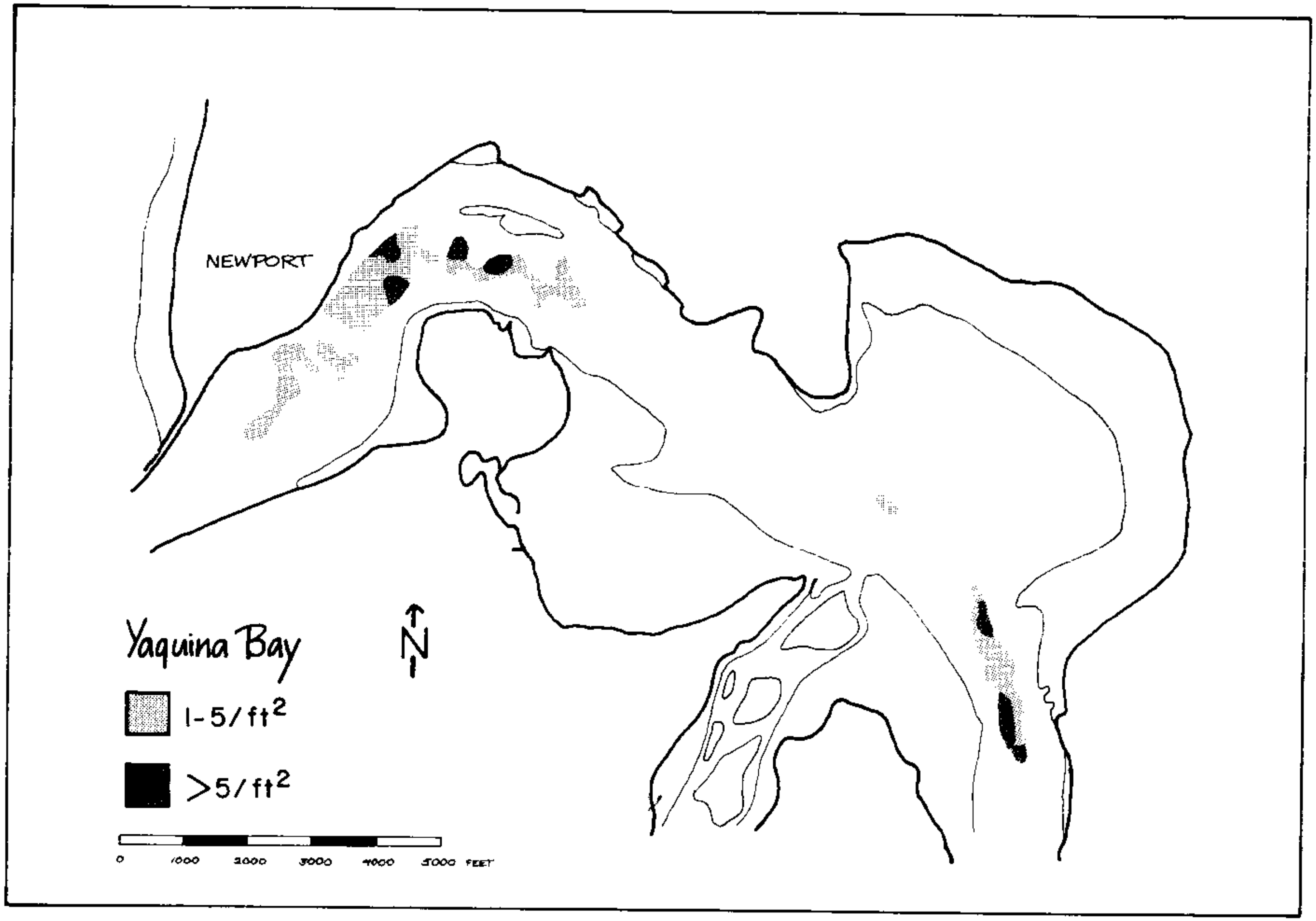

Figure II.C.3.-14. Distribution and density of butter clams (*Saxidomus giganteus*) in Areas 1-4, Yaquina Bay, Oregon.

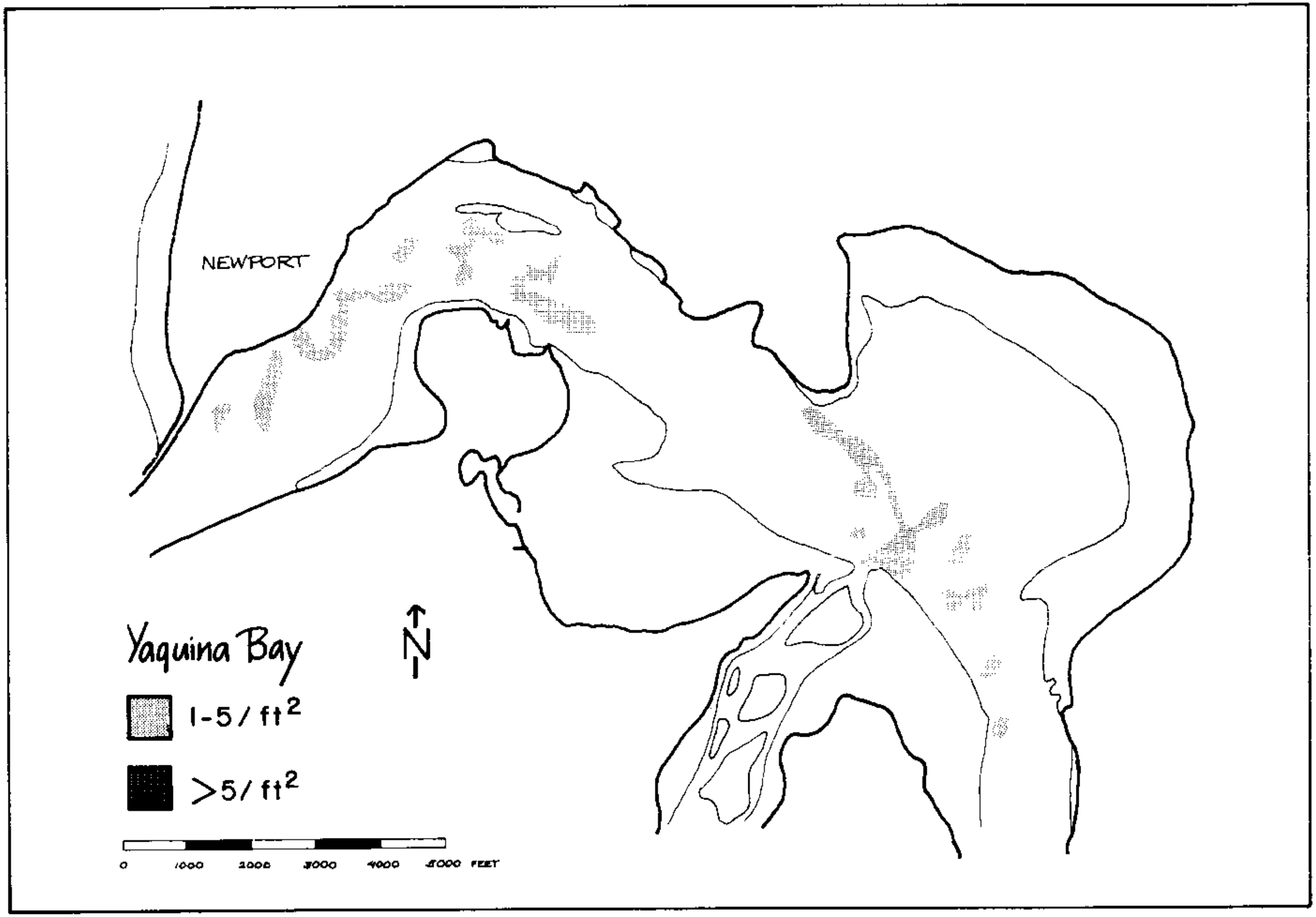

Figure II.C.3.-15. Distribution and density of cockle clams (*Clinocardium nuttallii*) in Areas 1-4, Yaquina Bay, Oregon.

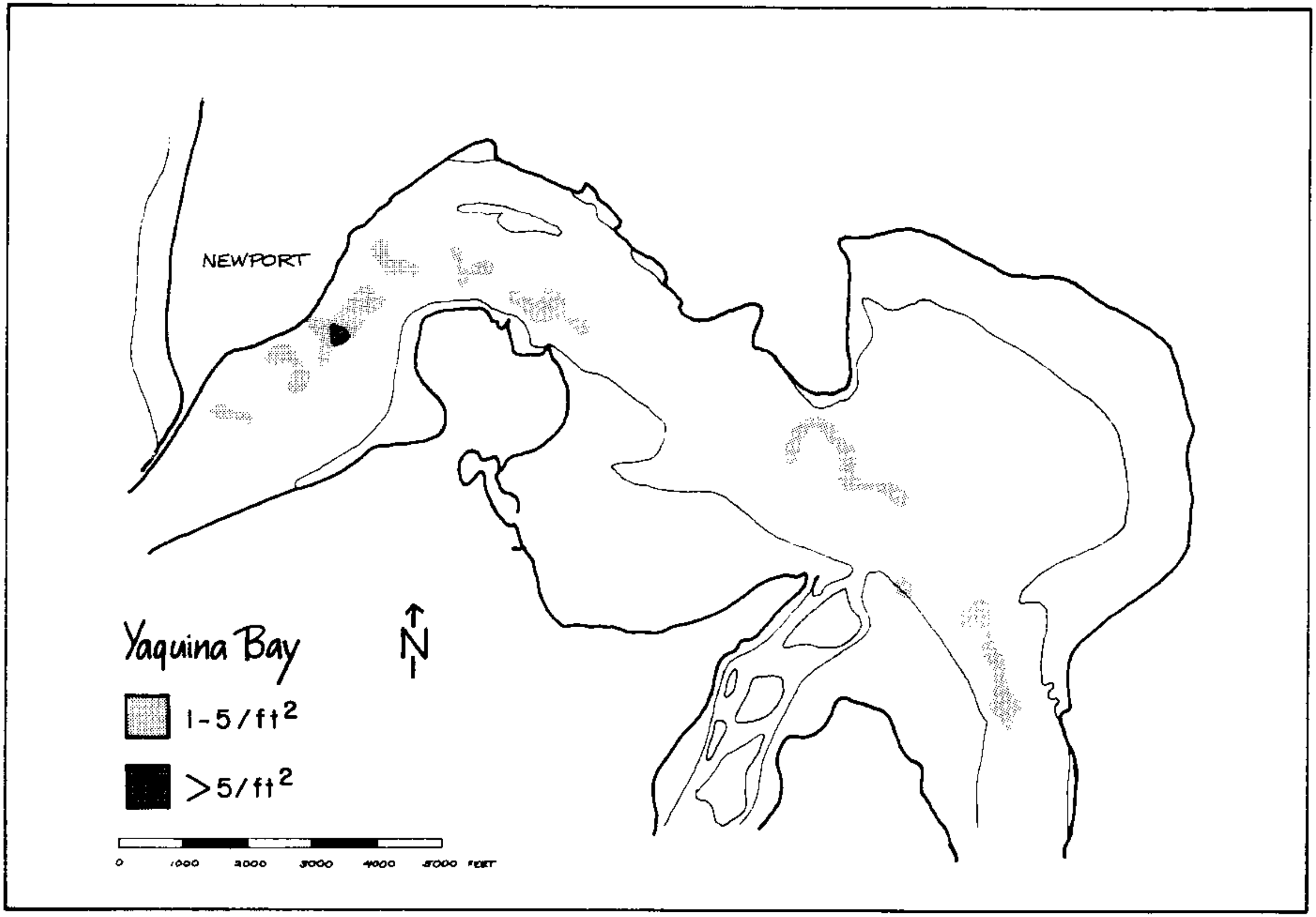

Figure II.C.3.-16. Distribution and density of littleneck clams (*Venerupis staminea*) in Areas 1-4, Yaquina Bay, Oregon.

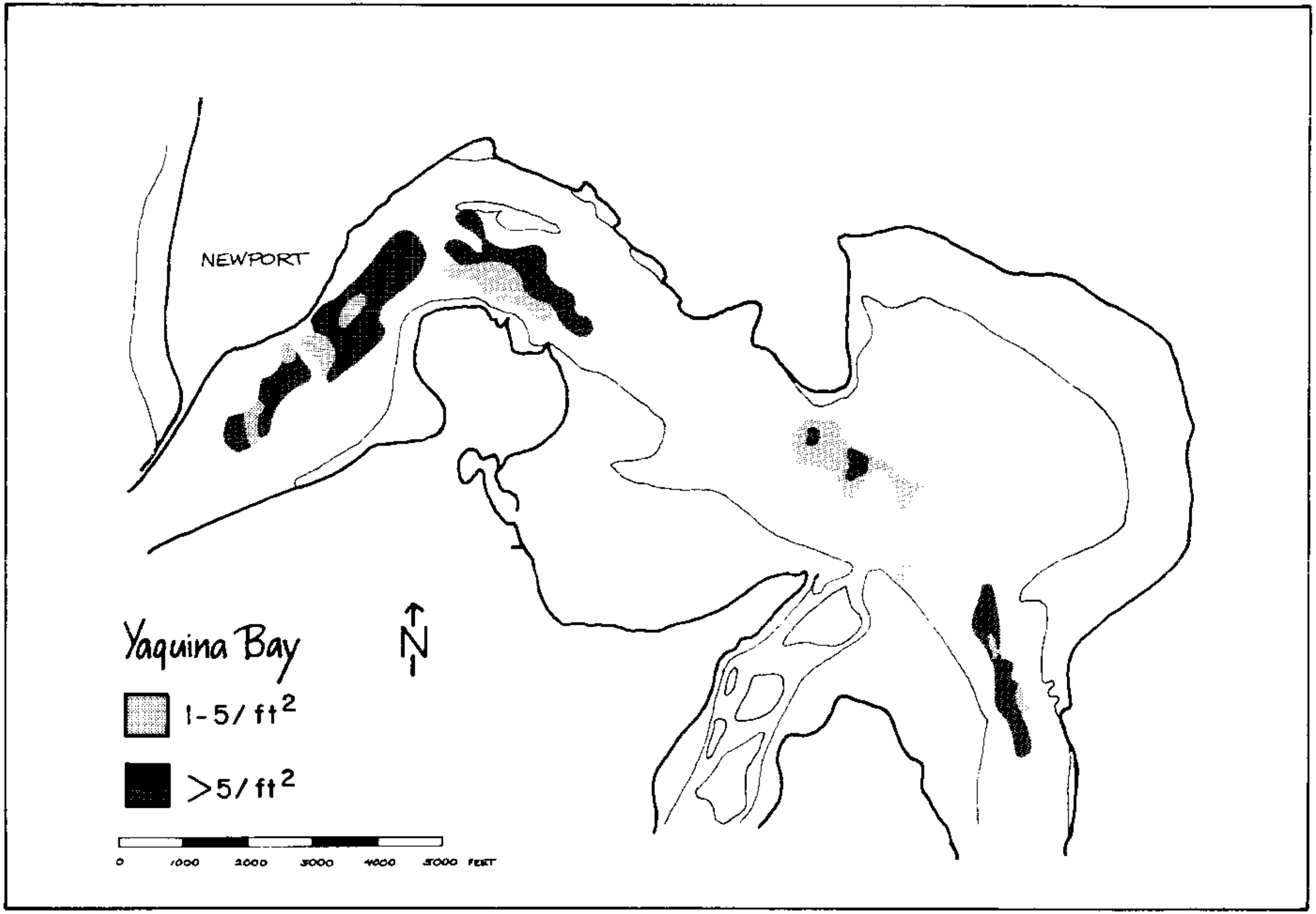

Figure.II.C.3.-17. Distribution and density of irus clams (*Macoma irus*) in Areas 1-4, Yaquina Bay, Oregon.

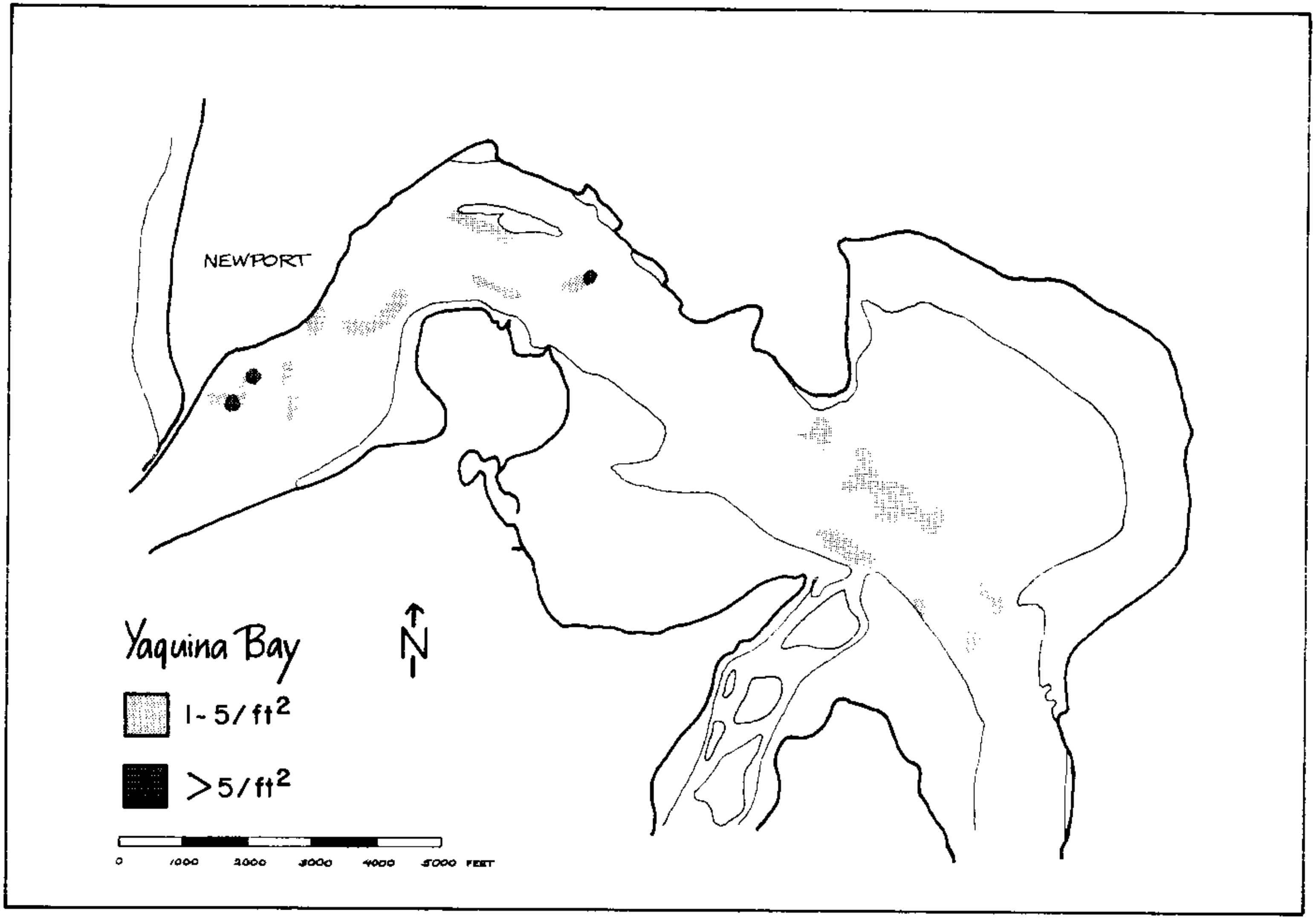

Figure II.C.3.-18. Distribution and density of piddock clams (*Zirfaea pilsbryi*), Bodega tellin (*Tellina bodegensis*), jackknife (*Solen sicarius*), and bentnose (*Macoma nasuta*) clams in Areas 1-4, Yaquina Bay, Oregon.

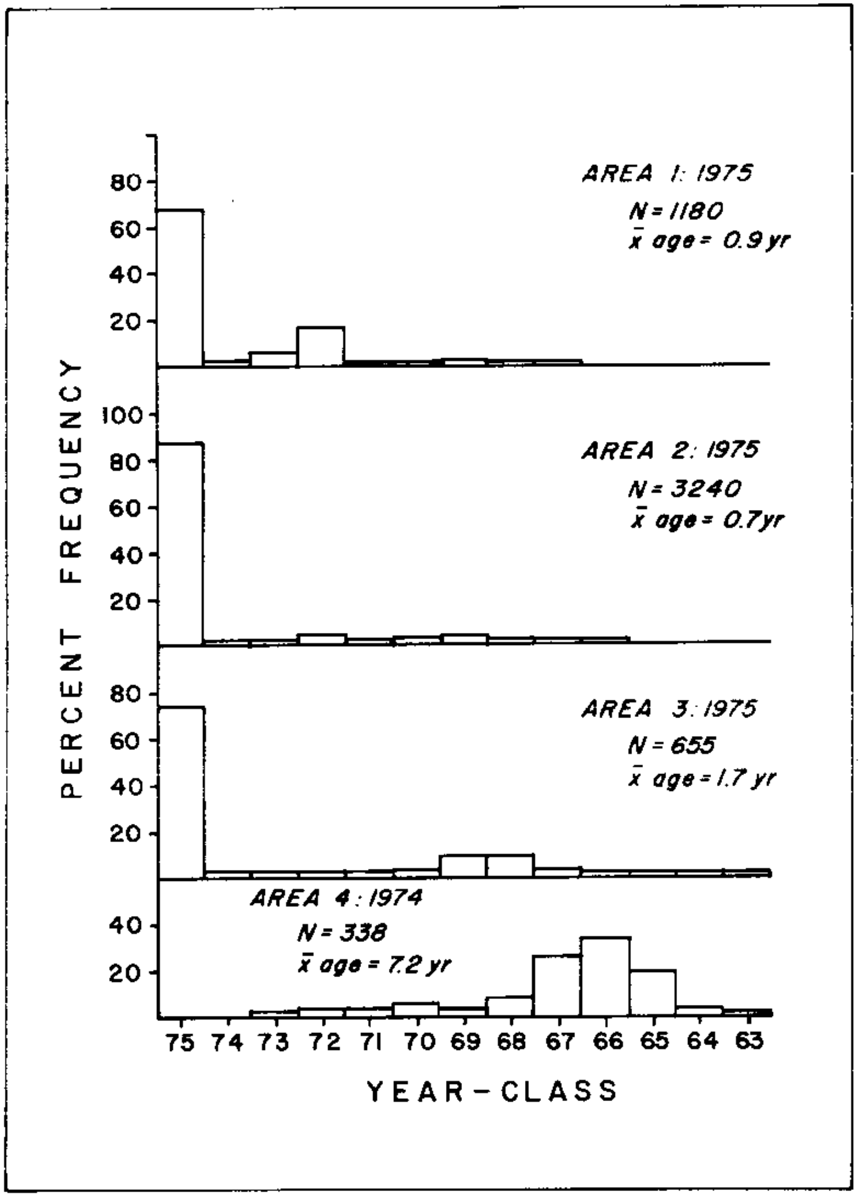

Figure II.C.3.-19. Year-class composition of subtidal gaper clams (*Tresus capax*) collected from Areas 1-4, Yaquina Bay, Oregon, 1974-1975.

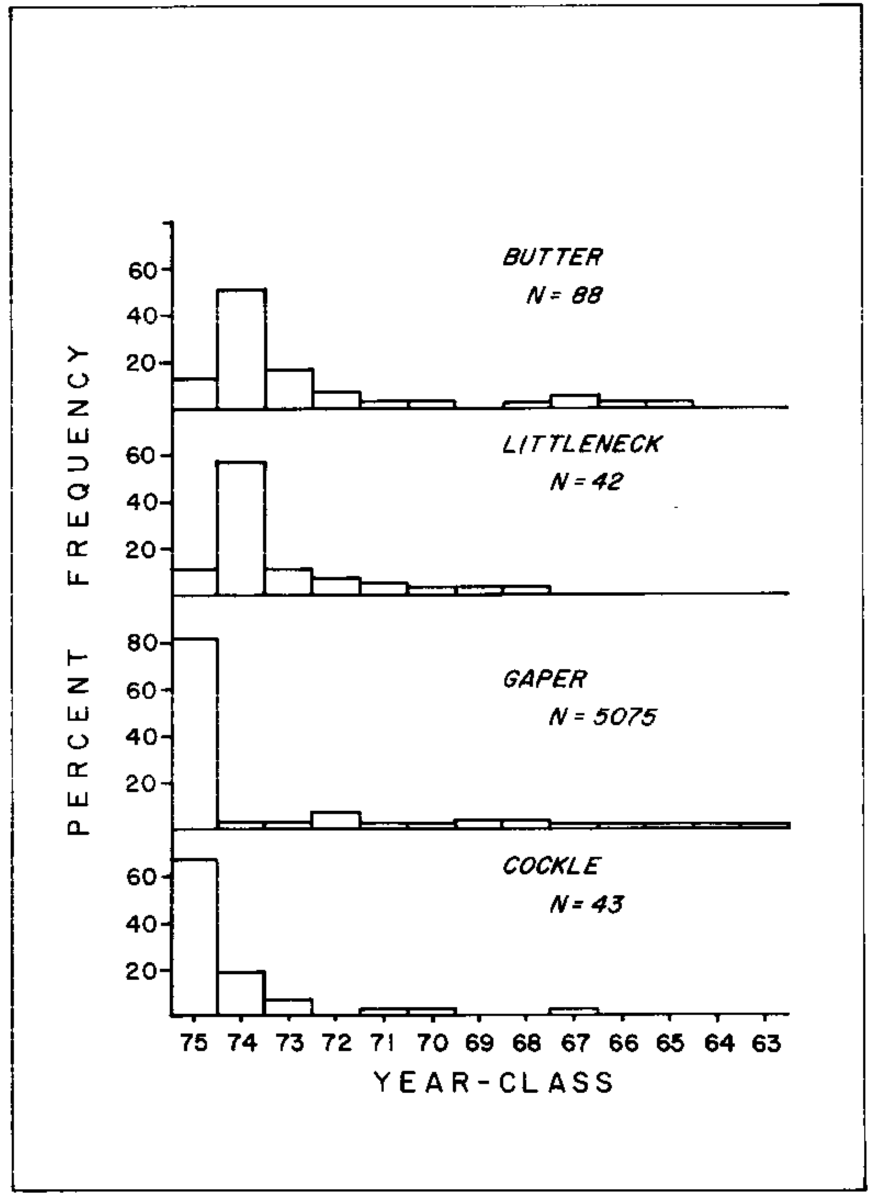

Figure II.C.3.-20. Year-class composition of subtidal clams collected from Areas 1-3, Yaquina Bay, Oregon, 1975.

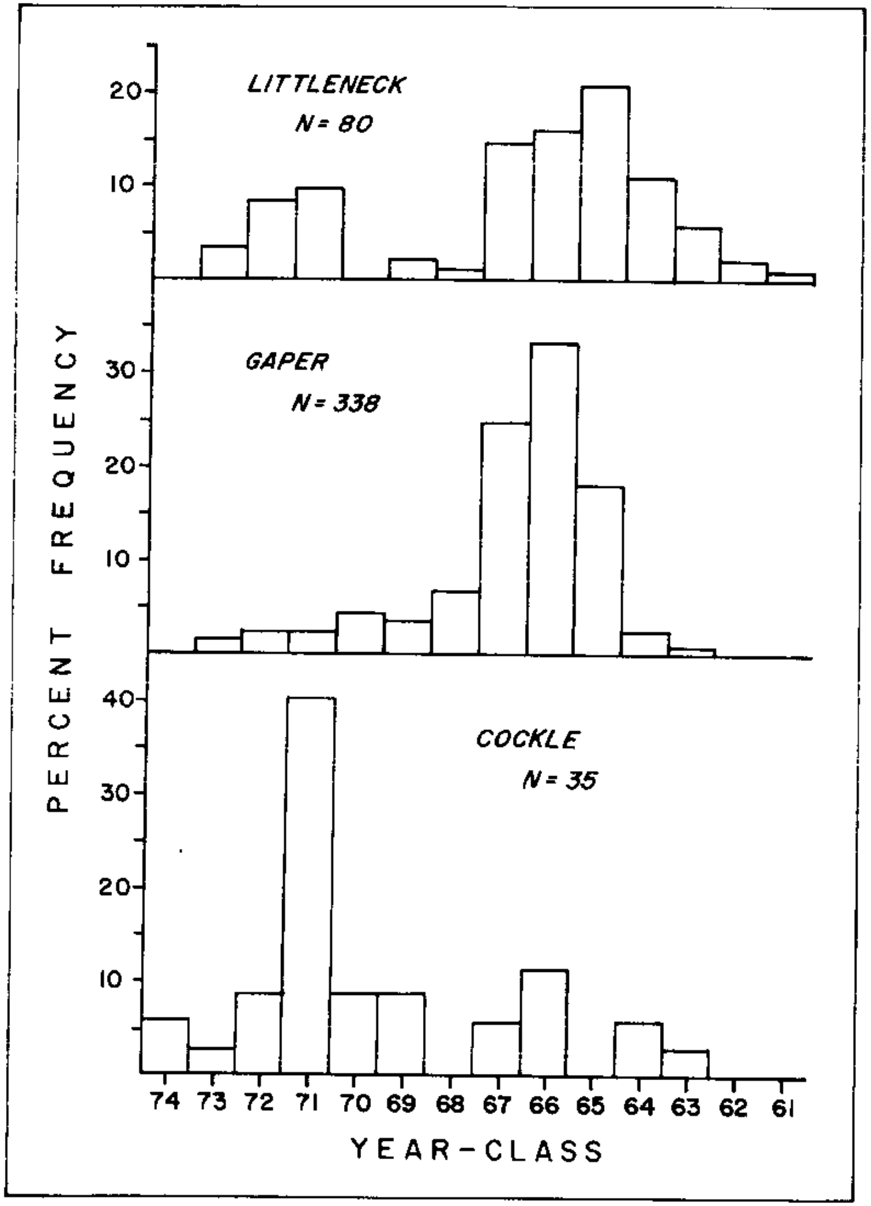

Figure II.C.3.-21. Year-class composition of subtidal clams collected from Area 4, Yaquina Bay, Oregon, 1974.

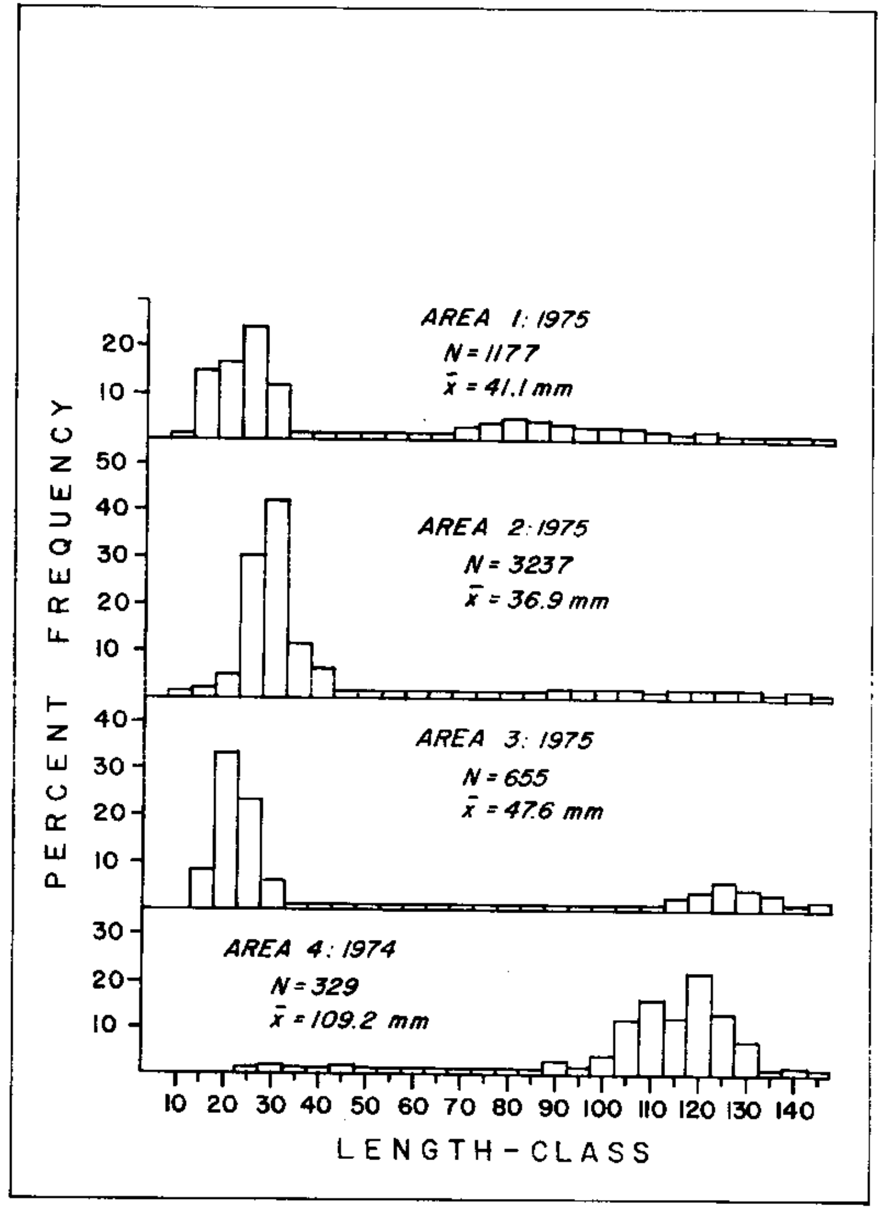

Figure II.C.3.-22. Length-class composition of subtidal gaper clams (*Tresus capax*) collected from Areas 1-4, Yaquina Bay, Oregon, 1974-1975.

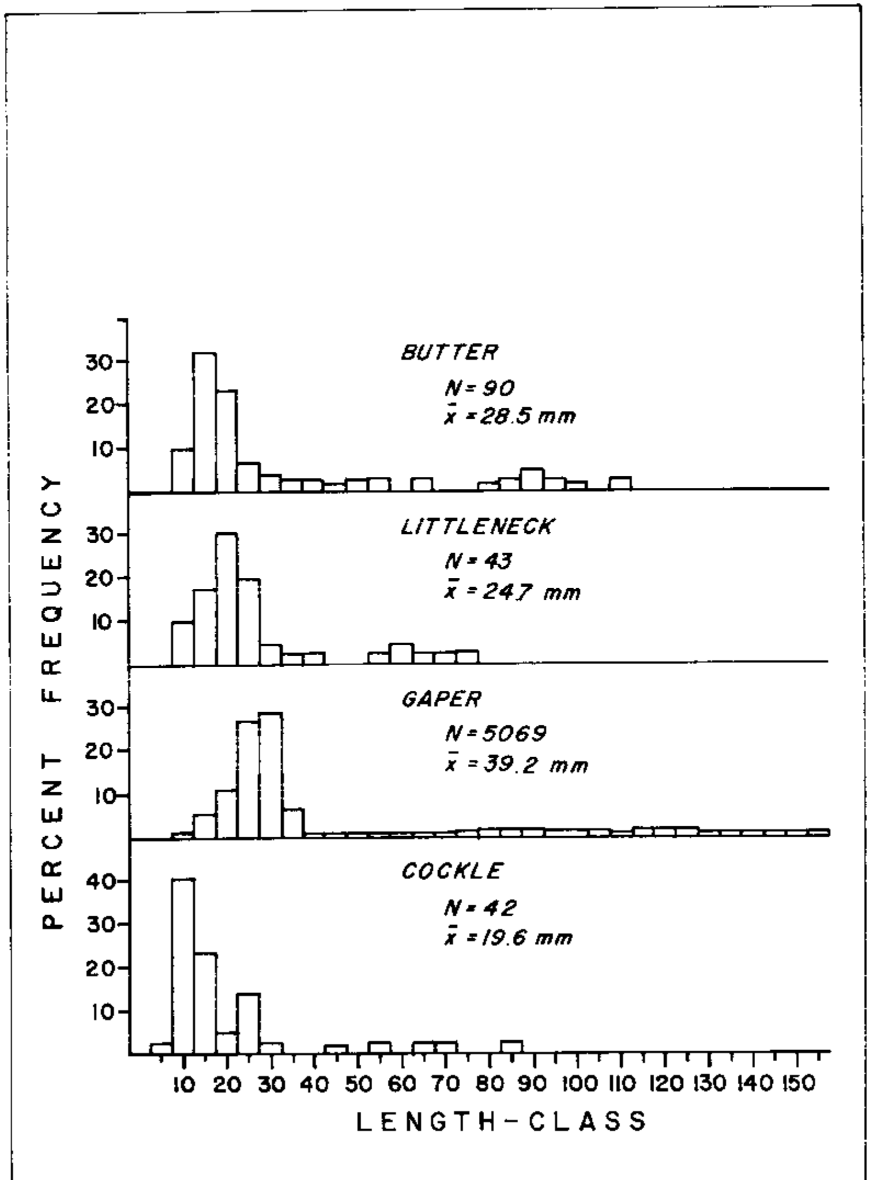

Figure II.C.3.-23. Length-class composition of subtidal clams collected from Areas 1-3, Yaquina Bay, Oregon, 1975.

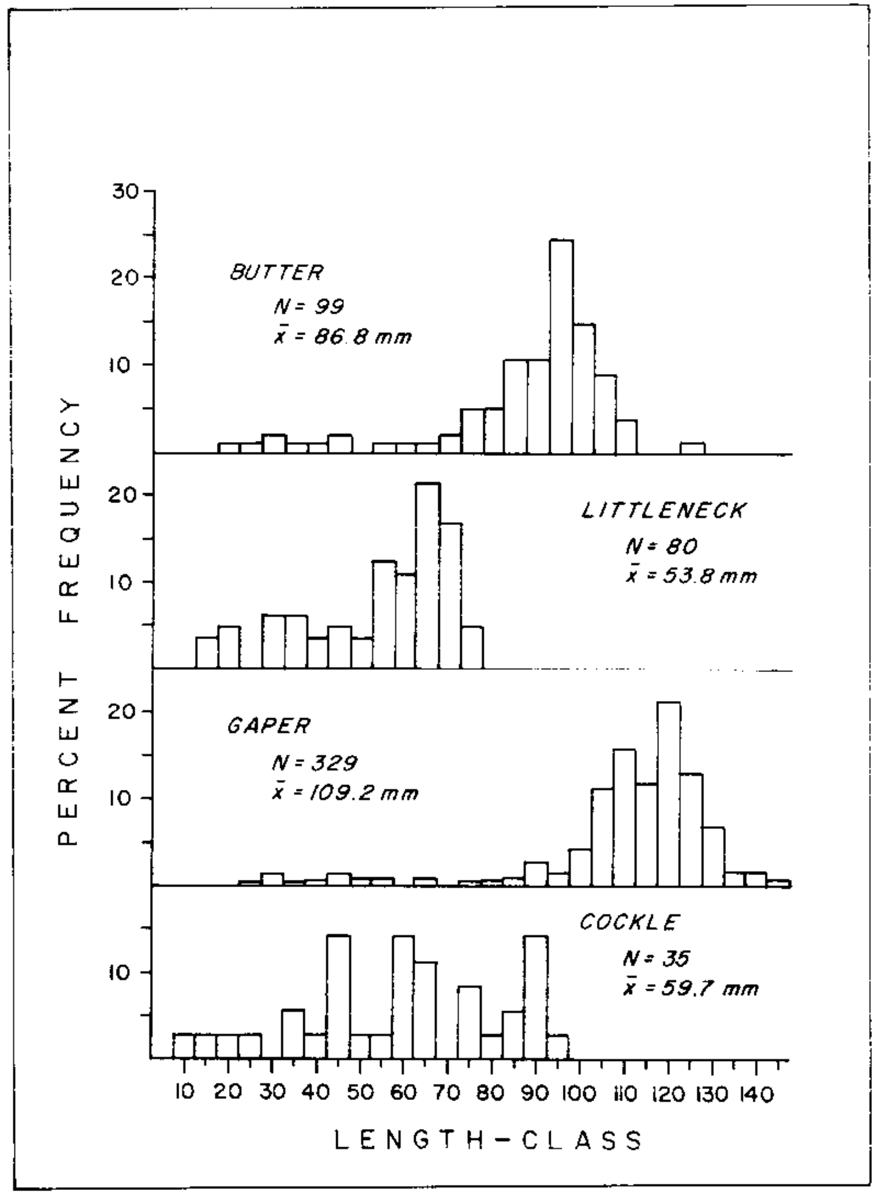

Figure II.C.3.-24. Length-class composition of subtidal clams collected from Area 4, Yaquina Bay, Oregon, 1974.

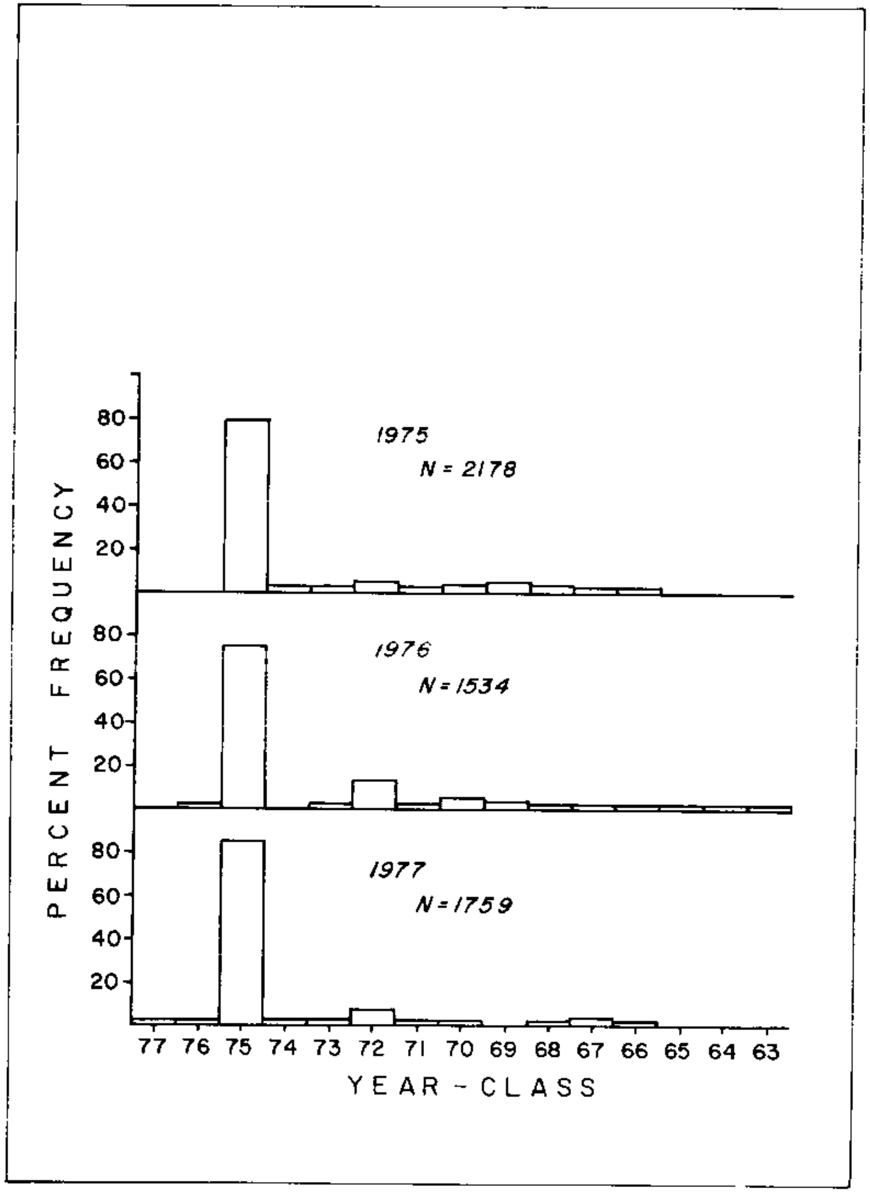

Figure II.C.3.-25. Year-class composition of subtidal gaper clams (*Tresus capax*) collected from Area 2, Yaquina Bay, Oregon, 1975-1977.

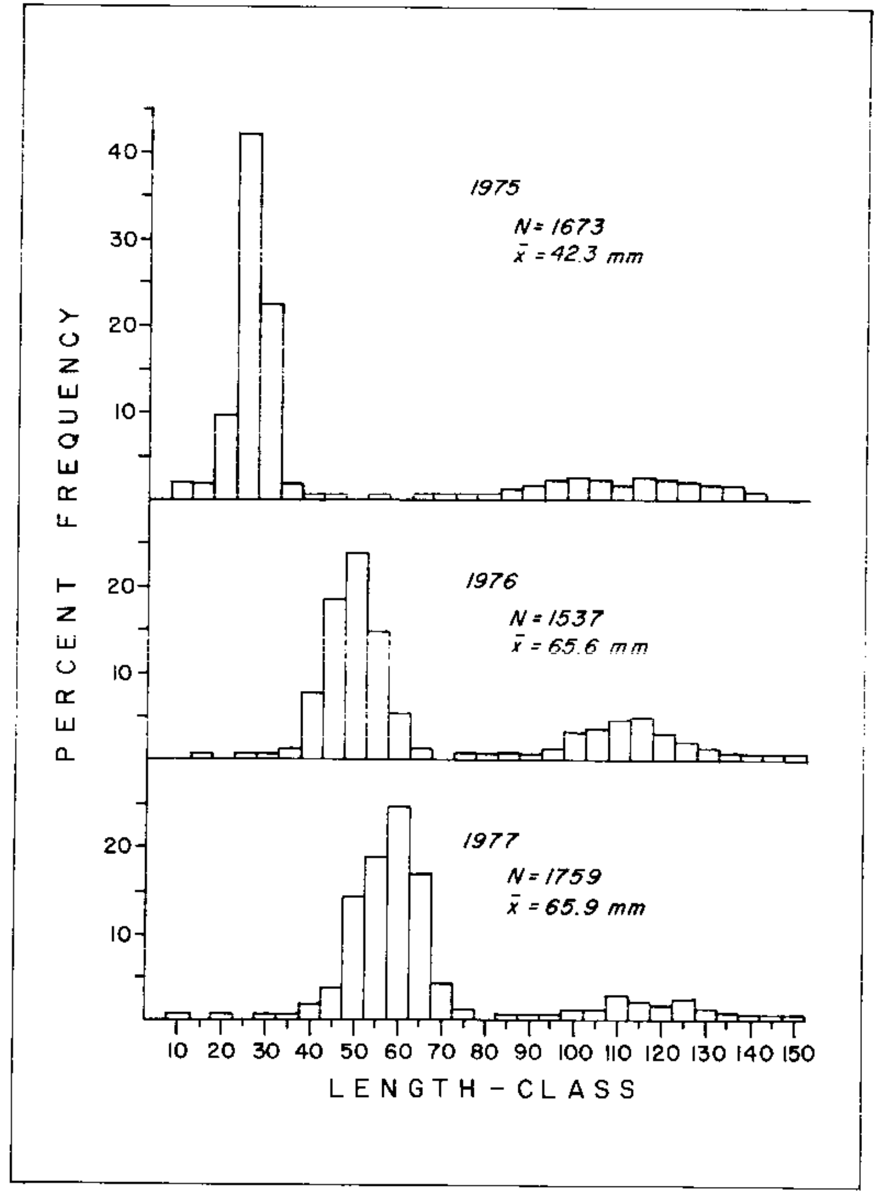

Figure II.C.3.-26. Length-class composition of subtidal gaper clams (*Tresus capax*) collected from Area 2, Yaquina Bay, Oregon, 1975-1977.

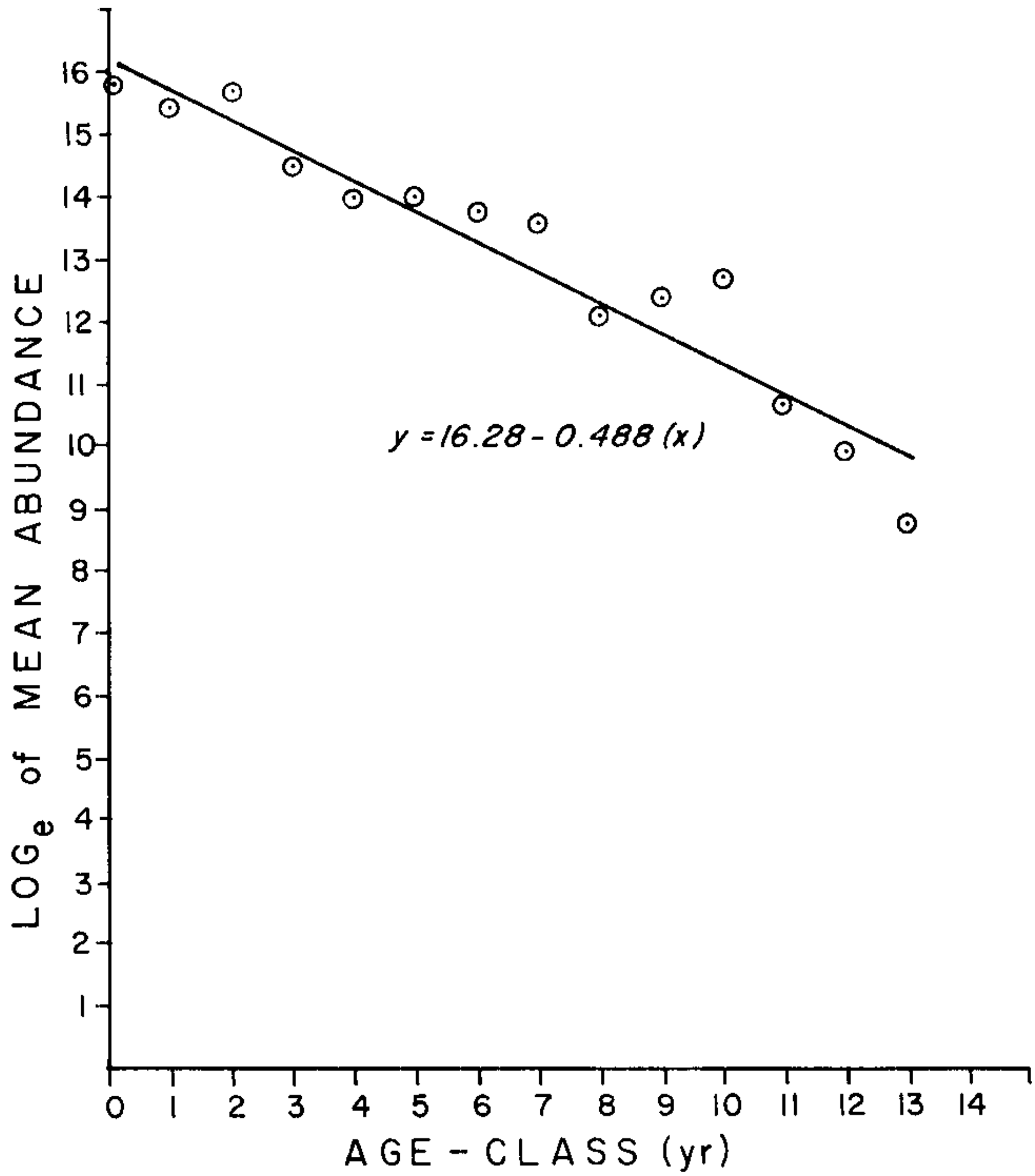

Figure II.C.3.-27. Abundance of age-class vs. age of gaper clams from Area 2, Yaquina Bay, Oregon, 1975-1978.

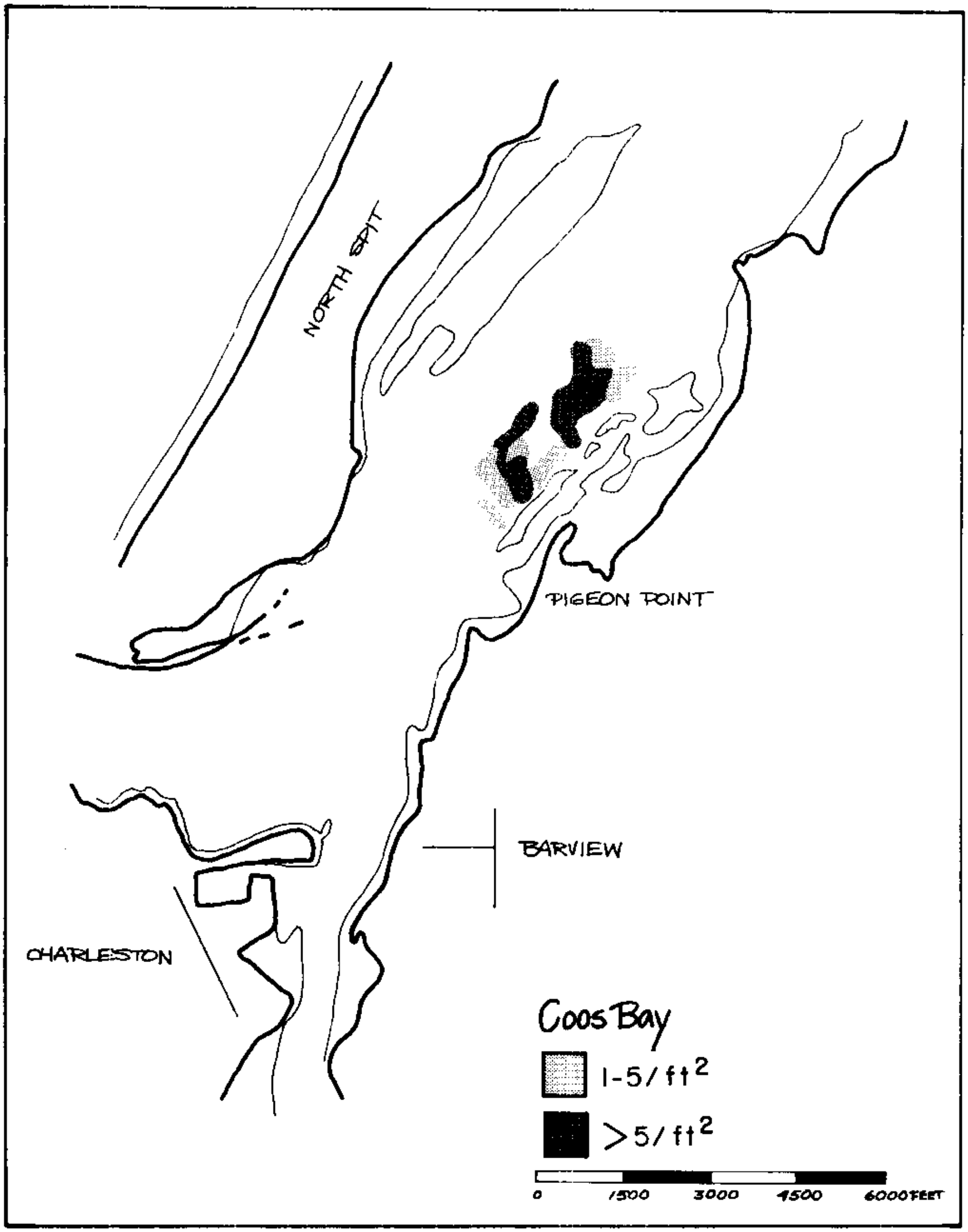

Figure II.C.3-28. Distribution and density of subtidal gaper clams (*Tresus capax*) collected from the Pigeon Point survey area, Coos Bay, Oregon.

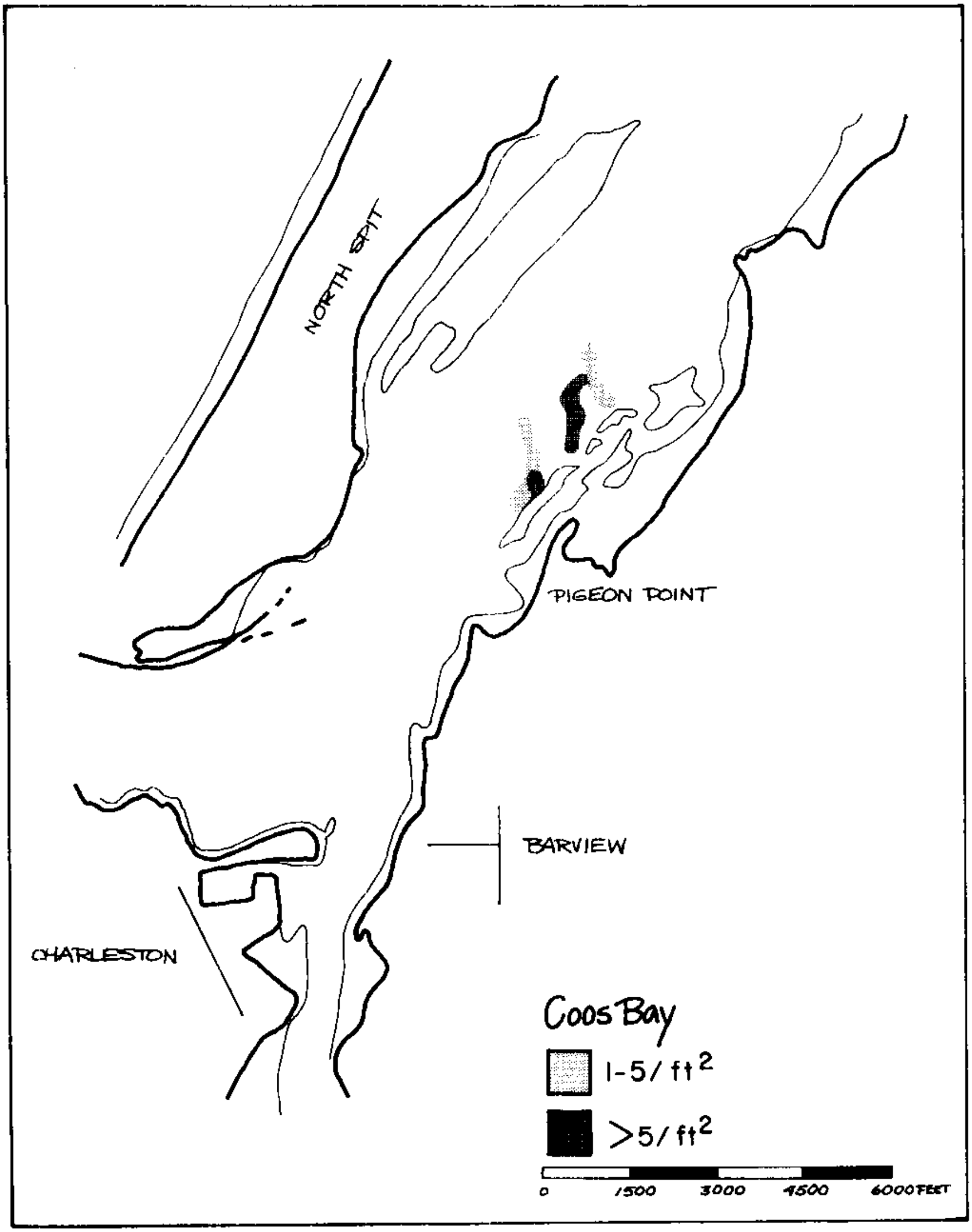

Figure II.C.3.-29. Distribution and density of butter clams (*Saxidomus giganteus*) collected from the Pigeon Point survey area, Coos Bay, Oregon.

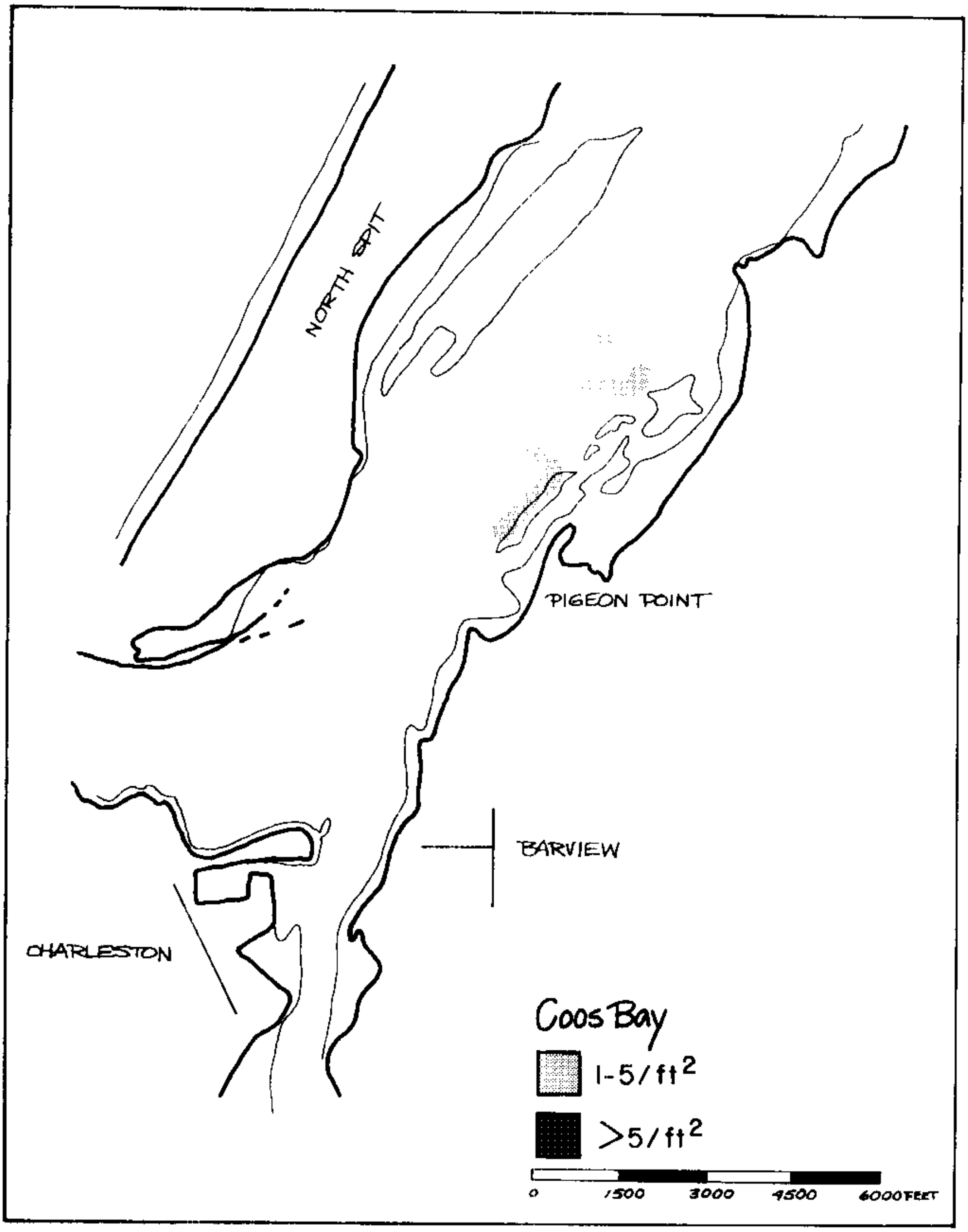

Figure II.C.3.-30. Distribution and density of cockle clams (*Clinocardium nuttallii*) collected from the Pigeon Point survey area, Coos Bay, Oregon.

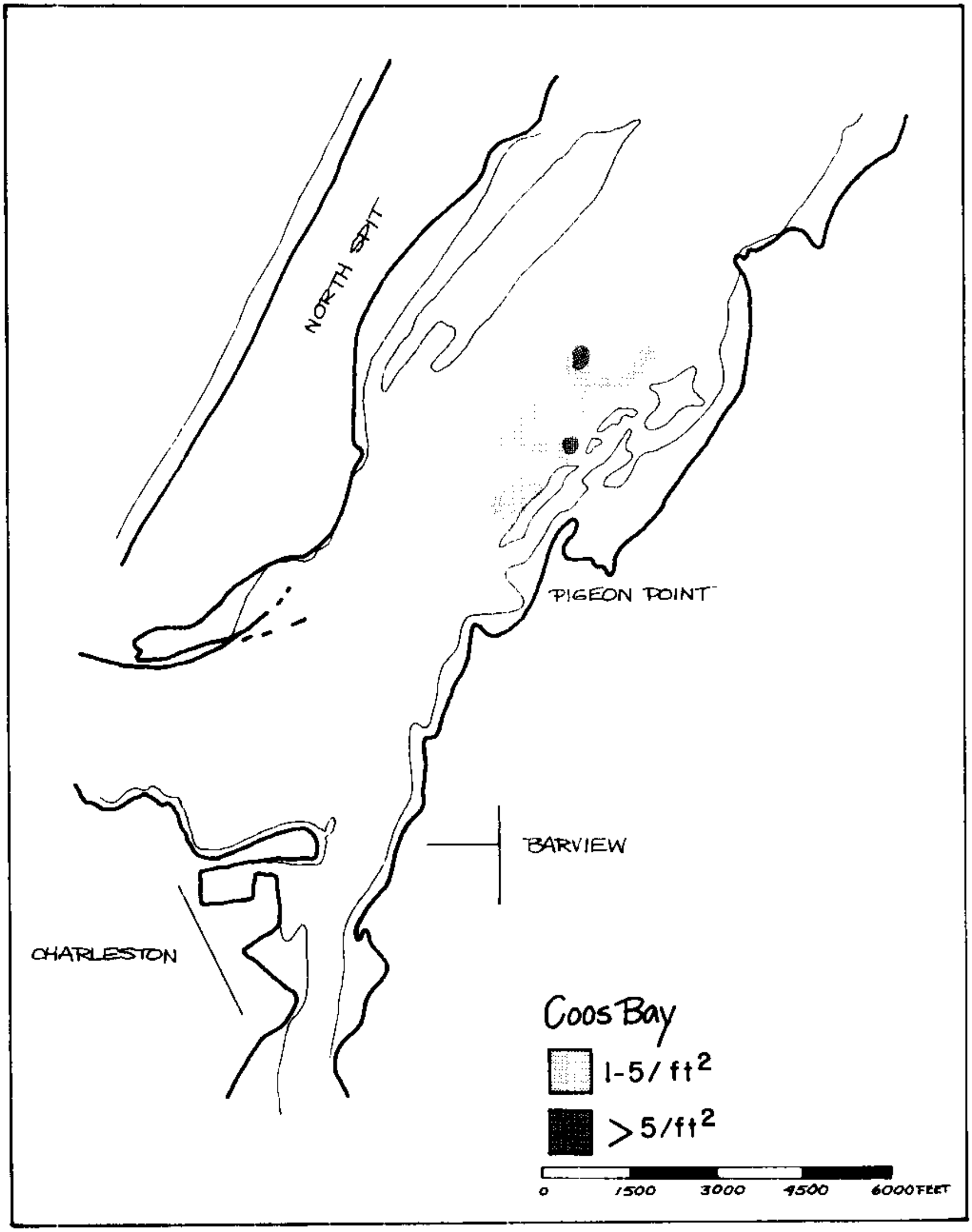

Figure II.C.3.-31. Distribution and density of native littleneck clams (*Venerupis staminea*) collected from the Pigeon Point survey area, Coos Bay, Oregon.

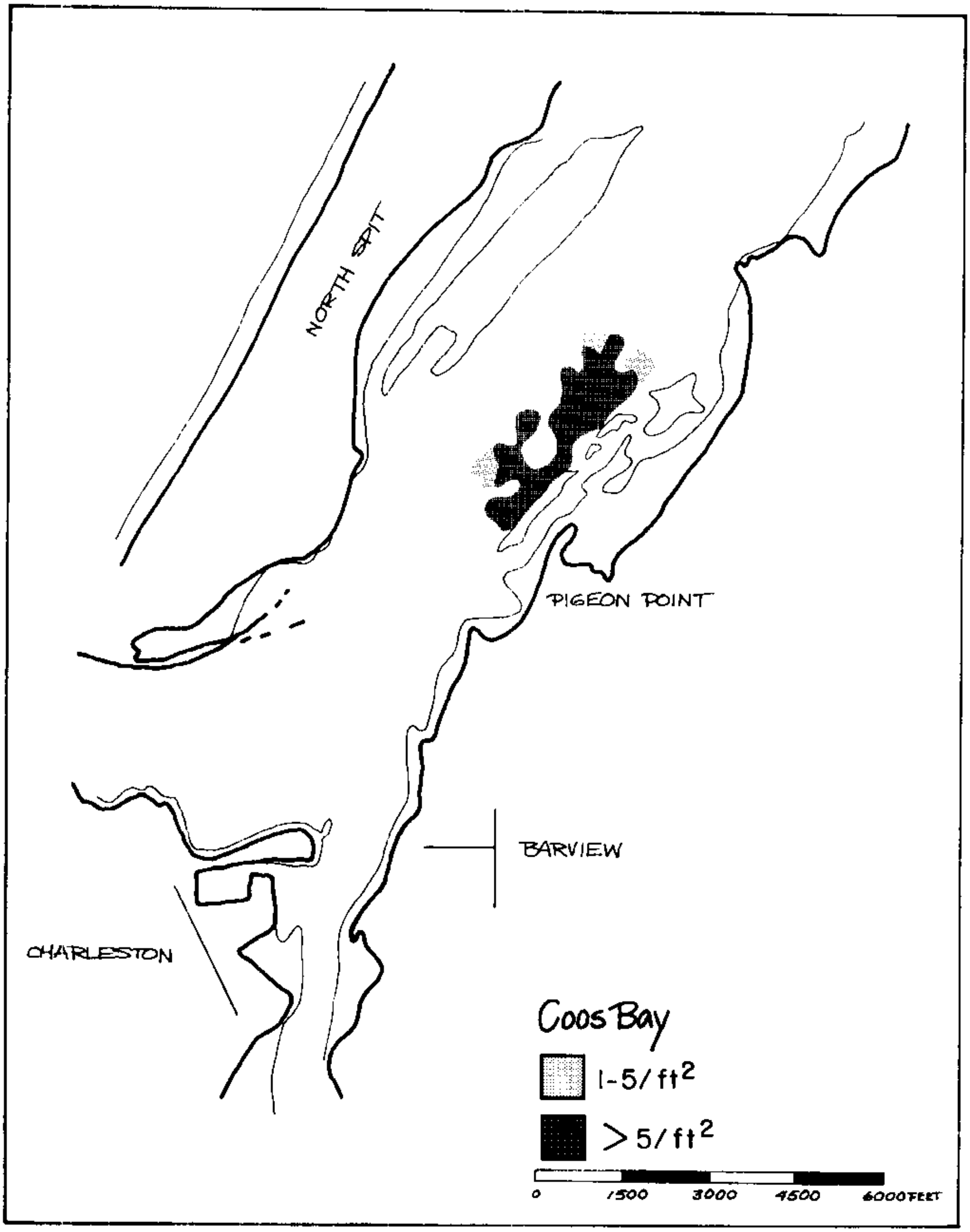

Figure II.C.3.-32. Distribution and density of irus clams (*Macoma irus*) collected from Pigeon Point survey area, Coos Bay, Oregon.

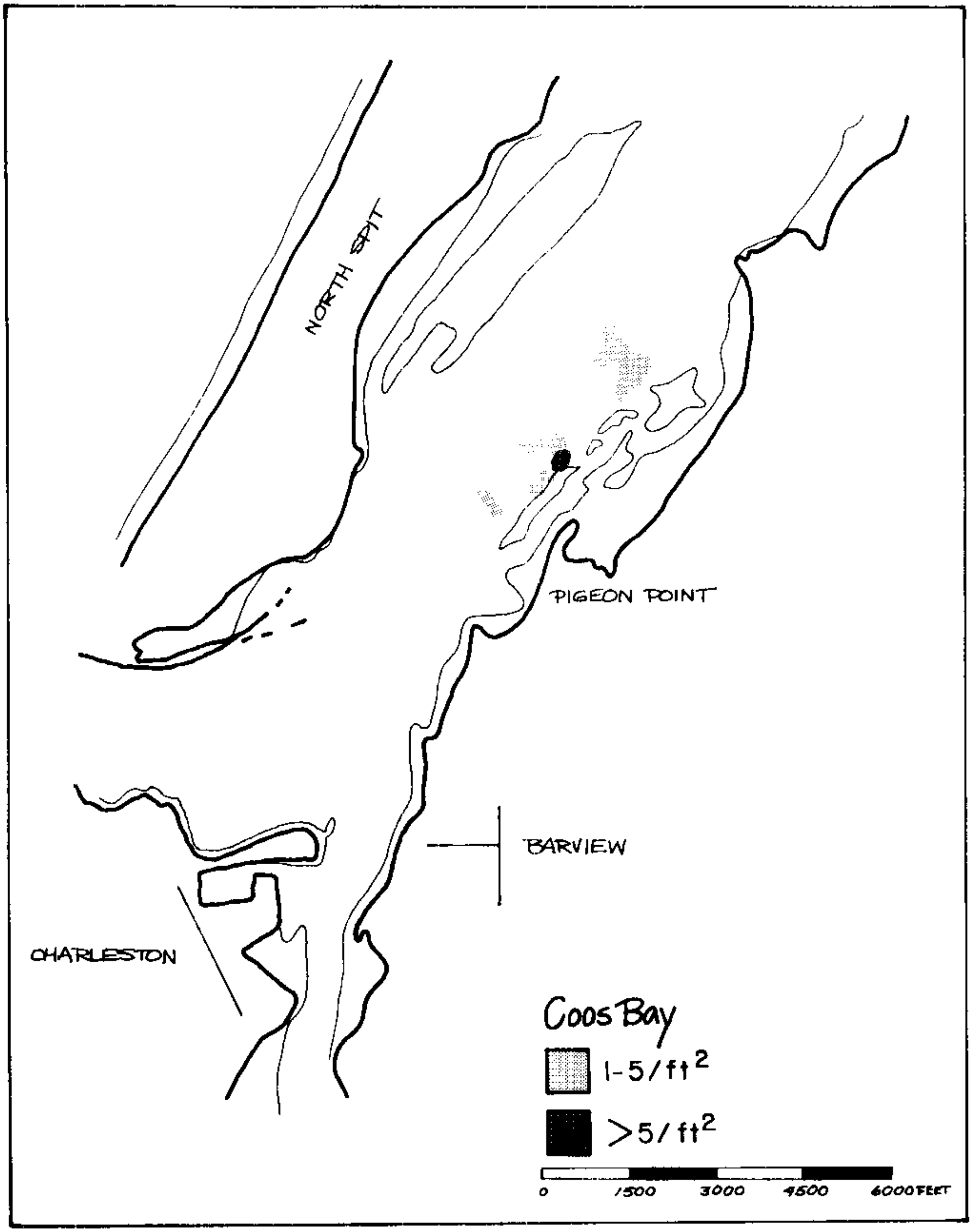

Figure II.C.3.-33. Distribution and density of *Petricola* sp., bentnose (*Macoma nasuta*), Bodega tellin (*Tellina bodegensis*), and California softshell (*Cryptomya californica*) in the Pigeon Point survey area, lower Coos Bay, Oregon.

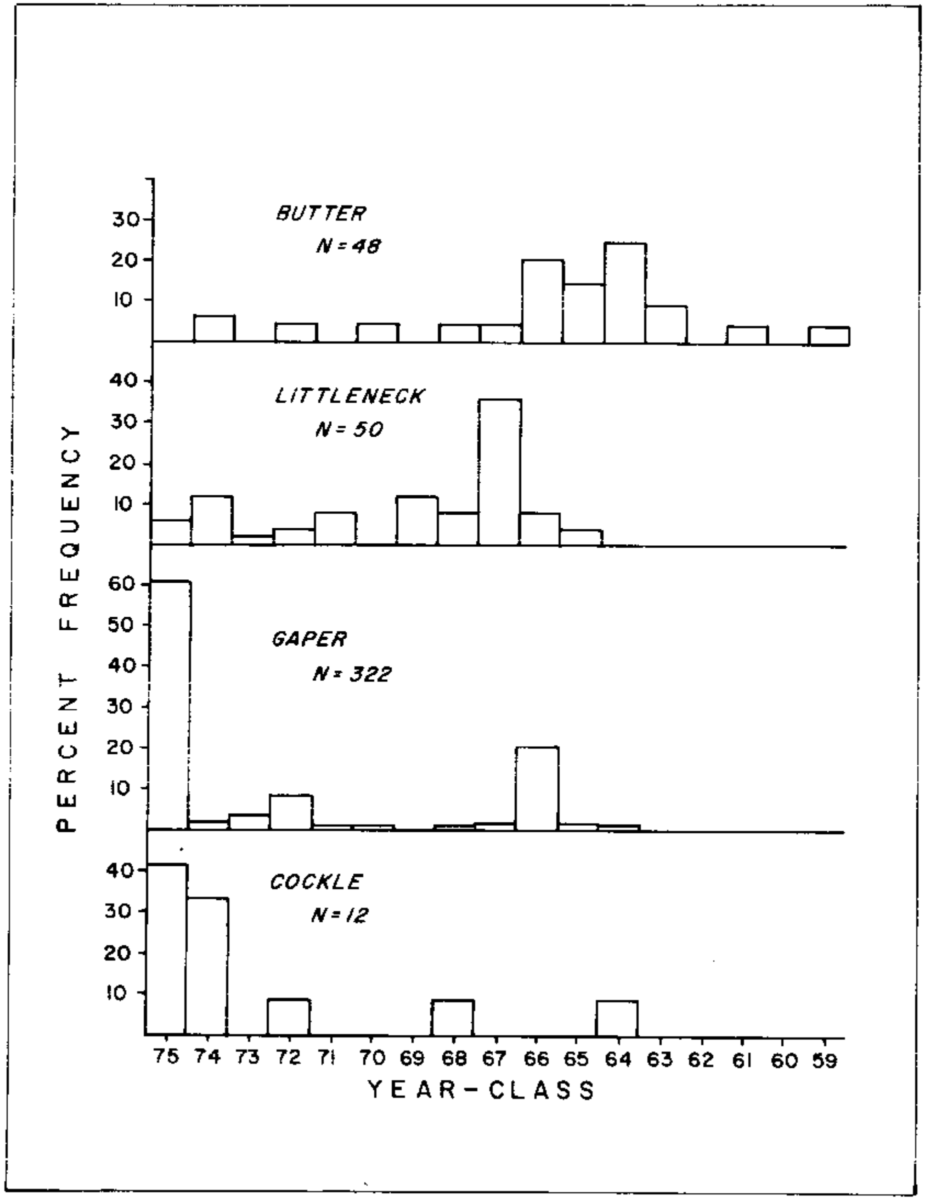

Figure II.C.3.-34. Year-class composition of subtidal clams collected from the Pigeon Point survey area, Coos Bay, Oregon, 1975.

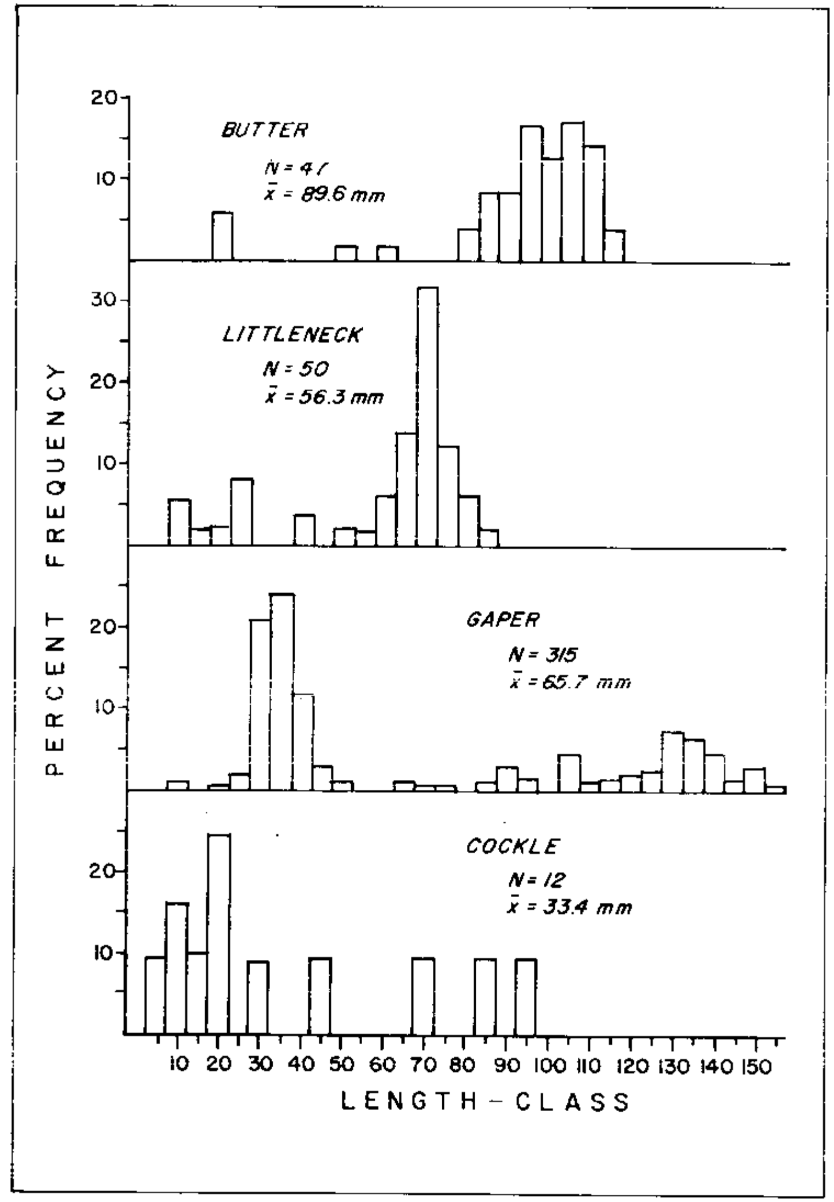

Figure II.C.3.-35. Length-class composition of subtidal Clams collected from the Pigeon Point survey area, Coos Bay, Oregon, 1975.

II. D. Commercial bay clam fisheries

THOMAS F. GAUMER
GREGORY P. ROBART

II.D.1. INTRODUCTION

Preliminary results of the subtidal clam surveys indicated a potential for a commercial clam fishery in Yaquina Bay. A clam density of 21.6/m² was arbitrarily selected for delineating potential clam harvesting areas. An experimental clam fishery was designed to study the effects of mechanical clam harvesting equipment on the clam resources and benthic environment. Two types of harvest equipment were permitted; a high pressure hand-held water jet and a suction pump.

In 1975 a permit was issued by the Oregon Department of Fish and Wildlife to one clam harvester to remove subtidal clams with a high pressure water jet from Yaquina Bay. Five commercial clam harvesters received special permits to mechanically harvest clams in 1976 (two in Yaquina Bay and three in Coos Bay). In 1977 six permits were issued (five in Yaquina Bay and one in Coos Bay).

Maximum sustainable yield data were not available to determine harvest rates prior to implementation of the first year's fishery. Consequently, a quota of approximately 10% of the available gaper clams was arbitrarily selected for harvest until such data were collected.

II.D.2. METHODS AND MATERIALS

Yaquina bay

In 1975 a 6.1 ha site was approved for the use of a high pressure water jet in Area 4 of Yaquina Bay (Figure II.D.2.-1A). The harvester was limited to a maximum harvest of 45.4 metric tons of clams.

In 1976 two adjacent 0.8 ha plots, A and B, were selected in Area 2 of Yaquina Bay for the commerical harvest of clams (Figure II.D.2.-1A). Harvest in plot A was restricted to the use of a high pressure water jet; a suction pump was required in plot B. These plots in area 2 were located immedi-

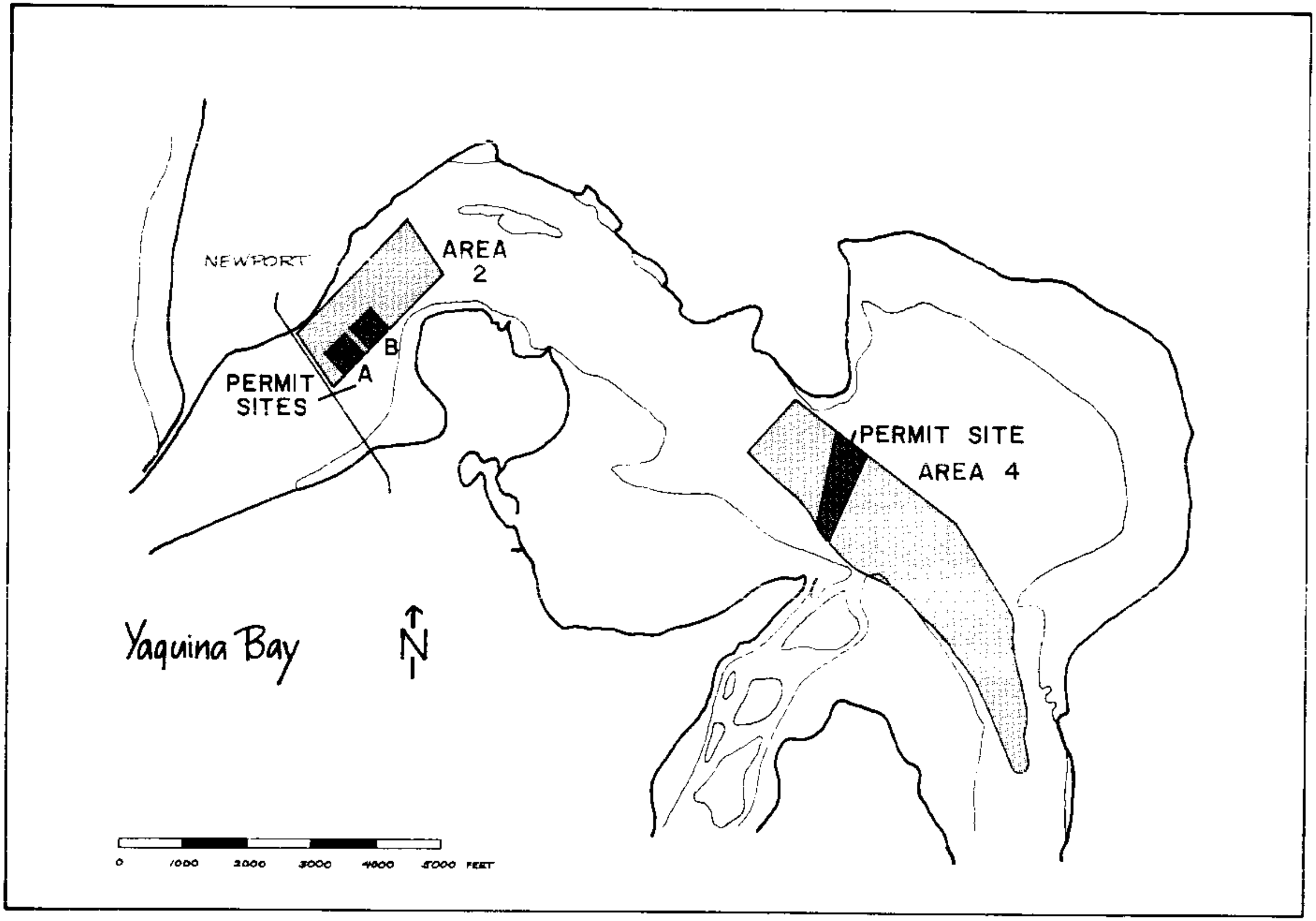

Figure II.D.2.-1A. Map of Yaquina Bay, showing those areas approved for commercial clam harvesting.

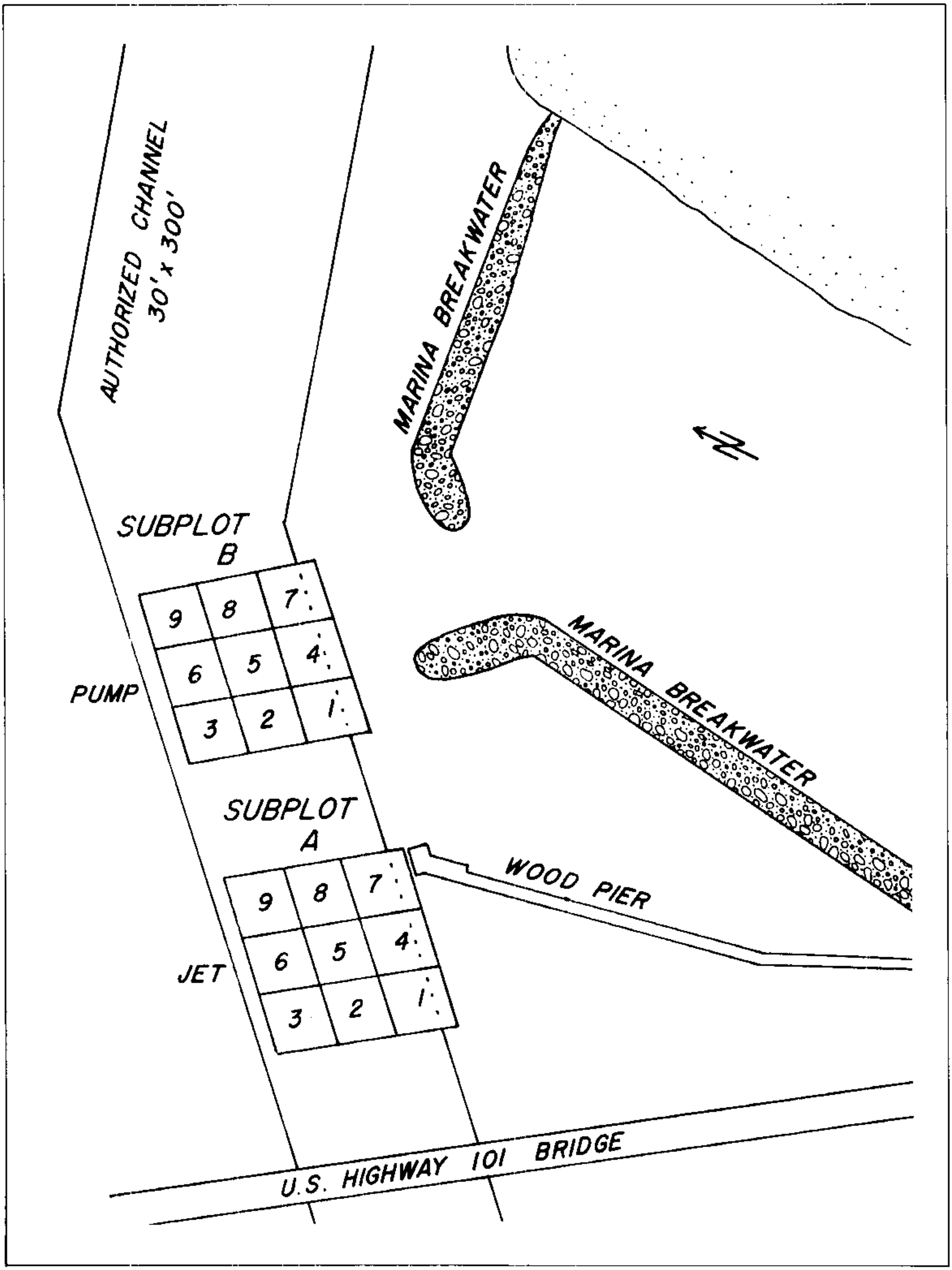

Figure II.D.2.-1B. Detail of permit Area 2, showing subsections of plots 2A and 2B.

ately north (up-bay) of the U.S. highway 101 bridge. Each plot was delineated with a polypropylene rope stretched around its perimeter. Each of these plots was further subdivided by polypropylene rope into 30.5 x 30.5 m sub-sections. Five dredge samples were taken from each of the sub-sections to provide estimates of species composition, age, biomass and size. Each sample station was excavated to a depth of approximately 45 cm. Surface area was 0.2/m^2. All biomass estimates were calculated by determining the mean weight of the clams by age and expanding by the population estimates for each age. All clams were weighed alive to the nearest gram on a Mettler analytical balance. Age or year-class for each species of clam was assigned to the calendar year that the parent clam spawned by counting annual growth rings.

In 1976 two permits were issued to harvest clams in Yaquina Bay; one each for the jet and pump plots. In 1977 two commerical clam harvesting permits were issued for the jet-approved plot and three for the suction pump site. Sub-sections 2-A-4 and 2-A-7 were "jet" areas and 2-B-1, 2-B-3 and 2-B-4 were "pump" areas (Figure II.D.2.-1B). The water jet approved for sub-section 2-A-4 was a hand-held discharge tube 15.2 cm in diameter (Figure II.D.2.-2A). Water velocity was regulated by the diver. The pump was powered by a 9 h.p. engine capable of discharging 787 liters/minute. The jet was most effectively used in blowing the substrate material from the clams, exposing them for hand-picking. The water jet approved for sub-section 2-A-7 was 1.9 cm in diameter (Figure II.D.2.-2B). This smaller jet unit was powered by a 8 h.p. engine capable of discharging 757 lpm. This jet was used to dislodge or loosen the surrounding substrate, enabling the diver to reach into the loosened material to retrieve the clams.

A suction pump with a 12.7 cm discharge (Figure II.D.2.-3A) was initially approved for sub-section 2-B-1. This equipment proved to be too small to effectively pump clams and was eventually replaced with a 20.3 cm discharge tube. The suction pump was powered by twin 16 h.p. engines each capable of discharging 2,082 lpm. All pumped material was surface-discharged onto a screening device aboard a barge. Clams were removed from the screen by hand and sorted by size and species. A 15.2 cm suction pump (Figure II.D.2.-3B) was approved for sub-section 2-B-4. This pump was powered by a 7 h.p. engine capable of discharging 946 lpm. All clams were hand-picked on the bottom. All spoils were discharged on the bottom behind the suction pump.

Each permittee was assigned a sub-section measuring 30.5 x 30.5 m and was restricted to this specific sub-section within the permit area until Department biologists approved moving to another sub-section. Quotas of 181.4 m.t. were established for both the 1976 and 1977 seasons; 90.7 m.t. for the jet-approved plot and a similar amount for the pump site. Each permittee was required to file monthly harvest reports listing sub-section worked, numbers and pounds harvested by species, and diving time. We periodically sampled each permittee's catch to obtain age, size and weight composition data.

During October 1977, it became apparent that a recently completed rock jetty surrounding the South Beach Marina was causing tidal currents which moved sand toward several of the commercial clam sub-sections. As much as 30.5 cm of recently deposited sand covered approximately 1,022/m^2 of clam beds adjacent to the commercial plots. Evidence of clam mortality was immediately seen. As a result, all permit holders were allowed to move into the sand-encroachment area to salvage the remaining live clams. After 11 days, the harvesters returned to their respective permit areas to resume fishing.

In addition to the ODFW permits, each clam harvester was required to have a special conditional use permit issued by the Oregon State Board of Health because both harvest plots existed within a restricted commercial shellfish harvest area. Conditional harvest restrictions were lifted by the State Board of Health providing that monthly samples of the commercial harvest be sent to them for bacteriological examination.

At the completion of the 1977 commercial fishing season, those portions of sub-sections 2-A-4 and 2-B-4 that were commercially worked were resurveyed to evaluate the effects of harvest on the clam stocks and substrate. Sub-sections 2-A-7, 2-B-1 and 2-B-3 were not resurveyed due to the little harvest effort expended in those areas.

Coos Bay

In 1975 the ODFW issued a commercial clam harvesting permit for the taking of subtidal clams from a 19.4 ha site which, at that time, was being considered by the U.S. Army Corps of Engineers as a dredge spoil site (Figure II.D.2.-4). This permit was nonre-

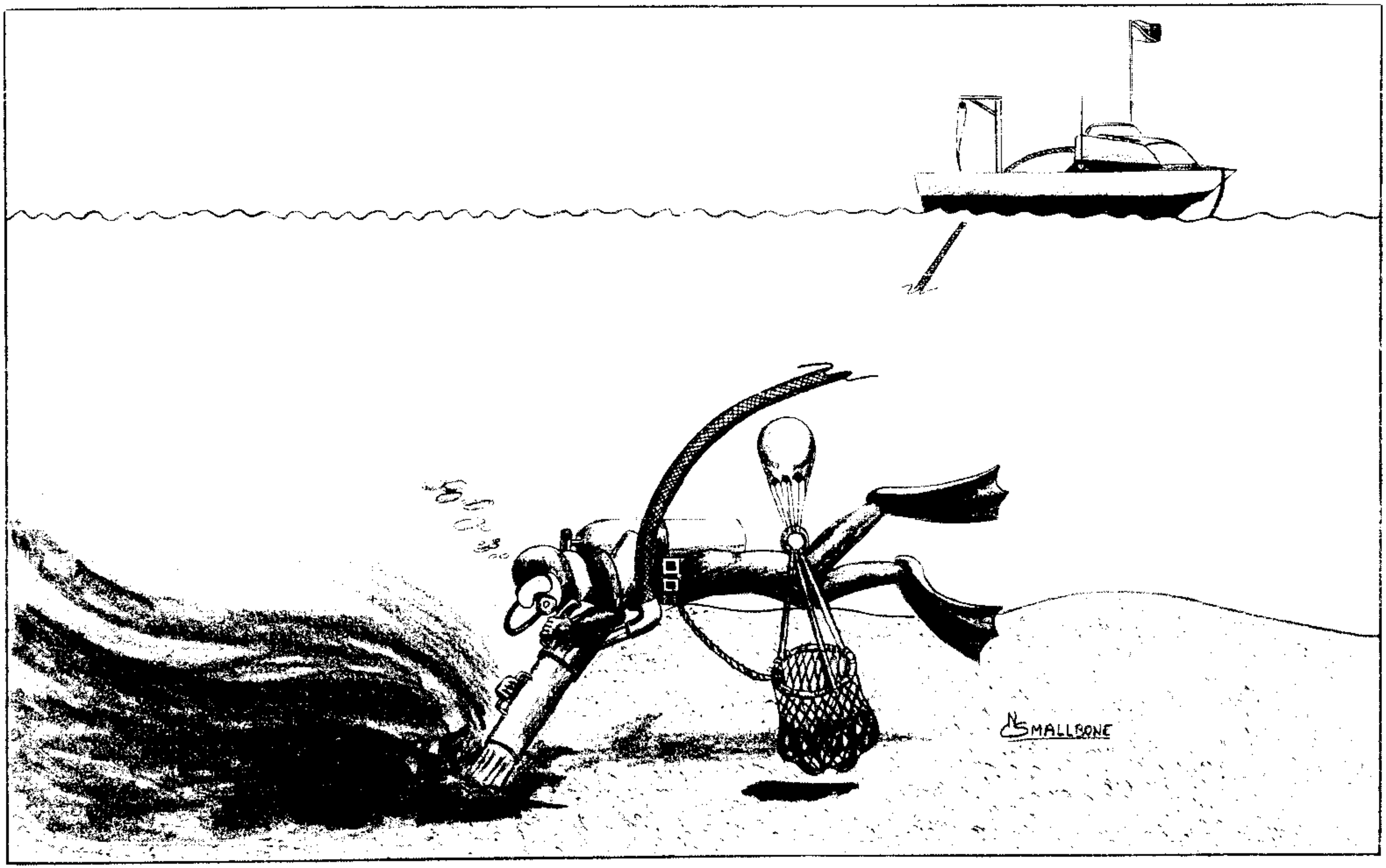

Figure II.D.2.-2A. Diagram of SCUBA diver operating the hand-held 15.2 cm water-jet harvesting equipment.

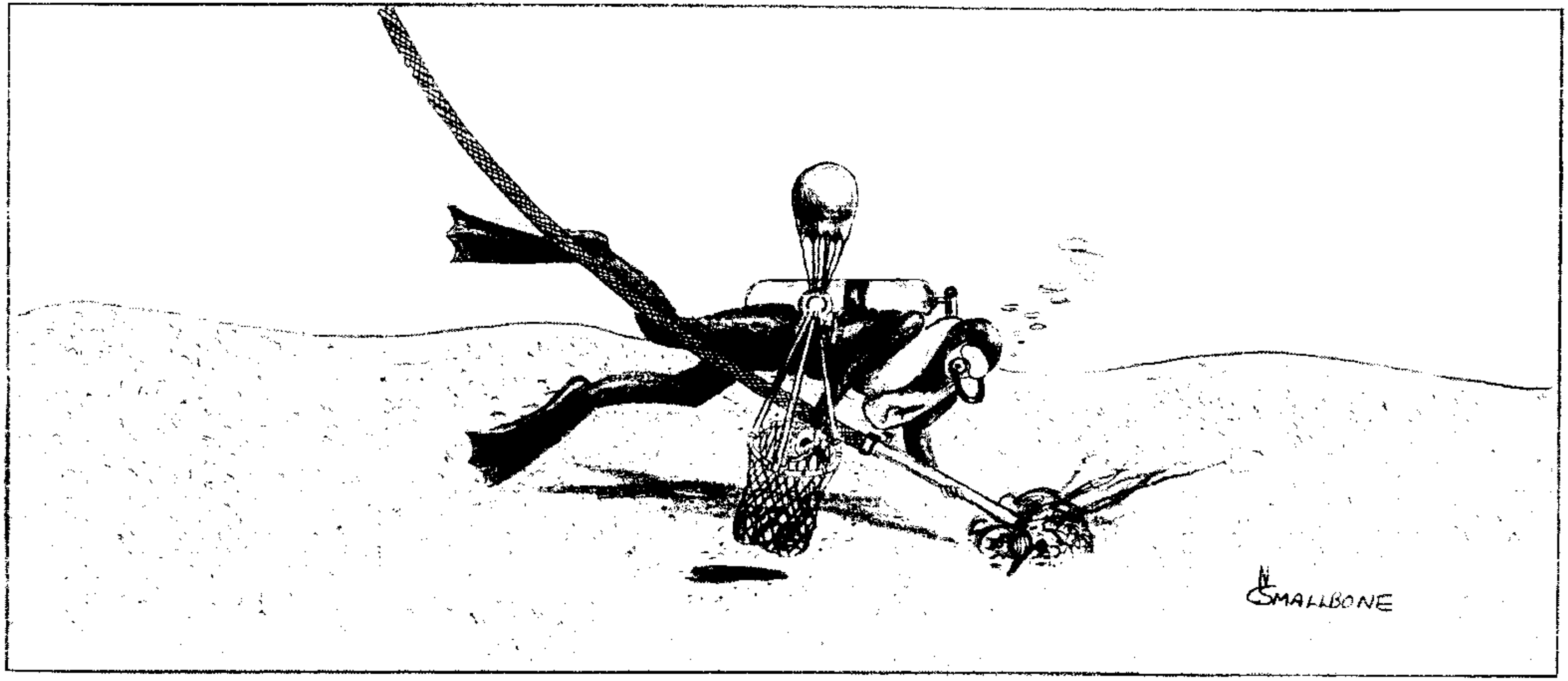

Figure II.D.2.-2B. Diagram of SCUBA diver operating the hand-held 1.9 cm water-jet harvesting equipment.

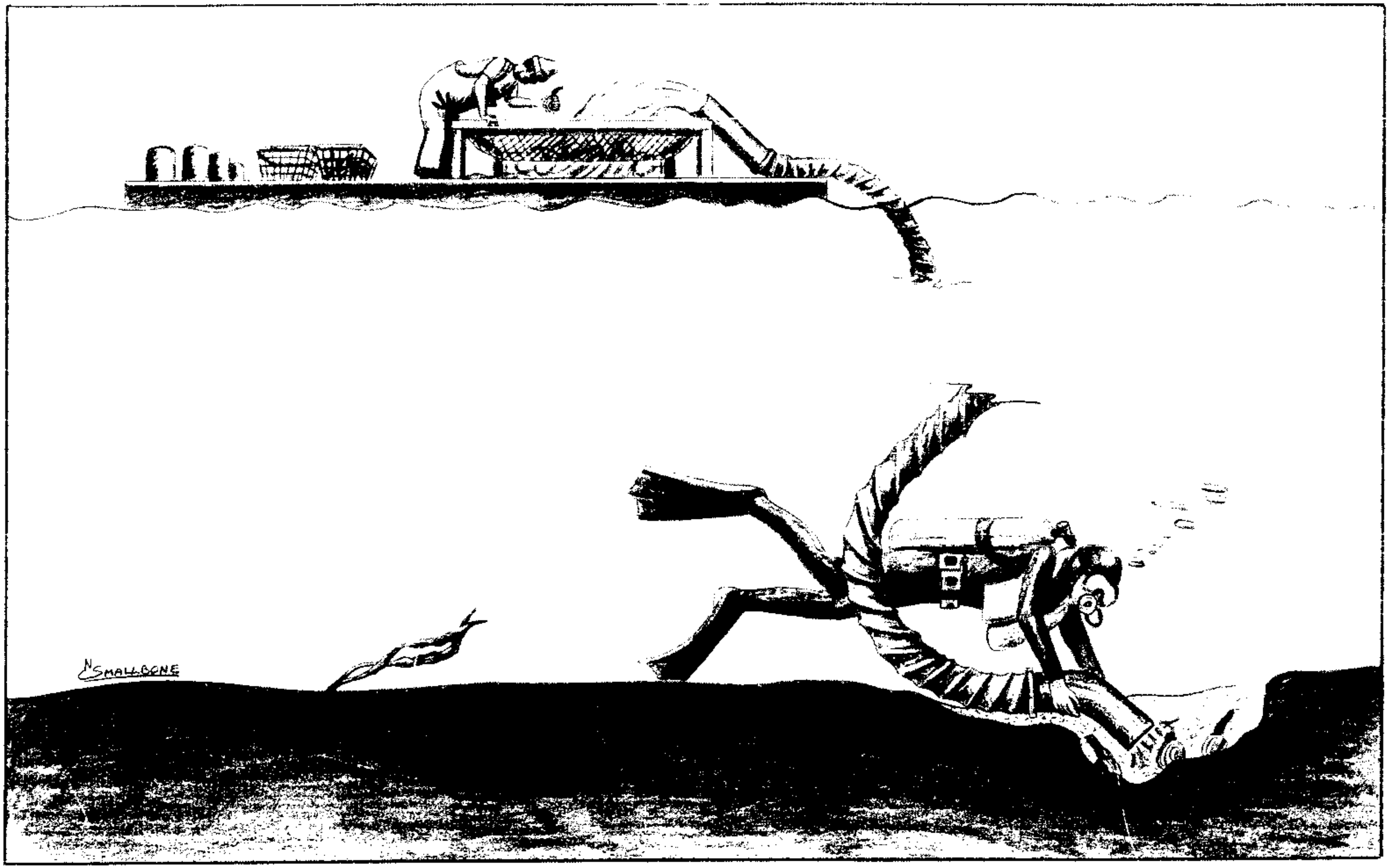

Figure II.D.2.-3A. Diagram of SCUBA diver operating the surface-discharging suction pump harvesting equipment.

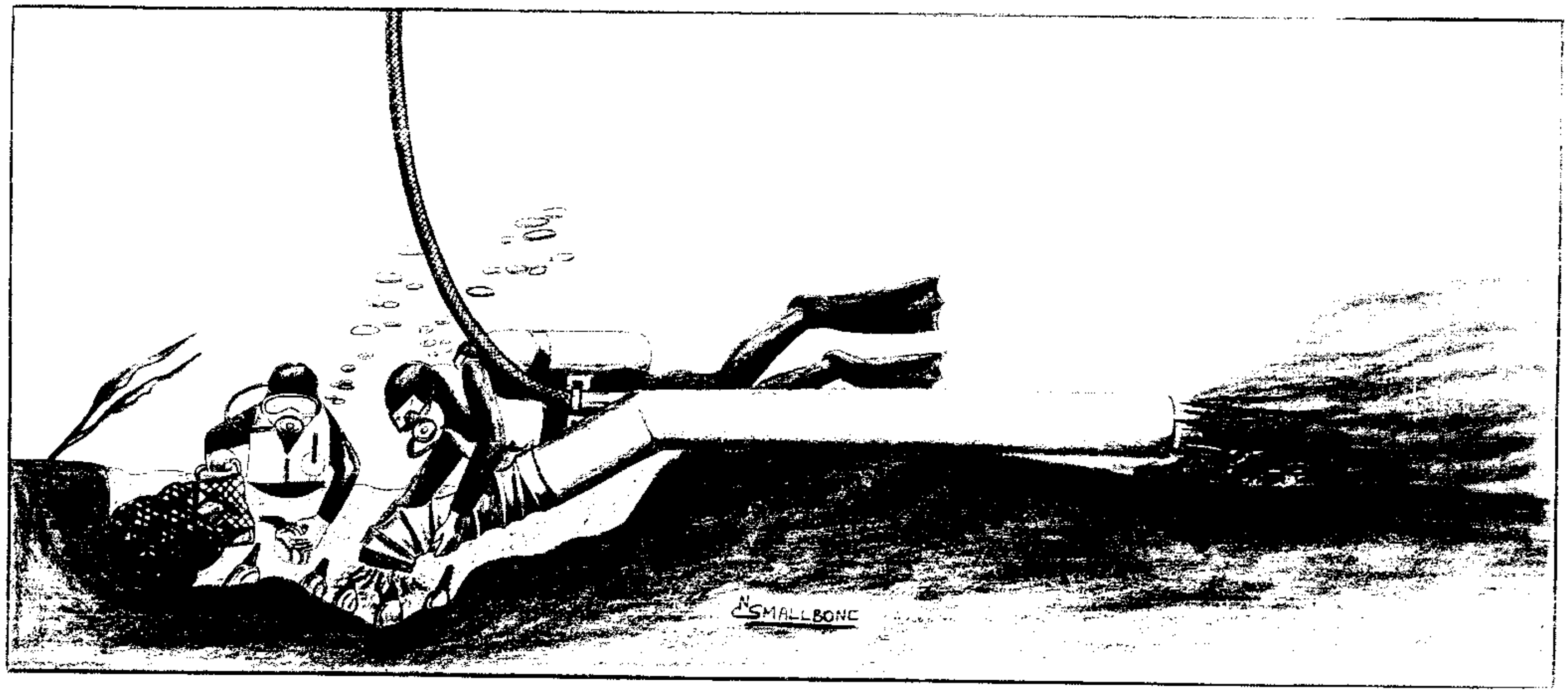

Figure II.D.2.-3B. Diagram of SCUBA diver operating the bottom-discharging suction pump harvesting equipment.

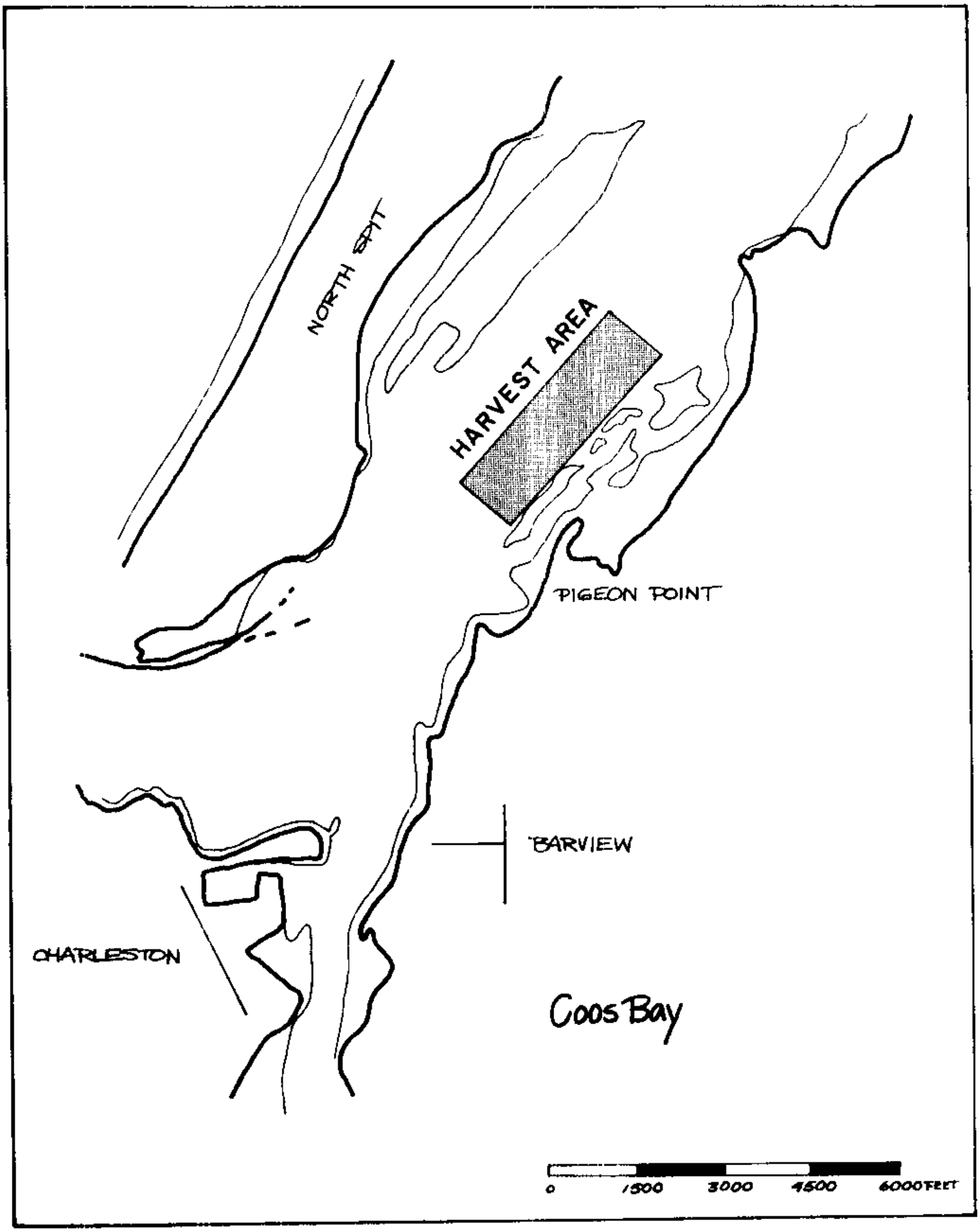

Figure II.D.2.-4. Map of lower Coos Bay, showing that area approved for commercial clam harvesting.

strictive for numbers or weight of clams harvested, since the intent was to salvage as many clams from this area as possible before dredge spoil deposition.

Following the 1975 season, the USACE decided not to use the proposed site as a spoil disposal area. As a result, harvest quotas were imposed for the 1976 season. Three commercial permits were issued for the 1976 season. Two of the permits covered 9.7 ha each; each area was within the 19.4 ha tract assigned in 1975. The two harvesters assigned to these units were allowed to use only a high pressure jet of water to remove clams. No restrictions were placed on where they could take clams within their respective units. Each fisherman was allowed to harvest 45.4 m.t. of clams.

The third permit restricted harvest to the main channel area downstream from Empire and the permittee was allowed to use a boat-towed hydraulic dredge to harvest clams. The hydraulic dredge was allowed in the channel, since the area was scheduled for deepening by the Corps of Engineers in 1977. No restrictions were placed on the numbers or species taken, although the cockle clam was the primary species of interest.

In 1977, one harvesting permit was issued for Coos Bay. The permit allowed the use of a water jet to harvest clams from within the same 19.4 ha permit area approved for the 1975 season. A harvest quota of 45.4 m.t. was placed on the area. As with Yaquina Bay clam harvesters, the permittee was required to submit monthly summaries of his harvest records to the ODFW.

II.D.3. RESULTS AND DISCUSSION

Yaquina Bay

The commercial fishery for clams in Area 4 of Yaquina Bay produced only 683 kg of clams in 1975. The low harvest was partially the result of poor market conditions. Figure II.D.3.-1 shows the year-class composition of the samples of gaper clams harvested. The 1969 year-class was prevalent although the 1968 and 1970 year-classes were nearly as strong.

Length-frequency distribution of the gaper clams sampled from the commerical harvest is shown in Figure II.D.3.-2. Mean length for the harvested clams was 122.7 mm.

In 1976 the commercial clam fishery was shifted to plots A and B of Area 2 of Yaquina Bay in which we estimated a total biomass of 822.3 m.t. of gaper clams (Table II.D.3.-1). Approximately half of this biomass was from clams considered by the processing industry to be too small (<100 mm) to be processed (John Becker, pers. comm.). Of this total, 533.7 m.t. occurred in jet plot A and 288.6 m.t. inhabited pump plot B. Small numbers of cockle, butter and littleneck clams precluded making biomass estimates for these species for plots A or B.

Although two permits were issued for the commercial harvest of clams in Yaquina Bay in 1976, neither harvester reported a take of clams. Both individuals were privately employed in other non-related full-time occupations and were unable to initiate a fishery.

Gaper clam biomass was again estimated in 1977 for plots A and B of Area 2 (Table II.D.3.-1) and totaled 584.7 m.t., a reduction of 237.6 m.t. from the 1976 estimate. Of the 1977 total, 385.9 m.t. occurred in the jet portion of Area 2 and 198.8 m.t. inhabited the pump section of Area 2.

At the 95% confidence level, no significant difference in biomass was exhibited between 1976 and 1977. The differences observed between 1976 and 1977 probably reflect sampling error due to small sample sizes each year.

Population and biomass estimates for the individual permit areas within plots A and B are also shown in Table II.D.3.-1. A total of 1.6 million clams weighing 128.2 m.t. inhabited the five areas. Biomass estimates ranged from 11.1 m.t. in sub-section 2-B-1 to 36.5 m.t. in unit 2-A-4.

Over 104,000 clams weighing 31.3 m.t. were taken in 1977 (Table II.D.3.-2). Gaper clams comprised 30.9 m.t. or 98.6% of the total harvest. The maximum harvest of gaper clams came from sub-section 2-A-4 where 16.7 m.t. were reported taken (Table II.D.3.-2). Midway through the season the permit holders for sub-section 2-A-4 were apprehended while harvesting clams unlawfully outside their assigned permit area. An estimated 6.3 m.t. were reported taken (Glen Wilber, pers. comm.). The total 16.7 m.t. included the unlawfully taken clams. The original estimate of gaper clam biomass for this sub-section was 36.5 m.t. available to the harvester. Post-harvest surveys showed that approximately 20% of the permit area had been worked. Production

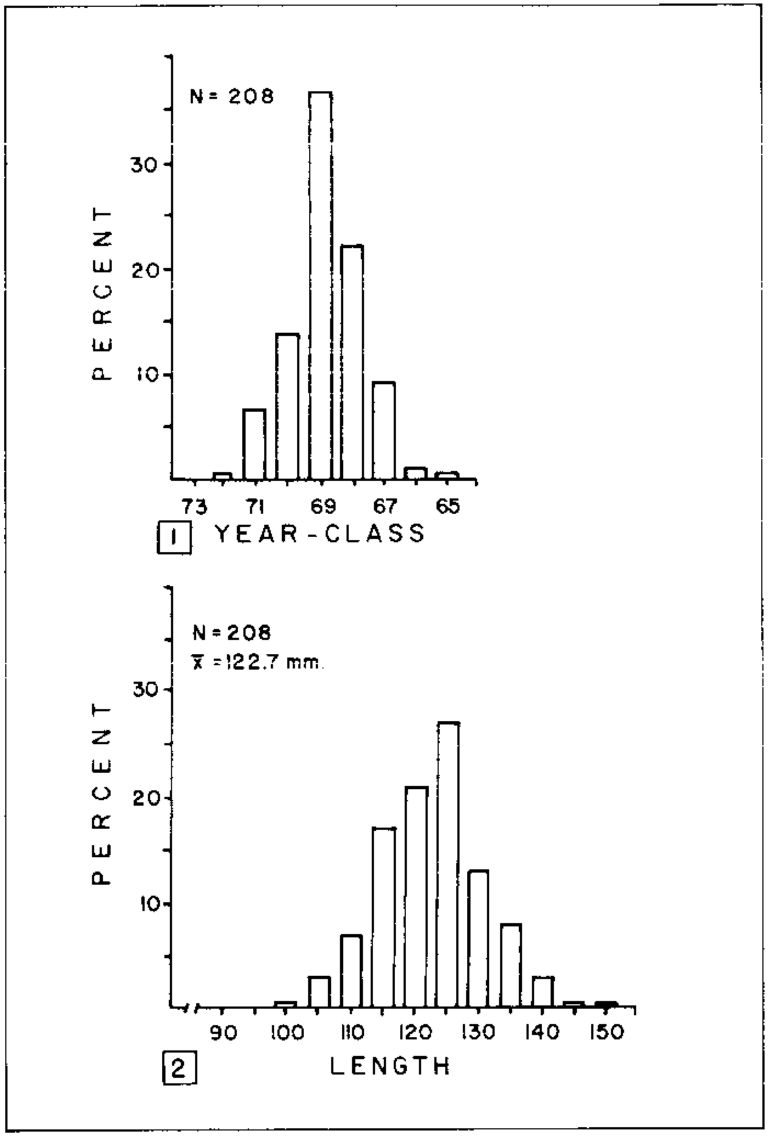

Figure II.D.3.-1. Year-class, and
Figure II.D.3.-2. Size-class composition of subtidal gaper clams (*Tresus capax*) harvested commercially from Area 4, Yaquina Bay, 1975.

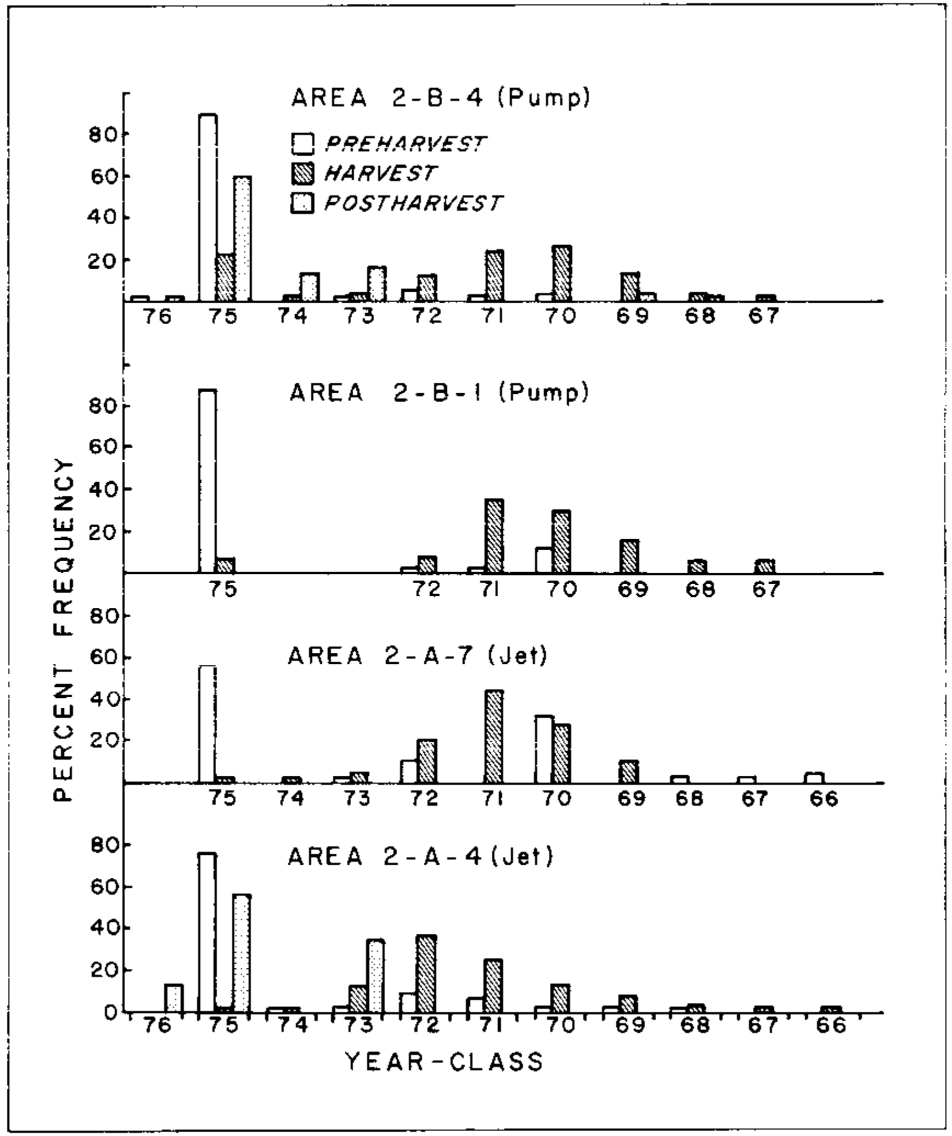

Figure II.D.3.-3. Year-class composition of subtidal gaper clams (*Tresus capax*) of commercially harvested sub-plots, Area 2, Yaquina Bay, 1977.

Plot No.	Year Sampled	Area Size (m^2)	Population Estimates (N)	Biomass Estimates (Pounds)	(Metric Tons)	95% Confidence Interval of Biomass (±%)
A	1976	8361	5,051,300	1,176,800	533.7	49.7
B	1976	8361	1,203,800	636,400	288.6	100.0
A	1977	8361	4,545,000	851,000	385.9	68.6
B	1977	8361	3,177,000	438,400	198.8	91.9
Total						
A & B	1976		6,255,100	1,813,200	822.3	41.7
A & B	1977		7,722,000	1,289,400	584.7	47.4

Sub-Section No.	Year Sampled	Area Size (m^2)	Population Estimates (N)	Biomass Estimates (Pounds)	(Metric Tons)	95% Confidence Interval of Biomass (±%)
2-A-4 (Jet)	1977	929	362,400	80,200	36.5	98.9
2-A-7 (Jet)	1976	929	100,900	43,500	19.7	83.4
2-B-1 (Pump)	1976	929	135,000	24,500	11.1	65.2
2-B-3 (Pump)	1976	929	465,100	62,300	28.3	100.0
2-B-4 (Pump)	1977	929	540,000	72,100	32.6	100.0
Total			1,603,400	282,600	128.2	53.8

Table II.D.3.-1. Summary of subtidal gaper clams in commercial clam harvesting plots and sub-sections of Yaquina Bay, Oregon.

from permit areas 2-A-7 and 2-B-3 was low because of the low effort expended in 2-A-7 and the inability of the harvester to maintain his boat in position in 2-B-3. Of the 31.3 m.t. of clams taken, 6.8 m.t. came from the salvage of clams being covered by sand during construction of the South Beach Marina jetty.

Catch per effort values ranged from 45.4 kg/hr in pump permit area 2-B-1 to 142.4 kg/hr in jet permit area 2-A-4 (Table II.D.3.-2). For all the permit areas combined, the average C/E was 103.9 kg/hr.

Figure II.D.3.-3 shows the year-class composition of subtidal gaper clams before and harvested from the commercial fishery in the four used permit areas. The 1975 year-class was prominent in each area prior to the commerical fishery. Year-class composition of the harvested clams showed that the strong 1975 year-class was generally ignored except for sub-section 2-B-4. The fishery was selective of the older clams with 32.7% of the clams harvested being five years of age or older.

The length-frequency of subtidal gaper clams sampled from each of the four main commercial clamming sub-sections is shown in Figure II.D.3.-4. Mean size before harvest ranged from 62.5 mm in sub-section 2-B-4 to 86.1 mm in sub-section 2-A-7. Mean size of harvested clams ranged from 107.0 mm in sub-section 2-B-4 to 117.7 mm in sub-section 2-B-1 (both were pump-harvested areas).

Results of the assessment of the effects of the commercial clam harvest on the clam stocks and surrounding habitat showed that only a small portion of each of the 30.5 x 30.5 m sub-sections was actually harvested. Only in sub-sections 2-A-4 and 2-B-4 were appreciable numbers of clams taken: 16.7 m.t. in 2-A-4 and 4.8 m.t. in 2-B-4.

In sub-section 2-A-4 the ODFW estimated that an area 6.1 x 30.5 m or 20% had been worked. Year-class composition of clams in the harvested area revealed that only clams of the 1973, 1975 and 1976 year-classes remained (Figure II.D.3.-3). All older clams had been removed. Prior to the harvest, gaper clam density averaged 391.0/m^2, whereas post-harvest density was 8.6/m^2.

Species		Yaquina Bay Sub-Section 2-A-4 "Jet"	2-A-7 "Jet"	2-B-1 "Pump"	2 B 3 "Pump"	2-B-4 "Pump"	Salvage "Jet & Pump"	Total
Gaper	(*T. capax*)							
	Pounds	36,852	1,083	4,159	774	10,506	14,700	68,074
	N	46,681	1,164	4,568	1,010	13,370	18,230	85,023
Cockle	(*C. nuttallii*)							
	Pounds	1	0	0	0	4	5	10
	N	2	0	0	0	22	13	37
Butter	(*S. giganteus*)							
	Pounds	516	9	1	4	43	18	591
	N	1,296	33	5	33	181	89	1,637
Littleneck	(*V.* sp.)							
	Pounds	45	<1	0	1	3	0	49
	N	176	1	0	5	15	0	197
Irus	(*M. irus*)							
	Pounds	0	0	91	0	14	229	334
	N	0	0	6,300	0	115	11,577	17,992
Softshell	(*M. arenaria*)							
	Pounds	0	<1	0	0	0	0	<1
	N	0	5	0	0	0	0	5
Total	Pounds	37,413	1,092	4,251	779	10,570	14,952	69,057
	Kilograms	17,006	496	1,932	354	4,805	6,796	31,390
	N	48,155	1,203	10,873	1,048	13,703	29,909	104,891
	Hours of Effort	119.1	6.3	42.5	7.0	79.7	47.0	301.6
	C/E (Pounds/hr.)	314	173	100	111	133	318	229
	(kg/hr.)	142.4	78.6	45.4	50.3	60.3	144.2	103.9

Table II.D.3.-2. Summary of subtidal clams harvested in the Yaquina Bay commercial fishery, 1977.

	Criteria tested by Oregon State Health Division		
	Fecal Coliform Density (MPN)	Standard 35 C Plate Count	Total Coliform (MPN)
Maximum allowable densities for market	230/100 gms	500,000/gm	>160,000/100 mls
Results of tests			
6/27/77	68	114,000	460
7/18/77	130	18,500	460
9/15/77	<18	5,600	2,200
9/21/77	130	800	460

Table II.D.3.-3. Results of testing by Oregon State Health Division for bacteriological contamination of commercially harvested gaper clams, Yaquina Bay, 1977.

An area similar in size to 2-A-4 was harvested in 2-B-4. Year-class composition of gaper clams was generally similar in each area prior to harvest. Post-harvest observations revealed that younger clams remained although some older clams were missed by the suction pump operation (Figure II.D.3.-3). Gaper clam densities in 2-B-4 prior to harvest averaged 583.2/m^2 whereas post-harvest densities were 57.2/m^2 indicating a nearly complete harvest from the worked area.

Results of the monthly Oregon State Board of Health testing for bacteriological contamination of commerically harvested clams are shown in Table II.D.3.-3. The maximum fecal coliform counts observed occurred in clams tested during July and September; both counts of 130 MPN/100 gms fell well below the FDA maximum allowable density of 230 MPN/100 gms. Standard 35 C plate counts and total coliform counts also fell below the maximum allowable densities for each sample period.

Coos Bay

The ODFW estimated in 1975 that 849.9 m.t. of clams inhabited the commercial clam plot in Coos Bay (Table II.D.3.-4). Of this total, 694.2 m.t. (81.7%) were gaper clams.

The commercial harvest from this area from 1975 through 1977 produced 59.3 m.t. of which 58.4 m.t. (98.5%) were gaper clams (Table II.D.3.-5). Butter clams were the only other species harvested. Peak year of harvest was 1976, when 47 m.t. were taken. The harvest from this area was taken entirely by hand-held water jet.

Catch per effort ranged from 71.2 kg/hr in 1977 to 102.4 kg/hr in 1976.

Year-class compositions of samples of the harvested subtidal clams for 1975, 1976 and 1977 are shown in Figure II.D.3.-5. The 1966 year-class was prominent in the 1975 and 1976 harvest. In 1977, the harvest shifted to younger aged clams with the 1969-1972 year-classes all showing well in the take. The change in age composition possibly illustrates a change in harvest location within the 19.4 ha permit area.

The length-frequency of samples of commercially harvested gaper clams in Coos Bay during 1975, 1976 and 1977 is shown in Figure II.D.3.-6. Mean sizes for each of the three years were similar, ranging from 131.8 mm to 133.2 mm. The harvest was entirely composed of 100-160 mm size clams.

Species	Population Estimates (N)	Biomass Estimates (Pounds)	Biomass Estimates (Metric Tons)	95% Confidence Interval of Biomass (±%)
Gaper (*T. capax*)	5,648,700	1,530,800	694.2	44.8
Cockle (*C. nuttallii*)	202,200	23,000	10.5	100.0
Littleneck (*V.* sp.)	843,000	71,600	32.6	49.7
Butter (*S. giganteus*)	809,200	248,200	112.6	58.2
Total	7,503,100	1,873,600	849.9	34.7

Table II.D.3.-4. Summary of subtidal clams in commercial clam harvesting areas of Coos Bay, Oregon, 1975.

Species		Pigeon Point 1975	1976	1977	Total
Gaper (*T. capax*)					
	Pounds	14,467	102,442	11,931	128,840
	N	20,991	---	---	20,991
Butter (*S. giganteus*)					
	Pounds	735	1,142	0	1,877
	N	---	---	0	---
Total	Pounds	15,202	103,584	11,931	130,717
	Kilograms	6,895	46,986	5,412	59,293
	N	20,991	---	---	20,991
	Hours of Effort	75.0	459.2	76.0	610.2
	C/E (pounds/hr.)	202.7	225.7	157.0	214.2
	C/E (kg/hr.)	91.9	102.3	71.2	97.2

Table II.D.3.-5. Summary or subtidal clams harvested in the Coos Bay commercial fishery, 1975-1977.

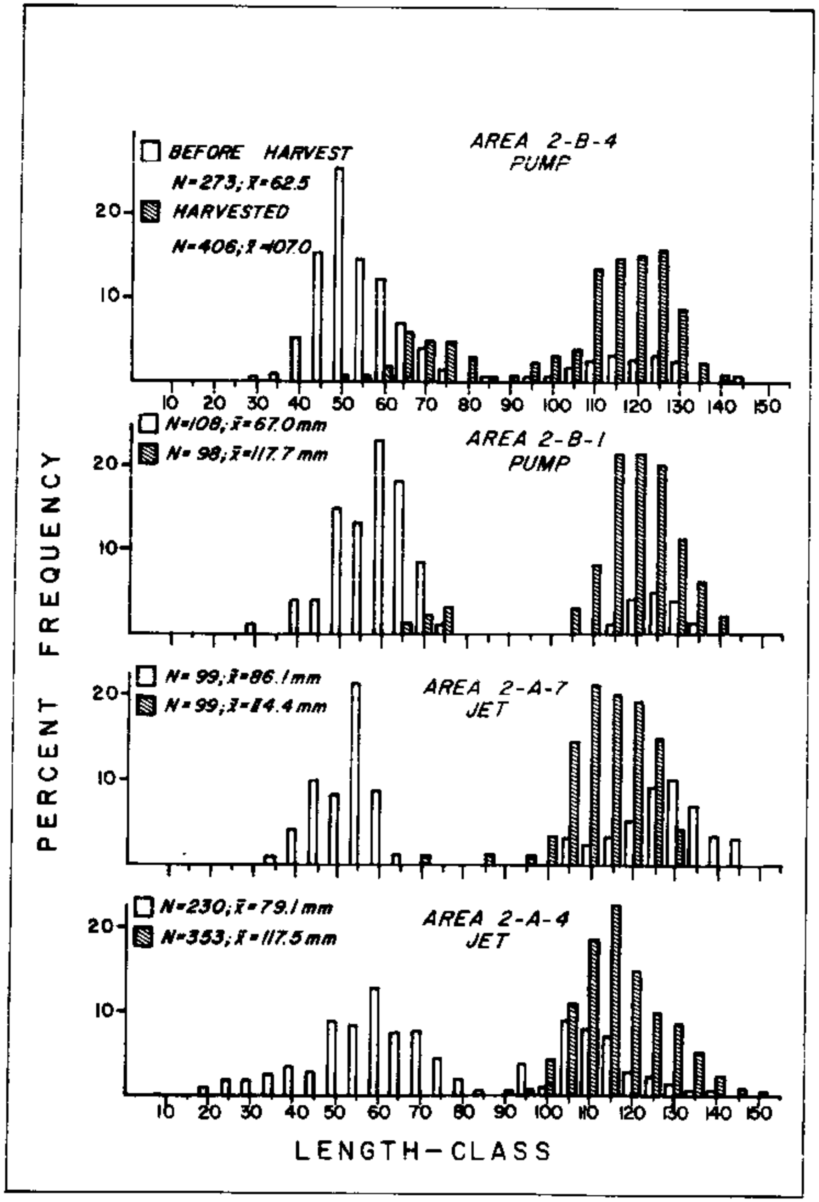

Figure II.D.3.-4. Size-class composition of subtidal gaper clams (*Tresus capax*) of commercially harvested sub-plots, Area 2, Yaquina Bay, 1977.

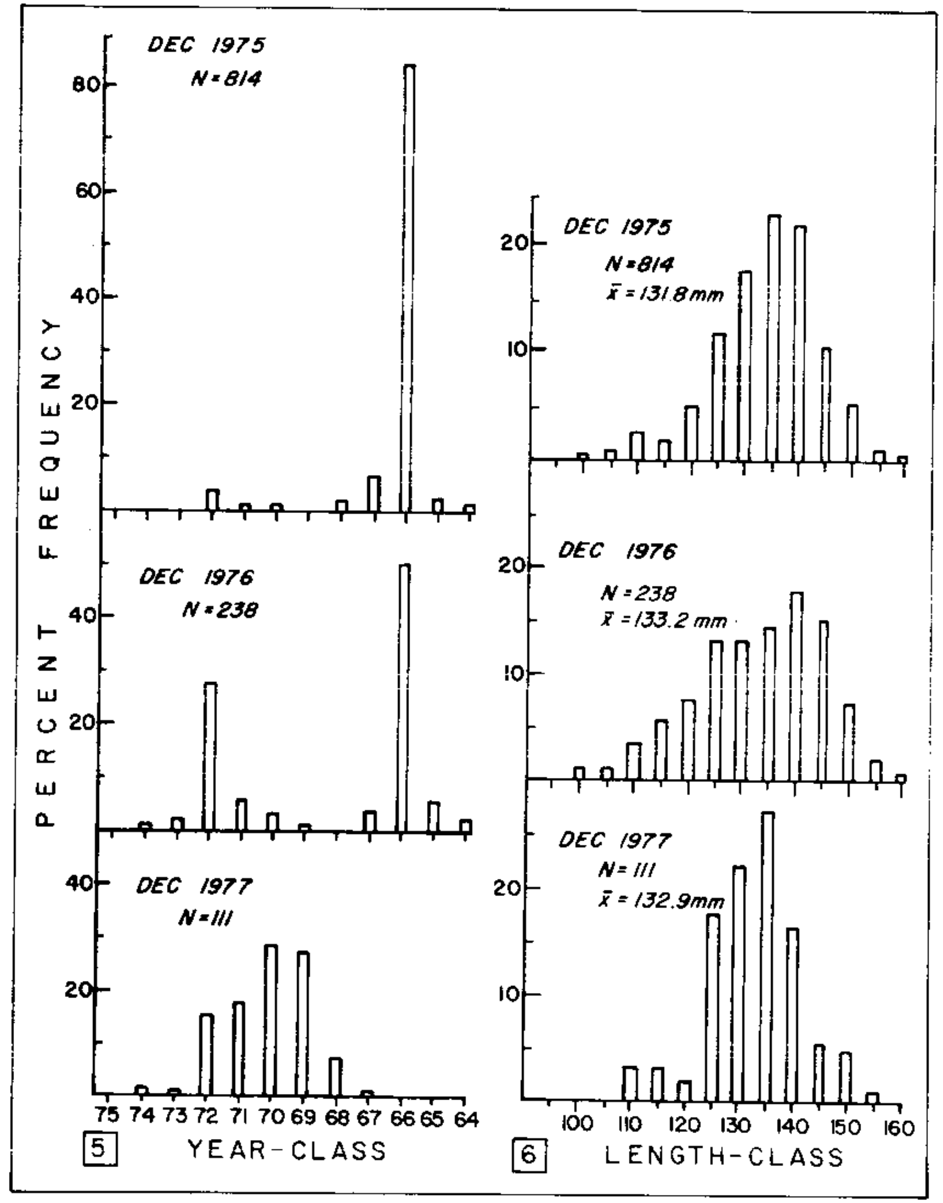

Figure II.D.3.-5. Year-class, and
Figure II.D.3.-6. Size-class composition of subtidal gaper clams (*Tresus capax*) commercially harvested from Pigeon Point, Coos Bay, 1975-77.

II. E. Economics—market conditions from harvest of gaper clams

THOMAS F. GAUMER
GREGORY P. ROBART

The market potential for gaper clams from Oregon has never been fully investigated. Until recently, East Coast bay and offshore surf clams have been available to meet market demands across the country. This availability has changed rapidly during the past several years due primarily to the substantial decline of the known stocks of East Coast surf clams resulting in failure to meet the growing national and world-wide demands for clam products. Consequently, market demand has increased for clam stocks from the West Coast of the United States, with the center of activity in the Puget Sound area of Washington. In 1976, clam processors from Washington state, with markets in the Orient, inquired about possible supplies of Oregon bay clams to supplement stocks being taken in Washington. One out-of-state processor was seeking a source in excess of 30,000 pounds (13.6 m.t.) per week. Since that initial request, several other out-of-state clam processors have requested information on the availability of clams for export.

The following is a summary of the recent development of the processing and marketing of gaper clams in Coos and Yaquina bays.

II.E.1. COOS BAY

In recent years nearly all the gaper clam harvest from Coos Bay has been taken subtidally by one harvester under special permit, using a hand-held water jet.

Harvest takes place in the fall, usually in November and December, following the salmon season. Production has been variable depending on the outcome of the salmon season and on prevailing weather conditions, since muddy water precludes the efficient use of a diver-held water jet.

In 1977, 5.4 m.t. of gaper clams were harvested in Coos Bay. Fishermen received 25¢/pound (live weight). Nearly all the clam production was processed by one company in Oregon. Processed clams were marketed as fried clam steaks at restaurants in Eureka, California.

In 1976 the ODFW monitored the changes in meat recovery during a special extension of the commercial clam season to allow salvage of clams at an Army Corps of Engineers spoil disposal site. Results of the survey showed that processed meat yield dropped from 22% in February to 19.4% in March (Table II.E.-1). The fishery was terminated in April due to the poor meat yield (reported at 17%) following the clam spawning season.

Date	Number of clams	Pounds of clams	Pounds of meat	Percentage yield
Jan. 19, 1976	100	87.00	18.50	21.2
Feb. [illegible]0, 1976	100	105.75	23.25	22.0
Feb. 16, 1976	100	99.00	19.75	20.2
Mar. [illegible]6, 1976	20	23.25	4.50	19.4

Table II.E.-1. Summary of meat yield data for gaper clams harvested in commercial clam fishery in Coos Bay.

II.E.2. YAQUINA BAY

The commercial subtidal gaper clam fishery in Yaquina Bay has been slow in developing due to poor marketing conditions prior to the 1977 season. In 1977, a restaurant chain contracted to use Yaquina Bay gaper clams in their chowder base. The following was provided by John Becker, Plant Manager of Mo's Newport Seafoods:

Although the market potential for Oregon's bay clam industry appears unlimited, present supply is only adequate to meet local restaurant demand. Mo's Seafood restaurant chain annually requires in excess of 11.3 m.t. of processed clam meats (equivalent to about 125,000 pounds of whole clams) for their chowder. Nearly all the production of gaper clams from Yaquina Bay was purchased by Mo's Seafood at 19¢/pound in the round. Small, unprocessed gaper clams not used by Mo's Seafood were sold to bait shops and returned $1.00/pound to the harvester. Approximately 0.5 m.t. (2%) of the total 30.9 m.t. gaper harvest was sold as bait. A small incidental "walk in" retail trade at Mo's Seafood provided fresh clam meat to the general public at $1.75/pound. An additional market for clam waste for either commercial crab bait or as a source of glycogen is potentially available as production increases.

Mo's processing facilities required a minimum of 1.4 m.t. of live clams per day to meet operating expenses. This production required a crew of nine working an eight-hour shift. Optimum production would require 1.8 m.t. of live clams per day.

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PART III Ecological Studies of the Gaper Clam, *Tresus capax*

III. A. Growth and reproduction

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III.A.1. INTRODUCTION

In order to initiate an effectively managed gaper clam fishery in Yaquina Bay, pertinent ecological information should be compiled. Swan and Finucane (1952) compared *Tresus* (=*Schizothaerus*) *capax* to *T. nuttalli* on the basis of gross observations and suggested that *T. capax* is a winter spawner. Pohlo (1964) described the relationship of age to changes in burrowing behavior and in ontogenetic form in *T. nuttalli*. *Tresus capax* and *T. nuttalli* were again differentiated by Pearce (1965), but on the basis of distribution, positional orientation, the presence or absence of a symbiotic pinnixid crab, and the presence or absence of a visceral skirt. The autecology of the two species from Humboldt Bay, California, was described by Stout (1967), who concluded that, although no significant difference existed between the distributional patterns of the two, density of both increased with increasing sediment size and/or decreasing organic content of the sediment. Reid (1969) related type and amount of food storage of *T. capax* to season, giving evidence that it spawned during the winter. More recently, thorough examinations of the reproductive cycle were made at Humboldt Bay (Machell and DeMartini, 1971), and near Vancouver Island, British Columbia (Bourne and Smith, 1972a), reflecting only slight variations in the cycle at the two areas.

Growth in commercial clams has been extensively studied but less consideration has been given the gaper clam or other members of the family Mactridae. Bourne and Smith (1972a) are the only researchers to have considered the growth rate of *T. capax*, finding it to be more rapid, over 100 mm/5 yr, than that of other commercial clams, and yielding generally 30% usable meat. They also studied the effects of temperatures and salinities on larval growth and survival (1972b). Other studies on mactrid clams have been about reproductive cycles only (Ropes, 1968; Calabrese, 1970).

Wilbur and Owen (1964) stated that allometric growth relationships, i.e., those of the growth of one body part relative to another or to the whole, can be expressed by the equation

$$y = a(x^b),$$

which can be transformed to the linear equation

$$\log y = \log a + (b) \log x,$$

where x and y are body dimensions and a and b are constants. Comparisons of growth rates among populations may then be made by determining the values of the constants a and b. Using this approach, significant differences between growth rates of inter- and subtidal bivalves were found (Dame, 1972; Brown, Seed and O'Connor, 1976). Rao (1953) found that mussels of a lower tidal height had greater shell weight for a given soft body weight than did higher level mussels. Weymouth, McMillin and Rich (1931) described how relative and absolute growth rates of razor clams differed with latitude.

During this phase of the study, a concerted effort was made by the Oregon State University School of Oceanography to provide information about growth rates and reproductive cycles of *T. capax* populations in Yaquina Bay to be used in management-planning decisions.

III.A.2. MATERIALS AND METHODS

Gaper clams (*Tresus capax*) for a reproductive cycle study were collected from April 1975, through February 1977, from four areas in Yaquina Bay, Oregon (Figure III.A.2.-1). Stations 1, 2 and 4 were subtidal. Substrate was removed with a suction dredge manipulated by SCUBA divers (Gaumer and Lukas, 1975), subsequently allowing the clams to be collected by hand. Collections at these stations were generally made at the slack of the daytime high tide at depths of approximately 5, 2.5 and 6 f (9.1, 4.6 and 11.0 m) respectively. Station 3 was located on a tidal mudflat; samples were taken at low tide by digging with clam shovels. Occasionally unfavorable tidal, weather, and sea conditions made uniform sampling difficult; nonetheless, most samples contained 10 clams from each station and the period between samples was approximately two weeks in November through February and one month during the remainder of the year.

Measurements of temperature and salinity were taken with an Industrial Instruments electrodeless induction salinometer (Model RS5-3) from each subtidal station every time a collection was made. Core samples of the substrate and its infauna were taken with a corer from all stations at the time of each collection. In an attempt to retain juvenile clams, the surface sediments were sampled with a 12.7 mm sieve; sediments below the surface were sieved through 25.4 mm screen.

Clams were transported immediately to the Oregon State University School of Oceanography where examination took place. Length, height and width were measured with vernier calipers to the nearest 0.1 mm (Figure III.A.2.-2). Age was determined by counting annual growth check rings of both valves and by counting the annuli in the chondrophore of either valve. The presence or absence of haplosporidan cysts was also observed.

A sample of gonadal tissue was taken from the middle of the foot of each clam. The tissue was fixed in Bouin's solution, embedded in paraplast, sectioned at 7 μm and stained with Harris' hematoxylin and eosin. Based on examinations of the slide preparations, the sex of each clam was identified and the stage of the reproductive cycle was assigned according to the criteria set by Ropes and Stickney (1965) and Machell and DeMartini (1971). The five phases of the cycle were 1) inactive, 2) active, 3) ripe, 4) partially spawned, and 5) spent. Oocyte and oocyte nucleus diameters from each ripe and partially spawned clam from stations 2 and 3 were measured with an ocular micrometer. At least 15 oocytes that were free in the lumina of several alveoli from each clam and that contained nucleoli were measured. Counts were made of oocytes attached to the alveolar walls and of those free in the lumina of the alveoli of the same clams as above. Only those cells from five alveoli and with nuclei were included.

Additional gaper clams were collected for a volumetric study when logistically possible at the same time and with the same methods as described above. Measurements of total wet weight and shell weight, in addition to the size data listed above, were taken immediately upon return to the laboratory. Dry body weight was measured after drying in a constant temperature oven (110 C) for 48-72 hr. Two methods were employed to measure shell volume: 1) one clean valve of each clam was filled with water and the volume of water was measured in a graduated cylinder, then doubled for the total; 2) the two clean valves of each clam were tightly secured together, sand was poured through the gap between the valves until full, and the volume of sand measured. Gonad tissue was not taken from these clams. Methods of statistical analysis are described below.

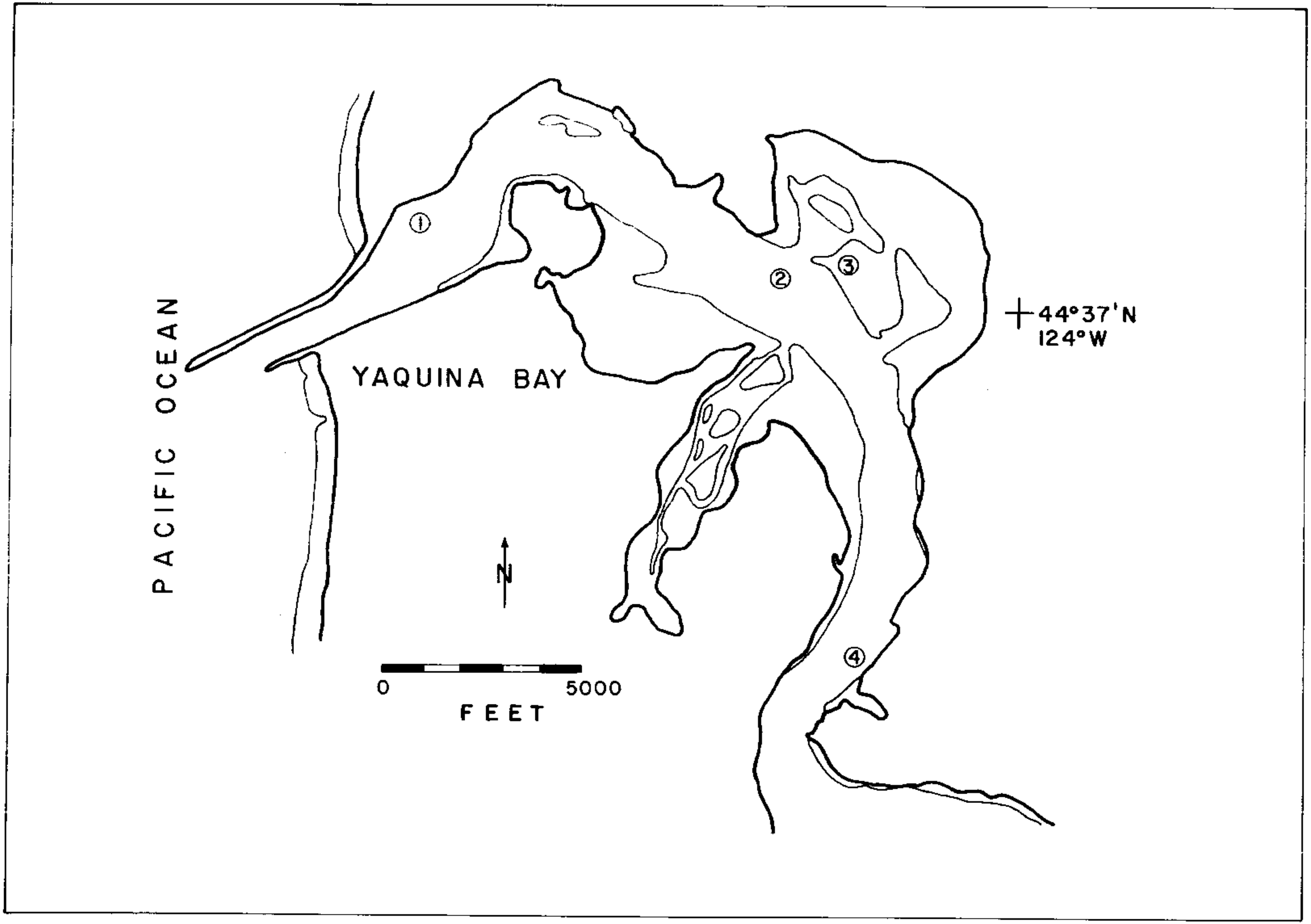

Figure III.A.2.-1. Location of sampling stations in Yaquina Bay, Oregon.

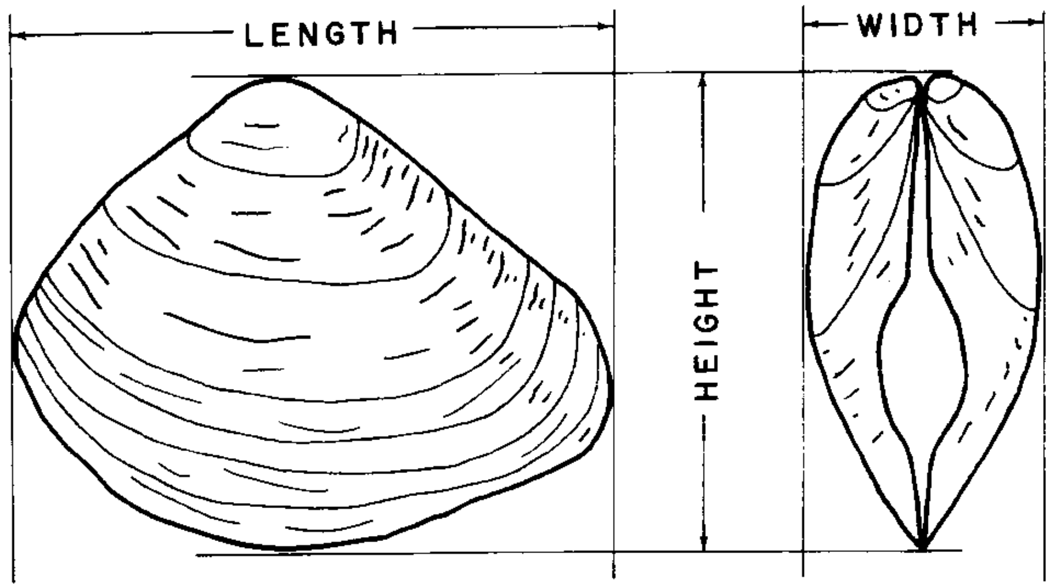

Figure III.A.2.-2. Length, width, and height dimensions of *Tresus capax*.

III.A.3. STATISTICAL ANALYSES

The statistical procedures used during this study follow the methods outlined by Steel and Torrie (1960) and Snedecor and Cochran (1967).

Growth

Absolute growth was determined by finding the mean length and its 95% confidence interval of the clams at each age. Student's t-test was used to compare all mean lengths. Generally, when the confidence interval of one mean length did not overlap another mean value, the means were significantly different.

Allometric relationships were calculated in concordance with the methods described by Steel and Torrie (1960) and Snedecor and Cochran (1967); computations were executed on a computer.

Reproductive Phase Synchronousness

To test the synchronousness of the reproductive phases among gaper clams at each sampling site, a mean day (MD) for each phase at each site was calculated:

$$MD = \frac{\Sigma D}{N}, \text{ where}$$

D = day number when clam observed to be in respective phase, numbered consecutively from day #1 = day when phase first observed in Yaquina Bay;

N = total number of clams in respective phase from respective site.

The 95% confidence interval (CI) for each MD was also calculated using:

$$CI = MD \pm \frac{t_{.05}(s)}{\sqrt{N}}, \text{ where}$$

t = Student's t-value at 0.05 probability level for (n-1) degrees of freedom;

s = $\sqrt{s^2}$ = standard deviation of sample;

N = total number of clams in respective phase at respective site.

Significant differences between MD's were tested with the Students' t-test. The normal F-distribution was used to test the difference of the population variances, σ_i^2, where

$$F = \frac{\text{larger } s^2}{\text{smaller } s^2}, \; s^2 \text{ being a statistical estimate of } \sigma^2,$$

and was compared to an F-distribution table for the corresponding degrees of freedom and 0.05 probability level.

When $\sigma_1^2 = \sigma_2^2$, a Student's t-test was used to test the significance of difference between the mean days of the reproductive phases among the sampling areas:

$$t = \frac{MD_1 - MD_2}{s_{\bar{d}}}, \text{ at } (n_1 - 1) + (n_2 - 1)\text{df where}$$

$$s_{\bar{d}} = \sqrt{s^2\left(\frac{1}{N_1} + \frac{1}{N_2}\right)} = \sqrt{s^2\left(\frac{N_1 + N_2}{N_1 N_2}\right)};$$

$$s^2 = \frac{(N_1-1)\, s_1^2 + (N_2-1)\, s_2^2}{(N_1-1) + (N_2-1)} = \text{a weighted average of variances when } n_1 \neq n_2.$$

When $\sigma_1^2 \neq \sigma_2^2$, a modified test was used:

$$t' = \frac{MD_1 - MD_2}{s_{\bar{d}}}, \text{ (t' indicating the criterion not distributed as t) where}$$

$$s_{\bar{d}} = \sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}} \text{ (sample variances were not pooled as above).}$$

This calculated t'-value was then compared to a tabulated t'-value for the chosen probability level:

$$t' = \frac{w_1 t_1 + w_2 t_2}{w_1 + w_2}, \text{ where}$$

$$w_1 = \frac{s_1^2}{N_1};$$

$$w_2 = \frac{s_2^2}{N_2};$$

$t_1 = t_{.05}$-value at N_1-1 degrees of freedom;

$t_2 = t_{.05}$-value at N_2-1 degrees of freedom.

To further compare synchronousness of reproductive phases, the X^2 test criterion was used to test independence of the distribution of the frequency of clams in each phase at each site

$$\chi^2 = \Sigma \frac{(\text{observed - expected})^2}{\text{expected}}, \ (r-1)(c-1)df.$$

III.A.4. RESULTS

Growth

Nearly 2000 clams were examined during the growth and reproductive studies. Both techniques for determining the age of the clams, counting either the annual growth checks (rings) on the valves or the annuli on the chondrophore, gave similar results, indicating that either method may be used confidently. Both methods were used throughout the study to ensure accuracy. The only reliable volume measurement technique proved to be the sand method (see Materials and Methods). Volume measurements using water could not be duplicated.

The mean lengths of each age class from each station are shown in Table III.A.4.-1 and Figure III.A.4.-1. The yearly mean lengths of subtidal clams (from stations 1, 2, 4) over 4 yr old were significantly larger than those of intertidal clams. Intertidal clams 4 yr and younger were not significantly different in size than subtidal clams of a similar age.

Linear growth rate, shown in Figure III.A.4.-2A, was rapid, 22 mm/yr during the first three years, and decreased quickly with little growth occurring after 7-8 yrs. A comparison of subtidal clam growth rate (pooled data) to the intertidal clam growth rate (Figure III.A.4.-2B) showed that the initial and final growth rates of the two groups were similar. However, the rate of growth of the intertidal clams decreased more rapidly between the ages 4-7 yr (inclusive) than it did for subtidal clams.

The mean volumes of each age class from each station are shown in Table III.A.4.-2 and Figure III.A.4.-3A. In Figure III.A.4.-3B, the data from the subtidal stations were pooled for a larger sample size. Clams under 3 yr of age were not available for this portion of the study. The volume of clams from subtidal stations was consistently larger than that for intertidal clams of similar age.

The oldest clams collected from subtidal sites were 10-12 yr of age; those collected from the intertidal site reached an age of 9 yr.

Allometric growth relationships were compared using the linear equation,

$\log y = \log a + (b) \log x$, which was transformed from the exponential growth equation,

$y = a(x^b)$. (see Methods and Materials above.)

The value b is the ratio of specific growth rates of y and x, i.e., the factor of differential growth and the slope of the log regression line. The value a is equivalent to y, when x = 1.

Results of the regression analysis of allometric growth are shown in Table III.A.4.-3, and are described below. The allometric coefficients given for the various morphological relationships are those which best fit the data collected. The regressions were applied only within the range of the data (Wilbur and Owen, 1964) (Figures III.A.4.-4 to III.A.4.-14). Significant differences of a pair were indicated when the 95% confidence intervals of those coefficients were non-overlapping.

The width/length and height/length relationships for subtidal and intertidal clams had signficantly different b values and were greater for the subtidal clams in both instances. The coefficients of determination (R^2) were, in all but one case, higher than 95%. No significant difference was found in the volume/length relationship between the a or b values for the subtidal and intertidal clams. These allometric ratios indicate that although shell height and width growth ratios were higher and increased more rapidly per unit length in subtidal clams than they did in intertidal clams, the volume/length ratio did not differ significantly between those clams.

The growth rate of total wet weight relative to length was higher in the intertidal clams than in the subtidal clams, but was not significantly different between the ripe and inactive clams. The rate of increase (the value b) was also greater in intertidal than subtidal clams, but not different between clams of different reproductive phases.

Because the R^2 values for the relationships of wet body weight/length and dry body weight/length were fairly high (73-86%) among the inactive and ripe clams and were very low (46-75%) among subtidal and intertidal clams, it appears that reproductive phase, not height in the littoral zone, had an influence on wet or dry body weight

	AGE (yr.)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
STATION NO. I													
$\bar{X}$	8.84	35.95	50.07	61.93	76.02	96.34	111.28	119.95	123.17	123.79	119.90		
N	200	41	15	123	122	13	41	98	108	36	6		
s	4.72	5.33	5.89	16.19	12.42	9.68	9.85	6.25	7.45	7.56	10.17		
CI (95%)	0.65	1.68	3.26	2.89	2.23	5.85	3.11	1.25	1.42	2.56	10.67		
STATION NO. II													
$\bar{X}$	5.18	24.01	49.30	86.20	97.95	112.20	119.16	125.96	123.43	123.74	125.50	123.50	122.00
N	56	59	22	8	23	67	107	85	30	10	2	2	1
s	1.82	7.75	11.37	10.47	9.45	8.02	7.04	6.01	10.75	10.45	4.95	4.95	0
CI (95%)	0.49	2.02	5.04	8.75	4.09	1.96	1.35	1.30	4.01	7.47	44.61	44.61	--
STATION NO. III													
$\bar{X}$	---	35.90	58.70	80.24	92.07	101.78	103.93	108.04	111.05	109.40			
N	---	3	1	45	73	88	75	21	4	3			
s	---	4.66	0	6.82	6.70	6.72	8.21	6.75	114.06	2.77			
CI (95%)	---	11.58	---	2.05	1.56	1.42	1.89	3.07	18.15	6.88			
STATION NO. IV													
$\bar{X}$	7.36	29.71	51.62	73.26	89.75	106.85	114.90	119.32	120.37	120.96	118.24		
N	53	22	9	5	11	41	75	95	48	34	5		
s	4.81	7.14	12.34	14.58	10.58	6.93	8.65	7.04	7.74	11.55	9.27		
CI (95%)	1.33	3.17	9.30	18.10	7.11	2.19	1.99	1.43	2.25	4.03	11.51		

Table III.A.4.-1. Mean lengths of *Tresus capax* of different ages from four sampling sites in Yaquina Bay, Oregon.

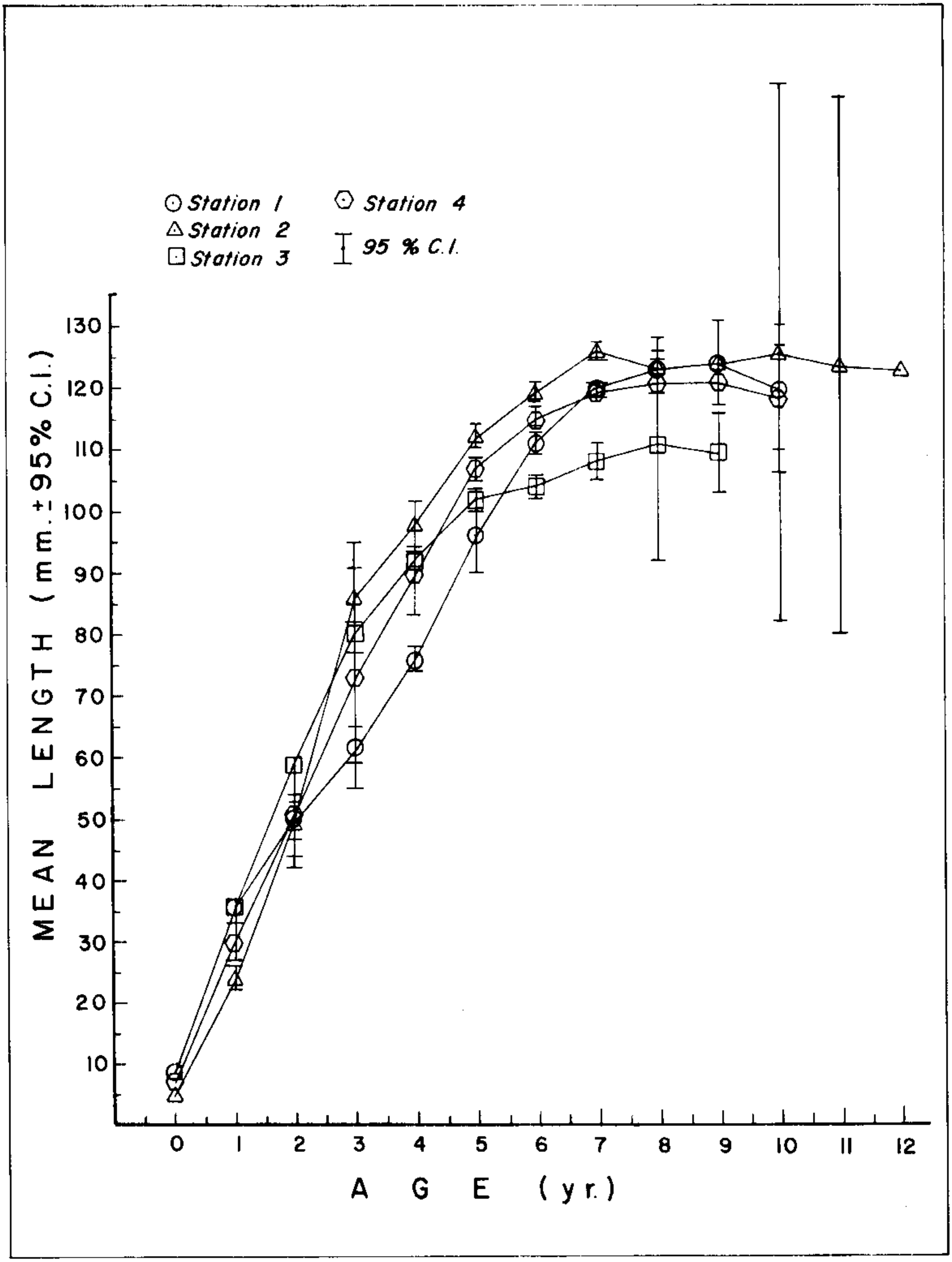

Figure III.A.4.-1. Absolute linear growth of *Tresus capax* from four sampling stations in Yaquina Bay, Oregon.

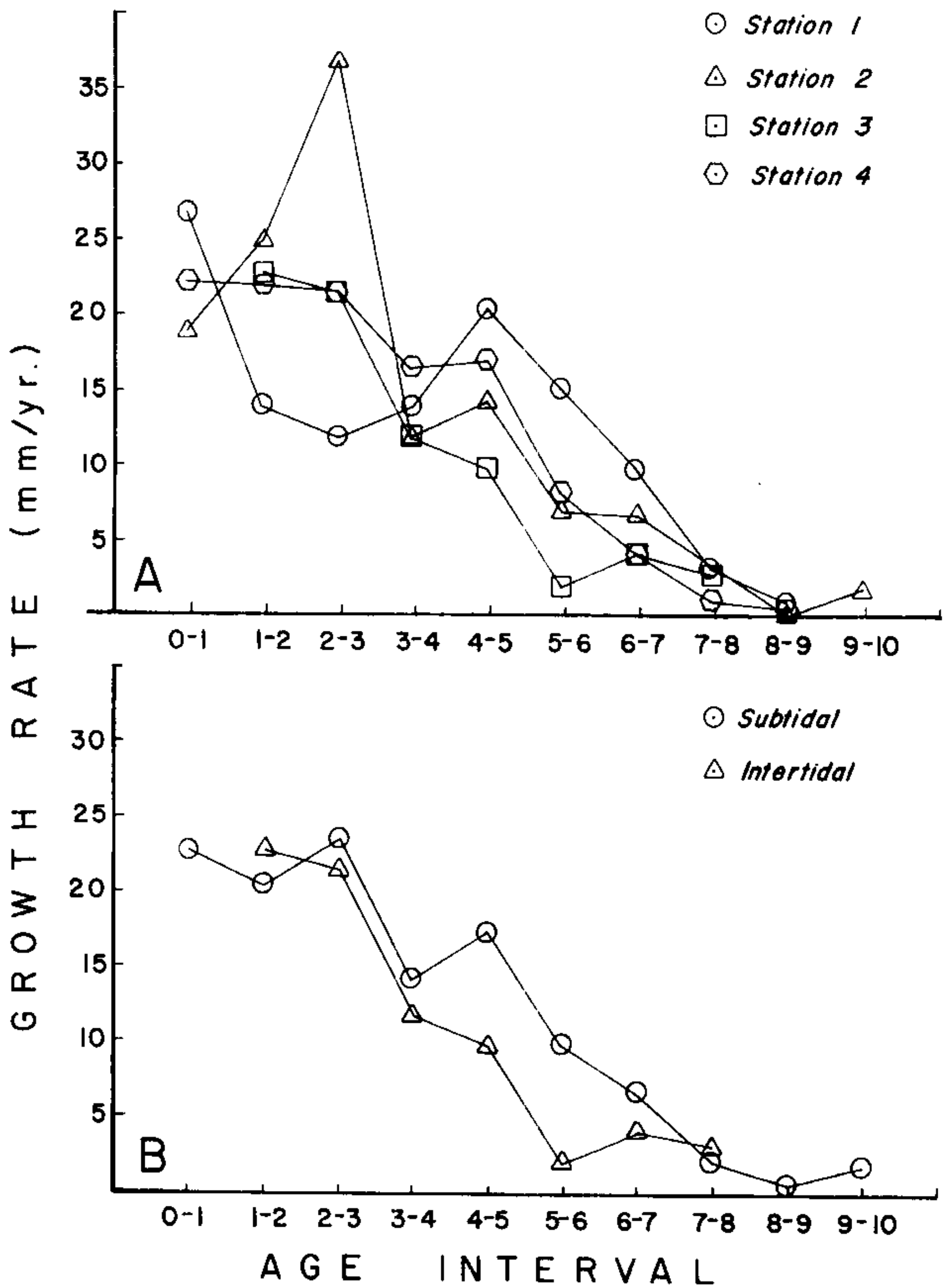

Figure III.A.4.-2. Linear growth rate of *Tresus capax* from four sampling stations in Yaquina Bay, Oregon. A. Data from four sampling stations. B. Combined data for subtidal and intertidal *Tresus capax*.

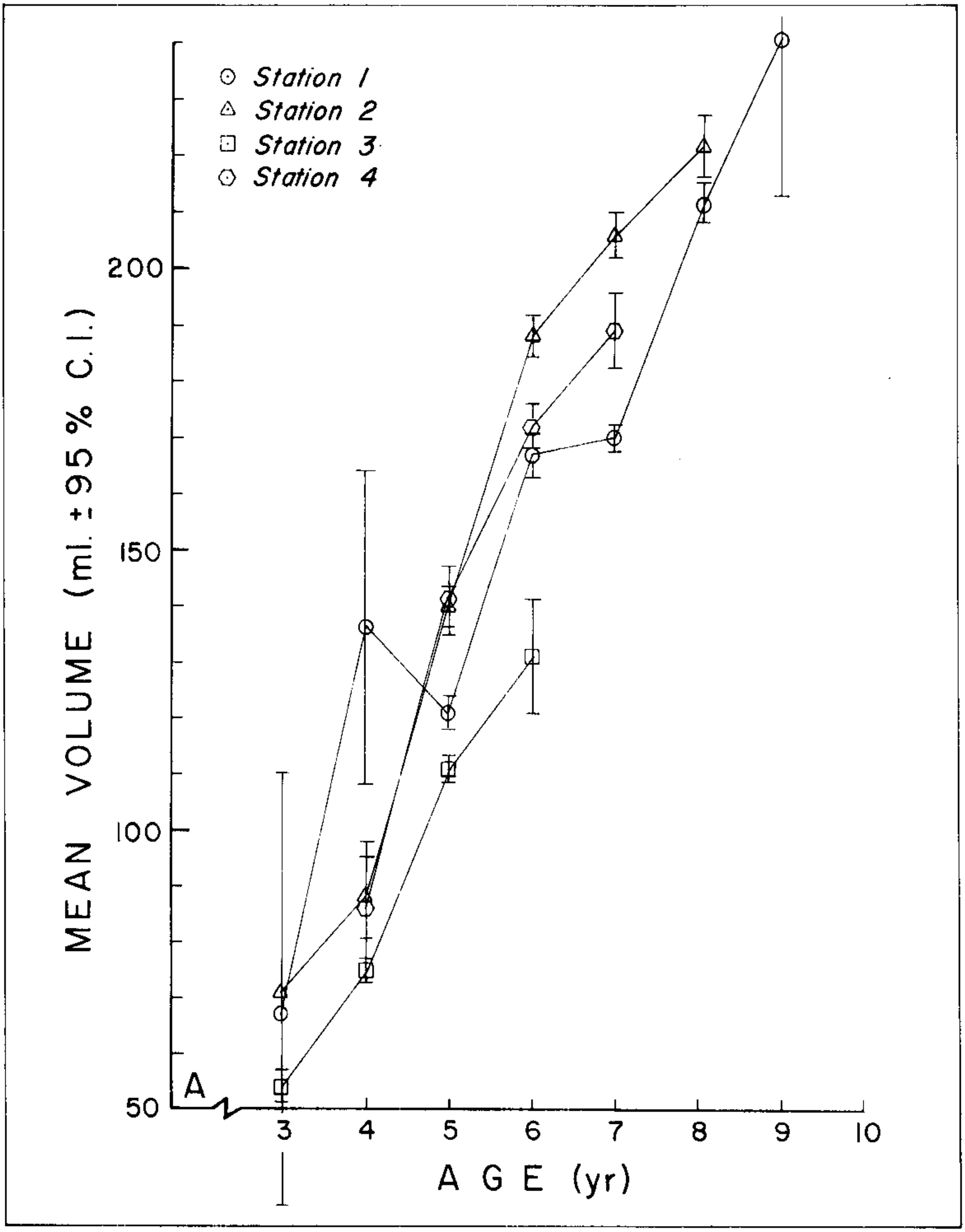

Figure III.A.4.-3. Absolute volumetric growth of *Tresus capax* from four sampling stations in Yaquina Bay, Oregon. A. Data from four sampling stations. B. Combined data for subtidal and intertidal *Tresus capax*.

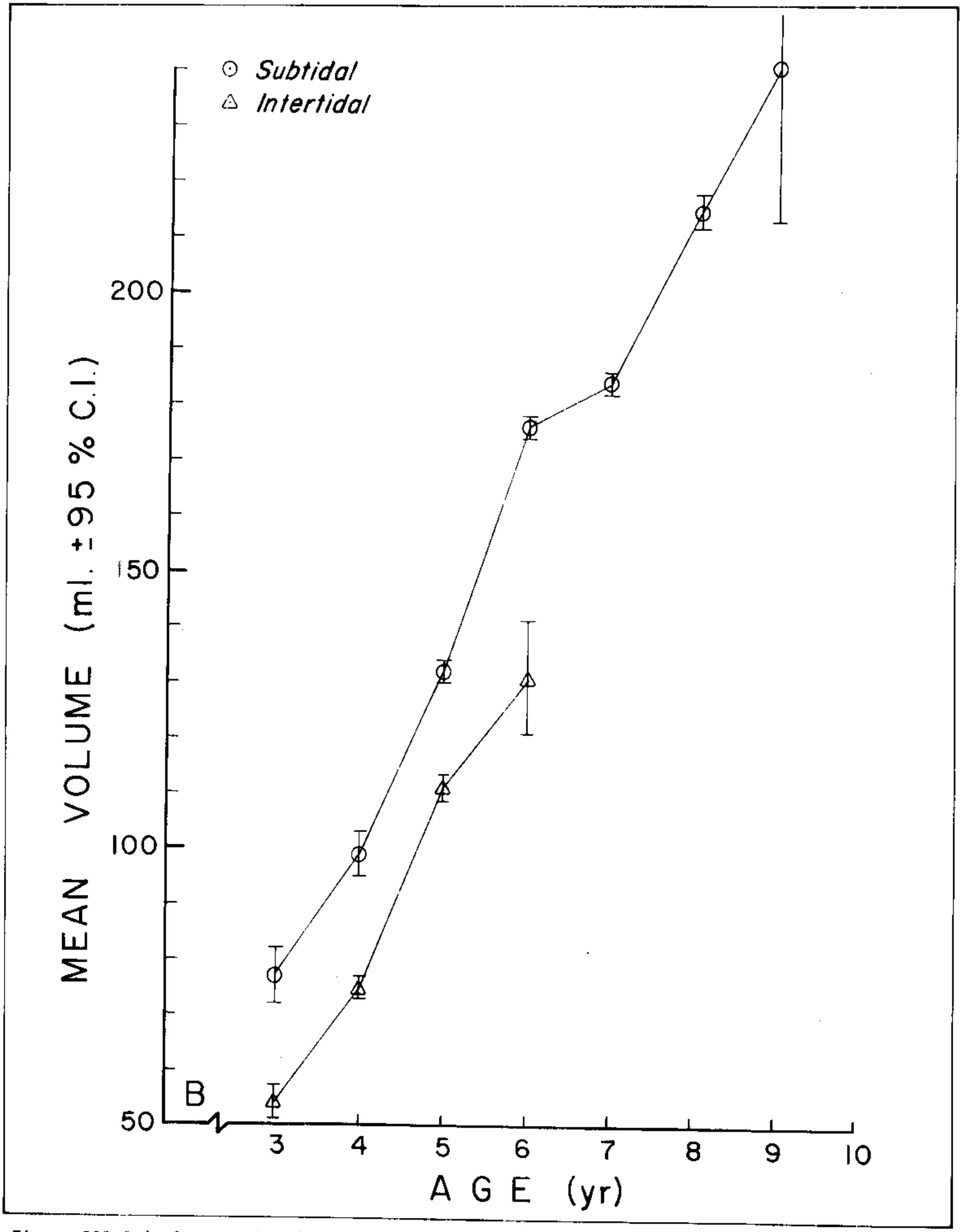

Figure III.A.4.-3. continued.

	AGE (yr.) 3	4	5	6	7	8	9
STATION NO. I							
$\bar{V}$	67.2	136.2	121.6	166.9	170.4	211.9	241.6
N	1	2	13	11	23	15	2
s	0	3.11	5.94	5.67	5.77	6.30	3.06
CI (95%)		27.94	3.59	3.81	2.50	3.49	27.49
STATION NO. II							
$\bar{V}$	70.8	87.7	139.8	188.5	205.9	221.8	
N	2	3	14	14	13	7	
s	4.35	2.91	6.28	6.44	6.48	5.80	
CI (95%)	39.11	7.23	3.63	3.72	3.92	5.36	
STATION NO. III							
$\bar{V}$	54.4	75.0	110.9	130.8			
N	11	15	17	3			
s	3.97	3.91	4.90	4.16			
CI (95%)	2.67	2.17	2.52	10.34			
STATION NO. IV							
$\bar{V}$		86.2	140.8	171.8	188.8		
N		3	6	14	4		
s		4.74	6.38	6.54	4.69		
CI (95%)		11.78	6.70	3.78	6.51		
STATION NOS. I, II, IV							
$\bar{V}$	69.6	99.3	132.8	176.4	183.8	215.0	241.6
N	3	8	33	39	40	22	2
s	2.05	5.14	6.17	6.30	6.20	6.11	3.05
CI (95%)	5.17	4.30	2.19	2.04	1.98	2.71	27.49

Table III.A.4.-2. Mean volumes of *Tresus capax* of different ages from four sampling sites in Yaquina Bay, Oregon.

Relationship y/x	Clam Population	Log a(±95% C.I.)	b(±95% C.I.)	N	R^2
Height / Length	Subtidal	-0.409(0.010)	1.149(0.006)	653	0.9957
	Intertidal	-0.300(0.058)	1.092(0.030)	212	0.9608
	Total	-0.406(0.008)	1.147(0.005)	865	0.9960
Width / Length	Subtidal	-0.716(0.094)	1.212(0.007)	603	0.9941
	Intertidal	-0.563(0.012)	1.137(0.048)	188	0.8968
	Total	-0.722(0.011)	1.216(0.006)	791	0.9939
Volume / Length	Subtidal	-3.488(0.329)	2.766(0.159)	146	0.8763
	Intertidal	-3.406(0.774)	2.711(0.396)	47	0.8085
	Total	-3.714(0.240)	2.874(0.117)	193	0.9165
Total Wet Weight / Length	Subtidal	-2.972(0.545)	2.586(0.264)	162	0.6958
	Intertidal	-3.922(0.654)	3.014(0.106)	47	0.8773
	Ripe	-3.689(0.668)	2.944(0.327)	57	0.8629
	Inactive	-4.319(1.300)	3.208(0.570)	33	0.8050
Wet Body Weight / Length	Subtidal	-2.648(0.618)	2.307(0.300)	162	0.5881
	Intertidal	-3.432(0.891)	2.662(0.456)	48	0.7503
	Ripe	-3.176(1.060)	2.581(0.390)	58	0.7590
	Inactive	-3.615(0.818)	2.753(0.399)	33	0.8644
Dry Body Weight / Length	Subtidal	-4.077(0.890)	2.627(0.432)	162	0.4691
	Intertidal	-3.683(1.021)	2.386(0.520)	48	0.6492
	Ripe	-4.670(1.302)	2.938(0.478)	59	0.7301
	Inactive	-4.903(1.106)	3.001(0.540)	34	0.8010
	Total	-4.691(0.550)	2.919(0.270)	211	0.6830
Wet Body Weight / Total Wet Weight	Subtidal	-0.192(0.097)	0.974(0.041)	162	0.9258
	Intertidal	-0.076(0.107)	0.937(0.054)	48	0.9639
	Ripe	-0.021(0.111)	0.911(0.048)	59	0.9623
	Inactive	0.012(0.138)	0.888(0.060)	33	0.9604
	Subtidal & Ripe	0.027(0.183)	0.891(0.078)	53	0.9114
	Subtidal & Inactive	-0.074(0.227)	0.924(0.097)	25	0.9061
Dry Body Weight / Wet Body Weight	Subtidal	-1.143(0.156)	1.177(0.074)	162	0.8601
	Intertidal	-0.655(0.147)	0.923(0.082)	48	0.9178
	Ripe	-1.002(0.190)	1.114(0.091)	59	0.9141
	Inactive	-0.979(0.136)	1.100(0.066)	33	0.9738
	Subtidal & Ripe	-1.547(0.303)	1.364(0.117)	53	0.8953
	Subtidal & Inactive	-0.878(0.376)	1.055(0.103)	25	0.9511

Table III.A.4.-3. Allometric growth coefficients for various morphological relationships of populations of *Tresus capax*.

Relationship y/x	Clam Population	Log a(±95% C.I.)	b(±95% C.I.)	N	R^2
Wet Body Weight / Dry Body Weight	Subtidal	1.130(0.061)	0.731(0.045)	162	0.8601
	Intertidal	0.798(0.089)	0.994(0.088)	48	0.9178
	Ripe	1.002(0.090)	0.821(0.067)	59	0.9141
	Inactive	0.921(0.067)	0.885(0.052)	33	0.9738
Shell Weight / Length	Subtidal	-4.038(0.491)	2.930(0.238)	162	0.7839
	Intertidal	-5.496(0.427)	3.594(0.218)	48	0.9598
	Total	-5.609(0.350)	3.683(0.172)	210	0.8947
Shell Weight / Dry Body Weight	Subtidal	1.120(0.223)	0.660(0.086)	163	0.5857
	Intertidal	0.554(0.116)	1.001(0.216)	48	0.6532
	Ripe	0.641(0.232)	0.967(0.126)	59	0.8061
	Inactive	0.628(0.170)	1.020(0.203)	34	0.7670

Table III.A.4.-3. continued.

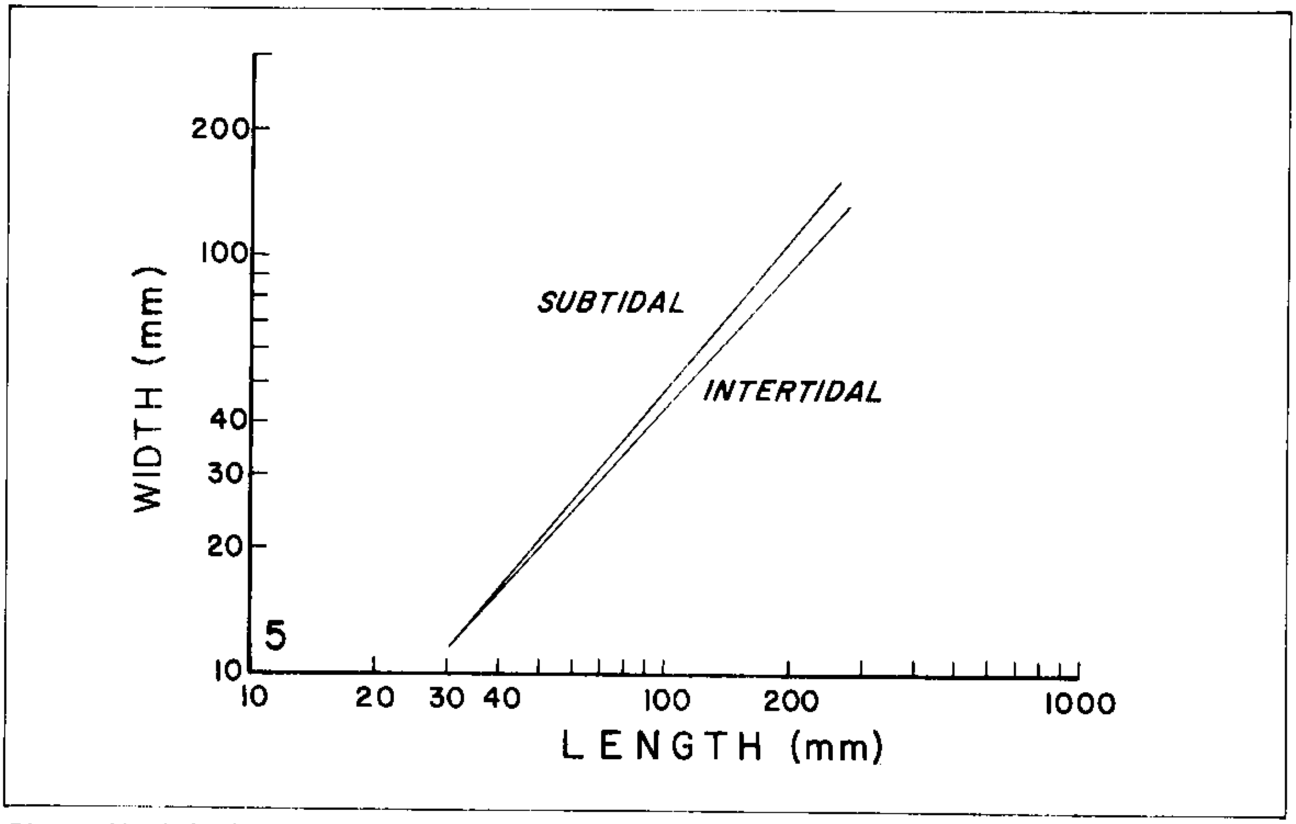

Figure III.A.4.-4. The fitted allometric curves for the width/length relationships for intertidal and subtidal *Tresus capax*.

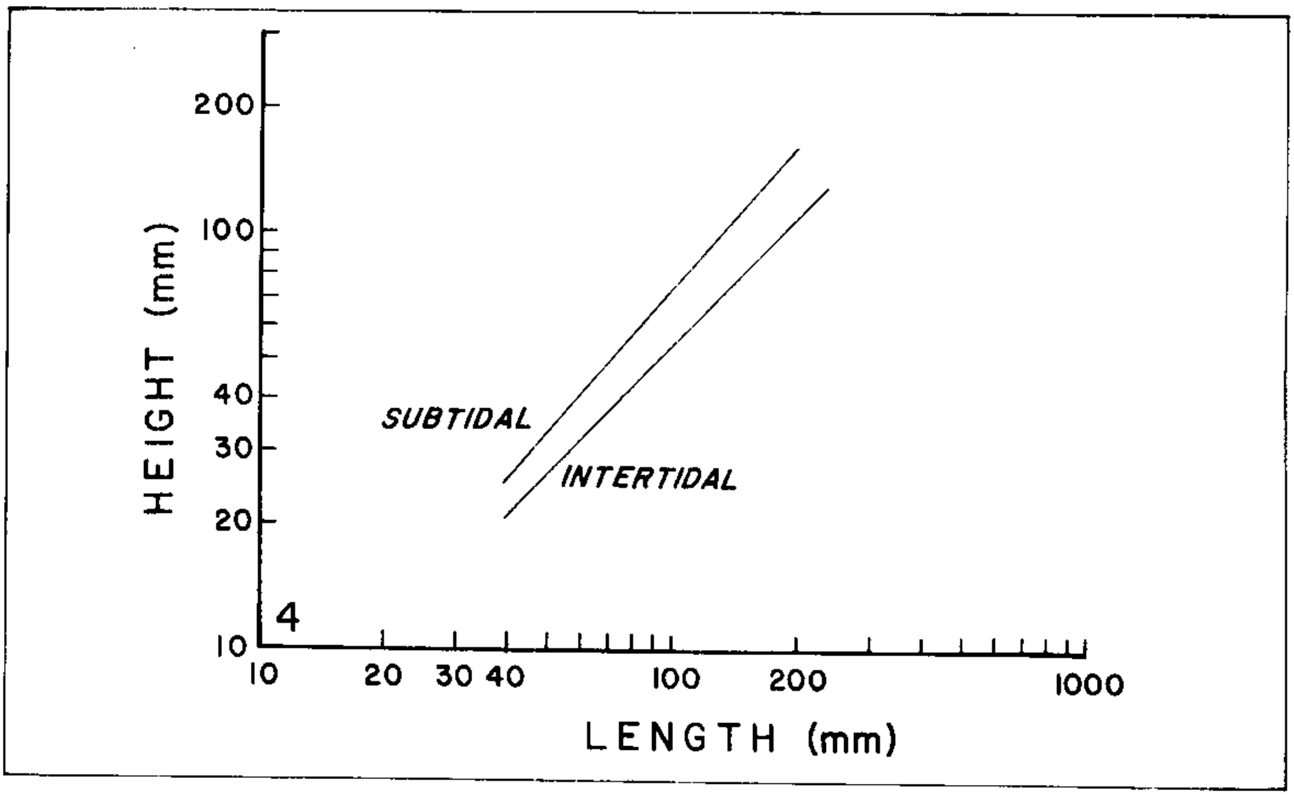

Figure III.A.4.-5. The fitted allometric curves for the height/length relationships for intertidal and subtidal *Tresus capax*.

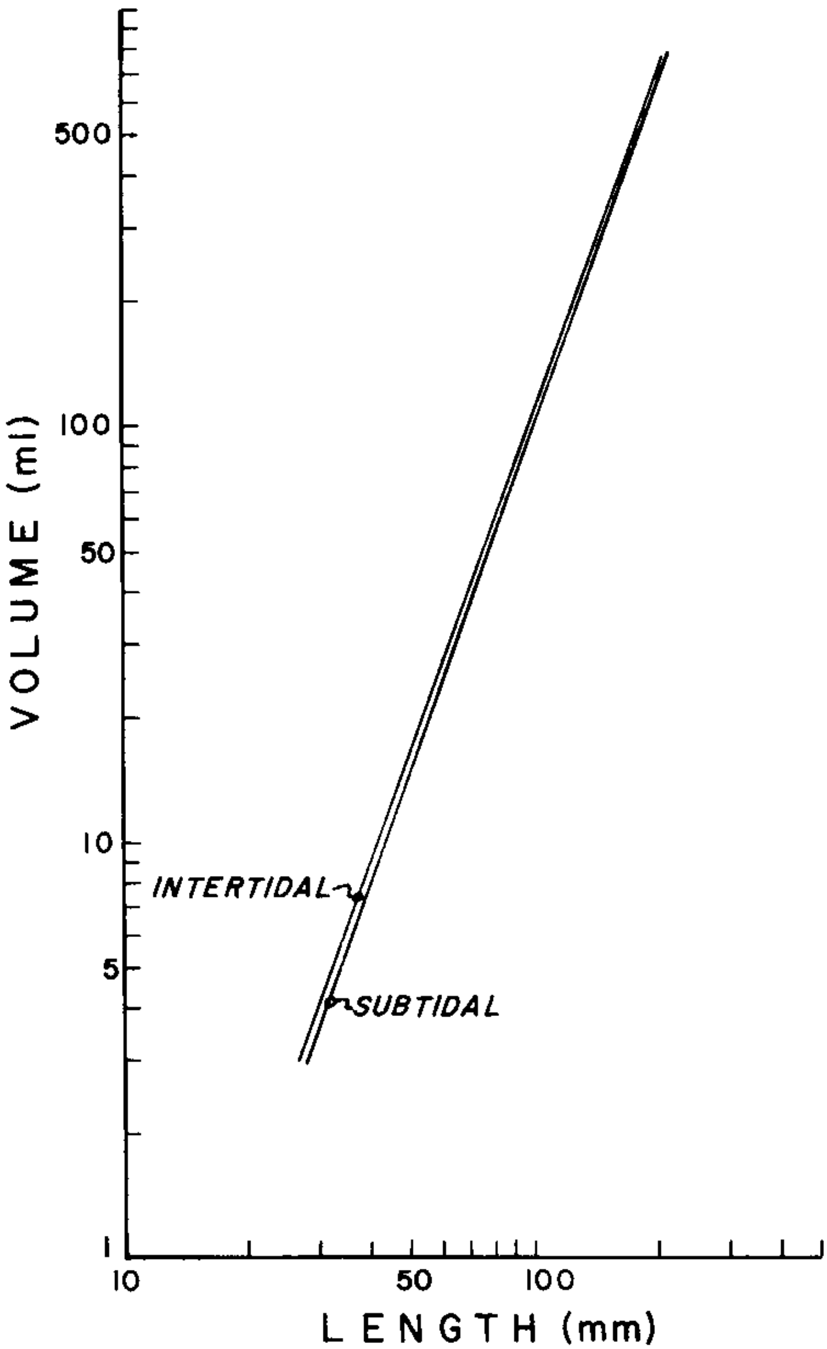

Figure III.A.4.-6. The fitted allometric curves for the volume/length relationships for intertidal and subtidal *Tresus capax*.

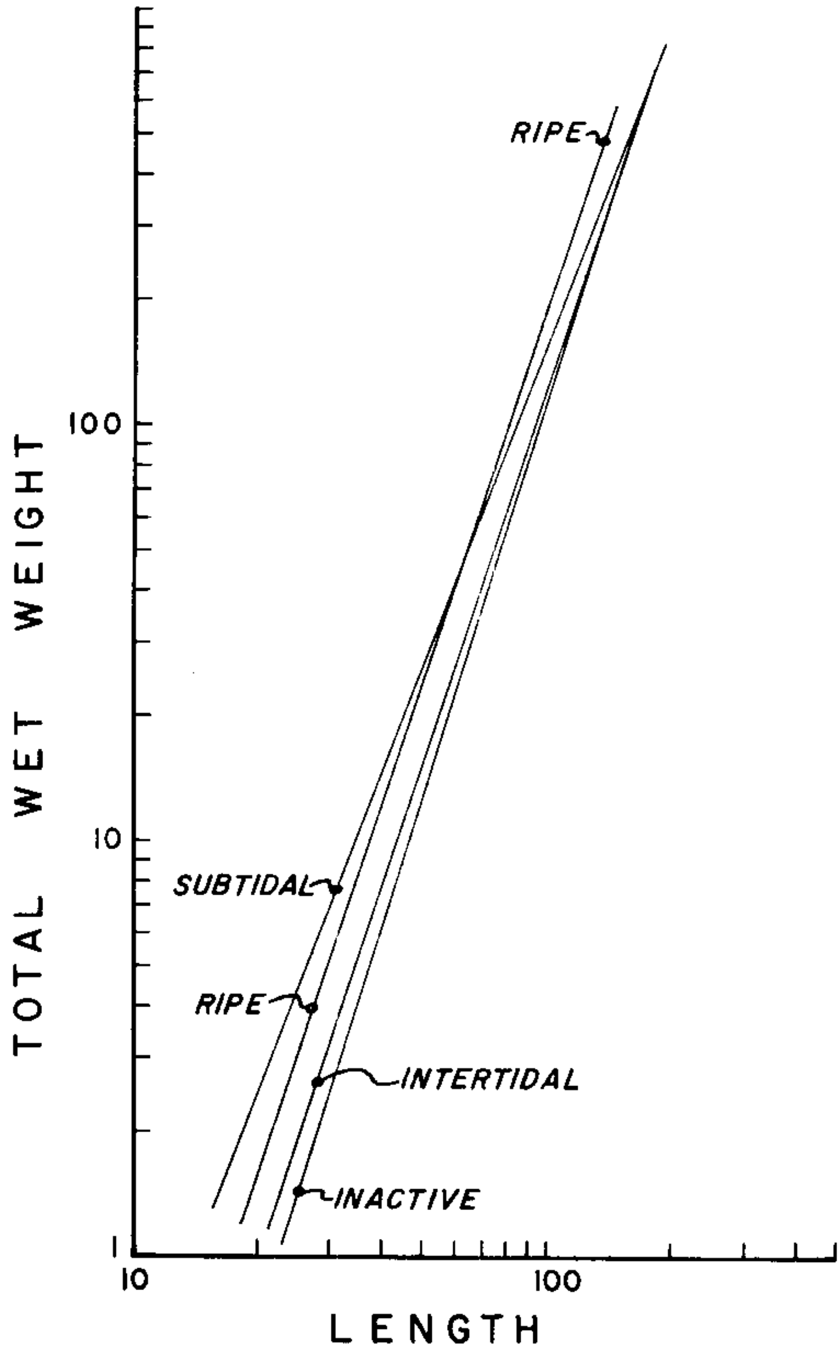

Figure III.A.4.-7. The fitted allometric curves for the total wet weight/length relationships for intertidal, subtidal, ripe and inactive *Tresus capax*.

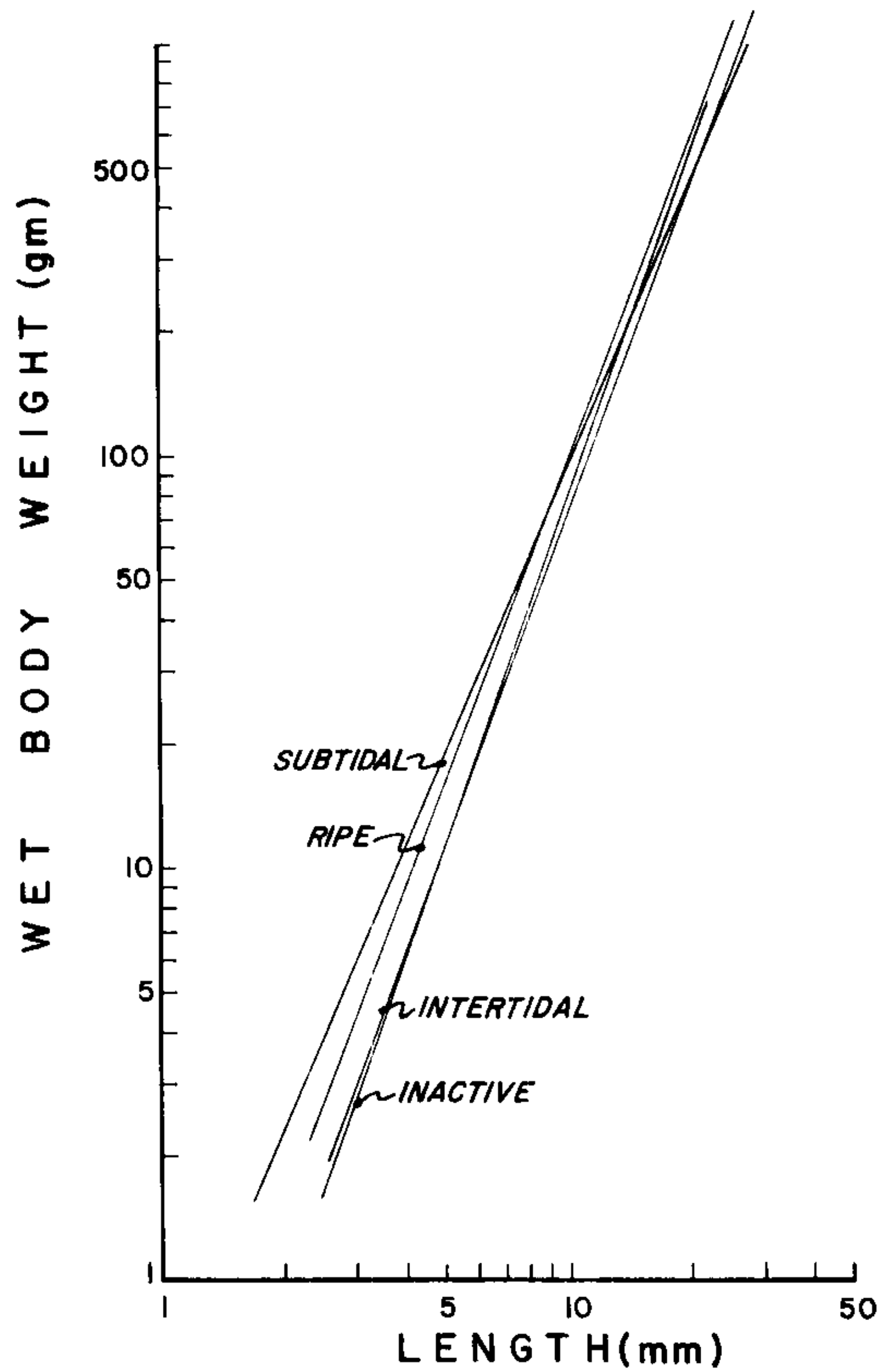

Figure III.A.4.-8. The fitted allometric curves for the wet body weight/length relationships for intertidal, subtidal, ripe and inactive *Tresus capax*.

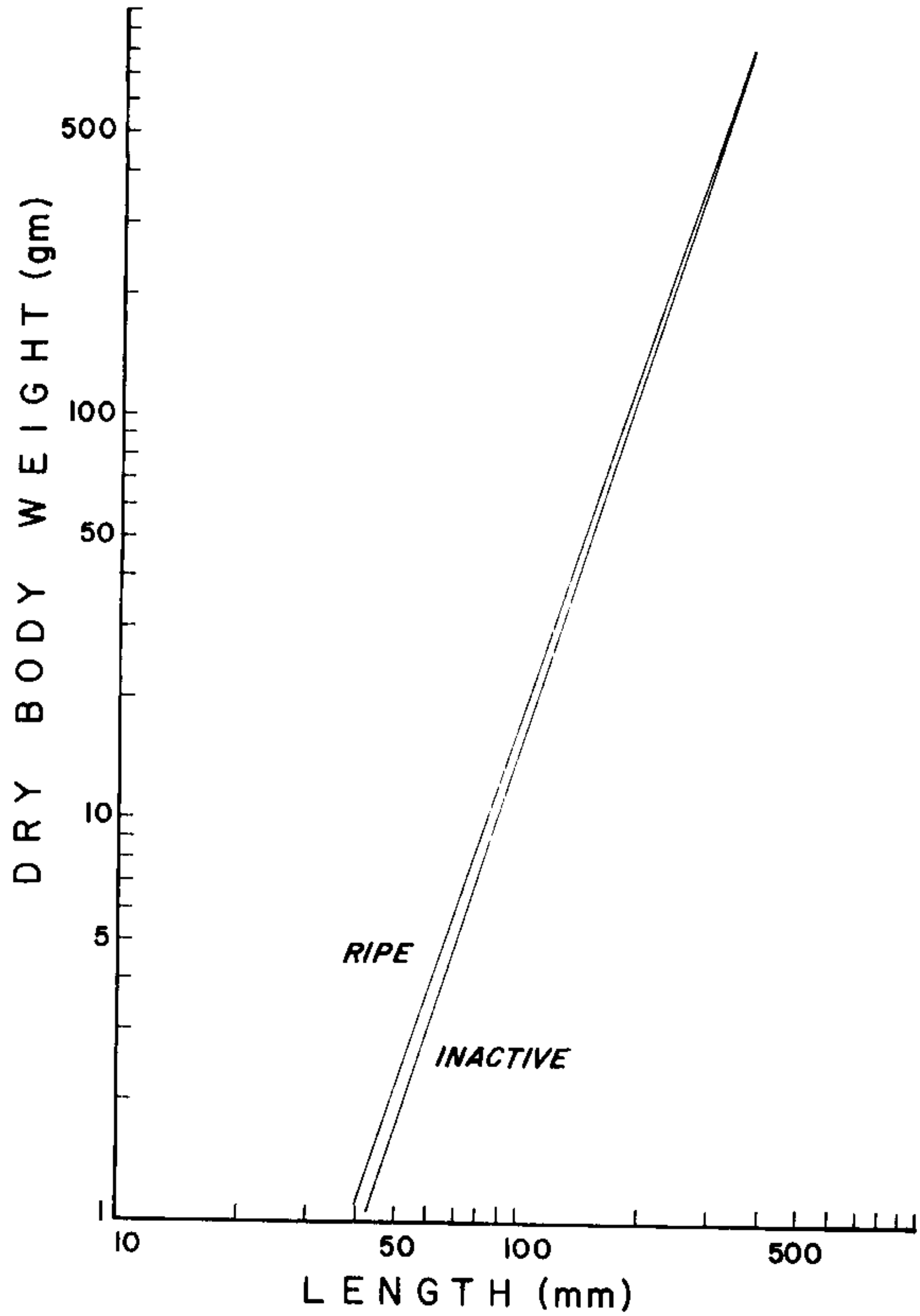

Figure III.A.4.-9. The fitted allometric curves for the dry body weight/length relationships for ripe and inactive *Tresus capax*.

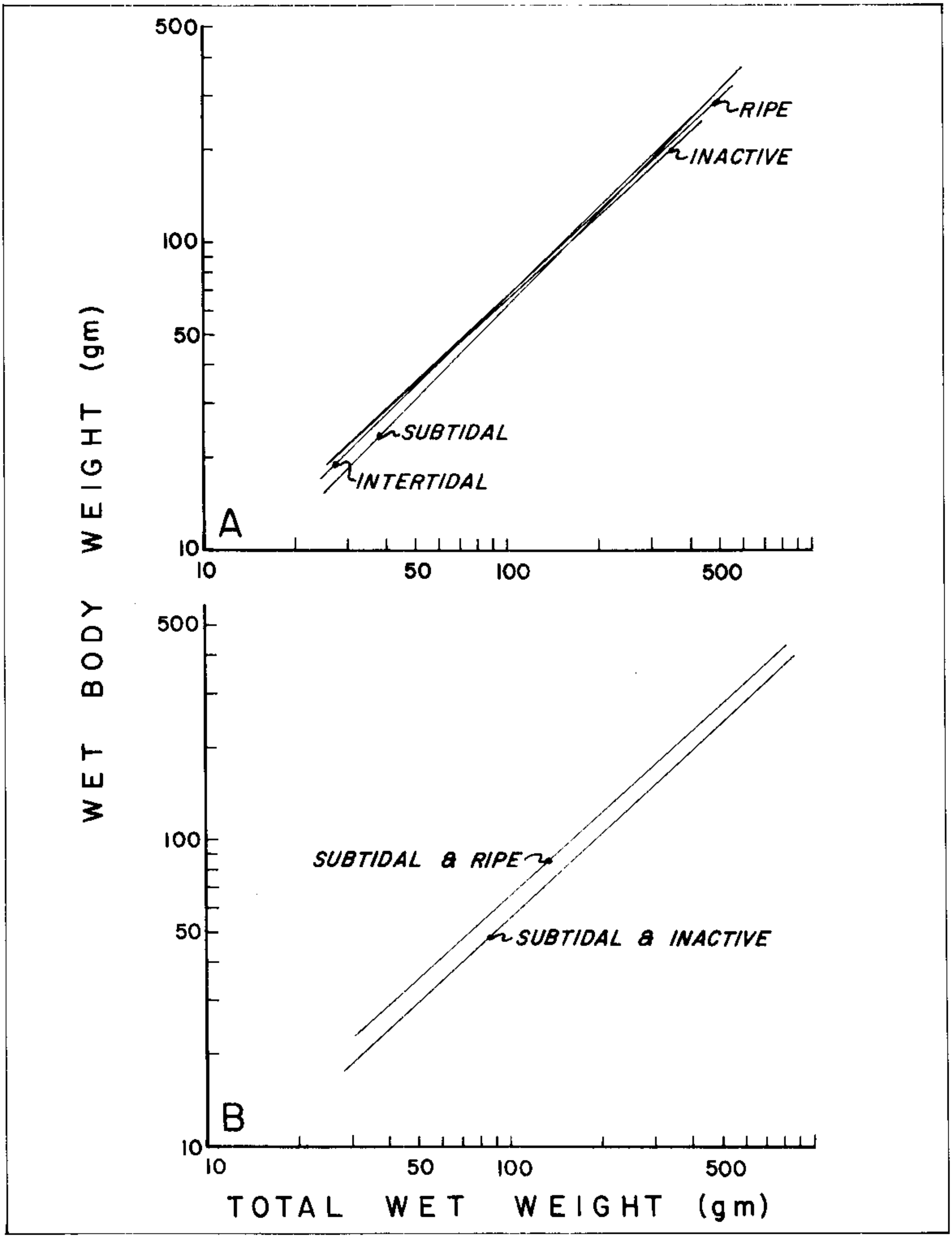

Figure III.A.4.-10. The fitted allometric curves for the wet body weight/ total wet weight relationships for intertidal, subtidal, ripe and inactive *Tresus capax*. A. Curves from intertidal, subtidal, ripe and inactive populations of *T. capax*. B. Curves from subtidal ripe and subtidal inactive *T. capax*.

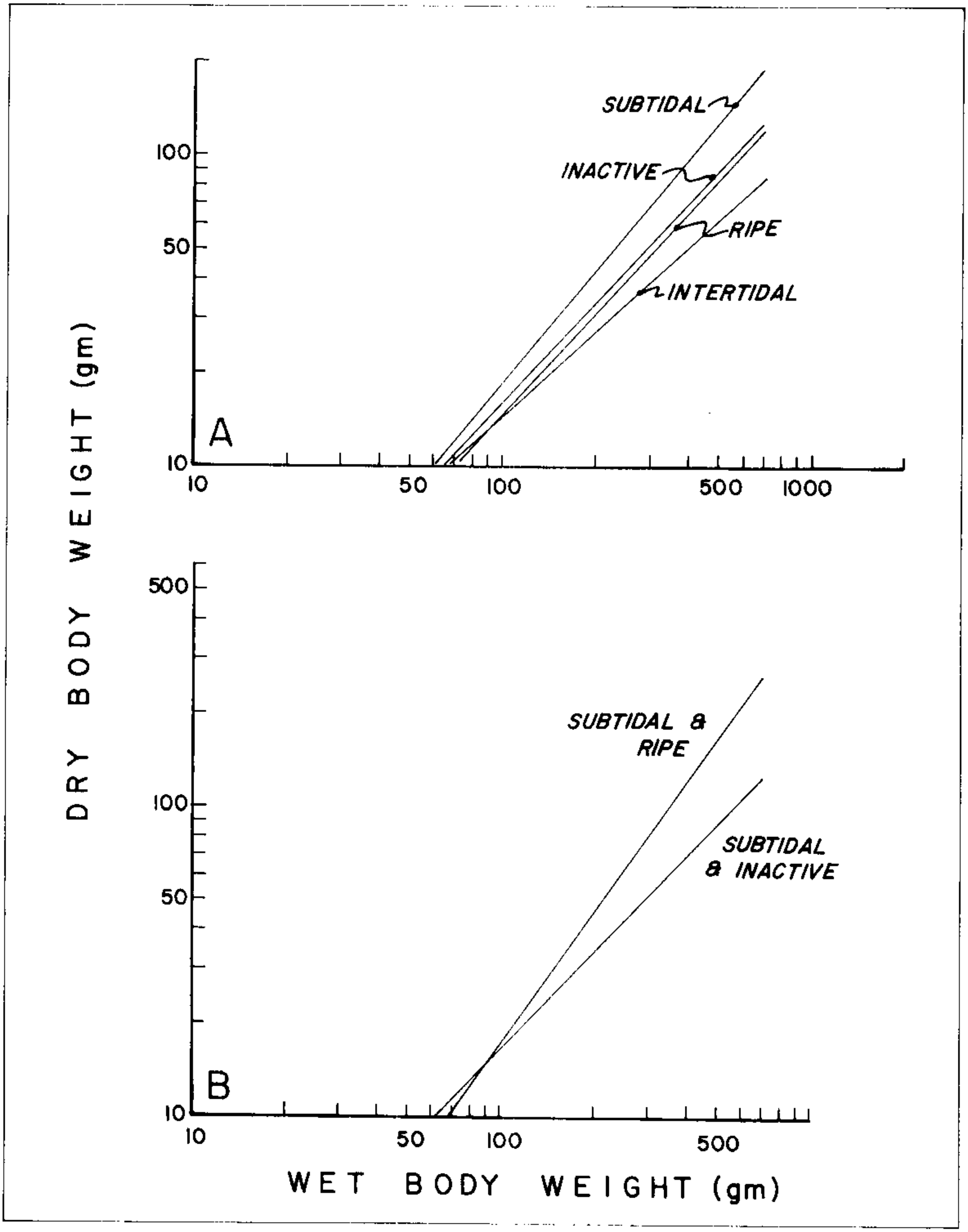

Figure III.A.4.-11. The fitted allometric curves for the dry body/weight/wet body weight relationships for subtidal, intertidal, ripe and inactive *Tresus capax*.
A. Curves for subtidal, intertidal, ripe and inactive *T. capax*.
B. Curves for subtidal ripe and subtidal inactive *T. capax*.

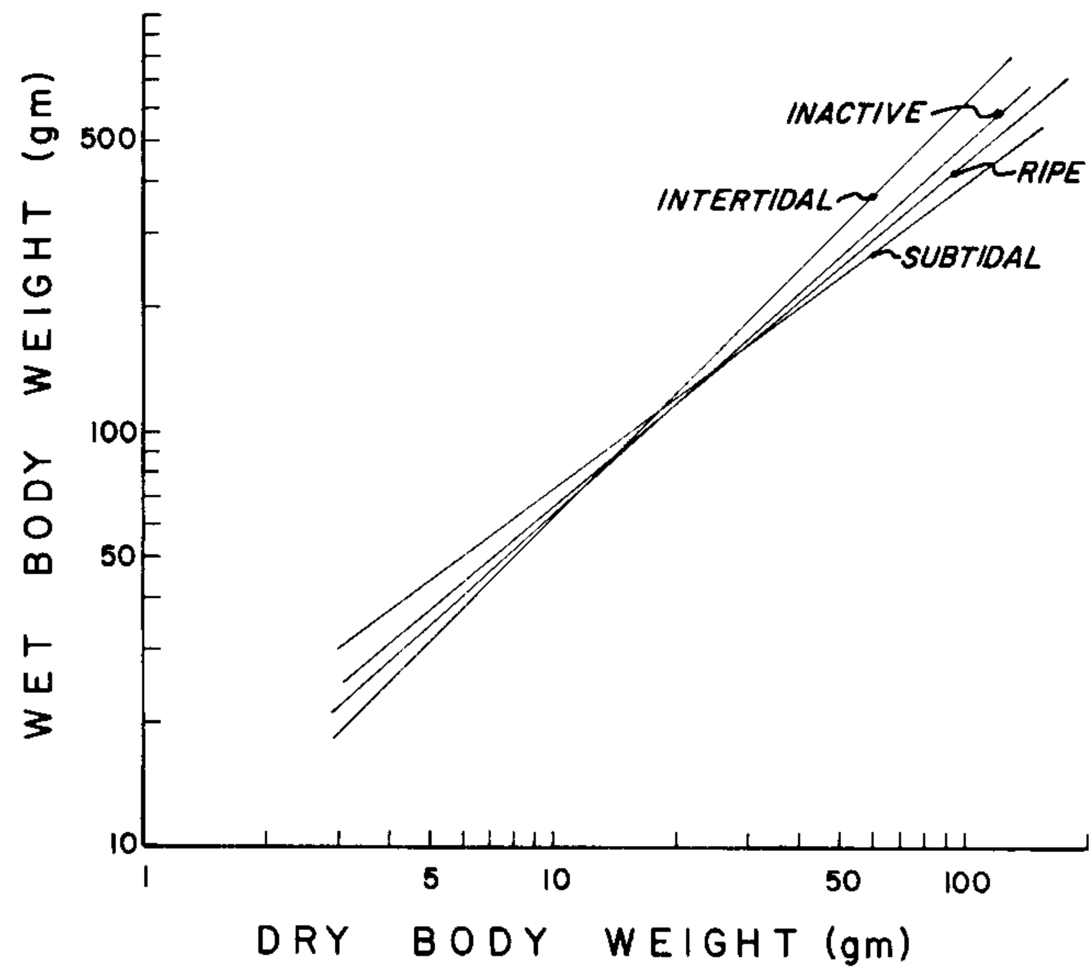

Figure III.A.4.-12. The fitted allometric curves for the wet body weight/dry body weight relationships for intertidal, subtidal, ripe and inactive *Tresus capax*.

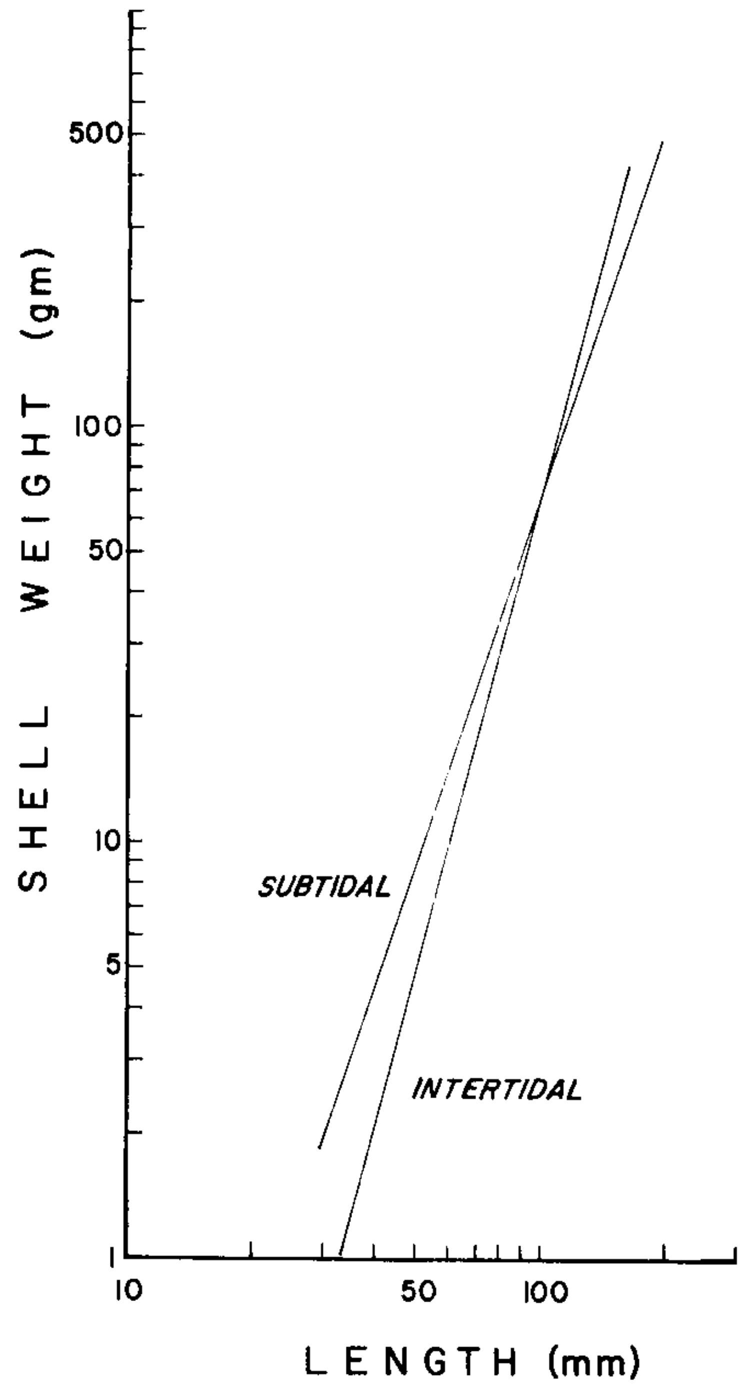

Figure III.A.4.-13. The fitted allometric curves for the shell weight/length relationships for intertidal and subtidal *Tresus capax*.

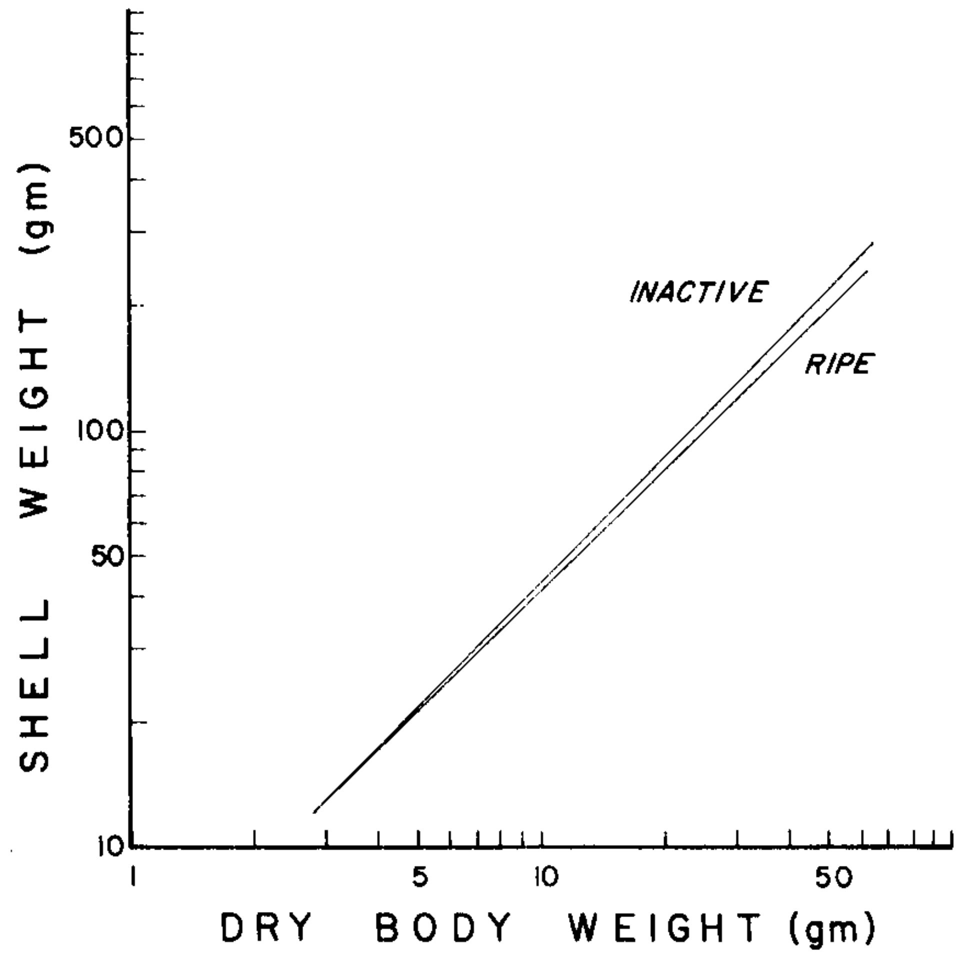

Figure III.A.4.-14. The fitted allometric curves for the shell weight/dry body weight relationships for the ripe and inactive *Tresus capax*.

growth. Nonetheless, the ratios of wet body weight/length, dry body weight/length and wet body weight/total wet weight were similar among all groups of clams.

The relationships of dry body weight/wet body weight and its reciprocal indicate the percent of moisture in the body tissues:

- 82.5% in subtidal clams (N = 163),
- 84.0% in intertidal clams (N = 48),
- 82.1% in ripe clams (N = 59),
- 83.1% in inactive clams (N = 33).

The percent of moisture appeared to be significantly higher with a faster rate of increase in the intertidal clams than in the subtidal clams. The significance of the intersection of the lines for the ripe and inactive clams (Figure III.A.4.-11) is discussed below.

Shell weight/length was slightly higher, for the most part, in subtidal clams than in intertidal clams. The rate of increase was faster in intertidal clams, so that the growth of the shell eventually overtook that of the subtidal clams.

Due to the low R^2 values, the relationship of shell weight/dry body weight appeared to have little correlation relative to tide height. There was a better correlation relative to reproductive phase, although no significant differences between the inactive and ripe clams were indicated.

Reproductive Cycle

Calendars of the five reproductive phases for the clams from the four collection sites are shown in Figures III.A.4.-15A-D. Because the histological characteristics of the phases of *Tresus capax* from Yaquina Bay were essentially the same as those of *T. capax* from Humboldt Bay, California, reported previously (Machell and DeMartini, 1971), they will not be redescribed here. The sex ratio was 1:1 for the phases in which sex was discernable.

The statistical mean day (MD) for each reproductive phase at each station is graphed, with its 95% confidence interval, in Figure III.A.4.-16. Generally, the MD's of one phase were distinct from the MD's of another phase; however, an overlap of confidence intervals was observed between the partially spawned and spent phases at stations 2, 3 and 4.

Within each phase, significant differences among the MD's for clams from each station were calculated and are shown in Table III.A.4.-4.

The statistical variations among MD's observed for the inactive, active, and spent phases appeared to be random, following no pattern from phase to phase or from station to station.

The X^2 test for independence of distributions of frequencies of clams throughout a reproductive phase also resulted in differences among stations except during the ripe and partially spawned phases (Table III.A.4.-4). The variations indicated by this test also appeared to be random. Results of the X^2 tests did not always agree with those of the t-tests for MD differences, there being fewer differences between distributions of numbers of clams of a particular phase than between MD's calculated at the four stations. The majority of this disparity can be explained by the difference in length of time interval used in the tests: one day for the t-tests and two weeks in the X^2 tests.

The onset of the inactive or undifferentiated phase was rapid, first beginning in May and lasting through November. All gaper clams from station 1 had inactive gonads in August; from stations 2 and 3, in July; and from station 4 in June and July.

The active phase, a period of spermatogenesis in the male and oocyte enlargement in the female, was first recorded in July and lasted, at one site, into March of the following year. Most or all of the clams collected were in this phase in September through November.

Ripe gonads, characterized by more detached than attached oocytes in the ovaries, or a majority of radially arranged spermatozoa in the testes, were first observed in October, peaked in occurrence in December-January, and continued into April (Figure III.A.4.-15C). Of the five phases, this one continued for the longest period of time. No significant differences in the ripe phase were found among the four stations. Oocytes of this phase had a mean diameter of 49 μm, and a mean nucleus diameter of 27 μm (Table III.A.4.-5).

Gonads partially emptied of ripe gametes and with disorganized follicular tissue, indicating spawning (termed "partially spawned"), were found in most samples from February through May or June. Peak occurrence was observed in April for stations 1 and 2, March for station 3, and February for station 4. Despite these observed differences, no statistically significant differences were found in the partially spawned phase at the four stations. Oocytes from

INACTIVE PHASE

STATION NO.	1	2	3	4
1	\	-	+	+
2	-	\	+	+
3	-	+	\	+
4	+	-	+	\

ACTIVE PHASE

STATION NO.	1	2	3	4
1	\	-	-	+
2	+	\	+	+
3	-	-	\	+
4	+	+	-	\

SPENT PHASE

STATION NO.	1	2	3	4
1	\	+	+	-
2	-	\	-	-
3	+	+	\	+
4	-	+	-	\

(No differences among ripe or partially spawned phases.)

* + = not significantly different at 95% probability level.

- = significantly different at 95% probability level.

** Top right portion of each table relates to X^2 tests between each station pair; bottom left portion relates to Students t-tests of MD differences.

Table III.A.4.-4. Comparison of the results* of the Student's t-test and X^2 tests** for differences between reproductive cycles of *Tresus capax* from the four sampling sites in Yaquina Bay, Oregon.

	Station #2 (subtidal)	Station #3 (intertidal)
Ripe Clams		
Oocyte Diameter	48.18 μm	48.84 μm
N	885	705
s	5.28	5.07
Nucleus Diameter	27.49 μm	27.05 μm
N	885	705
s	3.07	3.18
Partially Spawned Clams		
Oocyte Diameter	48.90 μm	49.68 μm
N	255	240
s	4.41	4.37
Nucleus Diameter	27.92 μm	27.86 μm
N	255	240
s	3.73	2.78

Table III.A.4.-5. Mean diameters of oocytes and oocyte nuclei from subtidal and intertidal gaper clams of different reproductive phases.

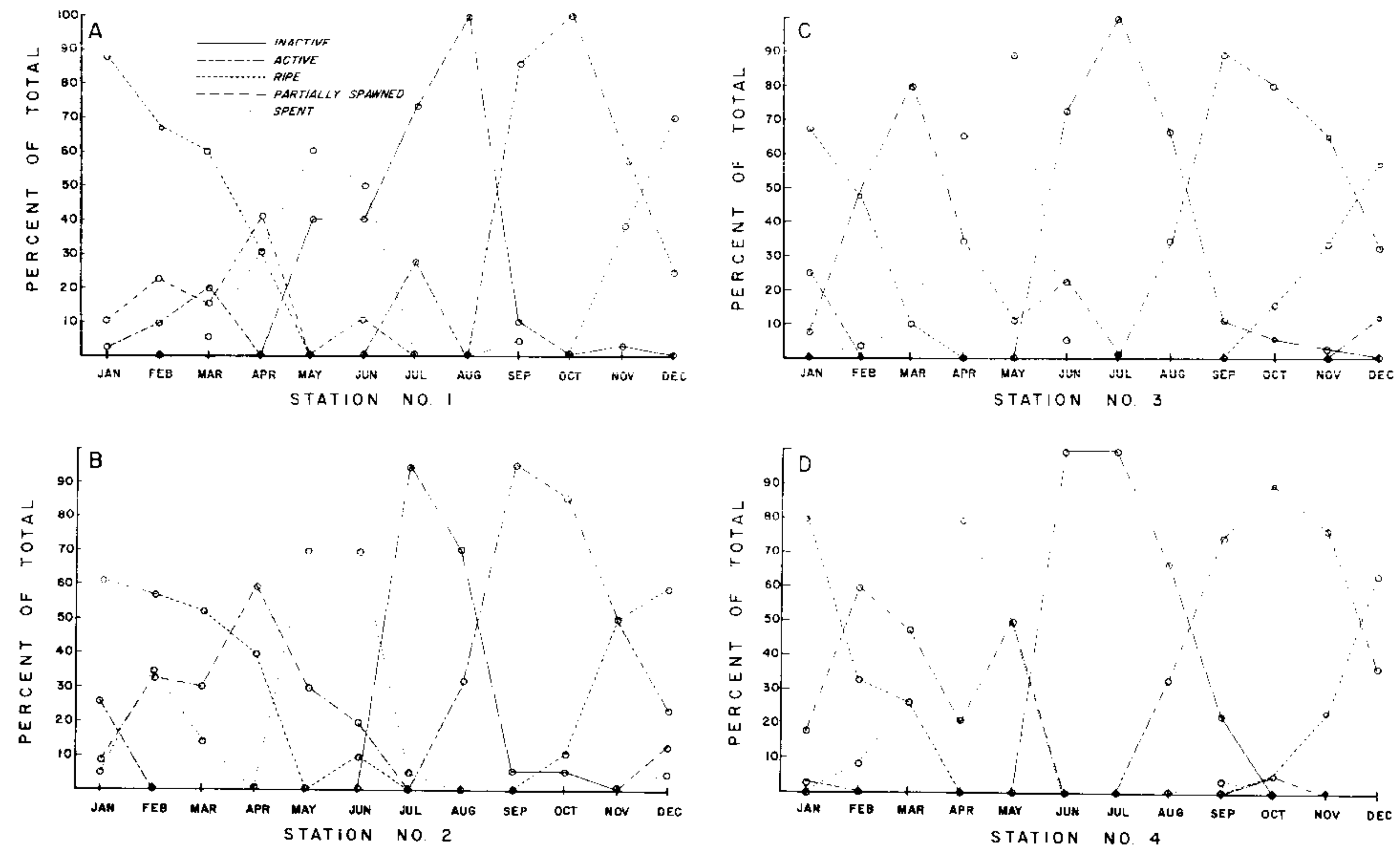

Figure III.A.4.-15. Calendar of the reproductive cycles of *Tresus capax* from the four sampling sites in Yaquina Bay, Oregon. A. Station 1. B. Station 2. C. Station 3. D. Station 4.

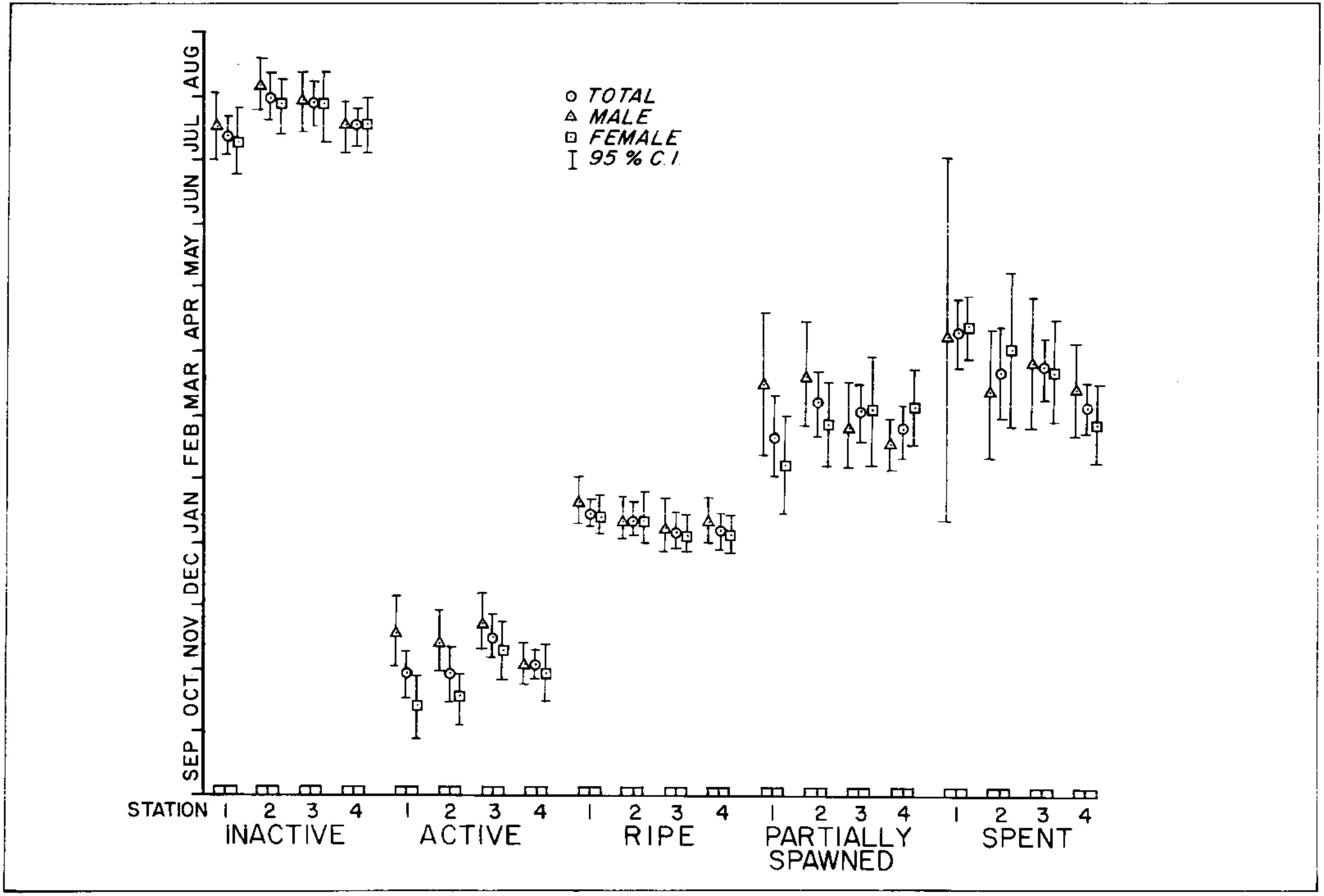

Figure III.A.4.-16. Statistical mean days (MD) of the reproductive phases of *Tresus capax* from the four sampling sites in Yaquina Bay, Oregon.

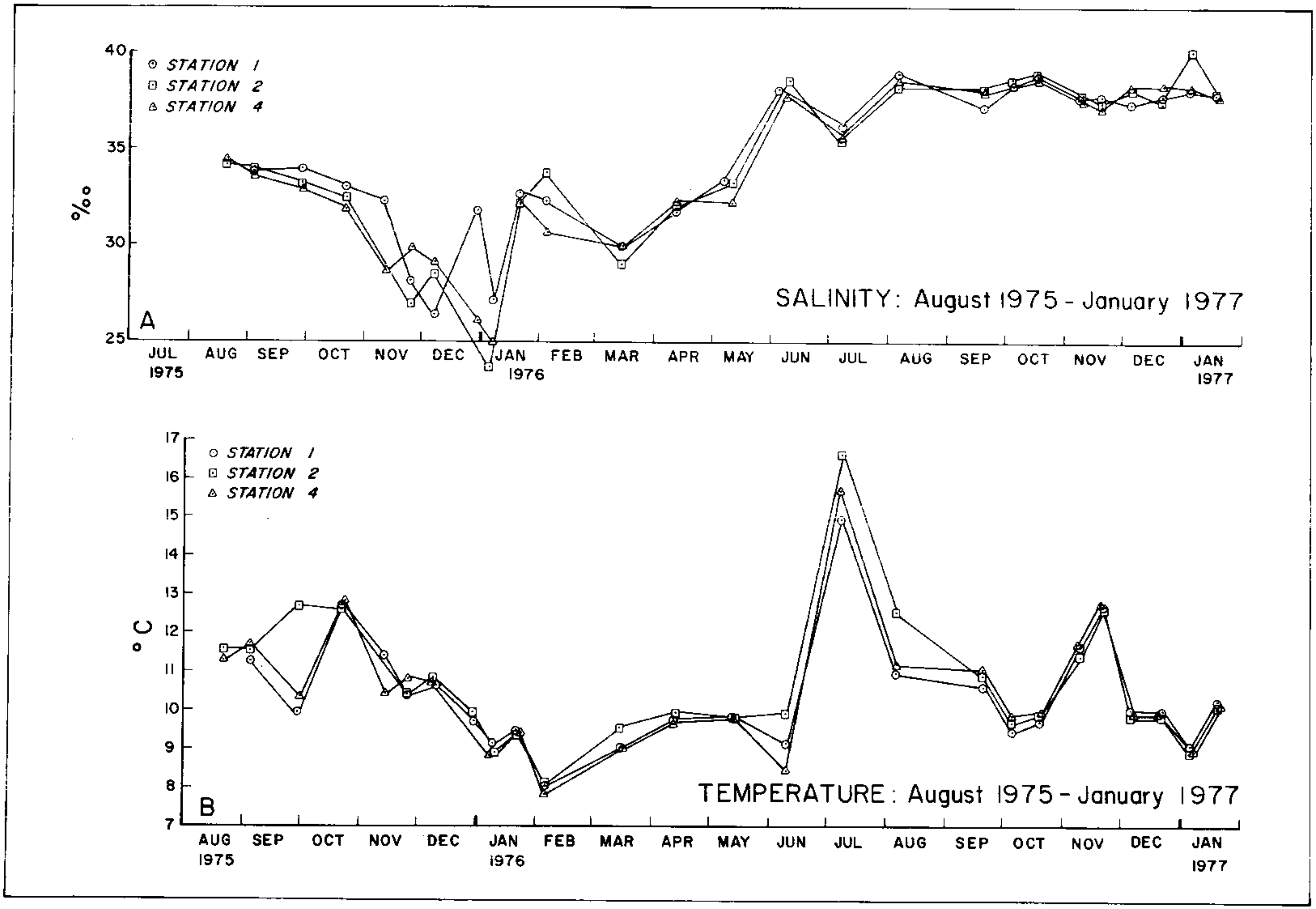

Figure III.A.4.-17. Salinity and temperature data from the four sampling sites in Yaquina Bay, Oregon, 1975-1977. A. Salinity. B. Temperature.

clams in this phase had a mean cell diameter of 49 μm, and mean nucleus diameter of 27 μm (Table III.A.4.-5).

Spent clams, those clams with gonads having thick-walled, shrunken alveoli containing debris or a few remaining gametes undergoing cytolysis, were first observed in February at station 2, later at the others, and were present through May or June. Most clams were in this phase of the reproductive cycle in May (stations 1 and 3), May-June (station 2), and April (station 4), after which a rapid drop in frequency of this stage occurred.

In almost every instance, the MD of reproductive phase for the female clams from a collection site preceded, although not always significantly, that of the male clams from that site, the greatest difference occurring during the active phase (Figure III.A.4.-16).

Temperature and Salinity

Temperature and salinity data recorded throughout this study at the three subtidal sampling stations are shown in Figure III.A.4.-17.

III.A.5. DISCUSSION

Growth

Growth rates of *Tresus capax* from Yaquina Bay, Oregon were comparable to those reported for intertidal gaper clams from British Columbia (Bourne and Smith, 1972a), although subtidal clams were not included in the latter study. Marriage (1954) reported that gaper clams from Yaquina Bay grew 127 mm/5 yr, a rate faster than was calculated in the present study. However Marriage's report could not be evaluated, as no data were included in his study.

Growth, growth rates, and their differences can be discussed in relation to:

1. the external factors of the environment;
2. the reproductive cycle;
3. intrinsic interrelationships of growth rates among the clam's component parts.

1) *Tresus capax* from intertidal areas of Yaquina Bay do not grow as rapidly as those clams from subtidal areas. Such differences in bivalve growth rates can be partially attributed to several environmental factors.

The oldest clams collected (10-12 yr) were from the subtidal sampling stations; intertidal clams collected reached a maximum age of 9 yr. In a study of the distribution of *T. capax* from intertidal areas of coastal Washington, Pearce (1965), observing that gaper clams from one area grew as much as 40 mm larger than gaper clams from another area, concluded that substrate type and composition somehow affected the linear shell growth and maximum size of the clams. If we assume that the larger size is correlated with an older age, it is possible that differences in substrate type, in addition to environmental stress, effect differences in maximum age reached by *T. capax* in Yaquina Bay. Swan (1952) also described differences in growth rate of *Mya arenaria* relative to substrate type. He found that clams in sand-dominated substrate grew faster (linearly) than did clams in a predominantly mud-gravel-shell substrate.

Kulm (1965) completed an extensive quantitative analysis of the substrate sediment in Yaquina Bay; the surveys made during the present study were more qualitative. The results from both studies as they relate to our sampling sites are shown in Table III.A.5.-1 below.

Unfortunately, neither set of results alone is completely reliable, due to the subjective nature of our sampling and to the time elapsed since the Kulm study; annual dredging of the bay and intervening construction could easily have effected changes in substrate type. Nonetheless, despite differences in the terminologies, the studies do show that the substrate of the subtidal stations is largely composed of sand; that of the intertidal station is of finer grain size.

Seed (1967) found that animal density had a marked effect on the shape of mussel shells, animals of dense populations being longer and narrower as opposed to rounder individuals of more sparse populations. Two conditions exist which suggest that the same may be true of *T. capax*:

a) subtidal clam populations were denser than intertidal populations;
b) subtidal clams, were consistently longer than intertidal clams.

Because shell shape may be influenced by density, we suggest that the measurement of volume be considered as a more reliable indicator of size than is length. In the case of *T. capax*, shell volume was strongly correlated to shell length, despite differences in shell shape. Subtidal clams were

Sample Site (Figure 2)	Substrate Type Kulm, 1965*	This study, 1975**
1 (subtidal)	fine & medium sand	sand-shell
2 (subtidal)	fine & medium sand	sand
3 (intertidal)	fine, medium sand & silty sand	mud
4 (subtidal)	fine & medium sand	sand-shell

* from categories of: fine sand, medium sand, silty sand, clayey sand, sandy silt, sand-silt-clay (see Wentworth, 1922).

** from categories of: bedrock, rock, gravel, sand, mud, shell, debris.

Table III.A.5.-1. Sediment types in Yaquina Bay, Oregon.

not only longer, but also had greater volume than similarly aged intertidal clams.

Bourne and Smith (1972a) studied the growth of two intertidal populations of *T. capax* and found differences between the absolute growth rates of the two populations. They showed that *T. capax* experienced spurts of growth in the summer and growth checks in the winter, coincident respectively with seasonal high and low temperatures, and suggested that water temperature and food availability were growth-controlling factors. There may be a similar relationship in this bay, which has a similar temperature regime to the one in British Columbia (Figure III.A.4.-17). Paul, Paul and Feder (1976) suggested that temperature also controlled the growth rate of littleneck clams in Alaska. Nosho and Chew (1972) found that substrate had little effect on settlement or growth of *Venerupis japonica* spat, temperature, salinity, food availability, and tide level being probable critical factors of growth.

Growth rates have been directly correlated to food availability and/or length of feeding periods by Smith (1928), Coe (1947), Coe and Fitch (1950), Fitch (1950), Stickney (1964), among others. Intertidal clams, as such, would experience limited periods of exposure to sea water and therefore of feeding, periods that are defined by the clams' height in the intertidal zone. In addition, intertidal clams in Yaquina Bay are subjected to various conditions of environmental stress caused by heavy freshwater run-off, freezing temperatures, and insolation that are otherwise not confronted or are not as extreme in the subtidal regions.

2) Periods of *Tresus capax* growth alternate with periods of gonad activity and spawning, a phenomenon not unusual in pelecypods. Reid (1969), in a study of the dietary demands of *T. capax* noticed an alternation of depletion and accumulation of glycogen, the major storage product, in the gonad coincident respectively with periods of food scarcity and abundance and with periods of gonad activity and quiescence. He suggested that, "the accumulation of gonadal lipid probably occurs at the expense of both gonadal glycogen and diverticular lipid," and that "the re-accumulation of glycogen lags about one month behind the re-availability of phytoplankton; the lag presumably reflects the increased energy requirements of the animals for growth." It is probable that stored and acquired energies in *T. capax* are being alternately devoted to growth and reproduction, each or both triggered by seasonal changes of the environment. Possible internal mechanisms of energy regulation were not investigated in this study.

Lammens (1967) reported that *Macoma balthica* growth started at the end of spawning, and conversely that gonad activity commenced when growth slowed. Coe (1947) and Fitch (1950) observed a reduction in growth rate of the Pismo clam coincident with gonad activity and spawning. The same was true of *Venus striatula* (Ansell, 1961). Fully developed gonads of the American oyster were reported to inhibit shell deposition (Galtsoff, 1964), possibly a mechanism for the regulation or distribution of energy.

3) It is not only likely that energy is budgeted between growth and reproduction, but that growth requires an energy budget of its own. Growth, whether linear or by

weight, is the result of a culmination of interactions of the relative growth of each individual's component parts. Mechanisms of the regulation of energy distribution were not included in the scope of this study, however.

Relative growth among the body parts appears to be dependent upon both the amount of exposure to sea water, i.e., the height in the littoral zone, and on the degree of gonal development. The results of the regression analyses indicated that intertidal clams grew heavier per unit length than did the subtidal clams. Clam weight, however, can be broken down into component parts:

- Total Clam Wet Weight
  - Wet Body Weight
    - Dry Body Weight
    - Water
  - Shell Weight

It was also shown that, of the wet body weight, intertidal clams had a higher moisture content than did the subtidal clams. Dame (1972), in a similar comparative study on oysters, suggested that the higher retention of water in the intertidal animals resulted from a physiological adaptation to the intertidal environment. In addition, intertidal clam shells, although not as heavy as subtidal clam shells, showed a significantly greater growth rate increase. Therefore, were these clams to live longer, it is possible that shell growth of the intertidal clams would eventually overtake that of the subtidal clams. Perhaps, because of limited exposure to sea water, intertidal clams have become more efficient in the absorption and metabolism of calcium from the water. Intraspecific studies of calcium uptake and shell secretion would be valuable to compare intertidal and subtidal clam shell growth.

Other studies comparing relative growth rates of subtidal and intertidal bivalves are few. Rao (1953) compared rates of shell growth among populations of inter- and subtidal mussels and concluded that shell secretion occurs at a rate directly proportional to submersion time, sea water being the calcium source. Subtidal mussels not only had heavier shells, but had more rapid secretion rates. A comparison between shell growth rates of inter- and subtidal oysters showed that subtidal animals had heavier shells, but there was no significant difference between rates of deposition (Dame, 1972).

It is apparent, then, that the higher total wet weight/length ratio of the intertidal clams is a result of:

a higher moisture content,
b higher rate of increase of wet body weight/length,
c higher rate of increase of shell weight/length.

It would be expected, as was shown, that ripe clams have a higher dry body weight/wet body weight ratio than do inactive clams; this is consistent with gonad development. Furthermore, the intersection of the regression lines for dry body weight/wet body weight of the ripe and inactive clams indicates the approximate size at which the clams become sexually mature. In this instance, the intersection fell at ~90 gm wet body weight which corresponded to ~80 mm length. Bourne and Smith (1972a) reported that gaper clams from British Columbia of ~70 mm had sexually differentiated gonads. It is possible that latitude-related environmental conditions such as temperature, photoperiod, and tidal regime influence the size at which sexual maturity occurs (see also Reproductive Cycle below). Histological studies of juvenile and young adult gaper clams are necessary before such a generalization can be made.

The reason for the higher tissue content in subtidal clams is not entirely clear. It is, of course, a function of water retention and could be related to feeding time. Brown, Seed and O'Connor (1976) studied three species of bivalves: *Cerastoderma edule*, *Mytilus edulis*, and *Modiolus modiolus*, the latter being the only subtidal species. In this study it was found that the two intertidal species had heavier shells and faster rates of shell growth than did the subtidal species. The authors suggested that when "moving from an intertidal to a subtidal position there appeared to be a progressive emphasis on tissue rather than on shell growth," and that the intertidal species tend to be more unstable in their habitat due to the instability of nutrients. The lower R^2 values for morphological relationships in the subtidal clams of our study would indicate the opposite is true. This phenomenon is not clearly understood.

Our results are not entirely inconsistent with these findings. However, gonad development was not considered as a factor of growth in the Brown et al. study. Their intertidal and subtidal species were collected and processed at two different seasons of the year; differences in body relationships including dry body weight could therefore be attributed to the stage of gonad development instead of to tidal height. Additional intraspecific comparisons are necessary to describe the relationship between tidal height and tissue growth.

Differences in growth between the subtidal and intertidal gaper clam populations may be attributed to environmental factors associated with the different habitats. Physiological adaptations of the two populations have possibly effected variations in their respective energy budgets reflected in differences in relative growth rates. Gonad development and the phase of the reproductive cycle also influence relative growth.

Reproductive Cycle

The results of the gonad examinations and plankton study confirmed that the *Tresus capax* from Yaquina Bay are late winter spawners and follow a reproductive cycle pattern similar to that of *T. capax* from Humboldt Bay, California (Machell and DeMartini, 1971). Gametogenesis was initiated in the late summer and continued through the autumn. Development of the gametes progressed until ripe gonads predominated; spawning began in the winter, peaking in March and April. A discrete inactive period was observed during the summer. The observation of gonads filled with deteriorating ripe gametes suggested that some clams may fail to spawn or may experience incomplete spawning.

The eastern Pacific range of *T. capax* extends from California to Alaska, yet few studies of its reproductive activity at different latitudes can be found in the literature. Machell and DeMartini (1971) studied the reproductive cycle of the gaper clam in Humboldt Bay, on the northern coast of California. Bourne and Smith (1972a) completed a similar study in southern British Columbia. Table III.A.5.-2 below shows the spawning seasons of the gaper clams at the three latitudes.

It appears that gaper clam populations of more southern latitudes have slightly earlier spawning periods than do more northern clams. In the above three instances, spawning occurred during the period of seasonal low temperatures. The Pismo clam (*Tivela stultorum*) also spawned slightly earlier at more southern latitudes of its range in California, but during the summer when temperatures were high (Coe and Fitch, 1950).

Lammens (1967), having indicated that ambient temperature, or its change, serves as a stimulus for spawning in *Macoma balthica*, suggested that the critical spawning temperature differs among species and among populations of the same species. Other examples of temperature-dependent spawning are in the literature. Caddy (1967) confirmed Lammens' finding that *M. balthica* spawned in the spring when temperatures begin to rise.

Latitude-related differences of reproductive cycles have been observed and may reflect those differences influenced by temperature. On the New England coast, Ropes and Stickney (1965) found that populations of *Mya arenaria* progressively north of Cape Cod had only slightly earlier spawning periods, while those south of Cape Cod had bimodal peaks of spawning. Porter (1974) studied *M. arenaria* in Washington and observed only one spawning peak in July-August, which occurred at approximately the same time as that of soft-shell clams of a similar latitude in eastern Canada, reported by Ropes and Stickney. A similar latitudinal difference in reproductive cycles was found with *Mercenaria mercenaria* also on the east coast. Loosanoff (1937a and b) reported a single summer spawning peak for the hard clams from Long Island Sound when the temperature reached its peak. Further south, in North Carolina, the hard clams were observed to have two spawning peaks between June and October when the temperature was above 20°C (Porter, 1964).

LOCATION	Jan	Feb	Mar	Apr	May	June
Seal Island, B.C. (49°12')			XXXXXXXXXXXXX			
Yaquina Bay, Or. (44°37')		XXXXXXXXXXXXX				
Humboldt Bay, Cal. (40°52')	XXXXXXXXXXXXX					

Table III.A.5.-2. Spawning seasons of *Tresus capax* at different latitudes on the west coast of North America.

Bimodal spawning for the gaper clams in more southern areas was not indicated by this study or by Machell and DeMartini (1971). However, *T. capax* is the only mactrid clam reported to spawn in the late winter/early spring. *Spisula solidissima* spawned at summer temperature peaks on the east coast (Ropes, 1968). Summer high temperatures also coincided with spawning of *Mulinia lateralis* (Calabrese, 1970). Both species experienced bimodal spawning.

Unlike what was found of *T. capax* in Humboldt Bay (Machell and DeMartini, 1971), female gaper clams in Yaquina Bay were histologically active before, ripe concurrently with, and spawned slightly before or after the male clams. Such observed differences in synchronousness between sexes may be: 1) actual differences in required development time between males and females, 2) an artifact of the subjectivity involved in the identification of the five histological phases of the reproductive cycle, or 3) an artifact of the statistics used.

Females of the Manila clam *Venerupis japonica* were also found to become active before those male clams (Holland and Chew, 1974). It was suggested that ripe females contain an enzyme that inhibits oogenesis until spawning, after which eggs immediately proliferate. Males, lacking such a mechanism, became active later. It is not known whether the gaper clams possess a similar mechanism.

Spawning of all clams was synchronous at the four sampling sites; no differences being indicated between the spawning period of sub- or intertidal populations. Multiple spawnings of individual clams were not conclusively indicated by our data. Nonetheless, the results of the plankton study of gaper clam larvae suggest a lunar periodicity of spawning in the population. Because collection of the adults did not necessarily coincide with the peaks of spawning during the period of maximum tidal range, indication of spawning periodicity was not discernable from the histological study. Spawning at maximum tidal amplitude would be of adaptive value, increasing the probabilities of fertilization and distribution throughout the bay.

Our studies confirm that *Tresus capax* from Yaquina Bay are late winter spawners. Furthermore, our results suggest that while latitude affects the onset of spawning, the lunar cycle influences its periodicity. Other factors such as temperature may also affect the reproductive cycle.

III. B. Abundance of gaper clam larvae in lower Yaquina Bay, Oregon from 12 January to 12 March, 1976

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III.B.1. METHODS

A sampling program to study the gaper clam larvae in Yaquina Bay, Oregon was conducted over a nine week period from 12 January to 17 March 1976. Samples were collected by hydraulic pump on high tide at seven stations (Figure III.B.1.-1). Six cubic meters of water were filtered for each sample. Five mid-bay stations extend across the channel from Sally's Bend shore to Idaho Flat shore, #1, #3, #5, #7 and #9. Two stations, #10 and #11, are located just seaward of the Yaquina Bay Bridge. The two mid-channel stations, #5 and #10, were sampled for surface and near bottom depths. Other stations were sampled near the bottom.

A total of 74 quantitative samples were counted and numbers per cubic meter have been determined. The counting procedure involved diluting each sample to 100 ml and then removing either 5 or 10 separate aliquots with a 1 ml stempel pipette. Larvae were separated into young "straight-hinge" and older "umbo" groups for counting and length measurements. Larvae were measured in each sample to establish the size range. Larvae of at least two clam species other than gapers were present in low varying numbers in the samples and were included in the gaper larvae counts. Positive identification has not been established. The numbers of these species were too low to have influenced the conclusions about gaper clams. Two types of very round larvae were found in the samples which are definitely not gapers. Both "straight-hinge" and "umbo" stages of this type were combined into one separate category termed "round larvae." Sixteen samples of the various larval sizes and types have been separated into vials for identification by specialists at the University of British Columbia.

III.B.2. RESULTS

The densities of gaper clam larvae in the straight-hinge and umbo developmental stage classes are summarized for all stations and dates in Tables III.B.2.-1 and III.B.2.-2.

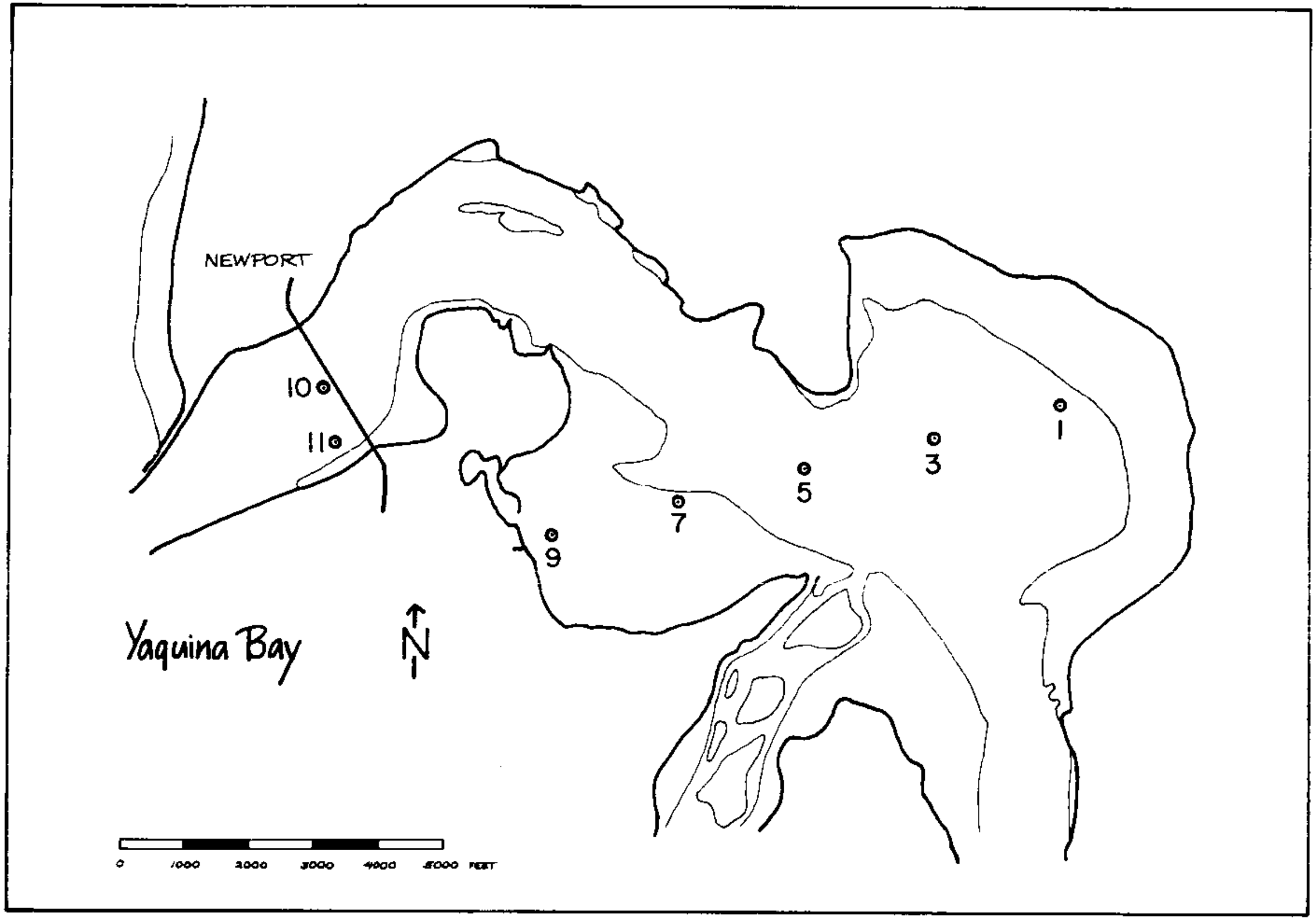

Figure III.B.1.-1. Location of plankton sampling stations in Yaquina Bay, Oregon.

Date	#1	#3	#5S	#5B	#7	#9	#10S	#10B	#11
					Station				
12-13 Jan	3	0	293	10	2	0	0	0	7
20-22 Jan	353	157	1130	397	1237	700	110	90	190
27-28 Jan	915	586	920	70	1407	85	510	257	88
3-6 Feb	38	73	205	77	87	7	17	3	148
11-13 Feb	23	133	197	30	113	--	153	37	80
18-19 Feb	2555	1330	1193	430	1200	393	1250	703	688
1-2 Mar	35	43	3	38	3	3	0	27	88
11-12 Mar	7	3	57	--	140	3	170	93	20

Table III.B.2.-1. Number per cubic meter of "straight-hinge" larvae.

Date	#1	#3	#5S	#5B	#7	#9	#10S	#10B	#11
					Station				
12-13 Jan	3	0	120	3	0	2	0	2	0
20-22 Jan	110	27	130	53	287	353	237	77	57
27-28 Jan	263	90	153	55	183	45	293	273	147
3-6 Feb	10	23	17	7	0	5	7	3	27
11-13 Feb	13	227	403	118	617	--	87	3	35
18-19 Feb	32	77	180	17	77	65	90	77	90
1-2 Mar	7	0	0	3	0	0	0	20	20
11-12 Mar	55	10	217	--	1990	17	380	333	107

Table III.B.2.-2. Number per cubic meter of "umbo" larvae.

Four hypotheses can be formed from these data: 1) gaper clams are cyclic spawners with maximum production of larvae during periods of greatest tidal range; 2) they develop in the field approximately according to the schedule predicted from laboratory rearing studies at comparable temperatures; 3) straight-hinge larvae are found in approximately constant density over the sampling area except for low densities at the Idaho Flat shore station, while umbo larvae tend to be most abundant over the channel (stations 4, 5, 6, 10 and 11); and 4) in deeper water near-surface samples give consistently higher estimates than near-bottom samples. Each of these hypotheses will be discussed in detail.

Spawning Cycle

The density estimates for straight-hinge larvae on each date (Table III.B.2.-1) were ranked separately at each station. The ranks were then summed for each date, producing the following sums of ranks:

Sampling Date	Sums of Ranks
12-13 Jan	67.5
20-22 Jan	24
27-28 Jan	23.5
3-6 Feb	43
11-13 Feb	47
18-19 Feb	12
1-2 Mar	55.5
11-12 Mar	51.5

A concordance estimate, W, was calculated from these sums. $W = 12\Sigma D^2/R^2(C^3 - C)$, where D is the difference between each observed sum and the expected sum under the null hypothesis that the ranks are random, R is the number of rankings, and C is the number of items ranked in each ranking. The result was W = 0.73, whose probability under the null hypothesis is less than 0.0001 (see Tate and Clelland, 1957). This implies that the stations are strongly concordant about which dates have high and which dates have low densities.

The dates with highest densities (lowest sums of ranks) are 27-28 January and 18-19 February. Both of the sampling periods followed immediately after a period of maximum tidal amplitude. It is well known that populations of many intertidal invertebrates have lunar periodicities in their spawning intensity, and it is important to find this may be the case for the gaper clam. Confirmation of this result will require data from at least one additional year.

Development Rate

The existence of cycles in abundance of the early straight-hinge larval phase leads to the expectation of a cycle in abundance of later larval phases that lag in time by the periods necessary for development. Cycles do exist in the abundance of the umbo stage clams. The data (Table III.B.2.-2) were ranked in the same fashion as the straight-hinge stage data. The sums of ranks were:

Sampling Date	Sums of Ranks (Umbo)	Sums of Ranks (Straight-hinge) (for comparison)
12-13 Jan	66.51	67.5
20-22 Jan	29.5	24
27-28 Jan	21	23.5
3-6 Feb	55.5	43
11-13 Feb	30.5	47
18-19 Feb	32.5	12
1-2 Mar	64.5	55.5
11-12 Mar	24	51.5

The concordance value is $W = 0.71$ ($p < 0.0001$). The peak periods (indicated by low sums) were 27-28 January, 11-13 February and 11-12 March. A suggested development time is indicated by the arrows. The 27-28 January peak probably derives from a spawning preceding the sampling period. For the 27-28 Janaury peak in straight-hinge larvae the period to the 11-13 February peak in umbo larvae is 15 to 16 days. For the 18-19 February straight-hinge peak the period to the 11-12 March umbo peak is about 22 days. Considering that the actual peaks do not necessarily fall on the sampling dates, and the uncertainty about temperature variations in the field, these intervals are consistent with the 19 day period expected from laboratory rearing studies at 8-11 C (F. Duane Phibbs, unpublished data).

Measurement data presented in Table III.B.2.-1 can be summarized for straight-hinge larvae by mean shell lengths as follows:

Sampling Date	Mean Shell Length (μm)	Numbers Measured
20-22 Jan	122	105
27-28 Jan	125	77
3-6 Feb	119	23
11-13 Feb	135	48
18-19 Feb	117	99
1-2 Mar	130	21
11-12 Mar	123	31

Almost all of the larvae on 18-19 February were very close to 116 μm (84 of 99 individuals), and since this date is at the strongest maximum of the spawning cycle, this is close to the size of the youngest straight-hinge larvae. On dates like 11-13 February, at maximum time after a spawning peak but before the next peak, the mean length of straight-hinge larvae has increased to 135 μm. Smallest umbo clams are much larger than this, 182 μm, which implies that, despite spawning peaks, a large fraction of straight-hinge clams are early in that phase at all parts of the cycle.

Distribution of Larvae in the Bay

Ranking of Tables III.B.2.-1 and III.B.2.-2 were performed for each date according to the order of the abundance estimates at the various stations. These ranks were then summed for each station. Dates with large numbers of zeros were dropped, and surface values were used for Stations 5 and 10. The sums were:

Station	Sums of Ranks (Straight-hinge)	Sums of Ranks (Umbo)
1	28	30
3	27.5	29.5
5 (surface)	19	17
7	20	18.5
9	41.5	31
10 (surface)	31	17.5
11	29	24.5
	$W = 0.241$	$W = 0.235$
	$p \simeq 0.20$	$p \simeq 0.20$

While the statistical significance of the deviation of the sets of sums from sets that might be expected under the null hypothesis (no agreement between dates about the ranking of the stations) is only at the 20% level, the direction of the deviations is in accord with a clear alternate hypothesis in

Sampling Date	Umbo Station 5 Surface	Umbo Station 5 Bottom	Umbo Station 10 Surface	Umbo Station 10 Bottom	Straight-hinge Station 5 Surface	Straight-hinge Station 5 Bottom	Straight-hinge Station 10 Surface	Straight-hinge Station 10 Bottom
12-13 Jan	120	3	0	2*	293	10	0	0*
20-22 Jan	130	53	237	77	1130	397	110	90
27-28 Jan	153	55	293	273	920	70	510	257
3-6 Feb	17	7	7	3	205	77	17	3
11-13 Feb	403	118	87	3	197	30	153	37
18-19 Feb	180	17	90	77	1193	430	1250	703
1-2 Mar	0	3*	0	20*	3	38	0	27*
11-12 Mar	217	--	380	333	57	--	170	93

each case. Younger larvae tend to be in lowest abundance at Station 9, above the tidal flats across the bay from the principal gaper clam beds. Station 9 is the only sampling site deviating consistently from the others. Umbo stage larvae are most abundant at stations over the channel (5 surface, 7, 10 surface, 11) and least abundant at stations over the flats (1, 3 and 9).

Vertical Distribution

Surface and bottom samples were analyzed for Stations 5 (mid-channel in mid-bay) and 10 (mid-channel near the bridge). The results extracted from Tables III.B.2.-1 and III.B.2.-2 are listed in the table above.

If the date-station-stage combinations with very low densities (indicated by an *) are eliminated, 24 of 25 date-station-stage combinations showed higher abundance at the near-surface depth. Gaper clam larvae live throughout the water column, but are somewhat more abundant near the surface.

Larvae of Species other than Gaper Clams

Density estimates of "round larvae" are presented in Table III.B.2.-3. The concordance between the stations about which dates had low and high densities was W = 0.49, which is lower than the values for gaper larvae, but still highly significant (p > 0.001). The dates with highest densities at most stations were the same (27-28 January and 18-19 February) as the dates of maximum spawning intensity of the gapers. The single highest value, 473 per cubic meter at Station #11 on 11-12 March, did not occur in agreement with this schedule. The other animals in that sample (*Calanus marshallae* Frost, for example) were characteristic of the coastal ocean well offshore, so it is likely the sample represents spawning by another species or population located in the ocean. No consistent spatial pattern is evident in the data for "round" larvae.

III.B.3. DISCUSSION

Analysis of January to March samples of gaper clam larvae from Yaquina Bay, Oregon

Date	Station #1	#3	#5S	#5B	#7	#9	#10S	#10B	#11
12-13 Jan	2	0	257	26	0	0	0	5	0
20-22 Jan	290	93	227	120	387	190	7	77	33
27-28 Jan	90	113	163	148	93	38	383	353	53
3-6 Feb	8	20	27	60	7	12	13	3	18
11-13 Feb	2	50	52	117	87	--	27	23	32
18-19 Feb	22	127	180	23	100	85	123	83	47
1-2 Mar	0	13	0	10	0	0	0	130	7
11-12 Mar	7	0	17	--	137	137	160	7	473

Table III.B.2.-3. Number per cubic meter of "round" larvae.

have established four hypotheses for further testing: 1) gaper clams have an approximately lunar cycle of spawning intensity with maximum production of larvae at the periods of greatest tidal amplitude; 2) the time required for development from "straight-hinge" to "umbo" stage is two to three weeks; 3) younger larvae are about evenly distributed through the lower estuary, except that they are less common over the tidal flats of the south shore; and 4) gaper clam larvae are found throughout the water column but are consistently most abundant in near surface depths.

Coincidence of maximum spawning with the period of maximum tidal range certainly has adaptive significance. The larvae could achieve an improved retention within the bay from this, provided that spawning is coincident with return of the water after very low tides. The flood tide would then carry the larvae to the maximum distance upstream, minimizing subsequent losses from the bay to the ocean. Establishment of the timing of spawning within the daily tidal cycle is thus an obvious next step for this research.

The approximate agreement between the observed time required in the field for transformation of straight-hinge larvae to the umbo stage and the time required in the laboratory suggests that the laboratory rearing is a realistic way to evaluate larval growth processes.

It is surprising to have found the maximum densities of both age groups of larvae to be near the surface. This should produce more flushing of larvae from the bay than concentration near the bottom, where net transport should be upstream. The fact, however, is quite strongly established.

III. C. Haplosporidan study

THOMAS F. GAUMER

III.C.1. METHODS

A microsporan parasite identified in the literature as a haplosporidan, occurs in gaper clams in Yaquina Bay (Armstrong and Armstrong, 1974). Gaumer and Lukas (1975) reported observing the haplosporidan infection in subtidal gaper clams. To increase our knowledge of the incidence and distribution of this infection, subsamples of gaper clams collected during our surveys were examined by Dr. Robert Olson, Oregon State University, Department of Zoology, under a Sea Grant funded study on microsporan diseases of shrimp and clams. Samples were collected from Tillamook, Yaquina, Netarts, Siuslaw and Coos bays. The parasitic infection was most intensively studied in Yaquina Bay where clams from five stations (Figure III.C.1.-1) were routinely sampled for one year and clams from two of these stations were studied for an additional year. Single samples were taken from each of the other bays. This section briefly reviews the results of Dr. Olson's studies which he will publish in more detail.

III.C.2. RESULTS

The parasite was found to occur at all stations in Yaquina Bay. Massive infections were observed at only one station (Area 4), where the incidence of the parasitized clams ranged from 51.6 to 89.0%.

Approximately 30% of the clams from Area 4 contained infections that were classified as heavy and were immediately evident upon gross examination. Although infection incidences in clams from the other Yaquina Bay sampling areas were often over 50%, the infection intensities were usually so light that close examination and dissection were required for detection.

Examination of gaper clams from Coos, Siuslaw, Netarts and Tillamook bays also revealed haplosporidan infection. Clams for these samples were collected from areas having known dense concentrations of gaper clams. The parasite occurred in all of these areas, but the infection levels were so low that detection was difficult and histological confirmation was required.

Haplosporidan cysts were not observed in any of the zero-age gapers. Gapers also appeared to be more heavily infected with increasing age. The disease was not observed in any other clam species.

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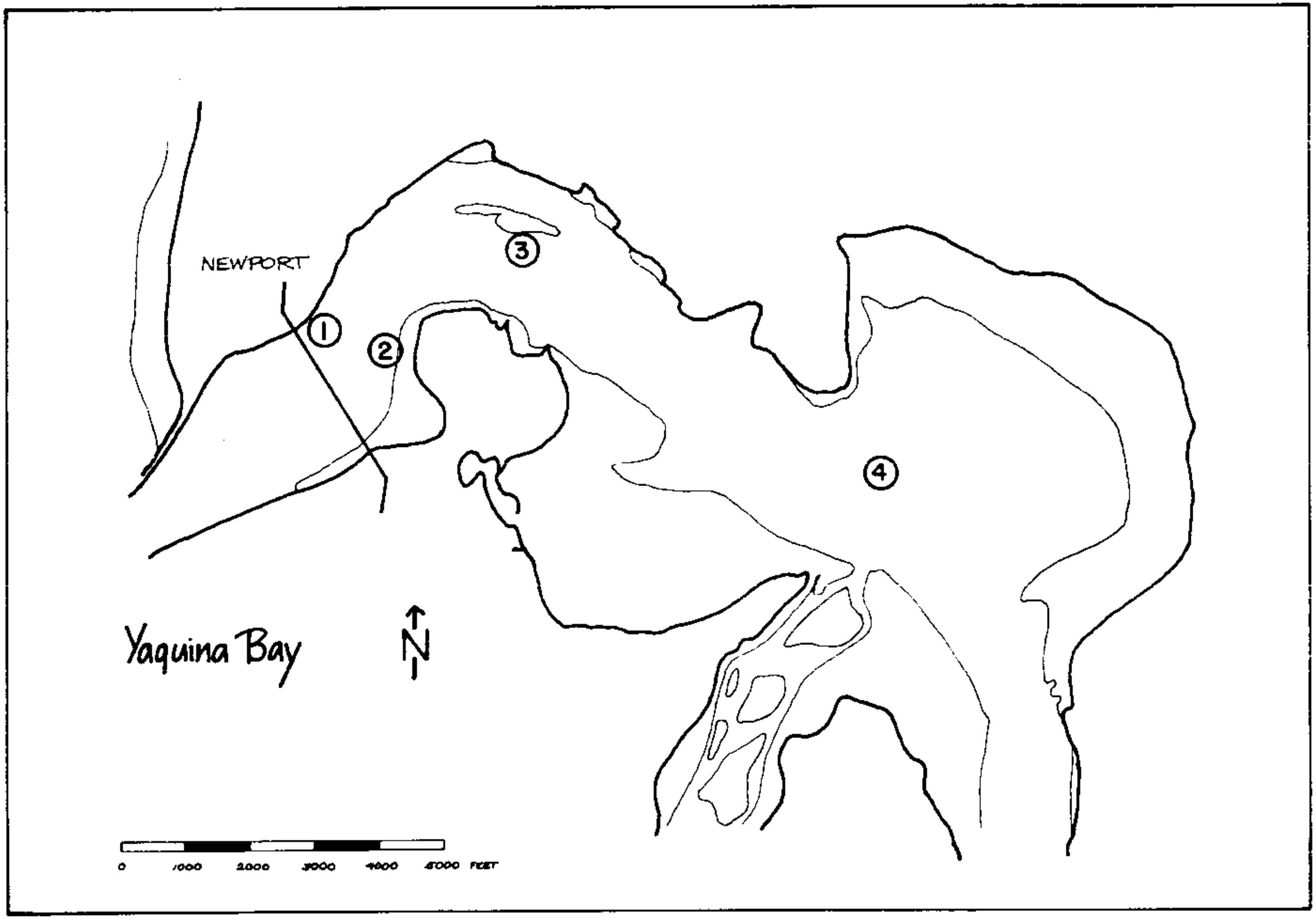

Figure III.C.1.-1. Location of haplosporidan sampling stations in Yaquina Bay, Oregon.

PART IV Applications

IV. A. Research Summary, Conclusions and Implications

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The purpose of the research on hardshell clam populations is to provide information on the natural history and ecology of the gaper clam, *Tresus capax*, which can be utilized by resource management interests.

The research scientist must be cognizant of the fact that for a variety of reasons, many of his research findings cannot or will not be utilized by resource interests in the management of a species. Our intent then is to summarize important findings, suggest how such findings may be applied or related to the management of the hardshell bay clams but not to provide a management program.

This section will attempt to integrate the findings of both the ODFW and the School of Oceanography at Oregon State University. Every effort will be made to provide a candid appraisal of existing information, the conditions of the data base as well as the shortcomings of our studies with an attempt to point out possible directions for future research.

IV.A.1. HISTORICAL PERSPECTIVES ON COMMERCIAL BAY CLAMS

Existing information on the history of commercial clamming in Oregon suggests several things:

1. Accurate and consistent data on clam landings by species and individual estuary is very rudimentary, not easily obtainable or interpretable. Our analysis of these data suggest the need for more precise records. It would be most helpful if the formatting and recording of these data from year to year were consistent. Information on catch per unit effort for both the recreational and commercial fishery would elucidate comments on the condition of the clam stocks. Economic information would also help in this manner.

2. Such historical data as exists suggests that the commercial clam harvest has been highly variable over the years. Reasons for these fluctuations appear highly

conjectural but have been suggested to be related to national politics such as night digging restrictions during WWII, poor market conditions and declining intertidal populations.

3. Data of the period from 1941-1975 show a general downward trend from the high of 139 m.t. landed in 1945.

4. Approximately 40% of Oregon's total bay clam production comes from Coos Bay with Tillamook Bay and Yaquina bays producing 25% and 20%, respectively, to the state's annual commercial harvest. The Coos Bay harvest is nearly all gaper clams; Tillamook is primarily cockles; while Yaquina is a mix of gaper and cockles. In spite of sporadic spatsets, gaper harvests have contributed as much as 60% to the total bay clam production in Oregon.

5. In 1961 a permit was issued for the taking of subtidal clams from Coos Bay by mechanical methods. Prior to this, all commercial bay clam landings came from the intertidal areas.

6. The landings for recreational uses is thought to far exceed reported commerical landings.

7. It appears that the ratio of recreational to commerical landings will change substantially if subtidal harvest by mechanical methods becomes acceptable, and market conditions remain strong.

IV.A.2. STUDIES OF THE DISTRIBUTIONS OF HARDSHELL CLAMS AND OTHER ECOLOGICAL FEATURES

1. Intertidal and subtidal distributional surveys were conducted on 10 of Oregons principal clam producing estuaries.

2. Surveys of the distribution and abundance of clams, shrimp and vegetation were completed on the Tillamook, Netarts, Nestucca, Salmon river, Siletz, Yaquina and Alsea estuaries. Surveys were conducted but not completed on the Nehalem, Siuslaw and Coos Bay estuaries.

3. The distributional surveys were extensive, examining over 518,000 m of transect, and included over 9,216 stations.

4. A total of 17 species of bivalves, two species of shrimp and four genera of vegetation were recorded.

5. Subtidal surveys produced new information on the location of clam beds having commercial harvest potential in Tillamook, Yaquina and Coos Bay estuaries. Stocks of clams in the other surveyed estuaries were either absent or too scattered to support a commercial fishery.

6. The Nestucca and Siletz estuaries contained no subtidal clams, although suitable habitat appeared to occur in each bay.

7. Gaper clams were found associated with eelgrass beds in many instances. Few clams were observed in areas having dense concentrations of sand and mud shrimp. These results tend to indicate the importance of substrate stability to the settling and/or survival of bay clams.

IV.A.3. AGING OF GAPER CLAMS

1. The knowledge of the age structure of the gaper clam population has extremely important management and scientific implications.

2. Five aging techniques were studied during the course of this research. The results of the five techniques were found be significantly different. The method of delineating chondrophore annuli by means of a high intensity light was the most accurate means of analysis.

IV.A.4. COMMERCIAL SUBTIDAL BAY CLAM FISHERIES

1. Using the value 21.6 clams/m^2 as an indicator of commercial potential, three areas in Tillamook Bay, four areas in Yaquina Bay and one area in Coos Bay were sampled. Over 9,000 m.t. of clams (primarily gapers and irus) were estimated to inhabit these areas at densities of up to 135 clams/m^2 in Tillamook and Coos bays and 627 clams/m^2 in Yaquina Bay. Over 7,000 m.t. of this total were deemed to be of commercially desirable sizes.

2. An experimental commercial fishery was initiated in 1975 in Yaquina Bay. Conditions included gear restrictions (to study the effects of mechanical harvesting), a limited harvest area, and a quota of 10% of the estimated available gaper clams. The State Board of Health moreover required monthly clam samples for bacteriological examination.

3. In 1975, one permittee using a high pressure water jet harvested 683 kg of clams from Yaquina Bay. In 1976, two commercial permits were issued for Yaquina Bay, but no harvest was reported.

4. In 1977, two commercial plots in Yaquina Bay were approved for water-jet harvesting, and three for diver-operated suction pump devices. Thirty-one m.t. were reported taken, but only 20% of the area was actually harvested. Catch per effort ranged from 45.5 kg/hr in a pump permit area to 142 kg/hr in a jet permit area.

5. The fishery appeared selective of the older clams with 82.7% of the clams harvested being five years of age or older. Year class composition studies revealed that only clams of the 1973, 1975 and 1976 year classes remained. Preharvest gaper density was $391.0/m^2$ and postharvest density was $8.6/m^2$.

6. Bacterial examination of harvested clams from Yaquina Bay indicated that plate counts and coliform counts fell below the maximum allowable for each sampling period.

7. The total commercial harvest in Coos Bay from 1975 through 1977 produced 59.3 m.t. of which 98% were gaper clams. Catch per effort values ranged from 71.2 kg/hr to 102.4 kg/hr and was entirely composed of clams 100 mm in length.

8. The assessment of the effects of the commercial harvest on the clam stocks showed only a small portion of each of the subsections was actually harvested, and only in two sub-sections were appreciable numbers of clams taken.

IV.A.5. SUMMARY OF MARKET CONDITION FOR COMMERCIAL HARVEST OF GAPER CLAM

1. The market potential for gaper clams from Oregon has never been fully investigated. Until recently, the East Coast bay and surf clams were available to meet market demands across the country. East coast clam availability has rapidly declined during the past several years and consequently market demand has increased rapidly for stocks from other sources.

2. In 1977 great interest in subtidal clam harvesting was shown by local industries because of the declining East Coast sources and the demonstration of the potential supply of Oregon's bay clams to meet local demands.

3. Meat recovery by seafood processors averaged 21% of live wet weight for gaper clams during the winter months. After spawning had occurred in April, meat yield reportedly dropped to 17%, which is not enough to justify a fishery during that season.

4. In addition to the interest in the use of the gaper for the local seafood market, there appears to be a ready market for undersized clams in the bait fishing market as well as a potential for the utilization of clam wastes as a source of glycogen.

IV.A.6. REPRODUCTION AND GROWTH OF THE GAPER CLAM

1. Pertinent ecological information on the gaper clam was obtained during this study with special emphasis on reproduction and growth. These data are important to the management of both the subtidal and intertidal stocks of clams for several reasons. These data a) provide information on the relationship of the subtidal to the intertidal populations, b) suggest optimal harvest size of clams based on growth curves for the different stocks, c) provide information on seasonal variations of meat quality, and d) provide information for establishment of harvest seasons and comparative differences between subtidal and intertidal stocks.

2. Growth rates of *T. capax* from both the subtidal and intertidal areas of Yaquina Bay were comparable to those rates reported for the intertidal from British Columbia.

3. The mean length of subtidal clams over 4 years old was significantly larger than those of intertidal clams.

4. These data suggest that gaper clams from intertidal areas do not grow as rapidly as clams from subtidal areas.

5. Differences in sediment types as well as density dependent factors and tidal exposure are most likely responsible for the observed differences in growth rates.

6. Relative growth among the body parts seem to be dependent on the amount of exposure to seawater and the degree of gonad development.

7. Intertidal clams grew heavier per unit length than did subtidal clams.

8. The wet body weight of intertidal clams had a higher moisture content than did subtidal clams.

9. Intertidal clam shells, while not as high as subtidal shells, showed a greater growth rate increase. The higher weight to length ratio of intertidal clams results from the high moisture content, the high rate of increase of wet body weight to length and the higher rate of increase of

shell weight to length.

10. Latitudinally related environmental conditions such as temperature, pH, photoperiod or tidal regime influence the size at which sexual maturity occurs.

IV.A.7. THE REPRODUCTION CYCLE OF THE GAPER CLAM

1. Data from our histological examinations and plankton studies confirm that the gaper is a late winter spawner but that the time of spawning was found to vary from that previously reported.

2. Gametogenesis is initiated in late summer and continued through autumn. Development of gametes progressed until ripe gonads predominated; spawning began in late winter, peaking in March and April.

3. A discrete inactive period was found during the summer.

4. Evidence suggests some clams fail to spawn or spawn incompletely.

5. Latitudinal variations in spawning were observed. Gapers in more southerly latitudes spawn earlier, while those of more northerly latitudes spawn later than clams from Yaquina Bay.

6. Female clams in Yaquina Bay were active before, ripe concurrent with, and spawned both slightly before and slightly after the male clams.

7. Observed synchronousness between sexes may be indicative of differences in development time between males and females.

8. Clams at all four stations in Yaquina Bay exhibited synchrounous spawning.

9. Multiple spawning of individual clams was not conclusively indicated by these data.

10. These data indicate that while latitudinal differences affect the onset of spawning, a lunar cycle influences its periodicity. Other factors such as temperature also influence the reproductive cycle.

IV.A.8. LARVAL STUDIES OF THE GAPER CLAM IN YAQUINA BAY

1. Analysis of preliminary plankton samples have indicated that gaper clams have an approximate lunar cycle of spawning with the maximum activity occurring during period of greatest tidal amplitude.

2. The time required for development from the straight hinge stage to the umbo stage is 2-3 weeks.

3. Young larvae are approximately evenly distributed throughout the estuary but are less common over the tidal flats of the south shore.

4. Gaper larvae are found throughout the water column but are consistently most abundant at the surface.

IV.A.9. HAPLOSPORIDAN INFECTION

1. The microsporan parasite identified in the literature as haplosporidan occurs in gaper clams in Yaquina Bay.

2. Concurrent studies have been examining haplosporidan infections in gaper clams from Tillamook, Yaquina, Netarts and Coos Bay estuaries.

3. The parasite was found in samples from all four stations in Yaquina Bay, however, massive infections were found at only one station (Sally's Bend region).

4. Haplosporidan infections were absent from zero age class gapers, the infections increasing with increasing age.

IV.A.10. GENERAL CONSIDERATIONS AND RESEARCH RECOMMENDATIONS

1. The abundance of subtidal gaper populations found in some of Oregon's estuaries, coupled with the synchrony of spawning, could conceiveably make the gaper an important food source for planktovores during a period when other zooplankton are much reduced. This consideration was not addressed in the scope of this research. Data on the utilization of gaper larvae, juveniles and gaper siphons by other species would also be beneficial.

2. The data on age, growth and abundance strongly indicates the requirement of the gaper clam for substrate stability. In shallow areas eelgrass appears to be related to bottom stabilization, while in other instances shell debris may armor the substrate. Since the settling gaper larvae also require protected areas with hard substrate for attachment, the returning of the shells of harvested gapers may have value.

3. Growth data suggest that the optimum age for harvest of the gaper clam in Yaquina Bay is about 5 years.

4. Although the gaper appears to spawn every year in Yaquina Bay, recruitment into the year classes is often sporadic. Careful consideration must be given to the allowable acreage for subtidal harvest.

5. Montoring the environmental effects of the mechanical harvesting of the gaper clam are continuing, however much of the information from other regions such as Puget Sound and Alaska is available and can be utilized.

6. Larval studies coupled with the spawning synchrony and other reproductive, growth, distribution and abundance information are extremely imporant factors in assessing the contribution of the subtidal gaper stocks to the intertidal stocks.

7. Information on the age of sexual maturity and age specific fecundity would be necessary to complete the determination of the contribution of the subtidal gaper populations to the intertidal populations.

8. Histological studies of juvenile and young adult gaper clams are necessary before the effects of latitudinal variations can be made.

9. Additional studies of calcium uptake would be valuable to compare intertidal to subtidal clam shell growth.