Publication No. 72-e28

THE DISTRIBUTION AND ABUNDANCE OF CLAMS IN GRAYS HARBOR AS RELATED TO ENVIRONMENTAL CONDITIONS

R. B. HERRMANN

AUGUST 17, 1972

INTRODUCTION

THE STAFFS OF THE WEYERHAEUSER ENVIRONMENTAL RESEARCH GROUP AND THE WEYERHAEUSER PULP MILL AT COSMOPOLIS CONDUCTED THIS STUDY IN 1967, AND 1968.

THERE ARE MANY PUBLISHED REPORTS DOCUMENTING GRAYS HARBOR WATER QUALITY. THERE ARE ALSO A LESSER NUMBER OF PUBLISHED FIN-FISH STUDIES AND WORK SPECIFICALLY ON OYSTERS. LACKING AT THE TIME WE BEGAN OUR SURVEY WERE STUDIES DOCUMENTING THE POPULATIONS OF NATIVE AND INTRODUCED CLAMS. THUS, WE FELT THERE WAS A NEED FOR SUCH STUDIES.

OUR OBJECTIVES IN THE GRAYS HARBOR STUDIES WERE:

1) TO DETERMINE WHAT CLAMS WERE PRESENT;
2) THEIR GEOGRAPHIC DISTRIBUTIONS AND ABUNDANCE; AND
3) THE RELATION BETWEEN THEIR DISTRIBUTIONS AND ABUNDANCES AND PREVAILING WATER QUALITY AND SUBSTRATE CONDITIONS IN THE BAY. WE HAVE ALSO CONDUCTED CLAM STUDIES IN WILLAPA BAY (SMITH AND HERRMANN: 1972) WITH SIMILAR OBJECTIVES.

FOR SEVERAL REASONS THE WILLAPA RESULTS OFFER A BASELINE FOR COMPARISON OF RESULTS WITH THOSE REPORTED FOR GRAYS HARBOR.

GRAYS HARBOR AND WILLAPA BAY COLLECTIVELY ARE CALLED THE "TWIN HARBORS" AREA. WHILE SIMILAR IN SIZE, 90 MI^2 AND 110 MI^2, RESPECTIVELY, THERE ARE SOME SIGNIFICANT DIFFERENCES BETWEEN THE TWO BAYS IMPORTANT TO

THEIR SHELLFISH FAUNA. GRAYS HARBOR HAS A RELATIVELY GREATER EXPANSE OF TIDE FLAT (55% VS. 45%) AND GREATER AVERAGE FRESH WATER INFLOW (11,400 CFS VS. 3,500 CFS.) THESE FEATURES CONTRIBUTE TO A HIGH FLUSHING RATE. IN WINTER GRAYS HARBOR'S HIGHER RIVER RUNOFF, APART FROM INCREASING THE BAY'S RELATIVELY HIGH FLUSHING, CAUSES REDUCED SALINITIES THROUGH MOST OF THE BAY. IN WINTER SIGNIFICANT AMOUNTS OF SEDIMENTS ARE SUPPLIED TO THE BAY AND AMOUNT TO 13.5×10^6 FT.^{3} ANNUALLY OR ABOUT .04% OF THE BAY'S VOLUME (GLANCY: 1971).

GRAYS HARBOR HAS TWO PULP MILLS AS WELL AS SEVERAL PLYWOOD AND SAWMILLS. PULP MILL EFFLUENT RELEASES ARE REDUCED IN RECENT YEARS. AT PRESENT IN SUMMER 70 TO 80×10^3 POUNDS OF BOD/DAY ARE RELEASED COMPARED TO 250 TO 300×10^3 POUNDS DURING AND SHORTLY BEFORE THIS CLAM SURVEY WAS CONDUCTED. APART FROM THESE LIQUID EFFLUENTS THERE ARE PRESENT IN THE TIDEFLATS SAWDUST FROM PAST SAWMILL OPERATIONS.

THESE FACTORS - WATER QUALITY, SALINITY, FLUSHING, SUBSTRATE TYPE AND QUALITY - INFLUENCE THE HABITABILITY OF AN AREA FOR CLAMS.

THIS PAPER REPORTS THE RESULTS OF DATA COLLECTED AT SOME 60 STATIONS IN THE BRACKISH AND SALT WATER PORTIONS OF GRAYS HARBOR. THESE STATIONS ARE FROM WITHIN ABOUT A MILE OF THE BAY MOUTH EASTERLY TO NEAR COW POINT IN HOQUIAM, SOME 14 MILES (FIGURE 1).

IN CONDUCTING OUR SAMPLING WE ATTEMPTED TO EXAMINE REPRESENTATIVE AREAS THROUGHOUT THE ENTIRE BAY. SAMPLING WAS CONDUCTED AT TIDAL ELEVATIONS FROM ABOUT -2 FT. TO HIGH TIDE ALTHOUGH THE BAY MARGINS HAD ONLY LIMITED SAMPLING. OUR PRIORITIES IN THE SAMPLING WERE:

1) ESTABLISH THE PRESENCE AND TYPE OR ABSENCE OF CLAM FAUNA QUALITATIVELY;
2) ESTABLISH QUALITATIVELY THE NATURE OF THE TIDEFLAT SUBSTRATE;
3) QUANTITATIVELY SAMPLE FOR CLAMS, AND
4) OBTAIN CORE SAMPLES OF THE TIDEFLAT SUBSTRATE TO DETERMINE ITS PARTICLE SIZE AND CHARACTER.

INFORMATION RELATING TO PRIORITIES 1) AND 2) WERE OBTAINED AT ALL STATIONS BUT ONLY AT 22 OF THE STATIONS WAS QUANTITATIVE CLAM SAMPLING PURSUED. SUBSTRATE CORE SAMPLES WERE OBTAINED AT 31 OF THE STATIONS.

QUANTITATIVE CLAM SAMPLING INVOLVED STAKING OUT ONE OR MORE 50 FT. TRANSECTS AT A STATION AND DIGGING OUT RANDOM SQUARE FOOT SAMPLES ALONG THE TRANSECT. THE SQUARE FOOT SAMPLE LOCATIONS WERE SELECTED USING A TABLE OF RANDOM NUMBERS. USUALLY FOUR OR MORE SQUARE FOOT SAMPLES WERE TAKEN ALONG EACH TRANSECT. SINCE WE DID NOT USE A SCREEN TO RECOVER CLAMS, THE SMALLER CLAMS BELOW 1/4 IN. PROBABLY WERE NOT RECOVERED IN PROPORTION TO THEIR ABUNDANCE. BECAUSE OUR SAMPLING WAS LIMITED COMPARED TO THE EXPANSIVE NATURE (50 MI^2) OF THE GRAYS HARBOR TIDEFLATS, THE QUANTITATIVE SAMPLING DATA CANNOT BE EXTRAPOLATED TO ESTIMATE THE ABUNDANCE OF INTER-TIDAL CLAMS THROUGH THE BAY. ANOTHER FACTOR IS THAT MORE EFFORT WAS GIVEN TO SAMPLING AREAS APPEARING SUITABLE FOR CLAMS. USUALLY THE VERY SOFT, WATERY-MUDDY AREAS AND UNSTABLE, STERILE-APPEARING, SANDY AREAS WERE NOT QUANTITATIVELY SAMPLED.

CLAMS RECOVERED IN SAMPLING WERE IDENTIFIED TO SPECIES AND MEASURED TO THE NEAREST 0.1 IN. OR 1 MM. THE TIDEFLAT SUBSTRATE CORE SAMPLES WERE ANALYZED AT TWO OR MORE DEPTHS FOR MOISTURE, ORGANIC CARBON,

KJELDAHL NITROGEN, AND GROSS VOLATILE SOLIDS. MANY OF THE SUBSTRATE SAMPLES ALSO WERE SCREENED FOR PARTICLE SIZE COMPOSITION.

ALTHOUGH SOME WATER SAMPLES FOR ANALYSIS WERE TAKEN DURING OUR SURVEYS, THE LIMITATIONS OF USING SUCH "SPOT SAMPLES" FOR INTERPRETING THE SURVEY RESULTS ARE OBVIOUS. ACCORDINGLY, IN ASSESSING THE POSSIBLE EFFECTS OF WATER QUALITY CONDITIONS ON THE CLAMS, MUCH OF THE HYDROGRAPHIC DATA PRESENTED HERE WAS FROM THE MORE RECENT PUBLISHED REPORTS OF BEVERAGE AND SWECKER (1969) AND WESTLEY (1967) AS WELL AS MANY PROCESSED HYDROGRAPHIC REPORTS AND DATA SUMMARIES OF THE WEYERHAEUSER COMPANY AND THE WASHINGTON DEPARTMENTS OF FISHERIES (WDF) AND ECOLOGY (DOE).

DISCUSSION

ENVIRONMENTAL CONDITIONS

SALINITY IS ONE OF THE IMPORTANT FACTORS IN THE BAY WHICH WE MENTIONED AS AFFECTING CLAM DISTRIBUTIONS. USUAL SUMMER AND WINTER SALINITIES FOUND IN VARIOUS REGIONS OF THE BAY ARE SHOWN IN FIGURE 2. THESE USUAL VALUES SHOULD NOT BE INTERPRETED AS EXTREMES ENCOUNTERED IN THESE AREAS, HOWEVER. THE REGION LINES IN THE FIGURE ARE BASED ON DATA EXTRACTED FROM WEYERHAEUSER, WDF, AND DOE HYDROGRAPHIC REPORTS. SUMMER SALINITIES THROUGH MOST OF THE BAY ARE HIGH. FOR EXAMPLE, IN THE JOHNS RIVER - PT. NEW AREA OF THE MIDDLE BAY, USUAL SUMMER SALINITIES ARE AROUND 25‰. FURTHER EASTWARD IN THE HOQUIAM AREA USUAL SALINITIES ARE AROUND 20‰. IN WINTER, HOWEVER, SALINITIES AROUND 20‰ OR MORE DO NOT OCCUR IN THE REGION EAST OF OCOSTA - OHYHUT AREA.

Summer and winter levels of pulp effluents as indicated by the PBI test in the various bay regions are shown in Figure 3. Again, these data are extracted from Weyerhaeuser, WDF, and DOE reports; maximum or minimum seasonal values are not indicated. Measurable levels of PBI occur throughout the bay at all seasons. The highest levels occur near the mill outfalls. Levels over the marine shellfish areas are highest in winter. In summer the effluent levels are reduced by two-thirds or more through impounding of wastes and secondary treatment.

Substrate quality is another factor affecting the development of clam population in various areas. Higher organic level substrates in Grays Harbor occur upbay and along the southeastern part of the bay. Organic levels tend to decrease progressing westward to the bay entrance. Figure 4 shows the carbon distribution in the intertidal substrates through the bay. Carbon levels - about 80 to 90% of the total organic level - were used since that was the expression used by Beaverage and Swecker (1969), the source of much of these data. Usual levels in the upper harbor are 2% to 3%; levels in the lower harbor are more around 1%.

The distribution of intertidal sediment types through the bay found in our sampling, is shown in Figure 5. We used the qualitative terminology: gravel, sand, and mud. Quantitatively in classifying substrates from the core samples, however, we used the terminology of Emery (1938), describing the median grain size, MGS.

CLAM DISTRIBUTIONS AND DENSITIES

ALTHOUGH WE FOUND NINE CLAM SPECIES IN THE SAMPLING, THE MOST WIDELY DISTRIBUTED WERE SOFTSHELL TYPES (FIGURE 6), NOTABLY MYA ARENARIA, THE EASTERN SOFTSHELL CLAM, AND MACOMA NATSUTA, THE BENTNOSE CLAM. TWO OTHER SMALL SOFTSHELL CLAMS, CRYPTOMYA CALIFORNICA AND MACOMA INCONSPICUA, WERE LOCALLY ABUNDANT. THESE LATTER TWO MINOR SPECIES ARE NOT CONSIDERED IN DETAIL IN THIS PAPER. HARDSHELL CLAMS WERE RESTRICTED TO THE MORE WESTERN PART OF THE BAY AND THERE, ONLY LOCALLY ABUNDANT. INCLUDED WERE CLINOCARDIUM NUTTALI, THE COCKLE; TRESUS CAPAX, THE HORSE-NECK CLAM; SAXIDOMUS GIGANTEUS, THE BUTTER CLAM; PROTOTHACA STAMINEA, THE NATIVE LITTLENECK, AND VENERUPIS JAPONICA, THE MANILA CLAM.

FIGURE 7 SHOWS THE AVERAGE DENSITY OF BOTH SOFTSHELL AND HARD-SHELL TYPE CLAMS AT STATIONS INCREASING IN DISTANCE FROM THE MOUTH OF THE BAY. THESE DATA FROM OUR QUANTITATIVE SAMPLING INDICATE HARDSHELL CLAMS OCCUR IN SIGNIFICANT NUMBERS ONLY IN THE LOWER THREE MILES OF THE BAY.

THE MOST COMMON SOFTSHELL SPECIES, MYA, OCCURRED AT 29 OF THE STATIONS COMPARED WITH CLINODARIUM, THE MOST COMMON OF THE HARDSHELL CLAMS, WHICH OCCURRED AT ONLY EIGHT STATIONS. MYA RANGED FROM NEAR DAMON PT. (STATION 45) NEAR THE MOUTH OF THE BAY EASTWARD TO THE HOQUIAM AREA OF THE NORTH CHANNEL (11, 9) AND TO NEAR NEWSKAH CREEK (4) IN THE SOUTH CHANNEL (FIGURE 1, 6). AT THE 21 QUANTITATIVELY SAMPLED STATIONS MYA DENSITY WAS $1.7/FT^2$, WITH A MAXIMUM OF $10./FT^2$ (TABLE 1). AT BOTH THE UPPER HARBOR AND THE NORTH BAY STATIONS (6 AND 11 STATIONS, RESPECTIVELY) MYA DENSITY AVERAGED $2.2/FT.^2$, while at the 4 South Bay stations the average density was 0.2/ft^2. The average size of the Mya clams recovered was about 2.1 inches; with the clams from the upper harbor being somewhat smaller than those from the outer bay.

The bentnose clam, Macoma natsuta, occurred at 11 stations; from near Damon Pt., (46) and Grass Island (54) near the mouth of the bay eastward to near Neds Rock (24) in North Bay and at least to upper Whitcomb flats (51) in South Bay (Figures 1, 6). At the 21 stations quantitatively sampled its average density was 0.3/ft^2 with a maximum of 3/ft^2; the average size was 1.6 in. (Table 1). Its eastward range was not so extensive as Mya and low salinities in the upper bay in winter may be restrictive to Macoma natsuta. Another Macoma species, M. inconspicua, occurs well upbay.

Cryptomya californica was another small clam (average size 0.6 in.) not covered in detail in our surveys. It was locally abundant in sandy areas from Whitcomb Flats (50) in the South Bay and Damon Pt. (43,44) in North Bay eastward at least to mid upper bay (Figures 1, 6).

The hardshell clams are considered as a group because of their more restricted abundance. Clinocardium, the most widespread clam in this group occurs from the bay mouth eastward in North Bay to near Neds Rock (25) and in the South Bay to Johns River (47) (Figures 1, 6). Other clams in this group apparently occur no further east than the Oyhut Channel area (36-39) in North Bay and the Grass Island area (54) of South Bay. The density estimate for hardshells at quantitatively sampled stations within their established range was 0.2/ft^2 with a maximum of 0.8/ft² (Table 1). Following cockles in abundance were the Manila clam Venerupis and horse clam, Tresus capax. Native littlenecks, Protothaca, and butter clams, Saxidomus, were uncommon.

Clam distributions are enhanced or restricted by environment conditions. Generally, clam larvae are more sensitive to water quality and substrate conditions; thus, the presence of lethal environmental conditions when clam larvae are present often controls the distribution of adult clam populations. Reduced salinities of 14‰ to 20‰ (Phibbs: 1971), various concentrations of domestic and industrial effluents including fairly low (6 - 12 ppm) concentrations of sulfite pulp effluents (Woelke: et. al 1970) and anaerobic water conditions (Walne: 1964) are deleterious to clam larvae. For adult clams, persistent very low salinities (Mya: <4.5‰; Macoma balthica <1‰ Lassig: 1965; Venerupis, 24‰; Fuijiya: 1962; Tresus $\lesssim 27$‰; McAlister and Burt: 1959), much higher sulfite pulp effluent levels (>1000 ppm for Mya and Macoma; NTAC: 1968) and substrates high in organics ($>4\%$) (Ito and Imai: 1955) are lethal.

Within the geographic range where a clam occurs, density and size are also affected by these stresses (but to a lesser extent) as well as by food abundance and exploitation by natural predators and man. In Grays Harbor, exploitation of clam stocks by man is low.

Low salinity is one of the important factors in the Grays Harbor potentially affecting clam distributions. Summare salinities, when most clams spawn (Tresus capax, a winter spawner is an exception) probably are suitable for survival of most clam larvae eastward at least to the Johns River - Pt. New area where usual summer salinities are around 25‰ (Figure 2). Salinity conditions in winter are not so favorable throughout the bay for survival of adult hardhsell clams, however, as summer salinities are for clam larvae. Usual winter salinities of around 20‰ or more which are suitable for most adult hardshells don't occur in the region east of the Ocosta - Oyhut area. In many winters, however, average salinities about two-thirds this level persist in the northern half of this western bay area for a month or more (Herrmann: 1969). In such winters areas further east, Pt. New for example, may go almost fresh for a prolonged period, a situation certainly lethal to most clams with the exception of Mya (Herrmann, unpublished data.).

Regarding the potential effects of pulp mill effluents on clams, in summer when clam larvae of most species occur, usual pulp effluent levels (as indicated by the PBI test) are from 5 ppm in the western bay to 50 ppm near the mill outfalls (Figure 3).

In WDF laboratory studies conducted by Dr.Woelke fresh sulfite pulp effluents at the higher range of concentrations just mentioned were lethal to early-stage clam larvae (Woelke et al: 1970) and even sulfite pulp effluent levels down to the lower range were deleterious. More recent WDF studies show secondary treatment of effluents signicantly reduced the toxicity to clam larvae (Woelke et al: 1971)

In these recent studies treated MgO wastes having a certain Pbi test value were one-third or less as toxic as untreated wastes with the same Pbi value. A major BOD portion of Weyerhaeuser's

Cosmopolis MgO pulp mill effluents in summer receive secondary treatment before release to the bay.

In other long-term studies with moderate concentrations of fresh pulp effluents in Willapa Bay, Haydu (1958) found juvenile clams of many species entered the continuous-flow bioassay system as larvae and colonized the mud substrates in flow-through test trays. The SWL pulp effluent level in the experimental treatment in these long-term studies was 90 ppm. as PBI.

The degree of lethality of the low summer pulp effluent levels to clam larvae in Grays Harbor is clouded by this diversity of results. It is especially difficult to extrapolate toxicity from the laboratory to the field on the basis of the PBI test. The toxicity to clam larvae of fresh effluents with a certain PBI would be greater than the situation in the field where there is a mixture of old (degraded) and new effluents with the same PBI.

If there is appreciable toxicity of pulp effluents to clam larvae in Grays Harbor, the larvae of the softshell types must have a certain resistance. Adult populations of all three genera - <u>Mya, Macoma, Cryptomya</u> - occur well upbay into areas where usual summer PBI levels are 30 to 50 ppm (Figure 3). Thus, larvae of these forms colonizing these areas are exposed to these levels during their development.

The hardshell clams with the exception of <u>Clinocardium</u> occur in areas where usual summer PBI levels are 5 to 10 ppm. <u>Clinocardium,</u> the cockle, occurs further eastward into areas where summer PBI levels are 15 to 35 ppm. Adult cockle populations in these areas suffer

WINTER DIE-OFFS DUE TO PROLONGED REDUCED SALINITIES, HOWEVER (HERRMANN, UNPUBLISHED DATA).

WITHIN THE DISTRIBUTIONS LIMITS OR RANGES FOR EACH CLAM SPECIES SUBSTRATE FACTORS ARE IMPORTANT, AFFECTING CLAM DENSITY AND PERHAPS ALSO SIZE. METAMORPHOSED LARVAE MAY NOT COLONIZE UNSUITABLE SUBSTRATES. FOR JUVENILES AND ADULTS, HIGHER THAN NORMAL MORTALITIES MAY OCCUR WHEN THEY ARE EXPOSED TO STRESSES ASSOCIATED WITH POOR SUBSTRATE QUALITY.

IN RELATING CLAM DENSITIES TO SUBSTRATE CHARACTER, DATA FOR WILLAPA BAY SURVEYS (SMITH AND HERRMANN: 1972) ARE INCLUDED. BOTH BAYS SHARE MANY OF THE SAME CLAM SPECIES. WE WOULD ASSUME THAT OTHER ENVIRONMENTAL CONDITIONS BEING EQUAL IN BOTH BAYS THAT A GIVEN SPECIES SHOULD OCCUPY SIMILAR SUBSTRATES.

FIGURES 8 AND 9 SHOW AVERAGE MYA AND MACOMA DENSITIES AT STATIONS WITH VARIOUS SUBSTRATE ORGANIC LEVELS. BOTH MYA AND MACOMA NATSUTA COLONIZED SUBSTRATES WITH A WIDE RANGE OF ORGANIC CONTENTS (0.4% TO 4.5%) AND MOISTURE CONTENTS (18% TO 50%). THE ORGANIC LEVELS AT THE SURFACE WERE USED IN THIS ANALYSIS. MYA AVERAGE DENSITIES IN GRAYS HARBOR WERE GREATER ON SUBSTRATES WITH 0.5% TO 1% ORGANICS. SUCH SUBSTRATES TEND TO OCCUR IN THE WESTERN BAY (FIGURE 4). IN WILLAPA, THE HIGHER MYA CLAM DENSITIES OCCURRED ON SUBSTATES WITH 2.0% TO 2.5% ORGANIC MATTER. BOTH WILLAPA AND GRAYS HARBOR DENSITY INFORMATION FOR MACOMA NATSUTA INDICATED HIGHEST DENSITIES AT STATIONS WITH 1.% TO 1.5% ORGANIC SUBSTRATES. THIS SPECIES DID NOT OCCUR IN GRAYS HARBOR'S HIGH ORGANIC LEVEL SUBSTRATES AS IT DID IN WILLAPA BAY. SUCH HIGH ORGANIC SUBSTRATES IN GRAYS HARBOR OCCUR IN THE EASTERN BAY WHERE THE LOW SALINITIES MAY NOT BE TOLERATED BY M. NATSUTA.

In both bays *Macoma* densities were higher at stations where substrate moistures were from 30% to 50% than at higher or lower moisture contents. (Figures 10, 11). Mid-depth moisture data were used since we thought these were least affected by conditions of sampling and sample storage. There was a higher density of *Mya* clams on higher moisture substrates in the Willapa samples (Figure 11) but in Grays Harbor densities were higher at stations where moistures were lower 10% to 30%. Moisture content at stations where these two species occurred ranged from 15% to 38%, indicating a need for a fairly firm substrate.

Cryptomya the other clam in the softshell group was more specific in its substrate requirements. At the stations we sampled it colonized most after substrates with low organic levels, (0.15% to 1.1%) usually with moisture contents of 20% to 30%.

For hardshell clams substrate specificity we used the pooled data for *Clinocardium* and *Venerupis* since both species tend to be surface dwellers. Too few stations were sampled in either bay where forms such as *Saxidomus* and *Tresus* occurred. Figure 12 shows average *Clinocardium* and *Venerupis* densities combined on various organic level substrates. Grays Harbor data excluded stations outside the known range of *Clinocardium*. The range of substrates colonized were from 0.5% to 1.5%. Average densities (mainly *Venerupis* clams) are much greater in Willapa than in Grays Harbor, a situation not observed for the softshell clams.

One obvious difference in the substrates inhabited by *Mya* and *Macoma* clams is particle size (Figures 13, 14). Greater *Mya arenaria* densities occurred at stations in both bays where the MGS (median grain size) was larger; densities decreased with decreasing MGS. Conversely, for Macoma natsuta, clam densities tended to be greater at stations where MGS was low than where MGS was high. The limited MGS data for Cryptomya indicates a narrow size preference, around 0.2 to 0.25 mm; substrates with larger and smaller particle sizes are uncolonized. Our MGS data for hardshells is also quite limited; for the few stations where these occurred where MGS was determined there was wide range of particle sizes: 0.2 mm to 0.5 mm. This situation is not unlike that found for Mya.

In summary, nine clam species were found in our survey of Grays Harbor with Mya arenaria and Macoma natsuta being the most abundant and widespread species. The Eastern distribution limits of the two species are the Hoquiam area and the Neds Rock - Johns River area, respectively. The more limited populations of hardshell clams occur only in the more western portions of the bay. We feel this restricted distribution is a reflection of the effect of the low salinities on adult populations in winter rather than of deleterious conditions of pulp effluents to clam larvae in summer. Substrates where softshell type clam populations are found were characterized by low to high organic contents and moisture contents. Mya and the hardshell clams as a group prefer coarser substrates, however, than Macoma. The hardshell clams Clinocardium and Venerupis and Cryptomya are more specific, colonizing lower organic level, generally coarser substrates.

R. B. Herrmann

REFERENCES

1. Beverage, J. P. and M. N. Swecker. 1969. Estuarine studies in upper Grays Harbor, Washington. Geo. Sur. Water Supply Paper 1873-B. 90 p.

2. Emery, K. O. 1938. Rapid method of mechanical analysis of sands. Jour. Sediment. Petrol. 8: 105-111.

3. Fujiya, M. 1962. Evaluation of the effects on bivalves (trans.) in Physiological studies on the effects of pulp mill wastes and aquatic organisms. Naikai Reg. Fish. Lab. Bull. 17. 100 p.

4. Haydu, E. P. 1958. A contribution to the development of oyster bioassay methodology. Weyerhaeuser Company, Longview, Wash. 174 p.

5. Herrmann, R. B. 1969. A study of the Pacific oyster and the estuarine environment in North Bay of Grays Harbor., February 1963 to December 1968. Weyerhaeuser Company, Longview, Washington. 34 p.

6. Ito, S. and Imai, T. 1955. Ecology of Oyster Bed (Part 1). On the decline in productivity due to repeated cultures. Tohoka Jour. of Agri. Res. 5 (4): 251-268.

7. Lassig, J. 1965. The distribution of marine and brackish water lamell. branches in the northern Baltic area. Soc. Sci. Fennica Comment Biol. (Helsinki) 28: 1-41.

8. McAlister, B. and W. Burt. 1959. Recent studies in the hydrography of Oregon estuaries. Ore. Fish Comm. Res. Briefs. 7: 14-27.

9. Phibbs, F. D. 1971. Temperature, salinity and clam larvae. Proc. Nat. Shellfish Assoc. 61 (abst.).

10. National Technical Advisory Committee. 1968. Water Quality Criteria. Marine and Estuarine Organisms. FWPCA: 234 p.

11. Smith, S., and R. B. Herrmann. 1972. Clam distributions and abundances in Willapa Bay and Grays Harbor as related to environmental conditions. Summary report. Weyerhaeuser Company, Longview, Washington. 54 pp.

12. Walne, P. R. 1964. The culture of marina bivalve larvae. In Physiology of the mollusca. Vol. 1, K. M. Wilbur and C. M. Yonge, eds. Academic Press. New York.

13. Westley, R. E. 1967. Phytoplankton photosynthesis and its relationship to oxygen in Grays Harbor, Washington. Wash. Dept. Fish 30 p.

14. Woelke, C. E., T. Shink, and E. Sanborn 1970. Development of an *in situ* marine bioassay with clams. Annual report for period of October 1969 - September 1970. Wash. Dept. Fish 48 p.

15. Woelke, C. E., T. Shink and E. Sanborn 1971. Relative toxicity of treated and untreated MgO pulping wastes. Supplemented Progress Report. Wash. Dept. Fish 9 p.

TABLE I. CLAM DENSITIES AND SIZES AT GRAYS HARBOR STATIONS*

Stations	Mya arenaria #/ft²	Mya arenaria Length	Cryptomya californica #/ft²	Cryptomya californica Length	Macoma natsuta #/ft²	Macoma natsuta Length	Protothaca staminea #/ft²	Protothaca staminea Length	Tapes semi-decussata #/ft²	Tapes semi-decussata Length	Clinocardium nuttalli #/ft²	Clinocardium nuttalli Length	Tresus nuttalli #/ft²	Tresus nuttalli Length	Saxidomus giganteus #/ft²	Saxidomus giganteus Length
Upper Harbor 4	14.3**	1.4	0		0		0		0		0		0		0	
9	1.2	2.9	0		0		0		0		0		0		0	
11	.3	-	0		0		0		0		0		0		0	
12	0	-	0		0		0		0		0		0		0	
16	5.6	.7	0		0		0		0		0		0		0	
18	.4	2.5	0		0		0		0		0		0		0	
19	5.7	2.5	0		0		0		0		0		0		0	
North Bay 21	1.4	2.7	0		0		0		0		0		0		0	
24	1.0	2.9	0		0	2.0	0		0		0		0		0	
25	1.7	2.9	0			1.7	0		0		0		0		0	
26	-	-	--		-	1.8	-		-		-		-		-	
27	-	0.9	-		-		-		-		-		-		-	
28	.9	2.3	0		0		0		0		0		0		0	
34	0		8.0	.6	0		0		0		0		0		0	
35	.2	-	0		0		0		0		0		0		0	
36	1.5	2.5	0		.1	-	0		0		.1	-	0		0	
37	-	.7	-		-		-		-		-		-		-	
38	10.0	2.4	0		.3	-	0		0		.3	-	.3	-	0	
41	5.1	2.5			0	-	0		.2	2.2	.5	1.9	0		.1	
43	.5	-	3.0	.7	1.2	1.6	0		0		0		0		0	
44	0		6.5	.6	1.7	1.2	0		0		0		0		0	
South Bay 49	0		0		0		0		0		0		0		0	
51	0		0		.2	-	0		0		0		0		0	
54	0		0		3.0	1.4	0		0		.2		.2	-	0	
60	.7	2.0	0		0		0		0		0		0		0	

* Stations not listed had no density or size data.

** Non-random sample

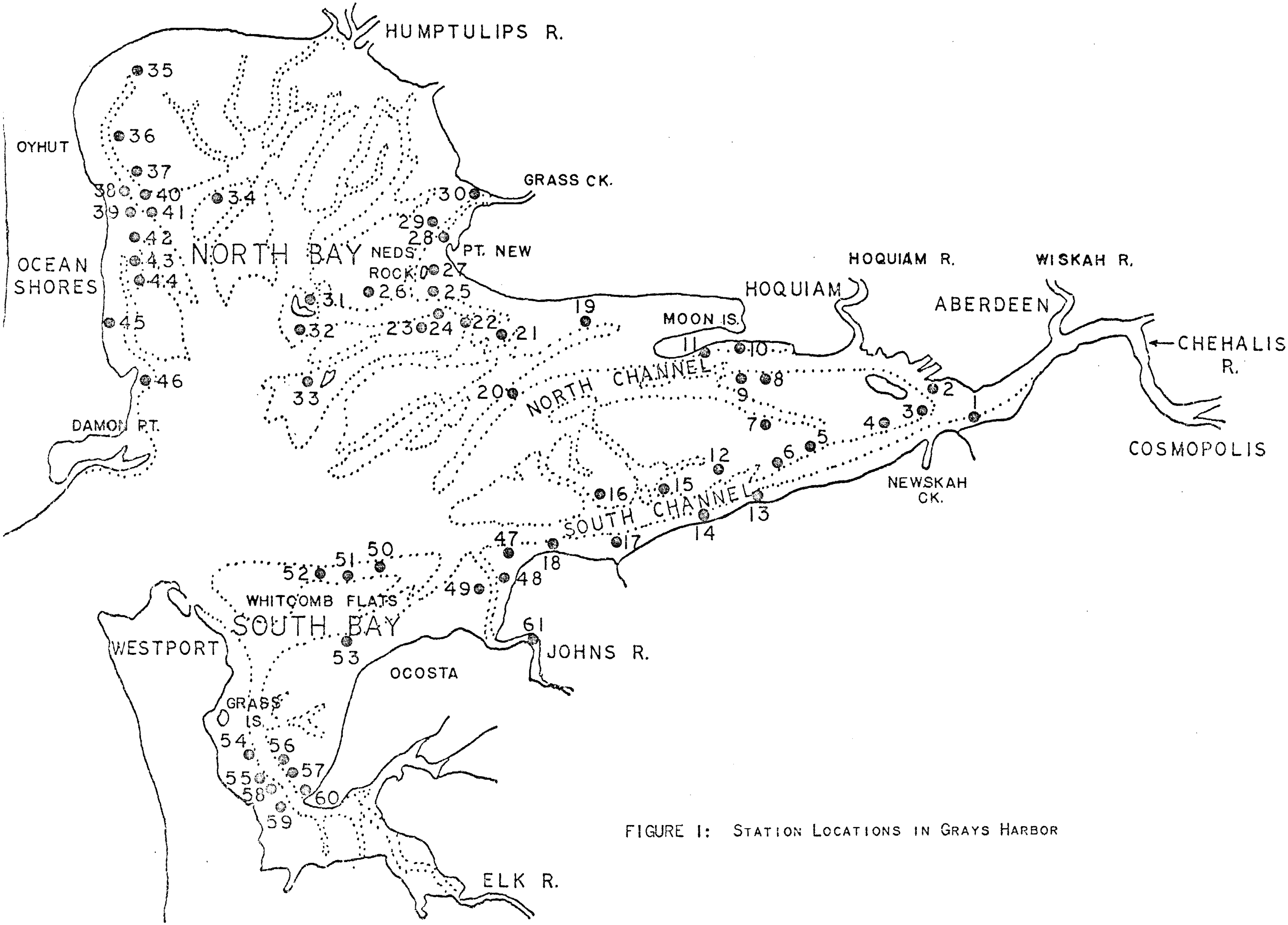


FIGURE 1: STATION LOCATIONS IN GRAYS HARBOR

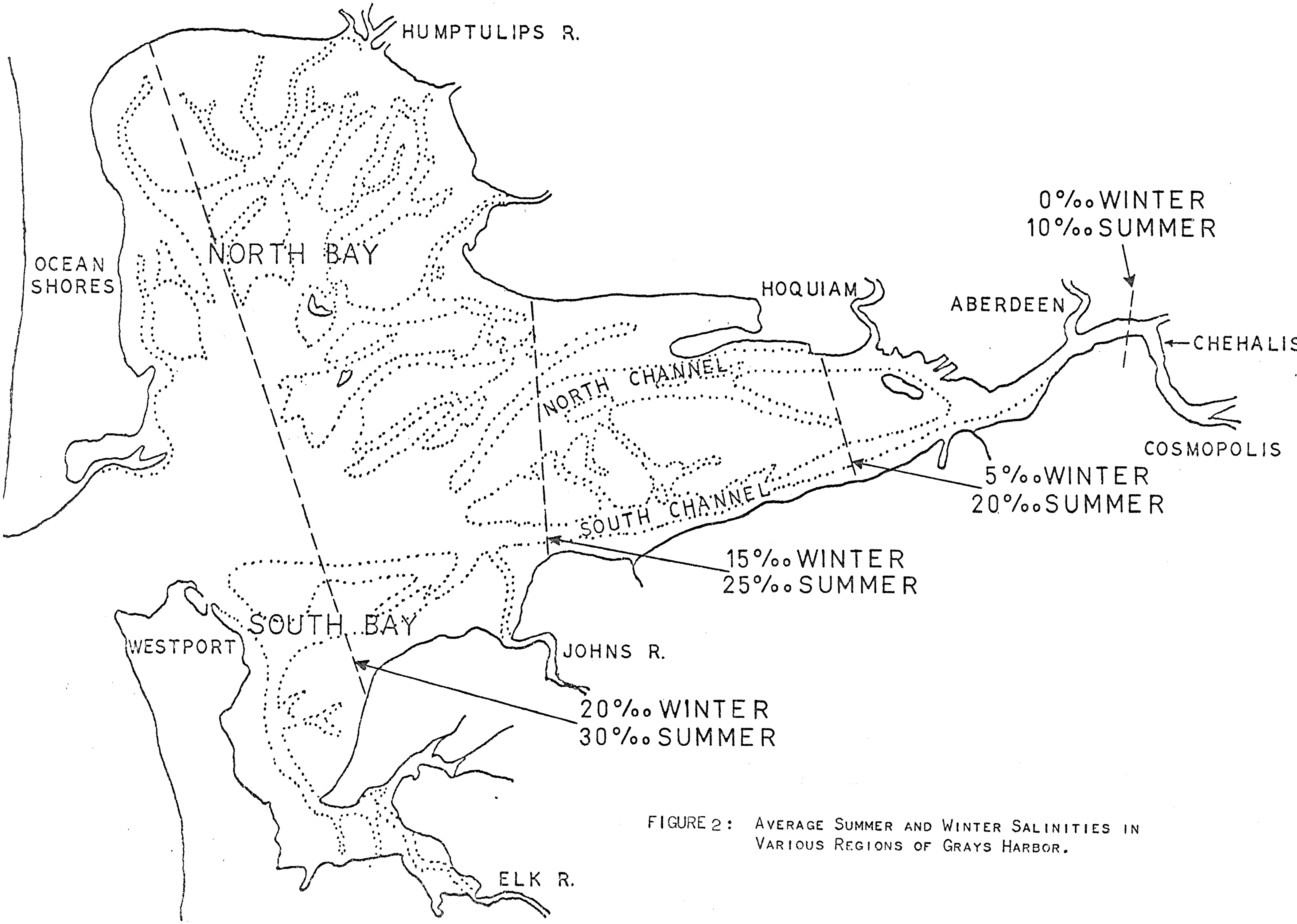


FIGURE 2: Average Summer and Winter Salinities in Various Regions of Grays Harbor.

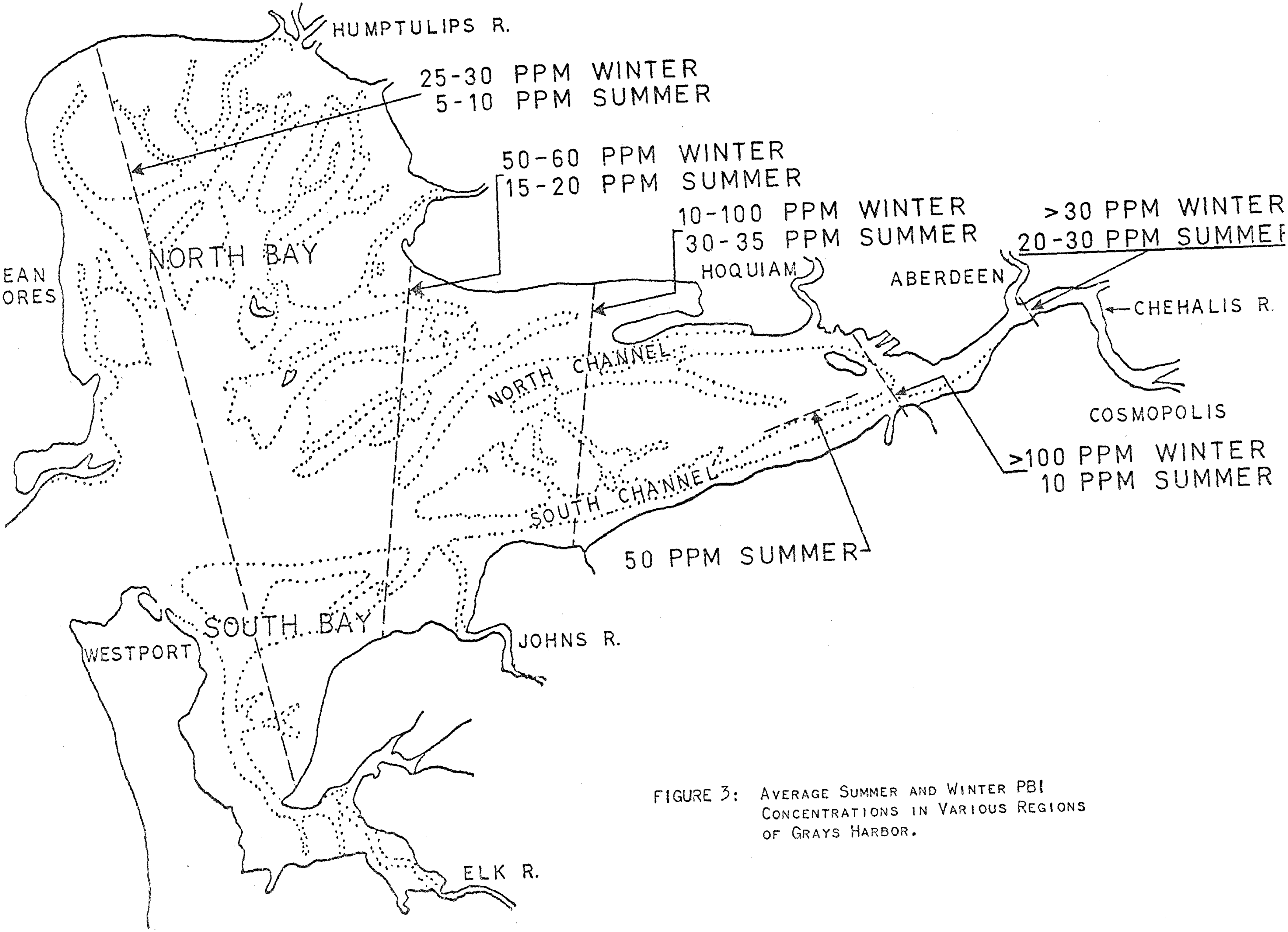


FIGURE 3: AVERAGE SUMMER AND WINTER PBI CONCENTRATIONS IN VARIOUS REGIONS OF GRAYS HARBOR.

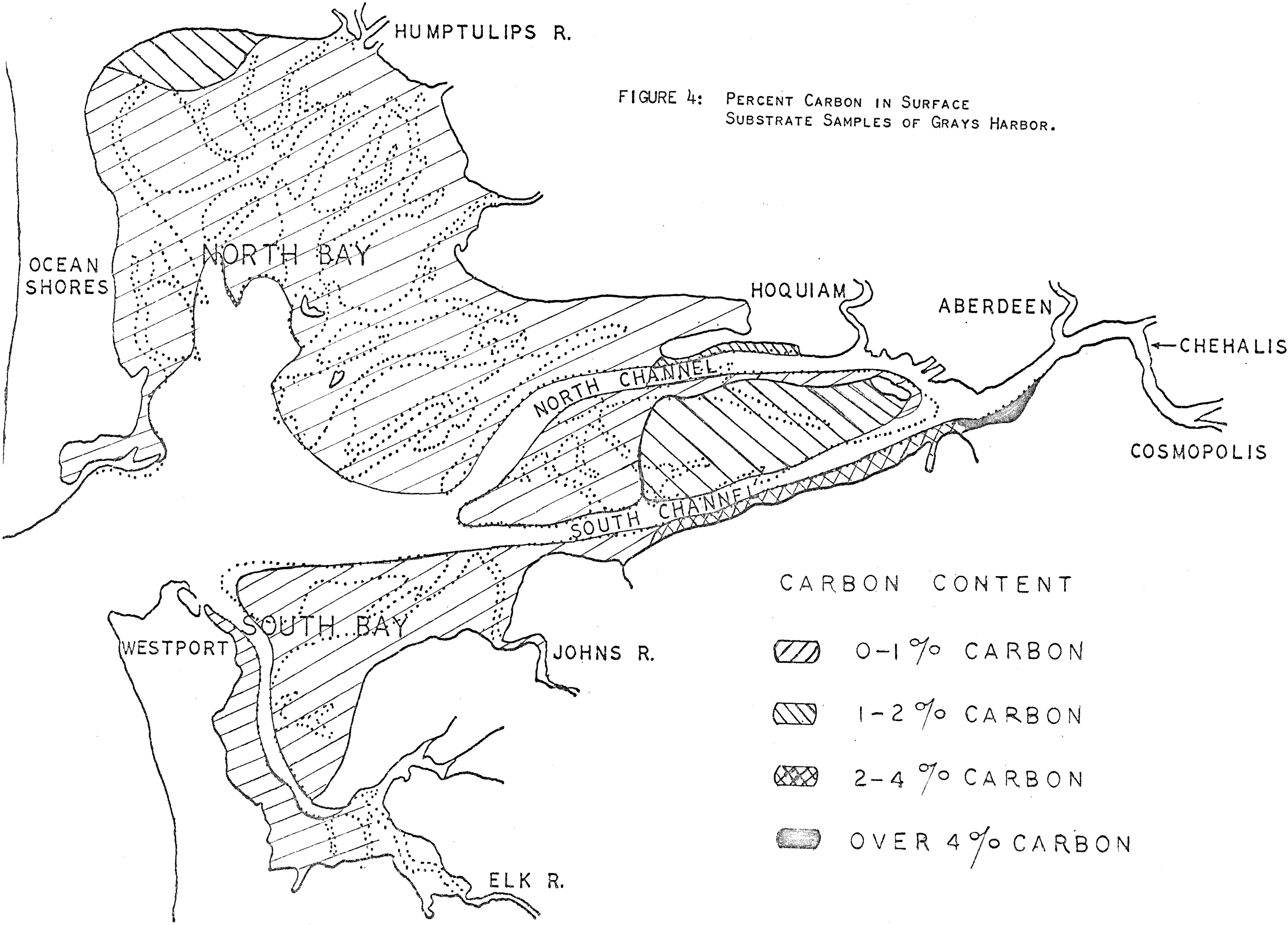


FIGURE 4: Percent Carbon in Surface Substrate Samples of Grays Harbor.

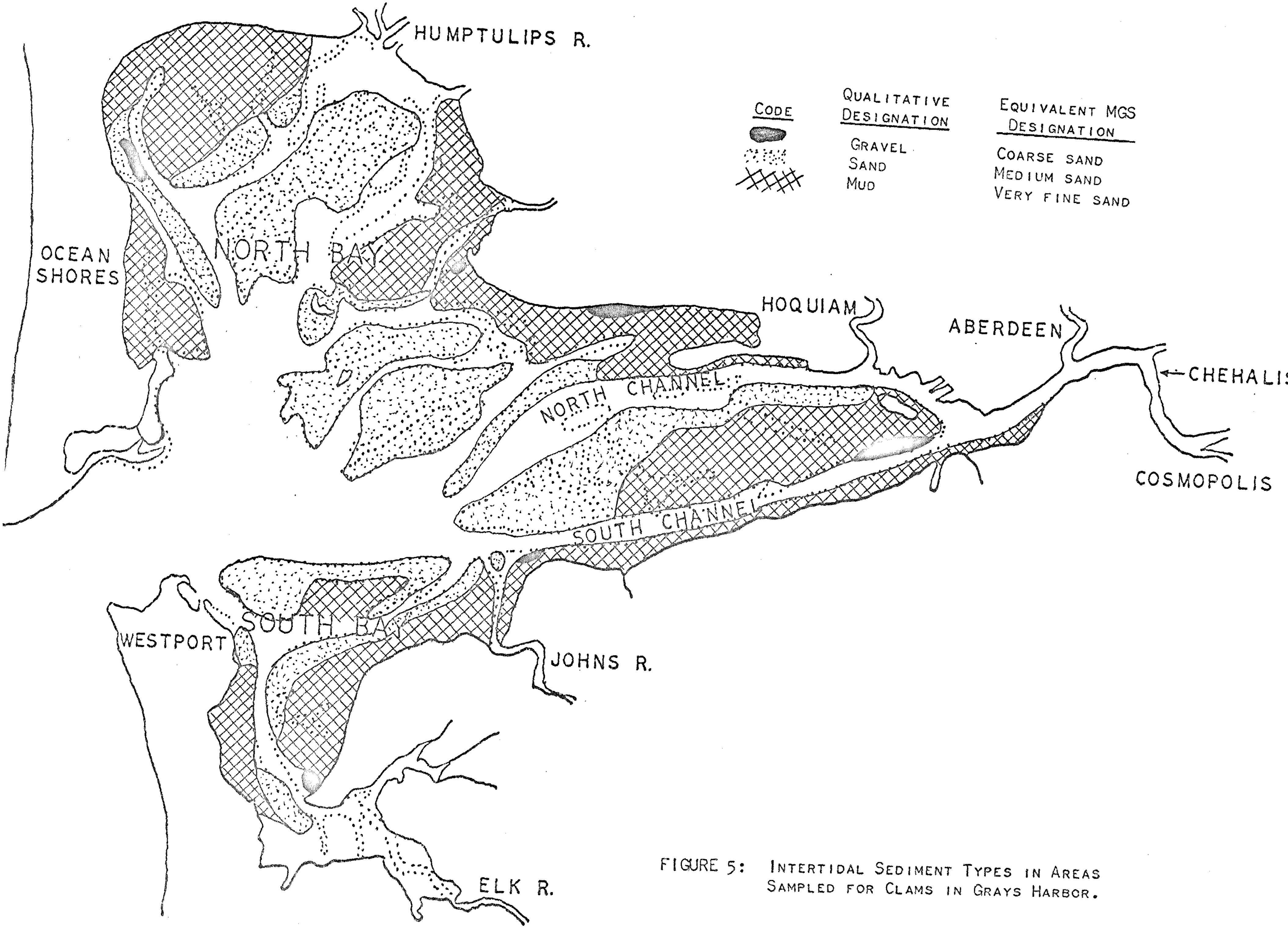


FIGURE 5: Intertidal Sediment Types in Areas Sampled for Clams in Grays Harbor.

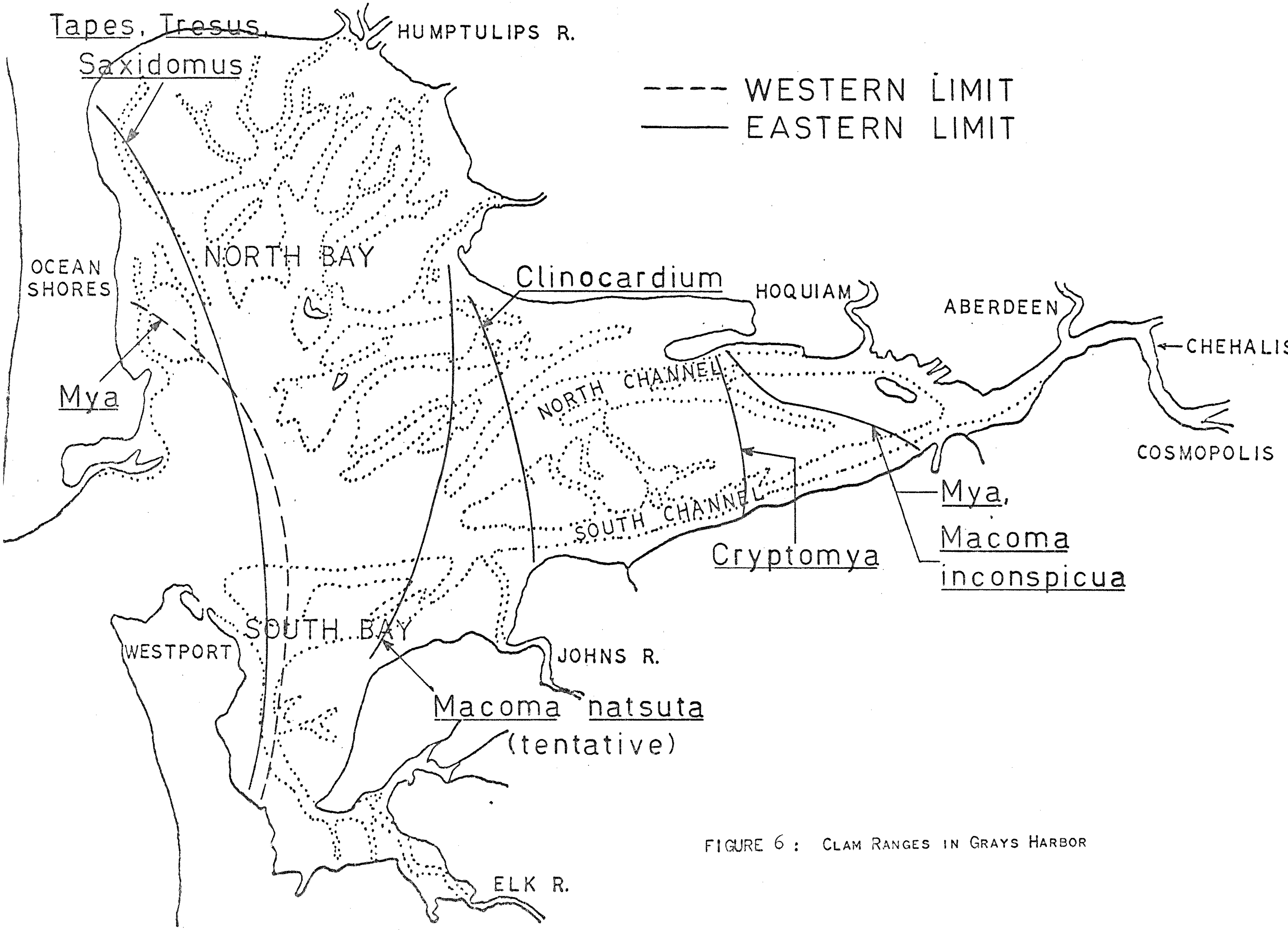


FIGURE 6 : CLAM RANGES IN GRAYS HARBOR

FIGURE 7: AVERAGE CLAM DENSITY AT STATIONS VARIOUS DISTANCES FROM THE BAY MOUTH IN GRAYS HARBOR.

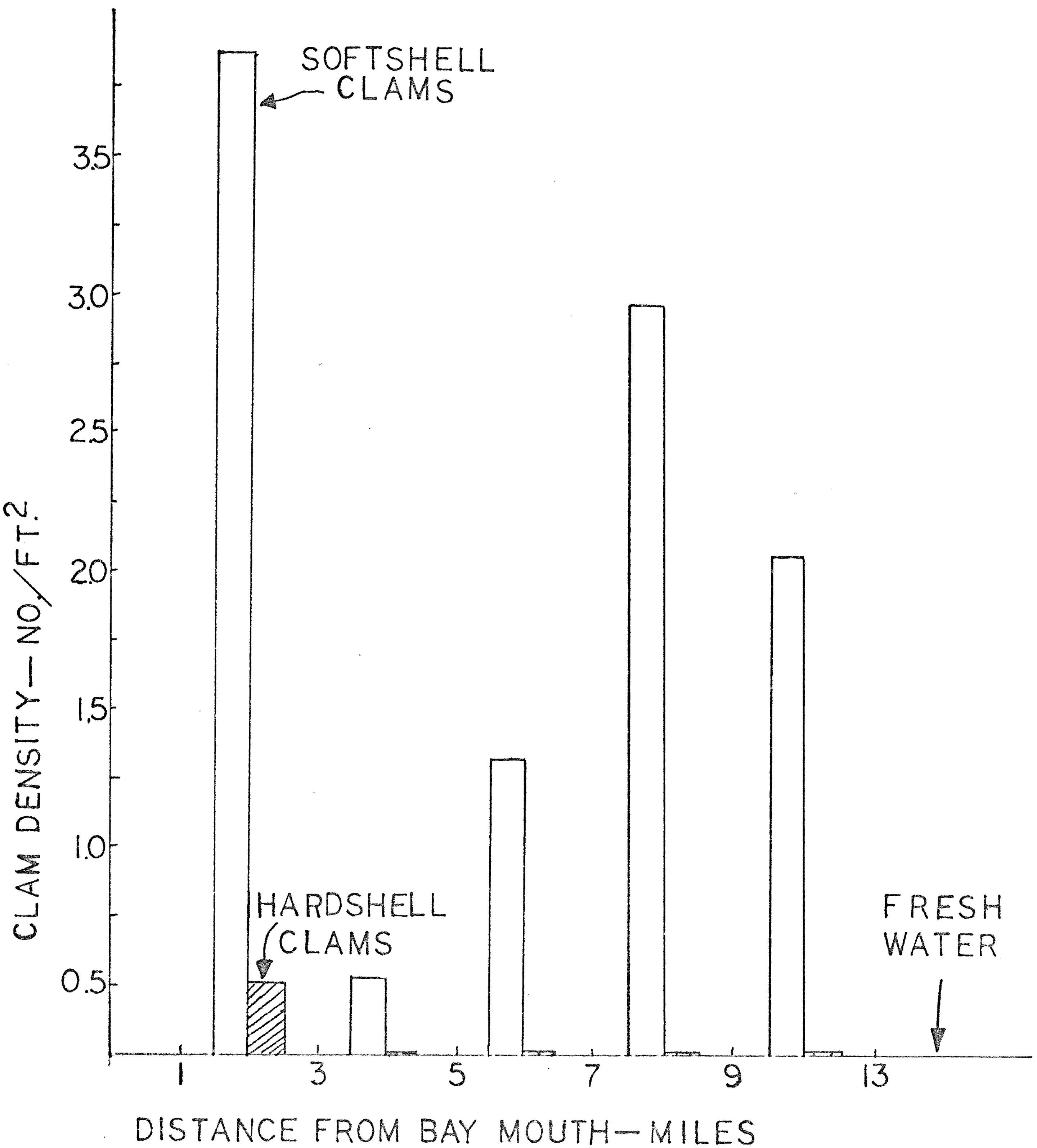


FIGURE 8. AVERAGE DENSITY OF MYA ARENARIA AT STATIONS WITH VARIOUS SUBSTRATE ORGANIC CONTENTS IN GRAYS HARBOR AND WILLAPA BAY.

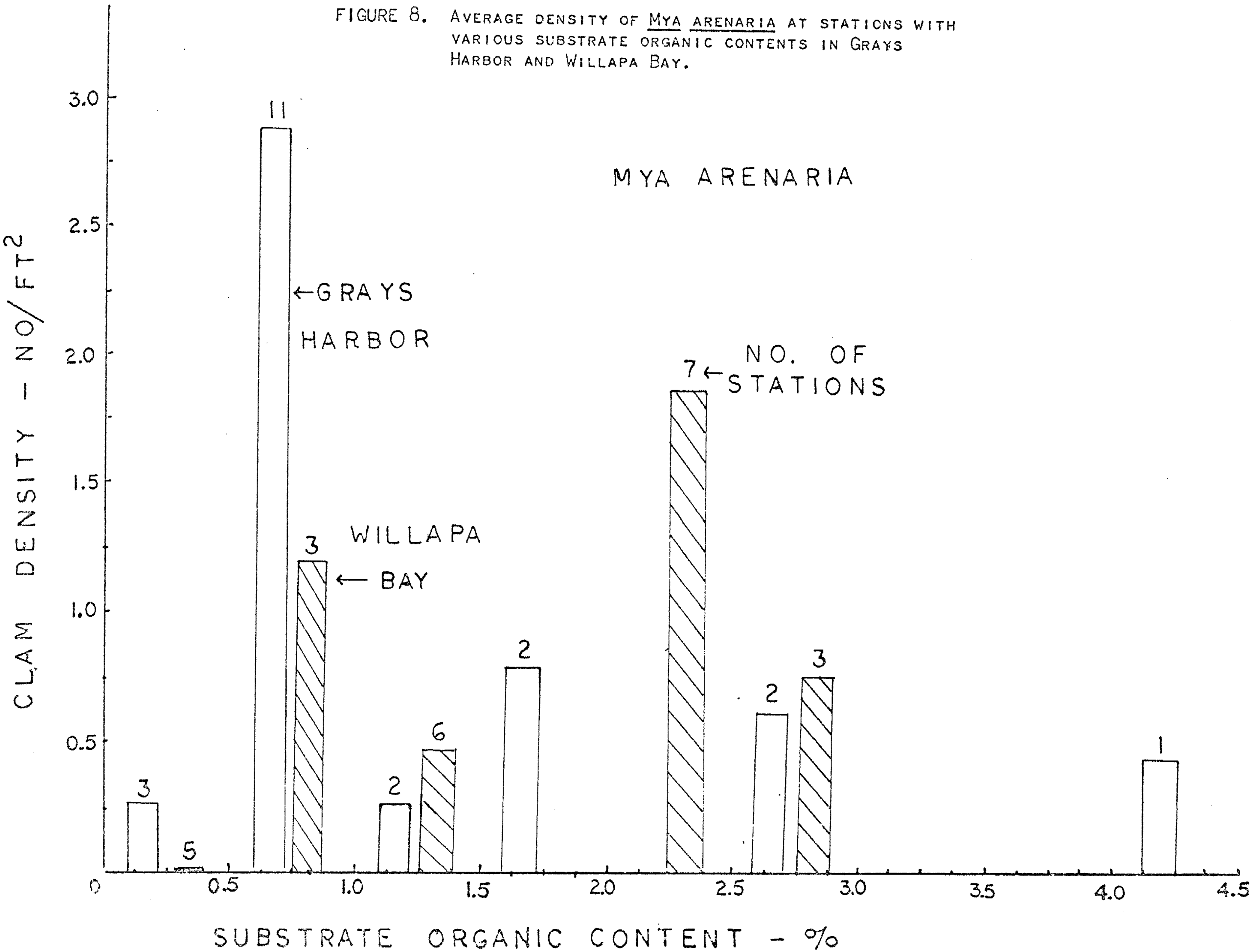


FIGURE 9: AVERAGE DENSITY OF *MACOMA NATSUTA* AT STATIONS WITH VARIOUS SUBSTRATE ORGANIC CONTENTS IN GRAYS HARBOR AND WILLAPA BAY.

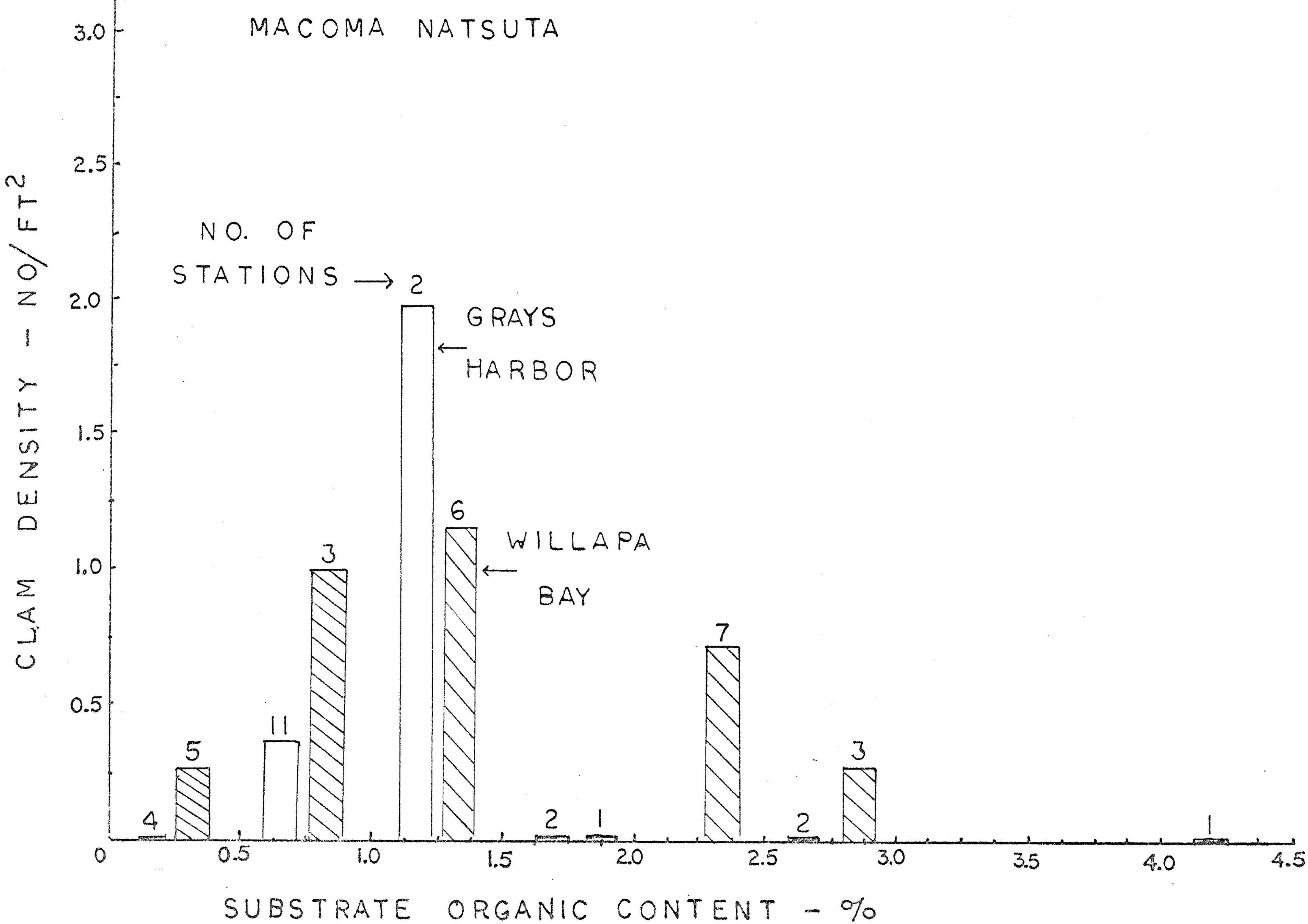


FIGURE 10: AVERAGE DENSITY OF <u>MACOMA NATSUTA</u> AT STATIONS WITH VARIOUS SUBSTRATE MOISTURE CONTENT IN GRAYS HARBOR AND WILLAPA BAY.

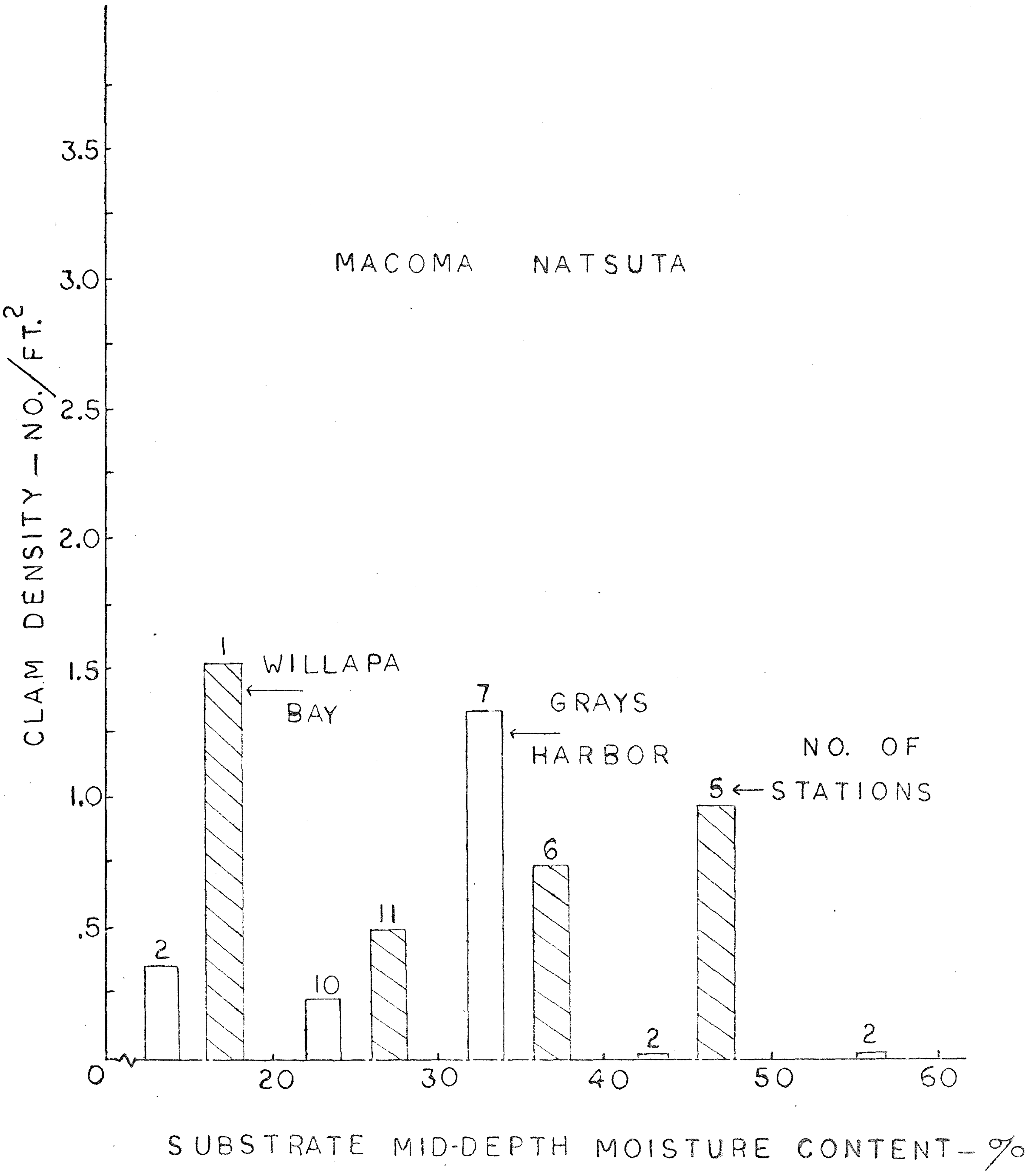
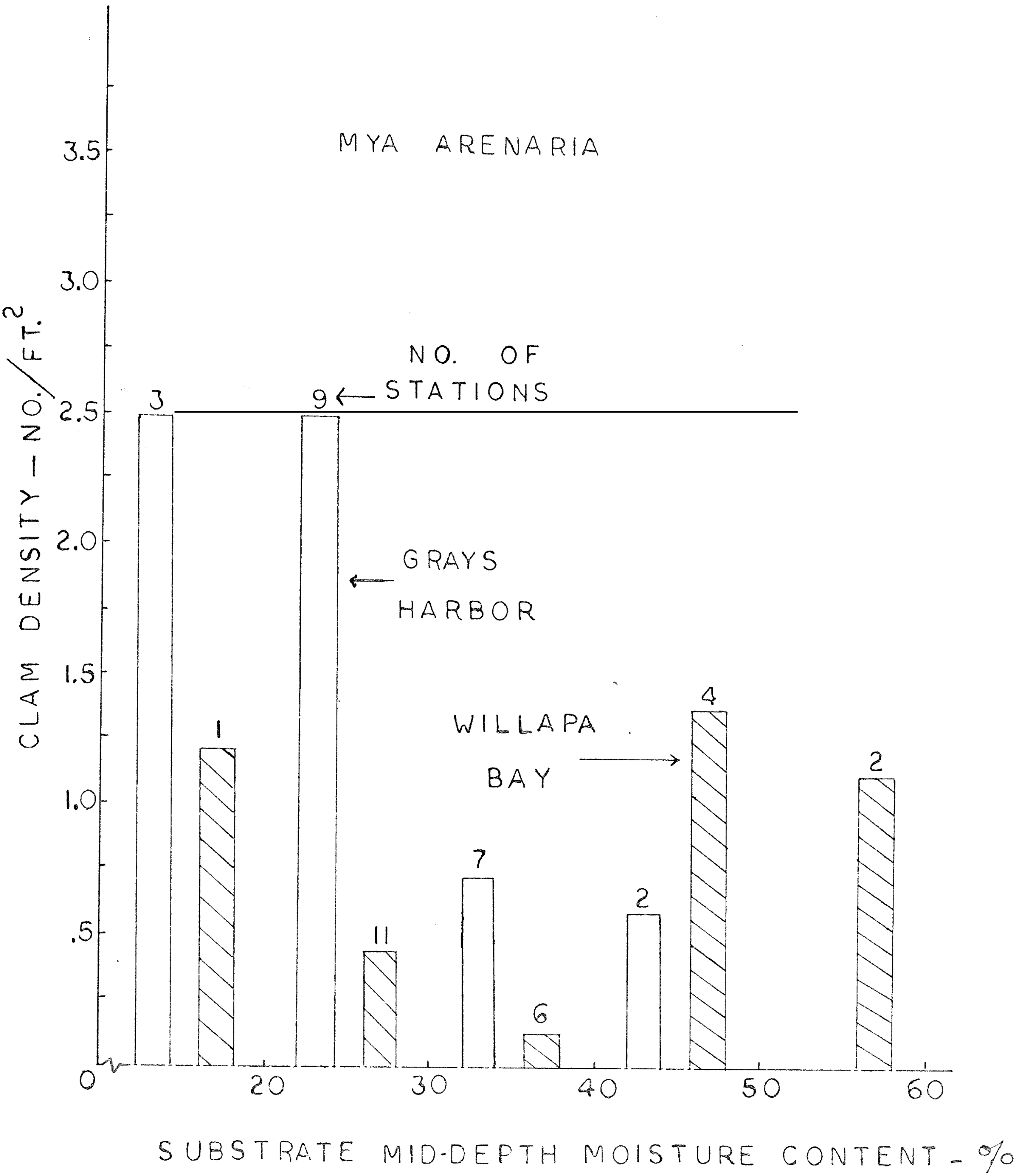


FIGURE 11: AVERAGE DENSITY OF MYA ARENARIA AT STATIONS WITH VARIOUS SUBSTRATE MOISTURE CONTENTS IN GRAYS HARBOR AND WILLAPA BAY.



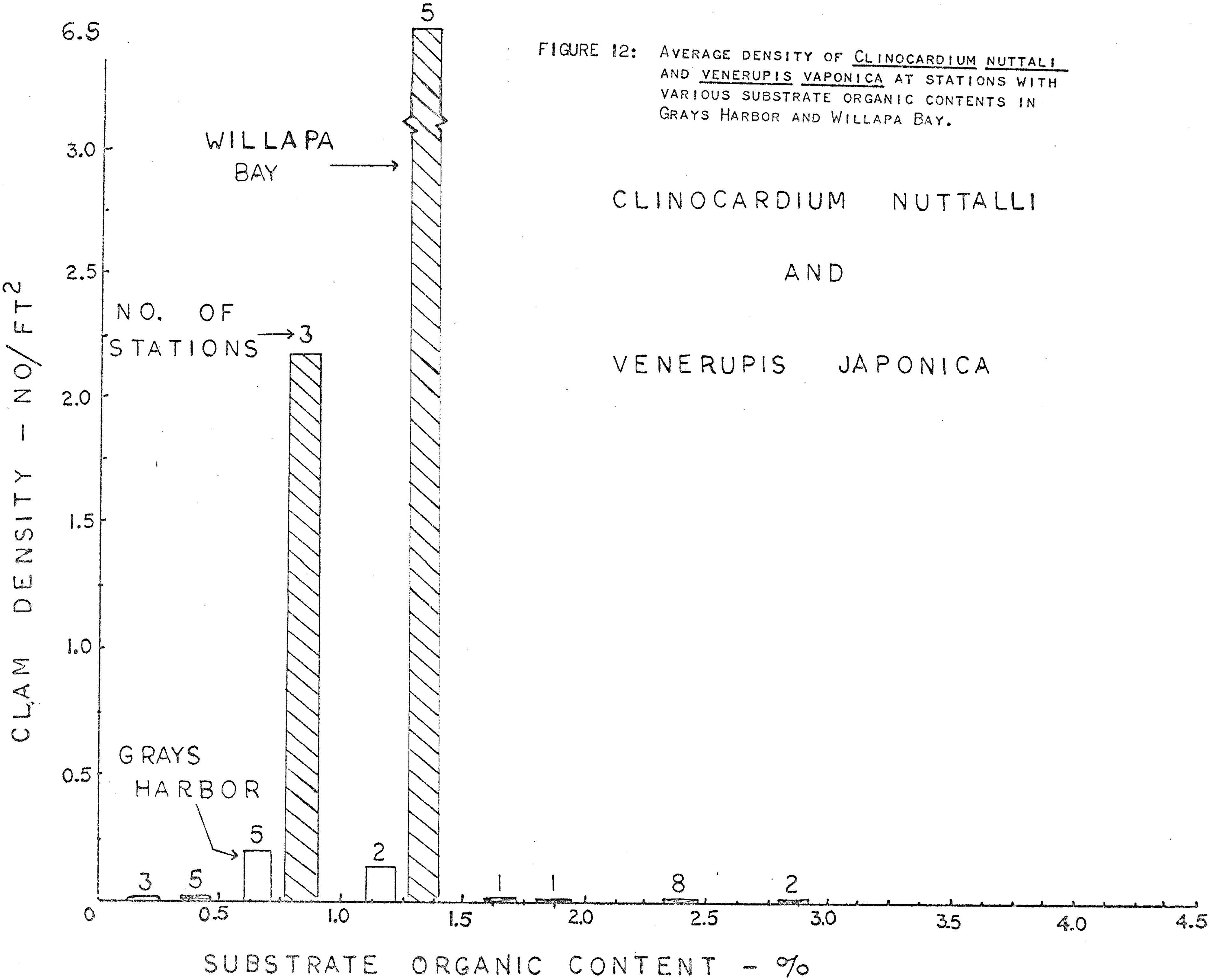


FIGURE 12: AVERAGE DENSITY OF *CLINOCARDIUM NUTTALI* AND *VENERUPIS VAPONICA* AT STATIONS WITH VARIOUS SUBSTRATE ORGANIC CONTENTS IN GRAYS HARBOR AND WILLAPA BAY.

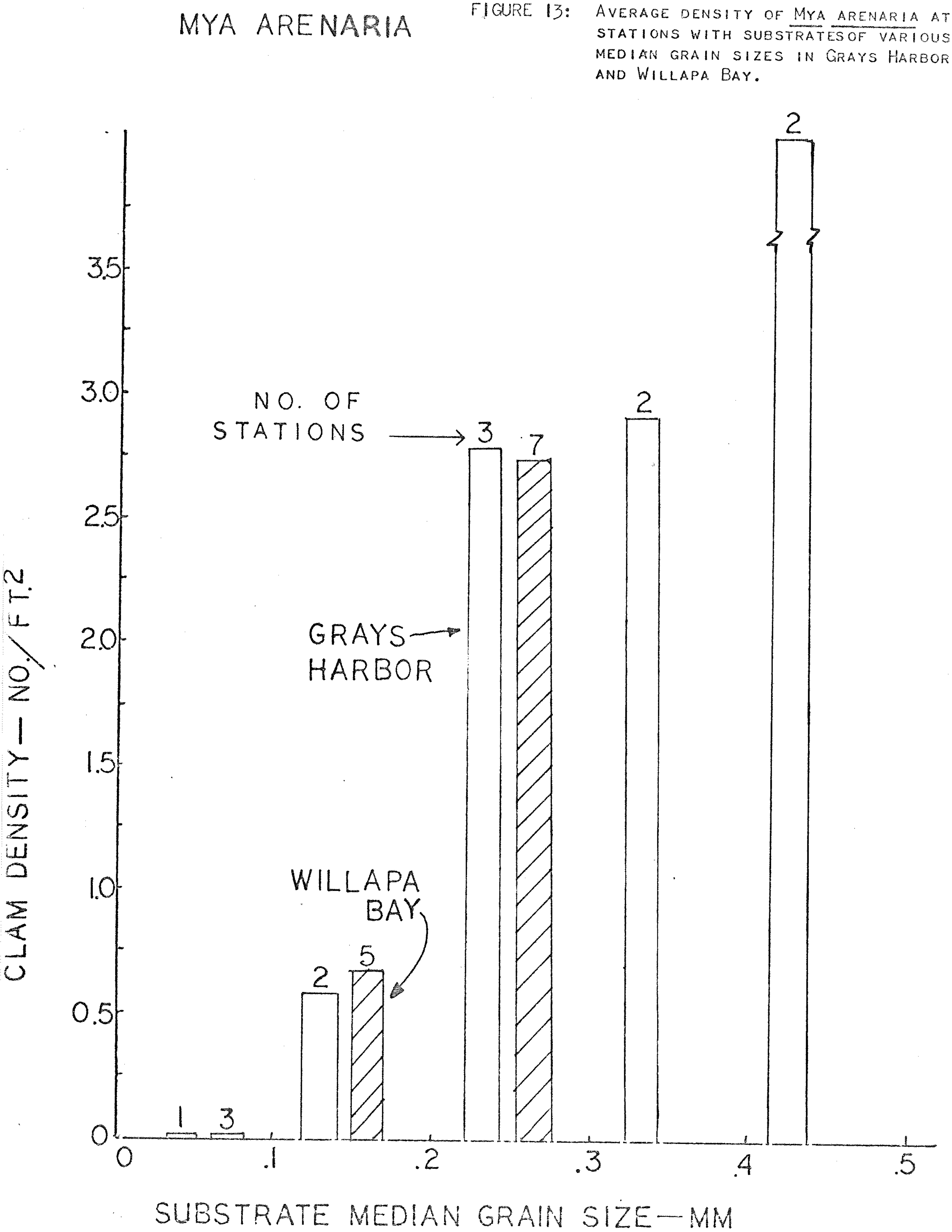


FIGURE 13: AVERAGE DENSITY OF MYA ARENARIA AT STATIONS WITH SUBSTRATES OF VARIOUS MEDIAN GRAIN SIZES IN GRAYS HARBOR AND WILLAPA BAY.

MACOMA NATSUTA

FIGURE 14: AVERAGE DENSITY OF ~~MACOMA NATSUTA~~ AT STATIONS WITH SUBSTRATES OF VARIOUS MEDIAN GRAIN SIZES IN GRAYS HARBOR AND WILLAPA BAY.