DISTRIBUTION AND ABUNDANCE OF SMALL FLATFISHES AND OTHER DEMERSAL FISHES IN A REGION OF DIVERSE SEDIMENTS AND BATHYMETRY OFF OREGON

WILLIAM G. PEARCY[1]

ABSTRACT

Demersal fishes were sampled at seven stations located inshore of Heceta Bank, on Oregon's continental shelf, over a 2-yr period with a 3-m beam trawl designed to catch small flatfishes. Two general assemblages of fishes were recognized: a shallow water (74-102 m), sandy-bottom association where Pacific sanddab, *Citharichthys sordidus*, was numerically the dominant species, and a deeper (148-195 m) assemblage, generally on mud, where the slender sole, *Lyopsetta exilis*, predominated. Rex sole, *Glyptocephalus zachirus*, was usually the second most common species at all stations. Dover sole, *Microstomus pacificus*, ranked fourth to sixth by numbers and composed the largest biomass (wet preserved weight) at three stations. Species diversity was lowest at the shallowest station where sediments were well-sorted, fine sands that contained only 0.1% organic carbon.

The biomass of all fishes captured ranged from 0.9 to 2.4 g m^{-2}. These values are low compared with estimates made by others off Oregon and Washington using commercial-sized otter trawls, presumably because of avoidance of the small beam trawl by large fishes.

An analysis of variance of the catches of all fishes combined, of Dover, rex, and slender soles, and of Pacific sanddab revealed few significant effects of sediment, depth or season. Sediment type had a significant effect on the catches of slender sole—largest catches were on a clayey-silt bottom. Catches of sanddab were inversely related to depth of water. Depth-season interactions were significant for all species combined and for rex and Dover soles, numbers were higher at the deepwater stations during winter than summer, indicating seasonal bathymetric movements. Annual variations were marked—total catches and catches of most species were larger for unknown reasons during 1968 and 1969 than 1970.

Based on length-frequency data, age-group 0 (<50 mm standard length) rex sole were found in high proportions at the deepest stations on the outer edge of the continental shelf. Small sanddab (<70 mm) composed a larger proportion of the catch by numbers on sandy silt than on sand where larger fish predominated.

Both sediment type and depth of water have been correlated with the abundance and species composition of benthic animals. According to Thorson (1957), the physical and chemical composition of sediments may be the main factor in determining the general pattern of distributions of infaunal and epifaunal invertebrates on the level sea floor. Direct influence of bottom type on demersal fishes may be less than on infauna and epifauna, but sediments may affect fishes indirectly by influencing the composition and abundance of available benthic food. Depth of water has frequently been related to faunal changes of both benthic invertebrates and vertebrates across the continental shelf and slope (Sanders and Hessler 1969; Alton 1972; Haedrich et al. 1975). In some studies, these faunal changes were related to concomittant changes in both sediment type and depth (Day and Pearcy 1968).

The influence of depth and sediments on the distribution of the benthos, however, is difficult to separate because these factors are usually closely correlated. Sediment texture generally decreases with increasing depth of water. Small particles are transported from regions of high energy waves and currents into deep, low energy sedimentary environments, while coarse sediments, such as sands, generally are deposited close to their continental source in shallow water.

This study is an attempt to analyze the relationships between sediment and depth on the species composition of benthic fishes and the abundance of small flatfishes in a localized region, mainly inshore of Heceta Bank along the continental shelf of Oregon. The bathymetry and sediments are variable in this region (Figure 1). This is an important factor in this study because the resulting sediment

---

[1] School of Oceanography, Oregon State University, Corvallis, OR 97331.

Manuscript accepted January 1978.
FISHERY BULLETIN: VOL. 76, NO. 3, 1978.

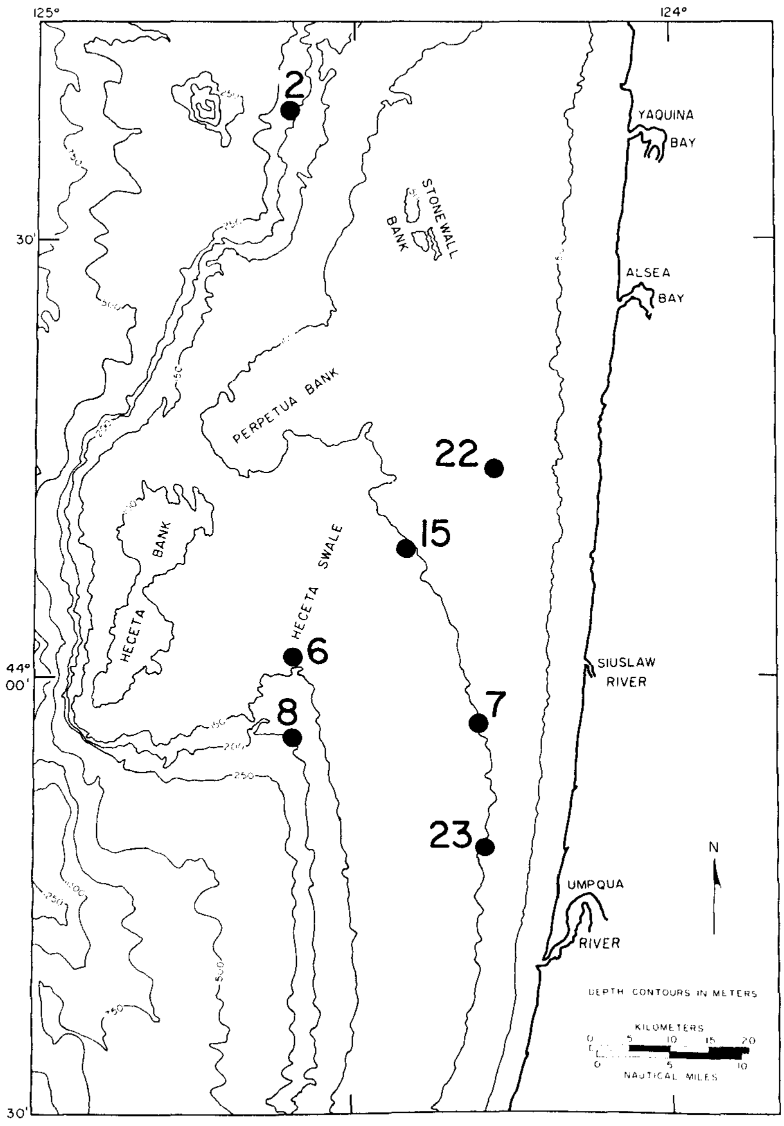

FIGURE 1.—Locations of the seven stations (numbered) off the central Oregon continental shelf that were selected for this study.

types are diverse and do not necessarily grade regularly from coarse sand on the inner shelf to finer sediments with increased depth (Kulm et al. 1975). Because of this heterogenous distribution of sediments, a natural experiment can be designed to differentiate between possible effects of depth and sediment type. Seven stations were selected in an attempt to provide different sediment types at the same depth and the same sediment types at different depths. The region inshore of Heceta Bank produces large commercial catches of flatfishes, such as Dover sole, rex sole, English sole, and Pacific sanddab (Demory et al.[2]).

METHODS

The sediment types for the stations were characterized by the percent sand, silt, and clay, percent of organic carbon and median particle size by Bertrand (1971) and Gunther (1972) (Table 1). A Phleger multiple corer was used to sample sediments. Initially sediments were sampled at the apices of a triangle (sides = 1 n.mi.) and at each

---

[2] Demory, R. L., M. J. Hosie, N. Ten Eyck, and B. O. Forsberg. 1976. Marine resource surveys on the continental shelf off Oregon, 1971-74. Oreg. Dep. Fish Wildl. Rep., 49 p.

TABLE 1.—Average sediment texture, percent organic carbon,[1] and median particle size[2] at the seven stations off Oregon (from Bertrand 1971). Stations are arranged according to depth.

	Station						
Item	22 74 m	7 100 m	23 102 m	15 102 m	6 148 m	2 190 m	8 195 m
Clay (%)	0.9	11.7	23.6	7.3	30.3	14.7	35.3
Silt (%)	0.4	22.1	48.1	8.6	66.6	16.8	62.1
Sand (%)	98.7	63.7	28.3	84.1	3.1	68.5	2.6
Organic C (%)	0.1	0.6	1.3	0.4	1.7	1.0	1.6
Median particle size (Md ϕ)	1.88	4.20	6.01	2.99	6.85	4.62	7.22

[1] The percent organic carbon was estimated by the difference in weight between total carbon and calcium carbonate carbon. Total carbon was determined by dry combustion in a Leco induction furnace and measurement of the evolved CO_2 in a Leco gas analyzer. Calcium carbonate was measured by acidifying ground, dried sediment with 0.1 N HCl and measuring the CO_2 evolved (Bertrand 1971). (Reference to trade names does not imply endorsement by the National Fisheries Service, NOAA.)

[2] $Md\phi = \phi_{50}$, where $\phi = -\log_2 D$ and D = diameter in millimeters. See Inman (1952).

station at the center of the triangle. The upper 2 cm of the cores were analyzed. Sediment particle size was measured by standard procedures (Krumbein and Pettijohn 1938). The coarse sand fractions were analyzed by the settling tube method (Emery 1938). Particle size of sediments in the vicinity of each station was similar (Bertrand 1971). Sediments were also sampled at each station during each cruise. According to Gunther (1972), seasonal variations of sediment grain size parameters within stations were not significant, but significantly different sediment types were found among stations at about the same depths, and fairly similar sediments occurred at different depths.

Three station-pairs were identified that had rather similar sediment characteristics but were located at different depths (Table 1): 1) Stations 6 and 8 (148- and 195-m depth, respectively) had highest percentages of clay and silt, lowest percentages of sand, and the highest organic carbon of all stations; 2) Stations 22 and 15 (74 and 102 m) had sandy sediments with low percentages of clay, silt, and organic carbon; Station 22, however, was almost entirely (99%) well-sorted beach sand; 3) Stations 7 and 2 (100 and 190 m) had 60-70% sand and intermediate percentages of clay and silt (12-22%) and organic carbon (0.6 and 1.0%). Station 2 had a thin overlying layer of silt that was absent at Station 7 (Roush 1970); 4) Station 23 located at 102-m depth, about the same as Stations 7 and 15, was intermediate in sediment texture and organic carbon between stations 7 and 2 and 6 and 8. Thus, stations were recognized with three different types of sediment at about 100 m and two different types at 190-195 m. These sediment types agree with three types recognized by Kulm et al. (1975) for the continental shelf off Oregon: 1) well-sorted detrital sands (former beach sands) with a high quartz content mainly on the inner shelf; 2) patchy mud facies largely at midshelf depths and concentrated near large rivers; and 3) mixed sand and mud between the sandy facies and the outer edge of the shelf. Glauconite, the principal authigenic constituent of shelf sands, occurs around the rocky outcrops such as Heceta Bank and along the outer edge of the continental shelf.

Fishes were collected in beam trawls 3 m or 2.7 m wide and 76 cm high at the same seven stations on the central Oregon continental shelf (Figure 1). This net has a small mesh size (13-mm stretch measure) and mouth opening and therefore caught mainly small species and juveniles of most commerical species. A total of 115 tows were made on nine cruises between August 1968 and August 1970. Trawls were made during daylight hours. Each station was sampled during the four seasons of each year. The trawl was streamed at a ship speed of 3.7 km/h (2 kn), and descended at 30 m wire/min until a scope of 1:4 was achieved, towed for about 15 min (mean, 16 min, SD 5.3), and then retrieved at 30 m wire/min. Two beam trawl tows were made at each station during each cruise with standardized trawling procedures by the same personnel.

An odometer wheel was mounted outside of each skid to provide estimates of the distance trawled over the bottom. Area sampled was calculated from the circumference of the odometer wheels, the number of revolutions recorded on odometer counters, and the distance between the skids (see Carey and Heyamoto 1972).

The two odometer readings for a tow were usually similar. Where they differed, I used the highest reading and assumed that slippage of the wheel in sediments or jamming by sea pens, etc. caused the low reading. Rigid stops were mounted on the skid frame to prevent turning of the wheels until they contacted the bottom.

The effectiveness of odometer wheels to estimate distance traversed by the beam trawl on the bottom has been assessed by Carney and Carey.[3] They recognized slippage of the wheels in the sediment and failure of the footrope to effectively tend the bottom at all times as possible errors in measuring actual areas sampled. For these

---

[3] Carney, R. S., and A. G. Carey, Jr. A report on the effectiveness of metering wheels for measurement of the area sampled by beam trawls. Unpubl. manuscr., 17 p.

reasons, catch per tow was used as a supplementary estimate of abundance in addition to catch per square meter derived from odometer readings.

All fishes were preserved with 10% buffered Formalin[4] at sea, and identified, measured (standard length, SL) and weighed (wet preserved weight) ashore.

RESULTS AND DISCUSSION

Fish Assemblages

The rank order of abundance of the 10 most common species are shown in Table 2. Pacific sanddab, *Citharichthys sordidus*, was the numerical dominant at the four shallowest (74-102 m) stations where it composed 25-86% of the total number of fishes captured. At the three deepest (148-195 m) stations, slender sole, *Lyopsetta exilis*, ranked first in abundance where it composed 38-42% of the number of fishes collected. Rex sole, *Glyptocephalus zachirus*, ranked second in abundance at all stations (except at Station 6 where it was third). The high rank of rex sole at all stations corroborates Hosie's [5] observation that rex sole is probably the most widely distributed sole on the continental shelf and upper slope off Oregon, occupying a large bathymetric range with diverse sediments. Dover sole, *Microstomus pacificus*, ranked fourth at the four inshore stations and fifth or sixth at the deeper stations.

Demory's (1971) study off northern Oregon and southern Washington showed that these flatfishes were most abundant at the following depths:

TABLE 2.—Ranks of the 10 most numerically abundant fishes at each of the seven stations, and the presence (+) of these species at other stations if they did not rank among the top 10. Absence of either a number or (+) indicates that a species was not captured at that station.

	Station						
Item	22 74 m	7 100 m	23 102 m	15 102 m	6 148 m	2 190 m	8 195 m
Citharichthys sordidus	1	1	1	1	6	+	4
Glyptocephalus zachirus	2	2	2	2	3	2	2
Microstomus pacificus	4	4	4	4	5	6	6
Lyopsetta exilis	8	5	6	6	1	1	1
Lycodopsis pacificus	+	3	3	10	2	8	3
Xeneretmus latifrons	+	+		+	4	3	7
Cymatogaster aggregata	5	6	7	3	+		
Parophrys vetulus	3	10	8	5			+
Sebastes juveniles					7	5	5
Eopsetta jordani	6	9	+	+	+		+
Sebastes crameri		7	5	+	9	10	10
Asterotheca pentacanthus			+		+	4	+
Poroclinus rothrocki		8	9	+	+		8
Thaleichthys pacificus	9	+	+	+	+	7	+
Allosmerus elongatus				7			
Icelinus borealis	7						
Merluccius productus		+	+	+	8	+	+
Sebastes elongatus					+	+	9
Radulinus asprellus	+	+	+	8	+		
Sebastes diploproa						9	+
Engraulis mordax		+	+	9	+		
Eptatretus stoutii		+	+	+	10	10	+
Microgadus proximus	10	+	+	+	+		
Citharichthys stigmaeus			10				+
Dominance and diversity information							
No. tows	15	15	16	15	17	18	16
No. fish	776	1,921	1,161	1,357	2,175	732	1,091
Percent of no. made up by dominant sp.	86	45	25	53	41	38	42
No. spp.	19	25	24	24	34	35	34
Diversity (H_e)	0.70	1.62	2.16	1.66	1.77	2.47	2.00
Number and biomass of fishes captured per square meter[1]							
All species (no./100 m^2)	1.7	4.0	3.0	2.4	4.0	1.4	1.6
(g/m^2)	1.2	2.2	1.4	1.1	2.0	0.9	1.2
(g/m^2 (TS))	1.2	2.3	1.5	1.7	2.4	0.9	2.0
Dover sole (g/10 m^2)	0.2	5.1	3.7	1.4	3.0	2.6	2.8
Rex sole (g/10 m^2)	2.2	3.2	2.0	2.4	2.3	0.2	2.0
Slender sole (g/10 m^2)	<0.1	0.7	0.8	<0.1	5.2	0.8	2.5
Pacific sanddab (g/10 m^2)	9.8	5.8	2.3	6.6	0.6	<0.1	0.4

[1] Based on odometer readings and based on estimates of distance trawled from times and ship's speed (TS).

---

[4] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[5] Hosie, M. J. 1976. The rex sole. Inf. Rep. 76-2, Oreg. Dep. Fish Wildl., 5 p.

Pacific sanddab, 37 to 90 m; slender sole, 90 to 183 m; small (≤180 mm TL) rex sole, 55 to 183 m; and small (≤180 mm TL) Dover sole, 55 to 150 m. Therefore the stations sampled in my study were not shallow enough to include all of the major depth range inhabited by Pacific sanddab, rex sole, or Dover sole. Furthermore, large Dover and rex soles are known to be distributed in deeper waters of the upper continental slope off Oregon (Demory 1971; Hosie see footnote 5; Demory[6]), regions unsampled in this study.

The ranks of the dominant species as well as the presence of other species implies a shallow water (74-102 m) and a deepwater (148-195 m) assemblage of fishes. *Cymatogaster aggregata* and *Parophrys vetulus* ranked within the top 10 species at the shallowest Stations 22, 7, 23, and 15 but not at deep Stations 6, 2, and 8 where they were usually absent. *Xeneretmus latifrons* and *Sebastes* juveniles, on the other hand, were only abundant at the deep stations.

Similarity among the stations was calculated as

$$\mathrm{SIMI} = \frac{\sum_{i=1}^{S} P_{1i} P_{2i}}{(Sd_1)\,(Sd_2)}$$

where S is the number of species present at both stations; P_{1i} is the proportion of the ith species at one station; P_{2i} is the proportion of the ith species at a second station; and $(Sd_1)\,(Sd_2)$ is the product of the square roots of estimators of Simpson's diversity index for Stations 1 and 2. This measure of similarity was used because it is analogous to a correlation coefficient, relates closely to Simpson's measure of concentration, and has maximum and minimum values of 1 and 0 (McIntire and Moore 1977).

Two assemblages of fishes, a deep and a shallow one, were evident based on high similarity in the species composition among the three deepest stations (2, 6, 8) and among three of the four shallow stations (15, 22, 7) (Table 3). Similarity between stations of each of these two groups varied from 0.85 to 0.95. Station 23, another station at about 100 m (like Stations 7 and 15) also had a fairly high similarity with the other shallow water stations. It was similar to Station 7 (0.92 m) but less similar to Stations 15 and 22 (0.77 and 0.65 m). The benthic environment of Station 23 differed from the other three shallow stations in that it had more than twice the percentage of clay and silt found at Station 22, 7, or 15, where sand was the major sediment component.

TABLE 3.—Indices of similarity (SIMI) for the species composition of fishes among each of the seven stations. Stations are arranged by depth.

	Station					
Station	22	7	15	23	6	2
Shallow:						
22						
7	0.86					
15	0.94	0.93				
23	0.65	0.92	0.77			
Deep:						
6	0.05	0.33	0.14	0.57		
2	0.04	0.26	0.13	0.38	0.85	
8	0.18	0.45	0.29	0.58	0.91	0.95

Based on sediment composition two of the three station pairs were very similar (Table 3): Stations 22 and 15 (SIMI = 0.94), and Stations 6 and 8 (SIMI = 0.91). Stations 7 and 2, another station pair, at 100 and 190 m, had a similarity of only 0.26. This disparity may be explained by the thin layer of silt overlying a predominantly sandy sediment at Station 2. For epifaunal organisms the sediment type at this station may have been more similar to that at Stations 6 and 8 than any other stations. This may explain why Station 2 is so similar in species composition to Stations 6 and 8. However Station 7 showed high similarity (0.92-0.93) with Stations 15 and 23, stations with different sediment types but both at the same depth. Thus clear separation of the effects of depth and sediment was not always possible. Nevertheless the most consistent and obvious assemblages were correlated with depth. Stations of different sediment types had high similarity within the shallow water assemblage.

These results agree with those of Day and Pearcy (1968) who studied the distribution of demersal fishes from 40 to 1,829 m along a transect just north of Heceta Bank. They delineated a species association at depths of 42-73 m on sandy sediments with Pacific sanddab as the dominant species and an association at 119-199 m on silty-sand sediments where slender sole predominated. Because the same species associations sometimes were found on different sediment types, they felt that factors other than sediment texture may govern the distribution of fish assemblages.

Diversity

The number of species of fishes collected was

---

[6] Demory, R. L. 1975. The Dover sole. Oreg. Dep. Fish Wildl. Inf. Rep. 75-4, 4 p.

highest (34-35) at the deep stations, intermediate (24-25) at the 100-m stations and lowest (19) at the shallow station (Table 2B). Species diversity calculated by the information function (Shannon and Weaver 1963):

$$H_e = -\Sigma_{pi} \ln_{pi},$$

varied between 0.7 and 2.5 at the seven stations. Diversity was lowest at the shallow, sand station where sanddab composed 86% of the catch. Diversity was highest at Station 2, which had the largest number of species, and next highest at Station 23, where the dominant species composed only 23% of the total number of fishes. Since the number of species was similar among the three 100-102 m stations or the three deep (148-195 m) stations, differences in diversity within these two groups are due to variations in the evenness of the proportions of the various species.

The values of diversity are similar to those found by others for demersal fish communities. Margalef (1968) reported that diversity (H) of bottom fishes trawled off the Spanish Mediterranean ranged from 1.0 to 2.4. Haedrich and Haedrich (1974) calculated $H = 0.7\text{-}1.7$ for demersal fishes of Block Island Sound [from the data of Merriman and Warfel (1948) and Richards (1963)], and $H = 1.6\text{-}1.8$ for bottom fishes on the continental slope off southern New England. Haedrich et al. (1975) give a value for H of 1.9 for 141-285 m on the continental slope south of New England.

Biomass Estimates

Based on odometer estimates of distance trawled, numbers varied from 1.4 to 4.0/100 m^2, and biomass ranged from 0.9 to 2.2 g m^{-2} (Table 2). Estimates of the biomass of fishes based on ships's speed (3,700 m h^{-1}), average trawling times on the bottom (16 min) and the width of the beam trawl are in agreement with the estimates that used odometer readings.

The biomass of the four common flatfishes at each station shows that the Pacific sanddab composed nearly all the biomass at Station 22 and also had the largest biomass at Stations 7 and 15. Dover sole predominated in catches at Stations 23, 2, and 8, and slender sole was the dominant fish at Station 6. These trends are similar to those noted earlier for species numbers (Table 2).

Catches of demersal fishes with the small beam trawl at these seven stations are low compared with other estimates made with commercial-sized otter trawls off Oregon and Washington. On the basis of surveys using an otter trawl with a 23-m footrope with 9.9-cm mesh (estimated to have a 9-m horizontal and a 1.5-m vertical mouth opening), Demory and Hosie[7] calculated that the average biomass of fishes on the continental shelf of Oregon was 19 g m^{-2} in 1971-72 and 16 g m^{-2} in 1973-74. Barss et al.[8] employed similar methods to estimate a standing stock of trawlable fishes on the continental shelf and upper slope (18-549 m) of Washington of about 15 g m^{-2}. In both of these studies, a large portion of the catch consisted of rockfishes, *Sebastes* spp., Pacific hake, *Merluccius productus*, other roundfishes, skates, and other elasmobranchs. The average biomass of flatfishes, the type of fishes that their trawl was designed to catch, was 5.7 and 5.4 g m^{-2} for 1971-72 and 1973-74, respectively, off Oregon and 9.0 and 7.5 g m^{-2} for 1975 and 1976 off Washington. Alverson et al. (1964), also using large otter trawls (28-m footrope) with large (11-cm) mesh, provided data from which a biomass of 8.0 g m^{-2} for demersal fish and 3.1 g m^{-2} for flatfishes can be estimated for the continental shelf of Oregon and Washington. Our estimates are also low compared with the values given by Oviatt and Nixon (1973) for New England waters.

Although all these values are approximations dependent on the accuracy of estimates of actual distance trawled and the effective mouth area, the otter trawl catches are several times larger than my beam trawl estimates. Nektobenthic fishes, such as hake and rockfishes, as well as large demersal flatfishes and skates are poorly sampled with the beam trawl because they are not available to the net or they avoid the trawl (see also Day and Pearcy 1968). Thus, retention of small species of fishes and juveniles of large species by the beam trawl, fishes that may escape through the meshes of the larger nets, do not compensate for fishes that avoid the beam trawl or nektobenthic species that range above the bottom.

Kuipers (1975) estimated that the catch efficiency of a 2-m beam trawl decreased exponentially with increasing length of plaice, *Pleuronectes platessa*, from approximately 100%

---

[7] Demory, R. L., and M. J. Hosie. 1975. Resource surveys on the continental shelf of Oregon. Fish Comm. Oreg., Annu. Rep., 9 p.

[8] Barss, W. H., R. L. Demory, and N. Ten Eyck. 1977. Marine resource surveys on the continental shelf and upper slope off Washington, 1975-76. Oreg. Dep. Fish Wildl. Rep., 34 p.

for plaice under 7 cm to 15-30% for plaice over 15 cm. Riley and Corlett (1965) and Edwards and Steele (1968) estimated catch efficiencies of 57% and <45% for 0-group plaice in 2-m and 4-m beam trawls, respectively. In this study, the 3-m beam trawl caught about one-fourth the biomass of flatfishes per square meter caught by Demory and Hosie (see footnote 7) off Oregon, indicating a low catch efficiency.

The length-frequency distributions of Pacific sanddab and rex sole caught in the beam trawl are compared in Figure 2 with those caught in two larger otter trawls with large-sized mesh by Demory and Robinson[9] off Oregon. The small-meshed beam trawl retained appreciably smaller individuals than the otter trawls, verifying that it was most effective in capturing small flatfishes and that large fishes effectively avoided this small net.

The disparity between the estimates of abundance by otter trawls and the beam trawl may be magnified by the effects of otter doors, bridles, and towing cables. The bridles from the otter doors to the net (sweeplines and dandy lines) in combination with the wake from the doors can herd fishes into the net from a wide area in front of the trawl, thereby increasing the effective mouth opening (Loverich[10]). Thus the abundance estimates cited above that are based on the horizontal spread of otter trawl nets are probably too large. The towing cable of the beam trawl, on the other hand, drags on the bottom immediately in front of the trawl and therefore may frighten fishes away from the net tow path. Size-dependent responses of fishes to the bottom disturbances created by trawl doors, bridles, and cables may contribute to the differences found in size of fishes captured by the two types of trawls. Large fishes, with better swimming capabilities, may be herded more effectively by otter trawl bridles than small fishes. Large fishes may also rapidly swim away from the towing cable of the beam trawl.

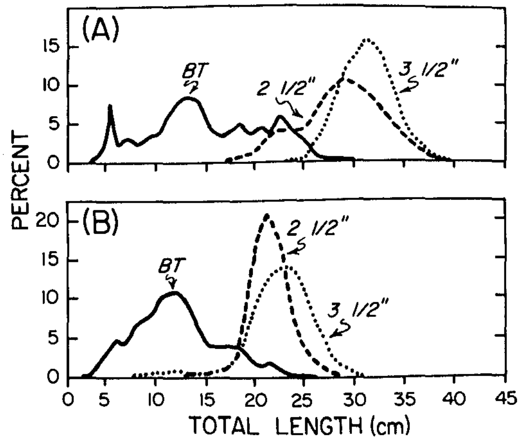

FIGURE 2.—Comparison of length-frequency distributions of (A) rex sole and (B) Pacific sanddab captured in the beam trawl (BT) with 13-mm mesh with those captured by Demory and Robinson (see footnote 9) in 3½-in (89-mm) mesh and 2½-in (64-mm) mesh otter trawls on the continental shelf off Oregon in 1971 and 1972.

Environmental Effects

An analysis of variance, using a linear model with depth as a continuous variable and sediment, season, and year as indicator variables, was completed on the untransformed data for numbers and weight of fishes per square meter and numbers and weight per tow. Sediment was classified as four types based on the percent of sand (2-4, 28, 63-69, 84-99%). Trawls were combined into two seasons, October-April (winter), and May-September (summer). Levels of significance, $P<0.05$ and $P<0.01$, are shown in Table 4. Because of the large number of tests, only effects with $P<0.01$ are considered significant, although $P<0.05$ are shown to provide indications of possible trends. Effects with $P<0.05$ will only be discussed if they reinforce an effect of $P<0.01$, or if two effects of $P<0.05$ were found in the same species-effect category.

Sediment Effects

The number and biomass of slender sole caught per tow appeared to be affected by sediment type (Table 4). This is curious because this species is primarily a pelagic feeder (Pearcy and Hancock 1978). Largest catches per tow were made at stations with high percentages of clay and silt, and lowest catches occurred on sandy sediments. Based on sediment types (and stations), catches of slender sole ranked as follows: 2-3% sand (6-8) >63-69% sand (2-7) >28% sand (23) >84-99% sand (22-15) (see also Table 2). The same trend with sediments is indicated ($P<0.05$) for slender sole weight per square meter, but because catches per square meter were more variable or mean differences were less, differences were not significant at $P<0.01$.

---

[9] Demory, R. L., and J. G. Robinson. 1973. Resource surveys on the continental shelf off Oregon. Fish. Comm. Oreg., Annu. Rep., 18 p.

[10] Loverich, G. 1975. Trawl nets evaluated by expert. Fisherman's News, Sept. 1975 and pers. commun.

TABLE 4.—Results of an analysis of variance (ANOVA) of the numbers and weights of fishes caught per square meter or per tow[1]; * indicates $P<0.05$; ** $P<0.01$. R^2 (coefficients of determination) values are given below.

		All species				Rex sole				Dover sole				Slender sole				Pacific sanddab			
		No.		Wt.		No.		Wt.		No.		Wt.		No.		Wt.		No.		Wt.	
Item	df	m²	Tow	m²	Tow	m²	Tow	m²	Tow	m²	Tow	m²	Tow	m²	Tow	m²	Tow	m²	Tow	m²	Tow
Year	2	**	**	**	**	**	*	**		**		**		*	*	*		**		**	
Sediments	3					*							*		**	*	**			*	*
Seasons	1													*							*
Sediment · season	3						*					*			*	*					
Depth	1		*		*			*	*									*	**	*	**
Depth · season	1	**		**		**	*	*		**	*									*	*
Error	95																				
Total	106																				
R^2 (tow)		0.18		0.20		0.23		0.16		0.17		0.16		0.36		0.33		0.28		0.34	
R^2 (m²)		0.39		0.51		0.47		0.40		0.46		0.43		0.24		0.28		0.36		0.37	

[1] An ANOVA using a square root transformation for the data on all species combined per tow and per square meter gave similar significance effects. The ANOVA was unbalanced because of unequal numbers of observations per station, season, depth, etc. Effects were tested using the extra sum of squares principle (Searle 1971).

The biomass of Pacific sanddab, on the other hand, showed opposite trends ($P<0.05$) and was large on sandy sediments and small on silt or clay sediments (see also Day and Pearcy 1968; Barss et al. see footnote 8). Since the effect of sediment was not significant for total fish catch by numbers or weight sandy stations with low percent organic carbon, apparently did not support a markedly lower abundance of demersal fishes (Table 2). Although adult Dover sole show a strong preference for mud or silt bottom (Barss et al. see footnote 8; Demory see footnote 6), this trend was not apparent for the small Dover sole caught inshore of Heceta Bank in this study.

A sediment-season effect was indicated for slender sole. They were caught in larger numbers per tow and weight per square meter ($P<0.05$) at the stations with a low percentage of sand (6-8) in the winter than the summer.

Depth Effects

The slope of the regression between depth and number and weight per tow of Pacific sanddab was significant ($P<0.01$) and negative. Catches per square meter on a number and weight basis gave the same trends ($P<0.05$). Sanddab were most abundant in shallow water. Weight of rex sole per square meter and per tow and total fish numbers and weight per tow also tended to decrease ($P<0.05$) with depth.

Depth-season interactions were significant on a square meter basis for all species combined (number and weight) and for numbers of rex and Dover soles. These effects were caused by appreciably larger catches in deep water in winter than summer. Seasonal differences were small in shallow water. This trend for lower catches on the outer edge of the continental shelf during summer than winter was obvious for Pacific sanddab. They were completely absent from the deep stations (2, 6, 8) during the summer but were present at all stations during winter. Seasonal bathymetric migrations, with spawning migrations into deep water in the winter and return to relatively shallow depths in the summer, have been described for Dover sole and rex sole by Hagerman (1952), Harry (1956), Alverson (1960), and Demory (1971). Such movements could explain these depth-season effects.

Seasons

No significant seasonal differences were detected, indicating little seasonal variation in catches of these species when all stations are combined.

Year Effect

On the basis of numbers and weight per square meter and per tow, more fishes were captured in 1969 and 1968 than in 1970 at all stations (Figure 3). This trend was significant ($P<0.01$) for all species combined and for rex sole, Dover sole, and Pacific sanddab. Year effects were also indicated for slender sole ($P<0.05$). I have no cogent explanation for these large annual variations. They could represent actual variations in abundance or availability, due to natural events or increased fishing activity, or to undetected changes in sampling efficiency. Dominant year classes have been reported for these flatfishes off Oregon (Demory and Robinson see footnote 9), which may contribute to these annual differences, though changes in length-frequency distributions were not obvious over this 2-yr period.

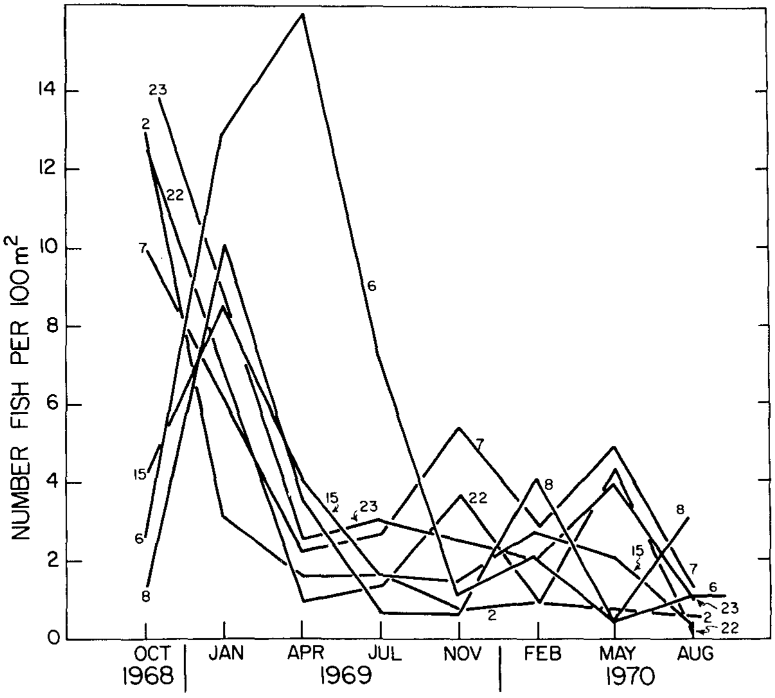

FIGURE 3.—Variations in the total numbers of fishes caught at each of the seven stations, 1968-71. The two tows at each station for each sampling period were averaged.

The amount of variability explained by the regression (R^2) of all effects on catches ranged from 0.16 to 0.51 (Table 4). Values were larger for the analysis based on catches per square meter than catches per tow, except for slender sole. These low values indicate that most of the variability was not accounted for by the variables of sediment, depth, year, and season. Large residual mean squares indicate that sampling variability associated with catches at individual stations is appreciable. Oviatt and Nixon (1973) completed a multiple regression analysis of biomass and numbers of benthic fishes in Narragansett Bay, R.I., with 14 environmental variables. Depth and sediment organic content contributed significantly to the regression for total fish numbers and fish biomass. But an R^2 of only 0.21 was found. In both of these studies, only a small fraction of the total variability was explained by the environmental factors included.

Size-Frequency Distributions

Differences in length-frequency distributions were sometimes obvious among the stations located at different depths or sediment types. For example, the main length mode of rex sole at the 100- and 102-m stations was 125 mm, but at 190- and 195-m depth there was a distinct bimodal distribution with peaks at 45 and 215 mm (Figure 4). These differences imply that young-of-the-year

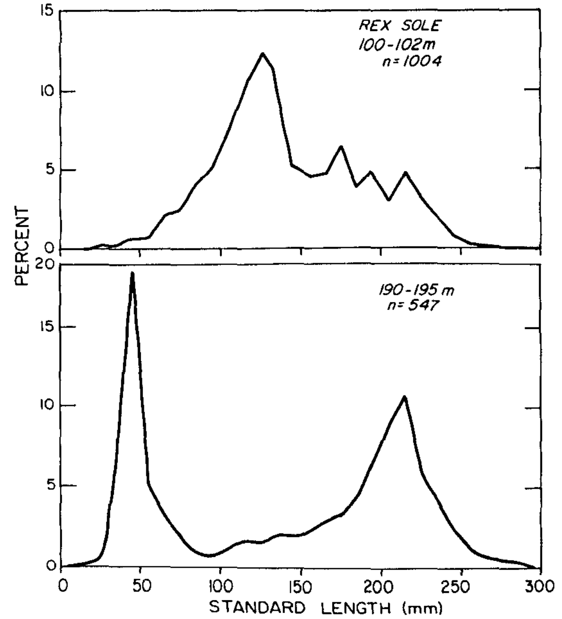

FIGURE 4.—Length-frequency data for rex sole at 100-102 m stations (above) and 190-195 m stations (below).

(<50 mm) and age-groups III-V (200-250 mm) rex sole (see Hosie and Horton 1977 for age-length data) preferentially inhabit deep waters on the outer edge of the continental shelf while intermediate sizes (75-150 mm) inhabit shallower waters of the inner shelf. The peak of young-of-the-year rex sole at 200 m corroborates the conclusion of Pearcy et al. (1977) about the depth of larval settlement and the nursery ground for early benthic life. They concluded that rex sole larvae settle to the bottom mainly on the outer continental shelf during the winter when they are >50 mm SL. Powles and Kohler (1970) and Markle (1975) believed that the nursery grounds of *Glyptocephalus cynoglossus* are also in deep waters off the east coast of the United States.

Small Pacific sanddab (<70 mm) composed a larger proportion of the catch at 102 m where sand was 28% of the sediment (Station 23) than at 74 and 102 m where sand made up over 64% of the sediment (Stations 22, 15) (Figure 5). Young sanddab appear to inhabit deeper water with finer sediments in early life and then aggregate on sandy bottom areas in shallow water where they often dominate the demersal fish fauna. Hence, this trend of decreasing depth with increasing age is similar to that found for rex sole.

SUMMARY

1. Demersal fishes were sampled at seven stations on Oregon's central continental shelf at various seasons of the year during a 2-yr period. A fine-meshed, 3-m beam trawl was used in order to quantitatively sample small flatfishes. The stations ranged from 74 to 195 m deep and had sediment types ranging from nearly 100% sand to clayey-silts with about 3% sand.

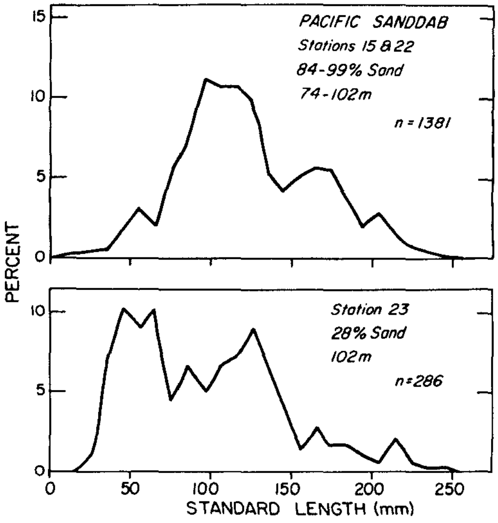

FIGURE 5.—Length-frequency data for Pacific sanddab at stations with 84-99% sand (above) and 28% sand (below).

2. Stations were selected in an attempt to separate the effects of depth and sediment on the assemblages of fishes and abundances of common species. Three station-pairs were recognized that had similar sediment types but were located at different depths. Separation of sediment and depth effects was complicated however by differences in measured (and possibly unmeasured) factors between station pairs.

3. Two general assemblages of fishes were recognized on the basis of species composition of fishes by numbers, biomass per square meter of dominant species, and similarity indices among the seven stations. These were a shallow water (74-102 m) assemblage dominated numerically by Pacific sanddab, and a deepwater (148-195 m) assemblage dominated by slender sole.

4. Species diversity (H) varied between 1.6 and 2.5 except at the shallow, sand station where it was only 0.7. Dominance was pronounced at this station: 86% of all the individual fishes captured were Pacific sanddab. The largest number of species (34 or 35) was recorded for the three deep stations. These values of H are similar to others for temperate, demersal fish communities.

5. Similarity indices of the species composition of fishes were high for two of the three station pairs with similar sediments. However, indices were also high among the four shallow stations of differing sediment types. Stations that were near each other geographically were similar, indicating the possibility of a proximity effect, but high similarity was also found among deep stations, one of which was over 65 km from the others.

6. An analysis of variance of the number and weight per square meter and per tow of Dover, rex, and slender soles, Pacific sanddab, and all species combined indicates some effects of sediments and depth. Largest catches of slender sole were at the clayey-silt station pair, and largest catches of Pacific sanddab were on sandy sediments. Catches of Pacific sanddab were significantly larger at the shallow stations. Catches of rex sole and all species combined also tended to decrease with increasing depth.

7. Differences in the length-frequency distributions of Pacific sanddab and rex sole were corre-

lated with depth or sediment type. Small sanddab predominated on the silty-sand station, whereas large sanddab preferred sandy sediments. Young-of-the-year rex sole were concentrated on the outer edge of the continental shelf (190-195 m).

8. Catches were sometimes larger in the winter than the summer, especially at the deep stations. This trend, which was noted for all four flatfishes and for all species combined, is probably the result of seasonal bathymetric movements.

9. A pronounced decrease in the catches of most species and total catch per square meter occurred during the 2 yr of this study. Reasons for this decline are unknown.

10. The biomass of benthic fishes ranged from 0.9 to 2.4 g m $^{-2}$ at the seven stations. Biomass was not appreciably lower at the pure sand stations, which had about 0.1% organic carbon in the sediment. This is related to the fact that the Pacific sanddab, the predominant species at this station, is a pelagic feeder (see Pearcy and Hancock 1978).

11. The weight of fishes per square meter caught in the 3-m beam trawl was several times lower than that estimated from larger otter trawls with coarser meshes. Although the beam trawl caught many small flatfishes, large fishes and nektobenthic species effectively avoided this small beam trawl, resulting in low biomass estimates.

ACKNOWLEDGMENTS

This research was sponsored by NOAA Office of Sea Grant, No. 04-5-158-2. I am especially grateful to D. L. Stein and G. L. Bertrand for their help at sea; to D. L. Stein for identifying the fishes; to F. L. Ramsey, W. L. Gabriel, and R. G. Petersen for analysis of data; and to J. Dickinson, A. G. Carey, Jr., and J. C. Quast for helpful comments on the manuscript.

LITERATURE CITED

ALTON, M. S.
1972. Characteristics of the demersal fish fauna inhabiting the outer continental shelf and slope off the northern Oregon coast. *In* A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 583-634. Univ. Wash. Press, Seattle.

ALVERSON, D. L.
1960. A study of annual and seasonal bathymetric catch patterns for commercially important groundfishes of the Pacific Northwest coast of North America. Pac. Mar. Fish. Comm., Bull. 4, 66 p.

ALVERSON, D. L., A. T. PRUTER, AND L. L. RONHOLT.
1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. H.R. MacMillan Lect. Fish., Inst. Fish. Univ. B.C., Vancouver, 190 p.

BERTRAND, G. A.
1971. A comparative study of the infauna of the central Oregon continental shelf. Ph.D. Thesis, Oregon State Univ., Corvallis, 113 p.

CAREY, A. G., JR., AND H. HEYAMOTO.
1972. Techniques and equipment for sampling benthic organisms. *In* A.T. Pruter and D.L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 378-408. Univ. Wash. Press, Seattle.

DAY, D. S., AND W. G. PEARCY.
1968. Species associations of benthic fishes on the continental shelf and slope off Oregon. J. Fish. Res. Board Can. 25:2665-2675.

DEMORY, R. L.
1971. Depth distribution of some small flatfishes off the northern Oregon-southern Washington coast. Res. Rep. Fish. Comm. Oreg. 3:44-48.

EDWARDS, R. AND J. H. STEELE.
1968. The ecology of 0-group plaice and common dabs at Lock Ewe. I. Population and food. J. Exp. Mar. Biol. Ecol. 2:215-238.

EMERY, K. O.
1938. Rapid method of mechanical analysis of sands. J. Sediment. Petrol. 8:105-111.

GUNTHER, F. J.
1972. Statistical foraminiferal ecology from seasonal samples, central Oregon continental shelf. Ph.D. Thesis, Oregon State Univ., Corvallis, 128 p.

HAEDRICH, R. L., AND S. O. HAEDRICH.
1974. A seasonal survey of the fishes in the Mystic River, a polluted estuary in downtown Boston, Massachusetts. Estuarine Coastal Mar. Sci. 2:59-73.

HAEDRICH, R. L., G. T. ROWE, AND P. T. POLLONI.
1975. Zonation and faunal composition of epibenthic populations on the continental slope south of New England. J. Mar. Res. 33:191-212.

HAGERMAN, F. B.
1952. The biology of the Dover sole, *Microstomus pacificus* (Lockington). Calif. Dep. Fish Game, Fish Bull. 85, 48 p.

HARRY, G. Y., III
1956. Analysis and history of the Oregon otter-trawl fishery. Ph.D. Thesis, Univ. Washington, Seattle, 329 p.

HOSIE, M. J., AND H. F. HORTON.
1977. Biology of the rex sole, *Glyptocephalus zachirus*, in waters off Oregon. Fish. Bull., U.S. 75:51-60.

INMAN, D. L.
1952. Measures for describing the size distribution of sediments. J. Sediment. Petrol. 22:125-145.

KRUMBEIN, W. C., AND F. J. PETTIJOHN.
1938. Manual of sedimentary petrography. Appleton-Century-Crofts, Inc., N.Y., 549 p.

KUIPERS, B.
1975. On the efficiency of a two-metre beam trawl for juvenile plaice (*Pleuronectes platessa*). Neth. J. Sea Res. 9:69-85.

KULM, L. D., R. C. ROUSH, J. C. HARLETT, R. H. NEUDECK, D. M. CHAMBERS, AND E. J. RUNGE.
1975. Oregon continental shelf sedimentation: interrelationships of facies distribution and sedimentary processes. J. Geol. 83:145-175.

MARGALEF, R.
1968. Perspectives in ecological theory. Univ. Chicago Press, Chicago, 111 p.

MARKLE, D. F.
1975. Young witch flounder, *Glyptocephalus cynoglossus*, on the slope off Virginia. J. Fish. Res. Board Can. 32:1447-1450.

MCINTIRE, C. D., AND W. W. MOORE.
1977. Marine littoral diatoms: Ecological considerations. *In* D. Werner (editor), Biology of diatoms, p.333-371. Blackwell Scientific Publ., Oxf.

MERRIMAN, D., AND H. E. WARFEL.
1948. 5. Studies on the marine resources of southern New England. VII. Analysis of a fish population. *In* A symposium on fish populations, p. 131-164. Bull. Bingham Oceanogr. Collect., Yale Univ. 11(4).

OVIATT, C. A., AND S. W. NIXON.
1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution and abundance. Estuarine Coastal Mar. Sci. 1:361-378.

PEARCY, W. G. AND D. HANCOCK.
1978. Feeding habits of Dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; slender sole, *Lyopsetta exilis;* and Pacific sanddab, *Citharichthys sordidus*, in a region of diverse sediments and bathymetry off Oregon. Fish. Bull., U.S. 76:641-651.

PEARCY, W. G., M. J. HOSIE, AND S. L. RICHARDSON.
1977. Distribution and duration of pelagic life of larvae of Dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; and petrale sole, *Eopsetta jordani*, in waters off Oregon. Fish. Bull., U.S. 75:173-183.

POWLES, P. M., AND A. C. KOHLER.
1970. Depth distributions of various stages of witch flounder (*Glyptocephalus cynoglossus*) off Nova Scotia and in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 27:2053-2062.

RICHARDS, S. W.
1963. The demersal fish population of Long Island Sound. I. Species composition and relative abundance in two localities, 1956-1957. Bull. Bingham Oceanogr. Collect., Yale Univ. 18(2):5-31.

RILEY, J. D., AND J. CORLETT.
1966. The numbers of 0-group plaice in Port Erin Bay, 1964-66. Mar. Biol. Stn. Port Erin Annu. Rep. 78:51-56.

ROUSH, R. C.
1970. Sediment textures and internal structures: a comparison between central Oregon continental shelf sediments and adjacent coastal sediments. M.S. Thesis, Oregon State Univ., Corvallis, 59 p.

SANDERS, H. L., AND R. R. HESSLER.
1969. Ecology of the deep-sea benthos. Science (Wash., D.C.) 163:1419-1424.

SEARLE, S. R.
1971. Linear models. John Wiley and Sons, N.Y., 532 p.

SHANNON, C. E., AND W. WEAVER.
1963. The mathematical theory of communication. Univ. Ill. Press, Urbana, 117 p.

THORSON, G.
1957. Bottom communities (sublittoral and shallow shelf). *In* J. W. Hedgpeth (editor), Treatise on marine ecology and paleoecology, Vol. 1, p. 461-534. Geol. Soc. Am. Mem. 67.