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Title THE ENDEMIC ZOOPLANKTON POPULATION AS A FOOD SUPPLY FOR YOUNG HERRING IN YAQUINA BAY

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Comparison of stomach content analyses of Pacific herring (*Clupea pallasii*) taken in Yaquina Bay, Oregon with the endemic zooplankton population sampled concurrently with quantitative plankton nets indicates that the bay is a feeding ground for one to four year old herring. Those species of zooplankton common to net samples taken within Yaquina Bay were usually the same species common to stomach samples.

Major food organisms appear to be the copepods, *Acartia clausii*, which is endemic to the bay, and *Pseudocalanus minutus* which is also found in large numbers within Yaquina Bay. A comparison of percentages of organisms in herring stomach contents and concurrent quantitative net samples suggests some selective feeding, particularly for *P. minutus* and larger organisms.

In general, typically benthic organisms such as harpacticoids, cumaceans, polychaete larvae and bivalve larvae were found in

herring stomachs at no greater percentage concentrations than were found in the net samples. In one exceptional case when the "normal food supply" was scarce in the quantitative net samples, comparative percentages between stomach contents and the net sample suggested a strong herring selection for ostracods. This single fish stomach contained in addition, large quantities of wood fragments, debris, and particles of mica. Sediment of this type is characteristically river derived and found on the bottom of Yaquina Bay as far downstream as McLean Point, about two nautical miles from the ocean.

THE ENDEMIC ZOOPLANKTON POPULATION AS A FOOD SUPPLY FOR YOUNG HERRING IN YAQUINA BAY

by

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THE ENDEMIC ZOOPLANKTON POPULATION AS A FOOD SUPPLY FOR YOUNG HERRING IN YAQUINA BAY

INTRODUCTION

In view of the generally held opinion that Pacific herring (Clupea pallasii Cuvier and Valenciennes) use the neritic zone as a spawning and feeding ground, the endemic zooplankton populations of estuaries and embayments such as Yaquina Bay probably constitute an important source of food for young herring. Due to the neritic character of the species, it could be expected that the dominant food organisms would be a function of the local zooplankton population. Furthermore, restrictive environmental influences such as pollution have an adverse effect on both fish fry and the zooplankton endemic to the area, and must have a corresponding negative effect on the strength of succeeding year classes of fish. Working on Baltic Sea herring, Dementjeva (9, p. 314) concluded that brood-strength in recent years has depended mainly on the survival of the fish larvae in the transition period to the stage of active feeding, quantity of plankton biomass available, and high discharge from the river Daugva.

Statement of the Problem

With the view of possibly delineating the qualitative food requirements of Pacific herring as found in Yaquina Bay and generally investigating the relationships between the zooplankton populations and the herring, this study was initiated in May of 1962.

The Atlantic Herring

Through the efforts of many European investigators (4, p. 140; 8, p. 11; 13, p. 239 ; 20, p. 140; 21, p. 161 and 163; 24, p. 62) a fairly comprehensive understanding of the feeding habits of Atlantic herring (Clupea harengus Linné) as found in the North, Norwegian, and Barents Seas has been elucidated. In general, adult herring feed on Calanus finmarchicus, C. hyperboreus and hyperiid amphipods (Themisto sp.) during the summer time. In autumn, Calanus finmarchicus and Themisto sp. are dominant, but Euphausiacea (Thysanoessa sp., Nyctiphanes sp. and Meganyctiphanes norvegica) begin to appear in their diet. During winter and spring, euphausiids are the dominant food organisms.

The presence of large numbers of Calanus finmarchicus usually serves as an indicator of herring shoals during summer in the North Sea (13, p. 239). However, catches made in areas of concentrations of phytoplankton (up to 2.5 million cells/M^3 of Biddulphia sinesis) (24, p. 62) or "small, white" jellyfish (16, p. 301) suggest that these organisms may exclude adult herring. Cushing (8, p. 11) indicates, however, that a re-evaluation of the effects that phytoplankton presumably have on herring abundance is in order. He found that herring catches were independent of densities of *Rhizosolenia styliformis* up to 100,000 cells/M^3.[1]

Young North Sea herring (up to 42 mm.) begin feeding on diatoms and flagellates; these are succeeded by copepod and cirripedia nauplii and small stages of copepodites, and finally by the copepods *Pseudocalanus elongatus* and *Temora* sp. The adolescent herring (42 - 130 mm.), erroneously named *Clupea sprattus* (white-bait), move into estuaries such as the Thames where the dominant food organism is an estuarine copepod, *Eurytemora hirundoides*. After about six months in the coastal environment, the young herring scatter into the North Sea (12, p. 53-55).

Sanders (22, p. 229) has shown that the herring of Block Island Sound on the Atlantic coast of the United States feed usually on the more abundant species of zooplankton found in net samples taken with a Clarke-Bumpus Plankton Sampler. Counts of organisms indicated that more than 80 percent of the zooplankton population in the lower water layers of Block Island Sound during the winter and an average of 73 percent of organisms in stomach contents of herring

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[1] Such values do not appear to be unusually high as concentrations up to one million cells per liter are not uncommon (personal communication from Dr. H. C. Curl, Department of Oceanography, Oregon State University). Furthermore, the author has made counts of *Chaetoceros decipiens* up to 144,300 cells per liter in Yaquina Bay during the spring diatom bloom.

taken in the same period consisted of the copepod *Pseudocalanus minutus*. In addition, the copepods *Centropages typicus* and *Temora longicornis* and the nauplius and cypris larvae of the barnacle *Balanus balanoides* were common food organisms. Size of zooplankton food organisms correlated with apertures of the gill raker apparatus of the herring suggest that fish actively select the larger sized crustaceans present in the zooplankton population (Sanders, 22, p. 234).

The Pacific Herring

Herring research along the Pacific coast, primarily in Canada, has usually been oriented toward problems related to the fishery, such as herring stocks, mortality, and numbers of spawners and recruits. Barkley Sound (west coast of Vancouver Island) studies indicate that juvenile herring exist in more or less discrete subpopulations in shallow embayments with less than 30 percent mixing between adjacent stocks, and remain in the Sound during summer but migrate seaward in early autumn (28, p. 118-119).

Clemens (7, p. 99-101) concluded that British Columbia herring appear to occur in more or less localized populations which have an annual migration between an inshore spawning area and an offshore feeding ground where plankton crustaceans constitute the chief food.

Wailes (29, p. 485) studied the feeding habits of British

Columbia herring and concluded that adults feed principally on Calanus tonsus during the spring and Euphausia pacifica during the rest of the year. This pattern is strikingly similar to that found by Rudakova (21, p. 161-163). The young British Columbia herring exhibit differences in feeding habits correlated with localities and seasons, suggesting that the food most readily available is taken provided it is of acceptable size (29, p. 484).

Summarizing the results of Soviet investigations of Pacific herring, Svetovidov (27, p. 168-169) reported the following information which is presented in tabular form:

Locale	Percent by Weight of Stomach Contents	
West coast of Sakhalin	Euphausiidae	82.1
	Calanus finmarchicus	5.12
	Sagitta elegans	9.04
Amur Bay (north end of the Gulf of Tartary)	Calanus cristatus	47.9
	Stylomysis sp.	32.4
	Sagitta sp.	14.9
Sea of Okhotsk (northern part)	Metridia sp.	40 - 50
	Themisto libellula	up to 90
	Calanus finmarchicus	10 - 15
	Pseudocalanus elongatus } Acartia longiremis }	25 - 30

METHODS

Description of the Study Area

The Yaquina River estuary is a narrow, winding embayment of the Oregon coast located approximately 110 miles south of Astoria (Figure 1). Principle towns are Newport, with a population of 5, 344 situated near the entrance to the bay, and Toledo, with a population of 3, 053 (1960 census), located about 11 nautical miles from the ocean. A small settlement is located at Yaquina, 3. 7 nautical miles from the bay entrance. Water depths in the narrow channel average about 20 feet at mean lower low water from the bay entrance to five nautical miles inland, a point 0. 5 nautical miles above Station 21. Channel depths average ten feet, further up-bay. Station 15 is located in the center of the channel three nautical miles from the entrance in a broadened section of the bay comprised of extensive sand and mud flats which are exposed at low water.

Herring Collection Methods and Field Procedures

Since the installation of a large trap or herring weir was not practical from the standpoint of both the initial investment as well as constituting an obstruction to navigation in Yaquina Bay, several smaller scale devices for fish collection have been employed in the course of this study. A nylon gill net with uniform 1-1/4" (stretch

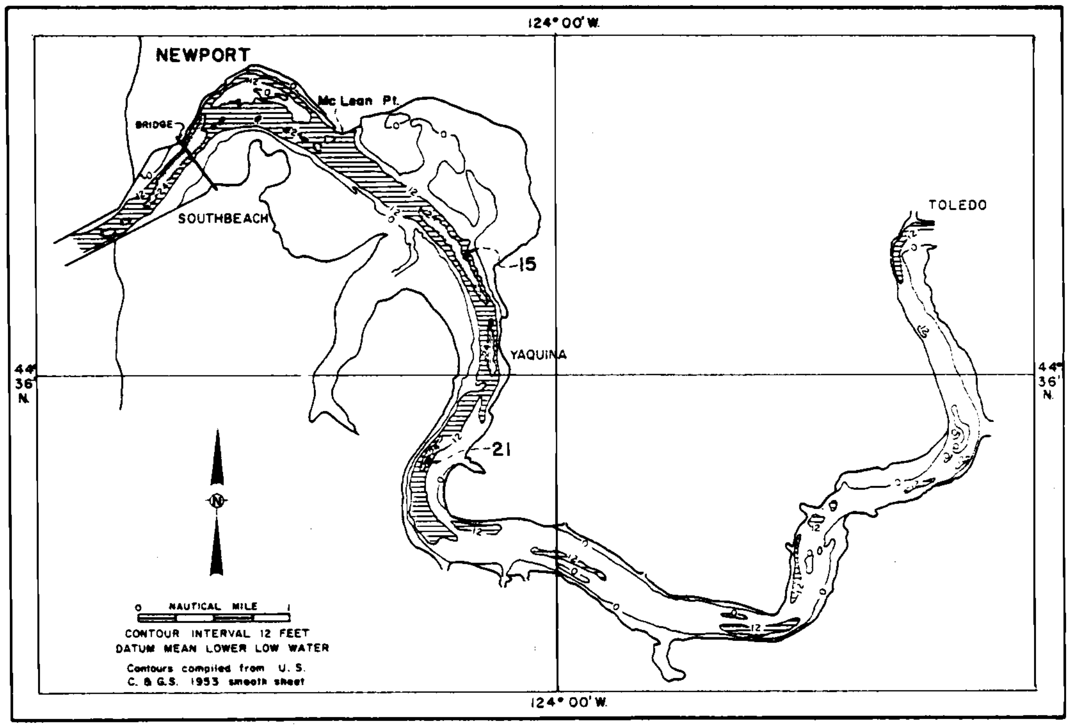

Figure 1. Yaquina Bay, Oregon. Fish collections were made at McLean Point, Station 15 and Station 21.

measure) mesh, 30 feet long and 10 feet deep was drift-fished during high tide on the night of May 13, 1962 in the vicinity of McLean Point in Yaquina Bay. Over a period of several hours only three fish were taken. On two later occasions, no fish were taken. All fish netted on May 13 had empty stomachs, suggesting that they may have regurgitated their stomach contents before dying in the mesh. There was some indication that the net was exerting size limitations on the fish in the catch. The fish taken ranged in standard length (the distance from the tip of the snout to the end of the vertebral column) from 163 mm. to 176 mm. Fish collected with a herring jig on July 22, 1962 were 74 mm. to 186 mm. in length. Therefore, as a general collection instrument in a limited study of this nature wherein the least size selectivity is desirable, a uniform mesh gill net is apparently precluded.

A Fyke net was quite unsatisfactory, at least in the area of Yaquina Bay between McLean Point and Buoy 15. This failure may be partially attributable to a lack of definitive movement of fish in this portion of the bay.

The most satisfactory collection method in terms of numbers of fish taken, variation in size, and simplicity of operation, was a herring jig attached to a fishing rod and line.

Fish collections were made on 11 successful sampling days of a total of 31 attempts from May 13, 1962 to August 24, 1963.

Results are based on a total of 57 herring. Twenty-six fish were taken at Station 15, 28 fish at Station 21, and 3 fish off McLean Point. Stomach analyses were made on 38 fish taken from all periods of the investigation.

To promote immediate preservation and arrest digestion, approximately one cc. of 40 percent formalin was injected into the body cavity as soon after collection as possible. Initially in the study, a hypodermic syringe was employed for this purpose; later a calibrated pipette was substituted. Both methods were equally effective, resulting in cleanly preserved samples.

Coincident with the time and locale of fish collection, the zooplankton population was sampled with Clarke-Bumpus Plankton Samplers (6) employing No. 6 mesh (0.239 mm. mesh aperture) and No. 12 mesh (0.119 mm. mesh aperture) nylon nets in oblique tows of usually 12 minute duration. In addition, surface and bottom water samples were taken with a Van Dorn water sampler to measure temperature, salinity and dissolved oxygen content.[2]

Laboratory Operations

In the laboratory, the following operations and measurements

[2] Using methods described by Strickland and Parsons (26, p. 11-17, 23-28), salinity and dissolved oxygen content for the water samples taken were analyzed by Dr. Kilho Park and his staff of the Department of Oceanography, Oregon State University.

were performed on the herring:

1. Length measurement. The distance from the tip of the snout to the end of the vertebral column (standard length) was measured.
2. Age determination by scale examination. In most cases scale annuli were rather difficult to detect but still readable. This is in line with both Boldovskiy (4, p. 140) and Kun (15, p. 141), who found that Pacific herring, while exhibiting seasonal variation in feeding rates, have no starvation period in the strict sense of the term. Ambroz (1, p. 140-141) stated that Pacific herring cease to eat for only a brief period immediately before and during spawning.
3. Examination of the gonads. The condition of the gonads was observed to give a measure of both sex and stage of sexual maturity. A scale of maturity developed by Naumov (19, p. 216-218) was used and appears in the appendix of this paper.
4. Stomach analysis. The organisms found in the stomach contents were identified as closely as possible and counted. Identifications often necessitated examination of the food organism's appendages. References used for making identifications included Brodsky (5), Giesbrecht (11), Mori (18), and Sars (23).

5. Plankton sample analysis. The net samples of zooplankton were identified and counted, utilizing the method by Froland-er (10, p. 6) in which all organisms extracted in a one cc. aliquot with a Stempel pipette are examined. Population densities in numbers per cubic meter were computed utiliz-ing calibrations obtained by towing the Clarke-Bumpus sam-plers over a measured course. Results have been express-ed as percentages of the total zooplankton population to facilitate correlations with the stomach analyses.

RESULTS AND CONCLUSIONS

Hydrographic Data

Hydrographic data for the period from May 13 to December 1, 1962 and August 1963, showing temperature and salinity for both surface and bottom water samples are presented in Figure 2. Data for dissolved oxygen content for the same period are presented in Figure 3. Only Station 15 data are on the curves. Data taken at Station 21 on dates when fish collections were made at this station are shown as isolated points.

In Yaquina Bay, salinities of $33^{o}/oo$ or greater during June, July and September 1962 were indicative of a period of upwelling. During August, weak, variable on/off-shore components of the southerly California Current were present off the coast of Oregon as described by Maughan (17, p. 33, Table 6). Yaquina Bay dissolved oxygen values with minima during June and July and to some extent in September, further suggest that upwelling occurred during these periods.

From July 22 to August 17, water temperatures at Station 15 rose precipitously from 6.8°C to 17.15°C. While this phenomenon could conceivably be due to an influx of high temperature water from the upper bay, the fact that it was observed at shore stations at both Otter Rock and Heceta Beach (25, p. 9-10) makes it highly unlikely (see Figure 4). Whatever its source, this high temperature water

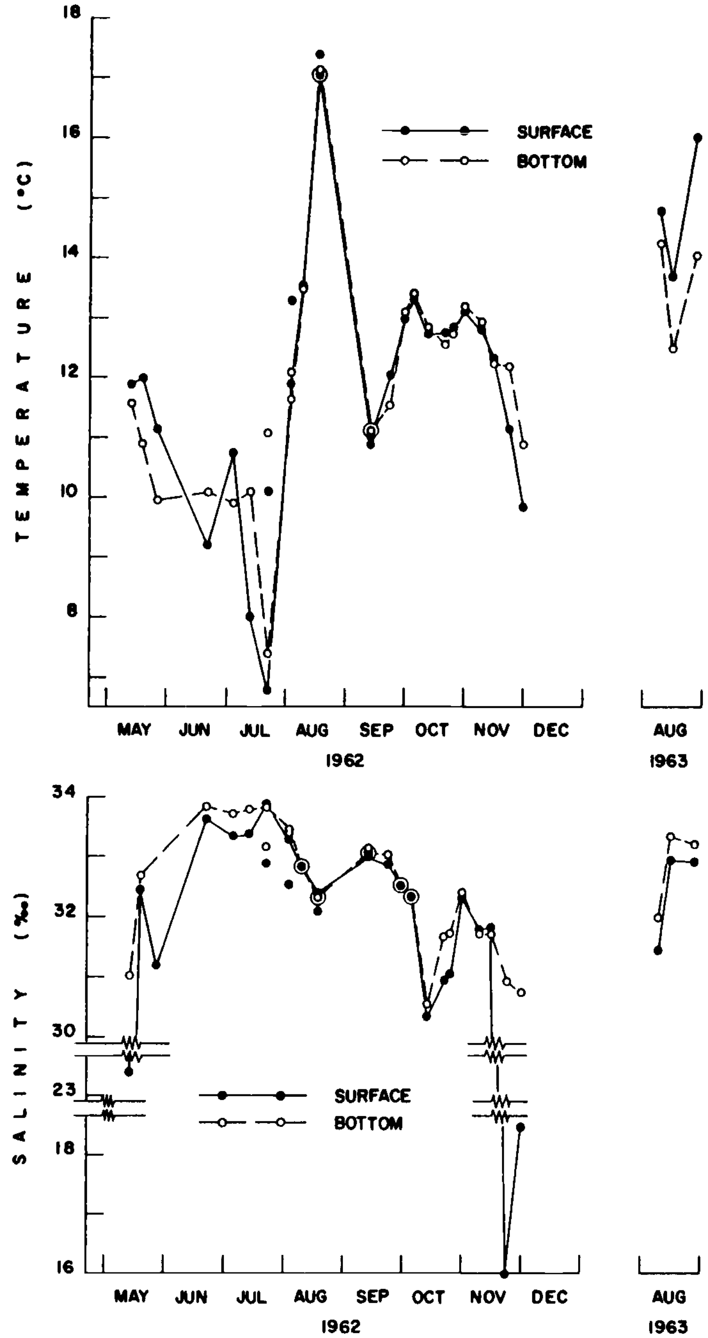

Figure 2. Temperature and salinity data for the surface and bottom at Station 15 on all sampling dates during 1962 and 1963 are shown on the curves. Station 21 data for dates that fish samples were taken at that station are shown as isolated points.

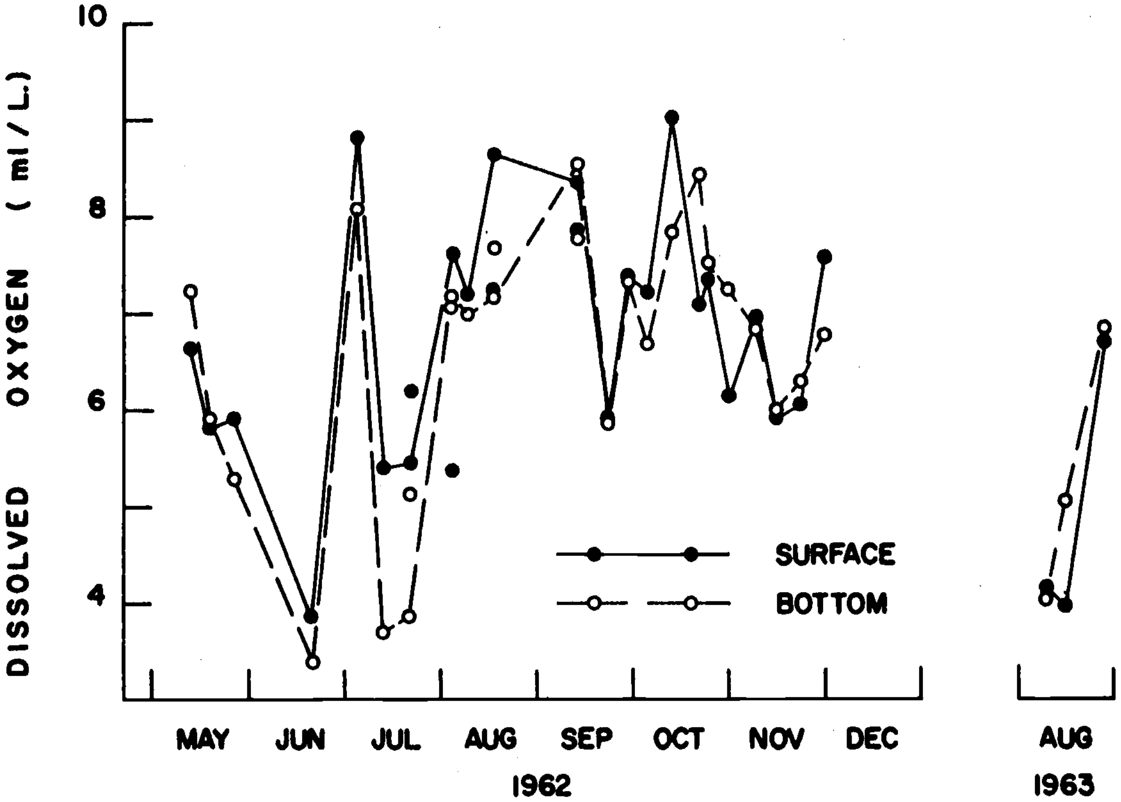

Figure 3. Dissolved oxygen content. Data for the surface and bottom at Station 15 on all sampling dates during 1962 and 1963 are shown on the curves. Station 21 data for dates that fish samples were taken at that station are shown as isolated points.

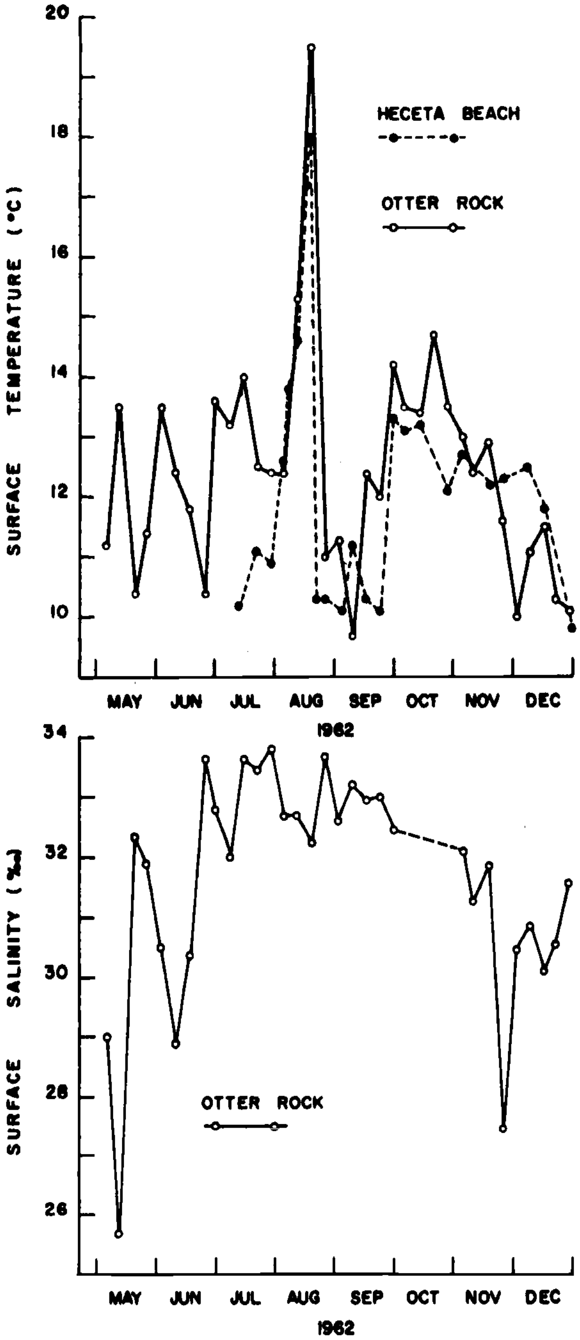

Figure 4. Surface temperature and salinity from shore stations on the Oregon coast.

observed in Yaquina Bay during August 1962 may have served as a barrier to Yaquina Bay for herring larger than those captured in the bay at that time. The mean standard length of herring taken on the 5th, 9th, and 17th of August was 147.6 mm., significantly lower than the over-all mean of 163.3 mm.

The Herring

Table 1 summarizes information relating to the physical description of captured herring. The size distribution of the fish taken from May to December 1962, as shown in Figure 5, suggests that the length of herring found in Yaquina Bay is cyclic in nature. The minimum mean standard length of 140.8 mm. which occurred on August 5, 1962 was during the period July 22 to August 17 when 22 out of 25 fish taken (88 percent) were two year old herring. The single one year old fish taken during the entire study was captured during this period. In May and again in December, three and four year old fish were taken with mean lengths from 171 to 200 mm. It is apparent, however, that this pattern is not necessarily constant from year to year. While the August 9, 1963 fish catch was very near in mean size (142.0 mm.) to that of one year previous, a few days later, on August 24, 1963, three and four year old fish with lengths up to 212 mm. were taken.

Some indication of whether or not the use of a herring jig in

Table 1. Physical Description of Captured Herring.

	Length (mm.)		Sex			Age (yr.)				Maturity Stage			
Date	Range	Mean	♂	♀	ǂ	1	2	3	4	I	II	III	IV
13 May 1962	163-176	171.0	3	--	--	--	--	3	--	--	3	--	--
19 May	200	200.0	--	--	--	--	--	--	1	--	--	--	--
22 July	74-186	152.7	--	1	16	1	15	1	--	16	1	--	--
5 August	133-144	140.8	3	2	--	--	5	--	--	3	2	--	--
9 August	150-180	165.0	--	2	--	--	1	1	--	--	2	--	--
17 August	147	147.0	--	--	1	--	1	--	--	1	--	--	--
21 September*	153-173	159.5	--	--	--	--	--	--	--	--	--	--	--
1 December	175-192	186.0	1	2	--	--	--	--	3	--	--	2	1
9 August 1963	142	142.0	--	--	1	--	1	--	--	1	--	--	--
15 August	163-172	167.0	--	3	--	--	--	3	--	--	3	--	--
24 August	154-212	165.6	7	9	--	--	--	15	1	1	15	--	--
	$\bar{a}$	163.33	14	19	18	1	23	23	5	22	26	2	1

*The 5 fish taken in the September 21 sample were not retained after the stomach contents were removed and length measurements were made.

ǂ Morphologically undifferentiated.

capturing fish gave a random sample of the fish present in the bay may be derived from Figure 6. Mean length versus age is shown for both the Yaquina Bay herring samples and British Columbia herring taken in the Port Edward and Vancouver Island areas with purse seines from 1933 to 1959 (14, p. 59-60). There do not appear to be any serious discrepancies in the two to four year old age classes. The length of one year old herring captured in Yaquina Bay is significantly smaller than that reported by the International North Pacific Fisheries Commission (14, p. 59-60); this smaller average size is

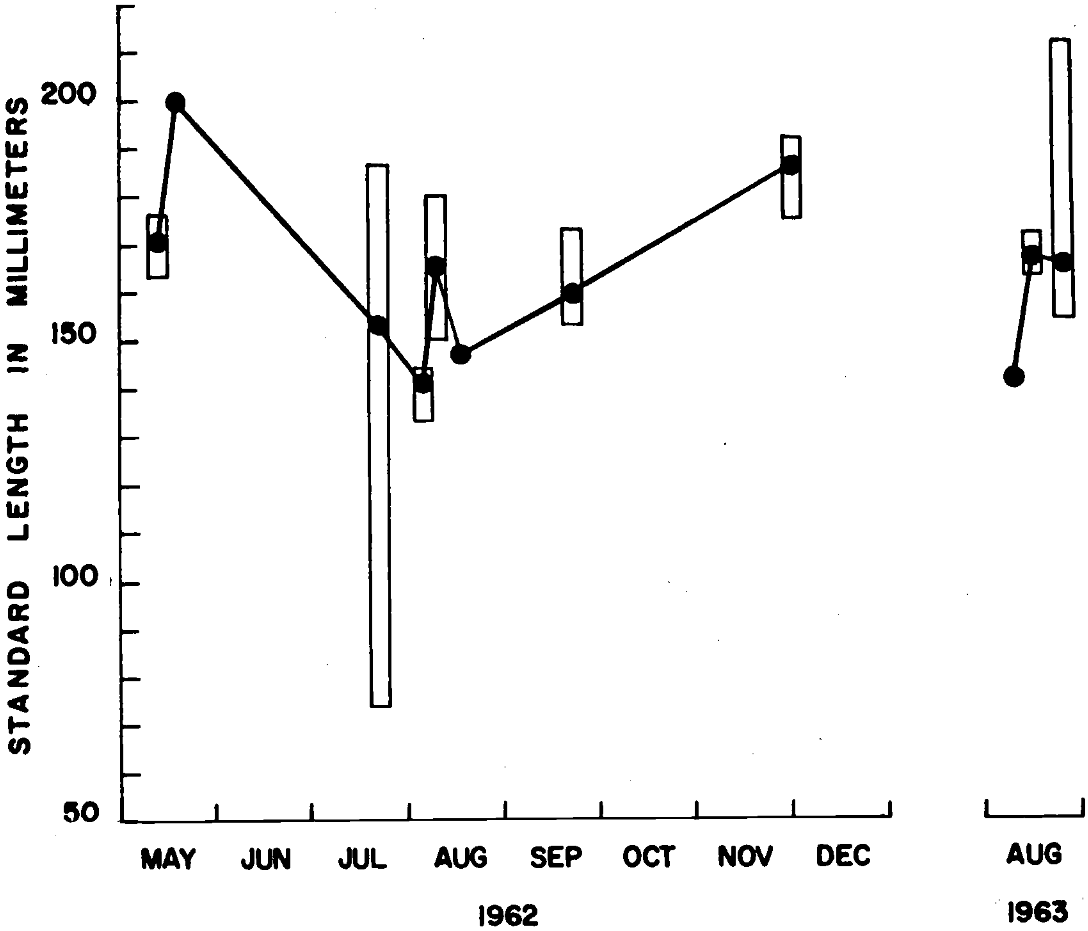

Figure 5. Mean standard length and range for Yaquina Bay herring samples taken during 1962 and August 1963.

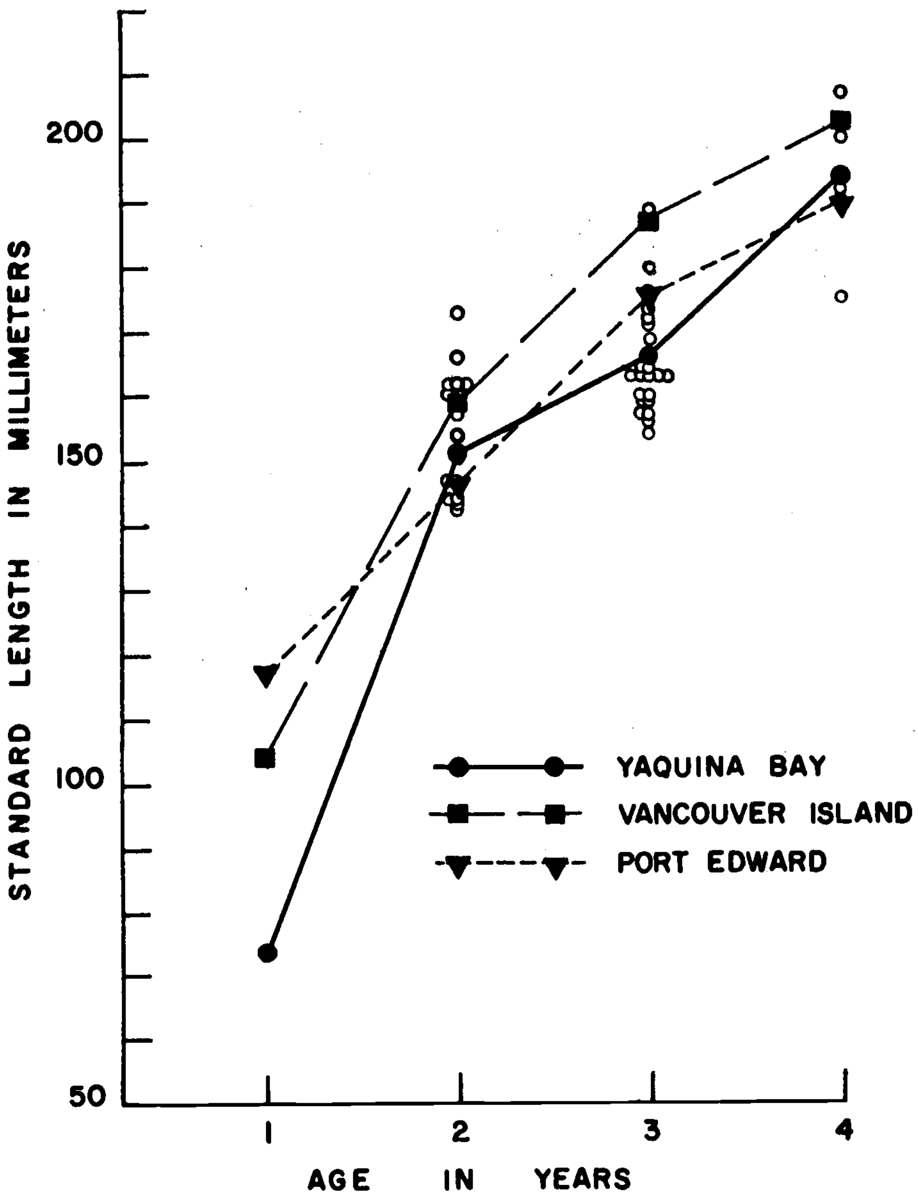

Figure 6. Mean standard length and range for Yaquina Bay herring of all age classes taken and mean lengths of two British Columbia herring populations from 1933 to 1959.

based on only one individual captured, however, and may reflect the low end of a normal length-distribution curve.

Stomach Analyses versus Net Plankton

Percentage composition of zooplankton organisms taken in net samples on eight sampling dates is presented in Table 2 and depicted in Figure 7. A comparison of the net plankton data with herring stomach analyses (Table 3 and Figure 8) indicates that essentially all species of zooplankton taken with the coarse mesh (0.239 mm. apertures) net were represented in the herring stomach contents. A single counted specimen of Microcalanus pusillus Sars and of a cumacean plus echinoderm "pluteus" larvae were the only forms found in net samples and not identified in stomach contents. The fact that the echinoderm larvae had a calculated density of 560 individuals per cubic meter comprising 41.3 percent of the August 9, 1962 net sample suggests that availability may not be the only criterion for determining food organisms of herring. Size, relative ease of capture and whether or not populations of a zooplankton organism exist in localized patches or water layers possibly not inhabited by herring are probably additional criteria.

Sanders (22, p. 234) has shown that Block Island Sound herring apparently exhibit size selectivity, feeding disproportionately, as compared to net samples, on the larger sized fraction of the

Table 2. Percentage of organisms found in the net plankton samples taken with the coarse (0.239 mm. aperture) mesh net on a Clarke-Bumpus Plankton Sampler.

	Date Plankton Samples Were Taken							
	1962							1963
Organism	V 19	VII 22	VIII 5	VIII 9	VIII 17	IX 21	XII 1	VIII 24
Clausocalanus arcuicornis	0.51	--	--	--	--	0.31	16.58	--
Pseudocalanus minutus	5.63	--	0.67	--	--	--	2.43	0.43
Acartia longiremis	--	0.94	6.69	1.22	0.14	2.05	51.75	1.94
Oithona sp.	24.30	0.94	1.34	--	0.42	1.13	10.92	0.76
Metridia lucens	--	--	--	0.91	--	--	0.02	5.29
Calanus finmarchicus	--	--	--	--	--	--	0.01	0.11
Candacia columbiae	--	--	--	--	--	--	0.01	--
Tortanus discaudatus	0.26	--	--	--	--	--	0.81	--
Epilabidocera amphitrites	--	--	--	--	0.14	--	0.01	--
Eucalanus bungii	--	--	--	--	--	--	0.14	--
Microcalanus pusillus	--	--	--	0.30	--	--	--	--
Paracalanus parvus	0.26	0.94	--	--	2.66	--	4.85	0.86
Acartia clausii	6.65	2.83	21.07	13.07	4.76	13.11	3.23	55.56
Eurytemora sp.	0.26	9.43	--	--	0.56	--	--	0.11
Acartia tonsa	--	--	--	--	0.56	--	--	0.43
Centropages mcmurrichi	1.28	3.77	1.34	0.61	2.52	--	2.83	--
Harpacticoida	0.77	6.60	0.67	1.82	0.42	1.13	1.21	0.32
Cumacea	--	0.94	--	--	--	--	--	--
Copepod nauplii	24.04	0.94	2.34	6.38	0.42	11.07	0.81	4.10
Barnacle nauplii	2.56	61.32	58.53	25.53	19.33	13.93	0.40	3.56
Amphipoda	--	--	0.33	--	--	--	--	0.05
Ostracoda	0.26	0.94	0.33	0.61	14.29	3.69	--	--
Cladocera	0.26	--	--	0.61	13.17	15.98	--	6.05
Mysidacea	0.51	--	--	--	--	--	0.13	--
Upogebia sp.	--	--	--	--	0.14	--	--	--

Table 2 (continued)

	Date Plankton Samples Were Taken							
	1962							1963
	V 19	VII 22	VIII 5	VIII 9	VIII 17	IX 21	XII 1	VIII 24
Organism								
Crab larvae	0.26	3.77	3.34	0.30	2.38	--	0.06	0.65
Medusae	--	0.94	0.33	0.61	0.42	--	--	--
Gastropod larvae	--	--	0.33	1.22	5.04	1.64	--	0.11
Pelycepod larvae	0.26	0.94	1.00	6.69	21.29	18.85	--	0.97
Echinoderm larvae	7.16	--	--	41.34	6.86	--	--	--
Polychaete larvae	3.32	0.94	0.33	--	0.28	2.05	0.25	0.65
Oikopleura sp.	3.84	--	--	--	3.64	13.93	2.43	0.65
Fish larvae	--	--	--	--	--	--	0.03	--
Ova	17.39	0.94	0.67	--	--	0.31	0.40	0.11
Miscellaneous	0.26	--	0.67	--	0.56	--	--	0.32

zooplankton population. In an attempt to compare Sanders' results, a similar analysis was made on Yaquina Bay herring. Using a binocular disecting microscope equipped with a calibrated occular micrometer, critical measurements were made of the herring gill-raker apparatus. Both the distance between gill-raker bars and between the individual teeth on each bar was measured.

Distance between gill-raker bars

Range	0.127 mm. - 0.307 mm.
Mean	0.207 mm.

Distance between teeth

Range	0.100 mm. - 0.200 mm.
Mean	0.141 mm.

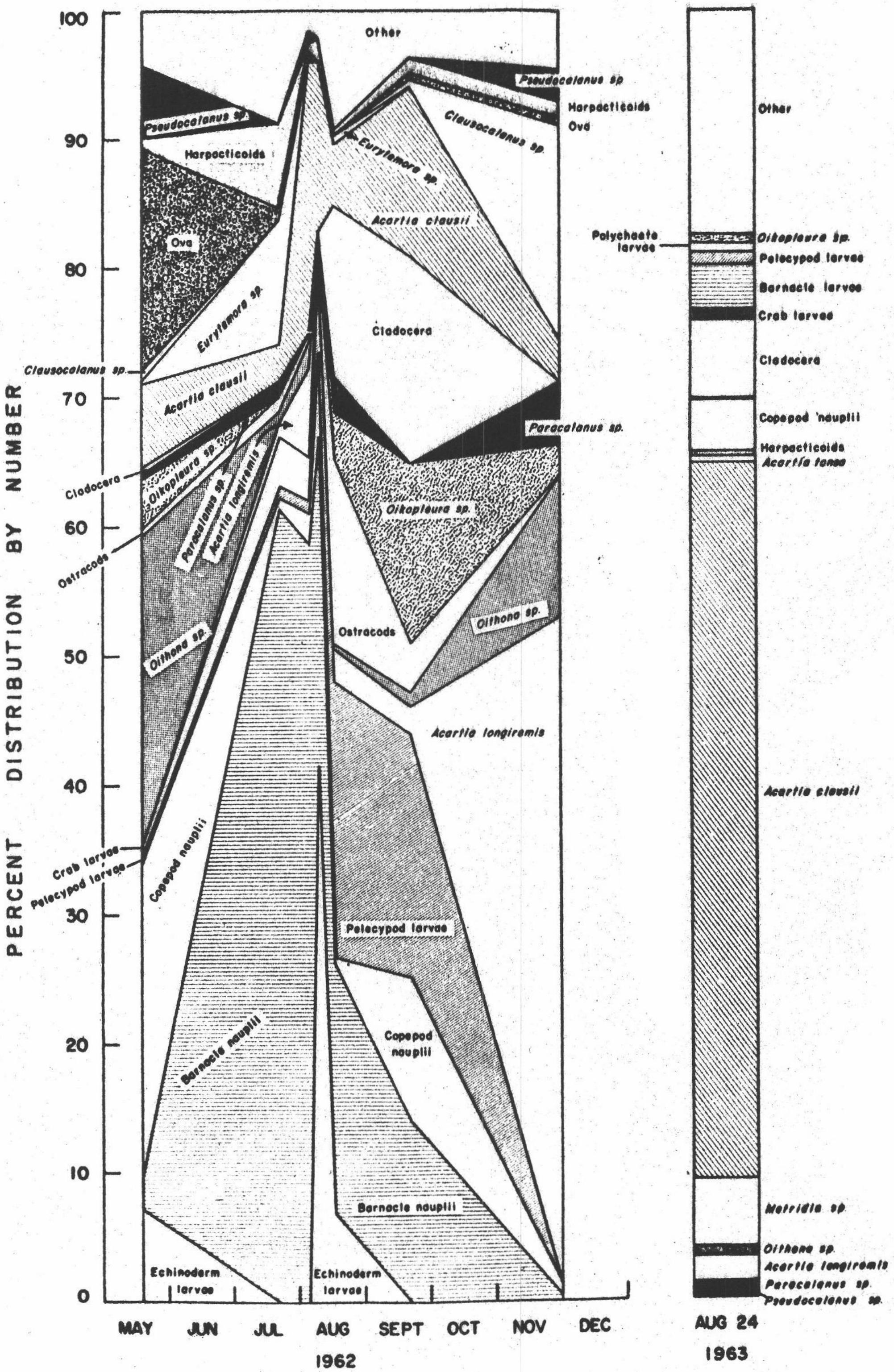

Figure 7. Percent distribution of organisms found in the net plankton samples taken on eight sampling dates with the coarse mesh net on a Clarke-Bumpus Plankton Sampler.

Table 3. Average percentage of organisms found in herring stomachs.

Organism	Date Fish Were Taken							
	1962							1963
	V 19	VII 22	VIII 5	VIII 9	VIII 17	IX 21	XII 1	VIII 24
Clausocalanus arcuicornis	--	--	0.48	--	--	0.41	27.23	--
Pseudocalanus minutus	33.33	--	--	--	--	0.20	3.56	0.86
Acartia longiremis	--	0.13	--	17.86	--	0.30	5.34	0.57
Oithona sp.	--	0.02	--	--	--	--	--	0.57
Metridia lucens	--	0.57	--	--	--	1.32	0.51	1.69
Calanus finmarchicus	--	0.02	--	--	--	0.20	1.27	--
Candacia columbiae	--	--	--	--	--	--	0.25	--
Tortanus discaudatus	--	--	--	--	--	--	1.02	--
Epilabidocera amphitrites	--	--	--	--	--	--	0.76	--
Eucalanus bungii	--	--	--	--	--	--	2.04	--
Calanus tenuicornis	--	--	--	--	--	--	0.76	--
Paracalanus parvus	--	--	--	--	--	--	3.31	0.57
Acartia clausii	--	54.98	65.11	32.14	--	94.12	0.25	29.80
Eurytemora sp.	--	0.02	4.30	--	--	0.30	--	0.29
Acartia tonsa	--	--	--	--	--	--	--	3.15
Centropages mcmurrichi	--	--	0.95	--	--	--	--	--
Harpacticoida	--	0.55	1.00	--	8.00	0.10	2.04	0.86
Copepod nauplii	--	0.11	0.05	--	--	0.20	--	14.90
Unidentified copepods	66.67	24.78	26.16	21.43	4.00	--	11.70	6.88
Barnacle nauplii	--	0.11	0.14	3.57	--	0.10	--	--
Amphipoda	--	0.04	0.10	7.14	4.00	--	0.25	0.86
Ostracoda	--	--	--	--	80.00	0.20	0.51	--
Cladocera	--	--	--	--	--	0.30	--	2.29
Mysidacea	--	--	--	14.29	--	--	0.51	4.87
Upogebia sp.	--	--	--	--	--	0.20	--	--

Table 3. (Continued)

Organism	Date Fish Were Taken 1962 V 19	VII 22	VIII 5	VIII 9	VIII 17	IX 21	XII 1	1963 VIII 24
Crab larvae	--	0.02	0.95	3.57	--	1.11	1.53	0.86
Medusae	--	--	--	--	--	0.10	--	--
Gastropod larvae	--	--	--	--	4.00	--	--	--
Pelycepod larvae	--	--	--	--	--	0.71	0.25	0.29
Polychaete larvae	--	0.11	--	--	--	--	--	--
Oikopleura sp.	--	--	--	--	--	--	36.90	0.29
Fish larvae	--	--	--	--	--	--	--	26.07
Ova	--	18.52	0.43	--	--	--	--	1.43
Miscellaneous	--	--	0.33	--	--	0.10	--	3.15

The herring examined ranged in length from 147 mm. to 192 mm., but there was no obvious correlation between size of fish and dimensions of the gill-rakers. Following these operations, length and width measurements of planktonic organisms in the stomach contents were made. The following data give mean dimensions for several zooplankton forms found in the herring stomachs.

Organism	Mean Length (mm.)	Mean Width (mm.)
Eucalanus bungii	3.17	0.61
Epilabidocera amphitrites	2.77	0.69
Tortanus discaudatus	1.68	0.43
Centropages mcmurrichi	1.20	0.32
Pseudocalanus minutus	1.17	0.30

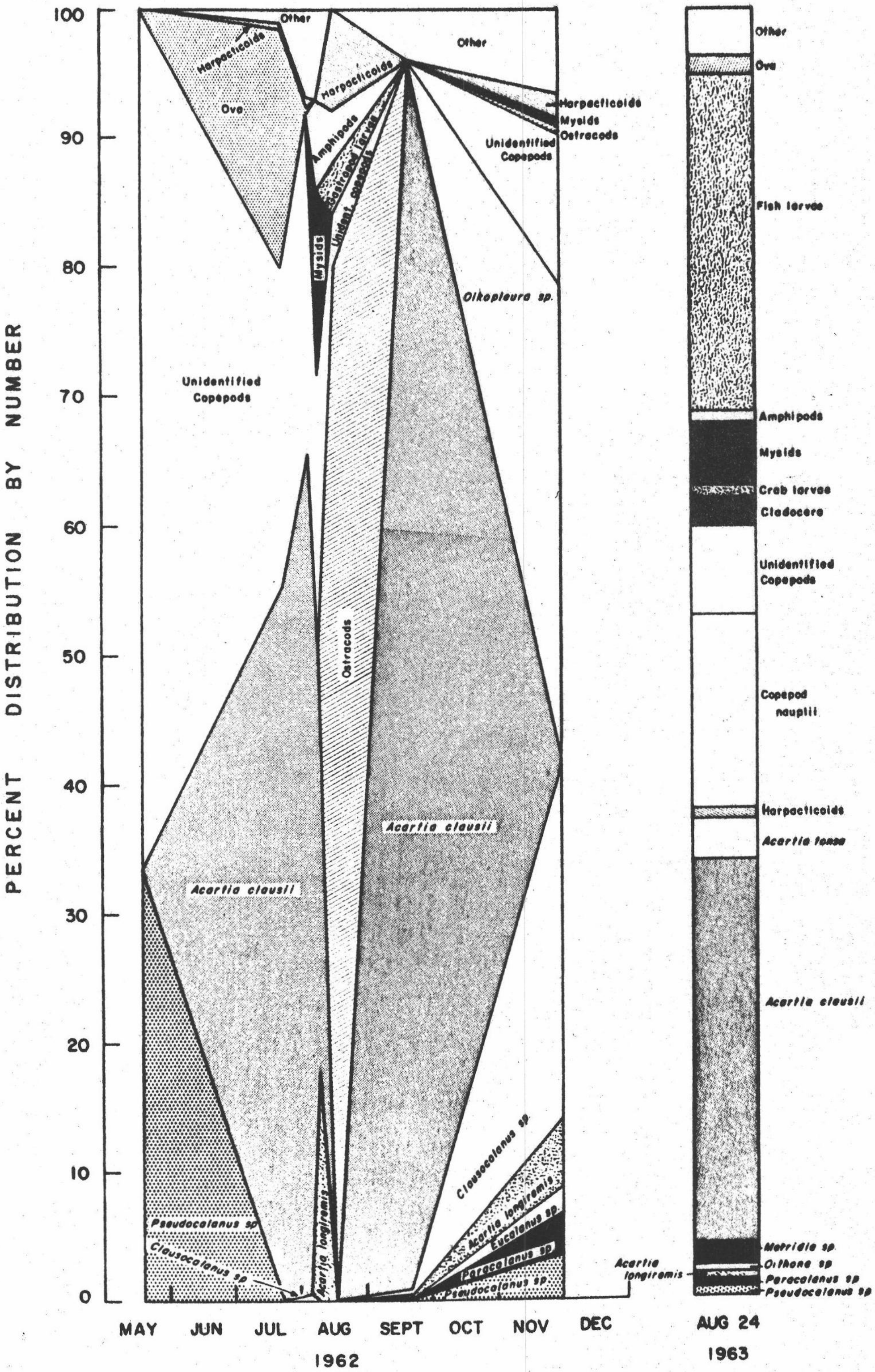

Figure 8. Percent distribution of organisms found in herring stomachs on eight sampling dates.

Organism (continued)	Mean Length (mm.)	Mean Width (mm.)
Paracalanus parvus	1.07	0.30
Acartia longiremis	1.01	0.24
Acartia clausii	0.95	0.25
Clausocalanus arcuicornis	0.85	0.25
Oithona similis	0.81	0.20
Ostracods	0.85	0.39
Barnacle nauplii	0.50	0.33

Considering 0.14 mm. as a critical minimum size of the smallest zooplankter expected to be caught in the gill-rakers, the percentage occurrence, in both the net samples and the stomach contents, of several common forms having mean widths greater than 0.14 mm. are listed in Table 4.

Pseudocalanus minutus (Krøyer) when present, was, with one exception, always found in higher average percentages in the stomach contents than the percentage in the comparable net haul.

Herring that were examined commonly took large numbers of Acartia clausii Giesbrecht during periods of its abundance excepting three occasions when large numbers of other organisms were present in the net haul. For two of these days, only one fish each was taken; in one case, high numbers of Pseudocalanus minutus were present and its percentage in the fish's stomach was five times that of the net sample. On the other occasion, large numbers of ostracods were present in both the net and stomach sample and the

Table 4. Percentage occurrence in net and stomach samples of several larger zooplanktonic food organisms.

Date:	Year	1962							1963
	Month	V	VII	VIII	VIII	VIII	IX	XII	VIII
	Day	19	22	5	9	17	21	1	24
Pseudocalanus minutus	S	33.	--	--	--	--	0.2	3.6	0.9
	N	5.6	--	0.7	--	--	--	2.4	0.4
	$\#/M^3$	244.	--	14.	--	--	--	44.	32.
Acartia clausii	S	--	55.	65.	32.	--	94.	0.3	30.
	N	6.7	2.8	21.	13.	4.8	13.	3.2	56.
	$\#/M^3$	288.	19.	436.	177.	208.	555.	58.	4070.
Centropages mcmurrichi	S	--	--	0.9	--	--	--	--	--
	N	1.3	3.8	1.3	0.6	2.5	--	2.8	--
	$\#/M^3$	55.	25.	28.	8.2	110.	--	51.	--
Clausocalanus arcuicornis	S	--	--	0.5	--	--	0.4	27.	--
	N	0.5	--	--	--	--	0.3	17.	--
	$\#/M^3$	72.	--	--	--	--	17.	300.	--
Acartia longiremis	S	--	0.1	--	18.	--	0.3	5.3	0.6
	N	--	0.9	6.7	1.2	0.1	2.1	52.	0.4
	$\#/M^3$	--	6.3	138.	14.	6.1	87.	936.	143.
Tortanus discaudatus	S	--	--	--	--	--	--	1.0	--
	N	0.3	--	--	--	--	--	0.8	--
	$\#/M^3$	11.	--	--	--	--	--	15.	--
Epilabidocera amphitrites	S	--	--	--	--	--	--	0.8	--
	N	--	--	--	--	0.1	--	0.01	--
	$\#/M^3$	--	--	--	--	6.1	--	0.15	--
Eucalanus bungii	S	--	--	--	--	--	--	2.0	--
	N	--	--	--	--	--	--	0.1	--
	$\#/M^3$	--	--	--	--	--	--	2.5	--
Ostracods	S	--	--	--	--	80.	0.2	0.5	--
	N	0.3	0.9	0.3	0.6	14.	3.7	--	--
	$\#/M^3$	11.	6.3	6.9	8.2	623.	156	--	--

Table 4. (Continued)

Date: Year	1962							1963
Month	V	VII	VIII	VIII	VIII	IX	XII	VIII
Day	19	22	5	9	17	21	1	24
Number of fish analyzed	1	5	3	2	1	5	3	15
Fish size range (mm.)	200	74-186	133-144	150-180	147	153-173	175-192	156-212

S denotes average percentage by number of the organism in stomach contents.
N denotes percentage by number of the organism in the net sample.
$\#/M^3$ is the computed concentration of the organism in the net sample.

percentage in the fish's stomach contents was more than five times that of the net sample.

During December, when Acartia clausii was less abundant, and large numbers of Clausocalanus arcuicornis (Dana) were present, Acartia clausii was almost absent from stomach analyses, but the average percentage of Clausocalanus arcuicornis in fish stomachs was almost double that of the net haul. For each of the three larger copepod species found in this December sample [Tortanus discaudatus (Thompson and Scott), Epilabidocera amphitrites (McMurrich), Eucalanus bungii Giesbrecht] the average percent present in the stomachs was greater than the percentage in the net sample. These copepods are not common to the bay, but are more oceanic in normal habitat and were accompanied by large numbers of Acartia longiremis (Lilljeborg) which are found in appreciable numbers within the bay only near the entrance. By contrast, Centropages mcmurrichi Willey, even when large numbers were present in the water, and despite the fact that it has a larger average size than Pseudocalanus minutus, was in all cases found in much lower percentages in the stomach contents than in the net sample. Such apparent negative selectivity may be related to the presence of Centropages mcmurrichi in a water mass not usually inhabited by herring but sampled by the net.

The small copepod, Oithona similis Claus, although abundant in May and December, 1962, with populations up to 1053 individuals per cubic meter in net samples, never appeared in significant amounts in stomach contents.

The data indicate that only a few organisms constitute the bulk of the food supply while the herring are in the bay. Of these, Acartia clausii is apparently the most important, based on its rather consistent appearance in stomach contents. The data suggest, however, that this position of dominance of A. clausii is a function of its abundance and acceptable size and may be replaced by other, larger copepods, such as Pseudocalanus minutus, if they are present in sufficient numbers, and further, that the larger a food organism is, the more intensively it is selected for by the herring.

Selectivity of the fish for larger organisms may be even greater than a percentage comparison with the net catch shows since the 0.239 mm. net mesh could permit smaller organisms to pass through, whereas the gill-rakers (0.14 mm. aperture) could capture more of those forms between 0.14 mm. and 0.239 mm. Thus, with a comparative net selectivity against forms less than 0.239 mm., the percent of forms larger than 0.239 mm. would appear larger in the net catch.

It is of interest to note that on August 17, 1962, when no single form constituted a very large percentage of the zooplankton population that ostracods constituted 14 percent of the net catch, but 80 percent of the stomach content. Stomach contents of the single fish taken on this day contained in addition, large quantities of wood fragments, unidentified debris and particles of mica. Wood fragments of the type found and mica are characteristic of river derived sediments which are found on the bottom as far downstream as McLean Point in Yaquina Bay.[3]

On August 24, 1963, despite the fact that the net sample contained very high concentrations of Acartia clausii (4070 individuals per cubic meter), the average percentage in the stomach contents of captured herring was only half that of the net sample. Although not

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[3]Personal communication from Mr. Vern Kulm of the Department of Oceanography, Oregon State University.

represented in the Clarke-Bumpus haul, up to 26 fish larvae ranging in length from 21 to 34 mm. (mean 26.2 mm.) were found in the stomach contents. On September 24, 1963, several fish larvae, tentatively identified as Clupeidae and similar morphologically to those in the August 24 stomach samples, were dip-netted at Station 21 with lengths from 22 to 35 mm. (mean 28.5 mm.), suggesting that they were from the same population which had been preyed upon by herring captured one month previously. While probable fish larvae escapement from the Clarke-Bumpus net haul precludes calculations of population densities (3, p. 291), it is most probable that the fish larvae captured by the herring on August 24 existed in numbers much less than that of species of zooplankters found in the net sample which could have served as food for the herring.

Evidence is not available in the present study for comparison of many factors determining choice of food supply, such as (1) relative capability of evasion from capture, (2) patchiness or layering of the prey, or (3) possible defense mechanisms such as toxins or unpleasant taste. However, efficiency in harvesting quantities of food suggests that the capture of a large unit of food such as fish larvae could represent a conservation of energy by the herring.

Clearing Rates Related to Stomach Analyses

In the light of work done by Battle, *et al* (2) on "clearing rates" for various portions of the alimentary tract of herring, the results of stomach analyses and net plankton samples in this investigation suggest that herring of the size and age sampled fed in areas dominated by Yaquina Bay water.

Utilizing the experimental results of Battle, *et al.* (2, p. 416), the following empirical equations have been derived:

$$Y=45.67\ e^{-0.0977x} \qquad (1)$$

$$Y=44.83\ e^{-0.1008x} \qquad (2)$$

Y is the clearing rate or time in hours for the gut to clear after a period of feeding for the whole digestive tract (1) or for the stomach alone (2); *x* is the temperature in degrees Centigrade.

Using water temperatures recorded at the time and place of fish capture and applying equation (2) it can be determined that the average time required for a herring to clear its stomach after feeding is approximately 12.3 hours. The temperature range for all sampling dates of $9.85^{\circ}C$ to $17.40^{\circ}C$ has a corresponding range in clearing time of 16.6 hours to 7.8 hours. Temperatures taken in the surf at Otter Rock on or near dates that herring samples were collected in Yaquina Bay average $13.2^{\circ}C$. Stomach clearing time at this temperature is about 11.9 hours. Therefore, one would expect that if the captured herring had fed on distinctly off-shore plankton not found in Yaquina Bay net samples during any time in the previous 12 hours before capture, a significant number would have appeared in the stomach contents. While it is not known where the captured fish did their feeding, it is significant that with one exception, a single specimen of Calanus tenuicornis Dana found in one December 1, 1962 herring stomach, all forms of zooplankton appearing in the diet were also found in net samples taken concurrently with the herring within Yaquina Bay.

SUMMARY

(1). Yaquina Bay, Oregon is a feeding ground for one to four year old Pacific herring (Clupea pallasii).

(2). Major food organisms found in the herring stomachs were Acartia clausii and Pseudocalanus minutus.

(3). When present, the larger copepods, such as Eucalanus bungii, Epilabidocera amphitrites and Tortanus discaudatus, were found in greater percentages in stomach contents than in the comparable net sample.

(4). Large numbers of clupeid fish larvae were present in herring stomachs in August, 1963. Percentage occurrence of Acartia clausii in fish stomachs at this time was proportionally much less than the percentage representation in the comparable net sample in sharp contrast to the much greater percentage typically present in herring stomachs during periods of abundance of this copepod. The data suggest selective feeding for larger sized prey.

(5). The much lower percentages of Centropages mcmurrichi in herring stomach contents than in comparable net samples suggests either (a) strongly negative selective feeding or (b) the presence of this copepod in a water mass other than that usually inhabited by the herring but sampled by the net.

(6). During a period of a lack of the usually abundant

zooplankton organisms in the net samples, ostracods constituted approximately 14 percent of the net catch, but was 80 percent of the stomach content in the single herring captured at this time along with quantities of wood fragments, debris, and particles of mica. The data are indicative of opportunistic feeding.

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APPENDIX

A SCALE OF THE MATURITY STAGES OF THE OVARIES IN THE MURMANSK HERRING

Stage I (Juvenile). Sex is not distinguishable by the naked eye. Ovaries are long, thin threads lying close to the dorsal spine. The left ovary is usually longer than the right. Color -- light yellow. Blood vessels feebly developed. Length of roe 40-50 mm. Weight not more than 0.5 percent of fish weight.

Stage II (Preparatory). Polygonal egg cells are easily seen with the naked eye. Roe of first time spawners is light yellow; in previous spawners, the roe is darker yellow to brownish yellow. Weight about three percent of body weight.

Stage III (Ripening). Roe occupies about 2/3 of the body cavity. Small rounded eggs are visible with the naked eye. Blood vessels are well developed. Weight of roe about six percent of body weight.

Stage IV (Ripe). Roe fills whole body cavity. Blood vessels well developed. Eggs are large, irregularily edged, close together. Roe membrane thin and easily torn. Color -- yellow-red. Weight -- 10 percent of body weight.

Stage V (Spawning). Roe occupies almost whole body cavity. Large, light eggs visible through transparent roe membrane. Ripe eggs fill the oviduct. Weight -- 9-21 percent average 14 percent of body weight.

Stage VI (Spent). Roe strongly shrunk, withered, containing much blood, purple color. Weight - one percent of body weight.