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Evaluation of the River Herring By-Catch in the Mackerel Fishery

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by

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INTRODUCTION

Alewives, Alosa pseudoharengus, blueback herring, Alosa aestivalis, and hickory shad, Alosa mediocris, which are collectively referred to as river herring, have been subjected to a fishery along the Atlantic seaboard since pre-colonial days (Bigelow and Schroeder 1953). The overall economic importance of the fishery has declined recently, yet the annual migration of river herring provides a valuable resource to many small coastal communities. The highest recorded domestic landings occurred in 1958 when the total U.S. catch was 33,952 mt. By 1984, total domestic landings of river herring declined to 4,718 mt (Table 1) with 88% reported from Virginia, North Carolina and South Carolina (Table 2). This decline in catches reflects declines in abundance, possibly as a result of overfishing of river herring stocks by foreign fleets during the 1960's and 1970's (Richkus and DiNardo 1984).

Since passage of the Magnuson Fishery Conservation and Management Act in 1976, foreign fleets have been restricted from harvesting river herring as a directed fishery, yet other species, such as mackerel, have been allocated to foreign fleets for directed, joint venture, or joint venture/directed operations. The overlap in geographic distributions of river herring and mackerel (Grosslein and Azarovitz 1982) subject river herring to fishing mortality as a by-catch in the mackerel fishery. In 1983 and 1984, the total allowable level of foreign fishing for river herring was 100 mt. This allocation was perceived as a potential threat to the domestic river herring resource and consequently time and area restrictions were added. Since April 1985 the river herring by-catch south of 37°30' N latitude has been limited to 0.25% of the total mackerel allocation. Increased demand to harvest the mackerel resource has warranted examination of the river herring by-catch in the mackerel fishery.

In this paper, I present exploratory analyses to determine possible factors related to river herring by-catch in the mackerel fishery including: (1) diurnal changes in catchability, (2) distribution patterns with respect to temperature, depth, and geographical location, and (3) fishery-related factors including distance between successive tows, vessel speed, and mesh size. The objective is to synthesize available information from several sources and to identify factors which could be used to minimize river herring by-catch in the directed mackerel fishery.

METHODS

Data Sources

Data used in the analysis were from four sources: (1) Northeast Fisheries Center (NEFC) bottom trawl surveys, (2) NEFC/Polish mackerel research cruises (referred to herein as Polish survey), (3) Northeast Region (NER) observer program for joint venture/foreign directed mackerel fisheries, and (4) Virginia commercial catch and effort statistics (Loesch and Kriete 1982, 1985). Hickory shad is a relatively unimportant component of the catch and in this paper I consider only alewife and blueback herring data. Data sources used for each analysis are provided in Appendix Table I.

Since the autumn of 1963 and spring of 1968, the NEFC has conducted semi-annual stratified random bottom trawl surveys of continental shelf waters between Nova Scotia and Cape Hatteras, North Carolina (Grosslein 1969, Clark 1982). One of two vessels makes a standardized 30-minute tow at each station and appropriate physical and biological data are recorded. Data from the spring and autumn surveys collected from 1976-1985 at stations between Cape Hatteras and Cape Cod, Massachusetts were used. A total of 5,682 stations were sampled during this period, with 2,998 stations in spring and 2,684 stations in fall.

Beginning in 1981, Poland has cooperated with the NEFC in conducting a survey of mackerel resources along the east coast of the United States. In exchange for research activities, Poland has been given an allocation of mackerel which could be taken as a commercial catch. The Polish survey between 1981 and 1985 involved six vessels using mid-water trawls with neither a completely random survey design nor a standard tow duration. In most cases the vessels operated as commercial trawlers and searched given areas specifically for mackerel, although some tows were made randomly on an exploratory basis. The objective of each tow was not recorded in the trawl logs. The Polish survey did not include areas south of 38°00'N during 1981 and 1982. During the five-year sample period, 1,660 tows were made. Variables recorded during the survey included vessel speed, depth, surface and bottom temperature, location, tow duration, and weight of each species caught. The inter-tow distance was calculated as the great circle distance (the distance between two points on the surface of a sphere) of consecutive tows using longitude-latitude coordinates. The distance between tows was used as an indication of size and local patchiness of mackerel schools.

Foreign observer data were collected in 1985 during the directed aspect of a joint venture/directed (JVD) mackerel fishery. Observer data included vessel, area, mesh size, tow speed, tow duration, total catch in weight and catch per species by weight.

Virginia commercial catch and effort data (metric tons caught and number of nets fished) from pound nets in the York and Rappahannock Rivers were available for the period 1977 to 1984 (Loesch and Kriete 1982, 1985). The ratio of catch to effort was taken as a measure of abundance.

Data Analysis

Observer and Polish catch-per-unit-effort was standardized to catch (metric tons) per hour towed for mackerel and river herring. Mean CPUE was calculated for each species and variances were estimated using the jackknife procedure (Smith 1980). The ratio of mean river herring CPUE to mean mackerel CPUE was expressed as percentage by-catch.

NEFC survey indices were calculated as stratified mean weight per tow using a delta distribution (Pennington 1983). NEFC indices were computed separately for blueback herring and alewives to determine if a single species was more indicative of commercial catches of river herring.

Relationships among the NEFC indices, Polish CPUE and Virginia CPUE were determined using the Spearman's rank order correlation coefficient. Relative annual differences in catch indices for Polish and NEFC surveys were examined by comparing the annual mean value of the index divided by the grand mean of the time series.

Catches were categorized into arbitrary weight intervals; mackerel were divided by 5,000 kg intervals with catches over 45,000 kg included in one category and river herring were divided by 1,000 kg intervals with catches over 8,000 kg in the last interval. Inter-tow distances were categorized into 10-mile increments and depths into 20-meter intervals.

RESULTS

Abundance Indices

River herring CPUE from the Polish survey and Virginia pound net fishery were compared to stratified mean catch (kg) per tow of blueback herring and alewives from the NEFC spring bottom trawl survey for the Middle Atlantic region (Table 3). The NEFC blueback herring index was significantly

correlated ($P<0.05$) with changes in the Polish river herring CPUE and Virginia commercial CPUE. Abundance indices are summarized in Table 4. The magnitude of the annual changes were greatest in the NEFC indices and least in the Virginia CPUE (Figure 1a).

Relative annual differences of mackerel CPUE from the Polish survey did not follow the same trend as the NEFC spring survey indices for mackerel in the Middle Atlantic (Table 4, Figure 1b). CPUE values for the Polish surveys were relatively constant while the NEFC indices for mackerel declined between 1981 and 1983, then sharply increased until 1985.

Distribution Patterns

Diurnal Variability

River herring catchability by time of day was examined by comparing catch rates from NEFC groundfish surveys (1982 to 1985) for four time periods: night (2000 to 0400 hours), dawn (0400 to 0800 hours), day (0800 to 1600 hours), and dusk (1600 to 2000 hours). The catches varied within season and year but there was no consistent trend for either species (Figure 2). River herring catches during the Polish survey using the same time periods also indicated no diurnal differences in availability. Accordingly, diurnal differences in catchability were not considered in subsequent analyses.

Temperature

The distribution of river herring and mackerel were similar relative to surface temperature (Figure 3). River herring catches in the Polish survey occurred at temperatures between 3°C and 11°C with most large catches occurring between 5°C and 7°C. Mackerel catches followed the same trend with maximum catches occurring between 5°C and 7°C.

Location/Depth

By-catch rates from the Polish survey computed by 1° of latitude and longitude (Figure 4) revealed a trend in river herring by-catch with respect to latitude and depth. The highest by-catch rates of river herring occurred between 75°W 38°N and 75°W 36°N (the southern extent of the survey) at the mouth of Chesapeake Bay. Previous analyses of the 1984 Polish data (ASMFC 1985) indicated that the highest by-catch occurred south of 37°30'N. Geographic differences in catches for the 1983 and 1985 Polish surveys were consistent with the 1984 survey (Table 5). The survey in 1981 and 1982 was north of 37°30' only. Average river herring CPUE during 1983-1985 was 0.1 mt/hr and 0.6 mt/hr north and south of the line, respectively, and was significantly greater in the south ($P<0.05$) (Appendix Table II). The 1984 values had the most extreme geographic differences at 0.1 mt/hr and 0.7 mt/hr north and south, respectively. The highest average catch rates (1981-1985) occurred in the south during January (0.9 mt/hr).

Geographic differences in mackerel catches were not as pronounced. The average CPUE in the south and the north during 1983-1985 were 6.7 and 12.8 mt/hr, respectively. The greatest difference between south and north occurred in 1985 when the average CPUE south and north of the 37°30'N line was 18.0 mt/hr and 5.0 mt/hr, respectively (Appendix Table II). The highest average value for mackerel in the north was 11.5 mt/hr during January. The highest mean monthly catch rates of mackerel (22.6 mt/hr) occurred during February south of the line; the overall mean for the south was 12.8 mt/hr. February was also the month with the lowest river herring to mackerel ratios in the southern region.

The coefficients of variation by one degree square for mackerel ranged from 99% to 267% and were largest on eastern Georges Bank and along the New Jersey coast. Coefficients of variation for river herring ranged from 178% to 568% and were also largest along the edge of the continental shelf east of 70°W (Appendix Figure 1).

Catch variations by depth were greater for river herring than for mackerel. Mean river herring and mackerel catches were determined for 20-meter depth intervals between 100 and 150 meters and ranked by weight (Table 6). Mackerel catches did not exhibit any obvious trend relative to depth. Minimum average weight of 7,674 kg at 110 m and the maximum mean weight of 15,753 kg at 50 m differed by 48.7%, however, maximum difference in weight between depths other than 110 m was only 18.0% (Appendix Table III). With each depth category, the probability of encountering large catches of mackerel was nearly equivalent (Figure 5).

In contrast, the range in mean weights for river herring, 8 kg at 130 m and 825 kg at 10 m, differed by two orders of magnitude. Dramatic decreases in catch occurred in depths greater than 100 m (Table 6). River herring catches were highest between depths of 20 and 40 meters, and declined slowly at depths greater than 40 meters (Figure 6). The majority of catches at all depths contained less than 1 mt and catches at depths greater than 100 meters were always less than 1 mt (Appendix Table IV).

Fishery Related Variability

Inter-tow Distance

The magnitude of the river herring by-catch was related to distance between tows. Small river herring catches (<1,000 kg/tow) occurred at inter-tow distances up to 110 miles, while catches over 1,000 kg/tow were most

prevalent at inter-tow distances below 20 miles (Figure 7). Catches greater than 1,000 kg accounted for 10.3% of all tows with 72.5% occurring within 10 miles and 91.2% within 20 miles of the previous tow. For tows with less than 1,000 kg of river herring, 66.2% were within a 10-mile radius and 80.4% within a 20-mile radius of the last tow (Appendix Table V). When the vessel travelled beyond 20 miles to the next tow, there was only 4.9% chance of having a river herring by-catch over 1,000 kg.

Mackerel catches were not as influenced by inter-tow distances. Catches of 10,000 kg/tow were made at all distance intervals with 56.6% occurring within 10 miles and 26.5% beyond 20 miles of the previous tow (Figure 8). Catches higher than 10,000 kg/tow occurred 69.0% within a 10-mile and 88.3% within a 20-mile radius. Inter-tow distances greater than 20 miles resulted in a 34.7% chance of encountering a catch greater than 10,000 kg per tow (Appendix Table VI).

Tow Speed

Vessel speed did not influence the CPUE of one species more than another. Ship speeds during the Polish survey ranged from 3.1 to 6.6 knots and mackerel and river herring catches were equally distributed around a speed of 4.7 to 5.0 knots. A chi-square test indicated no significant tow speed effect in catch between species ($P>0.05$).

Mesh Size

Mesh size affected the quantity of river herring and mackerel in the catch. Data obtained from the 1985 joint venture/directed mackerel fishery was used to examine mesh selectivity. Mesh sizes ranged from 45 mm to 69 mm. Mackerel CPUE increased with increasing mesh size (Table 7). Mean

mackerel CPUE increased from 8.6 mt/hr at 45 mm to 26.5 mt/hr at 69 mm mesh. River herring CPUE was more variable with mesh size, ranging from 0.003 mt/hr at 60 mm mesh to 0.06 mt/hr at 66 mm mesh, and showed no particular pattern.

Mackerel-River Herring Co-occurrence

A factor associated with the size of the river herring by-catch was size of the associated mackerel catch. Catches of river herring increased with increasing mackerel catch to approximately 10 mt of mackerel, and then generally decreased at higher mackerel catches (Figure 9). The high catch in the 22.5 mt mackerel weight interval was the result of two catches of river herring over 9000 kg which accounted for 6% of the interval weight. Mackerel catches exceeded 65 mt per tow, but 92.9% of all catches were under 30 mt (Appendix Table VII). River herring catches approached 33 mt per tow but were less than 2 mt in 93.9% of the tows. Mackerel catches less than 15 mt accounted for 55.7% of the total river herring by-catch.

High levels of river herring in the overall by-catch resulted from relatively few tows. Over the five year Polish survey, 675 mt of river herring were caught. In 3.1% of the tows (n=69) 3 mt or greater were taken. These tows accounted for 400 mt or 59.2% of the total weight. Mackerel were more equally distributed with tows greater than or equal to 35 mt occurring in 3.3% (n=118) of the tows but accounting for only 20.3% of the total weight.

DISCUSSION

The river herring by-catch in the mackerel fishery is subject to both spatial and temporal variations. By-catch varied on an annual and monthly basis, by latitude, depth, vessel efficiency and skill of the fishermen involved. Alteration of tow speed, diurnal period, or temperature regime

would not reduce river herring by-catch. Mesh size appeared to affect species catch rates differentially but the data are not conclusive and an experimental study would be needed.

The NEFC index of blueback herring was most indicative of river herring by-catch. The predominance of blueback herring in the Middle Atlantic region and in the by-catch had been previously reported by Richkus and DiNardo (1984).

The greatest catches of river herring occurred in southern waters, particularly near the mouth of Chesapeake Bay during March in depths less than 100 m. Unfortunately, CPUE for mackerel also approached the highest levels in this area. The area with the lowest percent by-catch was near the southeast edge of Georges Bank at the edge of the continental shelf. This was also the area with the highest inter-tow variations in catch for both species.

The principal factor regulating by-catch in the fishery appears to be population abundance. Polish river herring CPUE follows the same trend as the population indices from the NEFC stratified random survey. In contrast, the annual mackerel CPUE from the Polish survey occurs independent from the NEFC relative abundance estimates. Anderson (1976) showed that the NEFC indices provide a reasonable indication of trends in the population abundance of mackerel. Therefore, mackerel catches in the Polish survey vary independent of population size whereas the incidental by-catch is dependent on the population abundance of river herring. Variations in river herring by-catch in time and space occur with movement patterns and changes in population size. Catches of mackerel, the target species, are more dependent on the fishermen locating a school. The searching time may vary with mackerel abundance, but once a school is located, CPUE becomes independent of

population size. This characteristic makes pelagic schooling fishes such as mackerel or river herring potentially vulnerable to overexploitation (Crecco and Savoy 1985, Sinclair et al. 1985).

The probability of river herring capture may also be related in part to the time spent fishing in a given area. When a new school of mackerel is located, the catch of the target species may be large with a small by-catch. As the school of mackerel is reduced by fishing, the probability of intercepting a school of river herring may increase. Eventually mackerel catches will decline and river herring catches increase (Appendix Table VII). The size of the mackerel school relative to the river herring schools may determine the extent mackerel can be harvested within the patch before river herring catches increase.

The 1984 Polish survey data have been used in the past to make management recommendations concerning by-catch in the foreign mackerel fishery. The abundance index ($\bar{X}$ wt/tow) of blueback herring from the 1984 NEFC survey was over four times higher than the 1976-1985 average. This population index also corresponded with increased by-catch levels in the 1984 Polish catches (Table 3), indicating that 1984 data may not be representative of the average by-catch rate of river herring.

Application of the results from the Polish survey to the foreign fishery may also be misleading. The catch ratios of the joint venture/directed mackerel fishery for 1985 by month and latitude were generally an order of magnitude lower than the corresponding 1985 Polish data (Table 8). The overall river herring mean CPUE for the foreign fishery was 0.04 mt/hr while the Polish survey had an overall CPUE of 0.2 mt/hr. Mackerel CPUE for foreign

vessels was 13.8 mt/hr in contrast to the Polish survey CPUE of 6.9 mt/hr. The ratio of river herring to mackerel CPUE is 0.3% for joint venture directed catches and 2.6% for the Polish catches.

The by-catch of river herring remains a significant management problem. Incidental river herring catches depend primarily on river herring population levels and the ability of the fishermen to find mackerel and avoid river herring. The non-targeted nature of river herring cause greater variations in CPUE per tow as evidenced by the consistently larger coefficients of variation. The relatively few tows containing large catches of river herring contribute the greatest to high levels of by-catch. If these few large tows can be avoided, the by-catch levels may be reduced. Nevertheless, if the population of river herring increases, it appears that the by-catch will also increase to some degree, despite area closures.

Designed experiments could be undertaken to examine small-scale distributions of river herring and mackerel. The purpose of such experiments would be twofold. First, knowing the relative distribution of mackerel and river herring is important, because if river herring are interspersed within mackerel schools, ways to avoid river herring may be a moot point. Second, if a vertical segregation exists, this knowledge could be used to modify fishing methods to reduce the likelihood of by-catch. The absence of a swim bladder in mackerel creates a unique appearance on electronic fish-finders. This difference could be used to quantify relative locations during transects through mackerel schools. An initial sample would be collected with small nets to verify the species composition and should minimize disturbance of the schools integrity. Similar information may be collected using towed underwater camera equipment.

Without a further understanding of schooling dynamics and local distributions, the future options for controlling by-catch will be on a crude scale at best. Other issues such as stock structure, migratory patterns of river herring and niche overlap (e.g. competition) between mackerel and river herring also need to be addressed before the total impact of the mackerel fishery on river herring populations can be understood.

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Table 1. Annual catch of river herring in the United States, 1930-1985.

YEAR	LANDINGS (MT)	YEAR	LANDINGS (MT)	YEAR	LANDINGS (MT)
1930	17,825	1950	7,840	1970	16,251
1931	19,122	1951	26,160	1971	13,075
1932	15,346	1952	20,986	1972	12,652
1933	18,330	1953	23,212	1973	10,490
1934	-	1954	23,671	1974	11,179
1935	14,357	1955	21,389	1975	10,722
1936	-	1956	24,267	1976	6,526
1937	15,026	1957	25,948	1977	6,240
1938	20,141	1958	33,952	1978	5,478
1939	14,262	1959	22,601	1979	4,395
1940	12,992	1960	23,157	1980	4,980
1941	-	1961	23,852	1981	3,578
1942	-	1962	23,650	1982	6,107
1943	-	1963	25,494	1983	4,477
1944	-	1964	19,417	1984	4,718
1945	12,942	1965	29,186	1985	6,188
1946	-	1966	26,398		
1947	17,040	1967	26,793		
1948	16,544	1968	25,984		
1949	18,861	1969	26,212		

1930-1983 landings from Richkus and DiNardo 1984
1984-1985 landings from Thompson 1986
- Denotes no data available.

Table 2. 1984 River Herring landings by state.

STATE	LANDINGS (MT)	PERCENT
Maine	377	8.0
Massachusetts	57	1.2
New Hampshire	42	0.9
Rhode Island	-	*
Connecticut	19	0.4
New York	2	*
New Jersey	1	*
Delaware	5	0.1
Maryland	61	1.3
Virginia	580	12.3
North Carolina	2996	63.5
South Carolina	580	12.3
Georgia	-	*
Florida	-	*

Data source: 1984 landings from NMFS catch statistics

- Denotes < 1 MT
* Denotes < 0.05%

Table 3. Spearman Correlation Coefficients, significance level and sample size between NEFC Bottom Trawl Survey data, Polish Mackerel Survey data, and Virginia commercial fisheries data.

	NMFS RIVER HERRING WEIGHT/TOW (KG)	POLISH RIVER HERRING CPUE (MT/HR)	VIRGINIA POUND NET CPUE (MT/NET)	NMFS BLUEBACK HERRING WEIGHT /TOW (KG)
POLISH RIVER HERRING CPUE (MT/HR)	0.30 0.62 5			
VIRGINIA POUND NET CPUE (MT/NET)	0.31 0.46 8	1.00 0.00 4		
NMFS BLUEBACK HERRING WEIGHT/TOW (KG)	0.44 0.20 10	0.90 0.04 5	0.81 0.01 8	
NMFS ALEWIVE WEIGHT/TOW (KG)	0.82 0.01 10	-0.05 0.93 5	0.24 0.57 8	0.01 0.97 10

Table 4. Mean Weight ± 2 SE of blueback herring and mackerel from NEFC Bottom Trawl Surveys (1976-1985), river herring and mackerel from Polish Mackerel Surveys (1981-1985), and CPUE of river herring in the Virginia pound net fishery (1977-1984).

Year	Blueback Herring NEFC Survey 1	Mackerel NEFC Survey 1	River Herring Polish Survey 2	Mackerel Polish Survey 2	Virginia CPUE 3
1976	0.17 ± 0.30	0.16 ± 0.05			
1977	0.13 ± 0.18	0.06 ± 0.02			3.30
1978	0.92 ± 0.76	0.17 ± 0.04			7.47
1979	0.32 ± 0.24	0.09 ± 0.03			6.68
1980	0.43 ± 0.28	0.13 ± 0.03			4.49
1981	0.17 ± 0.16	0.64 ± 0.16	0.03 ± 0.02	7.50 ± 1.32	3.69
1982	0.89 ± 1.30	0.33 ± 0.09	0.37 ± 0.17	8.01 ± 1.02	5.29
1983	0.28 ± 0.30	0.13 ± 0.05	0.25 ± 0.11	9.20 ± 1.13	4.45
1984	2.79 ± 4.24	0.93 ± 0.68	0.38 ± 0.09	9.75 ± 0.95	6.04
1985	0.63 ± 0.54	0.89 ± 0.20	0.18 ± 0.05	6.92 ± 0.74	
X ± 2 SE	0.67 ± 0.84	0.34 ± 0.14	0.23 ± 0.09	8.09 ± 1.03	5.18

1 NEFC data in kg/tow from Spring Bottom Trawl surveys in the Mid-Atlantic.
2 Polish Survey data in MT/Hour
3 Virginia CPUE data in MT/Net based on data in Loesch and Kriete 1982 and Loesch and Kriete 1985.

Table 5. Percent by-catch of river herring during the Polish Mackerel Survey 1981-1985 calculated as (river herring CPUE / mackerel CPUE) x 100. N is north of 37°30′ and S is south of 37°30′.

YEAR	JANUARY N	JANUARY S	FEBRUARY N	FEBRUARY S	MARCH N	MARCH S	APRIL N	APRIL S	MAY N	MAY S	Mean N	Mean S	Overall Mean
1981	0.7	-	0.4	-	0.1	-	-	-	-	-	0.4	-	0.4
1982	1.1	-	2.3	-	5.0	-	8.3	-	-	-	4.6	-	4.6
1983	-	-	0.3	0.0	2.2	2.4	2.8	3.2	0.2	-	1.9	2.6	2.2
1984	0.7	7.7	0.9	0.6	3.4	7.2	2.0	2.6	-	-	1.3	6.7	3.9
1985	-	-	-	1.9	2.0	4.6	2.7	0.0	0.6	-	2.0	3.6	2.6
1981-1985	0.8	7.7	1.0	1.5	2.9	5.6	3.5	3.0	0.6	-	2.2	4.8	2.7
1983-1985	0.7	7.7	0.6	1.5	2.3	5.6	2.6	3.0	0.6	-	1.8	4.8	2.9

Table 6. Rank order of river herring weight vs. depth and mackerel weight vs. depth collected during the Polish Mackerel Survey (1981-1985).

MEAN RIVER HERRING WEIGHT (kg)	N	DEPTH	MEAN MACKEREL WEIGHT (kg)	N	DEPTH
825	82	10	15753	244	50
509	344	70	15185	583	30
498	222	90	14884	222	90
487	583	30	13615	344	70
148	244	50	13366	82	10
9	78	150	13064	78	150
9	90	110	12918	17	130
8	17	130	7674	90	110

Table 7. Mean river herring and mackerel CPUE (mt/hr) ± 2 SE for mesh sizes used in the foreign directed mackerel fishery.

MESH SIZE (mm)	MEAN RIVER HERRING CPUE ± 2 SE	MEAN MACKEREL CPUE ± 2 SE	N
45	0.024 ± 0.032	8.62 ± 1.64	153
55	0.037 ± 0.023	13.47 ± 1.57	273
60	0.003 ± 0.0003	10.64 ± 4.94	14
64	0.013 ± 0.014	16.21 ± 2.86	105
66	0.056 ± 0.069	19.74 ± 3.13	176
69	0.050 ± 0.078	26.49 ± 13.29	13

Table 8. River herring and mackerel CPUE ± 2 SE and percent by-catch from Polish Mackerel Survey and joint venture directed mackerel fishery by latitude and month. Data for 1985 only.

MONTH	35° RH	35° MAC	36° RH	36° MAC	37° RH	37° MAC	38° RH	38° MAC	39° RH	39° MAC	40° RH	40° MAC	OVERALL RH	OVERALL MAC
February														
POLISH CPUE	0.01	34.03	0.56	21.96	0.15	78.33							0.50	26.55
± 2 SE	0.02	26.42	0.63	7.87	0.24	51.55							0.54	8.70
Percent	< 0.1		2.6		0.2								1.9	
N	7		28		6								41	
JVD CPUE			0.23	27.07	<0.01	20.69	<0.01	18.11					0.07	21.63
± 2 SE			0.43	8.69	<0.01	7.15	<0.01	6.38					0.12	4.24
Percent			0.8		<0.1		< 0.1						0.3	
N			28		24		33						85	
MARCH														
POLISH CPUE			0.85	13.43	0.47	15.04	0.25	12.67					0.53	14.28
± 2 SE			0.55	4.84	0.27	3.46	0.22	5.78					0.20	2.50
Percent			6.3		3.1		2.0						3.7	
N			34		66		20						120	
JVD CPUE			0.04	18.68	0.02	20.03	<0.01	8.31	0.16	11.20	0.01	0.01	0.06	14.99
± 2 SE			0.06	10.36	0.02	3.88	<0.01	3.11	0.15	3.01	0.06	0.03	0.04	2.16
Percent			0.2		0.1		0.1		1.4		142.9		0.40	
N			61		79		25		41		2		208	
APRIL														
POLISH CPUE					0.03	7.26	0.15	8.04	0.16	5.42	0.16	4.68	0.15	5.61
± 2 SE					0.05	2.73	0.16	2.32	0.14	1.11	0.07	1.16	0.06	0.76
Percent					0.4		1.9		2.9		3.4		2.7	
N					7		30		63		64		164	
JVD CPUE					0.03	3.68	0.04	20.50	0.06	15.16	<0.01	11.45	0.03	14.07
± 2 SE					0.06	5.99	0.03	7.90	0.03	2.84	<0.01	1.55	0.02	1.82
Percent					0.8		0.2		0.4		<0.1		0.21	
N					3		27		135		81		246	
MAY														
POLISH CPUE											0.03	3.58	0.03	3.58
± 2 SE											0.02	0.85	0.02	0.85
Percent											0.8		0.8	
N											148		148	
JVD CPUE											<0.01	9.25	<0.01	9.25
± 2 SE											<0.01	1.73	<0.01	1.73
Percent											<0.1		<0.1	
N											140		140	
OVERALL														
POLISH CPUE													0.18	6.92
± 2 SE													0.05	0.74
Percent													2.6	
N													473	
JVD CPUE													0.04	13.85
± 2 SE													0.02	1.08
Percent													0.3	
N													750	

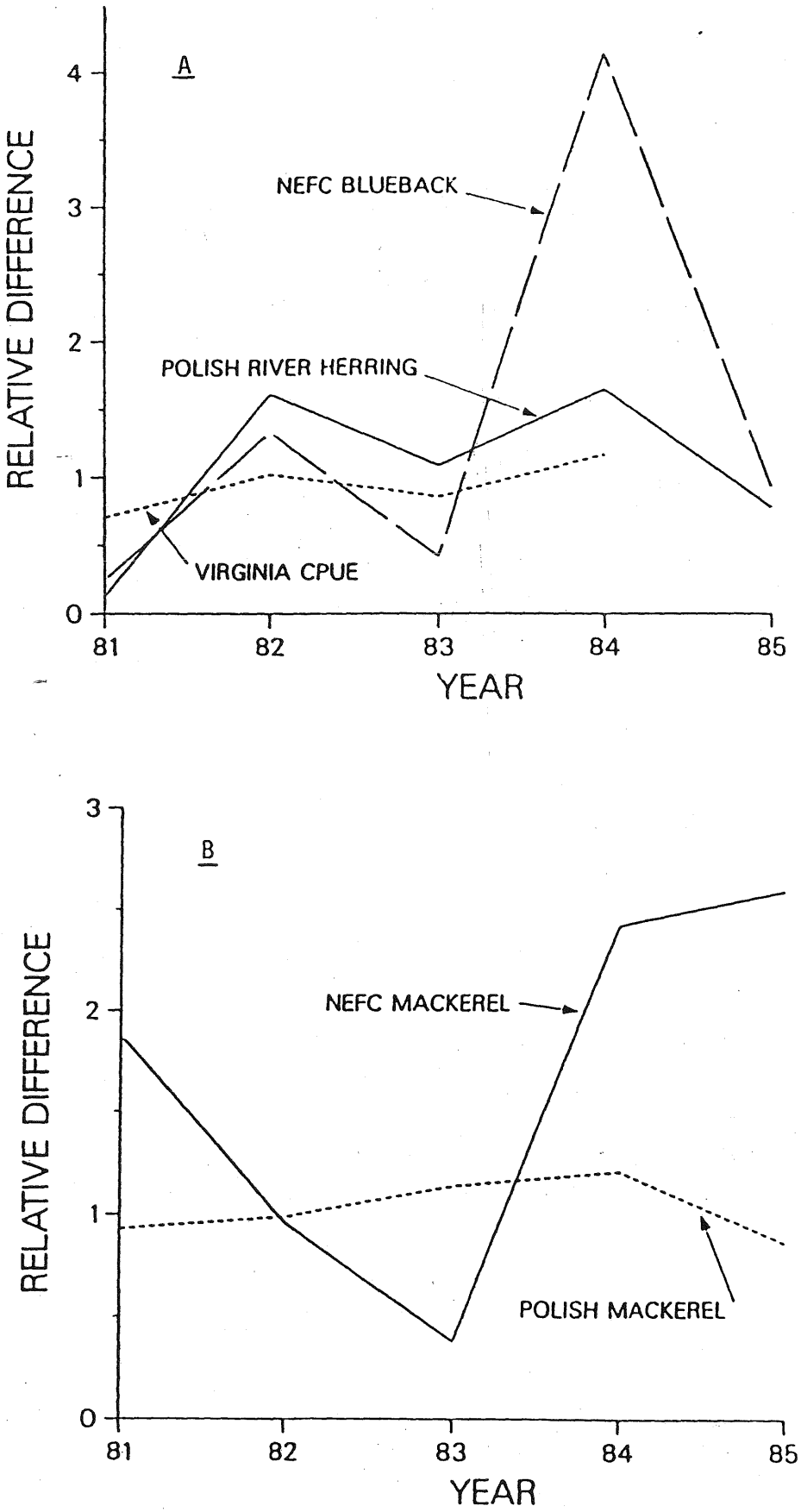


Figure 1. Relative annual difference of river herring (A) and mackerel (B) abundance indices for 1981-1985.

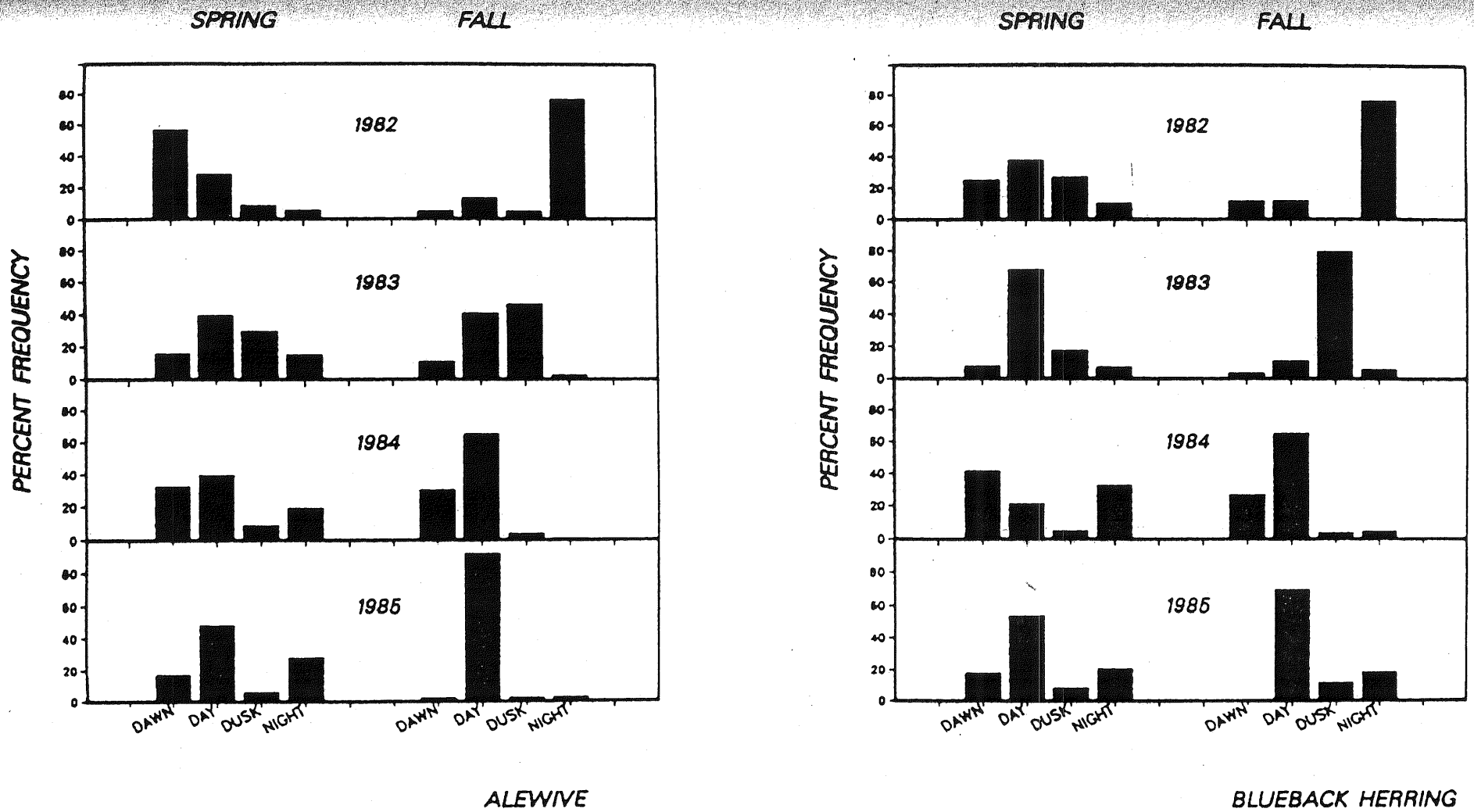


Figure 2. Diurnal variability in abundance for blueback herring and alewives from NEFC spring and fall surveys 1982-1985.

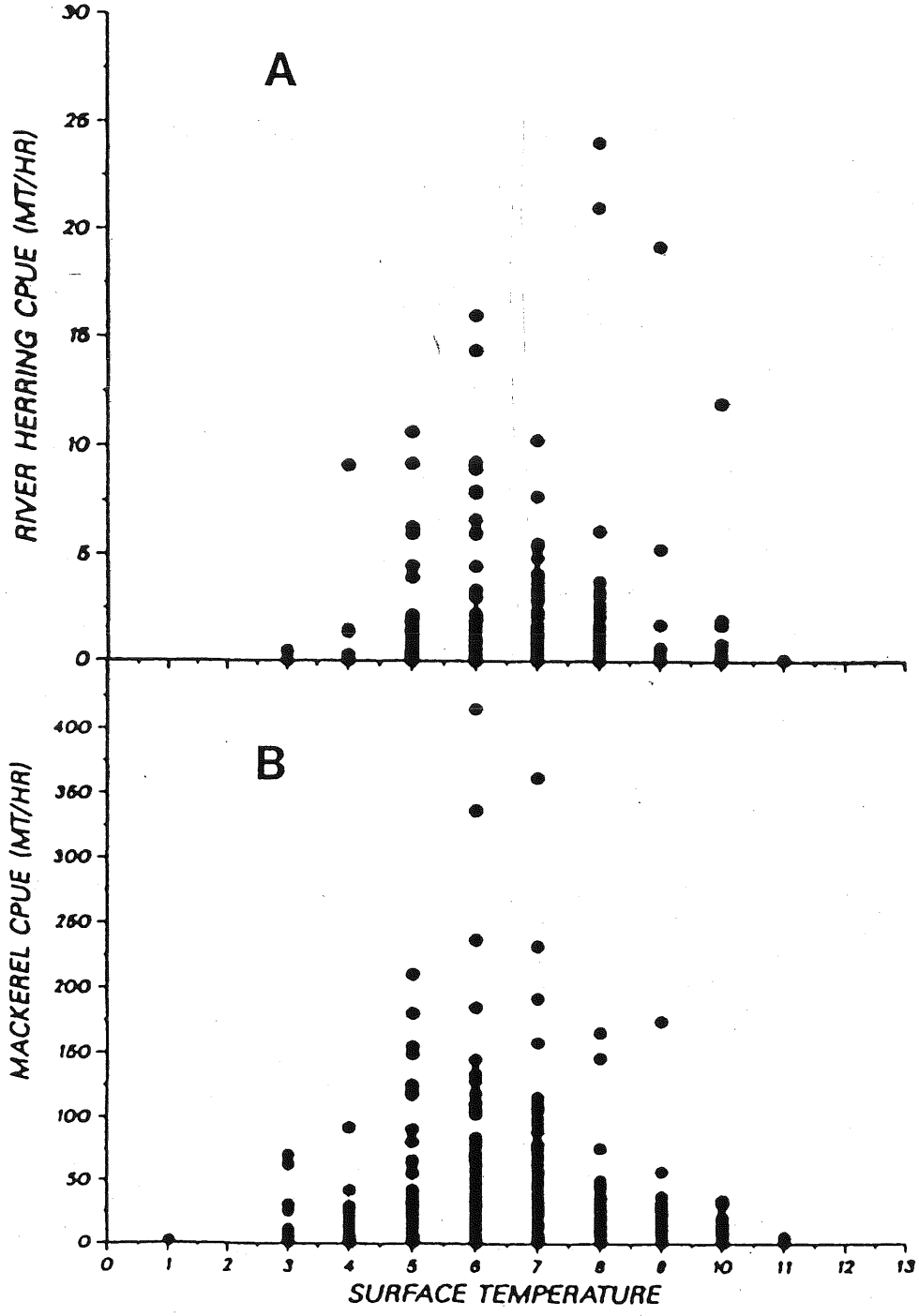


Figure 3. Distribution of river herring (A) and mackerel (B) CPUE relative to surface temperature from Polish Mackerel Survey (1981-1985).

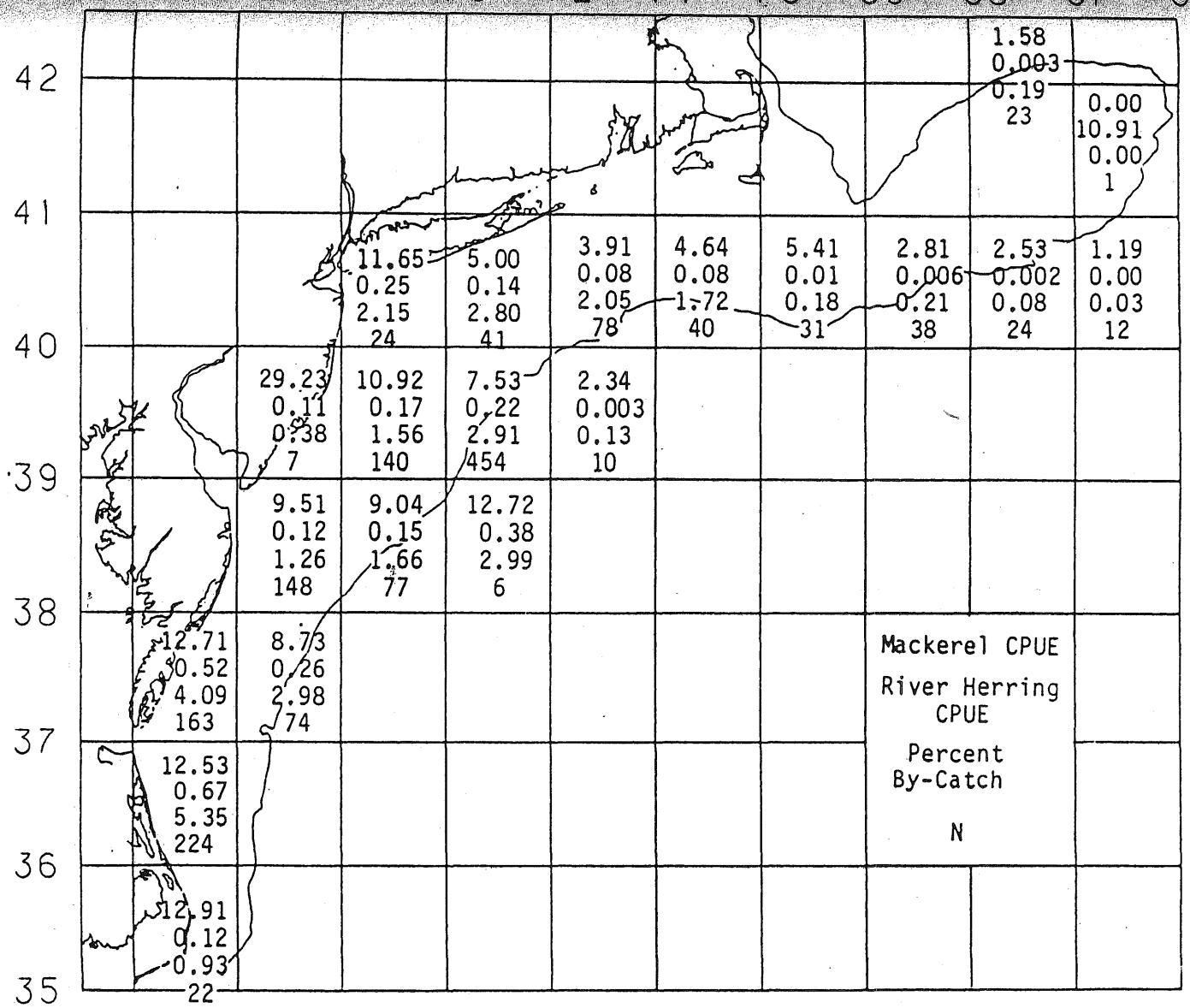


Figure 4. Mean CPUE, percent by-catch and number of observations of mackerel and river herring by 1° squares, collected during Polish Mackerel Survey (1981-1985).

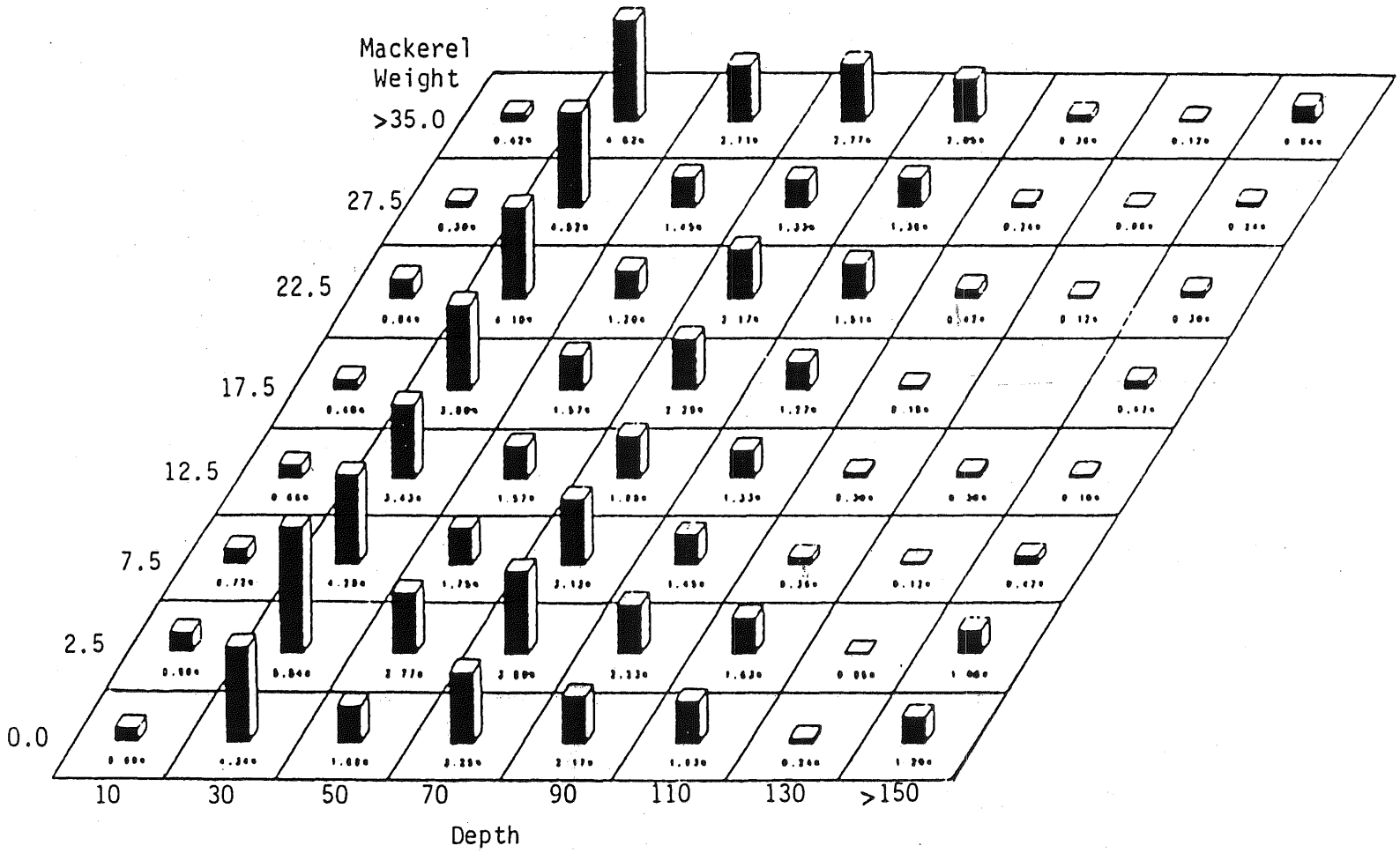


Figure 5. Percent occurrence of mackerel by weight intervals (MT) collected within depth intervals (m) from 1981-1985 Polish Mackerel Survey.

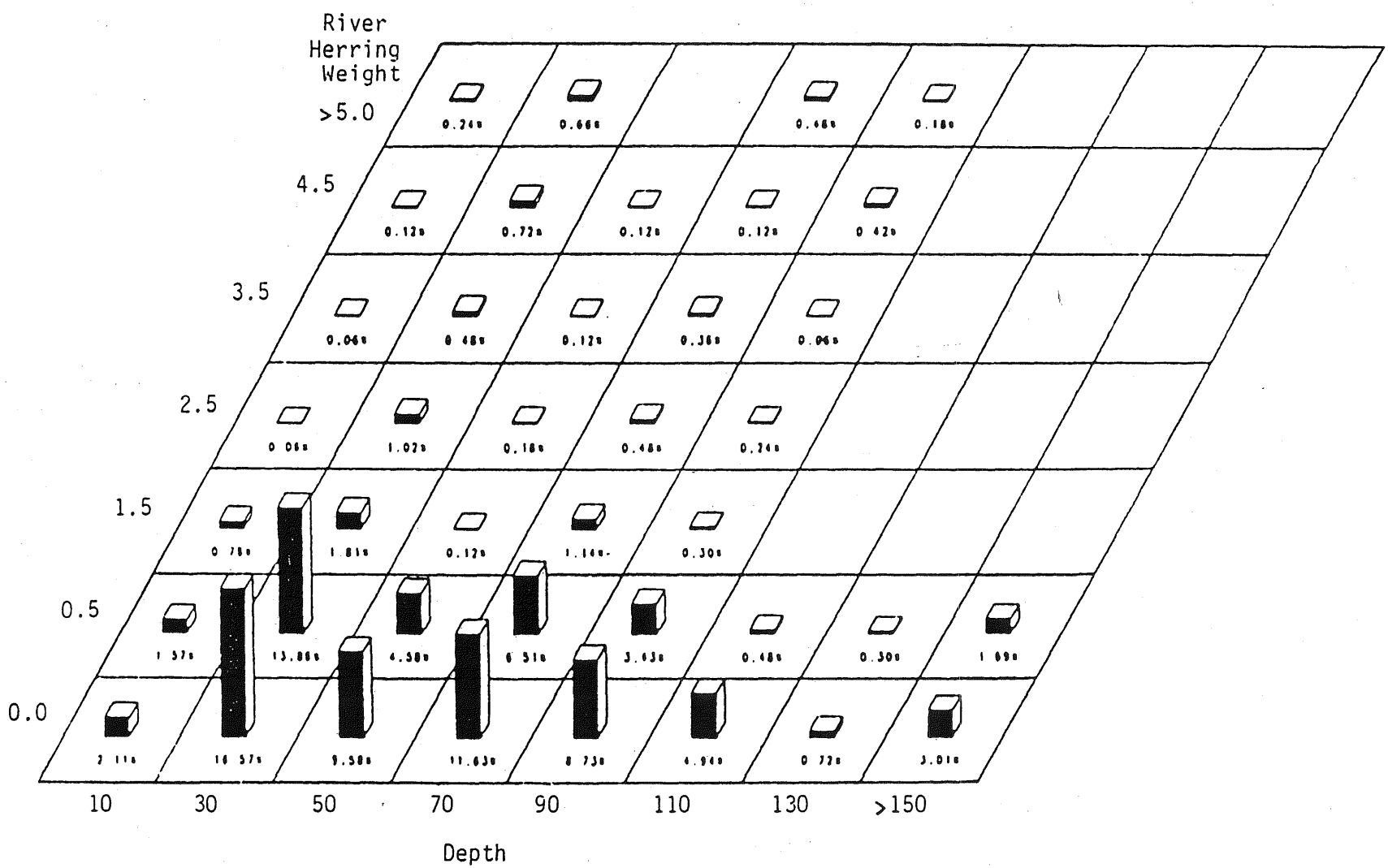


Figure 6. Percent occurrence of river herring by weight intervals (MT) collected within depth intervals (m) from 1981-1985 Polish Mackerel Survey.

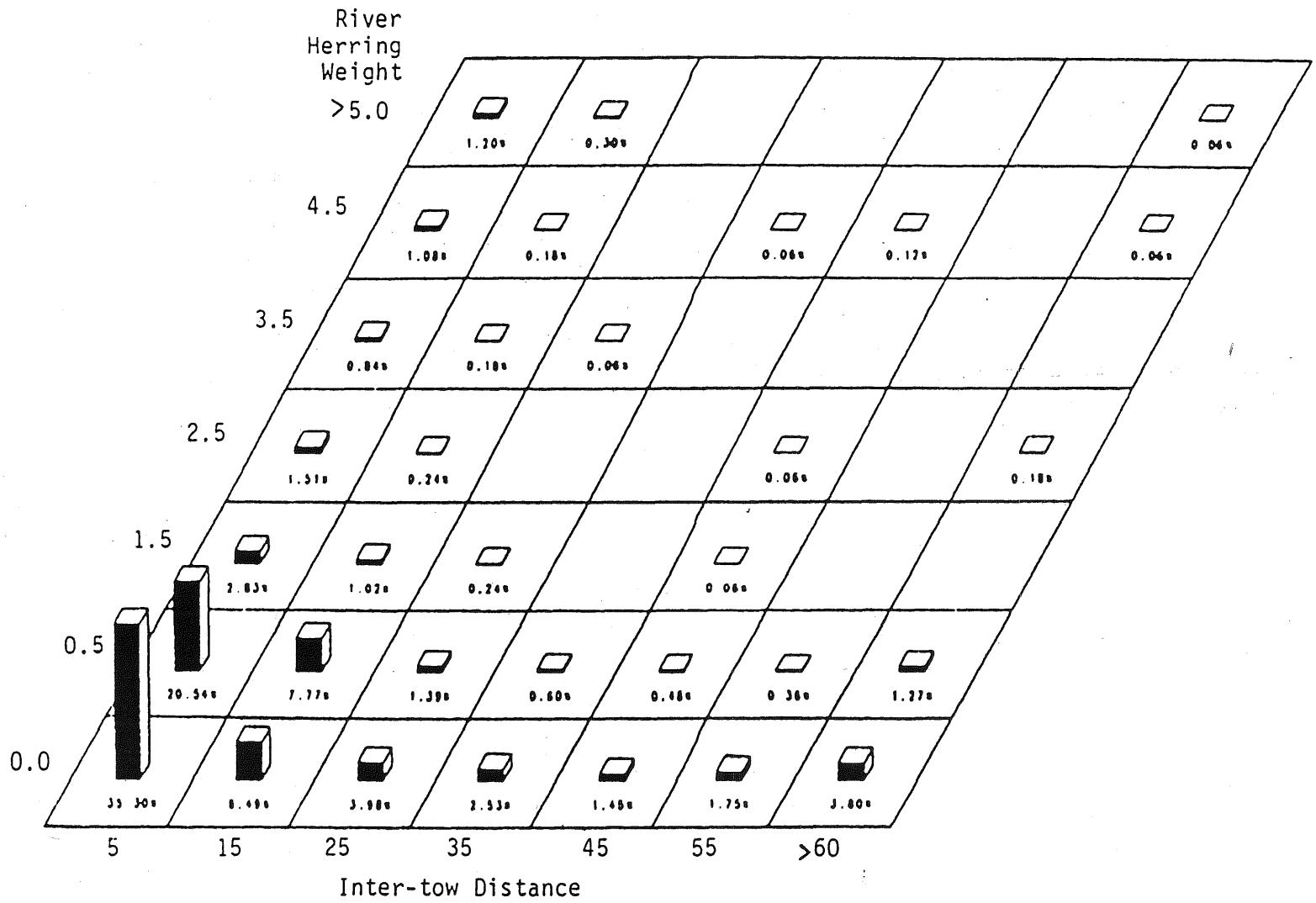


Figure 7. Percent occurrence of river herring by weight intervals (MT) collected within inter-tow distance intervals (nm) from 1981-1985 Polish Mackerel Survey.

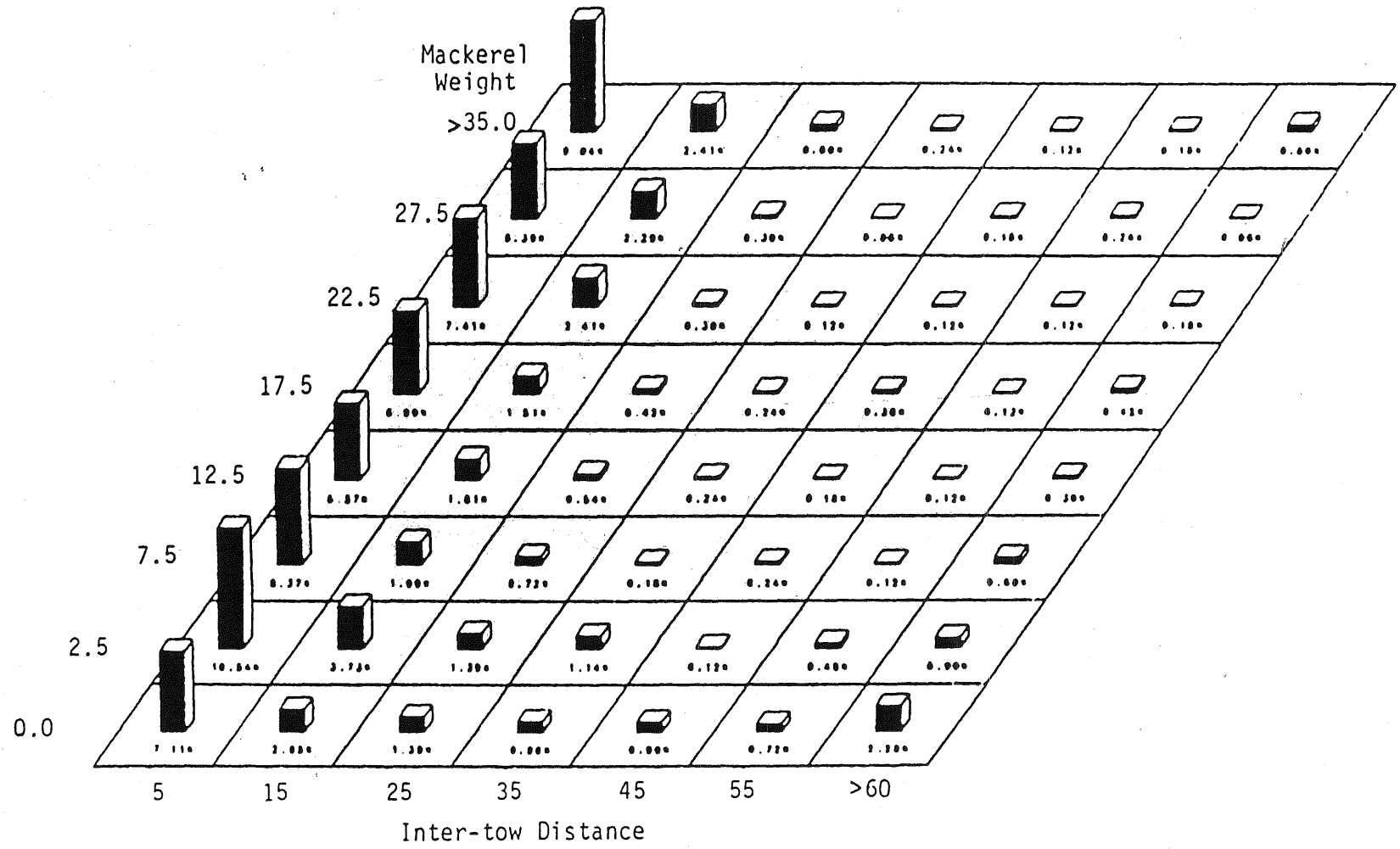


Figure 8. Percent occurrence of mackerel by weight intervals (MT) collected within inter-tow distance intervals (nm) from 1981-1985 Polish Mackerel Survey.

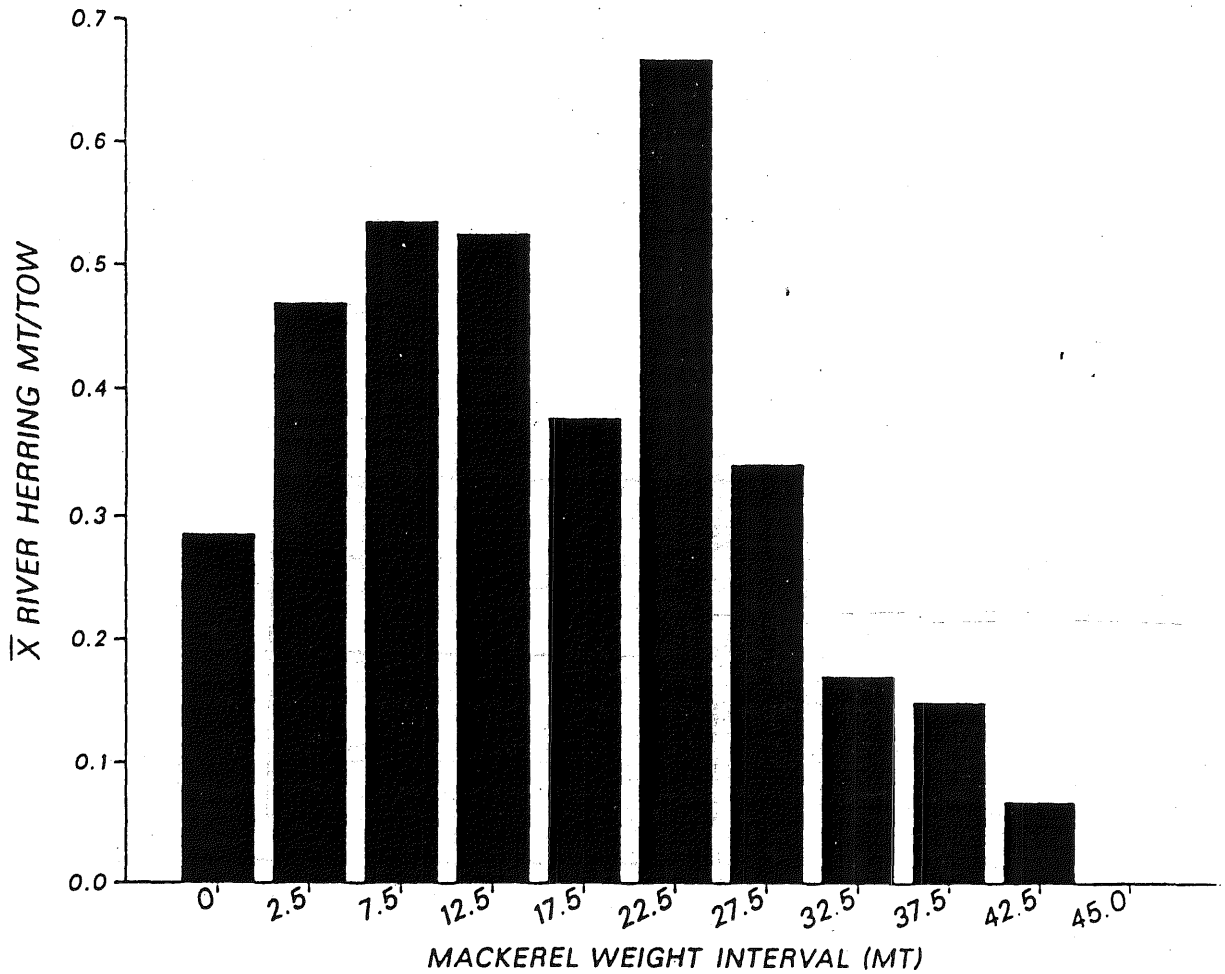


Figure 9. River herring mean catch (MT) per tow caught within mackerel weight intervals (MT) during 1981-1985 Polish Mackerel Survey.

APPENDIX TABLE I. Sources of information used in analysis of river herring by-catch.

INFORMATION CATEGORY	DATA SOURCE: NEFC SURVEY	POLISH SURVEY	OBSERVER DATA	VIRGINIA COMMERCIAL
ABUNDANCE INDICES	X	X		X
DIURNAL VARIABILITY	X	X		
TEMPERATURE		X		
LOCATION		X	X	
DEPTH		X		
INTER-TOW DISTANCE		X		
TOW SPEED		X		
MESH SIZE			X	
CO-OCCURRENCE		X		

APPENDIX TABLE II. River herring and mackerel mean CPUE ± 2 SE north and south of 37°30′ by month and year collected during Polish Mackerel Survey (1981-1985).

Mean CPUE ±2 SE (MT/HR)	January N	January S	February N	February S	March N	March S	April N	April S	May N	Group $\bar{X}$ N	Group $\bar{X}$ S
1981											
River Herring	0.10 ± 0.19		0.04 ± 0.06		0.004 ± 0.002					0.03 ± 0.02	
Mackerel	13.44 ± 6.15		9.60 ± 2.54		5.44 ± 1.39					7.50 ± 1.32	
(N)	(14)		(89)		(86)					(189)	
1982											
River Herring	0.07 ± 0.15		0.20 ± 0.28		0.48 ± 0.31		0.49 ± 0.51			0.37 ± 0.18	
Mackerel	6.27 ± 2.99		8.80 ± 2.61		9.56 ± 2.10		5.89 ± 1.45			8.12 ± 1.03	
(N)	(26)		(61)		(97)		(57)			(241)	
1983											
River Herring			0.06 ± 0.06	0.00	0.14 ± 0.28	0.34 ± 0.31	0.20 ± 0.14	0.33 ± 0.28	0.01 ± 0.01	0.15 ± 0.10	0.32 ± 0.20
Mackerel			17.94 ± 6.13	19.63 ± 64.65	6.30 ± 4.15	14.13 ± 5.68	7.04 ± 1.15	10.17 ± 2.78	5.18 ± 2.18	8.02 ± 1.14	12.49 ± 2.99
(N)			(46)	(4)	(27)	(29)	(134)	(38)	(34)	(241)	(71)
1984											
River Herring	0.10 ± 0.06	0.87 ± 0.71	0.08 ± 0.07	0.07 ± 0.10	0.28 ± 0.27	0.72 ± 0.19	0.11 ± 0.04	0.20 ± 0.16		0.12 ± 0.04	0.69 ± 0.18
Mackerel	14.33 ± 3.11	11:36 ± 3.45	8.85 ± 2.06	12.41 ± 6.29	8.30 ± 4.27	9.96 ± 1.57	5.58 ± 1.42	7.77 ± 7.77		9.25 ± 5.05	10.33 ± 1.37
(N)	(86)	(42)	(69)	(16)	(24)	(132)	(59)	(8)		(238)	(198)
1985											
River Herring				0.50 ± 0.54	0.25 ± 0.18	0.70 ± 0.32	0.15 ± 0.06	0.00	0.02 ± 0.02	0.10 ± 0.03	0.64 ± 0.27
Mackerel				26.55 ± 8.70	12.38 ± 3.81	15.38 ± 3.30	5.60 ± 0.77	6.83	3.18 ± 0.73	5.01 ± 0.60	18.01 ± 3.25
(N)				(41)	(40)	(80)	(164)	(1)	(147)	(351)	(122)
1981-1985											
River Herring	0.09 ± 0.07	0.87 ± 0.71	0.10 ± 0.08	0.33 ± 0.34	0.23 ± 0.10	0.68 ± 0.15	0.21 ± 0.10	0.29 ± 0.22	0.02 ± 0.01	0.16 ± 0.04	0.61 ± 0.13
Mackerel	11.46 ± 2.29	11.36 ± 3.45	10.21 ± 1.53	21.56 ± 6.17	7.94 ± 1.02	12.08 ± 1.49	6.09 ± 0.56	9.78 ± 2.47	3.45 ± 0.70	7.19 ± 0.46	12.84 ± 1.27
(N)	(126)	(42)	(265)	(61)	(274)	(241)	(414)	(47)	(181)	(1260)	(391)
1983-1985											
River Herring	0.10 ± 0.06	0.87 ± 0.71	0.07 ± 0.05	0.33 ± 0.34	0.23 ± 0.13	0.68 ± 0.15	0.16 ± 0.06	0.29 ± 0.22	0.02 ± 0.01	0.12 ± 0.03	0.61 ± 0.13
Mackerel	14.33 ± 3.11	11.36 ± 3.45	12.32 ± 2.62	22.56 ± 6.17	9.93 ± 2.36	12.08 ± 1.49	6.13 ± 0.60	9.78 ± 2.47	3.45 ± 0.70	6.72 ± 0.53	12.84 ± 1.27
(N)	(86)	(42)	(115)	(61)	(91)	(241)	(357)	(47)	(181)	(830)	(391)

APPENDIX TABLE III. Frequency and percent occurrence of mackerel weight categories by depth intervals from 1981-1985 Polish Mackerel Survey.

MACKEREL WEIGHT INTERVAL MID-POINT (KG)	DEPTH INTERVAL MID-POINT (M)								
FREQUENCY PERCENT	10	30	50	70	90	110	130	150	TOTAL
0	10 0.6	72 4.3	28 1.7	54 3.3	36 2.2	32 1.9	4 0.2	20 1.2	256 15.4
500	15 0.9	97 5.4	46 2.8	63 3.8	37 2.2	27 1.6	1 0.1	18 1.1	304 18.3
500	12 0.7	71 4.3	29 1.7	52 3.1	24 1.4	6 0.4	2 0.1	7 0.4	203 12.1
12500	11 0.7	57 3.4	26 1.6	33 2.0	22 1.3	5 0.3	5 0.3	3 0.2	162 9.8
17500	8 0.5	63 3.8	26 1.6	38 2.3	21 1.3	3 0.2	0	7 0.4	166 10.1
22500	14 0.8	68 4.1	20 1.2	36 2.2	25 1.5	7 0.4	2 0.1	5 0.3	177 10.6
27500	5 0.3	75 4.5	24 1.5	22 1.3	23 1.4	4 0.2	1 0.1	4 0.2	158 9.5
32500	3 0.2	47 2.8	22 1.3	20 1.2	17 1.0	2 0.1	0	5 0.3	116 6.9
37500	3 0.2	22 1.3	11 0.7	11 0.7	10 0.6	1 0.1	2 0.1	4 0.2	64 3.9
42500	1 0.1	6 0.4	5 0.3	11 0.7	5 0.3	3 0.2	0	2 0.1	33 2.1
>45000	0	5 0.3	7 0.4	4 0.2	2 0.1	0	0	3 0.2	21 1.3
TOTAL	82 4.9	583 35.1	244 14.7	344 20.7	222 13.4	90 5.4	17 1.0	78 4.7	1660 100.0
MEAN WEIGHT (KG)	13366	15185	15753	13615	14884	7674	12918	13064	

APPENDIX TABLE IV. Frequency and percent occurrence of river herring weight categories by depth intervals from 1981-1985 Polish Mackerel Survey.

RIVER HERRING WEIGHT INTERVAL (KG) MID-POINT	DEPTH INTERVAL MID-POINT (M)								
FREQUENCY PERCENT	10	30	50	70	90	110	130	50	TOTAL
0	35 2.1	275 16.6	159 9.6	193 11.6	145 8.7	82 4.9	12 0.7	50 3.0	951 57.4
500	26 1.6	230 13.9	76 4.6	108 6.5	57 3.4	8 0.5	5 0.3	28 1.7	538 32.5
1500	13 0.8	30 1.8	2 0.1	19 1.1	5 0.3	0	0	0	69 4.2
2500	1 0.1	17 1.0	3 0.2	8 0.5	4 0.2	0	0	0	33 2.0
3500	1 0.1	8 0.5	2 0.1	6 0.4	1 0.1	0	0	0	18 1.1
4500	2 0.1	12 0.7	2 0.1	2 0.1	7 0.4	0	0	0	25 1.4
5500	1 0.1	3 0.2	0	3 0.2	0	0	0	0	7 0.4
6500	1 0.1	4 0.2	0	2 0.1	1 0.1	0	0	0	8 0.5
7500	1 0.1	3 0.2	0	0	0	0	0	0	4 0.3
>8000	1 0.1	1 0.1	0	3 0.2	2 0.1	0	0	0	7 0.4
TOTAL	82 4.9	583 35.1	244 14.7	344 20.7	222 13.4	90 5.4	17 1.1	78 4.7	1660 100.0
MEAN WEIGHT (KG)	825	487	148	509	498	9	8	9	

APPENDIX TABLE V. Frequency and percent occurrence of river herring weight categories by tow distance intervals from 1981-1985 Polish Mackerel Survey.

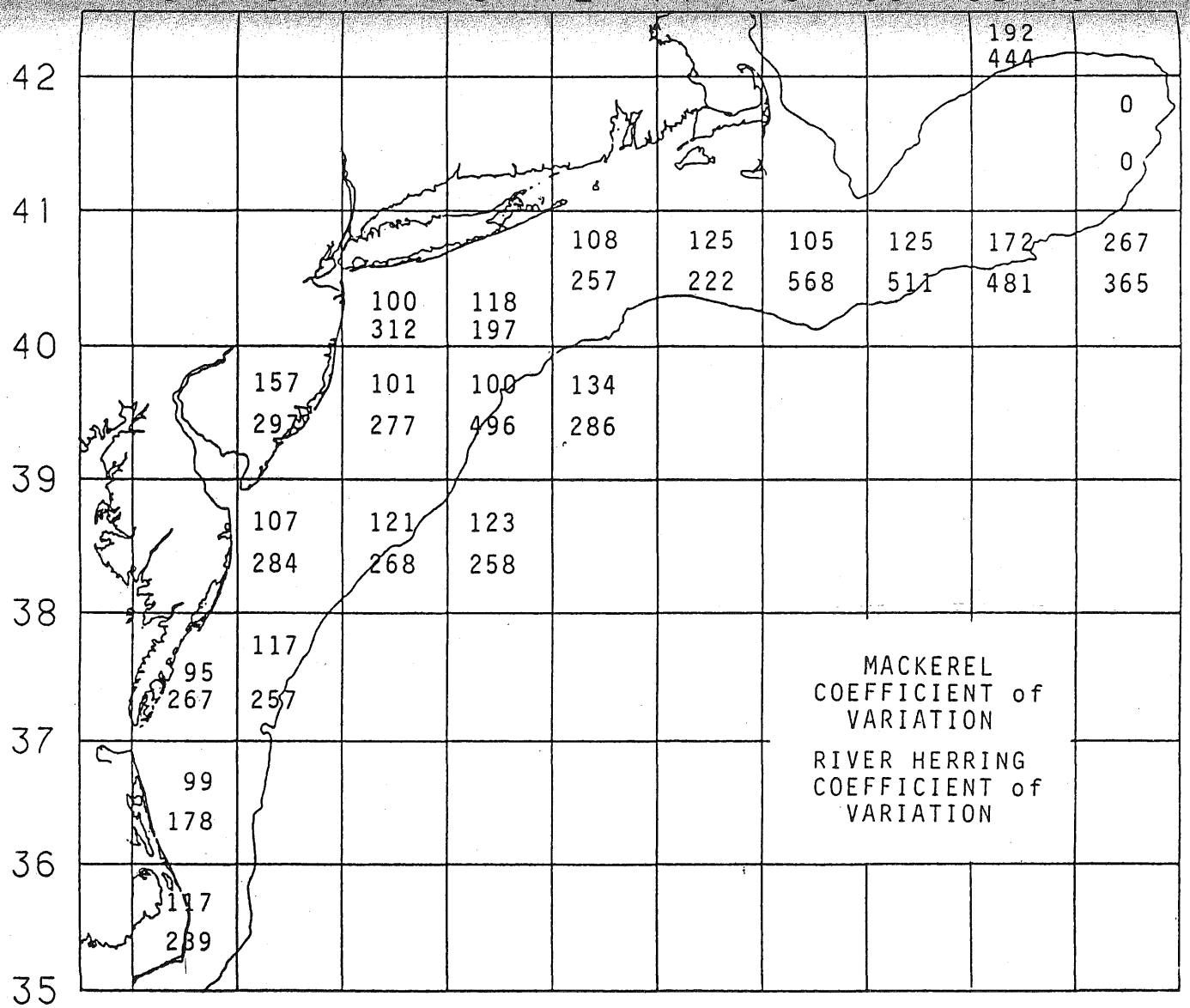
RIVER HERRING WEIGHT INTERVAL (KG)	INTER-TOW DISTANCE INTERVAL (NM)												
FREQUENCY PERCENT	5	15	25	35	45	55	65	75	85	95	105	115	TOTAL
0	586 35.3	141 8.5	66 4.0	42 2.5	24 1.5	29 1.7	4 0.2	17 1.0	6 0.4	7 0.4	6 0.4	23 1.4	951 57.3
500	341 20.5	129 7.8	23 1.4	10 0.6	8 0.5	6 0.4	2 0.1	3 0.2	1 0.1	2 0.1	2 0.1	11 0.7	538 32.4
1500	47 2.8	17 1.1	4 0.2	0	1 0.1	0	0	0	0	0	0	0	69 4.2
2500	25 1.5	4 0.2	0	0	1 0.1	0	1 0.1	0	1 0.1	0	1 0.1	0	33 2.1
3500	14 0.8	3 0.2	1 0.1	0	0	0	0	0	0	0	0	0	18 1.1
4500	18 1.1	3 0.2	0	1 0.1	2 0.1	0	0	0	1 0.1	0	0	0	25 1.6
5500	5 0.3	2 0.1	0	0	0	0	0	0	0	0	0	0	7 0.4
6500	6 0.4	2 0.1	0	0	0	0	0	0	0	0	0	0	8 0.5
7500	4 0.2	0	0	0	0	0	0	0	0	0	0	0	4 0.2
>8000	5 0.3	1 0.1	0	0	0	0	0	0	0	0	0	1 0.1	7 0.4
TOTAL	1051	302	94	53	36	35	7	20	9	9	9	35	1660
COLUMN PERCENT	63.3	18.2	5.7	3.2	2.2	2.1	0.4	1.2	0.5	0.5	0.5	2.1	100.0

APPENDIX TABLE VI. Frequency and percent occurrence of mackerel weight categories by tow distance intervals from 1981-1985 Polish Mackerel Survey.

MACKEREL WEIGHT INTERVALS (KG)	INTER-TOW DISTANCE INTERVALS (NM)												
FREQUENCY PERCENT	5	15	25	35	45	55	65	75	85	95	105	115	TOTAL
0	118 7.1	34 2.1	23 1.4	16 1.0	15 0.9	12 0.7	1 0.1	13 0.8	2 0.1	2 0.1	4 0.2	16 1.0	256 15.4
2500	175 10.5	62 3.7	23 1.4	19 1.1	2 0.1	8 0.5	2 0.1	1 0.1	2 0.1	2 0.1	2 0.1	6 0.4	304 18.3
7500	139 8.4	33 2.0	12 0.7	3 0.2	4 0.2	2 0.1	1 0.1	2 0.1	1 0.1	2 0.1	1 0.1	3 0.2	203 12.2
12500	109 6.6	30 1.8	9 0.5	4 0.2	3 0.2	2 0.1	0	1 0.1	1 0.1	1 0.1	0	2 0.1	162 9.8
17500	116 7.0	25 1.5	7 0.4	4 0.2	5 0.3	2 0.1	0	1 0.1	1 0.1	1 0.1	2 0.1	2 0.1	166 10.0
22500	123 7.4	40 2.4	5 0.3	2 0.1	2 0.1	2 0.1	2 0.1	0	0	0	0	1 0.1	177 10.7
27500	106 6.4	38 2.3	5 0.3	1 0.1	3 0.2	4 0.2	0	0	0	1 0.1	0	0	158 9.5
32500	81 4.9	20 1.2	7 0.4	1 0.1	0	1 0.1	0	0	2 0.1	0	0	4 0.2	116 7.0
37500	45 2.7	10 0.6	3 0.18	2 0.12	1 0.06	1 0.06	0	1 0.06	0	0	0	1 0.06	64 3.86
42500	25 1.51	6 0.36	0	0	1 0.06	0	0	1 0.06	0	0	0	0	33 1.99
>45000	14 0.84	4 0.24	0	1 0.06	0	1 0.06	1 0.06	0	0	0	0	0	21 1.27
TOTAL	1051	302	94	53	36	35	7	20	9	9	9	35	1660
COLUMN PERCENT	63.31	18.19	5.66	3.19	2.17	2.11	0.42	1.20	0.54	0.54	0.54	2.11	100.00

APPENDIX TABLE VII. Frequency of occurrence, percent occurrence and percent by-catch of river herring, by river herring and mackerel weight categories collected during Polish Mackerel Survey (1981-1985).

MACKEREL WEIGHT INTERVAL MID-POINT (KG)	RIVER HERRING WEIGHT INTERVAL MID-POINT (KG)											
FREQUENCY PERCENT % BY-CATCH	0	500	1500	2500	3500	4500	5500	6500	7500	>8000	TOTAL	CUMULATIVE PERCENT
0	219 13.2 0	22 1.3 0	4 0.2 0	3 0.2 0	1 0.1 0	3 0.2 0	1 0.1 0	0	2 0.1 0	1 0.1 0	256 15.4	15.4
2500	158 9.5 0	111 6.7 13.8	14 0.8 89.8	10 0.6 95.0	3 0.2 80.5	4 0.2 336.6	0	2 0.1 225.1	1 0.1 1254.9	1 0.1 946.4	304 18.3	33.7
7500	117 7.1 0	61 3.7 2.6	9 0.5 17.4	4 0.2 24.9	4 0.2 42.1	3 0.2 50.2	2 0.1 93.7	0	1 0.1 130.1	2 0.1 216.0	203 12.2	46.0
12500	88 5.3 0	52 3.1 1.5	10 0.6 10.0	2 0.1 18.5	2 0.1 27.5	3 0.2 41.1	2 0.1 36.6	2 0.1 47.2	0	1 0.1 127.4	162 9.8	55.7
17500	83 5.0 0	61 3.7 0.8	10 0.6 8.3	7 0.4 12.9	3 0.2 17.1	1 0.1 30.0	0	1 0.1 31.4	0	0	166 10.0	65.7
22500	77 4.6 0	69 4.2 1.1	11 0.7 6.1	7 0.4 10.5	1 0.1 18.1	7 0.4 18.7	2 0.1 26.2	1 0.1 24.8	0	2 0.1 43.0	177 10.7	76.4
27500	63 3.8 0	83 5.0 0.5	5 0.3 4.4	0	3 0.2 11.8	2 0.1 15.8	0	2 0.1 23.2	0	0	158 9.5	85.9
32500	68 4.1 0	43 2.6 0.4	3 0.2 3.6	0	0	2 0.1 12.7	0	0	0	0	116 7.0	92.9
37500	35 2.1 0	26 1.6 0.4	2 0.1 2.8	0	1 0.1 10.0	0	0	0	0	0	64 3.9	96.8
42500	24 1.4 0	8 0.5 0.3	1 0.1 2.5	0	0	0	0	0	0	0	33 2.0	98.7
>45000	19 1.1 0	2 0.1 < 0.1	0	0	0	0	0	0	0	0	21 1.3	100.0
TOTAL	951 57.3	538 32.4	69 4.2	33 2.0	18 1.1	25 1.5	7 0.4	8 0.5	4 0.2	7 0.4	1660 100.00	
CUMULATIVE PERCENT	57.3	89.7	93.9	95.8	96.9	98.4	98.9	99.3	99.6	100.0		



APPENDIX FIGURE I. Coefficients of variation of river herring and mackerel CPUE by 1° squares collected during Polish Mackerel Survey (1981-1985)