ZONAL VARIABILITY IN SALMONID CATCH RATES FROM RESEARCH VESSEL OPERATIONS WITHIN THE NORTH PACIFIC SQUID DRIFTNET FISHERY AREA

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Submitted to the
INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION

by the

U.S. NATIONAL SECTION

November 1988

This paper may be cited in the following manner: Ignell, S.E. 1988. Zonal variability in salmonid catch rates from research vessel operations within the North Pacific squid driftnet fishery area. (Document submitted to the annual meeting of the Int. N. Pac. Fish. Comm., Tokyo, Japan, November 1988.) 16 pp. Northwest and Alaska Fisheries Center, Nat. Mar. Fish. Serv., Nat. Oceanic Atmos. Admin., Auke Bay Laboratory, P.O. Box 210155, Auke Bay, AK 99821.)

INTRODUCTION

In the early 1980's the Government of Japan established regulatory measures for their squid driftnet fishery in the central North Pacific Ocean. These measures provided a fishing season extending from June through December and restricted vessel operations between 145°W and 170°E longitude, north of 20°N latitude and, depending upon the month, south of 40,42,44, or 46°N latitude (Fishery Agency of Japan, 1982). According to Japan, the monthly moving northern boundary was set to approximately coincide with the mean monthly position of the 15°C sea surface temperature isotherm. Such a provision was believed to restrict fishing to areas where the abundance of salmonids is low, thereby minimizing the potential impact of this fishery on salmonid stocks.

Several studies have been conducted in recent years to assess the effectiveness of these regulations for minimizing impacts to salmonids. Of primary interest has been the relationship of salmonid catch rates with respect to sea surface temperatures (SST) and the distributional overlap of flying squid and salmonids (Takagi, 1983; Ogura and Takagi, 1987; Dahlberg and Sigler, 1987; and Harris and Kautsky, 1987). In general, these studies have shown: (1) some overlap in salmonid and flying squid distribution; (2) negligible catch rates of salmonids in SST's above 14-15°C and low catch rates of squid in waters below 12°C; and (3) salmonid harvest within the squid area to be infrequent and low in magnitude, especially during warm years. Thus, most authors have concluded that the northern boundary was a effective management measure for limiting incidental catches of salmonids.

Other studies have analyzed the oceanographic features characteristic of the northern boundary of the squid regulatory area and how these features are potentially associated with salmonid harvest. Burgner et al. (1982) and Burgner and Meyer (1983) indicated that temperatures below 15°C are often found within the squid fishing area during each month of the fishing season. They also noted that the 12°C isotherm extends into the zone during most months of the fishery in cooler years and, more generally, that salmonid interceptions were potentially significant due to the large variability in SST's. Ignell (1987) identified the importance of the mesoscale environment along the northern boundary of the squid driftnet area for introducing cold water masses deep within this area. Ignell also documented the interannual variability in oceanographic conditions in this region and the persistence of cold water incident to the fishery during the past several years, concluding that the of climatological values in the establishment of a squid driftnet regulatory regime should be re-examined and an in-season management system explored.

Another issue pertaining to the continued suitability and viability of the current squid regulatory regime concerns the appropriateness of the number of management areas identified by the regime. Although the present regime has defined only one such area, there have been no studies to date examining the scientific implications of using only one management area. In recent years, sufficient data have been accumulated to allow analyses of the geographical effects on the relationship of salmonid catch rates within the squid regulatory area as a function of SST. In this paper, I compare catch rates as a function of SST and relate these results to present management regime for the North Pacific squid driftnet fishery.

METHODS

Data from 23 Canadian, Japanese, Taiwanese and ROK research vessel cruises were compiled and examined for salmonid catches as a function of SST's and geographical area (Table 1). Although most of these cruises consisted of Japanese vessels, data from Taiwanese, ROK and Canadian cooperative research cruises proved important due to the timing and location of fishing stations.

Thirty-two research gillnet operations from the 23 cruises were located within the northernmost 1/2 degree latitude of the squid regulatory area and used for the analyses. Four additional gillnet operations, occurring from 160 - 170°E longitude and satisfying the same latitudinal restrictions, were added to increase sample sizes as this region is adjacent and very similar, in terms of physical characteristics, to the western portion of the Japanese squid regulatory area.

To account for differing lengths of net deployed between and among cruises in calculating the probability of salmon harvest by geographical area and SST interval, the data used in tabular analyses were weighted according to the length of gillnet deployed in the set. Thus, data from a gillnet operation using 5 km of net were given five times the weight of data from an operation using 1 km of net. Although each vessel deployed a variety of gillnet mesh sizes per set, variation in mesh size was not adjusted for in the analyses.

Table 1. The Canadian, Japanese, Taiwanese and ROK research vessel cruises that provided data for analyses of salmonid catch as a function of SST's and geographical area.

		Year of Cruise with Available Data				
Nation	Vessel Name	83	84	85	86	87
Taiwan	Hai Kung				X	X
Korea	Pusan 851				X	X
Canada	Ricker				X	X
Japan	Oshoro maru	X	X	X	X	X
	Hokusei maru	X	X	X	X	X
	Iwaki maru		X			
	Shoyo Maru				X	X
	Kanki maru 58			X	X	
	Kuromori maru 38				X	
	Hokuho maru					X

For study purposes, the data were divided into two geographical regions (160°E - 175°W and 174 - 145°W, hereafter called the western and eastern region, respectively) according to similarity of physical characteristics. Within these two areas, the data were further divided for study purpose into three SST intervals (10-12.9°C; 13-15°C; and 15°C or greater). Although the length of net per set varied widely among operations (from 0.45 to 7.05 km), most of the 36 sets used 5 km or more of gillnet, for a total deployment of 169.94 kilometers of gillnet.

RESULTS

Thirteen gillnet operations harvested a total of 428 salmon and 1 steelhead, resulting in an overall catch rate (CPUE) of 2.52 salmonids per kilometer of gillnet. Chum and coho salmon were the predominant species caught, comprising 67% and 28% respectively of total catch. The remaining portion of the salmonid catch (5%) was chinook salmon, pink salmon and steelhead trout. Salmonid incidence (the proportion of sets encountering salmon, weighted by length of net set) west of 175°W was 47%, compared to an incidence rate of 8% east of 175°W longitude. In addition, catch per tan (50 m of gillnet) in the western and eastern regions were 0.152 and 0.007, respectively representing a twenty-two fold difference between regions. The percentage of gillnet operations occurring in sea surface temperatures less than 15°C equalled 82% in both regions.

The zonal cline in salmonid incidence was still prevalent when the data were stratified further by SST interval (Table 2). Forty-one percent of the gillnet operations located in the northwestern 1/2 degree longitude of the squid fishing area and in SST's from 13 - 15°C, encountered salmonids compared to 0.0% in the northeastern region. For gillnet operations in SST's less than 13°, salmonid incidence was 72% versus 19% between the western and eastern regions, respectively. Only one gillnet operation in SST's greater than 15°C encountered salmonids, resulting in an incidence of 22% and 0.0% for the western and eastern regions, respectively. In the western region, the catch per tan of chum and coho salmon was 0.26 and 0.05, respectively for gillnet operations in SST's of 11-12.9°C and 0.04 and 0.06, respectively for operations in SST's of 13-15°. The total salmonid catch per tan in the eastern region was 0.015 and 0.0 for operations within SST's of 11-12.9°C and 13-15°C, respectively.

Table 2. Gillnet effort stratified by region, SST interval and salmonid incidence. Data are the weighted number of research gillnet operations (standardized to 5 km segments) located in the northernmost 1/2 degree latitude of the squid fishing area.

	Weighted Effort (standardized to 5 km of gillnet)			
	160°E - 175°W		174°W - 145°W	
	SST (C)		SST (C)	
Salmonid Incidence	<13	13-15	<13	13-15
Present	6.3	5.8	0.5	0.0
Absent	2.4	8.2	2.2	2.4

DISCUSSION

Physical Characteristics of Salmonid Habitat Within the Squid Fishing Area

Two water masses separated by an extensive frontal zone characterize the major large scale features of the North Pacific Ocean. The northernmost water mass, hereafter called subarctic waters, are cool, low salinity waters often defined by the following three physical characteristics: (1) a salinity minimum at the surface; (2) surface salinities less than 33.2 ppt; and (3) a halocline 100-200 m below the surface that supports a temperature minimum (inversion during the summer).

South of subarctic waters and north of subtropical waters lies the Transitional Zone, a complex of two frontal zones, the Subarctic Front and Subtropical Front, and a transitional region between these fronts. The northern boundary of the Subarctic Frontal zone, marking the lower limit of subarctic waters, is sometimes referred to as the Polar Front (Roden et al., 1982). At the southern edge of the Subarctic Front is the Subarctic Boundary, usually defined by the location of the vertical 34 ppt isohaline. (There is considerable confusion in the oceanographic and fisheries literature regarding the structure of this region. Fishery scientists commonly refer to Transitional Domain as the portion of subarctic waters that lie just south of the Subarctic Domain and north of the Subarctic Front. Many physical oceanographers, however, view the Transitional Domain as part of a Subarctic Frontal zone, defined as that portion lying north of the Subarctic Boundary.)

Subarctic and Transition Zone waters can be divided zonally into two regions using $175^{o}W$ as a dividing line between the western and eastern region (Bernstein and White, 1977). Western North Pacific waters are distinguished by a intense boundary current formed by the confluence of the Kuroshio and Oyashio currents, intense eddy energy and topographical forcing due to effects of variability in the bottom topography. Eastern North Pacific waters are characterized by low eddy intensity, no strong boundary currents, little topographical forcing and diffuse frontal (especially temperature) structure. This reduction in eddy intensity, frontal intensities, etc. is due to effects of strong bottom topography variations associated with the Emperor seamounts (Roden et al., 1982), a large chain of seamounts located at about 170°E and comparable in size to the U.S. Rocky Mountains.

Salmonid Distribution

Research gillnet operations within the western portion of the squid driftnet regulatory area show a high probability of salmonid harvest (primarily chum and coho salmon) when SST's are less than 13°C, and very low incidence when SST's are above 15°C. These results generally reflect those of Ogura and Takagi (1987) which show that optimum water temperatures for chum and coho salmon end at about 13°C.

Catch rates from gillnet operations analyzed in this study and within the western region, however, were significantly less than those of Ogura and Takagi (1987). For instance, catch rates of chum salmon in the western squid regulatory area were 0.26 as compared to Ogura and Takagi's estimate of about 0.5 for gillnet operations in SST's of 11-12.9°C. Catch rates for coho salmon are even more disparate between the two data sets, ranging between 0.2 to 0.4 for SST's of 11-12.9° (Ogura and Takagi, 1987) as compared to 0.05 in my data.

Catch rates and salmonid incidence in the eastern region were much lower than those in the western region and approximately an order of magnitude (or more) less than those of Ogura and Takagi (1987). For instance, total salmonid catch per tan for gillnet operations in SST's of 11-12.9°C in the eastern area were 0.015 as compared to 0.33 in the western area. Several of the following factors may account for this: (1) regional differences in salmonid abundance; (2) small sample sizes; (3) systematic sampling differences among regions; and (4) that the southern limit of salmonid distribution is only broadly characterized by sea surface temperatures and a more precise characterization must incorporate additional biological or oceanographic parameters.

Of the first three factors, regional differences in salmonid abundance most likely contribute to the observed geographical variation in catch rates. An analysis of 1955-1960 U.S. research vessel data showed that the overall abundance of salmon was greatest in the western North Pacific and in the Bering Sea (Manzer et al., 1963). Recent data, although extensive for the western subarctic waters, cover very little of the eastern waters thereby limiting current comparisons of abundance between western and eastern areas.

Indubitably, the small number of gillnet operations used in these analyses add uncertainty to the results and conclusions. The magnitude of regional differences in catch rates are so great, however, that these differences are likely real, rather than due to chance.

Although the extent of sampling biases are unknown, they are probably similar between regions. Research vessel operations were conducted primarily during the same time period for each region. By stratifying the data according to SST intervals, differential effects in surface water conditions between regions were accounted for. Also, sampling dates may have contributed systematic bias, but this bias reduces, rather than increases, catch rate differences. Sampling dates of research vessels operating in the western region are weighted towards the end of the month. This sampling bias, however, is not apparent for operations in the eastern region. Since salmonid harvest within the squid fishing area is theoretically most probable during the beginning of summer months (Ignell, 1987), catch rates for the western region are likely biased downwards as compared to those in the eastern region.

There is growing evidence that salmon primarily inhabit subarctic waters and seldom migrate into the Transitional Domain (or the northern portion of the subarctic frontal zone), thus confirming the importance of water mass structure in determining the southern limit of salmonid distribution. For instance, Murata (1987) showed, in an analysis of four meridional transects across the Subarctic Frontal zone, that salmon catches in three transects were confined to subarctic waters and to the northernmost Transitional Domain station in the fourth transect (Murata, 1987). Limited CTD profile data (unpublished salinity/depth and temperature/depth contour plots from ROK and Taiwanese cooperative research cruises) provide evidence that subarctic water is, at times, found within the squid fishing area and that salmonid catches there are associated with this intrusion.

Geographical differences in the CPUE/SST relationship are easily explained if water mass structure is an important limiting factor of salmonid habitat. Although SST isotherms are almost strictly zonal across the North Pacific Ocean, the Subarctic frontal zone angles northward 4^{o}-6^{o} of latitude to the east

(Levine and White, 1981). Because of this angling northward, when SST's are below 15^{o}C in both the eastern and western portions of the squid area, subarctic water intrusions, as defined by the subsurface thermohaline structure, will less likely occur in the eastern portion.

Extrapolation to Commercial Fishery

The fundamental question regarding development of management regimes for the North Pacific squid driftnet fishery concerns the magnitude of salmon harvest of the commercial fishery when constrained by management guidelines. It is tempting to use research vessel CPUE data, stratified by time and area, to estimate potential salmonid catches by the commercial squid driftnet fleet. Such extrapolations are highly problematic for a number of reasons. For example, in 1985, more than 50% of the Japanese commercial squid driftnet effort occurred between September and December, a period with virtually no comparable research vessel data. Even for those months with research vessel data, the paucity of data compared to the extensive commercial fishing effort precludes the development of valid bycatch estimates. In addition, randomness in the within-month distribution of sampling effort is required to account for monthly and systematic changes in oceanic conditions and in the location of the northern fishing boundary. This requirement is violated in the western region; most research vessel operations there have occurred during the latter half of each month. Furthermore, gillnet operations conducted by research vessels are typically located at fixed, non-randomly located stations.

Commercial vessels operate under no such constraints; instead, they reportedly target on sharp gradients in surface temperatures and fish in groups thereby adjusting fishing location according to real time information on the abundance of squid.

CONCLUSIONS

1. Analyses of 1983-87 Japanese, Taiwanese, Canadian and ROK research vessel data indicate a zonal cline in salmonid incidence and catch rates when the data are stratified by SST interval and limited to operations occurring within the northernmost portion of the squid fishing area. Here, at the southernmost limit of salmonid habitat, gillnet operations within a given range of sea surface temperatures are more likely to encounter salmonids in the western portion than the eastern portion of the fishing area. This result is likely due to meridional differences in the southward intrusion of subarctic water between the western and eastern portions of the squid driftnet fishing area, indicating that water mass structure, not just surface features of the ocean, is a primary factor in determining the southern distribution of salmonids.

2. Most research gillnet operations occurring in the northernmost portion of the squid fishing area encountered SST's of less than 15°C. When these data are combined with data from satellites and ships of opportunity, they show that, in recent years, average SST's along the northern boundary of the current management regime have been

generally less than (and often considerably less than) 15°C.

RECOMMENDATIONS

1. An in-depth analysis of the physical and biological characteristics of the Transitional Zone and the importance of water mass structure as a factor limiting the oceanic distribution of salmonids is needed. Such an analysis, comparing research gillnet data with water mass structure, may be feasible using archived gillnet and oceanographic data from research cruises, ships of opportunity XBT data, and satellite data.

2. A management regime designed to limit salmonid harvest, and defined by a single boundary line extending from 170°E to 145°W, ignores significant zonal differences in oceanographic features and salmonid incidence (or catch rates) as a function of SST. A new regime, subdivided into two management areas, should be considered as it would allow increased precision and more flexibility for a management system designed to provide access to flying squid resources while protecting salmonid stocks.

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