A COMPARATIVE STUDY OF LONGLINE BAITS

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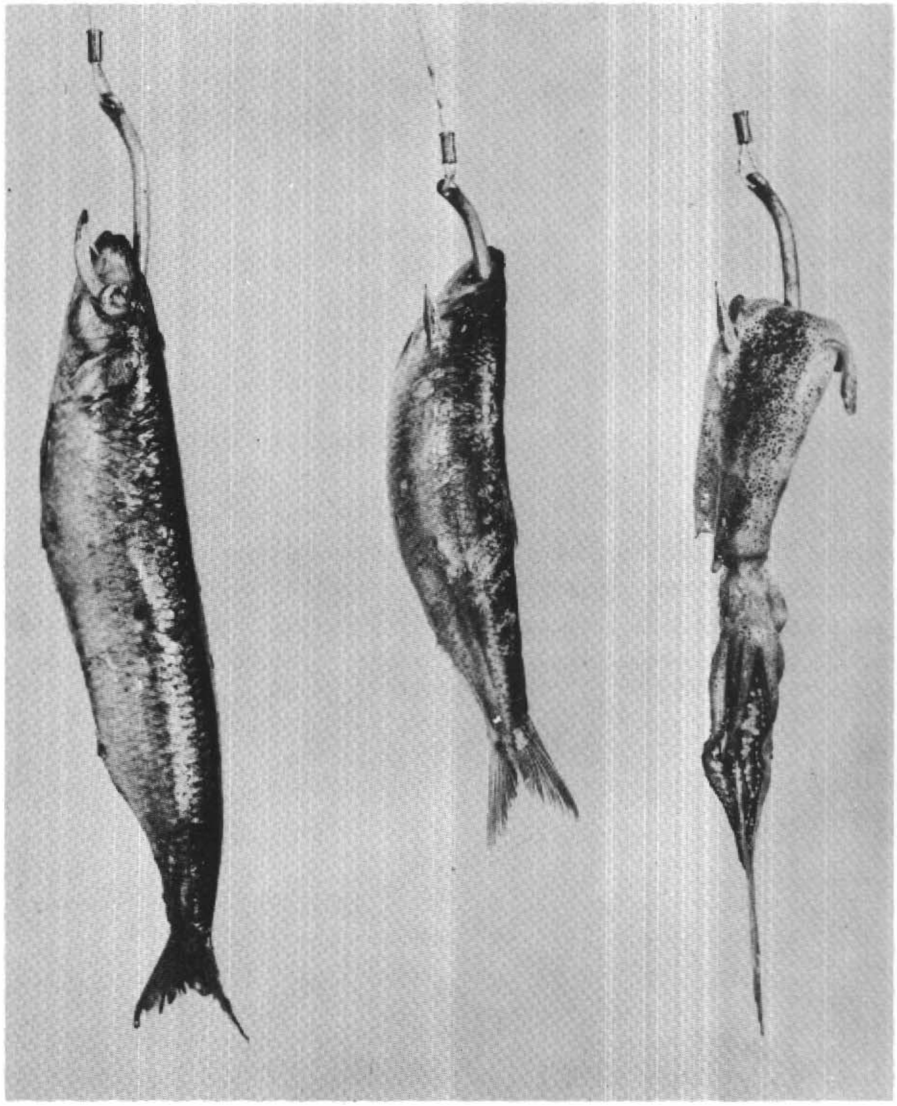

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The Pacific Oceanic Fishery Investigations (POFI) of the U. S. Fish and Wildlife Service is surveying the tuna resources of the central equatorial Pacific. Its investigations have proven the existence of a large population of deep-swimming yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel), in the vicinity of the Equator south of Hawaii. The only practicable method of sampling or harvesting these tuna is by the use of longline (also known as flagline) fishing gear, which consists of a mainline supported in the water at intervals by buoys and bearing a series of branch lines with baited hooks (Shapiro 1950). This fishing method, developed by the Japanese and used by fishermen in Hawaii, has been adopted as a sampling tool by POFI researchers.

In adapting the fishing gear used in the Hawaiian longline fishery to its purposes, POFI has introduced a number of modifications in the technique, one of the most significant of which has been a change in the kind of bait used. Hawaiian fishermen have traditionally used locally caught opelu, Decapterus pinnulatus (Eydoux and Souleyet), for bait, and have preserved it prior to fishing by packing it in rock salt (June 1950). Opelu, which brings a good price in the fresh fish market, has not often been readily available in the areas in which POFI vessels were fishing. It has, therefore, been more convenient and cheaper to use frozen West Coast sardine, Sardinops caerulea (Girard), herring, Clupea pallasii (Valenciennes), and squid, a practice which has also been followed in recent years by the Hawaiian commercial fleet.

This use of sardines and herring, and less often of squid, for longline bait has raised questions with regard to such matters as the comparative attractiveness of different baits to the various species of tuna taken on longlines, the comparative durability of the various baits while on the hook and "soaking", i.e., fishing immersed in the sea, and the effects of such preserving techniques as dry salting or brining and finally of different ways of impaling the bait on the hook. These questions are important from two points of view. First, it is desirable to determine by experimentation, if possible, what is the most effective bait and what is the best way of handling it, in order to be able to provide guidance to American fishermen who may wish to engage in tuna longline fishing. Second, it is essential to ascertain what effects, if any, variations in the kind of bait and the manner of its use have had on the catching efficiency of the gear employed on POFI fishing cruises, since the catch rates (tuna per 100 hooks per day) of this gear have been the primary index used by POFI in assessing the geographical and seasonal abundance of deep-swimming tunas. Thus the main objective of this study is to determine any adjustments that might be necessary to insure the comparability of POFI's basic longline fishing survey data.

The successful completion of the experiments was due to the efforts of the scientific personnel and crew members of the vessels Cavalieri, John R. Manning, and Hugh M. Smith. The author is also grateful to fellow staff members for their constructive criticisms of this report.

FISHING GEAR AND METHODS

The longline gear[1/] used in these experiments was made up of a number of 1,260-foot sections (known as "baskets") joined end to end to make up a set. With the exception of one experiment, each basket had 6 hook lines or droppers attached to the mainline at 180-foot intervals (fig. 1). Floats were attached by 60-foot lines at basket junctures to support the mainline. A total of 40-50 baskets were set each day at dawn and retrieved in the afternoon commencing at or shortly after noon. This procedure resulted in a range of fishing times for

1/ Detailed accounts of the construction of the longline gear have been given by various authors (Shapiro 1950, Shimada 1951, and Niska 1953).

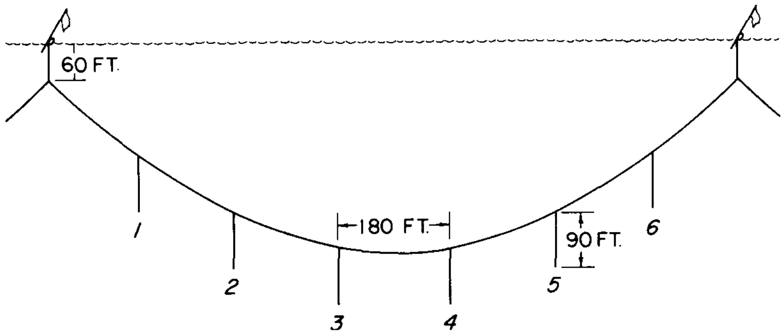

Figure 1.--Diagrammatic view of a basket of POFI longline gear.

individual baskets of 5 to 10 hours. The line was set slack in order to permit it to fish at various depths, and for this reason 40 or 50 baskets extended for only 9-10 miles.

DESIGN OF EXPERIMENTS AND TREATMENT OF DATA

Early in POFI's longline fishing program experiments were planned to compare bait species, baiting methods, and methods of bait preservation. The scope of the experimentation feasible on any one cruise was limited, e.g., to a comparison of sardine and herring, and it was soon found that the differences in catches were related mostly to soaking time and environmental conditions. Occasionally, too, it was necessary to use bait in poor condition. Therefore the experiments were designed to control statistically the effect of soaking time by alternating the variates (e.g. species or method of hooking) by baskets or groups of baskets. The environmental conditions were not controllable, but an attempt has been made to determine their effects in the analyses presented in this paper.

No single criterion is entirely satisfactory for evaluating these experiments. Of paramount concern is the effect on the catch of tuna, but in many experiments so few were caught that only gross differences could be expected to be significant. This has necessitated considerable reliance on the performance of the bait as judged by its retention on the hook.

During the course of the experimental fishing, detailed data were recorded as the line was hauled. Included in the information obtained was the soaking time of each basket and an exact record of the fate of each baited hook, i.e., the catch if any, presence or absence of bait, dropper lines broken, and fish lost during hauling.

Prior to analysis, several adjustments were made on the data as recorded in the field. Shark catches, particularly catches of the white-tipped shark, *Carcharhinus longimanus* (Poey)[2], tend to obscure the effects of other factors on the bait, since many of them are captured at or near the surface during hauling. For this reason the white-tipped and the similar silky shark have been counted as "bait on". The great blue shark, *Prionace glauca* (Linnaeus), the third species of shark frequently caught on the longline, has been included as part of the catch as many of them have been brought alongside the vessel dead or nearly dead, indicating capture during the soaking period, and also we have not seen them at the surface in tropical waters. The other species of sharks, only occasionally encountered, have also been included as part of the catch, since little is known of their habits.

A few additional corrections were made in order to make the recorded catch represent more closely the number of fish taking the baited hooks during the soaking period. One of these was to include broken branch lines as part of the catch in those analyses involving total catch. This would have been unnecessary if the number of broken lines were a linear function of the magnitude of the total catch, however, the number of broken lines differed among stations and among cruises, not because of differences in the abundance of fish, but because of the

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2/ The catches of the silky shark (*Carcharhinus* sp.) have been combined with the white-tipped shark catch because improper identification on earlier cruises does not permit separation. The results of more recent cruises in which identification was more certain show that the silky shark comprised only 23 percent of a total of 523 identified white-tipped and silky sharks.

quality of the lines. Finally, those fish lost during the hauling have been counted as part of the catch.

After these adjustments were made, the analysis was confined to a detailed examination of the catch and the bait return, and the relationships of these two variates with various methods of bait preservation, baiting methods, kinds of bait, and environmental conditions. In some instances the catches were separated and analyzed by tuna species rather than for the total catch, e.g., in the experiment on kind of bait, a separation was necessary to detect any bait preference by the different tuna species.

SOAKING TIME

As mentioned earlier, the experiments discussed in this paper were designed to control the factor of soaking time by alternating the variates by baskets or groups of baskets. The importance of time was recognized on earlier longline cruises, when it was observed that fewer baits were retrieved on the baskets that soaked longer. Actually this was to be expected, because the soaking time of the last basket of gear hauled may differ from the first by as much as 5 hours.

The results of the bait data of Manning cruise 11 (January-March 1952) are presented as an example to show the relationship of sardine bait returns with soaking time and to justify the experimental design used in the various experiments. This cruise was selected because only single-hooked sardines were used, simplifying the description. It is realized that varying results may be obtained with other types of bait and with different baiting methods, and therefore the results from the Manning cruise 11 data should be considered as solely descriptive of that cruise.

Two important effects of soaking time to be examined were: (1) whether there were any differences in the levels of the 27 station regressions of bait return with soaking time, and (2) whether there were significant differences among the slopes of the 27 regression lines. It was thought that differences in the levels of the 27 regression lines were highly probable, since the fishing stations on that cruise covered a very wide area extending from 155°W. to 180° longitude and from 8°N. to 8°S. latitude. Fishing over such a wide area involved varying fish abundance and different environmental conditions (Murphy and Shomura 1953b). As expected, the results indicated significant differences ($F = 8.43$, $P < 0.01$) among the levels of the 27 station regressions of bait return with soaking time (table 1). These differences in the levels of the station regression lines do not appear to have affected their slopes as indicated in the test for differences among regression lines (table 2). An average regression line was then calculated to represent the 27 station regression lines (table 26, fig. 2). It is clear from the slope of this line that experiments, to be meaningful, must control soaking time. As stated earlier, this was accomplished by alternating the variates by baskets or groups of baskets.

TREATMENT OF BAIT

During early POFI cruises the bait was placed in a box of rock salt for a few days prior to use to increase the firmness of the flesh and to prevent bacterial decomposition. The Hawaiian longline fishermen from whom this practice was adopted find it necessary because of the lack of mechanical refrigeration on their vessels (June 1950). Salting entails considerable effort in placing bait individually in the box of rock salt and this handling of bait in the soft, thawed-out condition increases the number of broken baits. Consequently, experiments were carried out on cruises 12 and 15 of the Manning to discover a better way of treating the bait. The three methods tested were (1) dry salting, (2) brining, and (3) untreated bait.

Table 1.--Analysis of covariance and test of significance of adjusted station means, soaking time vs. bait return, John R. Manning cruise 11 (based on data in table 24)

Source of variation	Degrees of freedom	Sum of squares and products Σx^2	Σxy	Σy^2	Sum of squares	Degrees of freedom	Mean square
Total	215	5580.50	-1821.10	5316.44	4722.16	214	-
Stations	26	76.33	-189.85	2653.06	-	-	-
Within stations	189	5504.17	-1631.25	2663.38	2179.93	188	11.60
For test of significance of adjusted means					2542.23	26	97.78

$$F = \frac{97.78}{11.60} = 8.43^{**1/}, \ P < 0.01$$

1/ Symbols used hereafter are:

* P significant at 5-percent level.
** P significant at 1-percent level.

Table 2.--Analysis of errors of estimate from average regression within stations (based on data in tables 1, 24, and 25)

Source	Degrees of freedom	Sum of squares	Mean square
Deviation from average (error) regression within stations	188	2179.93	-
Deviation from indiv. sta. regression	162	1941.79	11.99
Diff. among regression lines	26	238.14	9.16

$$F = \frac{9.16}{11.99} = 0.76, \ P > 0.05$$

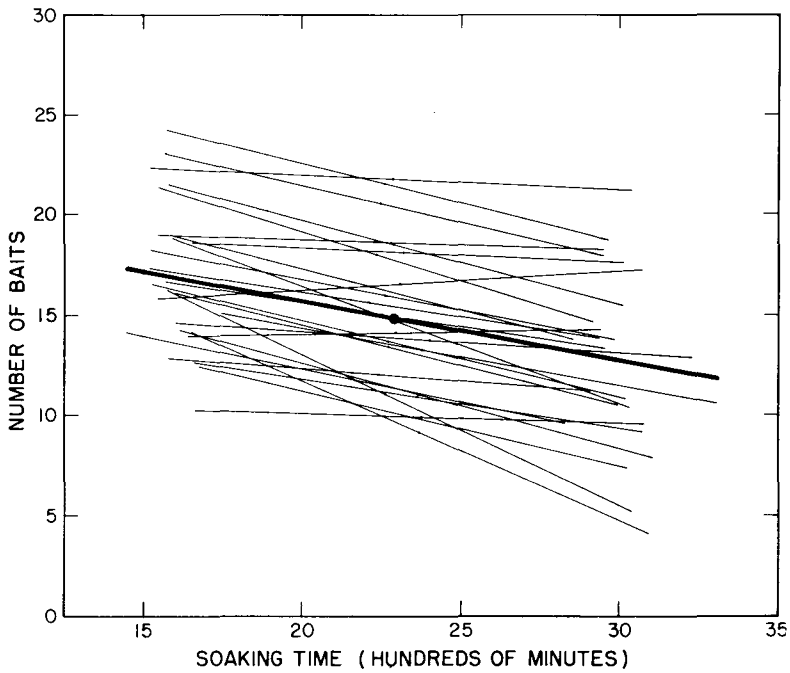

Figure 2.--Sardine bait return vs. soaking time, John R. Manning cruise 11. (Data presented in groups of 5 baskets.)

First, on cruise 12 (August-September 1952) an experiment was carried out with sardines to determine whether brined baits held up under fishing conditions as well as dry-salted baits. Brining was tried first because it involves less work and handling and yet should have the same preservative effect as dry salting. During the experiment some of the baits were brined by placing them in a saturated salt solution overnight (dry salting was done as described above). The bait returns from 720 hooks are given in table 3. The nonsignificance of the total, pooled, and interaction chi-squares ($P > 0.05$) indicates no difference in bait return under the two treatments. The division of the catch is also consistent with the similarity of bait returns, for of a catch of 21 fish 11 were caught with dry-salted sardines.

The second experiment, carried out on cruise 15 (May-June 1953), was designed to compare untreated and dry-salted baits. The results of this experiment are given in table 4. The lack of significant differences in bait return and catch with the two methods of preparation gives strong support to the idea that salting is unnecessary if refrigeration is available.

It appears that insofar as fishing efficiency is concerned there are no differences among dry-salted, brined, and fresh-thawed sardines. However, it should be pointed out that the experiments were confined to sardine baits and were carried out with a maximum soaking time of approximately 10 hours. Differences with bait treatment may appear during longer soaking periods or with different species of bait.

BAITING METHODS

In some instances small catches were coincident with small bait returns, and if these were causally related, the implication would be that an excessive number of baits had been lost during the soaking period. Under these circumstances the catch rate would not be indicative of the relative abundance of fish. To investigate this relationship and to discover ways of reducing bait loss, the usually single-hooked baits were impaled in various ways considered likely to improve the chances of their staying on the hook. The methods of baiting employed during these experiments are illustrated in figure 3. The experiments were conducted with sardine and herring. Because of anatomical differences that affect the tendency of the bait to remain on the hook, the sardine and herring experiments are considered separately.

Table 3.--Chi-square analysis of salted and brined sardine bait returns and summary of catch, *John R. Manning* cruise 12 (based on a total of 120 hooks for each treatment per station)

Station	Bait return		Total	χ^2
	Salted	Brined		
17	56	45	101	1.20
18	54	52	106	0.04
19	95	87	182	0.35
				1.59 Total χ^2 (3 d.f.)
Total	205	184	389	1.13 Pooled χ^2 (1 d.f.)
				0.46 Interaction χ^2 (2 d.f.)

Station	Total catch		Total
	Salted	Brined	
17	5	4	9
18	6	4	10
19	-	2	2

Table 4.--Summary of chi-square analyses of sardine bait return and catch by treatment (salted vs. fresh-thawed), *John R. Manning* cruise 15[1] (based on a total of 1,650 hooks per treatment; table 27)

	Source	Bait return		χ^2	Degrees of freedom
		Salted	Fresh-thawed		
Bait return	Total	-	-	3.76	14
	Pooled	1049	1039	0.05	1
	Interaction	-	-	3.71	13
Catch[2]	Total	-	-	9.46	10
	Pooled	91	115	2.80	1
	Interaction	-	-	6.66	9

1/ This and a number of subsequent tables include only summaries of the chi-square analyses. The individual analyses are similar to that presented in full in table 3.

2/ Stations have been combined to give expected values greater than 5.

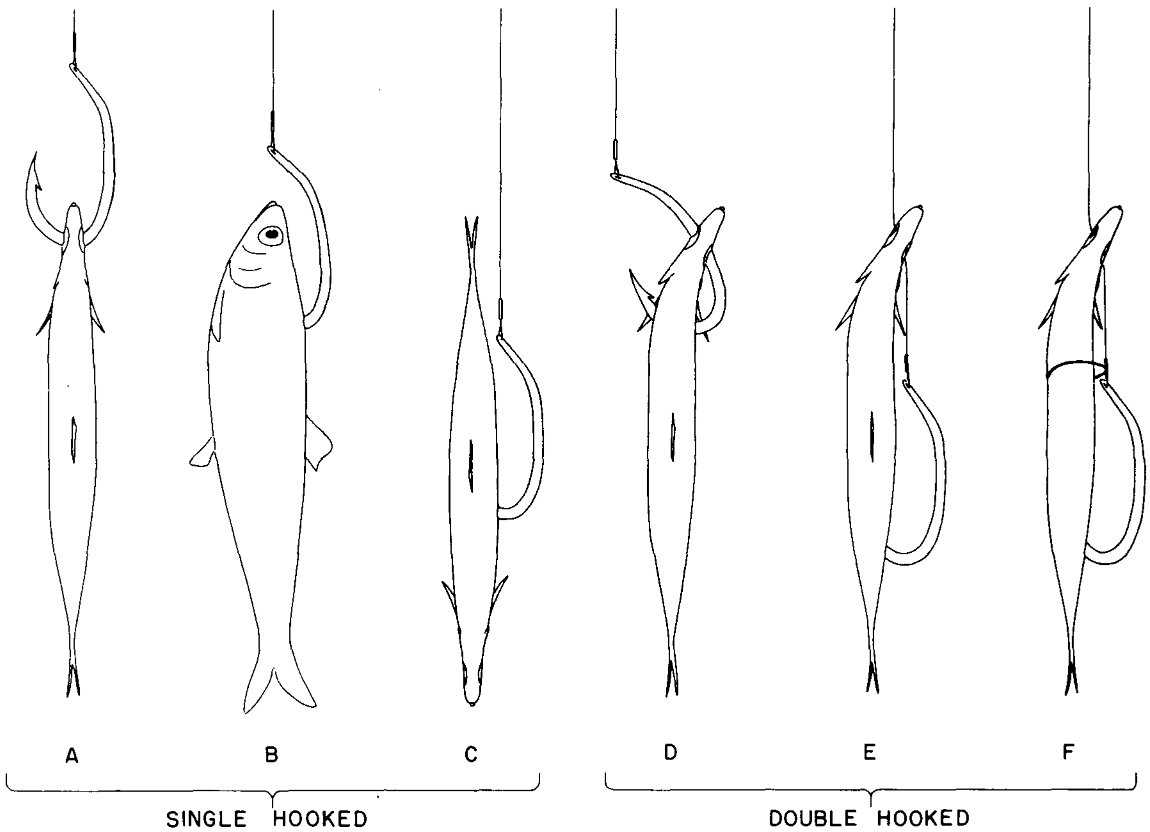

Figure 3.--Six methods of baiting.

Sardine

Two experiments comparing single hooking with two variations of double hooking were carried out on John R. Manning cruise 12. The first experiment was conducted on station 1 by alternating, by baskets, single-hooked sardines (fig. 3a) with double-hooked sardines (fig. 3e) for the entire set of 40 baskets. Of 120 baits recovered, 57 were single-hooked and 63 double. The lack of difference in bait returns is reflected in the catches, which consisted of 12 and 9 fish respectively. The experiment on station 6 was similar to that carried out on station 1 except that the double-hooked baits were fastened to the leader with rubber bands (fig. 3f). Because of the difficulty of baiting in this fashion, there were 3 times as many baskets (30 to 10) with single-hooked baits. Based on this ratio, there was a significantly higher number of double-hooked bait returns, as shown in table 5. The data on the catch (table 5) were insufficient for an analysis, but indicate no difference in catch with method of baiting.

A more extensive experiment conducted on Manning cruise 18 (December 1953) used sardines as bait and employed the single and double hooking methods illustrated in figures 3a and 3d. The results, given in table 6, show a definite advantage for double hooking in terms of bait return. Despite the higher bait returns from double hooking, it appears from the data in table 6 that the catch was not affected. This is an indication that a large part of the single-hooked sardine loss occurs during hauling, for if the loss occurred during the soaking period, it should be reflected in the catch. More direct evidence that baits are actually lost during hauling is furnished by observations made by the author on several of the longline cruises discussed in this report. From a total of approximately 1,500 baskets observed during the hauling operation, 55 sardine baits were seen to fall off while the droppers were being retrieved. It is thought likely that an even greater number of sardines may have pulled loose before the hooks became visible to the observer. There is no evidence to indicate that the rate of loss during hauling increases with soaking time.

Table 5.--Sardine bait return and total catch by method of baiting (single vs. double), station 6, John R. Manning cruise 12 (based on a total of 180 single-hooked baits and 60 double-hooked baits)

	3:1 ratio		Total	χ^2
	Single	Double		
Bait return	103	52	155	6.04*
Catch	9	2	11	-

Table 6.--Summary of chi-square analyses of sardine bait return and total catch by method of baiting (single vs. double), John R. Manning cruise 18 (based on a total of 1,260 hooks per method of baiting; table 28)

	Source	Method of baiting		χ^2	Degrees of freedom
		Single	Double		
Bait return	Total	-	-	98.17**	14
	Pooled	682	1064	83.58**	1
	Interaction	-	-	14.59	13
Total catch1/	Total	-	-	7.01	6
	Pooled	72	59	1.29	1
	Interaction	-	-	5.72	5

1/ Stations have been combined to give expected values greater than 5.

Herring

On Manning cruise 14 (January-March 1953) a single vs. double hooking experiment was carried out on eight fishing stations using herring. The method of double hooking was similar to that of the sardine experiment on station 1 (fig. 3e) of Manning cruise 12, which has already been discussed. The analyses of both bait return and catch are shown in table 7. The higher return of the double-hooked herring is statistically significant as indicated by the total and pooled chi-squares (both P values less than 0.01). The double-hooked returns ranged from 1.3 to 7.4 times as many as for single-hooked herring. The heavy loss of single-hooked baits appears to be reflected in the size of the catches, for the significant pooled chi-square of 4.76 ($P < 0.05$) indicates a tendency for more fish to be caught on the double-hooked baits (table 7). However, this should not be taken as conclusive evidence in view of the following experiment carried out on the Cavalieri cruise (August-September 1952).

Table 7.--Summary of chi-square analyses of herring bait return and total catch by method of baiting (single vs. double), John R. Manning cruise 14 (based on a total of 432 hooks per method of baiting; table 29)

	Source	Method of baiting		χ^2	Degrees of freedom
		Single	Double		
Bait return	Total	-	-	67.57**	8
	Pooled	94	233	59.09**	1
	Interaction	-	-	8.48	7
Total catch 1/	Total	-	-	9.22	5
	Pooled	32	52	4.76*	1
	Interaction	-	-	4.46	4

1/ Stations have been combined to give expected values greater than 5.

The results of the single vs. double hooking experiment (fig. 3a and 3e) conducted on the Cavalieri cruise are presented in table 8. A significant advantage for double hooking appears in the bait returns but not in the catch. However, an analysis of the catches resulted in a significant interaction chi-square of 14.34 ($P < 0.05$), which can be traced to the reversals of catch on stations 11 and 12 (table 30). At present no explanation can be advanced for this discrepancy in the catches.

Table 8.--Summary of chi-square analyses of herring bait return and total catch by method of baiting (single vs. double), Cavalieri cruise (based on a total of 1,308 hooks per method of baiting; table 30)

	Source	Method of baiting		χ^2	Degrees of freedom
		Single	Double		
Bait return	Total	-	-	288.43**	6
	Pooled	358	973	284.17**	1
	Interaction	-	-	4.26	5
Total catch	Total	-	-	14.36*	6
	Pooled	80	82	0.02	1
	Interaction	-	-	14.34*	5

Another experiment was conducted on the Cavalieri testing five different methods of baiting. Three of these were variations of single hooking and the other two were different double hooking methods (fig. 3a, b, c, d, and e). As in all of the other experiments, the bait returns showed a significant difference with method of baiting (table 9), the double-hooked baits giving higher returns. The catches of the two stations concerned were too small for analysis.

Table 9.--Chi-square analysis of five methods of baiting herring and a summary of total catch, *Cavalieri* cruise (based on a total of 120 hooks per method of baiting)

Bait return

Station	Single			Double		χ^2
	Eye	Head	Body	Eye and head	Eye and body	
1	19	29	24	49	33	17.04**
2	11	26	20	43	29	21.66**
						38.70** Total χ^2 (8 d.f.)
Total	30	55	44	92	62	38.01** Pooled χ^2 (4 d.f.)
						0.69 Interaction χ^2 (4 d.f.)

Total catch

Station	Single			Double	
	Eye	Head	Body	Eye and head	Eye and body
1	5	4	1	1	2
2	2	2	2	2	2
Total	7	6	3	3	4

In summarizing the results of the baiting experiments, it appears that the significantly higher returns of double-hooked sardines were due to loss of the single-hooked baits during the hauling operation. The evidence for this statement is the lack of difference in the catches by the two methods. In the case of the herring the difference in returns is of a greater magnitude, almost 3 times as many double-hooked as single-hooked herring have been retrieved, and furthermore it appears that a portion of the differential loss of single-hooked herring occurs during the soaking period, as indicated in one experiment (table 7) by the lower catches on single-hooked baits. Obviously this difficulty can be overcome by double hooking the herring.

KIND OF BAIT

Food studies undertaken by various authors (Kishinouye 1917, Nakamura 1950 and 1952, and Reintjes and King 1953) indicate that almost any pelagic marine organism of a suitable size may become food for tuna. However, a survey of the literature showed only a few experiments directed to a study of food preferences of the tunas by using different kinds of bait. One experiment conducted in 1951 on the Japanese research vessel *Sagami Maru* (Anonymous 1952) resulted in the general conclusion that the various tunas and marlins do not discriminate between frozen saury, *Colalabis saira* (Brevoort), and salted sardine, *Sardinia melanostica* (Temminck and Schlegel). Murphy and Otsu (1954), in their analysis of the catches of Japanese mothership expeditions, reached the same conclusion from a comparative study of the catch rates made by these two baits.

Further experiments were carried out by POFI to determine whether there were differences in catch rates with four kinds of bait, and if so to ascertain whether the differences were due to preference on the part of the fish or to superiority of the bait with respect to staying on the hook. The three experiments compared mullet vs. herring, sardine vs. squid, and sardine vs. herring.

Mullet vs. Herring

A limited experiment was conducted on Smith cruise 5 (July 1950) alternating, by baskets, mullet (*Mugil vaigiensis* Quoy and Gaimard and *M. longimanus* Günther) and herring for the entire set of 30 baskets[3]. Table 10 gives the results of the chi-square analysis of the yellowfin catch from this experiment. The reversals of the catch with the kind of bait indicate an absence of bait preference, although the total catch shows a higher number of yellowfin caught with mullet. Since data on bait return are not available for this cruise, it is not possible to determine whether the interaction shown in table 10 (χ^2 = 5.96, $P < 0.05$) was due to differences in retention of the two bait species.

Table 10.--Chi-square analysis of yellowfin catch by herring and mullet baits, *Hugh M. Smith* cruise 5 (based on 90 hooks per bait per fishing station)

Station	Herring	Mullet	χ^2
2, 3	3	14	7.12**
4, 5	14	11	0.36
			7.48* Total χ^2 (2 d.f.)
Total catch	17	25	1.52 Pooled χ^2 (1 d.f.)
			5.96* Interaction χ^2 (1 d.f.)

Sardine vs. Squid

A more extensive experiment alternating, by basket, salted sardine and frozen squid (probably *Loligo opalescens* Berry) for 50 baskets was carried out at 25 stations on cruise 13 of the *Manning* (October-November 1952). The chi-square analyses, testing for differences in catch and bait return, are given in table 11. A study of the total catch by the two kinds of baits shows a significantly higher number of fish caught on the sardine baits (pooled χ^2 = 4.60, $P < 0.05$). However, the significance of the statistical test only indicates a tendency for more fish to be caught with sardine, since the total chi-square is nonsignificant ($P > 0.05$). Before attributing this difference to bait preference, bait availability must be considered. An analysis of the bait returns showed that more squid remained on the hooks, and the difference gave highly significant total and pooled chi-squares ($P < 0.01$). However, the interaction chi-square was also significant ($P < 0.01$), indicating the presence of a factor or factors not accounted for. The bait returns (table 31) show that squid were retrieved in greater numbers than sardine on all but five stations. A possible reason for the reversals is discussed in a later section.

Examination of the results by species of catch indicates some variation in the effectiveness of the two baits (table 11). Of a total of 135 yellowfin, 77 were caught on sardine and 58 on squid baits. However, the difference of 19 yellowfin was not statistically significant ($P > 0.05$); thus no preference can be established. The analysis of bait return at stations with yellowfin catches showed that 1.3 times more squid than sardine remained on the hooks, the total, pooled, and interaction chi-squares being significant ($P < 0.01$).

3/ The gear used on this early cruise differed in some respects from that used on subsequent cruises. Each basket had five branch lines of varying lengths (two 72 feet, two 132 feet, and one 252 feet) attached at equal intervals to a mainline section of 1,440 feet.

Table 11.--Summary of chi-square analyses of bait return and catch by kind of bait (sardine vs. squid), John R. Manning cruise 13 (based on data in table 31)

	Number of hooks per kind of bait	Source	Bait return		χ^2	Degrees of freedom
			Sardine	Squid		
All stations	3,750	Total	-	-	187.31**	25
		Pooled	2135	2831	97.55**	1
		Interaction	-	-	89.76**	24
Yellowfin	3,000	Total	-	-	163.69**	20
		Pooled	1647	2190	76.84**	1
		Interaction	-	-	86.85**	19
Bigeye	1,650	Total	-	-	73.03**	11
		Pooled	981	1290	42.04**	1
		Interaction	-	-	30.99**	10
Skipjack	1,650	Total	-	-	87.40**	11
		Pooled	934	1239	42.80**	1
		Interaction	-	-	44.60**	10

	Source	Total catch[1]		χ^2	Degrees of freedom
		Sardine	Squid		
Total catch	Total	-	-	16.56	21
	Pooled	185	146	4.60*	1
	Interaction	-	-	11.96	20
Yellowfin	Total	-	-	5.15	10
	Pooled	77	58	2.67	1
	Interaction	-	-	2.48	9
Bigeye	Total	-	-	9.23**	2
	Pooled	22	6	9.14**	1
	Interaction	-	-	0.09	1
Skipjack	Total	-	-	4.00	2
	Pooled	9	19	3.57	1
	Interaction	-	-	0.43	1

1/ Stations were combined to give expected values greater than 5.

Although the catch of the bigeye tuna, Parathunnus sibi (Temminck and Schlegel), was small, the evidence--as given by significant total and pooled chi-squares ($P < 0.01$)--suggests a preference for sardine over squid baits. Of a total catch of 28 bigeye tuna, 22 were caught with sardine. The evidence for preference is further strengthened by the total bait return of 981 sardines as compared to 1,290 squids. However, this conclusion should be taken with reservations in view of the significant interaction between baits and the small catch of bigeye.

Of a total catch of skipjack, Katsuwonus pelamis (Linnaeus), of 28 only 9 were taken on sardine baits. This is a reversal of the findings for bigeye discussed above. However, the difference of 10 fish was not statistically significant.

The albacore, Germo alalunga (Gmelin), catch of 22 was almost equally divided between sardine and squid baits, with catches of 10 and 12 respectively.

Sardine vs. Herring

Experiments were conducted on Manning cruise 14 and Smith cruise 18 (October-November 1952) to test for differences between sardine and herring, the most common baits available to U. S. fishermen. On the Manning cruise both types of baits were single-hooked through the eyes, whereas on the Smith cruise the herring were double-hooked.

A summary of the analyses for the Manning experiment testing single-hooked sardines and herring is given in table 12. The results are arranged in accordance with the catch, i.e., when considering total catch the bait returns for all stations are utilized, and the bait analyses for individual species are based only on those stations at which the particular species were taken. Considering the total catch, 95 fish were caught with sardine and only 77 with herring, but the difference was statistically non-significant ($P > 0.05$) even though 3.5 times as many sardine as herring were retrieved. As in the previous experiment on sardine and squid, there was a significant interaction chi-square ($P < 0.01$). A study of the individual tuna species shows that more yellowfin, bigeye, and albacore were caught on sardine. However, the statistical tests showed that only in the case of the albacore was the catch on sardine significantly higher than the catch on herring (pooled $\chi^2 = 7.20$, $P < 0.01$). Of a total of 20 albacore caught, only 4 were taken on herring. The great difference in bait return at stations with albacore catches (4.6 times as many sardine as herring) suggests that this difference in catch may be attributable to a differential availability of the two baits during the fishing period, and that the nearly equal catch of yellowfin and bigeye was the result of a smaller differential in bait return. This then suggests that the factor(s) responsible for the differential availability of bait changed in intensity from station to station.

The second experiment on sardine and herring (Smith cruise 18) does not parallel that carried out on the Manning, for in this trial the herring were double-hooked and the sardine single-hooked. The similarity of the bait returns in this instance (table 13) clearly indicates that double hooking overcomes the differential loss of herring. The total catch and the catches of the individual tuna species show virtually no differences between the two kinds of bait.

It is evident that the bait return is a function of loss during fishing plus loss during setting and hauling. It appears that at times differential loss during hauling is responsible for differences in returns, e.g., in the single- and double-hooked sardine experiment the differences in bait return are not reflected in the catch. At other times, usually characterized by very high differential returns, e.g., in the single- and double-hooked herring experiment, the differential loss is reflected in the catch, indicating that part of the bait loss occurred during the soaking period. Indication of a further confounding factor in the experiments is the shift in relative return within an experiment (cruise). This is shown, for instance, in the presence of interaction in bait return in some of the groups of data in table 12, and its absence in others. An explanation of this phenomenon is advanced in the following section on environmental factors.

ENVIRONMENTAL FACTORS

Thus far only certain physical factors of baiting and the baits themselves have been considered in determining bait loss. Bait stealers (tunas, small fish, and invertebrates) and sea conditions also appear to affect the bait during the soaking and retrieving periods.

Bait Stealing

The larger tunas themselves have been noted to take more than one bait, as indicated by the results of stomach examinations shown in table 14. Of a total of 822 stomachs examined, 695 (84.5 percent) contained no bait fish, 112 (13.6 percent) contained one bait, and 15 (1.8 percent) held two or more baits. This would indicate that in most cases the bait is lost at the time of capture. Even

Table 12.--Summary of chi-square analyses of bait return and catch by kind of bait (sardine vs. herring), John R. Manning cruise 14 (based on data given in table 32)

	Number of hooks per kind of bait	Source	Bait return		χ^2	Degrees of freedom
			Sardine	Herring		
All stations	2,040	Total	-	-	519.91**	18
		Pooled	1178	336	468.27**	1
		Interaction	-	-	51.64**	17
Yellowfin	1,488	Total	-	-	403.40**	13
		Pooled	816	209	359.46**	1
		Interaction	-	-	43.94**	12
Bigeye	678	Total	-	-	134.63**	6
		Pooled	365	119	125.03**	1
		Interaction	-	-	9.60	5
Albacore	696	Total	-	-	199.05**	6
		Pooled	383	83	193.13**	1
		Interaction	-	-	5.92	5

	Source	Total catch 1/		χ^2	Degrees of freedom
		Sardine	Herring		
Total catch	Total	-	-	19.50	12
	Pooled	95	77	1.88	1
	Interaction	-	-	17.62	11
Yellowfin	Total	-	-	3.21	6
	Pooled	38	27	1.86	1
	Interaction	-	-	1.35	5
Bigeye	Total	-	-	-	-
	Pooled	7	3	1.60	1
	Interaction	-	-	-	-
Albacore	Total	-	-	-	-
	Pooled	16	4	7.20**	1
	Interaction	-	-	-	-

1/ Stations have been combined to given expected values greater than 5.

where there is only one bait in the stomach, the possibility still exists that it might have been "stolen" from another hook prior to capture, but where there are two or more baits in the stomach they constitute firm evidence of bait stealing by tuna. An extreme case of bait stealing by tuna was observed on station 9 on cruise 16 of the Manning (July-August 1953), when 9 baits were recovered from a single yellowfin stomach.

Bait stealing by smaller fish and invertebrates has not yet been proven; however, these organisms presumably are able to feed on the longline baits without getting caught, as is indicated by partially eaten or shredded baits (fig. 4). In addition, stomach examinations of miscellaneous species of fish caught on the longline such as the barracuda, *Sphyraena barracuda* (Walbaum), and wahoo,

Table 13.--Summary of chi-square analyses of bait return and catch by kind of bait (sardine vs. herring), Hugh M. Smith cruise 18 (based on data in table 33)

	Number of hooks per kind of bait	Source	Bait return		χ^2	Degrees of freedom
			Sardine	Herring		
All stations	2,682	Total	-	-	127.45**	23
		Pooled	1645	1739	2.61	1
		Interaction	-	-	124.84**	22
Yellowfin	1,728	Total	-	-	109.26**	15
		Pooled	1024	1074	1.19	1
		Interaction	-	-	108.07**	14
Bigeye	1,728	Total	-	-	101.47**	15
		Pooled	987	1133	10.05**	1
		Interaction	-	-	91.42**	14
Skipjack	456	Total	-	-	35.11**	4
		Pooled	237	247	0.21	1
		Interaction	-	-	34.90**	3

	Source	Total catch 1/		χ^2	Degrees of freedom
		Sardine	Herring		
Total catch	Total	-	-	10.30	13
	Pooled	116	107	0.36	1
	Interaction	-	-	9.94	12
Yellowfin	Total	-	-	0.93	4
	Pooled	29	24	0.47	1
	Interaction	-	-	0.46	3
Bigeye	Total	-	-	0.57	3
	Pooled	19	15	0.47	1
	Interaction	-	-	0.10	2
Skipjack	Total	-	-	-	-
	Pooled	4	10	2.57	1
	Interaction	-	-	-	-

1/ Stations have been combined to give expected values greater than 5.

Acanthocybium solandri (Cuvier and Valenciennes), have often revealed more than one bait, indicating their ability to take a bait without getting caught. Not much is known about bait stealing by invertebrates, however, it should be mentioned that squids are abundant in equatorial waters and may be responsible for a major share in bait losses of this type.

The loss of bait during the fishing period by bait stealing tends to lower the efficiency of the gear. It has not been possible to ascertain whether differences in the rate of bait stealing occur from station to station and cruise to cruise. Though differences must exist, it does not appear that they have appreciably affected the results of the experiments. However, within stations and experiments differences in the rate of stealing probably account for at least

Table 14.--Frequency of occurrence of one or more baits in stomachs of longline-caught yellowfin and bigeye tuna

Cruise	Number of tuna examined	1 bait	2 or more baits
Honolulu market	29	5	2
Smith - 3	1	-	-
Smith - 5	52	3	-
Smith - 7	120	16	1
Smith - 11	190	24	3
Smith - 18	57	4	2
Manning - 11	65	7	1
Manning - 12	6	2	-
Manning - 13	65	4	2
Manning - 14	88	18	2
Manning - 15	47	12	1
Gilbert - 1	61	10	-
Cavalieri	41	7	1
	822	112	15

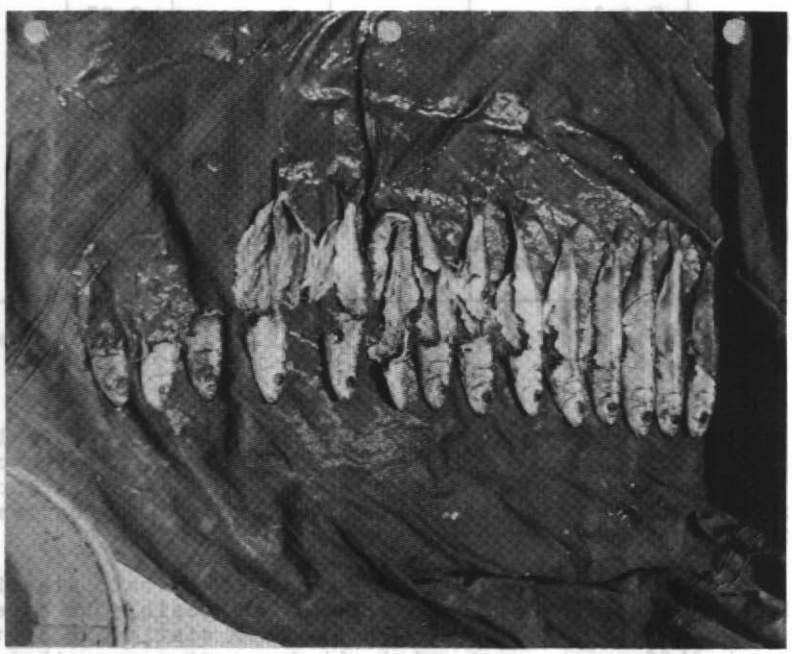

Figure 4.--Various conditions of retrieved sardine baits, John R. Manning cruise 11 (photograph by Garth I. Murphy).

some of the differences noted when comparing, for instance, sardine vs. herring and single vs. double hooking, and it follows that multiple hooking of the baits may reduce the amount of bait stealing. Double-hooked baits should withstand a greater amount of pulling before coming off than single-hooked baits, for only a slight tug and twist on a single-hooked sardine or herring will take it off the hook.

Sea Condition

Loss of bait during the fishing and retrieving period over and above that removed by animals must be the result of motion of the baited hooks. Aside from the setting and hauling periods the only source of motion is the action of the sea (ignoring movement of the line by hooked fish) during the fishing period. An indication of the effect of the motion of the sea on bait loss may be obtained from an examination of the rate of return with relative hook depth. Data from the early cruises indicated a progressive increase in the number of baits retrieved with increase in the relative hook depth (table 15). When this is considered in the light of a parallel increase in the catch with relative depth (table 16), it becomes evident that either bait stealing is less operative at greater depths or some other environmental factor or factors give the bait a better chance to remain on the deeper hooks[4]. There is no evidence of a decrease in bait stealing with depth, but there is a possibility that the action of the sea on the gear varies inversely with depth. This could arise if the wave-induced up and down movement of the buoys were transmitted with diminishing intensity to the deeper hooks. To investigate this relationship, one end of a model longline[5] was raised to various heights simulating the effect of wave action on the gear. Accurate measurements of the usual seas (3 to 8 feet) encountered could not be made because of the small size of the model; however, indications showed an inverse displacement of hooks with depth; e.g., a 10-foot movement gave relative motions of 1.6, 1.4, and 1.0 feet for the shallow, intermediate, and deep hooks respectively.

The effect of the sea-induced motion may also help to explain the persistently higher sardine returns as compared to the herring when considering single-hooked baits. The larger eye diameter of the herring and its relatively narrower cranial width (fig. 5) make it more apt to drop off the hook if the hook is moved up and down by the sea.

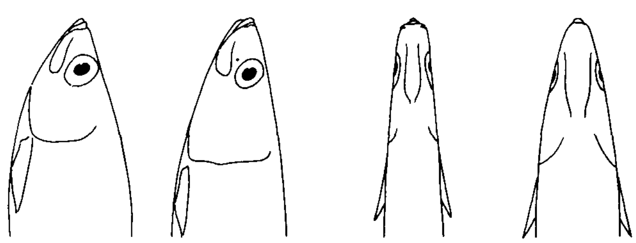

Figure 5.--Lateral and dorsal views of the sardine and herring baits.

Since it appears that loss of bait is related to relative differences in the amount of motion within sets of gear, it might be expected that under different sea conditions bait loss may vary. This is borne out by the lower returns of single-hooked sardines with increasing sea intensities (fig. 6, table 17). If the sea varies during the course of experiments on type of bait and method of hooking, the relative returns should be different under different sea intensities. In the following sections, the experiments are re-examined to ascertain whether the significant interaction chi-squares noted in several experiments could have been caused by changes in relative bait retention induced by variations in sea intensity.

4/ The problem of whether increased catch at greater depths is a function of better bait return is not under consideration. However, it is evident from a comparison of tables 15 and 16 that the catch increased more rapidly with depth than the bait return, indicating some independence of the two events.

5/ The longline model was made of chain and was proportional to the dimensions of the real gear. The chain was allowed to sag freely giving a catenary curve like that assumed to exist during fishing.

Table 15.--Bait return by the relative depth of hooks, Hugh M. Smith cruise 11, August-September 1951 (based on a total of 80 hooks per depth at each station)

Station	Shallow hooks (1 and 6)	Intermediate hooks (2 and 5)	Deep hooks (3 and 4)	Sea condition
1	19	33	29	3
2	14	22	36	2
3	31	46	60	2
4	31	36	37	3
5	28	41	40	2
6	51	59	51	1
7	39	53	50	2
8	32	34	43	1
9	19	32	40	1
10	23	21	21	3
11	26	26	27	3
12	46	35	38	2
13	28	37	42	2
15	45	50	51	2
16	38	29	40	3
17	36	34	46	1
18	49	48	51	2
19	31	39	38	2
20	18	27	34	3
21	25	43	43	3
22	25	21	27	2
23	36	36	33	2
24	55	51	61	3
25	25	43	48	3
26	20	43	44	3
27	24	39	44	2
28	18	38	34	2
Total	832	1015	1108	
$\bar{x}$	30.8	37.6	41.0	

Table 16.--Summary of catch by relative depth, Hugh M. Smith cruise 11

Species	Shallow	Intermediate	Deep
Yellowfin	115	165	175
Bigeye	13	31	49
Albacore	-	3	4
Skipjack	3	12	8
Others1/	20	8	11
Total	151	219	247

1/ Excluding sharks.

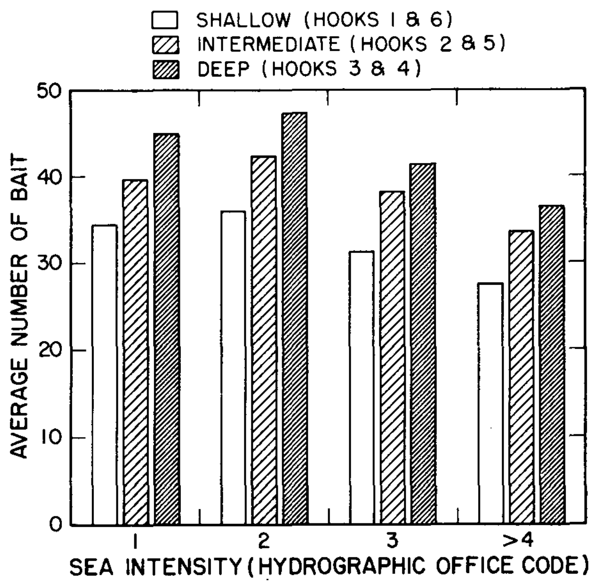

Figure 6.--Sardine bait return by relative hook depth, Hugh M. Smith cruise 11 and John R. Manning cruise 11.

Effect of Sea on Different Kinds of Bait

The presence of unaccounted factor(s) affecting the bait returns in the preference experiments was indicated by the significant interaction chi-squares (tables 11, 12, and 13). Table 18 presents the bait returns for the sardine vs. squid experiment tabulated by sea condition. The analysis of variance shows significant differences with kind of bait and a significant interaction between baits under different sea conditions. From the bait return means given in table 18 the interaction can now be attributed to the combination of the relatively stable squid returns regardless of the sea intensity and a precipitous decrease in sardine bait returns with increasing seas. This is consistent with the physical characteristics of the two baits. The tough, fibrous squid are not likely to work free, while the more delicate sardine can easily work off the hook.

The results of the rearranged data for catches made with sardine and squid as given in table 19 present a peculiar situation. The chi-square analysis of catches made in 1 and 2 seas was non-significant in all respects. In the analysis of catch for sea intensities greater than 2, the difference in catch by the two baits was significant (pooled $\chi^2 = 4.79$, $P < 0.05$) with 123 fish caught with sardine baits of a total catch of 214 fish. This then, means a significant increase in the catch on sardine as compared to squid with increasing sea intensity, even though it appears that sardines do not stay on the hook as well in higher seas. No explanation is advanced at this time except to suggest a possible change in the relative attractiveness of the two baits with increasing seas. This could be the result of the silvery sardine's being visible for a relatively greater distance when moved up and down in a rough sea.

Table 17.--Sea conditions (Hydrographic Office code)

Beaufort code	Approximate height of sea
0	0
1	less than 1 foot
2	1 - 3 feet
3	3 - 5 feet
4	5 - 8 feet
5	8 - 12 feet
6	12 - 20 feet
7	20 - 40 feet
8	40 feet and over
9	confused

Table 18.--Analysis of variance of bait return by kind of bait and sea condition, John R. Manning cruise 13 (based on data in table 31)

	Sea condition							
	0-2		3		4		5	
	Sardine	Squid	Sardine	Squid	Sardine	Squid	Sardine	Squid
	110	126	91	133	96	114	90	128
	88	125	97	136	44	100	71	97
	92	118	94	117	69	116	46	93
	118	114	122	118	62	119		
	111	81	99	82	53	118		
	114	110	69	111				
	85	112	79	120				
	114	130	68	112				
			53	109				
n	8	8	9	9	5	5	3	3
Total	832	916	772	1038	324	567	207	318
$\bar{x}$	104.0	114.5	85.8	115.3	64.8	113.4	69.0	106.0

Analysis of variance				
Source	Degrees of freedom	Sum of squares	Mean square	F
Sea condition	3	3486.64	1162.21	1.44
Bait	1	9912.32	9912.32	12.30*
Sea condition - bait interaction	3	2417.96	805.99	2.87*
Within subclasses	42	11781.56	280.51	

The results of the experiment on Manning cruise 14, testing the differences between single-hooked sardine and herring, have been re-examined in the light of changes in the environment (tables 20 and 21). The analysis of variance of bait return (table 20) shows significant differences with sea condition and between kinds of bait. Consideration of sea height appears to have eliminated the interaction noted in the original analysis (table 12). The means in table 20 indicate a progressive decrease in the returns of both baits with higher seas. Furthermore, it is to be expected that herring, which come off the hooks more easily than sardine, would be more severely affected by an increase in movement, as is indicated in table 20.

In addition to bait return, the relative catches on sardine and herring appear to be affected by variations in sea height. In 1 and 2 seas there were 2.7 times more sardine than herring retrieved, and this, combined with the identical catches made on the two baits (table 21), suggests that a large part of this higher herring loss occurred during hauling. An examination of the bait return under sea conditions above 2 shows that the difference in bait return was much greater, with 5.3 times as many sardine as herring retrieved. The analysis of the catch made with the two baits under sea conditions above 2 showed a significantly

Table 19.--Chi-square analyses of total catch by kind of bait and sea condition, *John R. Manning* cruise 13 (based on data in table 31)

Sea condition 0 - 2				
Station	Sardine	Squid	Total	χ^2
1	6	5	11	0.09
7	5	7	12	0.33
8	8	5	13	0.69
9	6	5	11	0.09
11	13	16	29	0.31
14	11	8	19	0.47
16	8	4	12	1.33
18	5	5	10	0.00
				3.31 - Total χ^2 (8 d.f.)
	62	55	117	0.42 - Pooled χ^2 (1 d.f.)
				2.89 - Interaction χ^2 (7 d.f.)

Sea condition higher than 2				
Station	Sardine	Squid	Total	χ^2
2	6	4	10	0.40
3	11	4	15	3.27
4	5	6	11	0.09
6, 10	12	7	19	1.32
15	6	9	15	0.60
17, 19	21	12	33	2.45
20	13	7	20	1.80
21	7	6	13	0.08
22	7	3	10	1.60
23	6	6	12	0.00
24	12	6	18	2.00
25	8	13	21	1.19
26, 27, 28	9	8	17	0.06
				14.86 - Total χ^2 (13 d.f.)
	123	91	214	4.79* - Pooled χ^2 (1 d.f.)
				10.07 - Interaction χ^2 (12 d.f.)

higher catch with sardine baits (pooled $\chi^2 = 3.96$, $P < 0.05$). Of a total catch of 73 fish, 45 were taken on sardine. This indicates that a significant portion of the higher herring loss during rough seas occurred during the fishing period.

In contrast to the above, analyses of the re-examined data from the sardine vs. herring experiment of *Smith* cruise 18 showed no differences in bait return or catch between the two kinds of bait under different sea intensities (tables 22 and 23). As stated previously, this was probably the result of double hooking the herring, thus overcoming their tendency to fall off the hooks.

Table 20.--Analysis of variance of bait return by kind of bait and sea condition, *John R. Manning* cruise 14 (based on data in table 32)

	Sea condition							
	1		2		3		4	
	Sardine	Herring	Sardine	Herring	Sardine	Herring	Sardine	Herring
	92	44	80	24	71	22	53	13
	92	30	48	13	66	1	50	4
			77	44	54	18		
			74	18	61	14		
			43	29	49	11		
			72	17	69	14		
			49	14	78	6		
n	2	2	7	7	7	7	2	2
Total	184	74	443	159	448	86	103	17
$\bar{x}$	92.0	24.7	63.3	22.7	64.0	12.3	51.5	8.5

Analysis of variance				
Source	Degrees of freedom	Sum of squares	Mean square	F
Sea condition	3	2823.18	941.06	8.04**
Bait	1	19693.45	19693.45	168.15**
Sea condition - bait interaction	3	301.97	100.66	0.86
Within subclasses	28	3279.29	117.12	
Total	35	26097.89		

GENERAL DISCUSSION

Thus far the experiments have been discussed individually without any consideration of the ultimate goal of determining the best longline bait. An evaluation of the various experiments leads to the selection of the sardine as the best of the four bait species studied.

A direct comparison of the sardine with mullet cannot be made because the data on mullet are limited to a single experiment comparing mullet with herring. It should be pointed out that fresh mullet commands a good price in the Hawaiian market and would thus be an expensive bait. This does not, however, preclude the use of mullet in the equatorial region, since they possibly can be caught in large enough quantities for longline bait in the lagoons of the various atolls near the Equator.

The superiority of sardines over squid as bait is conclusive in view of the higher catches with sardines in sea intensities greater than 2. This has been tentatively attributed to the differences in the visibility of the two baits. It

Table 21.--Chi-square analyses of total catch by kind of bait and sea condition, _John R. Manning_ cruise 14 (based on data in table 32)

Sea condition 0 - 2				
Station	Sardine	Herring	Total	χ^2
1	1	10	11	7.36
2, 7	8	5	13	0.69
8, 10	5	6	11	0.09
11	8	5	13	0.69
12	8	8	16	0.00
21	5	7	12	0.33
24	15	8	23	2.13
				11.29 - Total χ^2 (7 d.f.)
	50	49	99	0.01 - Pooled χ^2 (1 d.f.)
				11.28 - Interaction χ^2 (6 d.f.)

Sea condition higher than 2				
Station	Sardine	Herring	Total	χ^2
3, 4, 5	4	6	10	0.40
6, 17	13	7	20	1.80
18, 19	12	6	18	2.00
20	11	4	15	3.27
22	5	5	10	0.00
				7.47 - Total χ^2 (5 d.f.)
	45	28	73	3.96* - Pooled χ^2 (1 d.f.)
				3.51 - Interaction χ^2 (4 d.f.)

can be assumed that the silvery sardine would be seen at a greater distance than the colorless, nearly translucent squid at the depths fished by the longline gear, particularly when the sea causes the baits to move.

The selection of sardines over herring was based solely on the necessity of double hooking the latter to attain comparable catching efficiency. That double hooking is unnecessary for sardines was shown in the single- vs. double-hooked sardine experiment. The double-hooked sardines were retrieved in greater numbers but did not have a higher catch than the single-hooked sardine baits. On the other hand, one experiment on single- and double-hooked herring showed a higher catch with double-hooked baits. Further evidence of the superiority of the sardine was shown in the sardine vs. herring experiment in which both baits were single hooked. Relatively more sardines were retrieved when the seas were greater than force 2, and at the same time the catch on sardines was higher.

In the above discussion visibility and availability have been considered to be the principal reasons for the superiority of sardines over squid and herring. However, several peculiarities were noted in the results of the experiments. In

Table 22.--Analysis of variance of bait return by kind of bait and sea condition, *Hugh M. Smith* cruise 18 (based on data in table 33)

	Sea condition							
	1		2		3		4	
	Sardine	Herring	Sardine	Herring	Sardine	Herring	Sardine	Herring
	91	75	80	89	76	80	83	90
	100	70	72	98	76	88	27	95
			83	91	85	84	75	29
			61	87	71	99	91	53
			73	61	62	83		
					57	52		
					39	57		
					44	79		
					73	65		
					72	93		
					61	75		
					90	46		
					39	57		
n	2	2	5	5	13	13	4	4
Total	191	145	369	426	845	958	276	267
$\bar{x}$	95.5	72.5	73.8	85.2	65.0	73.7	69.0	66.8

Analysis of variance				
Source	Degrees of freedom	Sum of squares	Mean square	F
Sea condition	3	1448.55	482.85	1.460
Bait	1	275.52	275.52	0.833
Sea condition - bait interaction	3	1079.62	359.87	1.088
Within subclasses	40	13226.12	330.65	
Total	47	16029.81		

the sardine vs. squid experiment, visibility was considered to be the factor responsible for the higher catch of yellowfin and bigeye with sardine baits. From this it might be reasoned that albacore, considered to be a very deep-swimming fish in equatorial waters, would be caught in greater numbers on sardine baits. That this was not true is shown by the almost equally divided catch of 10 albacore caught with sardine baits and 12 with squid baits. The distribution of the skipjack catch also differed from those of yellowfin and bigeye, with a catch of 19 skipjack on squid and only 9 on sardine. However, visibility is possibly not as important a factor with this surface species as it is for the deeper swimming tunas, and if this were true, differential bait retention on the shallow hooks may have been the cause of the discrepancy.

One of the objectives of this study was to determine whether the various baits and baiting methods used in tuna longline fishing modify the catch rates sufficiently to affect their comparability when used as indices of tuna abundance.

Table 23.--Chi-square analysis of total catch by kind of bait and sea condition, *Hugh M. Smith* cruise 18 (based on data in table 33)

Sea condition 0 - 2				
Station	Sardine	Herring	Total	χ^2
5, 9, 10	6	5	11	0.09
25	10	8	18	0.22
31	6	5	11	0.09
32	4	8	12	1.33
33	5	5	10	0.00
				1.73 - Total χ^2 (5 d.f.)
	31	31	62	0.00 - Pooled χ^2 (1 d.f.)
				1.73 - Interaction χ^2 (4 d.f.)

Sea condition higher than 2				
Station	Sardine	Herring	Total	χ^2
6	5	5	10	0.00
7, 8	10	10	20	0.00
12, 14	6	7	13	0.08
16	6	5	11	0.09
18, 20	15	15	30	0.00
22, 23	2	9	11	4.45
27, 29	7	5	12	0.33
30	11	7	18	0.89
35, 36, 37	23	13	36	2.78
				8.62 - Total χ^2 (9 d.f.)
	85	76	161	0.50 - Pooled χ^2 (1 d.f.)
				8.12 - Interaction χ^2 (8 d.f.)

It was found that the differences in the catch between hooks baited with sardine and those baited with herring (tables 12 and 13) were small and non-significant. Considered in relation to geographical and temporal variations (Murphy and Shomura 1953a, b), and in relation to random variability (Murphy and Elliott 1954) they are too small to warrant any adjustment of the catch rate data to compensate for them. The most extreme difference appeared in an experiment comparing sardine and squid (table 19), where of a total catch of 331 fish, 185 (56 percent) were taken with sardine baits. Though statistically significant, this difference is still small relative to the differences attributable to time, space, and random variability. Also these are differences of total catch of all fish, corrected for broken gear and surface sharks and not actual catches of individual species for which the variability from sources other than differences in baits might be still greater. Adjustment to compensate for the lower catching effectiveness of squid-baited longlines would appear warranted only for special types of analysis of pooled data where the bias may emerge above the other sources of variability.

SUMMARY

1. A study of bait returns shows a progressive decrease in the number of sardine baits retrieved with increasing soaking time.

2. With respect to sardine, there were no differences in catches as between salted and brined or between salted and fresh-thawed baits.

3. Of the three principal bait species studied (sardine, herring, and squid), the evidence shows the sardine to be the best longline bait. The sardine need only be single hooked, whereas the herring in order to attain equal efficiency must be double hooked. The sardine's superiority over squid is based on higher catches in moderate to rough seas. If this advantage is due to visibility, then the herring, which is similar in appearance to the sardine, should also be superior to the squid in rough seas, providing the herring are double hooked. Thus the order of preferability of the commonly available longline bait is single-hooked sardines, double-hooked herring, and finally squid.

4. The differences in the catch related to the kind of bait are not attributable to dietary preference but are explained on the basis of availability or visibility during the soaking period.

5. It is unnecessary to make adjustments to the catches made by the different species of bait and different baiting methods for POFI's general study of tuna abundance in the equatorial Pacific, because the differences in catch were small in magnitude when contrasted with other sources of variability.

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Table 24.--Total soaking time and total sardine bait return, John R. Manning cruise 11 (data combined into groups of 5 baskets)

Station number		Basket number							
		40-36	35-31	30-26	25-21	20-16	15-11	10-6	5-1
1	X1/	17.43	19.41	21.00	22.68	26.64	29.03	30.64	23.11
	Y2/	19	22	12	9	8	17	15	4
2	X	15.97	17.73	19.67	21.70	26.05	28.41	30.39	32.22
	Y	16	13	14	13	14	16	12	12
3	X	16.54	18.04	19.80	21.69	25.62	27.69	29.27	30.91
	Y	14	15	12	9	6	6	5	6
4	X	15.74	17.09	18.50	19.87	24.12	26.83	28.77	30.37
	Y	17	18	13	13	10	7	6	5
5	X	15.15	16.64	18.08	19.63	23.87	26.16	27.74	29.34
	Y	16	21	16	15	12	15	16	14
6	X	15.43	17.11	18.56	19.93	24.25	26.34	27.69	29.14
	Y	23	18	23	17	14	18	18	13
7	X	15.92	17.49	18.93	20.51	25.08	27.82	29.38	30.85
	Y	16	19	20	13	5	17	18	10
8	X	15.99	17.45	18.89	20.39	24.24	26.41	28.03	29.96
	Y	11	18	13	21	9	18	9	8
9	X	15.84	17.34	18.74	20.05	23.69	25.63	27.18	28.55
	Y	18	20	19	15	14	16	19	10
10	X	16.34	17.78	19.31	21.03	24.86	26.70	28.12	29.39
	Y	11	17	15	14	14	13	14	15
11	X	15.67	17.25	18.89	20.29	24.32	26.33	27.70	29.52
	Y	20	12	15	19	12	11	17	14
12	X	15.78	17.42	18.83	20.38	24.69	26.88	28.64	30.09
	Y	21	26	19	15	19	13	19	16
13	X	16.51	18.00	19.46	20.77	24.98	27.14	28.59	30.09
	Y	20	24	19	19	16	19	17	14
14	X	16.58	18.39	19.95	21.54	25.54	27.82	29.43	30.78
	Y	14	13	7	7	5	8	10	15
15	X	16.57	18.14	19.57	21.17	25.62	27.84	29.22	30.69
	Y	15	6	11	19	8	7	11	10
16	X	16.76	18.30	19.72	21.11	25.32	27.45	28.93	30.24
	Y	9	12	14	13	8	7	11	5
17	X	16.07	17.87	19.62	21.51	25.71	27.91	29.40	31.10
	Y	16	13	9	13	13	9	7	8
18	X	15.75	17.18	18.53	19.95	24.25	26.44	27.80	29.12
	Y	7	21	12	10	11	14	12	9
19	X	14.45	16.16	18.03	19.60	23.45	25.47	27.17	28.88
	Y	14	16	10	12	11	13	12	7
20	X	15.17	16.69	18.30	20.39	24.81	26.93	28.39	29.86
	Y	14	20	16	22	17	13	10	16
21	X	15.40	16.83	18.48	19.95	24.16	26.18	27.70	29.46
	Y	22	19	20	14	19	14	19	22
22	X	15.88	17.49	19.16	20.65	24.97	27.17	28.68	30.31
	Y	21	17	17	13	14	13	13	9
23	X	15.20	17.00	18.77	20.38	24.97	27.19	28.75	30.38
	Y	21	22	26	18	24	24	18	21
24	X	15.65	17.09	18.54	19.99	24.29	26.64	28.00	29.49
	Y	23	26	19	22	17	20	15	22
25	X	15.69	17.27	18.77	20.29	24.42	26.57	28.15	29.66
	Y	24	21	23	27	21	19	16	21
26	X	15.37	16.82	18.29	20.98	25.59	27.72	29.20	30.70
	Y	14	21	14	13	20	19	12	19
27	X	15.19	16.81	18.46	20.04	24.79	27.31	28.75	30.19
	Y	21	14	13	16	8	8	16	13

1/ Total soaking time in hundreds of minutes.
2/ Total bait return.

Table 25.--Analysis of covariance (total soaking time vs. total bait return), *John R. Manning* cruise 11

Station	d.f.	Σx^2	Σxy	Σy^2	n	b	$\Sigma d_y x^2$	d.f.
1	7	151.5972	- 43.725	259.500	-0.220	-0.2884	246.888	6
2	7	259.8793	- 27.855	17.500	-0.413	-0.1072	14.514	6
3	7	205.1665	-143.095	112.875	-0.940	-0.6975	13.066	6
4	7	220.2977	-166.700	168.000	-0.867	-0.7567	41.857	6
5	7	204.2146	- 50.521	45.875	-0.522	-0.2474	33.377	6
6	7	189.6990	- 92.680	92.000	-0.702	-0.4886	46.720	6
7	7	232.6472	- 75.265	183.500	-0.364	-0.3235	159.151	6
8	7	189.6838	- 76.450	173.875	-0.421	-0.4030	143.063	6
9	7	159.7292	- 66.312	77.875	-0.595	-0.4152	50.345	6
10	7	173.2695	+ 3.379	20.875	+0.056	+0.0195	20.809	6
11	7	186.4292	- 44.640	80.000	-0.366	-0.2394	69.311	6
12	7	207.2983	- 88.215	112.000	-0.579	-0.4255	74.460	6
13	7	186.9044	- 13.712	66.875	-0.123	-0.0734	65.869	6
14	7	200.9148	- 8.666	106.875	-0.059	-0.0431	106.501	6
15	7	205.2888	- 50.368	130.875	-0.307	-0.2454	118.517	6
16	7	186.2919	- 69.731	68.875	-0.616	-0.3743	42.774	6
17	7	222.6415	- 95.430	70.000	-0.764	-0.4286	29.096	6
18	7	186.5088	- 22.760	124.000	-0.150	-0.1220	121.223	6
19	7	199.8627	- 63.249	50.875	-0.627	-0.3165	30.859	6
20	7	223.3634	- 67.560	102.000	-0.448	-0.3025	81.565	6
21	7	196.5782	- 10.780	67.875	-0.093	-0.0548	67.284	6
22	7	208.2789	-122.137	91.875	-0.883	-0.5864	20.253	6
23	7	230.3300	- 17.040	57.500	-0.148	-0.0740	56.239	6
24	7	197.6141	- 72.805	86.000	-0.558	-0.3684	59.177	6
25	7	195.8814	- 77.950	76.000	-0.639	-0.3979	44.980	6
26	7	249.3341	+ 22.325	90.000	+0.149	+0.0895	88.000	6
27	7	234.4678	- 89.262	129.875	-0.512	-0.3807	95.893	6
	189	5504.1723	-1631.204	2663.375	-0.426	-0.2964	1941.791	162

Table 26.--Test of average regression coefficient from $\beta = 0$, *John R. Manning* cruise 11

Average regression line:

$$\hat{Y} = \bar{y} + b(X - \bar{x})$$

$$\hat{Y} = -0.2964\ X + 21.585$$

Test from $\beta = 0$:

$$\Sigma d_{y.x}^2 = 2179.955$$

$$s_{y.x}^2 = 10.1867$$

$$s_b = 0.0430$$

$$t = \frac{b - \beta}{s_b}$$

$$t = \frac{-0.2964}{0.0430}$$

$$t = -6.893^{**}\ (P < 0.01)$$

Table 27.--Summary of sardine bait return and total catch by method of treatment (dry-salted vs. fresh-thawed), *John R. Manning* cruise 15

Station	Number of baskets set per treatment	Salted		Fresh-thawed	
		Bait return	Total catch	Bait return	Total catch
1	20	111	2	114	2
2	17	60	5	65	7
3	20	72	5	59	12
5	20	64	9	70	5
6	20	79	6	83	3
7	19	37	16	38	19
8	20	58	13	61	18
10	20	78	6	85	4
11	20	83	4	76	3
12	20	82	2	79	9
13	19	84	3	85	4
14	20	88	6	79	10
15	20	91	5	81	8
16	20	62	9	64	11

Table 28.--Summary of sardine bait return and total catch by method of hooking (single vs. double), John R. Manning cruise 18 (based on 15 baskets per method of baiting per station)

Station	Sea condition	Single-hooked		Double-hooked	
		Bait return	Total catch	Bait return	Total catch
2	3	42	4	70	7
5	3	39	5	71	4
8	3	36	14	67	8
10	3	69	1	81	-
12	3	62	3	76	3
14	4	40	4	72	5
16	4	44	6	75	3
18	3	33	17	66	8
19	3	65	3	78	5
21	3	50	2	80	2
23	1	61	4	83	3
25	2	39	1	85	1
27	2	46	6	80	7
29	3	56	2	80	3

Table 29.--Summary of herring bait return and total catch by method of hooking (single vs. double), John R. Manning cruise 14

Station	Number of baskets set per treatment	Sea condition	Single		Double	
			Bait return	Total catch	Bait return	Total catch
27	10	1	5	4	37	3
28	10	3	18	1	38	4
29	9	2	8	2	22	7
32	10	3	16	9	37	7
33	6	3	6	7	18	7
35	7	3	15	1	19	9
36	10	3	12	4	28	10
37	10	3	14	4	34	5

Table 30.--Summary of herring bait return and total catch by method of hooking (single vs. double), Cavalieri cruise

Station	Number of baskets set per treatment	Sea condition	Single		Double	
			Bait return	Total catch	Bait return	Total catch
11	38	2	78	32	177	15
12	35	2	75	4	162	15
13	39	2	68	11	175	17
14	39	2	61	10	180	8
15	30	2	39	8	132	9
16	37	2	37	15	142	18

Table 31.--Summary of bait return, catch, and sea condition, *John R. Manning* cruise 13 (based on 25 baskets per kind of bait per station)

Station	Sardine						Squid						Sea condition
	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	
1	114	6	-	-	3	-	130	5	-	-	3	-	1
2	96	6	-	3	-	-	114	4	-	1	-	-	4
3	91	11	-	6	-	-	133	4	-	1	-	1	3
4	90	5	-	-	-	1	128	6	-	1	-	-	5
6	97	5	-	4	-	-	136	1	-	-	-	-	3
7	110	5	1	1	-	-	126	7	2	-	-	-	2
8	88	8	5	1	-	-	125	5	3	-	-	-	2
9	92	6	2	2	-	-	118	5	2	1	-	-	2
10	94	7	3	3	-	-	117	6	4	-	-	-	3
11	118	13	11	-	-	-	114	16	10	-	-	2	2
14	111	11	7	-	-	1	81	8	5	1	-	1	2
15	122	6	1	-	-	4	118	9	2	-	-	6	3
16	114	8	6	-	-	-	110	4	3	-	-	-	2
17	99	5	1	-	-	-	82	3	3	-	-	-	3
18	85	5	3	-	-	-	112	5	2	-	1	-	2
19	44	16	7	2	4	-	100	9	2	-	5	-	4
20	69	13	6	-	2	-	111	7	4	-	2	-	3
21	79	7	4	-	-	-	120	6	3	-	-	1	3
22	68	7	2	-	1	1	112	3	-	1	1	1	3
23	69	6	2	-	-	1	116	6	2	-	-	1	4
24	62	12	8	-	-	-	119	6	3	-	-	1	4
25	53	8	3	-	-	1	109	13	6	-	-	4	3
26	53	2	2	-	-	-	118	1	1	-	-	-	4
27	71	3	1	-	-	-	97	3	-	-	-	1	5
28	46	4	2	-	-	-	93	4	1	-	-	-	5

Table 32.--Summary of bait return, catch, and sea conditions, John R. Manning cruise 14

Station	Number of baskets set per kind of bait	Sardine						Herring						Sea condition
		Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	
1	19	92	1	-	-	-	-	44	10	-	-	-	-	1
2	19	92	1	-	1	-	-	30	1	-	-	-	-	1
3	18	71	-	-	-	-	-	22	1	-	-	-	-	3
4	19	53	4	-	1	-	-	13	-	-	-	-	-	4
5	20	50	-	-	-	-	-	4	5	3	-	-	1	4
6	19	66	7	5	-	-	-	1	2	2	-	-	-	3
7	20	80	7	2	-	-	1	24	4	2	-	-	-	2
8	14	48	4	4	-	-	-	13	5	3	-	-	1	2
10	18	77	1	1	-	-	-	44	1	1	-	-	-	2
11	18	74	8	7	-	-	3	18	5	3	1	-	-	2
12	20	43	8	6	2	-	-	29	8	5	1	-	-	2
17	17	54	6	-	2	1	-	18	5	-	-	-	2	3
18	20	61	6	3	-	1	-	14	3	-	-	1	-	3
19	20	49	6	3	1	-	-	11	3	1	1	-	-	3
20	20	69	11	1	-	5	-	14	4	2	-	1	1	3
21	20	72	5	1	-	2	-	17	7	2	-	1	-	2
22	19	78	5	1	-	2	-	6	5	-	-	1	-	3
24	20	49	15	4	-	5	-	14	8	3	-	-	-	2

Table 33.--Summary of bait return, catch, and sea condition, Hugh M. Smith cruise 18

Station	Number of baskets set per kind of bait	Sardine						Herring						Sea condition
		Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	Bait return	Total catch	Yellow-fin	Bigeye	Alba-core	Skip-jack	
5	20	80	1	-	-	-	-	89	2	-	1	-	-	2
6	20	76	5	-	3	-	-	80	5	-	-	-	-	3
7	20	83	4	-	1	-	-	90	4	-	-	-	-	4
8	19	76	6	-	3	-	-	88	6	-	5	-	-	3
9	19	72	1	1	-	-	-	98	0	-	-	-	-	2
10	20	83	4	-	-	-	-	91	3	-	-	-	-	2
12	18	85	3	1	1	-	-	84	4	2	1	-	-	3
14	20	71	3	-	1	-	-	99	3	-	-	-	-	3
16	19	62	6	2	1	-	-	83	5	2	-	-	-	3
18	16	57	2	2	-	-	-	52	7	2	1	1	3	3
20	20	27	13	7	3	-	-	95	8	7	-	-	-	4
22	16	39	1	1	-	-	-	57	2	-	1	-	-	3
23	20	44	1	1	-	-	-	79	7	2	2	-	1	3
25	20	61	10	4	2	-	1	87	8	2	1	-	4	2
27	20	73	3	1	-	-	-	65	3	1	-	-	-	3
29	20	72	4	3	-	-	-	93	2	2	-	-	-	3
30	20	61	11	-	2	-	-	75	7	-	-	-	-	3
31	20	91	6	2	-	-	-	75	5	1	-	-	-	1
32	20	100	4	-	-	-	-	70	8	1	-	-	-	1
33	20	76	5	2	-	-	-	61	5	2	-	-	-	2
35	20	90	5	1	-	-	-	46	3	-	2	-	-	3
36	20	75	14	1	2	-	3	29	8	-	1	-	2	4
37	20	91	4	-	-	-	-	53	2	-	-	-	-	4