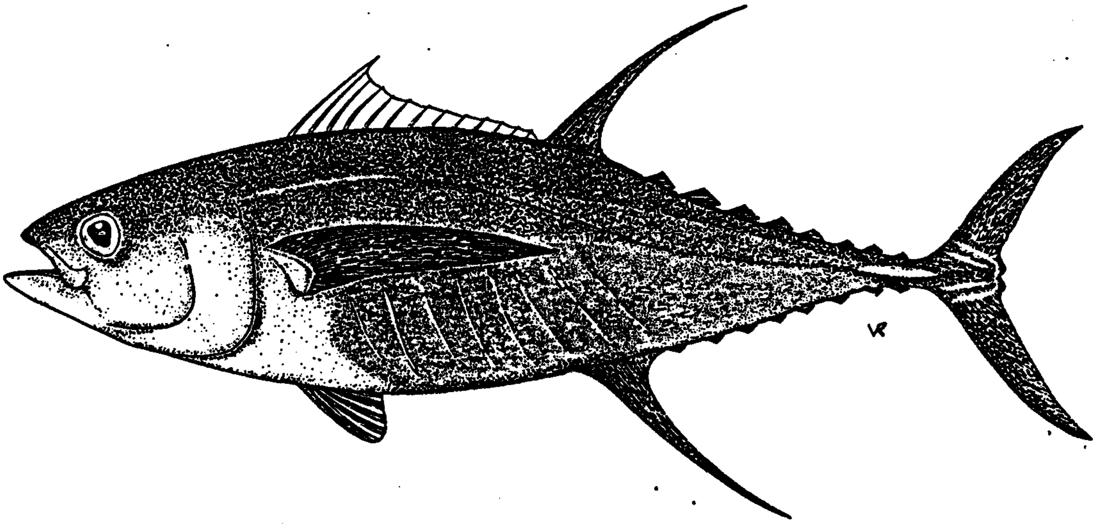
THIRD STANDING COMMITTEE ON TUNA AND BILLFISH

6-8 June 1990
Noumea, New Caledonia

WORKING PAPER 4

PRELIMINARY ANALYSIS OF SOLOMON ISLANDS IN-COUNTRY TAGGING PROJECT DATA



Tuna and Billfish Assessment Programme
South Pacific Commission
Noumea, New Caledonia

June 1990

1. INTRODUCTION

The Solomon Islands In-Country Tuna Tagging Project (SITP) was developed jointly by the Fisheries Division, Ministry of Natural Resources, Solomon Islands and the South Pacific Commission Tuna and Billfish Assessment Programme, and is funded by the Australian International Development Assistance Bureau. The more broadly directed Regional Tuna Tagging Project (RTTP), funded by the Sixth European Development Fund, will also contribute to the SITP with specific tagging cruises in the Solomon Islands EEZ.

The aim of the SITP is to provide information on skipjack population dynamics and fishery interaction necessary to guide the rational development of the Solomon Islands tuna fishery, currently the largest of its type in the Pacific Islands region. The specific objectives are:

(i) To estimate skipjack population parameters (natural mortality, fishing mortality, transfer rates, tag shedding rates, tag reporting rate) necessary to assess the existing and/or potential interactions between the Solomon Islands pole-and-line and purse-seine fisheries. If artisanal statistics are available for the period of the tagging programme, artisanal-industrial interaction can also be addressed.

(ii) To update SSAP estimates of skipjack standing stock, turnover, throughput and harvest ratio in the Solomon Islands region.

(iii) To estimate other skipjack population parameters of interest (e.g., growth, long range movements, school integrity).

(iv) To obtain preliminary information on the attraction of tagged skipjack to fish aggregation devices (FADs), movement to FADs and residence time on FADs.

(v) To train a local Solomon Islands fisheries officer in all aspects of conducting a tagging experiment, including experimental design, tagging and field sampling methods, tag return data collection and processing, data analysis and report writing, so as to enhance the research capability of the Solomon Islands Fisheries Division.

To date, three cruises on Solomon Taiyo Ltd (STL) pole-and-line vessels and two cruises on the RTTP chartered vessel, *Te Tautai*, have been completed. The final cruise, using a STL vessel, is scheduled to take place in June 1990. In this paper, a preliminary analysis of the results of cruise 1 is presented in order to demonstrate some of the techniques that can be used to analyse data of this nature. The analysis was also undertaken so as to assess the appropriateness of these standard analytical techniques and to indicate directions for further methodological development, if required (as requested in Action Item 1 of the 1989 SCTB meeting).

2. TAG RELEASES

The numbers of tagged tuna released for the five cruises undertaken to date are as follows:

Cruise	Vessel	Dates	Number Released				
			Skipjack	Yellowfin	Bigeye	Unid.	Total
SB1	*Soltai* 8	17/7-14/8/89	4,034	176	0	0	4,210
SB2	*Soltai* 8	1/11-3/11/89	111	3	0	0	114
RT1	*Te Tautai*	21/12/89-3/1/90	472	400	29	21	922
RT2	*Te Tautai*	28/2-31/3/90	594	1,344	11	4	1,953
SB3	*Soltai* 6	10/3-28/3/90	1,241	232	1	0	1,474
TOTALS			6,452	2,155	41	25	8,673

For details of tagging methods, size distributions, etc, the reader is referred to the individual cruise reports available from the Secretariat.

The geographical distribution of releases from all cruises is shown in Figure 1. Most of the releases on SB cruises have been concentrated in the area south of New Georgia outside the Main Group Archipelagic (MGA) baseline, a prime fishing area for both pole-and-line and purse seine vessels. A line of FADs extends along the MGA baseline in this area. The group seine operation routinely sets on FADs. Pole-and-line and single seine vessels also fish FAD-associated schools, but also fish free-swimming schools or schools associated with flotsam.

Releases on RTTP cruises were distributed mainly in areas not normally fished by STL pole-and-line vessels. This strategy was adopted to increase the geographical coverage of releases so as to obtain a better insight into exchange of fish from within and outside the MGA. (SPC and Fisheries Division has no control over the location of fishing when tagging from STL vessels.)

3. TAG RECOVERIES

The tag recoveries and recovery rates as at 31 May 1990 are as follows:

Release Cruise	Number Recovered						
	Skipjack	(%)	Yellowfin	(%)	Unid.	Total	(%)
SB1	515	12.8	23	13.1	28	566	13.4
SB2	1	0.0	0		0	1	0.0
RT1	20	4.2	20	5.0	17	57	6.2
RT2	12	2.0	16	1.2	3	31	1.6
SB3	155	12.5	21	9.1	0	176	11.9
TOTALS	703	10.9	80	3.7	48	831	9.6

Tags are still being received and data quality continually being enhanced, therefore any analysis of results at this stage must be considered preliminary. However, for the purposes of this paper, it is instructive to look in more detail at the results of cruise SB1, the longest running experiment for which most recoveries have been recorded.

4. ANALYSIS OF CRUISE SB1 RESULTS

4.1 Geographical distribution of recoveries

The geographical distribution of recoveries from cruise SB1 releases is shown in Figure 2. Thirty-one recoveries, mainly by Philippines purse seiners, from outside the Solomon Islands EEZ are not shown. Recoveries by pole-and-line vessels are widely distributed both inside and outside the MGA baseline. Most purse seine recoveries were recorded by the group seine operation in sets on FADs adjacent to the main release area. The distribution of recoveries corresponds reasonably well with the distribution of skipjack catch for pole-and-line and purse seine vessels during the recovery period (July 1989 - March 1990) (Figure 3).

Three separate release areas for cruise SB1 releases are indicated on Figure 1. The monthly (August - December) distributions of recoveries from these three release areas are shown in Figures 4-8. Dispersal of tagged skipjack appears to have been rapid, with August recoveries from release groups 1 and 2 being widely distributed. Most of the recoveries from release group 3 were recaptured on the day following release.

The impression of rapid dispersal gained from the recovery maps is important for the quantitative analyses to estimate throughput, standing stock and fishing mortality. For these analyses, it must be assumed that, at some point, the tagged fish are randomly mixed with the untagged population. Rapid dispersal of tagged fish would, of course, assist compliance with this assumption.

4.2 Estimates of throughput, standing stock, harvest ratio and components of tag attrition

Estimates of throughput, standing stock, harvest ratio and components of tag attrition, derived by SPC's Skipjack Survey and Assessment Programme (SSAP), have formed the basis of current knowledge of the Western Pacific skipjack resource. The estimates for the Solomon Islands fishery, based on the 1980 SSAP cruise were as follows:

Standing stock (mt x 10^3)	89	(49-185)
Throughput (mt x 10^3 per month)	13	(9-22)
Turnover rate (per month)	0.16	(0.09-0.26)
Average fishing mortality (per month)	0.027	(0.014-0.047)
Harvest ratio	0.17	

It is possible to repeat this analysis using the results of cruise SB1.

4.2.1 The simple tag attrition model

Kleiber et al. (1987) used a least squares procedure to obtain parameter estimates for the tag attrition model, where the expected number of returns during the jth period after mixing of tagged fish in the untagged population is assumed to have taken place may be written as

$$\bar{r}_j = N_0 \, e^{-\left(q\sum_{i=1}^{j-1} f_i + (j-1)M\right)} \, \frac{qf_j}{qf_j+M} \, \beta \left[1 - e^{-(qf_j+M)} \right] \qquad (1)$$

where N_0 is the number of fish alive at the beginning of the time period in which complete mixing is assumed to have occurred, q is the catchability coefficient, f_i is the fishing effort during period i, M is the rate of natural mortality, tagging mortality, continuous tag shedding and emigration combined and β is the probability that a recaptured tag will be returned. The use of fishing effort to parameterize fishing mortality, F, assumes that

$$F_i = qf_i \, . \qquad (2)$$

This parameterization poses difficulties in the case of the Solomon Islands fishery because two gear types (having different catchability coefficients) are used, therefore no single value of total effective effort can be easily obtained. The alternative parameterization is one involving catch instead of effort:

$$F_i = \frac{C_i}{P} \qquad (3)$$

where C_i is the catch in period i and P is the equilibrium standing stock (expressed in the same units as C_i). The use of equation (3) in the tag attrition model fitted to the present data set involves the implicit assumption that there is a single population of skipjack simultaneously vulnerable to both gears. Using equation (3) to parameterize F, the expected number of returns during the jth period becomes

$$\bar{r}_j = N_0 \, e^{-\left(\frac{1}{P}\sum_{i=1}^{j-1} C_i + (j-1)M\right)} \, \frac{C_j}{C_j+PM} \, \beta \left[1 - e^{-\left(\frac{C_j}{P}+M\right)} \right] . \qquad (4)$$

As noted earlier, it is necessary to omit returns from periods immediately after release to allow for the assumption of mixing. For the analyses of these data, returns were grouped into 10-day periods. Inspection of the data grouped by time period suggested that the first 4 periods should not be included in the analyses. Therefore, N_0 in equations (1) and (4) is actually the number of tagged fish remaining at the beginning of the fifth recovery period. If $N_0{}^*$ fish are originally tagged, N_0 can be calculated by the Pope (1972) equation:

$$N_0 = N_0^* e^{-4M} - \frac{r_1}{\beta} e^{-\frac{7M}{2}} - \frac{r_2}{\beta} e^{-\frac{5M}{2}} - \frac{r_3}{\beta} e^{-\frac{3M}{2}} - \frac{r_4}{\beta} e^{-\frac{M}{2}} \qquad (5)$$

and substituted into equations (1) or (4). The subscripts in the equations presented here thus refer to time periods after mixing, rather than after tagging.

Previous analyses of this type (e.g. Kleiber *et al.* 1987) have employed a nonlinear least squares estimation procedure to find the set of model parameters that best fits the data. A problem with the least squares procedure is that the sum of squares must be appropriately weighted or biased parameter estimates may result. Maximum likelihood estimation is more straight forward as no weighting of the likelihood function is necessary. Let R = the total number of recaptures after k periods of time and p_j = the probability of recapture during the j th period and the tag returned. Then, as shown by Seber (1973), the observed numbers of tag returns (r_j) have a joint multinomial distribution thus,

$$f(\{r_j\}) = \frac{N_0!\,(1-P_k)^{N_0-R}}{\left\{\prod_{j=1}^{k} r_j!\right\}(N_0-R)!} \prod_{j=1}^{k} \left\{p_j^{r_j}\right\} \qquad (6)$$

where $P_k = \sum_{j=1}^{k} p_j$ = the probability of recapture before the end of period k. Assuming that $F_j = C_j/P$,

$$p_j = e^{-\left(\frac{1}{P}\sum_{i=1}^{j-1} C_i + (j-1)M\right)} \frac{C_j}{C_j + PM} \beta \left[1 - e^{-\left(\frac{C_j}{P} + M\right)}\right] . \qquad (7)$$

Maximum likelihood estimates of M and P and their asymptotic variances, are obtained by minimizing $L = -\log_e [f(\{r_j\})]$ using a function minimization routine (e.g. subroutine MINIM programmed by D. E. Shaw, CSIRO Division of Mathematics and Statistics, P.O. Box 218, Lindfield, NSW 2070 Australia using a Nelder-Mead simplex algorithm).

4.2.2 Results

The model described above was fitted to tag-return data from cruise SB1 and skipjack catch data aggregated by 10-day periods, as given below (the beginning of period 1 is 21 July 1989) (skipjack catch, effort and CPUE are summarised in Appendix 1):

Period	Returns	Catch (mt)	Period	Returns	Catch (mt)
1*	1	1,178	14	11	425
2*	19	1,552	15	3	193
3*	117	1,525	16	0	71
4*	24	1,142	17	0	68
5	90	1,293	18	0	316
6	34	753	19	1	58
7	50	932	20	0	170
8	35	906	21	0	200
9	37	754	22	0	148
10	31	776	23	5	145
11	11	460	24	0	192
12	25	383	25	3	725
13	7	554	Number released = 4,034		

* Data not included in calculation of the likelihood function

β was arbitrarily assumed to equal 0.9. The parameter estimates and their 95% confidence intervals obtained by fitting the simple tag attrition model to these data are as follows:

Standing stock (mt x 10^3)	29	(22-36)
Throughput (mt x 10^3 per month)	11	
Turnover rate (per month)	0.39	(0.27-0.41)
Average fishing mortality (per month)	0.047	(0.036-0.058)
Harvest ratio	0.12	

Note that the estimate of standing stock is much lower and the estimate of turnover rate much higher than those derived by the SSAP. This might have resulted because of (i) concentration of the fishery in a relatively small area during the period of the recent tagging experiment; (ii) a greater tendency for skipjack to move away from Solomon Islands waters during the recent experiment (as evidenced by the large number of international recoveries); or (iii) the preliminary nature of the present data. Partly because of the high correlation between P and M (–0.87), the estimate of throughput is similar to the previous estimate, while harvest ratio (proportion of total attrition due to fishing) is somewhat lower. The plot of observed and expected r_j (Figure 9) indicates that the fitted model describes the data reasonably well.

4.2.3 Gear specific estimates

The following table details tag returns and catch by 10-day periods by gear type (11 returns could not be classified by gear type).

Period	Returns		Catch (mt)	
	PL	PS	PL	PS
1*	1	0	1122	56
2*	17	2	1383	169
3*	24	92	1370	155
4*	10	14	913	229
5	36	53	1139	154
6	13	19	674	79
7	16	34	755	177
8	19	15	793	113
9	12	22	669	85
10	20	10	675	101
11	9	2	443	17
12	10	14	340	43
13	5	2	514	40
14	11	0	415	10
15	1	1	72	121
16	0	0	0	71
17	0	0	0	68
18	0	0	0	316
19	0	1	0	58
20	0	0	0	170
21	0	0	0	200
22	0	0	16	132
23	0	5	107	38
24	0	0	192	0
25	0	3	341	384

* Data not included in calculation of the likelihood function

Gear-specific estimates of F can be obtained by defining:

$$F_{pj} = \frac{C_{pj}}{P} \quad \text{and} \quad F_{sj} = \frac{C_{sj}}{P} \qquad (8)$$

where F_{pj} and F_{sj} are partial fishing mortality rates for the pole-and-line and purse seine fisheries, respectively. The joint likelihood function for returns from the pole-and-line fishery (r_{pj}) and the purse seine fishery (r_{sj}) may then be written:

$$f(\{r_{pj}, r_{sj}\}) = \frac{N_0 \left(1-P_k\right)^{N_0-R}}{\left\{\prod_{j=1}^{k} r_{pj}!\ r_{sj}!\right\} \left(N_0-R\right)} \prod_{j=1}^{k} \left\{ p_{pj}^{r_{pj}} \cdot p_{sj}^{r_{sj}} \right\} \tag{9}$$

where

$$p_{pj} = e^{-\left(\frac{1}{P}\sum_{i=1}^{j-1} C_i + (j-1)M\right)} \frac{C_{pj}}{C_j+PM}\ \beta \left[1-e^{-\left(\frac{C_j}{P}+M\right)} \right] \tag{10}$$

$$p_{sj} = e^{-\left(\frac{1}{P}\sum_{i=1}^{j-1} C_i + (j-1)M\right)} \frac{C_{sj}}{C_j+PM}\ \beta \left[1-e^{-\left(\frac{C_j}{P}+M\right)} \right] \tag{11}$$

and

$$P_k = \sum_{i=1}^{k} p_{pi} + p_{si}\ . \tag{12}$$

The resulting parameter estimates are essentially identical to those obtained for data aggregated by gear type:

Standing stock (mt x 10^3)	30	(23-37)
Throughput (mt x 10^3 per month)	12	
Turnover rate (per month)	0.39	(0.31-0.47)
Average fishing mortality (per month)		
pole-and-line	0.034	(0.026-0.042)
purse seine	0.011	(0.009-0.014)
Harvest ratio	0.12	
pole-and-line	0.087	
purse seine	0.029	

While the parameter estimates are consistent with the previous fit, the plots of observed and expected recoveries by gear type clearly indicate that the model is inadequate. In particular, the observed numbers of recoveries by pole-and-line vessels (Figure 10) are much less than those that are predicted by the model. Conversely, the observed numbers of purse seine recoveries (Figure 11) are much higher than those expected. This suggests that the tagged skipjack were consistently more available to purse seiners than to pole-and-liners. A possible explanation for this is that most of the skipjack tagged during cruise SB1 were released in the vicinity of FADs. If the tagged skipjack tended to remain associated with these FADs for some time after release, the probability of their capture by purse seine would be greater than by pole-and-line. More complex models of tagged fish dynamics therefore need to be developed to adequately describe this situation.

5. DISCUSSION

5.1 Interpretation of parameter estimates

As explained by Hilborn (1990), throughput is an estimate of the maximum possible average monthly yield (assuming, as is reasonable for skipjack, that recruitment is insensitive to exploitation at levels likely to be achieved under realistic conditions). As such, it is probably the single most useful estimate to consider from a fisheries development viewpoint. It also has the advantage of being statistically precise and stable, being the product of two highly correlated parameters Z (= M+F) and P.

Using the estimated monthly throughput (11,000 mt) as an estimate of maximum yield, the absolute maximum possible yield of skipjack from the Solomon Islands fishery as it is currently distributed would be approximately 130,000 mt. This yield could only be taken at very high levels of F (ignoring the possibility of growth overfishing, with a harvest ratio approaching 1.0) and a very low standing stock that would almost certainly render the fishery uneconomic. Kleiber *et al.* (1987) suggested that harvest ratios of 0.5-0.7 would result in a fully exploited skipjack resource. Harvest ratios of this magnitude in the Solomon Islands would produce annual yields of approximately 65,000-90,000 mt, although there is no guarantee that such yields could be economically taken. More detailed analyses to produce a reasonable development target for the Solomon Islands fishery are not appropriate at this stage, given the preliminary nature of the data and the deficiencies identified in the simple models used.

5.2 Estimation of fishery interaction

The initial indications obtained from the examination of the geographical distribution of tag recoveries was that skipjack mixed rapidly over much of the area of the Solomon Islands fishery. This, and the overlapping distributions of the pole-and-line and purse seine fisheries suggested that the skipjack resource was simultaneously vulnerable to both gears. In this case, the assessment of interaction would reduce to a simple multi-gear yield-per-recruit problem. However, the predominance of tag returns from the purse seine fishery suggest the the tagged population was not randomly distributed with respect to the two gears and that FADs played a significant role in this observation. This would suggest that the tag release data need to be stratified into FAD-associated and non-FAD-associated components. In any case, further consideration therefore needs to be given to developing models that better account for the effect of FADs on the interaction between the purse seine and pole-and-line fisheries.

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Figure 9. Plot of observed and expected tag recoveries.

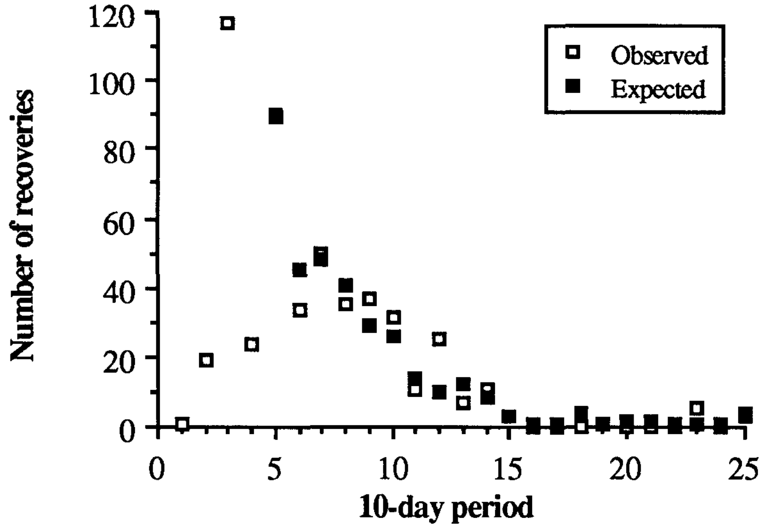


Figure 10. Plot of observed and expected recoveries by pole-and-line vessels.

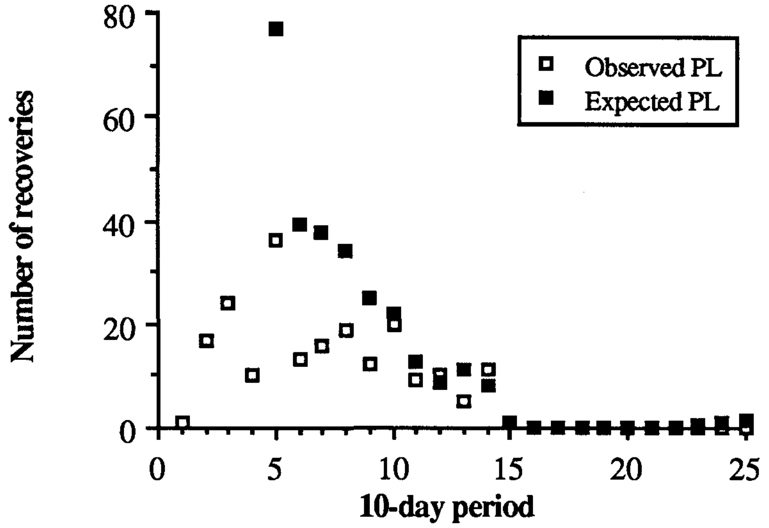
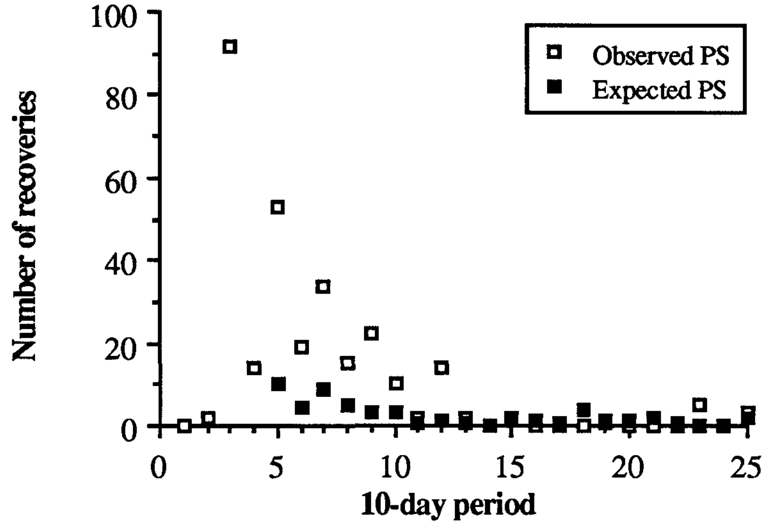


Figure 11. Plot of observed and expected recoveries by purse seine vessels.



Appendix 1
Skipjack catch, effort and CPUE, July 1989-March 1990

10-day period		Pole-and-line			Purse seine		
		Catch (mt)	Effort (days)	CPUE (mt/day)	Catch (mt)	Effort (days)	CPUE (mt/day)
Jul	21-31	1,122	312	3.60	56	4	14.00
Aug	1-10	1,383	271	5.10	169	7	24.14
	11-20	1,370	285	4.81	155	7	22.14
	21-31	913	290	3.15	229	6	38.17
Sep	1-10	1,139	276	4.13	154	9	17.11
	11-20	674	204	3.30	79	7	11.29
	21-30	755	275	2.75	177	5	35.40
Oct	1-10	793	220	3.60	113	8	14.12
	11-20	669	246	2.72	85	4	21.25
	21-31	675	290	2.33	101	9	11.22
Nov	1-10	443	228	1.94	17	7	2.43
	11-20	340	215	1.58	43	5	8.60
	21-30	514	253	2.03	40	5	8.00
Dec	1-10	415	248	1.67	10	5	2.00
	11-20	72	51	1.41	121	10	12.10
	21-31	0	0	-	71	13	5.46
Jan	1-10	0	0	-	68	28	2.43
	11-20	0	0	-	316	26	12.15
	21-31	0	0	-	58	23	2.52
Feb	1-10	0	0	-	170	13	13.08
	11-20	0	0	-	200	32	6.25
	21-28	16	11	1.45	132	18	7.33
Mar	1-10	107	69	1.55	38	12	3.17
	11-20	192	111	1.73	0	5	0.00
	21-31	341	172	1.98	384	14	27.43
TOTALS		11,933	4,027	2.96	2,986	282	10.59