Status of interactions of Pacific tuna fisheries in 1995

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INTERACTION BETWEEN SMALL-SCALE FISHERIES IN KIRIBATI AND THE INDUSTRIAL PURSE SEINE FISHERY IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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ABSTRACT

The Gilbert Islands of the Republic of Kiribati straddle the equator at 173°–177°E, and are located towards the eastern extreme of the tropical tuna fishery in the western and central Pacific Ocean. Industrial purse seine vessels are licensed to fish in this area, and catches have increased substantially over the past three years. Domestic pole-and-line vessels and artisanal fishermen also target tuna in the vicinity of the Gilbert Islands. The recent increase in purse seine catches and reported declines in pole-and-line and artisanal catches have led to concerns that purse seining is reducing the supply of tuna available for capture by local fishermen.

Correlation analyses of yellowfin catch rates by artisanal troll fishermen, as determined from landing surveys, and industrial purse seine catches at various distances from and times prior to the surveys suggest that the correlations are generally weak. Over large areas, e.g., within radii of 300-600 nm of the islands, artisanal catch rates and purse seine catches are generally positively correlated, suggesting that, on this scale, variations in the abundance or catchability of yellowfin affect both purse seiners and artisanal catches in the same way. However, some negative correlations were found for smaller area (< 60 nm) and time scales, indicating that localised effects may occur. Such negative correlations were detected during 1991-93 but not during 1985-90. The possible influence of El Niño conditions on these observations is discussed.

Analyses of tagging data were carried out to estimate the average impact of purse seine fishing on Kiribati pole-and-line and artisanal catch rates. A spatially aggregated model for the Gilbert Islands area indicated only a modest overall impact of local purse seine catches on pole-and-line and artisanal catch rates. A regional model with 1° square spatial structure indicated a slightly higher overall impact of the regional purse seine fishery on skipjack catches by the Kiribati pole-and-line fishery. The results of the correlation and tagging data analyses suggest that adverse impacts of purse seine fishing on artisanal and pole-and-line catches in the Gilbert Islands are more likely to occur at a small scale (1° square or

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less) due to local concentrations of purse seine effort, rather than at a regional scale or on a scale of tens of degrees.

1. INTRODUCTION

The Republic of Kiribati is comprised of three groups of islands, the Gilbert, Phoenix, and Line Islands. The 33 atolls have a total land mass of only 825 km^2, but the exclusive economic zone (EEZ) is discontinuous across 3,200 km of the equatorial Pacific and occupies an area of 3,550,000 km^2 (Figure 1). This report analyses interaction issues that concern the pole-and-line and artisanal fishing operations that occur primarily in the Gilbert Islands, therefore this portion of the Kiribati EEZ is the focus of the study.

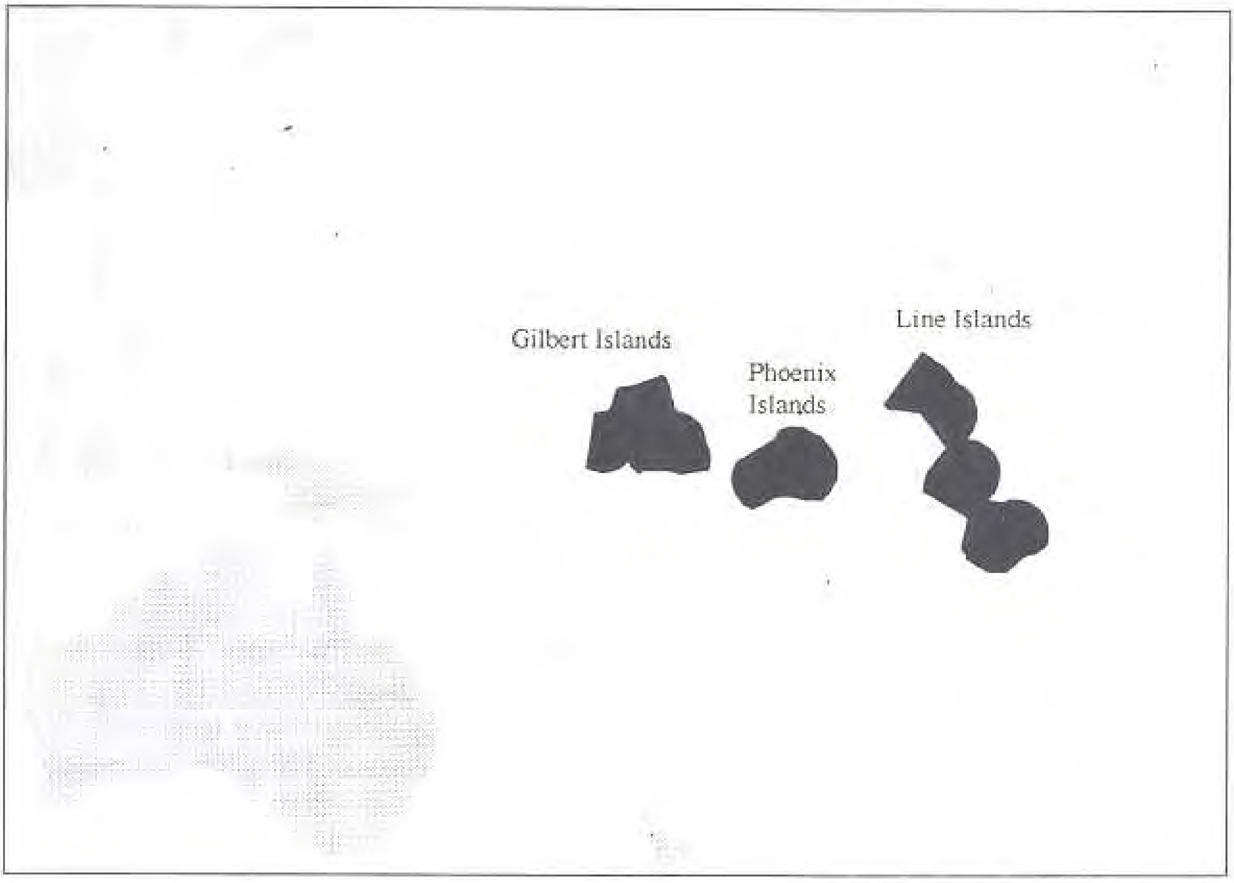

Figure 1. Map of the western Pacific Ocean, showing the Kiribati EEZ (black).

The Gilbert Islands are a group of 15 atolls that extend approximately NNW to SSE across the equator at 173°–177°E (Figure 2). The marine environment in this area is strongly influenced by the major equatorial current systems, particularly the westward-flowing South Equatorial Current and the eastward-flowing equatorial undercurrent. The equatorial upwelling, a result of the interaction of the equatorial current and easterly trade winds, frequently occurs in the vicinity of the Gilbert Islands. The upwelling brings to the surface nutrient-rich water, which provides suitable conditions for high primary and secondary production. These conditions are thought to provide the forage base for the large stocks of tuna that occur throughout the western tropical Pacific.

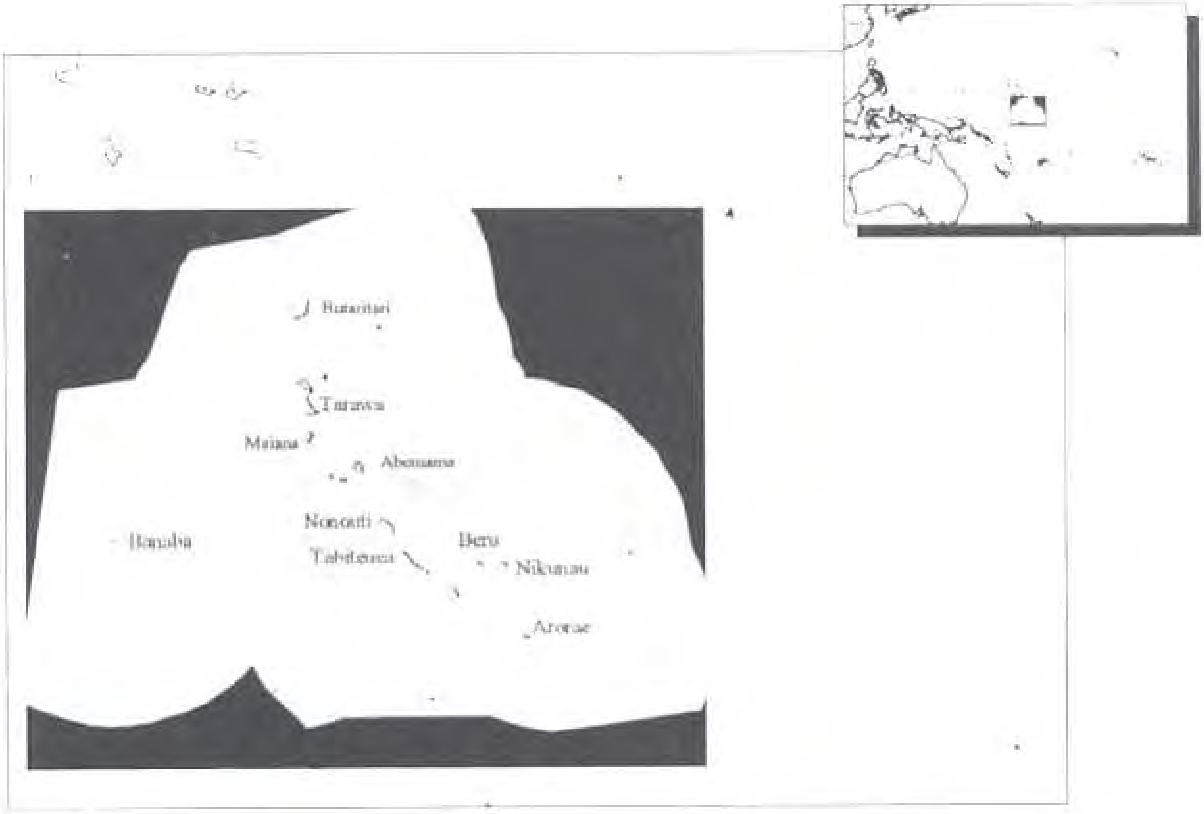

Figure 2. Map of the Gilbert Group framed by 5°N-5°S, 168°E-180°.

The western and central Pacific Ocean (WCPO), extending from the Philippines and eastern Indonesia to about 150°W, now provides in excess of 50% of world tuna production. Catches peaked at more than 1.4 million mt in 1991 and have exceeded 1 million mt since 1989 (Lawson, 1994). Most of the catch is comprised of skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*), with smaller amounts of bigeye (*T. obesus*) and albacore (*T. alalunga*) also taken. The major gear type in terms of catch weight is purse seine, which has accounted for 650,000–850,000 mt of skipjack and yellowfin since 1990. Domestic surface fisheries in the Philippines and eastern Indonesia are also substantial, collectively landing 320,000–380,000 mt since 1990. Pole-and-line fishing has declined somewhat in recent years (140,000–200,000 mt, mainly of skipjack, since 1990), but important locally-based fleets continue to operate in Solomon Islands, Fiji and Kiribati. Longline fishing, targeting mainly bigeye and yellowfin for the valuable sashimi market, continues to generate annual catches in the vicinity of 100,000 mt.

The Gilbert Islands lie towards the eastern extreme of this activity, where average production is somewhat less than in the area north of Papua New Guinea and in the Philippines/eastern Indonesia areas (Figure 3). Nevertheless, Kiribati has been an important fishing area for some purse seine fleets in recent years, as the fishing area expanded to the east possibly in response to conditions associated with the El Niño episode that has been in evidence in the WCPO since 1991.

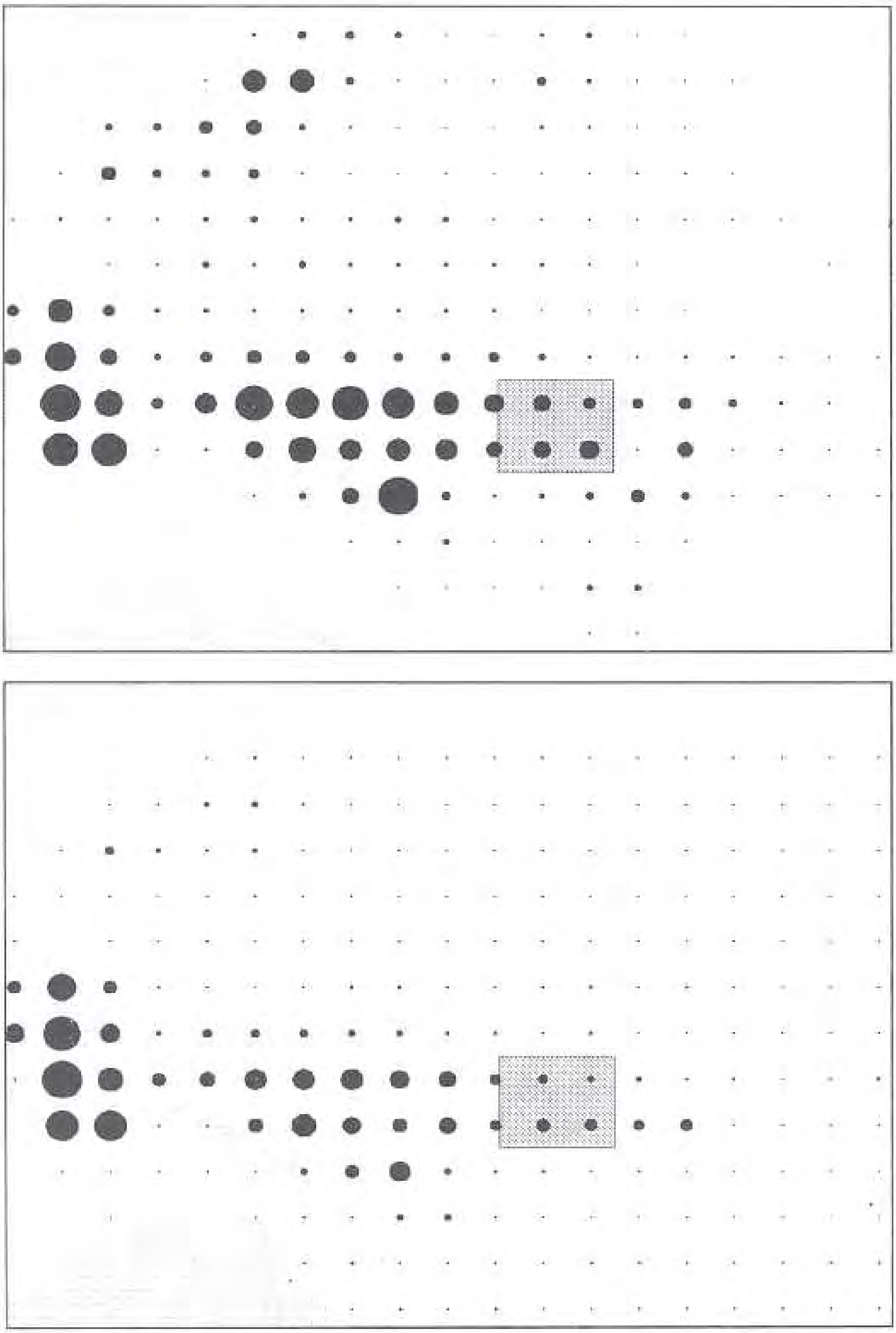

Figure 3. Distribution of skipjack (top) and yellowfin (bottom) average catch in the western Pacific Ocean, 1988–92. The maximum circle size represents annual catches of 39,200 mt for skipjack and 26,000 mt for yellowfin. The rectangle indicates the Gilbert Islands area.

Tuna fishing in the vicinity of the Gilbert Islands is carried out at several levels, with skipjack and yellowfin being the main target species in all cases. An artisanal fishery, employing a range of gear types and operating in close proximity to the various islands, provides food, and in some cases income, to much of the local population. The total annual catch of all species from artisanal fisheries in the Gilbert Islands group, including commercial and subsistence sectors, has been estimated at 11,500 mt (Mees et al., 1988). The species composition varies with the area fished, which includes lagoons, reefs, and ocean, and the gear type, which includes various types of hook-and-line, nets, and traps, but tuna, primarily yellowfin, are the most common species caught. Landing surveys indicate that yellowfin account for 65% of the catch by troll lines and 60% of the catch by drop stone lining.

Estimates of total artisanal tuna catches in the Gilbert Islands are not available. However, there is some evidence that the artisanal tuna catch has declined since 1990. Since 1987, the government-owned fishing company, Te Mautari Ltd (TML), has purchased tuna which the artisanal fishermen based on Tarawa could not otherwise market or consume. From 1988 to 1990, the amount of tuna sold to TML averaged about 175 mt per annum. The amount dropped to less than 20 mt per annum in 1991 and 1992, and in 1993, less than one metric ton was sold to TML.

TML has operated a fleet of small Japanese-style pole-and-line vessels since 1981. Up to six vessels have fished, occasionally in Fiji and Solomon Island waters as well as in the Gilbert Islands. The catch of skipjack and yellowfin peaked at 2,300 mt in 1989, but has declined in recent years (293 mt in 1993).

The Government of Kiribati also licenses distant-water fishing nation (DWFN) fleets to fish in its waters. Japanese pole-and-line and longline fleets have been licensed to fish in the EEZ since 1978. Pole-and-line fishing has been sporadic, with catches in the vicinity of the Gilbert Islands exceeding 20,000 mt in only a few years. Longlining has generated yellowfin and bigeye catches of the order of several thousand mt per year. Purse seine fishing by various fleets occurred in the Gilbert Island area during the 1980s, generally recording annual catches of less than 10,000 mt. However, since 1990, purse seine catches, mainly by USA vessels, have increased dramatically, reaching approximately 120,000 mt in 1993. This trend has continued in 1994, with Korean, Japanese and Federated States of Micronesia vessels also being licensed to fish in the area.

The trends in catches in the vicinity of the Gilbert Islands, particularly the increasing purse seine catch and declining artisanal and TML pole-and-line catches since 1990, have caused concerns that fishery interaction is taking place. Specifically, the concern is that the large catches by USA and now other purse seiners (which are highly visible to the local community, as transshipment of purse seiners in Tarawa is now routine) are directly reducing the supply of tuna available for capture by artisanal fishermen and the TML pole-and-line fleet.

The objective of this report is to examine in detail the question of interaction between the DWFN purse seine fishery and domestic fishing activities in the Gilbert Islands. We first use simple regression models, in which artisanal troll CPUE for yellowfin (the dominant species caught) is the dependent variable and purse seine yellowfin catch is the independent variable, to indicate possible relationships between these fisheries. We then analyse tag recapture data to parameterise two population dynamics models, the first being a spatially-aggregated model applied to both skipjack and yellowfin in the Gilbert Islands area, and the second being a high-resolution (1° square) spatial model applied to skipjack in a large area of the WCPO. These models are used to estimate the impacts of various levels of purse seining in the WCPO generally and in the Gilbert Islands area on the performance of the Kiribati artisanal and TML pole-and-line fleets.

2. CORRELATIONS BETWEEN ARTISANAL FISHERY CATCH RATES AND PURSE SEINE CATCHES

The trends in catches and catch rates in the Gilbert Islands have led to concerns that large purse seine catches deplete the local abundance of tuna and impact the catch rates of artisanal fishermen and the TML pole-and-line fleet. These concerns have so far not been supported by any analysis of data. In this section, a series of statistical analyses are carried out to determine the correlation between purse seine catch and artisanal catch rates under various spatial and temporal stratifications. Of particular interest is whether significant negative correlations, which might be indicative of adverse impacts of purse seine catches on artisanal catch rates, exist in the data. The analysis is restricted to purse seine–artisanal correlations, as recent TML pole-and-line data of the required resolution are not yet available.

2.1 Sources of Data

From 1985 to 1987 and from 1989 to 1993, surveys of the artisanal fisheries on several islands in Kiribati were undertaken by the Fisheries Division of the Ministry of Environment and Natural Resource Development. The surveys were conducted at landing sites, usually on a weekly basis. Data on catch and effort for a variety of fishing methods were collected. Table 1 presents the total catch of skipjack and yellowfin sampled during 1985-87 and 1989-93, for those fishing methods for which skipjack and yellowfin occurred in at least one sample. Yellowfin represented 38.1% of the total catch sampled for such fishing methods, while skipjack represented 2.4%. The amount of skipjack may be slightly underestimated since some skipjack were included in the "yellowfin" catch sampled during 1992-93. Since skipjack represented only a small proportion of the catch of tuna sampled from the artisanal fisheries, only yellowfin were considered in the correlations between artisanal catch rates and purse seine catches.

Drop-stone lining and trolling accounted for 40% and 52% respectively of the yellowfin catch sampled during the surveys; yellowfin catches for other fishing methods represent only a small proportion of the catch. No yellowfin were sampled from catches by drop-stone-lining during 1985 and 1989, whereas yellowfin were sampled from troll catches for each year; therefore, only survey data for trolling were considered in the analysis. Annual skipjack and yellowfin catches sampled for trolling are given in Table 2; yellowfin represents almost two-thirds of the total troll catch.

Catches of yellowfin by purse seiners were determined from logbook data held at SPC. The logbook data, which contain the catch by species for each purse seine set, with the set position recorded to the nearest minute of latitude and longitude, were provided to SPC by coastal states in the region; the coastal states collected the data either from distant-water purse-seine fleets under access agreements or from domestic fleets. Coverage of catches by the purse-seine fleets of South Korea and Taiwan by logbook data held at SPC is poor for most of the period under consideration. However, purse-seine catches in the proximity of the Gilbert Islands have been taken almost entirely by the USA fleet; the Japanese and Taiwanese purse-seine fleets were not licensed to fish in the waters of Kiribati during the period under consideration, while Korean purse seiners have been licensed to fish in the waters of Kiribati only since 1993. The USA fleet has been licensed to fish in the waters of Kiribati during most of the period under consideration, from 1987 to 1988 under access agreements between the Kiribati government and certain vessel owners, and from 1988 to the present under the multilateral treaty between the USA and certain Pacific island nations. Purse seiners from the former Soviet Union were licensed to fish in the waters of Kiribati from 1985 to 1986, and purse seiners from the Federated States of Micronesia (FSM) have been licensed since 1991; coverage by logbook data of catches by the Soviet fleet are poor, although catches are considered to have been low, while coverage of catches by the FSM fleet is high.

Table 1. Skipjack (SKJ), yellowfin (YFT) and total catches (kg) sampled by Kiribati artisanal landings surveys during 1985-87 and 1989-93. Only fishing methods for which skipjack and yellowfin were sampled are included.

Fishing method	SKJ	%	YFT	%	Total
Hand nets	-	-	18.0	0.5	3867.4
Fixed gillnets	-	-	5.1	0.0	11138.9
Drift gillnets	-	-	19.0	0.2	11228.6
Gillnets unspecified	-	-	40.0	0.9	4400.2
Handlines	128.2	1.0	1788.5	14.3	12527.3
Tuna pole-and-line	321.3	19.8	371.6	22.9	1623.4
Vertical longline	34.5	0.3	1850.7	14.8	12510.3
Drop stone lining	1071.2	3.1	20636.2	59.9	34473.3
Drift longlines	-	-	128.0	24.3	526.0
Trolllines	1717.5	4.1	26787.2	64.6	41457.0
Hook and line unspecified	20.0	1.3	133.2	8.4	1586.9
Unspecified	30.0	3.5	52.6	6.2	850.6
Total	3322.7	2.4	51830.1	38.1	136189.9

2.2 Method

Correlations between yellowfin catch rates in the troll fishery and purse seine catches of yellowfin were determined as follows. The dependent variable in the linear regression was the troll catch rate determined by aggregating catch and effort data for individual trips by island and week; the aggregation resulted in 240 island-week strata based on data for 916 fishing trips. The independent variable associated with each stratum was the amount of yellowfin caught by purse seiners within a specified distance from the island and within a specified time period prior to the week surveyed. Correlations were determined for distances of 60, 120, 180, 300 and 600 nautical miles from the island surveyed; for each distance from the island, correlations were determined for time periods of 2, 4, 8, 12 and 24 weeks prior to the week surveyed.

Table 2. Annual skipjack (SKJ), yellowfin (YFT) and total catches (all in kg) by troll lines sampled by Kiribati artisanal landings surveys.

Year	SKJ	%	YFT	%	Total
1985	137.0	31.1	205.0	46.6	440.0
1986	67.5	3.2	1,047.7	50.3	2,084.4
1987	138.4	5.6	1,743.8	70.6	2,469.3
1988	—	—	—	—	—
1989	—	—	2,359.2	98.4	2,397.3
1990	1,242.1	7.2	9,411.0	54.4	17,305.8
1991	132.5	3.7	178.0	5.0	3,573.4
1992	—	—	5,906.2	88.8	6,649.0
1993	—	—	5,936.3	90.8	6,537.8
Total	1,717.5	4.1	26,787.2	64.6	41,457.0

Two definitions of troll catch rate were used to determine the dependent variable. The first was simply the average number of yellowfin caught per trip for the island-week stratum. The second was determined as follows. During the landing survey, information on the duration of each trip in hours and the number of fishermen per trip were collected. Regressions of the number of yellowfin caught per trip on (1) the number of fishermen per trip, (2) the number of hours per trip and (3) the number of man-hours per trip, for 916 trips, indicated that the number of yellowfin caught per trip was related most strongly to the number of fishermen per trip (Table 3). The number of fishermen per trip presumably determines the number of troll lines used per trip. It is possible that the number of hours per trip and the number of man-hours per trip were less strongly related to the number of yellowfin caught per trip than the number of fishermen because the number of hours per trip may have included the time in transit to and from the fishing grounds, rather than actual time spent fishing. The second definition of troll catch rate used to determine the dependent variable was the number of yellowfin per fisherman per trip.

Table 3. Relationships between the number of yellowfin caught per troll line trip and three measures of fishing effort. The number of trips (N), the correlation coefficient (r), the proportion of the variation in yellowfin catch per trip explained by the regression (R^2) and the F statistic are presented. The significance of the F statistic at the 0.01 level is denoted with **

Fishing effort	N	r	R^2	F
Number of men	916	0.408	0.166	182.27 **
Hours fished	916	0.017	0.000	0.27
Man-hours fished	916	0.276	0.076	75.27 **

The amount of data and average catch rates for both the troll and the purse-seine fishery are summarised by year in Table 4. For those years for which the number of strata is large, the trends in the number of yellowfin per troll trip and the number of yellowfin per fisherman are similar. The purse-seine data exhibit a high degree of contrast, with annual yellowfin catches ranging from less than 500 mt to over 30,000 mt.

Table 4. Number of strata (island-weeks), number of troll line trips, number of yellowfin caught (YFT), number of yellowfin caught per trip (CPUE 1) and number of yellowfin caught per man (CPUE 2), determined from Kiribati artisanal surveys, and the number of days fished or searched, metric tonnes of yellowfin caught (YFT) and metric tonnes of yellowfin caught per day fished or searched (CPUE) by purse seiners in the vicinity of the Gilbert Islands, determined from logbooks held at SPC.

	Kiribati landings survey : troll lines					Purse seine		
Year	Strata	Trips	YFT	CPUE 1	CPUE 2	Days	YFT	CPUE
1985	4	8	29	3.63	1.12	16	35	2.19
1986	24	69	186	2.70	1.26	—	—	—
1987	29	74	276	3.73	1.73	268	2,807	10.47
1988	—	—	—	—	—	136	548	4.03
1989	2	59	270	4.58	2.76	166	365	2.20
1990	122	319	1,410	4.42	2.23	2,150	22,785	10.60
1991	7	50	38	0.76	0.20	864	1,112	1.29
1992	13	162	2,259	13.94	5.10	2,100	10,956	5.22
1993	39	175	1,544	8.82	4.15	4,701	31,926	6.79
Total	240	916	6,012	6.56	2.90	10,401	70,536	6.78

2.3 Results and Discussion

Table 5 presents the results of correlations between the number of yellowfin caught per troll trip and purse-seine catches of yellowfin. For purse-seine catches within 60 nm, the correlations are negative; however, the amount of variation in troll catch rates explained by the regression is low and the regressions are not statistically significant. For a distance of 180 nm and time periods of 2 and 4 weeks, the correlations are positive and significant; however, the positive correlations are weak. For distances of 300 nm and 600 nm, the correlations are positive and statistically significant; the positive correlations are weak to moderate. The amounts of variation explained by the regression and the values of the F-statistic declined with an increase in the time period for distances of 300 nm and 600 nm; the decline appears to be gradual for 300 nm and steep for 600 nm.

Table 6 presents the results of correlations between the number of yellowfin caught per fisherman per troll trip and purse-seine catches of yellowfin. The results are similar to those for correlations with the number of yellowfin per troll trip (Table 5), with non-significant negative correlations for 60 nm, and significant positive correlations for 180, 300 and 600 nm; significant positive correlations are also evident for a distance of 120 nm.

Tables 5 and 6 also present the number of strata for which the purse-seine catch of yellowfin was positive. For a distance of 60 nm and a time period of 2 weeks, only 33 out of a possible

240 strata are associated with a positive purse-seine catch. The number of strata with a positive purse-seine catch increases with distance and time, such that for a distance of 600 nm and a time period of 24 weeks, 231 out of 240 strata are associated with a positive purse-seine catch. Thus for relatively short distances and time periods, the results are weighted towards strata with zero purse-seine catch.

Table 5. Correlations between yellowfin catch rates (number of fish per trip) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. The number of strata (island-weeks) for which the purse seine catch was positive (N^+) and the correlation coefficient (r) are given for regressions of troll catch rates for 240 island-week combinations on purse seine catches within various distances (nm) from the island surveyed and time periods (weeks) prior to the landing survey. Statistical significance at the 0.05 level is noted with *; significance at the 0.01 level is noted with **.

Distance	Time	N^+	r
60	2	33	-0.076
60	4	54	-0.066
60	8	72	-0.059
60	12	82	-0.071
60	24	122	-0.093
120	2	69	0.124
120	4	94	0.109
120	8	117	0.010
120	12	136	-0.008
120	24	173	0.040
180	2	101	0.134 *
180	4	134	0.140 *
180	8	163	0.056
180	12	180	0.060
180	24	192	0.102
300	2	148	0.296 **
300	4	169	0.329 **
300	8	189	0.272 **
300	12	195	0.281 **
300	24	201	0.220 **
600	2	193	0.270 **
600	4	204	0.255 **
600	8	216	0.178 **
600	12	218	0.175 **
600	24	231	0.128 *

Table 6. Correlations between yellowfin catch rates (number of fish per man) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. See caption for Table 5.

Distance	Time	$N^{\dagger}$	r
60	2	33	-0.048
60	4	54	-0.035
60	8	72	-0.017
60	12	82	-0.035
60	24	122	-0.080
120	2	69	0.198 **
120	4	94	0.158 *
120	8	117	0.040
120	12	136	0.020
120	24	173	0.031
180	2	101	0.193 **
180	4	134	0.181 **
180	8	163	0.069
180	12	180	0.060
180	24	192	0.064
300	2	148	0.317 **
300	4	169	0.309 **
300	8	189	0.240 **
300	12	195	0.236 **
300	24	201	0.156 *
600	2	193	0.268 **
600	4	204	0.224 **
600	8	216	0.150 *
600	12	218	0.143 *
600	24	231	0.088

Table 7 presents the results of correlations between the number of yellowfin caught per troll trip and purse-seine catches of yellowfin, after excluding strata for which the purse-seine catch was zero. For distances of 300 and 600 nm, for which the number of strata with a positive purse-seine catch is high, the results are similar to those for the regressions which included zero purse-seine catches. For 60 nm, however, statistically significant weak to moderate negative correlations are evident, whereas when zero purse-seine catches are included, the negative correlations are weak and non-significant.

Table 8 presents the results of correlations between the number of yellowfin caught per fisherman per troll trip and purse-seine catches of yellowfin, after excluding strata for which the purse-seine catch was zero. Again, the results are similar to those for correlations with the number of yellowfin per troll trip, after excluding strata for which the purse-seine catch was zero (Table 7).

Table 7. Correlations between yellowfin catch rates (number of fish per trip) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. Replicates for which there were no purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
60	2	33	-0.440	**
60	4	54	-0.319	*
60	8	72	-0.298	*
60	12	82	-0.238	*
60	24	122	-0.268	**
120	2	69	0.236	*
120	4	94	0.138	
120	8	117	-0.063	
120	12	136	-0.061	
120	24	173	-0.073	
180	2	101	0.100	
180	4	134	0.088	
180	8	163	0.012	
180	12	180	0.014	
180	24	192	0.035	
300	2	148	0.281	**
300	4	169	0.319	**
300	8	189	0.258	**
300	12	195	0.251	**
300	24	201	0.185	**
600	2	193	0.228	**
600	4	204	0.220	**
600	8	216	0.150	*
600	12	218	0.148	*
600	24	231	0.111	

Statistically significant negative correlations are only evident for a distance of 60 nm. In order to determine in greater detail the distances and time periods for which significant negative correlations exist, the correlations were also determined for distances of 40, 50, 60, 70 and 80 nm and time periods of 1, 2, 3, 4 and 5 weeks. The results (Tables 9 and 10) indicate that significant negative correlations are evident only for distances of 50 and 60 nm; however, the numbers of strata for a distance of 40 nm and time periods of 1 to 4 weeks are small.

In summary, when large areas, i.e., circles of 300 and 600 nm radius about an island, are considered, the correlation between the troll catch rate and the purse-seine catch is generally positive (e.g., Figure 4). If we consider that such areas are too large for local interactions to occur or to be detected, a positive correlation would be expected if the abundance of yellowfin within a large area affects the success of both trolling and purse-seining in the same manner. When fish are generally abundant in a large area, both trollers and seiners would be expected to do well; when fish are sparse, both trollers and seiners (at least those that remain in the area) would be expected to do poorly.

Table 8. Correlations between yellowfin catch rates (number of fish per man) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. Replicates for which there were no purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N$^+$	r	
60	2	33	-0.402	*
60	4	54	-0.274	*
60	8	72	-0.216	
60	12	82	-0.220	*
60	24	122	-0.266	**
120	2	69	0.346	**
120	4	94	0.217	*
120	8	117	-0.012	
120	12	136	-0.020	
120	24	173	-0.058	
180	2	101	0.193	
180	4	134	0.171	*
180	8	163	0.057	
180	12	180	0.031	
180	24	192	-0.009	
300	2	148	0.340	**
300	4	169	0.329	**
300	8	189	0.229	**
300	12	195	0.205	**
300	24	201	0.112	
600	2	193	0.240	**
600	4	204	0.182	**
600	8	216	0.119	
600	12	218	0.112	
600	24	231	0.065	

When small areas, i.e., circles of 50 to 60 nm radius around an island, are considered, the correlation between the troll catch rate and the purse-seine catch is generally negative (e.g., Figure 5). However, the negative correlation is statistically significant only when strata for which the purse-seine catch is zero are excluded. When strata with zero purse seine catches are included in the analysis, the correlation is not significant, presumably because local abundance in these strata is so low that troll catch rates are also depressed. While the same type of abundance effect producing positive correlations would also be expected to occur on the smaller scale, the negative correlations could have been the result of high local fishing mortality by purse seiners depleting local yellowfin abundance and thus impacting artisanal troll catch rates. Presumably, this competition effect predominates over the abundance effect at small spatial and temporal scales.

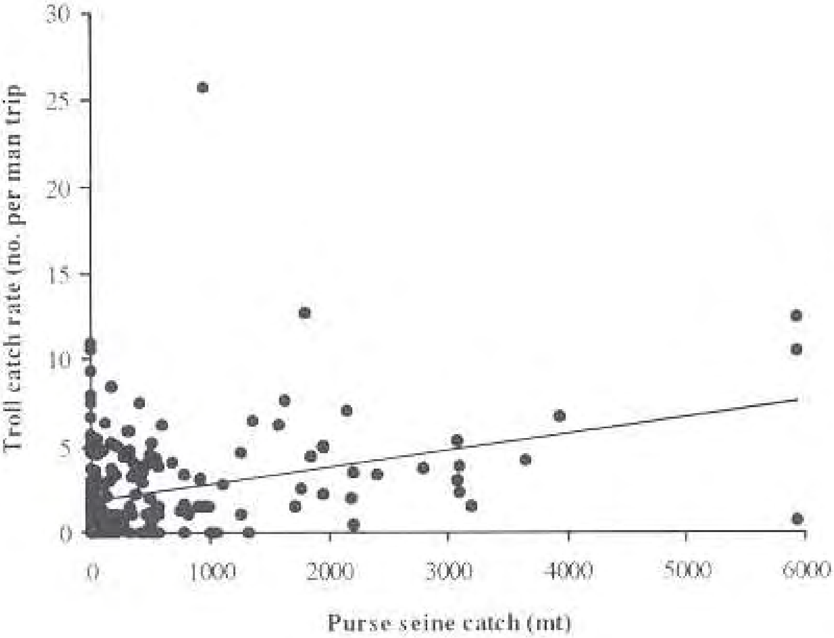

Figure 4. Regression of Kiribati troll catch rate (number of yellowfin per man per trip) on yellowfin catches by purse seiners within 300 nm of the island surveyed and two weeks prior to the week surveyed.

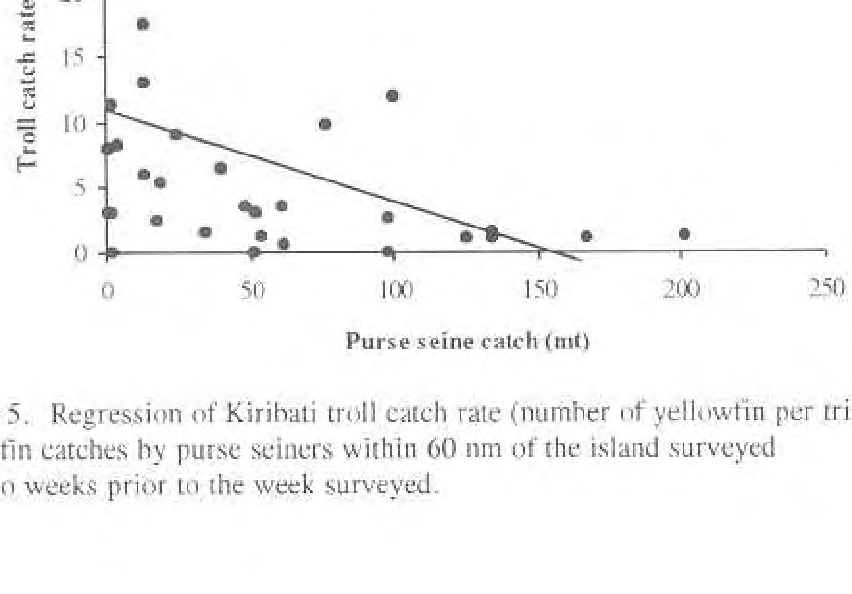

Figure 5. Regression of Kiribati troll catch rate (number of yellowfin per trip) on yellowfin catches by purse seiners within 60 nm of the island surveyed and two weeks prior to the week surveyed.

Table 9. Correlations between yellowfin catch rates (number of fish per trip) by troll lines and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
40	1	9	-0.368	
40	2	16	-0.317	
40	3	21	-0.155	
40	4	28	-0.251	
40	5	33	-0.144	
50	1	17	-0.429	
50	2	29	-0.380	*
50	3	37	-0.274	
50	4	47	-0.389	**
50	5	53	-0.375	**
60	1	19	-0.473	*
60	2	33	-0.440	**
60	3	44	-0.226	
60	4	54	-0.319	*
60	5	60	-0.320	*
70	1	22	-0.316	
70	2	38	-0.266	
70	3	50	-0.047	
70	4	60	-0.182	
70	5	66	-0.174	
80	1	25	-0.181	
80	2	45	-0.072	
80	3	57	-0.017	
80	4	70	-0.133	
80	5	77	-0.135	

Negative correlations on small spatial and temporal scales are not a consistent feature throughout the entire time series. For the period 1985-90, the negative correlations are generally small and not statistically significant (Table 11). On the other hand, for the period 1991-93, the negative correlations are stronger and highly significant for temporal scales of up to 8 months (Table 12). Different environmental conditions characterised these two periods – during 1991-93, El Niño conditions persisted over much of the WCPO, while the earlier period was a mix of normal conditions, a weak El Niño in 1986-87 and a La Niña (anti- El Niño) in 1988.

There are two hypotheses, both related to El Niño, that might explain the stronger negative correlations, and by implication, greater purse seine–artisanal interaction, in recent years. First, the distribution of purse seine effort was somewhat displaced to the east in 1991-93. This shift in effort, primarily by USA purse seiners, might have been encouraged by a higher catchability of skipjack and yellowfin due to the shallower thermocline that is typical of El Niño conditions in the WCPO, and a preference by skippers to operate close to their unloading port (Pago Pago) when fishing conditions in this area are good. The easterly concentration of effort may then have resulted in higher exploitation rates in the Gilbert Islands area and therefore increased the potential for interaction with the domestic fisheries.

Table 10. Correlations between yellowfin catch rates (number of fish per man) by troll lines and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no corresponding purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N*	r
40	1	9	-0.332
40	2	16	-0.295
40	3	21	-0.127
40	4	28	-0.240
40	5	33	-0.126
50	1	17	-0.451
50	2	29	-0.369 *
50	3	37	-0.274
50	4	47	-0.413 **
50	5	53	-0.390 **
60	1	19	-0.438
60	2	33	-0.402 *
60	3	44	-0.143
60	4	54	-0.274 *
60	5	60	-0.277 *
70	1	22	-0.262
70	2	38	-0.248
70	3	50	0.039
70	4	60	-0.103
70	5	66	-0.113
80	1	25	-0.150
80	2	45	-0.102
80	3	57	0.009
80	4	70	-0.101
80	5	77	-0.121

A second hypothesis is that productive waters near the equator between about 130°E and 165°E are pushed eastwards by stronger westerly winds and easterly setting equatorial currents during El Niño periods. If this hypothesis is correct, it is possible that tuna that generally tend to aggregate around the banks fished by Kiribati troll fishermen during non- El Niño periods are more dispersed during El Niño periods because of the more widespread availability of baitfish resulting from the easterly expansion of high primary and secondary production. While this hypothesis is untested at present, the observation of higher occurrence of the oceanic anchovy *Stolephorus punctifer* in the stomachs of skipjack and yellowfin sampled during tagging cruises in 1991 and 1992 (24% occurrence – SPC, unpublished data) compared with similar samples taken on tagging cruises in 1978 and 1979 (10% occurrence – Kleiber and Kearney, 1983) lends some support. If the hypothesis is correct, greater mixing of tuna between the banks fished by Kiribati troll fishermen and the offshore waters fished by purse seiners might be expected during El Niño periods, which would tend to facilitate the negative interactions that have been detected for the 1991-93 period.

Either or both of these hypothesised effects of El Niño could have led to the observed patterns in the correlations. More research on the effects of El Niño on tuna catchability and movement would be required to test these hypotheses.

Table 11. Correlations between yellowfin catch rates (number of fish per trip) by troll lines during 1985-90 and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no corresponding purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^{+}	r
60	2	11	-0.252
60	4	23	-0.229
60	8	36	-0.161
60	12	42	-0.255
60	24	73	-0.255 *
120	2	33	0.347 *
120	4	51	0.212
120	8	67	-0.047
120	12	82	-0.049
120	24	114	-0.038
180	2	57	0.236
180	4	88	0.227 *
180	8	113	0.031
180	12	125	0.000
180	24	133	0.112
300	2	103	0.409 **
300	4	123	0.447 **
300	8	135	0.378 **
300	12	137	0.314 **
300	24	142	0.285 **
600	2	139	0.247 **
600	4	148	0.241 **
600	8	157	0.155
600	12	159	0.142
600	24	172	0.142

Table 12. Correlations between yellowfin catch rates (number of fish per trip) by troll lines during 1991-93 and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no corresponding purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r
60	2	22	-0.564 **
60	4	31	-0.565 **
60	8	36	-0.490 **
60	12	40	-0.294
60	24	49	-0.342 *
120	2	36	-0.024
120	4	43	-0.048
120	8	50	-0.087
120	12	54	-0.062
120	24	59	-0.106
180	2	44	-0.048
180	4	46	-0.081
180	8	50	-0.022
180	12	55	0.028
180	24	59	-0.096
300	2	45	0.119
300	4	46	0.130
300	8	54	0.092
300	12	58	0.156
300	24	59	0.035
600	2	54	0.256
600	4	56	0.234
600	8	59	0.165
600	12	59	0.171
600	24	59	0.056

3. TAG-RECAPTURE MODELS

3.1 Tagging Experiments in the Western Tropical Pacific

Two major tagging experiments have been carried out in the western tropical Pacific by the South Pacific Commission - the Skipjack Survey and Assessment Programme (SSAP) and the Regional Tuna Tagging Project (RTTP). In the SSAP, approximately 140,000 skipjack were tagged during the period October 1977 and August 1980 (Kleiber et al., 1983). Fish were released throughout the SPC statistical area from Palau to French Polynesia and more than 6,000 tag returns, mostly the result of recapture by pole-and-line vessels, were received. Skipjack was the target species of the SSAP; only 9,000 yellowfin and less than 100 bigeye were tagged.

The RTTP began in July 1989, with tagging continuing until December 1992. A total of 132,779 releases[1] were distributed from the Philippines and eastern Indonesia to about 180°, across a latitudinal range of 10°N–20°S (Figure 6). Unlike the SSAP, the RTTP attempted to release large numbers of yellowfin and bigeye; approximately 34,000 yellowfin and 7,000 bigeye were released along with 92,000 skipjack. As of 30 June 1994, 14,635 returns had been received, with return rates for skipjack and yellowfin of about 11% and for bigeye of about 7%. Small numbers of returns continue to be received.

Both projects made visits to Kiribati, and to the Gilbert Islands in particular. In the Gilbert Islands area defined for the purpose of this study (5°N–5°S, 168°E–180°), 4,569 skipjack were released by the SSAP, mostly in July 1978. Most releases were made in the vicinity of Butaritari. Recaptures were recorded from two survey vessels (JICA and FAO/UNDP) fishing near the release site (346), the Japanese pole-and-line fleet fishing in the area (27), the SSAP tagging vessel (10) and artisanal fishermen (2). Most of these recaptures occurred in the Gilbert Islands area. Locally, movements were mostly to the east, west and south of the main release site (Kleiber and Kearney 1983).

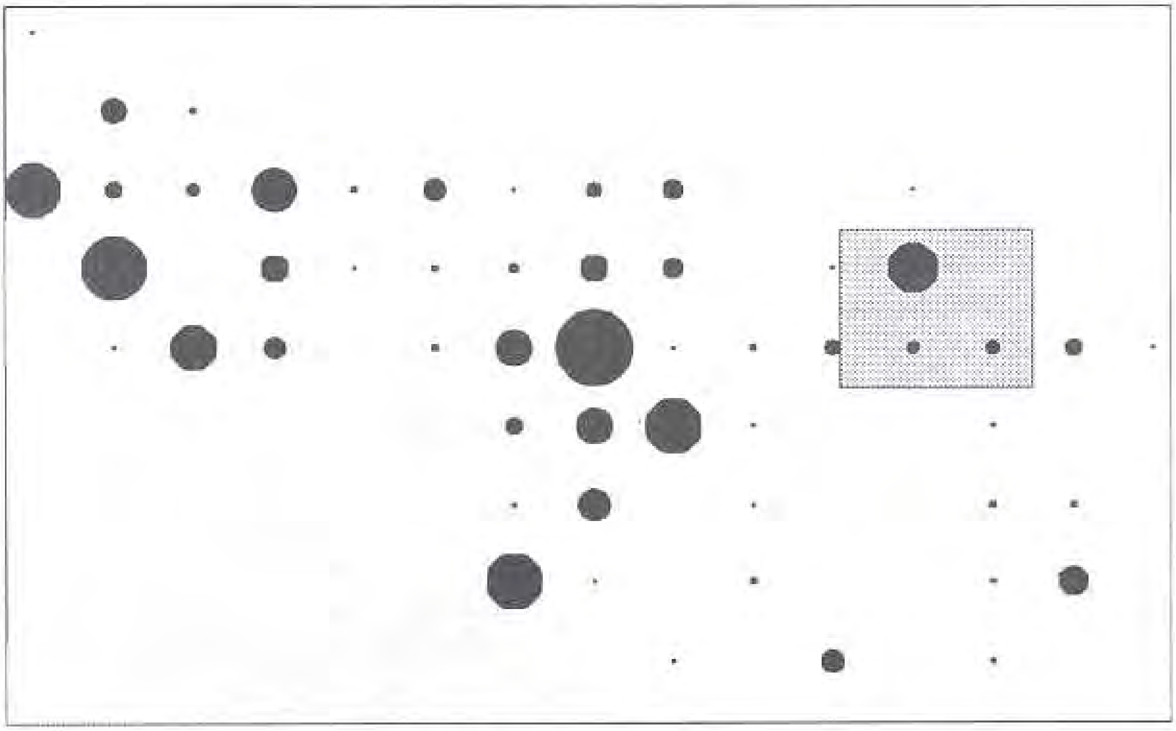

Figure 6. Distribution of RTTP releases (all species). The maximum circle size represents 23,000 releases. The rectangle indicates the Gilbert Islands area.

The RTTP visited the Gilbert Islands area in October 1990, August–September 1991 and March–April 1992, releasing a total of 14,427 tagged tuna (10,070 skipjack, 2,787 yellowfin and 580 bigeye). Most releases were made in the vicinity of Maiana and Abemama (Figure 7). Of these releases, 779 skipjack, 212 yellowfin and 63 bigeye have

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[1] These figures do not include an additional 13,695 tuna tagged in a dedicated research project in the Philippines in August–October 1992, or the subsequent 3,563 recoveries.

been recovered and the tags returned. In contrast to the SSAP recaptures, many of the RTTP recaptures were made outside the Gilbert Islands area (Figure 8). Of the recaptures within the Gilbert Islands area, most were made by USA purse seine vessels in the area surrounding the Gilbert Islands chain. Smaller numbers were recaptured by TML pole-and-line vessels and artisanal skiffs close to the release locations (see Table 13 for details of recapture numbers by fleet).

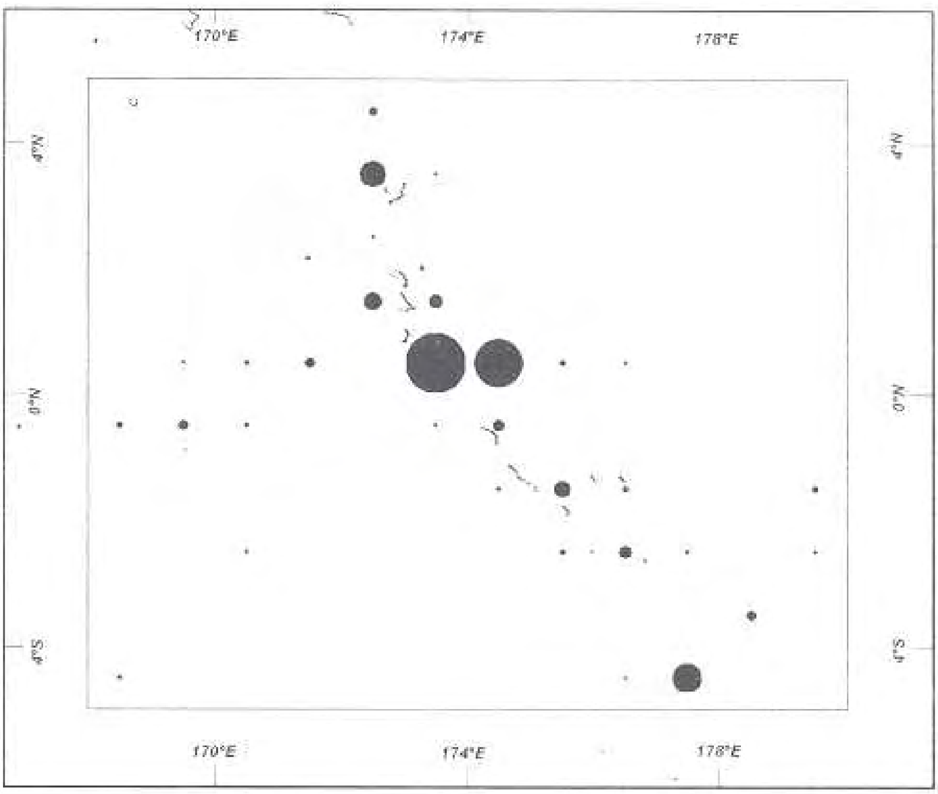
Table 13. Release and return numbers for tuna released in the Gilbert Islands area during the RTTP. Local recaptures refers to recaptures within the 200 nm zone surrounding the Gilbert Islands. Regional recaptures refers to recaptures outside this area.

Release/recapture category	Skipjack	Yellowfin	Bigeye	Total
Releases	10,070	2,787	580	13,437
Local recaptures				
Tagging vessel	4			4
TML PL	68	5		73
Artisanal	2	3		5
Japan PL	1			1
Japan PS	1			1
USA PS	152	27	17	196
Sub-total	228	35	17	280
Regional recaptures	551	178	47	776
Total	779	213	64	1,056

In this section, we analyse the RTTP skipjack and yellowfin data for the Gilbert Islands area first using a simple aggregate tag-attrition model. The objective of this analysis is to derive estimates of the natural mortality/emigration rate and fishing mortality rates by the DWFN purse seine, TML pole-and-line and artisanal fleets operating in the Gilbert Islands area. These estimates can then be used to develop estimates of interaction among the fleets, assuming that the skipjack and yellowfin in the Gilbert Islands area are simultaneously available to all fleets. We then carry out a regional analysis of the skipjack data using a model with fine-scale spatial resolution in order to estimate the average effect of the total western Pacific purse seine fisheries on the TML pole-and-line fleet. This model explicitly recognises the different spatial distributions of effort of the different fleets, as well as the skipjack movement pattern, natural mortality rate and catchability as estimated from the RTTP tagging data.

3.2 Interaction Analysis Using a Simple Tag-Attrition Model

Tag-attrition models have been used extensively to analyse time series of tagging data, usually aggregated over some defined area, for the purpose of estimating mortality rates, standing stocks, turnover rates and throughputs. Kleiber et al. (1983) described the basic models and applied them to various SSAP data sets. Kleiber and Kearney (1983) described an application to SSAP data for Kiribati. In this section, we use two versions of the tag-attrition model to analyse RTTP tagging data for the Gilbert Islands area, and use the results of one to develop estimates of interaction.



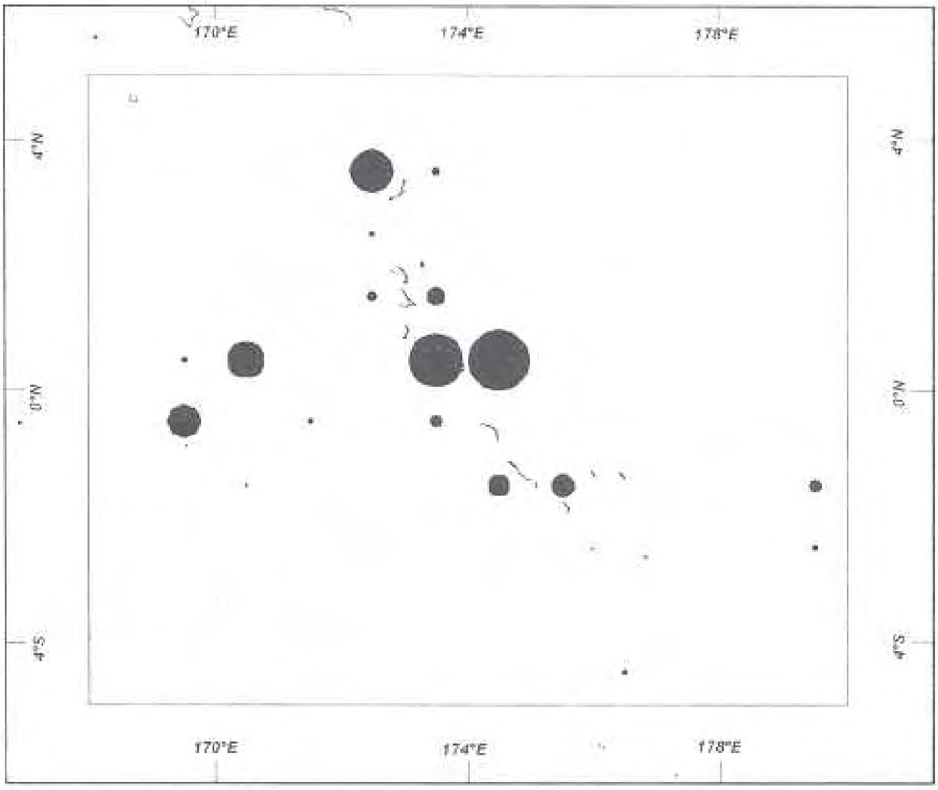


Figure 7. Distribution of skipjack (top) and yellowfin (bottom) releases in the vicinity of the Gilbert Islands. The maximum circle size represents 3,700 skipjack releases and 750 yellowfin releases.

Figure 8. Distribution of skipjack (top) and yellowfin (bottom) recaptures from releases in the vicinity of the Gilbert Islands. The rectangle indicates the Gilbert Islands area.

3.2.1 Tag-attrition models

A tag-attrition model describes the rate of decrease in tag-return rate over time, and attempts to estimate the various components of this rate of decrease, or attrition, that are of interest. Attrition occurs because natural mortality, fishing mortality and emigration reduce the size of the tagged population over time. For ease of mathematical representation, we usually assume that these processes occur continuously over time, although the rates themselves may be allowed to vary under some circumstances. If the disaggregation of attrition into its components is to be unbiased, we must also account for other losses of tags, such as non-reporting and tag shedding. The two equations that we generally use to predict the number of tag returns $\hat{r}_{ij}$ during time period i by fishing fleet j are

$$\hat{r}_{ij} = \alpha\beta N_i \frac{F_{ij}}{\sum_j F_{ij} + M}\left[1-\exp\left(-\sum_j F_{ij} - M\right)\right] \qquad (3.1)$$

and

$$N_{i+1} = N_i \exp\left(-\sum_j F_{ij} - M\right) + R_{i+1} \qquad (3.2)$$

where a is the survival rate from immediate tag loss;
b is the reporting rate of recaptured tags;
N_i is the number of tagged tuna alive at the beginning of period i;
F_{ij} is the fishing mortality rate in time period i by fleet j;
M is the rate of natural mortality plus emigration from the area under consideration; and
R_i is the number of tag releases in time period i (assumed, for simplicity, to have occurred at the start of the time period).

Note that the tagged population N_i in month i can consist of tagged tuna that were released in a variety of different months. This type of structure has been termed the pooled or aggregate cohort structure (Kleiber and Hampton, 1994; Sibert et al., 1996). This essentially involves the assumption that tuna released in different "cohorts" (here, a cohort is simply defined by a release month) have similar mortality and vulnerability characteristics. Another key assumption of the model is that the tagged population is immediately and equally available to each fishing fleet upon release. As we shall see, this assumption is difficult to satisfy in practice where the area is large and the effort distributions of the fleets are different. We also had to assume a value for the product ab, as it is generally difficult to estimate independently from the tag return data. Based on various auxiliary information (tag shedding, tag seeding, etc.), a value of 0.6 was used in the estimations.

The parameters to be estimated are M and F_{ij}. In practice, we usually cannot independently estimate i x j fishing mortality rates; F_{ij} is usually assumed constant across time periods or is re-parameterised in terms of either catch C_{ij} or effort f_{ij}.

$$F_{ij} \approx \frac{C_{ij}}{\bar{P}} \quad \text{or} \quad F_{ij} = q_j f_{ij} \qquad (3.3)$$

In the latter case, the estimated parameters are either the standing stock $\bar{P}$ or catchability coefficients for each fleet q_j.

We fitted models to the tagging data using both the catch and effort re-parameterisations of fishing mortality. Only recaptures from the Gilbert Islands area were included in the analysis. Actual catch and effort data for the purse seine fleet and TML pole-and-line fleet were used in the analysis. Reliable estimates of catch and effort for the artisanal fleet were not available, so constant, "dummy" values were used, which essentially constrained fishing mortality for this fleet to be constant. In the case of catch data, estimates based on Table 1 and a total artisanal catch of 11,500 mt (Mees et al., 1988) were used. The complete data sets used in the estimations are given in Table 14.

A Poisson likelihood function was used to fit the model. The likelihood of the tag recapture data **r** given the model, the release numbers and the catch or effort data is therefore

$$f(\mathbf{r}|\hat{\mathbf{r}}) = \prod_i \frac{\hat{r}_i^{r_i}}{\exp(\hat{r}_i)\, r_i!} \qquad (3.4)$$

Table 14. Data used in fitting the models. PS, PL and Art refer to the purse seine, TML pole-and-line and artisanal fleets, respectively.

Month	Skipjack				Yellowfin				Effort (days)			Skipjack catch (t)			Yellowfin catch (t)		
	Releases	Recaptures			Releases	Recaptures			PS	PL	Art.	PS	PL	Art.	PS	PL	Art.
		PS	PL	Art.		PS	PL	Art.									
90-10	644	0	0	0	156	0	0	1	81	2	10	195.9	0.0	23	4,064.6	0.0	364
90-11	0	0	0	1	0	0	0	0	266	0	10	1,372.3	0.0	23	2,072.7	0.0	364
90-12	0	0	0	0	0	0	0	0	259	0	10	4,784.6	0.0	23	500.4	0.0	364
91-01	0	0	0	0	0	0	0	0	28	0	10	10.0	0.0	23	0.0	0.0	364
91-02	0	0	0	0	0	0	0	0	10	0	10	0.0	0.0	23	0.0	0.0	364
91-03	0	0	0	0	0	0	0	0	7	0	10	0.0	0.0	23	0.0	0.0	364
91-04	0	0	0	0	0	0	0	0	5	0	10	0.0	0.0	23	0.0	0.0	364
91-05	0	0	0	0	0	0	0	0	55	5	10	1,942.8	0.5	23	4.5	0.5	364
91-06	0	0	0	0	0	0	0	0	324	0	10	9,955.9	0.0	23	165.5	0.0	364
91-07	0	1	0	0	0	0	0	0	266	20	10	14,095.0	9.9	23	76.9	15.8	364
91-08	5,479	0	5	0	1,257	0	0	0	49	22	10	2,652.7	16.6	23	75.3	25.3	364
91-09	2,952	6	28	0	798	0	2	0	51	26	10	666.2	8.4	23	12.0	13.2	364
91-10	0	6	25	1	0	1	0	1	156	40	10	3,294.4	24.4	23	743.6	29.0	364
91-11	0	23	10	0	0	5	3	1	87	32	10	914.4	6.3	23	167.7	15.2	364
91-12	0	0	0	0	0	0	0	0	34	43	10	238.6	3.2	23	37.2	6.8	364
92-01	0	1	0	0	0	1	0	0	88	42	10	464.4	10.3	23	725.9	8.6	364
92-02	0	1	0	0	0	0	0	0	135	55	10	973.1	18.2	23	2,336.9	20.7	364
92-03	178	6	0	0	195	2	0	0	419	54	10	7,303.7	31.4	23	3,427.1	60.2	364
92-04	813	0	0	0	371	1	0	0	229	31	10	5,817.8	6.9	23	4,373.3	17.2	364
92-05	0	4	0	0	0	0	0	0	93	31	10	2,055.2	6.2	23	1,032.1	6.5	364
92-06	0	5	0	0	0	2	0	0	101	25	10	3,453.1	11.6	23	289.0	10.9	364
92-07	11	26	0	0	10	1	0	0	342	26	10	13,852.3	4.3	23	306.5	9.7	364
92-08	0	2	0	0	0	0	0	0	89	32	10	829.3	15.7	23	264.7	25.5	364
92-09	0	22	0	0	0	3	0	0	194	37	10	6,032.4	36.3	23	566.3	31.4	364
92-10	0	9	0	0	0	0	0	0	192	49	10	3,827.7	24.7	23	721.0	18.2	364
92-11	0	4	0	0	0	2	0	0	312	34	10	6,689.5	26.2	23	1,119.2	12.2	364
92-12	0	14	0	0	0	0	0	0	346	13	10	8,066.5	4.0	23	814.3	12.6	364
93-01	0	11	0	0	0	3	0	0	459	10	10	9,986.2	0.7	23	919.9	1.9	364
93-02	0	4	0	0	0	1	0	0	325	22	10	4,140.4	11.2	23	2,728.2	15.6	364
93-03	0	3	0	0	0	1	0	0	492	47	10	12,407.2	19.8	23	4,684.7	11.4	364
93-04	0	2	0	0	0	2	0	0	205	42	10	1,689.2	23.2	23	1,492.2	10.4	364
93-05	0	0	0	0	0	0	0	0	390	22	10	6,767.7	15.0	23	1,457.2	3.2	364
93-06	0	0	0	0	0	1	0	0	392	25	10	12,094.2	13.8	23	3,642.4	11.3	364
93-07	0	0	0	0	0	1	0	0	491	33	10	13,070.0	8.7	23	7,088.1	22.5	364
93-08	0	0	0	0	0	0	0	0	390	14	10	5,638.6	0.0	23	3,524.2	2.8	364
93-09	0	1	0	0	0	0	0	0	746	23	10	12,602.8	1.1	23	8,795.3	10.0	364
93-10	0	1	0	0	0	0	0	0	446	15	10	7,115.2	0.0	23	1,015.4	6.0	364
93-11	0	0	0	0	0	0	0	0	253	1	10	2,502.3	0.0	23	531.8	0.0	364
93-12	0	0	0	0	0	0	0	0	563	12	10	10,355.2	5.2	23	510.8	0.0	364

3.2.2 Results and discussion

The estimated natural mortality rates are high relative to estimates for the region as a whole (SPC, 1994) and obviously contain a large component of emigration (Table 15). This is further suggested by the fact that much larger recapture numbers were recorded outside the Gilbert Islands area (see "Regional returns" in Table 13). Estimated total fishing mortality rates are low compared with regional estimates (SPC, 1994) and reflect the low recovery rate of tags within the Gilbert Islands area (2.3% for skipjack, 1.3% for yellowfin). Most of the fishing mortality that did occur was attributed to the purse seine fleet, again reflecting the distribution of tag returns among the fleets.

Table 15. Parameter estimates obtained from the tag-attrition model fits to RTTP Kiribati tagging data. All rates are per month; $\overline{P}$ and T ($T = Z\overline{P}$) are in mt.

	Skipjack	Yellowfin
Effort parameterisation		
M	0.179	0.157
q purse seine	3.30E-05	1.59E-05
q pole-and-line	6.71E-05	1.54E-05
q artisanal	6.81E-06	2.91E-05
F purse seine average	0.00793	0.00381
F pole-and-line average	0.00151	0.000346
F artisanal average	6.18E-05	0.000291
Z average	0.189	0.161
Catch parameterisation		
M	0.203	0.155
$\overline{P}$	367,047	424,642
F purse seine average	0.0138	0.0036
F pole-and-line average	2.54E-05	2.63E-05
F artisanal average	6.27E-05	0.0009
Z average	0.217	0.159
T	79,767	67,723

The fits of the models to the observed tag returns are poor (Figure 9). Returns in periods soon after tags were released are generally under-estimated by the model for the TML pole-and-line fleet. This is likely to be because most tag releases were made in the vicinity of Maiana and Abemama, which is an area favoured by the TML fleet. Most of the returns by this fleet therefore resulted from fishing in the vicinity of the tag releases before the tagged fish had dispersed. Conversely, the model tends to over-estimate purse seine returns during these initial periods because movement away from the release sites to surrounding areas where purse seiners fish (outside the 12 nm territorial limit) had not yet occurred. Very few tagged skipjack or yellowfin were recaptured by the artisanal fleet. The model, which can predict fractional returns, will not be able to accurately predict very small integer numbers of observed returns, hence the apparent lack of fit to these returns in Figure 9.

Clearly, this type of spatially aggregated model, which takes no account of tuna movement or the spatial distributions of releases and fishing effort, does not provide a very adequate representation tagged tuna dynamics in the Gilbert Islands area. Nevertheless, it is possible that some general features of skipjack and yellowfin exploitation (such as relative average fishing mortality rates by the different gear types and stock turnover rates in the area) have been captured by the analysis, at least in approximate form. We will therefore proceed with an analysis of interaction using the results obtained from the model with the catch re-parameterisation of fishing mortality. This form of the model is convenient for the interaction analysis because the standing stock estimate allows an estimate of average throughput, T, to be determined by

$$T = Z\overline{P} \tag{3.5}$$

where $Z = F_{av} + M$. We wish to estimate the impact on pole-and-line catch C_p and artisanal catch C_a of different levels of purse seine catch C_s. Assuming that average fishing effort by the pole-and-line and artisanal fleets remains constant (and hence their fleet-specific average fishing mortality rates remain constant) and the level of throughput remains constant for various levels of catch and local standing stock, the relationship between the three catch levels is defined by the following series of equations:

$$\overline{P}_{\text{new}} = \frac{T - C_s}{M + F_p + F_a} \tag{3.6}$$

$$C_p = F_p \overline{P}_{\text{new}} \quad \text{and} \quad C_a = F_a \overline{P}_{\text{new}} \tag{3.7}$$

where $\overline{P}_{\text{new}}$ is the new equilibrium standing stock under the new catch regime. The percentage change in pole-and-line and artisanal catches in response to various percentage changes in purse seine catch are shown in Figure 10 (only one response curve for each species is shown as the changes in pole-and-line and artisanal catches in percentage terms are identical). The levels of interaction appear slight – about a 7% reduction in equilibrium pole-and-line and artisanal skipjack catches results from the October 1990–December 1993 average purse seine catch of 5,000 mt per month (compared to the equilibrium catches that would be attained with zero purse seine catch). The corresponding results for yellowfin are a 3% reduction in equilibrium pole-and-line and artisanal catches for the average purse seine catch of 1,500 mt per month.

As noted above, the confidence that we can place in these results is limited by the poor quality of the fits of the tag-attrition model to the tag recapture data. These deficiencies seem to result from lack of spatial resolution in the model. Also, the lack of spatial resolution and the small reference area (Gilbert Islands) for the analysis means that interaction effects of the purse seine fishery on a regional scale cannot be assessed. In the next section, we attempt to address these difficulties by using a high-resolution spatial model to assess the effect of the regional purse seine fishery on the skipjack catch of the TML pole-and-line fleet.

3.3 Interaction Analysis Using a High-Resolution Spatial Model

The effect of the large-scale purse seine fishery on the Kiribati pole-and-line fishery can be analysed using a population dynamics model having relatively detailed spatial resolution. Such a model has been described by Sibert and Fournier (1993) and Sibert et al. (1996).

The advantage of using this type of model over the spatially-aggregated tag-attrition model is that more detailed information regarding the spatial distribution of effort and regional variation in movement pattern can be incorporated into the analysis. We used such a model to firstly estimate the skipjack population and fishery parameters from RTTP tagging data, and secondly to apply these estimated parameters in a population biomass simulation in which purse seine effort was manipulated and the resulting effects on Kiribati pole-and-line catch observed. Potentially, the same analysis could be carried out for yellowfin and could include the Kiribati artisanal fishery (given data of the required resolution), but this has not yet been attempted.

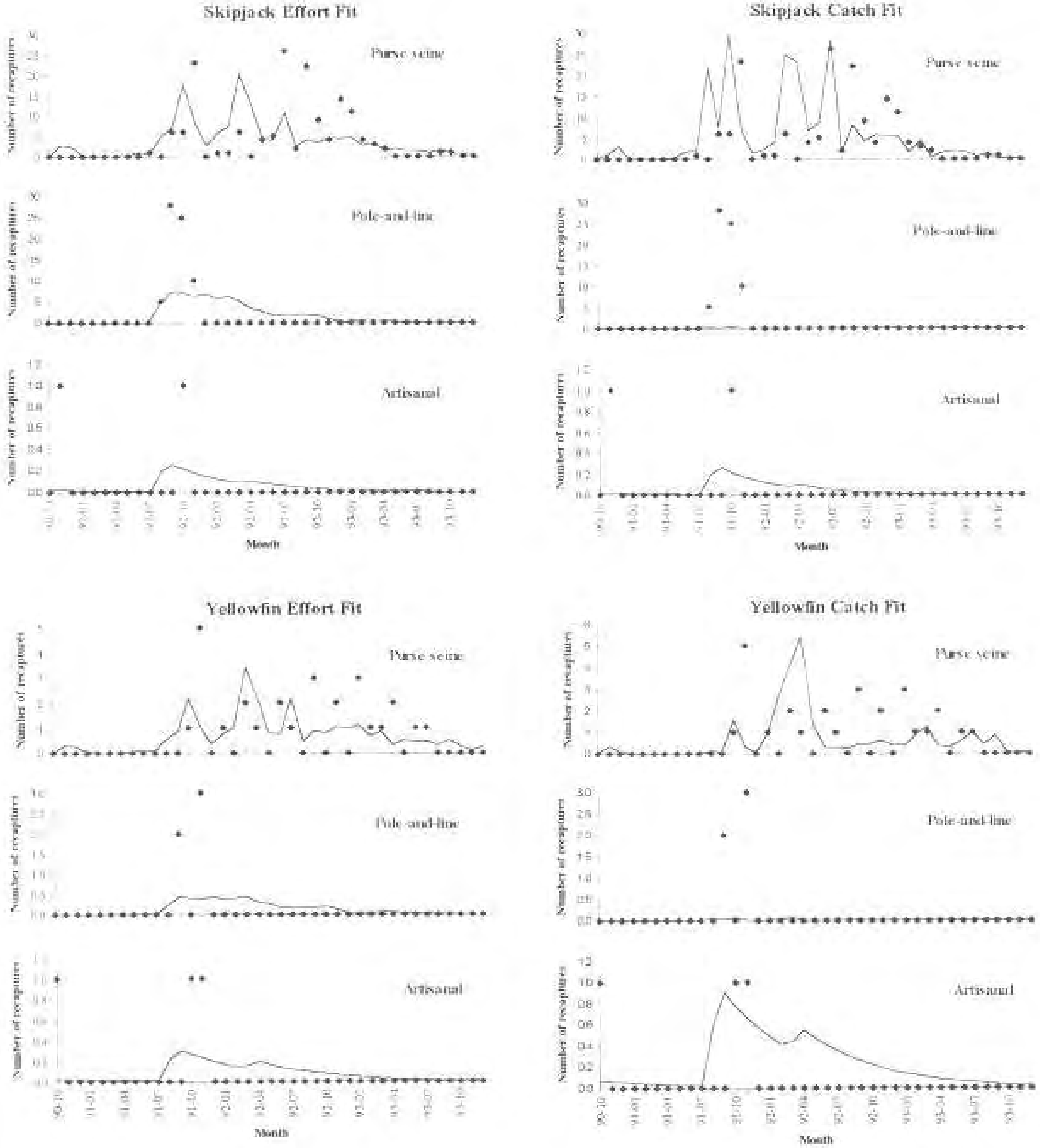


Figure 9. Fits of the models (solid lines) to the observed tag recapture data.

3.3.1 Estimation model – methods and data

We applied the model described in Sibert et al. (1996) to RTTP skipjack data to estimate parameters that would provide the basis for the interaction analysis. The spatial resolution of the model was a 1° by 1° grid on the area 10°N–25°S, 130°E–170°W, with land masses excluded as shown in Figure 11. A monthly time step over the period July 1989–December 1993 was used, and a total of 230 tagged skipjack cohorts (a cohort being defined as a group of tagged skipjack released in a particular spatial cell in a particular month) defined. The spatial distribution of these releases is also shown in Figure 11.

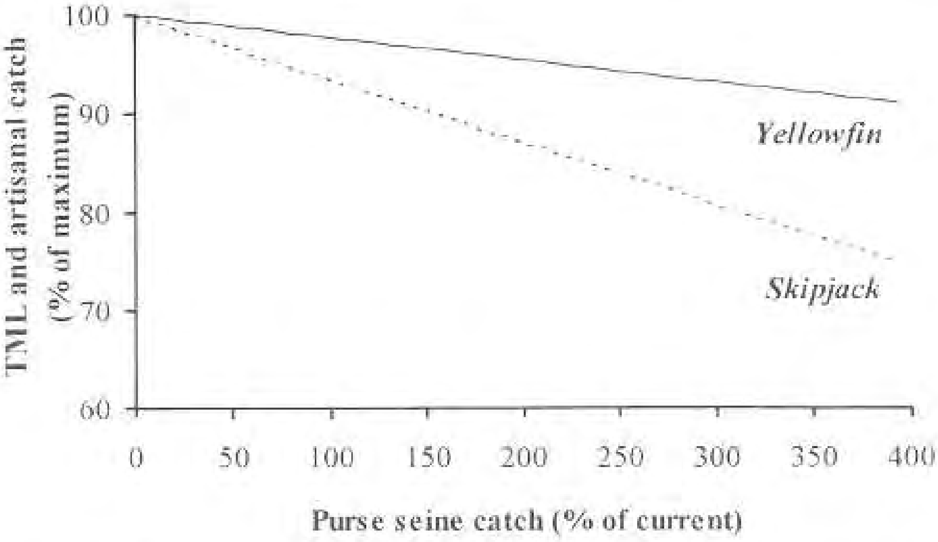


Figure 10. Response of the TML pole-and-line and artisanal catch rates to changes in purse seine catch in the Gilbert Islands area.

These fleets accounted for 92% of all skipjack tag returns within the study area. However, many returns for some fleets could not be incorporated into the estimation model because the precision of the recapture data was less than the 1° square–month resolution required. This was a major problem with the Korean and Taiwanese purse seine fleets; recapture locations were rarely available because the tags were generally recovered in canneries after transshipment. We dealt with this problem, and the problem of incomplete tag reporting generally, by introducing a series of specified reporting rates into the estimation model (in a similar fashion as was done with the simple tag-attrition model). A global reporting rate of 0.923 was used to account for the proportion of total tag returns attributable to the fleets included in the analysis. A series of fleet-specific reporting rates was also applied. These reporting rates accounted for the variable performance of the fleets in returning tags at all, and returning them with sufficiently accurate recapture information to allow their inclusion in the analysis. The proportions of tags reported for each fleet were estimated from tag-seeding experiments and other information (SPC, 1994). The proportions of returned tags that had usable recapture information were computed from the tag returns for each fleet. These proportions and their product, which represents the overall fleet-specific vector of reporting rate, are shown in Table 16.

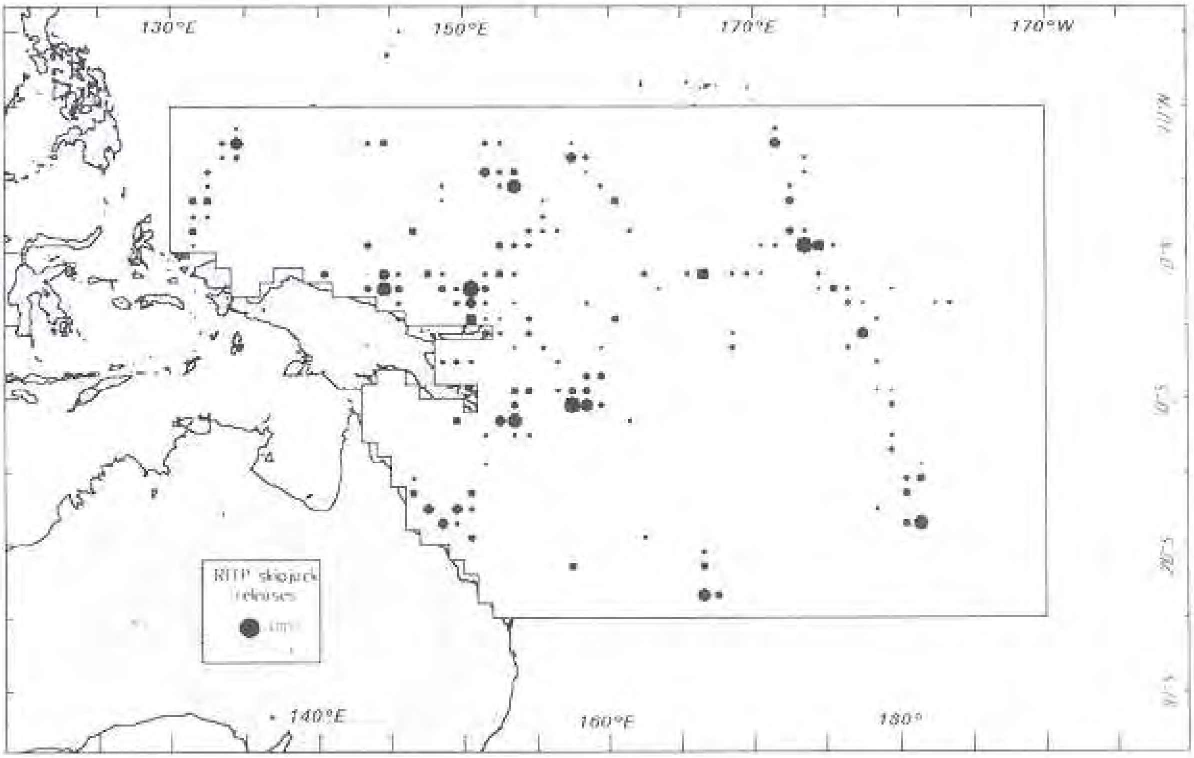


Figure 11. Spatial distribution of tagged skipjack releases analysed using the high-resolution spatial model. The solid line indicates the spatial boundary of the model. Four pole-and-line (Japan, Fiji, Solomon Islands and Kiribati) and six purse seine fleets (Japan, USA, Korea, Taiwan, Philippines and Solomon Islands) were individually treated in the model. Their effort distributions during the study period are shown in Figure 12.

Skipjack movement was parameterised according to regions and seasons, as described in Sibert et al. (1996). Movement was represented by directed (advective) and random (diffusive) components, with the two advection (north↔south and east↔west) and one diffusion parameters assumed to be constant in time and space within regions and seasons. Catchability coefficients for each fleet and the instantaneous rate of natural mortality were assumed to be constant across regions and seasons.

The definition of regions and seasons was somewhat arbitrary, although different structures can be compared using the log-likelihood values of the maximum likelihood solutions. We chose a ten-region and two-season (April–September, October–March) stratification, as shown in Figure 13.

With this model structure, 71 parameters were required to be estimated – one natural mortality rate, ten catchability coefficients (one for each fleet) and sixty movement parameters (two advection and one diffusion parameter for each region-season stratum). As for the aggregate tag-attrition model, we used the "pooled cohort" version of the model, whereby tagged skipjack behaviour is assumed to be independent of their release cohort (see Sibert et al., 1996, for details). This effectively means that the release of tagged skipjack occurs as a series of events analogous to "recruitment", and that members of a particular cohort subsequently become indistinguishable from other tagged skipjack that occur in the same grid cell during the same month.

Table 16. Tag reporting rates and proportions of usable tag return data, by fleet. For each fleet, the overall "reporting rate" is the product of the fleet-specific tag reporting rate, the proportion of usable data, and the proportion of all tag returns attributable to the fleets included in the analysis (0.923).

Fleet	Reporting rate	Proportion of usable data	Overall "reporting rate"
Fiji pole-and-line	0.900	0.994	0.826
Japan pole-and-line	0.417	0.977	0.376
Japan purse seine	0.420	0.928	0.360
Kiribati pole-and-line	0.700	1.000	0.646
Korean purse seine	0.263	0.105	0.025
Philippines purse seine	0.799	0.904	0.667
Solomon Is. pole-and-line	0.899	0.795	0.660
Solomon Is. purse seine	0.892	0.866	0.713
Taiwan purse seine	0.394	0.043	0.016
USA purse seine	0.728	0.757	0.509

For any set of model parameters, a complete set of tag returns by fleet, grid cell and month can be simulated, using the observed distributions of tag releases (by grid cell and month) and fishing effort (by fleet, grid cell and month) to drive the simulation. We used non-linear optimisation methodology (see Sibert et al., 1996, for details) to find the set of model parameters that resulted in the best fit of observed and simulated tag returns according to a Poisson likelihood function. Details of the likelihood function and equations used for simulating the tag returns are given in Sibert et al. (1996).

If the estimated parameters are to be interpreted as representative of the population in general (i.e., not just the tagged population), we need to assume that the probability of capture of tagged skipjack within a grid cell-month stratum is the same for untagged fish. This might not be the case, particularly soon after release, if the tagged and untagged fish are not randomly mixed within the grid cell and the distribution of fishing effort is also non-random, such that the tagged fish are either more or less likely to be captured than untagged fish. We found some evidence of this in the RTTP skipjack data; for several tagged cohorts released in the vicinity of fish aggregating devices (FADs), the number of recaptures in the first month after release in the grid cell of release was either much greater or much fewer than expected by the model. We interpret this as resulting from short-term retention of the tagged skipjack near the release site by the FADs (thus inhibiting mixing). Large numbers of returns would occur in the first month if effort occurred at the release site (FAD), whereas few returns would occur if no fishing occurred at the release site. To avoid biased parameter estimates that might result because of lack of mixing in the first month, we excluded seven release cohorts from the analysis (February 1991 releases in the Solomon Sea) that showed extreme symptoms of non-mixing.

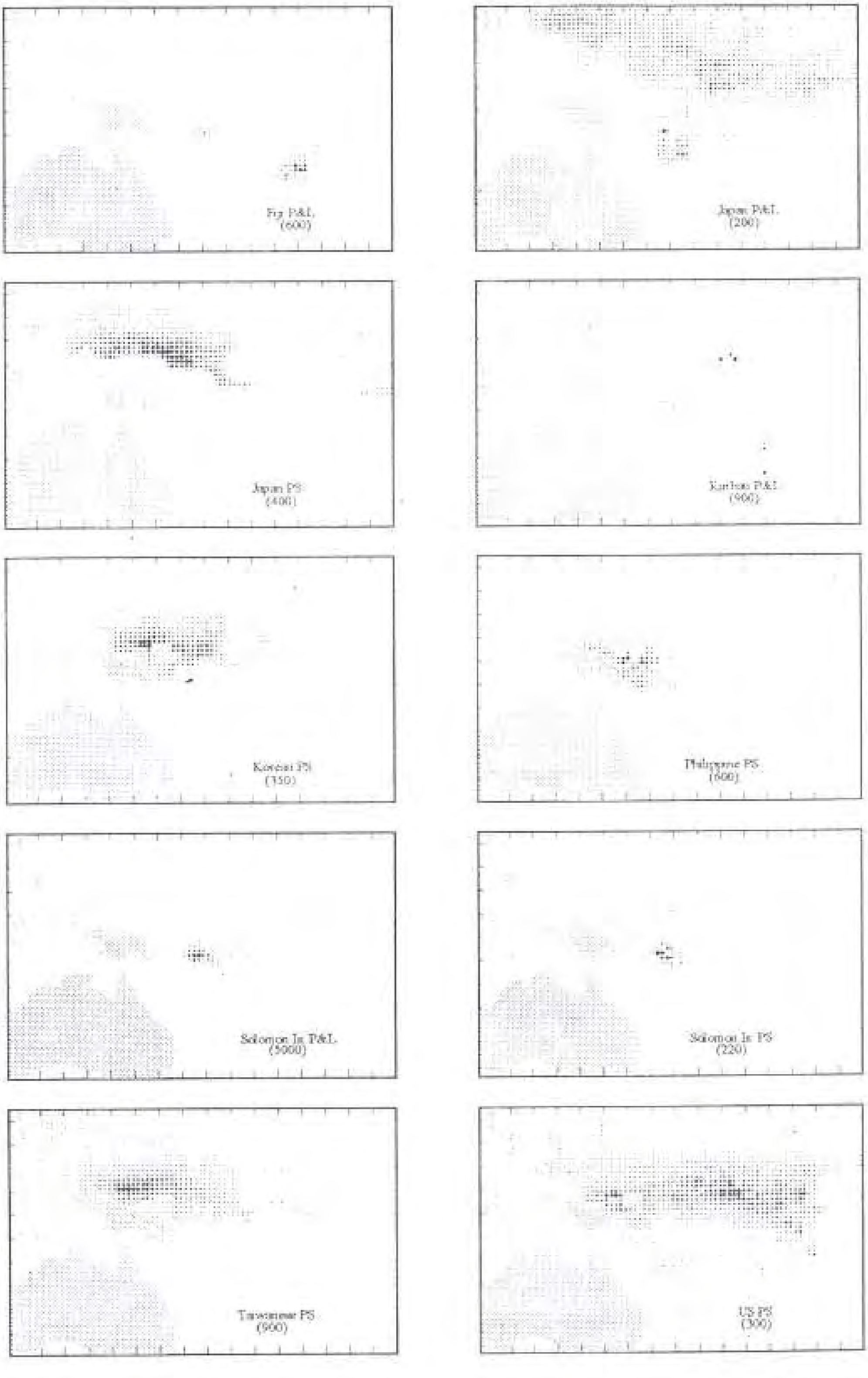


Figure 12. Effort distributions for the fleets included in the high-resolution spatial analysis. The time period covered is July 1989–December 1993. The effort (days fished) represented by the maximum circle size is given in parentheses for each fleet. The solid line indicates the model area boundary.

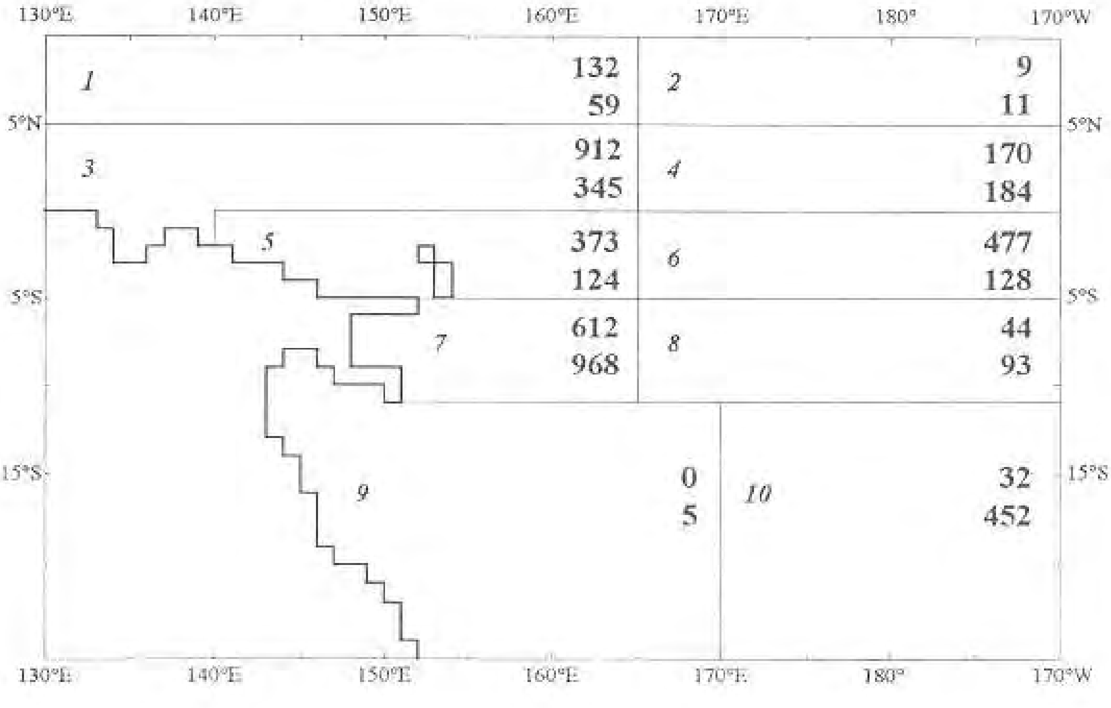


Figure 13. The definition of the ten regions in the high-resolution model. The numbers near the right boundary of each region are the numbers of usable skipjack tag returns for season 1 (April – September, upper number) and season 2 (October – March, lower number).

Boundary conditions for the model need to be specified. Boundaries comprised of cells that consist of land (e.g., the east coast of Australia) are obviously non-permeable and were assumed in the model to be closed and reflective. Boundaries that are comprised of open cells (i.e., water) may be considered permeable, in which case fish are assumed to be able to migrate out of the study area, or closed and reflective as for land-mass boundaries. The former assumption would be reasonable if the study area was a substantially smaller sub-area of the total known stock area, while the latter assumption would be appropriate if the boundaries were thought to represent approximate limits to the distribution of at least the majority of the stock. For the results reported here, we assumed that all boundaries were closed.

3.3.2 Estimation model – results and discussion

In preliminary fits of the model to the RTTP tagging data, we attempted to estimate all 71 parameters using a sequential parameter relaxation procedure. In most of the fits so far carried out, the estimated value of M converged to biologically unreasonable values very close to zero. The reasons for this are not yet clear and are the subject of further investigation. For the purpose of deriving parameters that could be used in the interaction analysis, two fits with fixed M were carried out. In fit 1, M was fixed at 0.1 mo^{-1}, a value consistent with estimates from a spatially aggregated analysis of RTTP tagging data (SPC, 1994). In fit 2, M was fixed at 0.05 mo^{-1} to see if the results of the interaction analysis were sensitive to this assumption. The parameter estimates for the two fits are given in

Tables 17 and 18, respectively. The estimated movement patterns for the two fits are similar in most respects although there are some differences in the advection parameters in particular for areas 9 and 10 (Figures 14 and 15). The catchability coefficients are slightly smaller in fit 2.

It is difficult to display the fits in relation to the observed data because of the multi-dimensional nature of the model. Some sense of goodness of fit can however be gained from plots of spatially aggregated observed and predicted tag returns over time (Figure 16). It is clear that there are some deficiencies in the fits, particularly with the under-estimation of recoveries in months 24 and 27 and the over-estimation of recoveries by the model during the last 12 months of the time series. Some of the larger discrepancies might be due to non-compliance with the assumption of complete and immediate mixing within one-degree squares. The lower than expected numbers of returns at the end of the time series might be due to declines in tag reporting rates, although there is no evidence of this is the tag-seeding data (SPC, 1994). Further investigation of these matters is required and will be undertaken in due course.

3.3.3 Biomass simulation – methods

We used a population biomass simulation to investigate the long-term average impact of the large-scale purse seine fishery on the Kiribati pole-and-line fishery. The simulation model has the same structure as the tag estimation model with the following adaptations:

- The density of population biomass and skipjack catches by the various fleets by 1° square and month are modelled instead of the density of tagged skipjack and tag returns; and
- Skipjack recruitment (in biomass) by 1° square and month rather than the release numbers of tagged skipjack define the initial conditions of the model.

The natural mortality, catchability and movement parameters estimated (or assumed) for tagged skipjack, along with monthly effort by 1° square for each fleet averaged over the period 1989-93 were used to predict the catches by each fleet. Recruitment was assumed to be uniform in space and time across the model area for the duration of the simulation. Arbitrary biomass units were used to define recruitment, with the resulting population biomass and catches taking the same units. Simulations were initiated by allowing the model to run for a ten-year period with only the four pole-and-line fleets active. This "spinning-up" period is necessary to allow the population to build up and reach an equilibrium; at the end of this period, we have a stable population being exploited by pole-and-line fleets at their 1989-93 average levels of effort with no purse seine fishing. Interaction is measured by the decline in pole-and-line catch at various levels of purse seine catch and effort. Catches by the Kiribati and other pole-and-line fleets at the end of the initial ten-year period thus provide a reference point against which later catches at various levels of purse seine effort can be compared.

The six purse seine fleets begin fishing in year 11 of the simulation. Their effort increases in ten increments, with each increment representing 20% of their 1989-93 average effort. The simulation is allowed to run for three years (using the fit 1 parameters) or five years (using the fit 2 parameters) at each purse seine effort level to allow the population and catches to re-equilibrate. (A longer equilibration period for fit 2 parameters was required because of the lower *M*.) At the end of the simulation (40 or 60 years), purse seine effort is twice its 1989-93 average level. The difference in pole-and-line catches between those in year 10 (no purse seine effort) and those at the end of each incremental period is a measure of the impact of the respective purse seine catches.

3.3.4 Biomass simulation – results and discussion

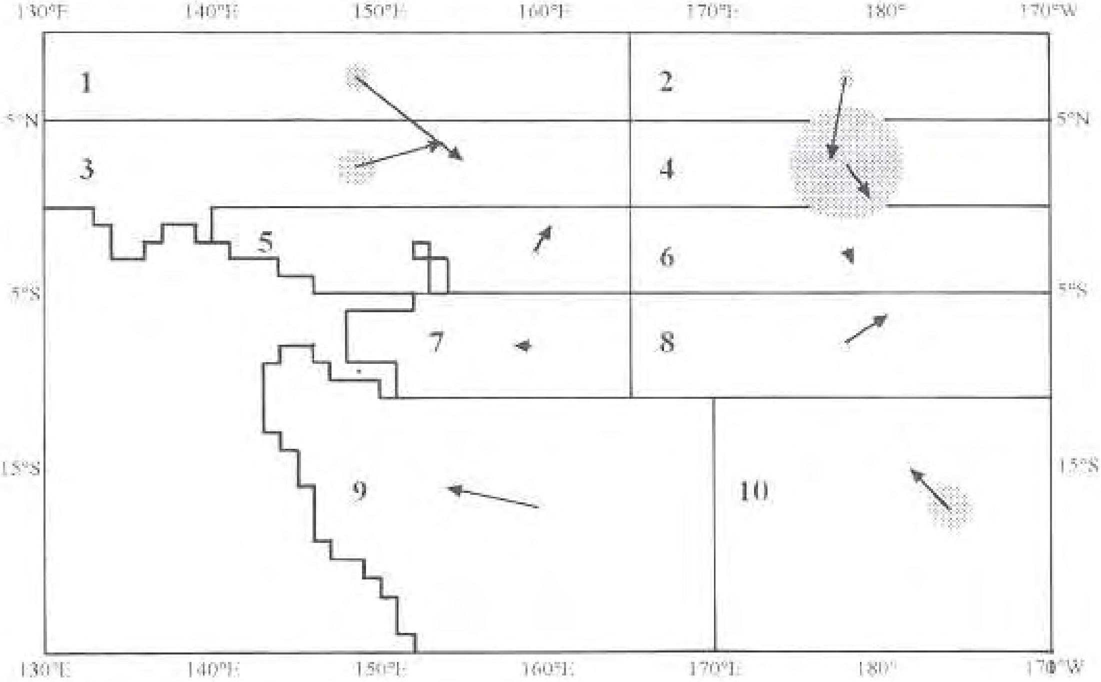
The results of the simulations are summarised in Figure 17. The simulations indicate that average Kiribati pole-and-line catch is reduced by about 10% (fit 1) to 12% (fit 2) from its predicted level in the absence of purse seining when the 1989-93 average purse seine effort is applied. Pole-and-line catches decline at similar rates for further increases in purse seine effort.

The impact of purse seining on the other pole-and-line fleets appears to vary according to the fishing location of the fleet. Fiji pole-and-line catches, which are largely taken in the vicinity of Fiji, well to the south of the main purse seine fishing area, are the least affected by purse seine catches. The greater impact on Fiji pole-and-line catches in fit 2 is probably because of the differences between fits in estimated advection in area 10 in season 1 (northwesterly in fit 1, southeasterly in fit 2). Similarly, the impact of purse seine catches on the Solomon Islands pole-and-line fleet are estimated to be slight. Large-scale purse seining occurs mainly to the north of the Solomon Islands, with only a few domestic vessels fishing in close proximity to the pole-and-line fleet. Also, estimated diffusion and advection are small in area 7, inferring some degree of localisation of the skipjack population in this area. The Japanese and Kiribati pole-and-line fleets, which have effort distributions overlapping with the large-scale purse seine fishery, predictably show the highest levels of interaction.

4. GENERAL DISCUSSION

Several different approaches were taken in this study to investigate the impact of purse seine fishing on the domestic pole-and-line and artisanal fisheries operating in the vicinity of the Gilbert Islands of Kiribati. We first examined survey data for the artisanal troll fishery and attempted to correlate surveyed yellowfin catch rates with yellowfin catches by large-scale purse seiners fishing at varying distances from the survey locations and at varying time periods prior to surveys. For large areas around the surveyed island, e.g., 300 or 600 nm, the correlations were generally positive, suggesting that variability in yellowfin abundance had at least the same directional impact on purse seine catch and artisanal catch rate – when purse seine catches are high, artisanal catch rates also tend to be high. For areas of 50 or 60 nm around a surveyed island, negative correlations between purse seine catch and artisanal catch rate were common, although these were not generally significant when zero purse seine catches were included in the analysis. There is, therefore, some empirical evidence that purse seine catches of yellowfin affect artisanal troll catch rates on small spatial scales through direct competition.

Season 1 (April–September)



Season 2 (October–March)

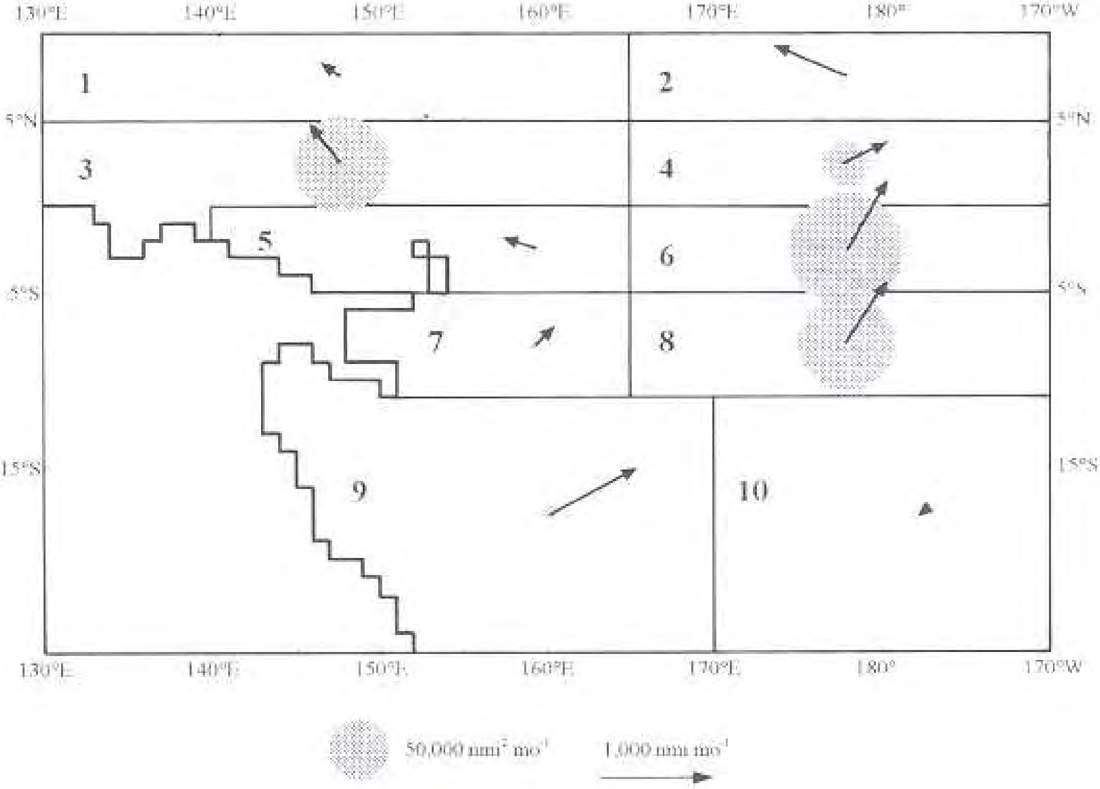
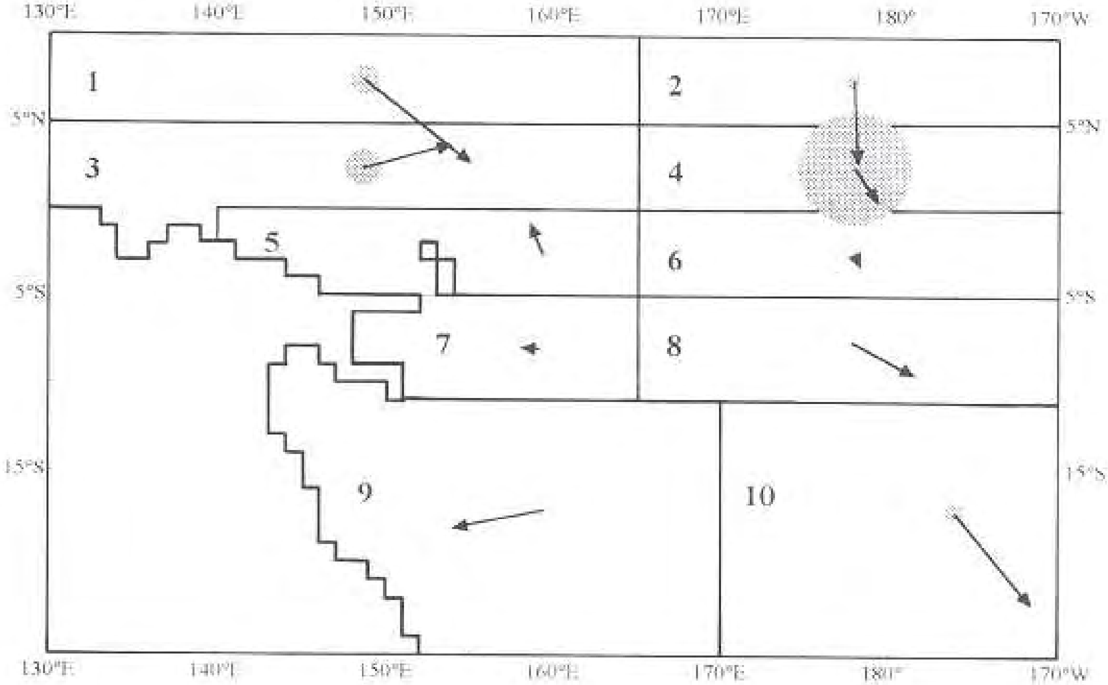


Figure 14. Graphical representation of estimated movement parameters for fit 1 (M=0.1 mo^{-1}). The arrows represent advection and the circles represent diffusion.

Season 1 (April–September)



Season 2 (October–March)

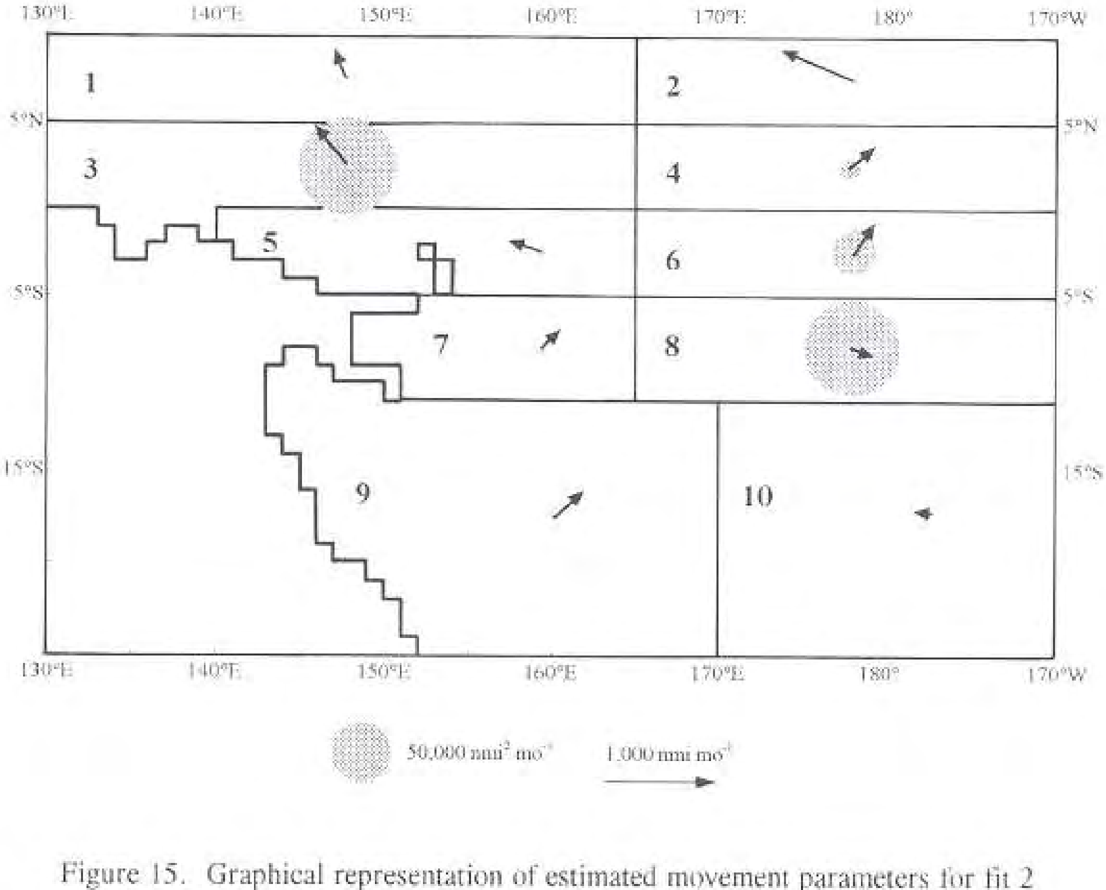


Figure 15. Graphical representation of estimated movement parameters for fit 2 (M=0.05 mo^{-1}). The arrows represent advection and the circles represent diffusion.

Table 17. Parameter estimates obtained from fit 1 of the spatial model to the RTTP skipjack data set. PL and PS refer to pole-and-line and purse seine, respectively. Movement parameters *u* and *v* refer to movement in the *x* and *y* directions (in degrees per month); σ is the diffusion rate in nm^2 per month.

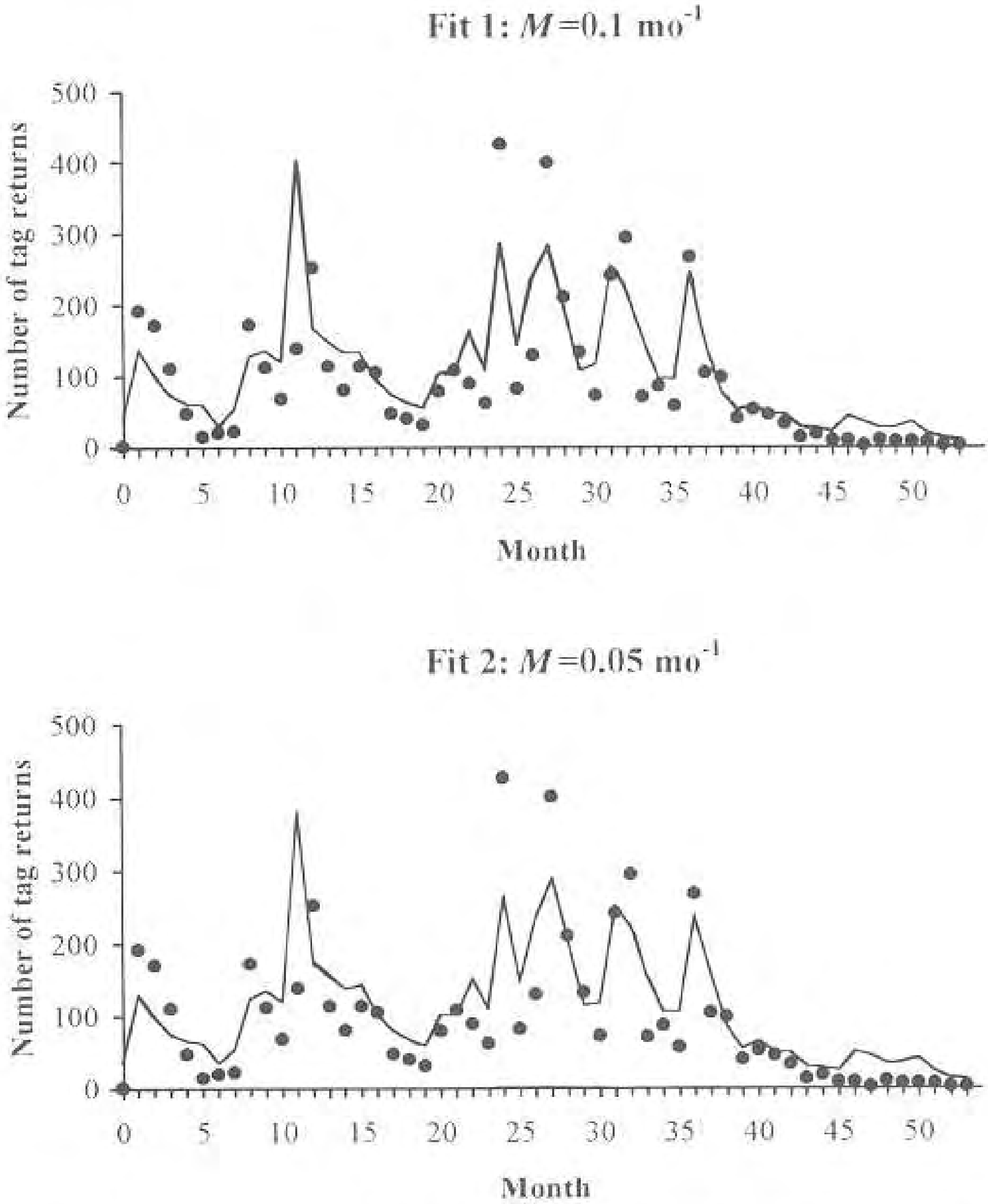
Natural mortality rate (mo.$^{-1}$)	0.1	(fixed)		
Catchability coefficients	Fiji PL	0.007197	Philippines PS	0.007857
	Japan PL	0.000801	Solomons PL	0.000692
	Japan PS	0.021026	Solomons PS	0.019788
	Kiribati PL	0.001752	Taiwan PS	0.009310
	Korea PS	0.039126	USA PS	0.012587
Movement parameters	*u*	*v*	σ	
Season 1 (Apr–Sept)				
Region 1	18.9542	-16.8083	21748	
Region 2	-2.4775	-18.9461	13165	
Region 3	19.0999	5.6958	31502	
Region 4	3.2057	-9.3385	96298	
Region 5	1.0865	7.8533	7139	
Region 6	0.1332	-1.4003	3027	
Region 7	-1.0603	0.0452	1627	
Region 8	10.3506	0.0582	8940	
Region 9	-16.5674	1.6079	2535	
Region 10	-8.3189	12.1047	36806	
Season 2 (Oct-Mar)				
Region 1	-3.5820	1.9146	2371	
Region 2	-13.6989	5.7517	2476	
Region 3	-3.7698	5.5672	82610	
Region 4	6.4508	3.2039	38357	
Region 5	-4.9856	2.7107	6153	
Region 6	6.1796	14.6270	97357	
Region 7	0.9635	0.4823	4501	
Region 8	5.4282	11.4130	81106	
Region 9	18.9628	5.5972	11489	
Region 10	-0.2096	0.0078	1379	

It is clear that estimates of local exploitation rates and other aspects of the tuna's population dynamics are required to more fully understand the interaction questions addressed in this study. We have made a first attempt to do this by developing population dynamics models for skipjack and yellowfin based on tagging data. Spatially aggregated models for the Gilbert Islands area indicated low to moderate impacts of recent purse seine catches in this area on average skipjack (~7%) and yellowfin (~3%) catch rates by the TML pole-and-line and artisanal troll fleets. However, these models were not particularly satisfactory, probably because of the lack of spatial structure and assumptions regarding mixing of tagged fish. We therefore developed a spatial model for a large area of the western and central Pacific at one-degree square spatial resolution and applied it to skipjack tagging data. Biomass simulations based on the estimated parameters gave slightly higher (~10–12%) estimates of the impact of recent purse seine catches at a regional level on average skipjack catch rates by the TML pole-and-line fleet.

Table 18. Parameter estimates obtained from fit 2 of the spatial model to the RTTP skipjack data set. PL and PS refer to pole-and-line and purse seine, respectively. Movement parameters *u* and *v* refer to movement in the *x* and *y* directions (in degrees per month); σ is the diffusion rate in nm^2 per month.

Natural mortality rate (mo.$^{-1}$)	0.05	(fixed)		
Catchability coefficients	Fiji PL	0.006668	Philippines PS	0.006581
	Japan PL	0.000718	Solomons PL	0.000633
	Japan PS	0.016167	Solomons PS	0.018121
	Kiribati PL	0.001539	Taiwan PS	0.010999
	Korea PS	0.041546	USA PS	0.009155
Movement parameters	*u*	*v*	σ	
Season 1 (Apr–Sept)				
Region 1	18.9495	-16.0937	23992	
Region 2	0.0902	-15.6285	10232	
Region 3	19.0859	5.3825	30467	
Region 4	7.5674	-10.2749	97397	
Region 5	-0.1753	8.0505	4606	
Region 6	0.8884	-4.0870	2569	
Region 7	-0.9840	0.0691	1677	
Region 8	10.9593	-6.1599	2522	
Region 9	-14.6596	-1.2416	2577	
Region 10	12.5894	-18.9527	15600	
Season 2 (Oct-Mar)				
Region 1	-1.4299	3.3663	2305	
Region 2	-13.1786	6.5233	2492	
Region 3	-4.7377	6.7455	85609	
Region 4	6.3973	4.4328	14358	
Region 5	-5.6364	3.5791	5811	
Region 6	4.5752	6.9757	37591	
Region 7	1.9005	1.6480	4098	
Region 8	2.3094	-0.2976	87738	
Region 9	4.9776	1.9435	4132	
Region 10	-0.1432	0.0044	1380	

These results should be considered preliminary, as many enhancements to the spatial model are possible, including: expansion of the model area to better represent the biological range of the stock; use of environmental data to parameterise movement and possibly catchability; and the inclusion of catch data into the estimation procedure to hopefully provide better determination of some parameters. Also, the tendency of the model to estimate near-zero values of *M* for the skipjack data set requires further investigation. The parameter *M* is an important determinant of interaction – this is clear from the differences in estimated interaction between fits 1 and 2 in this paper and that estimated in Sibert et al. (1996), which used the model estimate of *M*. If *M* for skipjack is in fact lower than the value of 0.05 mo^{-1} assumed in fit 2 (which is unlikely given other information on skipjack biology), the interaction levels reported here may be under-estimates. These matters are the subject of ongoing research.



Fit 1: M=0.1 mo^{-1}

Fit 2: M=0.05 mo^{-1}

Figure 16. Observed (dots) and predicted (line) tag returns by month of recapture aggregated over the whole model area. Month 0 is July 1989.

The estimates of interaction derived from the analyses of tagging data represent average, long-term expected impacts. It is reasonable to expect that there would be substantial variation in the actual impact over time and at particular locations. This is suggested by the monthly distributions of estimated fishing mortality obtained from the high-resolution spatial analysis; very high local fishing mortality occurs in some 1° squares in some months. This is consistent with the results of the correlation analysis in suggesting that adverse impacts of purse seine fishing on artisanal and pole-and-line catches in the Gilbert Islands are more likely to occur at a very small scale (1° square or less) due to local concentrations of purse seine effort, rather than at a regional scale or on a scale of tens of degrees. The obvious remedy to the small-scale problem would be to exclude purse seining within, say, 60 nm from the areas fished by the artisanal and pole-and-line fleets. However, the costs of such actions (due to possibly reduced access fees) should be carefully weighed against the potential benefits.

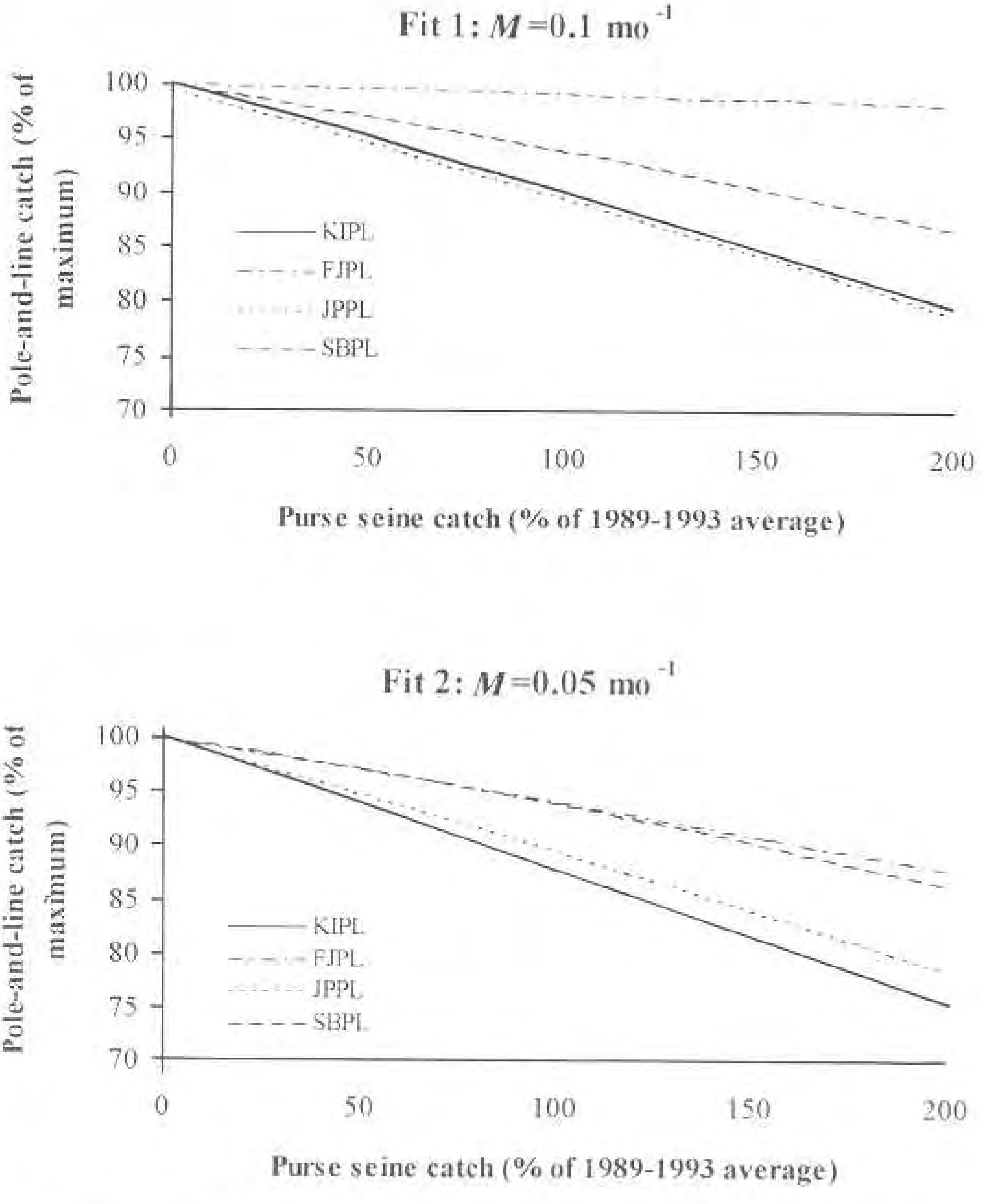


Figure 17. The average effect of various levels of western and central Pacific purse seine skipjack catch on catches by the Kiribati (KIPL), Fiji (FJPL), Japan (JPPL), and Solomon Islands (SBPL) pole-and-line fleets.

The possibility of changes in movement patterns resulting from changes in environmental conditions was raised earlier. The inclusion of various environmental data into the estimation and simulation models as determinants of movement and catchability, as foreshadowed above, would be one way to address this question. However, it is possible that some of the tuna movement characteristics that are important determinants of the extent of fishery interaction in the Gilbert Islands area occur at a spatial scale even smaller than the one-degree square scale used in the spatial model applied here. It is possible, for example, that the aggregational effects on tuna of the islands and banks fished by Kiribati fishermen are important in determining the level of interaction with purse seine vessels operating in the near vicinity. Such effects, if they exist, have been ignored in the models applied here. A possible extension of this work, given adequate data, would therefore be to apply a very-fine-scale spatial model of the Gilbert Islands area (possibly at half-degree square resolution or finer), incorporating parameters to describe the effects of islands and banks on tuna movement. A similar model has been applied to the Solomon Islands area (Kleiber and Hampton, 1994).

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