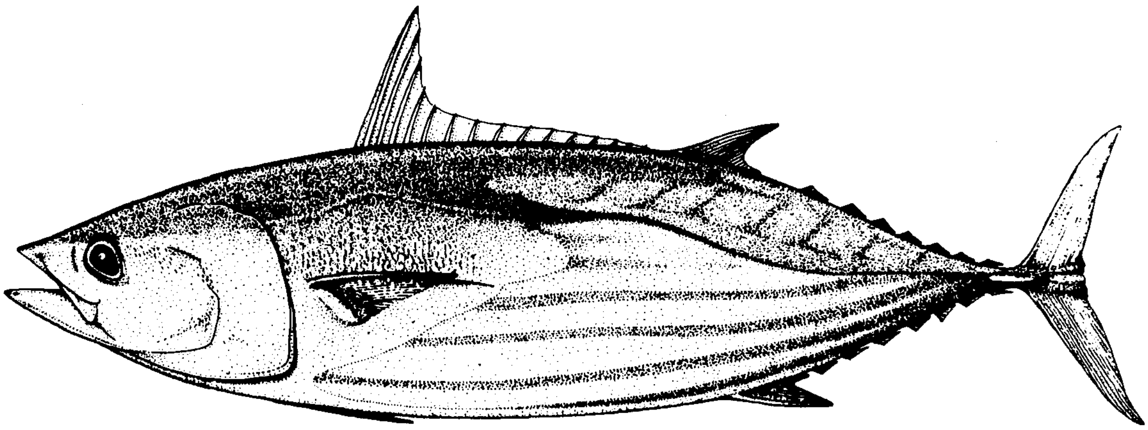
AN ASSESSMENT OF THE SKIPJACK AND BAITFISH RESOURCES OF PAPUA NEW GUINEA



Skipjack Survey and Assessment Programme
Final Country Report No. 12

South Pacific Commission
Noumea, New Caledonia
March 1984

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PREFACE

The Skipjack Survey and Assessment Programme was an externally funded part of the work programme of the South Pacific Commission. Governments which provided funding for the Programme were Australia, France, Japan, New Zealand, United Kingdom and the United States of America.

The Skipjack Programme has been succeeded by the Tuna and Billfish Programme which is receiving funding from Australia, France, New Zealand and the United States of America. The Tuna Programme is designed to improve understanding of the status of the stocks of commercially important tuna and billfish species in the region. Publication of final results from the Skipjack Programme, including results from the Skipjack Programme's investigation of yellowfin tuna resources of the region, is continuing under the Tuna Programme. Reports have been prepared in a final country report series for each of the countries and territories for which the South Pacific Commission works. Most of these reports have been co-operative efforts involving all members of the Tuna Programme staff in some way.

The staff of the Tuna Programme at the time of preparation of this report comprised the Programme Co-ordinator, R.E. Kearney; Research Scientists, A.W. Argue, C.P. Ellway, R.S. Farman, R.D. Gillett, L.S. Hammond, P. Kleiber, J.R. Sibert, W.A. Smith and M.J. Williams; Research Assistants, Susan Van Lopik and Veronica van Kouwen; and Programme Secretary, Carol Moulin.

The Tuna Programme wishes to sincerely thank staff of the Fisheries Division, Department of Primary Industry, Papua New Guinea, for assistance in many aspects of the surveys and preparation of this report, particularly Mr Kieran Kelleher, who supplied many of the fishery statistics. The Ministry of Foreign Affairs, Papua New Guinea, kindly facilitated entry and exit from Papua New Guinea. Dr A.D. Lewis, Fisheries Division, Ministry of Agriculture and Fisheries, Fiji, provided invaluable advice and discussion.

Tuna Programme
South Pacific Commission

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AN ASSESSMENT OF THE SKIPJACK AND BAITFISH RESOURCES OF PAPUA NEW GUINEA

1.0 INTRODUCTION

Papua New Guinea was among the first of the countries in the South Pacific Commission area to participate actively in the escalating exploitation of skipjack tuna (*Katsuwonus pelamis*) in the western Pacific in the last two decades. Its pole-and-line fishery was established in 1970 in joint venture with Japan and developed rapidly, becoming the largest locally based tuna fishery in the region. The average annual tuna catch between 1970 and 1981 was 25,958 tonnes, with a maximum of 48,933 tonnes in 1978 (Wankowski 1980a; Papua New Guinea Department of Primary Industry unpublished data). Apart from skipjack, only small yellowfin tuna (*Thunnus albacares*) contributed significantly to the fishery.

However, the total annual yield from the waters of Papua New Guinea during the same period was even greater. In addition to the catch by locally based vessels, an average of 22,868 tonnes of tuna were taken annually between 1970 and 1981 by foreign-based vessels (Wankowski 1980a; PNG DPI unpublished data), which have fished the region since the 1950s (Kearney 1977a). The maximum catch by all fleets in any one year was 105,514 tonnes in 1974 (Wankowski 1980a). The relative contributions of the local and foreign fleets to the total annual catch have varied considerably, in response to changes in gear technology in the fishery, to altered conditions of access, and to different economic conditions within the industry. At present, the fishery is based on foreign purse-seine, pole-and-line and longline vessels, licensed to operate in Papua New Guinea's 200-mile Declared Fishing Zone (DFZ). Yields remain high; 67,379 tonnes were taken in 1982 by Japanese purse-seiners and longliners alone (PNG DPI unpublished data).

Many of the questions which the Skipjack Survey and Assessment Programme was designed to consider, such as assessment of the size of the skipjack and baitfish resources and the degree of interaction among skipjack fisheries, first arose after the successful development of the Papua New Guinea fishery. Consequently, research in Papua New Guinea has featured prominently in the Programme's activities. The considerable amount of background information available from the established commercial operations and from research previously carried out in the area by the Fisheries Division of the Department of Primary Industry, suggested Papua New Guinea as the logical starting point for the Skipjack Programme's field surveys.

The Skipjack Programme made two visits to Papua New Guinea waters. During the first (2 October - 1 November 1977), field procedures were established, personnel trained and the vessel made fully operational for the special requirements of the field programme. Research activities were specifically directed towards areas in which the commercial fleet did not operate (Kearney 1977b). On the second visit from 14 May to 2 July 1979, efforts were concentrated on the main fishing area to provide data for comparison with both the results of previous work in Papua New Guinea by the Fisheries Division and the Programme's results from other countries in the region. Preliminary analyses from the two visits have been outlined in Kearney (1977b) and Kearney & Hallier (1979), respectively. This report presents the final results from both visits and discusses their implications for future development and management.

1.1 Background to the Tuna Fishery

1.1.1 Geography and oceanography

With the declaration of its 200-mile DFZ in March 1978, Papua New Guinea acquired a fishery zone ranking fourth in size in the SPC region and generally regarded as highly productive. This zone, approximately 2,500,000 square kilometres in area and lying within the boundaries of 3°N to 15°S latitude and 141°E to 162°E longitude, is contiguous with those of the Federated States of Micronesia to the north, Australia to the south, Solomon Islands to the east and Indonesia to the west, as well as two high seas corridors to its northeast and northwest. With the exception of that of Australia, the adjoining country zones all support substantial skipjack fisheries.

Papua New Guinea's land area consists of the eastern half of New Guinea and numerous islands in the northern Solomon group and the Bismarck and Louisiade Archipelagos (Figure 1). The mainland and the three major islands, New Britain, New Ireland and Bougainville, are rugged and covered in dense tropical rain-forest, and subject to high annual rainfall, in some places in excess of 250 cm. The long coastline with many shallow bays, fringing reefs and abundant freshwater inflow provides a large amount of habitat favourable to baitfish (Hallier, Kearney & Gillett 1982).

The mainland and islands partially separate two bodies of water from the western equatorial Pacific Ocean; the Bismarck Sea in the north, between the mainland and the semicircular sweep of the Bismarck Archipelago, and the Solomon Sea, between eastern Papua New Guinea and Solomon Islands. The latter sea is continuous with the Coral Sea, which impinges on the south coast of the mainland and the Louisiade Archipelago. Three major ocean currents, the South Equatorial Current, the Equatorial Counter Current and the New Guinea Coastal Current determine gross patterns of water movement. Enrichment events associated with these currents have been described by Donguy et al. (1978). Surface currents have been charted in the Coral and Solomon Seas using ships' observations (Wyrtki 1960), and inferred for the Bismarck Sea and adjacent waters to the north by Yamanaka (1973) from comprehensive records of drift of tuna longline gear.

1.1.2 Locally based fishery

With the southward expansion of the Japanese distant-water pole-and-line fleet into equatorial waters during the 1960s, interest in developing fisheries in Papua New Guinea increased. Under the 1968 Japan-Australia Fisheries Treaty, which covered fisheries activities in the waters of the then Territory of Papua and New Guinea, research into the tuna and bait resources of the area was initiated. Following the promising results obtained by six Japanese research cruises in 1968, 1969 and 1970 and the recommendations of a United Nations Development Programme (UNDP) team which visited the area in 1969 (Anon. 1969), joint-venture fishing operations were encouraged and the first company commenced fishing out of Kavieng, New Ireland in 1970. The establishment and growth of this fishery, from one joint-venture company and 2,430 tonnes of catch in 1970, to four companies and 41,780 tonnes of catch in 1974 has been documented by Kearney (1975a, 1977a). Yields in these and subsequent years are shown in

FIGURE 1. THE AREA OF PAPUA NEW GUINEA WATERS SURVEYED BY THE SKIPJACK PROGRAMME (light shading). Areas where most fish were tagged and released are depicted by outlined, dark shading.

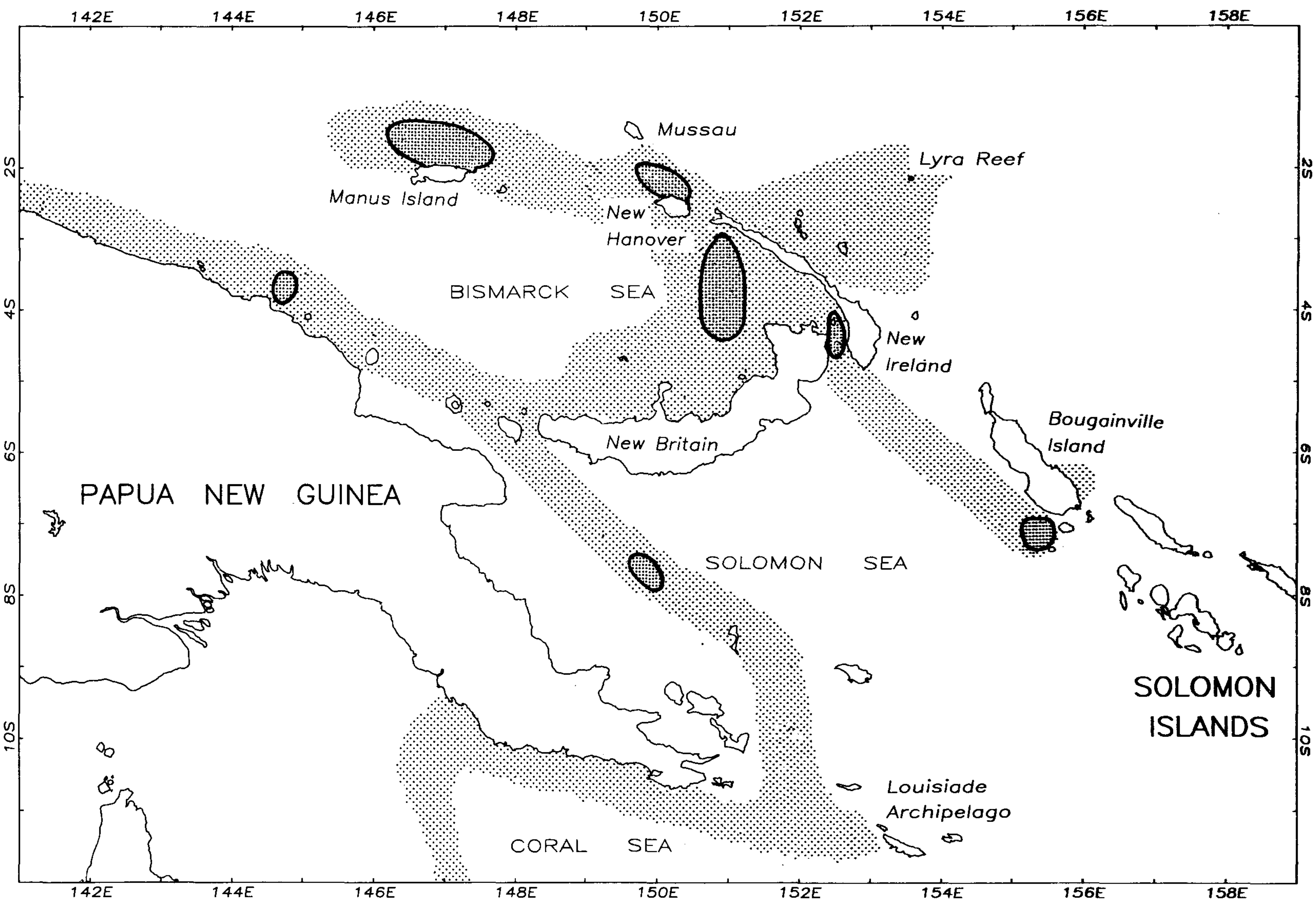


Table 1; skipjack comprised an average 90 per cent of the catch. One company left the fishery after the 1975 season and another after the 1978 season (Wankowski 1980a), while the remaining two suspended activities in early 1982 pending an improvement in economic conditions in the industry (Doulman 1982). Re-establishment of joint-venture, pole-and-line operations with Japanese interests was proposed for the 1983-1984 season (Forum Fisheries Agency unpublished data).

TABLE 1. ANNUAL TUNA AND BAITFISH CATCH AND EFFORT STATISTICS FOR THE LOCALLY BASED POLE-AND-LINE FISHERY IN THE WATERS OF PAPUA NEW GUINEA*

Year	Total Tuna Catch (tonnes)	Per cent Skipjack	Total Days Fished	Average Tuna Catch per Day (tonnes)	Total Bait Catch (tonnes)	Total Nights Fished	Average Bait Catch per Night (kg)
1970	2,430	97	511	4.8	75.0	511	147
1971	17,003	99	4,060	4.2	561.0	4,060	138
1972	13,123	89	4,915	2.7	825.0	4,915	168
1973	28,330	96	7,719	3.7	1,135.5	7,719	147
1974	41,780	96	9,408	4.4	1,295.2	9,408	138
1975	17,398	90	6,435	2.7	951.7	6,435	148
1976	33,014	74	7,901	4.2	956.0	7,901	121
1977	24,411	82	9,736	2.5	1,876.3	10,346	181
1978	48,933	94	9,941	4.9	1,907.0	10,503	181
1979	26,945	89	8,184	3.3	1,376.3	8,930	154
1980	34,098	91	9,483	3.6	1,669.5	9,669	173
1981	27,705	87	7,361	3.3	1,422.2	7,181	198

* Source: Papua New Guinea Department of Primary Industry

From the inception of the locally based fishery, Okinawan-style, 59-tonne pole-and-line vessels were predominant, operating in groups serviced by a mothership with freezer and storage facilities. Most fishing occurred within about 100 km of the mothership's base. Catches were unloaded, usually on a daily basis, to the mothership for freezing and subsequent transhipment to freighters. Apart from the diversion of a small proportion of the catch to local production of dried skipjack or "katsuobushi" for export (maximum input: 2,005 tonnes in 1976; Wankowski 1980a), the catch was exported as frozen, whole fish. As it was the Government's intention that much of the catch would eventually be processed locally, frozen fish attracted an export levy of five per cent of the freight-on-board price.

Aggregate catches peaked in the winter months (Figure 2), apparently in direct response to increased effort during the period of most favourable weather. Average daily catches in each month show no such seasonal pattern (Figure 3), although they have been highly variable over time. They varied widely among years, from a low of 2.5 tonnes/boat-day in 1977 to 4.9 tonnes/boat-day in 1978 (Table 1). There appears to be no pattern to the annual fluctuations in catch rate.

FIGURE 2. MONTHLY SKIPJACK CATCHES BY PAPUA NEW GUINEA POLE-AND-LINE VESSELS, 1970-1981

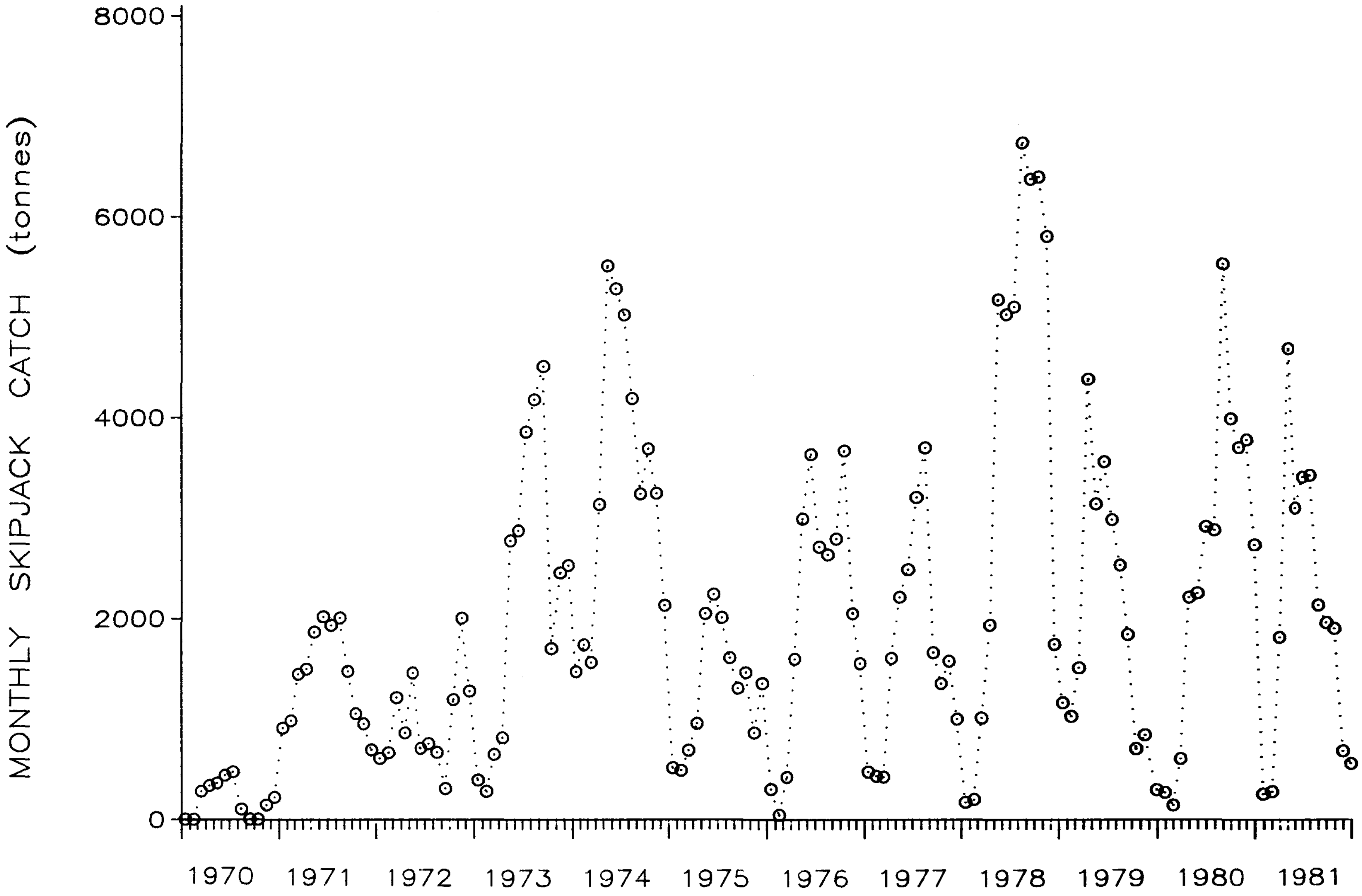
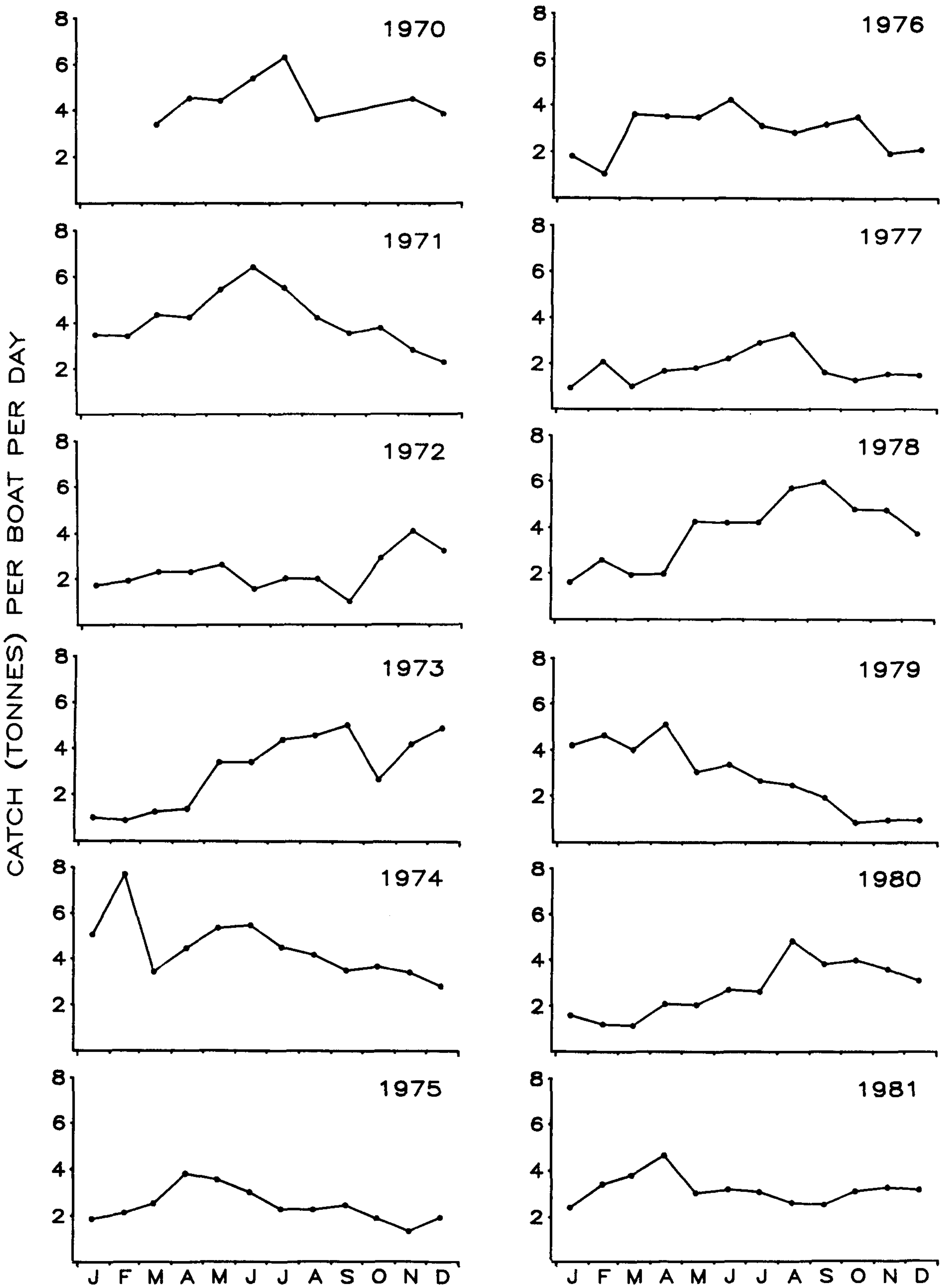


FIGURE 3. MONTHLY AVERAGES OF CATCH PER UNIT EFFORT (tonnes per boat-day) BY THE LOCALLY BASED POLE-AND-LINE FLEET BETWEEN MARCH 1970 AND DECEMBER 1981



The development of the pole-and-line fishery utilising motherships had some important implications for the bait fishery. Motherships were located in areas, adjacent to fishing grounds, which were capable of supporting fleet baiting activity for extended periods. Notwithstanding the extensive availability of baitfish habitats along the coastline of Papua New Guinea, there are few areas capable of supporting the operations of a large fleet. Some of these areas were or have become unavailable for socio-political reasons. Therefore, early in the development of the fishery, the concept of exclusive baiting areas was introduced to segregate the efforts of the different companies (Kearney 1975a). Six baiting grounds supported a tuna fishery extending in an arc from the southwestern Bismarck Sea to New Ireland and New Hanover (Wankowski 1980a). After 1975, as the fishery contracted eastwards into areas which experience had shown to provide more consistent tuna catches, the baiting grounds in East New Britain (Cape Lambert) and New Hanover (Ysabel Pass) assumed greatest importance. At the same time, additional baiting and fishing areas north of Manus Island, on the south coast of New Britain (Solomon Sea), and in the Coral Sea were developed. Operations in the last two areas allowed the fishing season to extend through the northwest monsoon season (December-March) when conditions in the Bismarck Sea become unworkable. However, the Manus Island and Coral Sea (Cheshunt Bay) baiting grounds were subsequently closed for socio-political reasons, placing pressure on the East New Britain and New Hanover areas. Sharp declines in catches were experienced in both the Ysabel Pass baitfishery, in early 1979, and the Cape Lambert baitfishery, in mid-1980 (Anon. 1982). Both recovered within a few months, but in the Ysabel Pass area a management plan was declared which partitioned the area and provided for entry to a restricted number of boats on a rotational basis (Wankowski 1980b). This system stands in contrast to that prevailing in countries such as Solomon Islands and Fiji, where access is more lightly regulated.

1.1.3 Foreign-based fisheries

Asian longline vessels have been active in the Papua New Guinea area since the 1950s (Kearney 1977a; Wankowski 1980a). Catch and effort statistics for Japanese vessels operating in the 200-mile zone of Papua New Guinea between 1962 and 1977, and Taiwanese vessels operating there between 1967 and 1977, are listed in Skipjack Programme (1981a). Tonnages landed in the 200-mile zone by Japanese and Taiwanese vessels between 1972 and 1976, and by Korean vessels between 1975 and 1976, were tabulated by Klawe (1978). Declared catches by Japan since 1972 are included in Table 2, and have fluctuated between 1,874 and 14,104 tonnes per year, with yellowfin comprising an estimated 65-70 per cent of the catch (Klawe 1978; Wright 1980). Since 1978, longline activity in the 200-mile zone has been subject to access agreements; catch statistics are available only from Japan, which took 10,925 tonnes in 1982 (PNG DPI unpublished data).

The Japanese distant-water pole-and-line fleet fished extensively in the Papua New Guinea area in the early 1970s. Catches steadily increased until 1974, when 56,595 tonnes of tuna (97% skipjack) were taken within 200 miles of Papua New Guinea by Japanese pole-and-line vessels (Table 2). Catches since then have not approached these levels, as effort was directed away from the area, largely in response to the imposition of access conditions in 1978 by Papua New Guinea (Wankowski 1980a).

Successful purse-seining for skipjack and yellowfin in the South Pacific Commission region is a relatively recent phenomenon. Techniques appropriate to the western tropical Pacific were first developed in the waters immediately north of Papua New Guinea's DFZ, where major current interfaces and the presence of many floating logs produce suitable conditions for purse-seining operations. This area remains the centre of purse-seine activity in the western Pacific, although considerable expansion eastwards has occurred in recent years (Tuna Programme unpublished data). Purse-seine catches in Papua New Guinea's 200-mile zone, insignificant before 1976, increased rapidly to at least 57,000 tonnes (70% skipjack) in 1982 (Table 2). Japanese, Taiwanese, Korean and American vessels are now fishing in the area under access agreements, but full catch statistics are not yet available.

TABLE 2. ANNUAL CATCHES OF TUNA IN PAPUA NEW GUINEA WATERS BY JAPANESE FISHING FLEETS (NA=data not available). United States, Korean and Taiwanese purse-seine or longline vessels also fish in the waters of Papua New Guinea, but catches are not currently available.

	Distant-water Pole-and-line		Purse-seine		Longline	
Year	Tuna Catch (tonnes)	Percentage Skipjack	Tuna Catch (tonnes)	Percentage Skipjack	Tuna Catch (tonnes)	Percentage Skipjack
1970	N.A.	-	0	-	1,343	N.A.
1971	N.A.	-	83*	N.A.	5,318	N.A.
1972	10,858*	87	51*	78	4,147*	<1
1973	22,228*	95	554*	60	8,346*	<1
1974	56,595*	96	100*	99	3,993*	<1
1975	18,079*	94	84*	83	3,095*	<1
1976	8,389**	92	4,377*	76	4,466*	<1
1977	18,801**	84	6,537*	78	10,284*	<1
1978	2,617**	94	6,071*	76	8,489*	N.A.
1979	503***	95	913*	87	1,874***, ****	N.A.
1980	99***	94	12,680***	82	12,295***	N.A.
1981	16***	94	18,364***	70	12,992***	N.A.
1982	N.A.	-	56,454***	70	10,925***	N.A.

Sources:
- * Wankowski (1980a)
- ** Skipjack Programme (1980a)
- *** PNG DPI unpublished data
- **** Underestimate; see Wankowski (1980a, p 18).

1.2 Previous Research

From March 1971, a comprehensive research programme initiated by the Department of Primary Industry accompanied the development of the pole-and-line fishery, a situation unique within the South Pacific Commission region. Collection and analysis of catch data, tagging and biological studies, aerial surveys of the resource and investigations of bait species and the fishery for them were major components of the programme (Kearney 1974). These investigations provided much of the original impetus for the establishment of the Skipjack Programme and the results have substantially aided its development.

The detailed catch statistics provided the basis for several descriptions of the fishery (Kearney 1973, 1975a, 1977a; Lewis and Smith 1977a; Anon. 1979, 1980b). These data also have been used to examine the relationships among skipjack catch, bait catch and the lunar cycle (Kearney 1977c), and to develop projections of the quantity of bait required to support a skipjack fishery (Kearney 1975b). Length frequency data obtained from the catch have been used to derive skipjack and yellowfin growth estimates (Wankowski 1981).

Aerial survey work carried out during 1972-73 (Kearney, Lewis & Smith 1973; PNG DPI, unpublished data) confirmed that the surface tuna resource was large, and identified areas of abundance not fished by the fleets at the time. Several of these, notably the south coast of New Britain and mainland south coast, were subsequently exploited. Aerial detection of schools has been used intermittently since then to provide rapid assessments of apparent abundance in particular areas.

Over 13,000 tagged tuna, predominantly skipjack, were released in the Papua New Guinea area from 1971 to 1976, either from DPI research cruises or from various Japanese vessels in joint projects with DPI (Table 3). Tagging techniques developed during this period were adopted subsequently by the Skipjack Programme. Recoveries from these releases demonstrated for the first time that there were long skipjack migrations in the western Pacific, with fish released in Papua New Guinea travelling far beyond the borders of Papua New Guinea's 200-mile zone. Analysis of returns from 1971-74 releases led to the formulation of a model of skipjack migration in the Bismarck Sea, Solomon Sea and waters to the north of Papua New Guinea (Lewis 1980a, 1980b). Growth estimates derived from tag recapture data (Josse et al. 1979) yielded evidence that skipjack growth may show considerable geographical variation.

The tagging cruises generated biological data which have been used to examine skipjack reproduction, feeding habits and size composition of schools (Kearney, Lewis & Smith 1972; Lewis, Smith & Kearney 1974; Wilson 1982). Since 1975, DPI staff have collected over 6,000 skipjack blood specimens from commercial catches for analyses of skipjack population genetics. These results (Lewis 1981) complement Skipjack Programme blood genetics data from other countries and territories in the South Pacific Commission region (Section 4.3.4).

The geographical and seasonal coverage provided by the initial baitfish surveys by Japanese vessels (1968-1970) was considerably extended on trips undertaken by PNG DPI (Kearney, Lewis & Smith 1972; Lewis, Smith & Kearney 1974), providing further knowledge of the distribution and abundance of the baitfish resource (Lewis 1977). Handling techniques which reduced the high mortality associated with the bait species in common use (Smith 1977) were successfully developed. Biological studies of the major species and collection of catch and effort statistics from the bait fishery were upgraded in 1976 when the intensity of baitfishing effort in one area, Ysabel Pass, gave cause for concern. The results of a four-year study between 1976 and 1980 formed the basis of management regimes subsequently introduced for the area (Wankowski 1980b; Dalzell & Wankowski 1980; Anon. 1982). A similar research programme in the Cape Lambert baitfishing grounds was initiated in 1980 (Anon. 1982).

TABLE 3. SUMMARY OF ALL KNOWN TAGGED TUNA RELEASES IN PAPUA NEW GUINEA WATERS (SJ=skipjack, YF=yellowfin, OT=other species).

Date	Agency*	Vessel	Area	Single Tags SJ	Single Tags YF	Single Tags OT	Double Tags SJ	Double Tags YF	Double Tags OT	Total Fish Tagged	Skipjack Recoveries
71/12	DPI	Tagula	Solomon Sea	74	0	0	0	0	0	74	1
72/03	DPI	Tagula	Solomon Sea	14	0	0	0	0	0	14	1
72/05	DPI	Tagula	Bismarck Sea	143	0	0	0	0	0	143	17
72/07	DPI	Tagula	Bismarck Sea	299	0	0	0	0	0	299	43
72/10	DPI	Tagula	Bismarck Sea	2065	24	0	0	0	0	2089	155
72/11	DPI	Tagula	Bismarck Sea	947	89	0	0	0	0	1036	60
73/02	DPI	Rossel	Coral Sea	62	0	0	0	0	0	62	1
73/04	DPI	Tagula	Solomon Sea	34	0	0	0	0	0	34	2
73/06	DPI	Tagula	Bismarck Sea	1763	215	0	294	19	0	2291	153
73/07	DPI	Tagula	Bismarck Sea	400	0	0	0	0	0	400	64
73/08	DPI	Tagula	Bismarck Sea	501	0	0	54	0	0	555	74
73/09	DPI	Tagula	Bismarck Sea	600	0	0	0	0	0	600	38
73/10	DPI & JFA	Fuji Maru	Nth New Hanover	240	9	0	0	0	0	249	9
73/10	DPI	Tagula	Bismarck Sea	326	0	0	0	0	0	326	19
	DPI & JFA	Fuji Maru	Solomon Sea	143	0	0	0	0	0	143	4
73/12	DPI	Tagula	Coral Sea	300	0	0	0	0	0	300	3
74/01	DPI	Rossel	Coral Sea	212	0	0	10	0	0	222	0
74/06	DPI	Daido Maru	Nth New Hanover	1066	45	1	10	12	0	1134	83
74/10	JFSFRL	Shoyo Maru	Manus Is	59	0	0	0	0	0	59	1
75/11	DPI & JFA	Fuji Maru	Coral Sea	386	0	0	0	0	0	386	na
	DPI & JFA	Fuji Maru	Solomon Sea	992	120	0	0	0	0	1112	na
75/12	DPI & JFA	Fuji Maru	Solomon Sea	222	210	28	0	21	4	485	na
75/?	DPI	Rossel	Coral Sea	386	177	0	0	0	0	563	na
76/10	DPI	Rossel		52	0	0	0	0	0	52	na
	DPI	Daido Maru		271	0	0	0	0	0	271	na
76/11	DPI & JFA	Fuji Maru	Bismarck Sea	93	15	0	0	0	0	108	na
			Manus Is	45	15	4	0	0	0	64	na
			Nth New Hanover	124	11	1	0	0	0	136	na
77/10	SPC	Hatsutori	Bismarck Sea	22	14	0	4	0	0	40	1
		Maru No.1	Solomon Sea	874	2	0	0	2	0	878	6
79/03	DPI	Various	Coral Sea	381	0	0	0	0	0	381	9
79/05	SPC	Hatsutori	Bismarck Sea	2723	199	2	0	0	0	2924	516
		Maru No.1	Solomon Sea	504	0	0	0	0	0	504	21
79/06	SPC	Hatsutori Maru No.1	Bismarck Sea	4423	617	0	0	0	0	5040	572
TOTALS				20746	1762	36	372	54	4	22974	1853

Agency

DPI	Papua New Guinea Department of Primary Industry formerly Department of Agriculture Stock and Fisheries
DPI & JFA	Joint Project with the Japanese Fishery Agency
JFSFRL	Japanese Far Seas Fisheries Research Laboratory
SPC	South Pacific Commission Skipjack Survey and Assessment Programme.

The research conducted by various agencies in the Papua New Guinea region thus provided valuable guidance for formulating the directions and procedures of the Skipjack Programme, and a useful data base for both long-term evaluation and comparison with the Programme's results.

2.0 METHODS

2.1 Skipjack Programme Research Plan

The objectives of the Skipjack Programme were to survey the skipjack and baitfish resources of all countries and territories within the area of the South Pacific Commission and to assess the status of the stocks and the degree of interaction among individual fisheries for skipjack, within the region and beyond. These assessments were to provide a basis for both rational development of skipjack fisheries throughout the region and sound management of the resource. The Programme's fieldwork spanned almost three years, from October 1977 to August 1980 inclusive, and incorporated surveys in all of the countries and territories in the area of the South Pacific Commission, as well as the North Island of New Zealand and the east coast of Australia (see Figure A, inside front cover). Eight hundred and forty-seven days of chartered vessel time were spent in the region and 25 countries and territories were visited. Seventy-seven days were spent in the waters of Papua New Guinea in 1977 and 1979.

2.2 Vessel and Crew

The first of the two vessels chartered by the Skipjack Programme, the Hatsutori Maru No.1 of 192 gross tonnes (see Kearney 1982), was used on both visits to Papua New Guinea. The vessel was chartered from a commercial fishing company, Hokoku Marine Products Company Limited, Tokyo, Japan, and was slightly modified to accommodate the requirements of fisheries research work.

The Hatsutori Maru No.1 was operated with three or four Skipjack Programme scientists, nine Japanese officers and between nine and twelve Fijian crew. Observers from the Papua New Guinea Fisheries Division were on board for varying times throughout the survey. On the first visit, two Japanese observers, one from the Japan Fisheries Agency and the other from the Tohoku Regional Fisheries Research Laboratory, were also on board. Names of all personnel and details of the times scientists and observers spent on board are given in Appendix A.

2.3 Baitfishing

The majority of baitfishing carried out by the Programme in the waters of Papua New Guinea employed a "bouki-ami" net, set at night around bait-attraction lights. Procedures were similar to those used by commercial vessels, but were modified where necessary to meet the Programme's special requirements. Beach-seining during daylight was examined as an alternative bait catching technique at two localities. Details of both techniques and all modifications employed by the Skipjack Programme were given by Hallier, Kearney & Gillett (1982).

2.4 Skipjack Fishing, Tagging and Biological Sampling

Operations aboard the Hatsutori Maru No.1, a commercial live-bait, pole-and-line fishing vessel, followed the basic strategy of approaching and chumming schools normally employed with such vessels. As in commercial fishing, minor variations in technique were tried from day to day, depending upon the behaviour of skipjack schools and the quantity and quality of live bait carried.

The number of crew was fewer than the Hatsutori Maru No.1 carries when fishing commercially. The effective number of fishermen was further reduced because at least one crew member was required to assist each scientist in the tagging procedures. Moreover, the need to pole skipjack accurately into the tagging cradles reduced the speed of individual fishermen. Clearly, these factors decreased the fishing power of the research vessel. During the first survey in the waters of Fiji (26 January to 10 April 1978), the relative fishing power of the Hatsutori Maru No.1 was calibrated by comparing its catches with those of the commercial fleet operating in the same area, and with catches achieved during a period of one month when the vessel fished commercially under the same captain while using an enlarged crew complement. From these comparisons, it was estimated that the fishing power of the Hatsutori Maru No.1 under survey conditions was 29 per cent of its commercial fishing power (Kearney 1978a).

As tagging was the primary tuna-research tool, attempts to tag large numbers of fish normally dominated the fishing strategy. The tagging techniques and alterations to commercial fishing procedures have been described in detail by Kearney & Gillett (1982).

Specimens of tuna and other pelagic species that were poled or trolled, but not tagged and released, were routinely analysed. Data collected include length, weight, sex, gonad weight, stage of sexual maturity, and a record of stomach contents. In addition, a log was maintained of all fish schools sighted throughout the surveys. Where possible the species composition of each school was determined. Records were kept of the chumming response and catch by species from each school. Argue (1982) described methods used for the collection of these data.

Skipjack blood samples for genetic analysis were collected according to methods described by Fujino (1966) and Sharp (1969), and then frozen and packed on dry ice for air freighting to the Australian National University, Canberra, Australia, where they were electrophoretically analysed (Richardson 1983).

After December 1979, skipjack body cavities were examined for the presence of macro-parasites. Five complete sets of gills and viscera from each school were frozen and subsequently shipped to the University of Queensland, St Lucia, Australia, for detailed examination. No parasite samples were collected in Papua New Guinea.

2.5 Data Compilation and Analysis

Five separate logbooks were used for compiling data accumulated during the fieldwork outlined in Sections 2.3 and 2.4. The techniques used to enter data from these logs into computer files and to process data were discussed by Kleiber & Maynard (1982). Results of electrophoretic analyses of blood samples were also coded and filed on the computer. Data processing was carried out on the Programme's Hewlett Packard 1000 computer in Noumea.

Assessment of the skipjack resource and of possible interactions between skipjack fisheries in Papua New Guinea and those in other countries required several different approaches. Records of the migration of tagged skipjack have formed the basis of investigations of movement patterns and fishery interactions, using analytic techniques described in Skipjack Programme (1981b) and Kleiber, Sibert & Hammond (ms.). Evaluation of the magnitude of the skipjack resource and its dynamics, based on tagging data, has been described by Kleiber, Argue & Kearney (1983). Methods employed in studies of growth are described in Sibert, Kearney & Lawson (1983) and Lawson, Kearney & Sibert (ms.), and of juvenile abundance in Argue, Conand & Whyman (1983). Procedures used to compare fishing effectiveness of different bait species are described in Skipjack Programme (1981d) and Argue, Williams & Hallier (ms.). Evaluation of population structure across the western and central Pacific was based on a comparison of the tagging results with the blood genetics work (Anon. 1980a, 1981; Skipjack Programme 1980b, 1981c) and analyses of the occurrence and distribution of skipjack parasites (Lester et al. ms.).

3.0 SUMMARY OF FIELD ACTIVITIES

During the two surveys 77 days were spent in the waters of Papua New Guinea, of which 61 were spent fishing, 4 baiting, 5 steaming, and 7 in port (Table 4). Included in this table are two fishing days, portions of which were spent in the waters of the Solomon Islands during the first visit. Two hundred and sixty-eight skipjack (not shown in Table 4) tagged in Solomon Islands waters on these two days have been included in the assessment of the skipjack resources of Solomon Islands (Argue & Kearney 1982).

Baitfishing activities are summarised in Table 5. Eighteen separate localities were fished using the bouki-ami night-baiting technique (Figure 4). At two of these localities, day baiting using a beach seine was also carried out.

During the first visit, Manus Island, New Hanover, New Ireland, Lyra Reef, the north coast of New Britain and the west and south coasts of Bougainville were surveyed (Figure 1). This extensive coverage was in response to low apparent abundance and poor chumming response of skipjack at the time, and the consequent need to find alternative fishing grounds. As a result, only 918 tagged tuna were released (98% skipjack), mostly in the eastern Solomon Sea near Bougainville Island, adjacent to the border with Solomon Islands.

Bad weather during the early part of the second visit curtailed survey activities in the western Solomon Sea and along the south and east coasts of New Guinea. Only 504 tuna, all skipjack, were tagged and released in this period. However, a further 7,964 tuna (90% skipjack) were tagged and released in the commercial fishing areas of the eastern and northern Bismarck Sea, near East New Britain, New Ireland, New Hanover and Manus Island. As of 1 March 1982, 1,149 recoveries (12.2%) had been received from the 9,386 releases in Papua New Guinea waters.

Skipjack fishing activities, including sightings, tagging success and catches, are summarised in Table 4. On fishing days, an average of 9.4 hours were spent searching and fishing. Four hundred and seventy-two surface schools were sighted, at an average of 0.79 schools per hour spent sighting. The average sighting rate during the entire Skipjack Programme was 0.75/hour. The total catch in Papua New Guinea of 37.7 tonnes (average 618 kg per fishing day) comprised mainly skipjack (34.3 tonnes) and

TABLE 4. SUMMARY OF DAILY FIELD ACTIVITIES IN THE WATERS OF PAPUA NEW GUINEA. Schools sighted are identified by species: SJ = skipjack or skipjack with other species except yellowfin, YF = yellowfin or yellowfin with other species except skipjack, S+Y = skipjack with yellowfin or skipjack with yellowfin and other species, OT = other species without skipjack or yellowfin, UN = unidentified, but most likely schools with tuna.

Date	General Area	Principal Activity	Bait Carried (kg)	Hours Fishing and Sighting	Schools Sighted (numbers)					Fish Tagged (numbers)			Fish Caught (kg)		Total Catch (kg)
					SJ	YF	S+Y	OT	UN	SJ	YF	OT	SJ	YF	
05/10/77	New Ireland	Steaming	0	0	-	-	-	-	-	-	-	-	-	-	-
06/10/77	New Hanover	Fishing	195	10	4	0	1	0	0	7	0	0	27	6	33
07/10/77	New Hanover	Fishing	150	4	0	0	0	0	0	0	0	0	0	0	0
08/10/77	Manus Is	Fishing	113	8	0	5	1	0	0	0	0	0	0	0	0
09/10/77	Manus Is	Fishing	105	12	0	0	1	1	1	0	0	0	0	0	2
10/10/77	Manus Is	Fishing	38	9	6	0	0	1	0	3	0	0	9	0	13
11/10/77	New Hanover	Fishing	15	11	1	0	0	0	0	0	0	0	0	0	2
12/10/77	New Hanover	Fishing	323	3	0	0	0	0	0	0	0	0	0	0	0
13/10/77	Lyra Reef	Fishing	98	11	0	3	0	1	1	0	0	0	0	10	172
14/10/77	New Ireland	Fishing	45	11	2	1	0	0	0	1	0	0	7	0	7
15/10/77	Kavieng	In Port	23	0	-	-	-	-	-	-	-	-	-	-	-
16/10/77	New Ireland	Fishing	113	11	1	2	3	0	0	13	14	0	55	73	175
17/10/77	Rabaul	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
18/10/77	Rabaul	In Port	0	0	0	0	0	1	0	0	0	0	0	0	6
19/10/77	Cape Lambert	Fishing	303	10	2	17	0	1	1	2	0	0	19	0	19
20/10/77	Cape Hollman	Fishing	135	10	0	10	1	1	1	0	0	0	0	0	2
21/10/77	Witu Is	Fishing	210	10	2	11	0	0	1	0	0	0	0	11	11
22/10/77	Witu Is	Fishing	210	9	1	8	1	0	1	0	0	0	0	2	2
23/10/77	Kimbe Bay	Fishing	465	5	0	0	0	0	2	0	0	0	0	0	0
24/10/77	NE Solomon Sea	Fishing	345	12	0	1	1	1	2	2	0	0	6	4	25
25/10/77	*Bougainville Is	Fishing	270	5	0	0	0	0	2	0	0	0	0	0	0
26/10/77	Bougainville Is	Fishing	330	9	6	1	0	2	0	457	0	0	2900	0	2912
27/10/77	Shortland Is	Fishing	90	13	2	0	3	0	0	360	4	0	1907	99	2006
28/10/77	Tonolei Harbour	Baiting	45	0	-	-	-	-	-	-	-	-	-	-	-
29/10/77	*Shortland Is	Fishing	50	2	0	1	0	0	0	0	0	0	0	0	0
30/10/77	Shortland Is	Fishing	90	7	4	0	0	0	1	55	0	0	191	0	191
31/10/77	Kieta Harbour	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
14/05/79	S of Pt Moresby	Fishing	15	7	0	0	0	0	3	0	0	0	0	0	0
15/05/79	Port Moresby	Steaming	12	4	0	0	0	0	2	0	0	0	0	0	0
16/05/79	SW Samarai	Steaming	12	9	0	0	0	0	1	0	0	0	0	0	0
17/05/79	Milne Bay	Baiting	11	3	0	0	0	1	1	0	0	0	0	0	2
18/05/79	Milne Bay	Fishing	171	9	0	1	2	1	1	22	0	0	80	0	82
19/05/79	Milne Bay	Fishing	126	12	0	1	0	1	0	0	0	0	0	0	0
20/05/79	Solomon Sea	Fishing	108	11	3	0	0	0	0	482	0	0	1639	0	1639
21/05/79	Umboi Is	Fishing	68	12	0	1	0	5	4	0	0	0	0	0	8
22/05/79	NW New Britain	Fishing	48	11	3	0	0	0	2	0	0	0	0	0	0
23/05/79	Garove Is	Fishing	153	11	0	0	0	2	3	0	0	0	0	0	0
24/05/79	Cape Hollman	Fishing	120	11	1	1	2	1	0	5	0	0	18	17	42
25/05/79	Cape Lambert	Fishing	143	11	0	1	0	3	1	0	0	0	0	2	14
26/05/79	Cape Lambert	Fishing	122	4	0	1	0	0	2	0	0	0	0	0	0
27/05/79	Cape Lambert	Fishing	399	9	3	0	0	0	1	851	0	0	3649	0	3651
28/05/79	Dyaul Is	Fishing	260	9	2	2	2	0	1	685	14	0	2772	69	2890
29/05/79	Dyaul Is	Fishing	74	10	4	0	0	0	3	20	0	0	110	0	110
30/05/79	St George's Ch.	Fishing	174	11	5	0	4	1	4	516	159	0	2001	486	2501
31/05/79	St George's Ch.	Fishing	81	5	2	0	5	1	2	646	26	0	2335	66	2411
01/06/79	St George's Ch.	Fishing	342	12	3	1	5	2	2	101	113	0	421	296	730
02/06/79	St George's Ch.	Fishing	39	9	1	0	0	0	11	0	0	0	0	0	2
03/06/79	Cape Lambert	Fishing	161	11	3	0	5	0	4	1232	29	0	4618	113	4733
04/06/79	Rabaul	Steaming	0	0	-	-	-	-	-	-	-	-	-	-	-
05/06/79	Cape Lambert	Baiting	0	4	0	0	0	0	5	-	-	-	-	-	-
06/06/79	Cape Lambert	Fishing	369	10	3	1	2	1	4	98	8	0	371	43	454
07/06/79	Cape Lambert	Fishing	282	12	1	5	4	0	5	195	55	0	665	126	791
08/06/79	Cape Lambert	Fishing	147	11	1	0	3	0	1	280	6	0	1088	25	1115
09/06/79	St George's Ch.	Fishing	84	8	1	1	3	1	5	311	58	0	1012	130	1166
10/06/79	Rabaul	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
11/06/79	Rabaul	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
12/06/79	Rabaul	Baiting	0	4	0	0	0	1	3	-	-	-	-	-	-
13/06/79	E Bismarck Sea	Baiting	20	2	0	0	0	0	3	0	0	0	0	0	0
14/06/79	Manus Is	Fishing	9	4	2	0	0	0	1	0	0	0	12	0	12
15/06/79	Manus Is	Fishing	137	6	1	0	1	1	2	515	220	1	1648	763	2423
16/06/79	Manus Is	Fishing	126	12	5	0	1	2	6	52	1	0	302	3	321
17/06/79	Manus Is	Fishing	56	6	4	0	0	0	3	184	0	0	628	0	630
18/06/79	Manus Is	Fishing	302	12	3	0	0	3	8	91	0	1	220	0	248
19/06/79	Manus Is	Fishing	179	12	0	1	2	0	6	133	38	0	486	170	655
20/06/79	Manus Is	Fishing	261	10	0	0	0	2	4	0	0	0	0	0	8
21/06/79	NW New Hanover	Fishing	206	12	7	0	0	0	2	207	0	0	818	0	818
22/06/79	Dyaul Is	Fishing	287	12	4	0	2	0	6	1	0	0	9	4	17
23/06/79	S New Hanover	Fishing	215	5	5	0	3	0	1	291	56	0	1086	226	1312
24/06/79	Dyaul Is	Fishing	462	12	0	1	1	1	7	21	0	0	85	4	89
25/06/79	Dyaul Is	Fishing	266	7	0	1	1	0	1	31	2	0	127	17	144
26/06/79	N New Hanover	Fishing	111	11	4	2	2	0	4	236	3	0	1067	29	1102
27/06/79	NW New Hanover	Fishing	330	12	2	0	3	1	9	309	28	0	1097	85	1186
28/06/79	Garove Is	Fishing	99	11	1	0	0	2	3	0	0	0	0	0	2
29/06/79	Long Is	Fishing	27	12	0	1	0	0	6	0	0	0	0	0	0
30/06/79	Manam Is	Fishing	24	11	2	4	1	0	7	135	0	0	814	1	817
01/07/79	Wewak	Baiting	27	0	-	-	-	-	-	-	-	-	-	-	-
02/07/79	W of Wewak	Fishing	24	6	0	1	0	0	7	0	0	0	0	0	0
TOTALS				597	107	87	66	42	170	8550	834	2	34298	2880	37702

* During the first visit, a portion of each of two fishing days was spent in the waters of the Solomon Islands. Figures for hours sighting, schools sighted and fish caught and tagged are those from the time spent in Papua New Guinea waters. Each day counts as a fishing day for calculation of average daily catch (Section 4.2 and Tables 11 and 12).

TABLE 5. SUMMARY OF BAITFISHING EFFORT AND CATCH BY THE SKIPJACK PROGRAMME IN THE WATERS OF PAPUA NEW GUINEA

Locality Number	Anchorage	Time of Hauls	Number of Hauls	Major Species*	Estimated Average Catch per Haul (kg)	Mean Length (mm)	Other Common Species*
1	Three Island Hbr			*Stolephorus buccaneeri*	17	45	*Herklotsichthys quadrimaculatus*
	02°22′S	Night	2	*Stolephorus heterolobus*	15	60	*Stolephorus devisi*
	150°10′E			*Spratelloides gracilis*	12	50	*Thrissina baelama*
	Three Island Hbr			*Spratelloides gracilis*	30	51	*Stolephorus bataviensis*
	02°23′S	Night	2	*Stolephorus heterolobus*	28	56	*Herklotsichthys quadrimaculatus*
	150°09′E			*Stolephorus devisi*	26	48	*Archamia lineolata*
2	Nausen Island			*Stolephorus heterolobus*	71	59	*Spratelloides gracilis*
	02°37′S	Night	1	*Pterocaesio* sp.	12	77	*Herklotsichthys quadrimaculatus*
	150°46′E			*Pterocaesio pisang*	6	63	*Thrissina baelama*
	Nausen Island			*Sardinella sirm*	82	147	*Spratelloides gracilis*
	02°38′S	Night	4	*Gymnocaesio gymnopterus*	35	59	*Sardinella leiogaster*
	150°45′E			*Herklotsichthys quadrimaculatus*	26	76	*Apogon(Rhabdamia) cypselurus*
3	Ketengi Anchorage			*Stolephorus buccaneeri*	80	65	*Thrissina baelama*
	05°30′S	Night	1	*Stolephorus devisi*	71	48	*Rastrelliger kanagurta*
	149°05′E			*Stolephorus heterolobus*	51	57	*Decapterus maruadsi*
4	Peter Haven			*Spratelloides delicatulus*	60	44	*Hypoatherina ovalaua*
	04°40′S	Night	1	*Spratelloides gracilis*	15	48	*Herklotsichthys quadrimaculatus*
	149°33′E			*Hypoatherina barnesi*			*Apogon(Rhabdamia) cypselurus*
5	Garua Harbour			*Stolephorus heterolobus*	579	69	*Rastrelliger kanagurta*
	05°18′S	Night	1	*Stolephorus devisi*	264	56	*Saurida undosquamis*
	150°04′E			*Stolephorus buccaneeri*	159	47	*Spratelloides delicatulus*
6	Tonolei Harbour			*Stolephorus heterolobus*	42	55	*Stolephorus buccaneeri*
	06°46′S	Night	2	*Stolephorus devisi*	26	41	*Pellona ditchela*
	155°53′E			*Dussumieria* sp.	18	71	*Gazza minuta*
	Tonolei Harbour			*Stolephorus devisi*	5	41	*Dussumieria* sp.
	06°45′S	Night	1	*Stolephorus heterolobus*	2	56	*Sardinella sirm*
	155°54′E			*Pellona ditchela*			*Rastrelliger kanagurta*
	Tonolei Harbour			*Stolephorus devisi*	9	35	*Sardinella sirm*
	06°44′S	Night	1	*Stolephorus indicus*			*Stolephorus heterolobus*
	155°54′E			*Atule mate*			*Dussumieria* sp.
	Tonolei Harbour			*Stolephorus devisi*	36	37	*Pellona ditchela*
	06°45′S	Night	2	*Dussumieria* sp.	7	72	*Gazza minuta*
	155°53′E			*Bregmaceros* sp.			*Sardinella* sp.
7	Kieta Bay						
	06°13′S	Night	1	No significant catch			
	155°38′E						
8	Bagaman Island			*Herklotsichthys quadrimaculatus*	62	90	Sp. of Sphyraenidae
	11°08′S	Day	1	*Antherinomorus lacunosa*	6	74	*Caranx* sp.
	152°41′E			*Selar crumenophthalmus*			
	Bagaman Island			*Hypoatherina ovalaua*	23	59	Sp. of Acanthuridae
	11°08′S	Night	2	*Spratelloides delicatulus*	14	55	Sp. of Synodontidae
	152°42′E			*Antherinomorus lacunosa*	7	72	*Selar crumenophthalmus*
9	Rein Bay			*Stolephorus devisi*	162	36	*Antherinomorus lacunosa*
	05°08′S	Night	2	*Stolephorus buccaneeri*	15	42	*Sardinella melanura*
	149°11′E			*Stolephorus heterolobus*	1	51	*Secutor* sp.
10	Kimbe Bay			Sp. of Siganidae	21	28	Sp. of Syngnathidae
	05°32′S	Night	2	*Stolephorus devisi*	9	39	*Caranx* sp.
	150°12′E			Sp. of Lutjanidae	1	22	*Stolephorus bataviensis*
11	Matupit Bay			*Stolephorus heterolobus*	149	53	*Decapterus* sp.
	04°14′S	Night	1	*Stolephorus buccaneeri*	57	52	*Secutor* sp.
	152°12′E			*Sardinella* sp.			*Sardinella sirm*
	Simpson Harbour			*Spratelloides delicatulus*	2		*Selar boops*
	04°15′S	Night	1	*Hypoatherina ovalaua*	2		*Pterocaesio pisang*
	152°10′E			*Gymnocaesio gymnopterus*			Sp. of Apogonidae
12	Foul Bay			*Sardinella sirm*	57	159	Sp. of Chaetodontidae
	04°10′S	Night	4	*Sardinella leiogaster*	23	181	Sp. of Acanthuridae
	152°26′E			*Spratelloides gracilis*	1	43	Sp. of Sphyraenidae

Locality Number	Anchorage	Time of Hauls	Number of Hauls	Major Species*	Estimated Average Catch per Haul (kg)	Mean Length (mm)	Other Common Species*
13	Cape Lambert 04°10′S 151°36′E	Night	6	Stolephorus heterolobus	159	60	Sp. of Holocentridae
				Stolephorus devisi	19	55	Sp. of Chaetodontidae
				Rastrelliger kanagurta	13	69	Sp. of Priacanthidae
	Cape Lambert 04°09′S 151°36′E	Night	1	Stolephorus heterolobus	6	60	Sp. of Acanthuridae
				Spratelloides lewisi	3	42	Apogon(Rhabdamia) cypselurus
				Rastrelliger kanagurta			Sp. of Holocentridae
	Cape Lambert 04°12′S 151°43′E	Day	3	Hypoatherina ovalaua	6	38	Priacanthus sp.
				Herklotsichthys quadrimaculatus	4	51	Sp. of Hemirhamphidae
				Sardinella melanura	2		Sp. of Belonidae
	Cape Lambert 04°12′S 151°43′E	Night	2	No significant catch			
14	Seeadler Harbour 01°59′S 147°20′E	Night	2	Stolephorus devisi	46		Pterocaesio sp.
				Stolephorus bataviensis	3		Gymnocaesio gymnopterus
				Stolephorus heterolobus	3		Pterocaesio pisang
	Seeadler Harbour 02°00′S 147°18′E	Night	4	Stolephorus devisi	62	47	Stolephorus bataviensis
				Stolephorus heterolobus	8		Dussumieria sp.
				Stolephorus sp. (j)	7		Thrissocles setirostris
	Seeadler Harbour 01°59′S 147°19′E	Night	2	Stolephorus heterolobus	15	57	Spratelloides gracilis
				Stolephorus devisi	9	57	Stolephorus bataviensis
				Gymnocaesio gymnopterus	3	65	Sp. of Fistulariidae
15	Nares Harbour 01°55′S 146°39′E	Night	4	Stolephorus devisi	79	60	Spratelloides delicatulus
				Spratelloides gracilis	35	47	Gymnocaesio gymnopterus
				Stolephorus heterolobus	12		Apogon(Rhabdamia) cypselurus
16	South Ysabel Pass 02°37′S 150°27′E	Night	2	Thrissina baelama (j)	42	31	Hypoatherina ovalaua
				Sardinella clupeoides	14	160	Herklotsichthys quadrimaculatus
				Sp. of Holocentridae	1	34	Stolephorus bataviensis
17	North Ysabel Pass 02°20′S 150°18′E	Night	2	Stolephorus heterolobus	84	51	Herklotsichthys quadrimaculatus
				Stolephorus devisi	77	45	Pterocaesio pisang
				Gymnocaesio gymnopterus	10	70	Apogon(Rhabdamia) gracilis
18	Kairiru Island 03°19′S 143°30′E	Night	1	Gymnocaesio gymnopterus	29	56	Herklotsichthys quadrimaculatus
				Stolephorus buccaneeri			Antherinomorus lacunosa
				Spratelloides gracilis			Sp. of Squid

* Until recently, Herklotsichthys quadrimaculatus was known as Herklotsichthys punctatus (Wongratana 1983) and Atherinomorus lacunosa was known as Pranesus pinguis (Whitehead & Ivantsoff 1983).

Explanatory Notes

Anchorage : Recorded positions are truncated to the nearest minute. For large bays there may be more than one position tabulated.

Time of Hauls : Day hauls - 0600-1759 hrs inclusive
Night hauls - 1800-0559 hrs inclusive

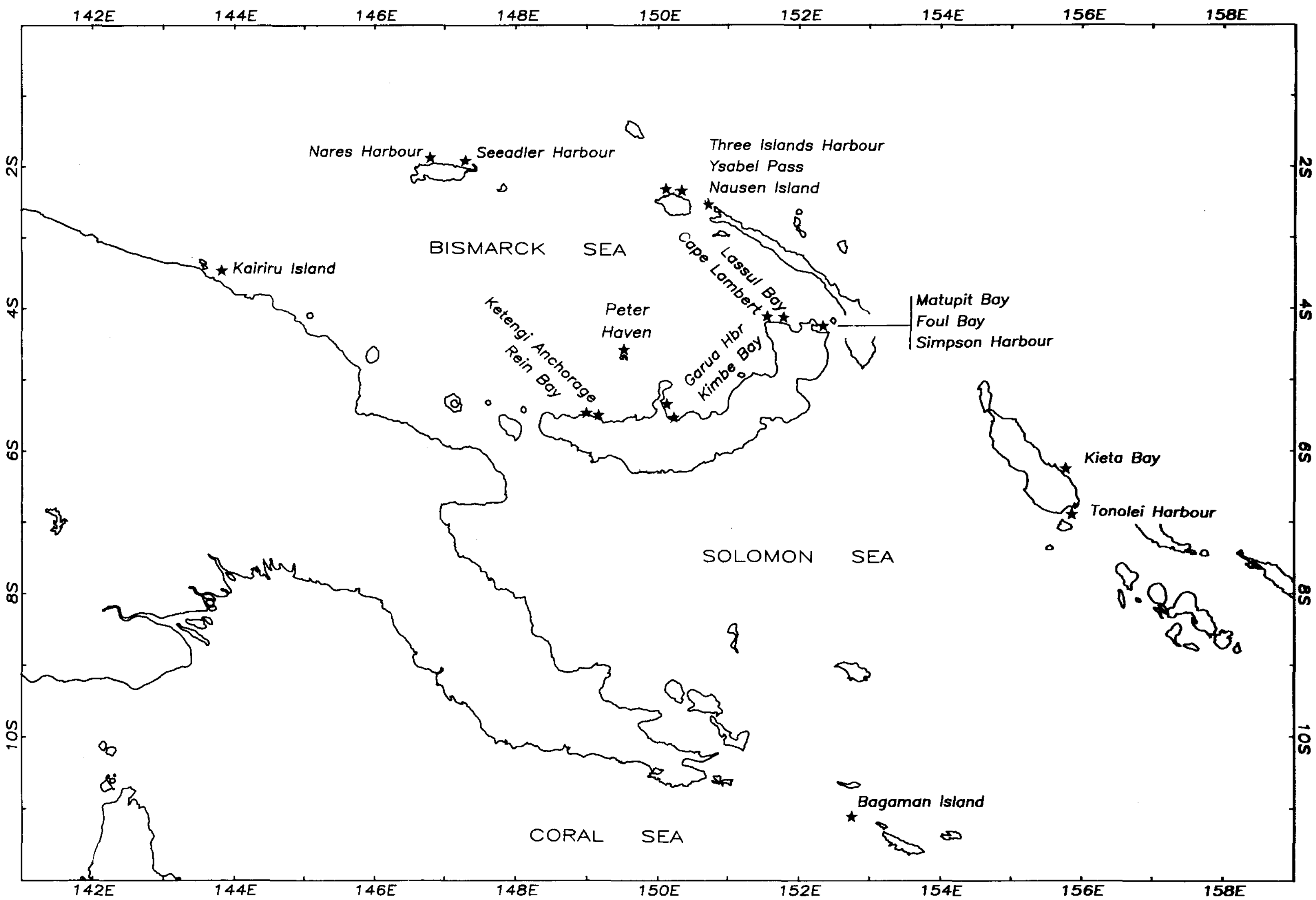
Number of Hauls : Number of hauls at the anchorage position, either day or night as specified. A haul is defined as any time the net was placed in the water.

Species : Those species that made up at least one per cent of the numbers caught from one or more bait hauls at a particular location.

Average Catch (species) : Total catch includes bait loaded, bait discarded alive and bait discarded dead at the location. The average catch in kilograms per haul is the product of total catch in kilograms and weighted numerical percentage of the catch for a particular species, divided by the total number of hauls at the location. The weighted numerical percentage is the product of numerical percentage, a constant, and the cube of the species′ average standard length. (In the absence of a mean SL for the species, the numerical percentage itself is used.) The sum of the weighted percentages equals the sum of the total of the numerical percentages. In this way the smaller (numerically abundant) fish are suppressed in their contribution to the catch while the less common, larger fish are proportionally enhanced in their representation. Catches are expressed in kilograms for the dominant three species; thus, the sum of the average species catches will often be less than the average location catch.

Mean Length : Weighted by numerical abundance when there were multiple hauls at the same location.

FIGURE 4.   LOCATION OF SKIPJACK PROGRAMME BAITFISHING SITES IN PAPUA NEW GUINEA



yellowfin (2.9 tonnes). Other species incidental to the catch (0.5 tonnes) included mackerel tuna (Euthynnus affinis), frigate tuna (Auxis thazard) and rainbow runner (Elagatis bipinnulatus).

A summary of numbers of fish sampled for biological data is given in Table 6. The range of sizes of all skipjack sampled or tagged in Papua New Guinea waters was 29-70 cm (Figure 5) with a great majority between 50 and 60 cm. The size frequency distribution did not differ significantly between the tagged sample and the biological sample on either visit, or between the samples taken on the two visits (Figure 5). On average, fish were slightly (0.7 cm) smaller in 1979 than in 1977. However, skipjack tagged in Papua New Guinea waters were significantly larger (Student's t-test, $p<0.001$) than the mean fork length of 50.4 cm recorded overall during the Skipjack Programme. Tagged yellowfin averaged 49.6 cm in length and sampled yellowfin, 49.3 cm. Skipjack gonad maturity data are summarised in Figures 6 and 7. The incidence of tuna juveniles in stomachs of sampled skipjack, yellowfin and other species is given in Table 7, and a summary of major items of skipjack diet is given in Table 8. Skipjack blood samples were taken from 217 individuals from two schools during the second visit, one in the western Solomon Sea (20 May 1979) and the other near Cape Lambert (3 June 1979); results of blood genetic analyses are included in Figure 8 (Section 4.3.4).

4.0 RESULTS AND DISCUSSION

4.1 Baitfishing

Results from the Programme's baiting at each of the 18 localities in Papua New Guinea are shown in Table 5. For large localities, such as Three Islands Harbour and Tonolei Harbour, results are shown separately for all anchorages which were one nautical mile or more apart. An estimated total of 6,843 kg of bait was taken in 57 bouki-ami hauls (Table 9), with an average catch of 120 kg per haul. Most (78%) of this catch was loaded into holding tanks aboard the Hatsutori Maru No.1; 14.8 per cent was excess to capacity and was released alive, while the remainder (7.5%) was discarded due to mortality incurred during capture and handling (Table 9). Four day-time beach-seine hauls produced only 99 kg of bait.

Over 140 species or taxonomic entities were recognised from the bait catch (Appendix B), including many that had been previously recorded for Papua New Guinea waters (Kearney, Lewis & Smith 1972; Lewis, Smith and Kearney 1974). The Papua New Guinea bait catch was the most diverse recorded in the South Pacific Commission region by the Programme (Table 10). Catch data for the 12 species which each comprised more than one per cent by weight of the total catch are summarised in Table 9. The 12 species together accounted for 90 per cent of the total catch weight. Each of the 12 species, with the exception of large specimens of the mackerel, Rastrelliger kanagurta, exhibit characteristics which make them effective bait for pole-and-line fishing (Baldwin 1977; Smith 1977; Argue, Williams and Hallier ms.).

Two anchovies, Stolephorus heterolobus and S. devisi, dominated the catch, providing approximately 60 per cent by weight on each visit (Table 9). A third anchovy, S. buccaneeri, contributed significantly to 1977 catches (14%), but was of minor importance on the second visit. Ranked next in importance (14%) were sardines and herrings, including Sardinella sirm, S. clupeiodes and Herklotsichthys quadrimaculatus, which

TABLE 6. NUMBERS OF FISH FROM PAPUA NEW GUINEA WATERS SAMPLED FOR BIOLOGICAL DATA

Species	Number Measured	Number Weighed	Number Examined for Sex	Number Examined for Stomach Contents	Number Examined for Tuna Juveniles	Number Sampled for Blood Analyses
Skipjack *Katsuwonus pelamis*	1492	826	909	404	904	217
Yellowfin *Thunnus albacares*	352	239	248	172	248	0
Rainbow Runner *Elagatis bipinnulatus*	91	39	39	39	39	0
Mackerel Tuna *Euthynnus affinis*	62	57	57	37	57	0
Frigate Tuna *Auxis thazard*	28	26	26	11	17	0
Double Lined Mackerel *Grammatorcynus bicarinatus*	20	20	20	5	5	0
Dolphin Fish *Coryphaena hippurus*	13	9	11	6	6	0
Bigeye Tuna *Thunnus obesus*	1	1	1	1	1	0
Shark *Carcharinus* sp.	1	1	1	1	1	0
TOTALS	2060	1218	1312	676	1278	217

FIGURE 5. LENGTH FREQUENCY DISTRIBUTIONS OF SKIPJACK SAMPLED OR TAGGED IN 1977 AND 1979 IN PAPUA NEW GUINEA

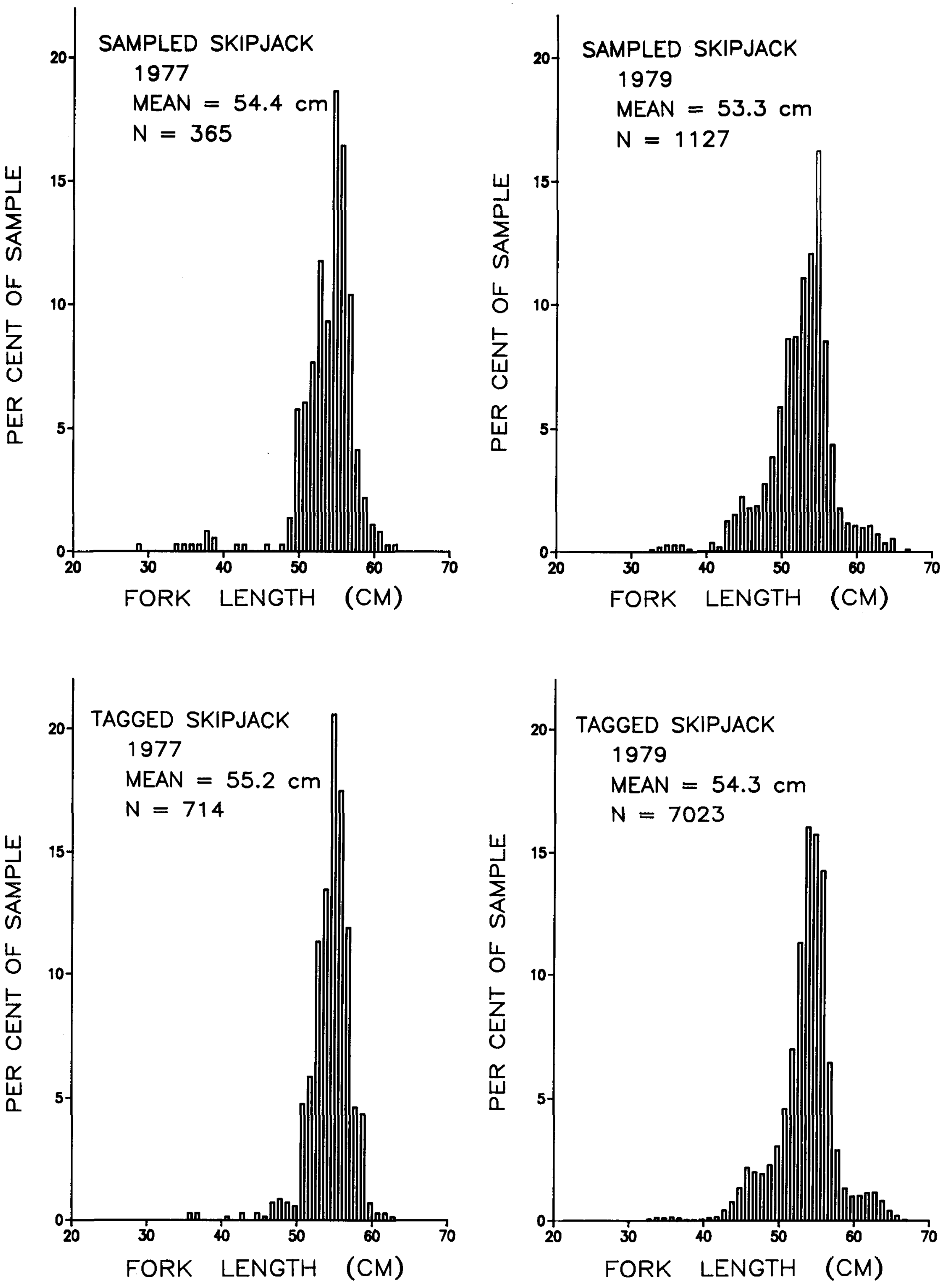


FIGURE 6. DISTRIBUTION OF FEMALE SKIPJACK BY MATURITY STAGE FOR SAMPLES FROM PAPUA NEW GUINEA (BOTH VISITS COMBINED)

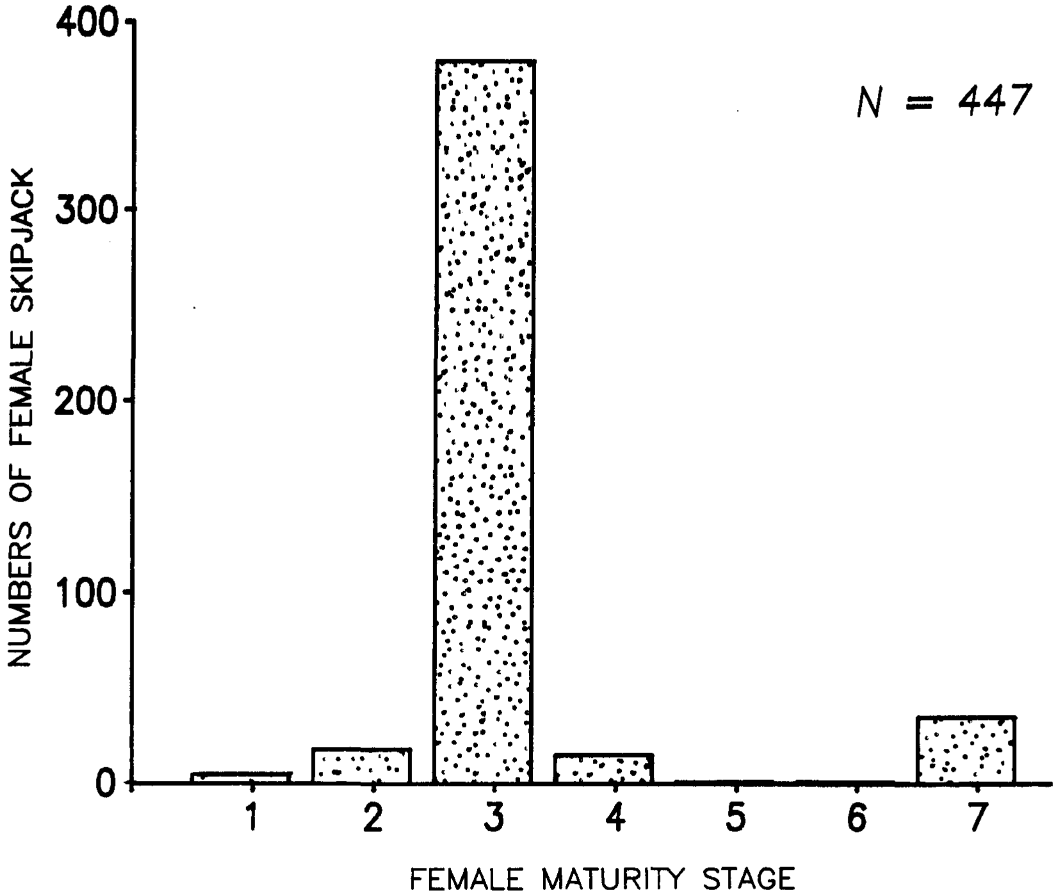


FIGURE 7. LENGTH FREQUENCY DISTRIBUTIONS AND PROPORTIONS OF MATURE (STAGE 3 ONWARDS) SPECIMENS OF FEMALE SKIPJACK FROM BIOLOGICAL SAMPLES FROM PAPUA NEW GUINEA IN 1977 AND 1979

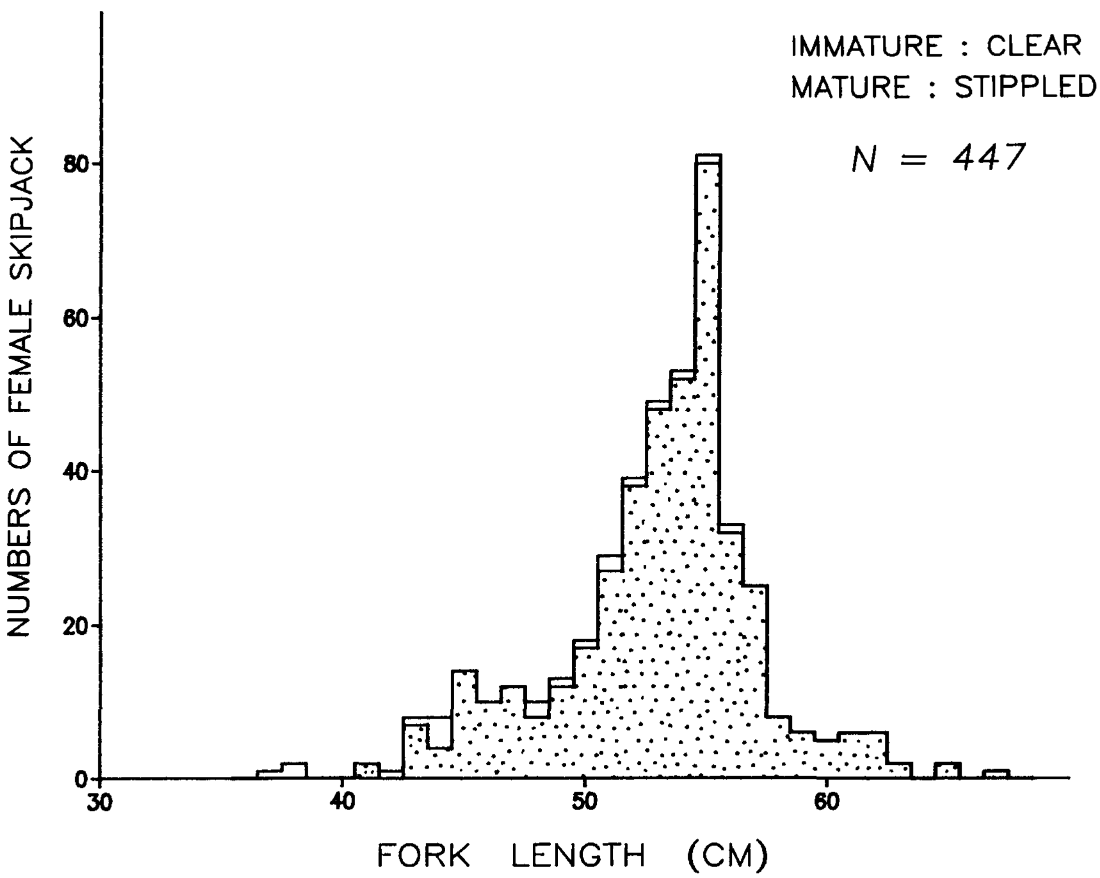


TABLE 7. OCCURRENCE OF PREY TUNA IN STOMACHS OF PREDATOR TUNA IN PAPUA NEW GUINEA. Data from both survey visits are combined.

Predator	Number of Predators Examined	Prey Species	Number of Prey	Numbers of Predators with Prey	Number of Prey per 100 Predators	Percentage of Predators with Prey
Skipjack	904	Skipjack	63	38	6.97	4.20
		Yellowfin	1	1	0.11	0.11
		Mackerel Tuna	2	2	0.22	0.22
		Frigate Tuna	2	1	0.22	0.11
Yellowfin	248	Skipjack	40	3	16.13	1.21
		Frigate Tuna	1	1	0.40	0.40
Mackerel Tuna	57	Mackerel Tuna	2	1	3.51	1.75
Rainbow Runner	39)					
Frigate Tuna	17)					
Dolphin Fish	6)					
Bigeye Tuna	1)	No tuna juveniles found				
Double-lined Mackerel	5)					
Shark	1)					
TOTAL	1278		111			

TABLE 8. ITEMS OCCURRING IN MORE THAN 10 PER CENT OF SKIPJACK STOMACHS EXAMINED IN PAPUA NEW GUINEA. Details of all items found are given in Appendix C.

Item No.	Item	Number of Stomachs	Percentage Occurrence
1	Chum from Hatsutori Maru No.1	246	60.89
2	Fish remains (not chum)	212	52.48
3	Cephalopoda (squid)	121	29.95
4	Acanthuridae	94	23.27
5	Stomatopoda (alima stage)	77	19.06
6	Balistidae	56	13.86
7	Synodontidae	46	11.39
8	Euphausiacea	45	11.14
9	Decapoda (shrimp)	45	11.14
10	Stomatopoda	42	10.40
11	Exocoetidae	41	10.15
12	Holocentridae	41	10.15
	Total Stomachs Examined	404	

FIGURE 8. SKIPJACK SERUM-NAPTHYL ESTERASE GENE FREQUENCY FOR 163 SCHOOLS VERSUS LONGITUDE OF THE SAMPLE LOCATION. Each point is the average for approximately 100 specimens sampled from a single school on the same day. Papua New Guinea samples are shown as circles.

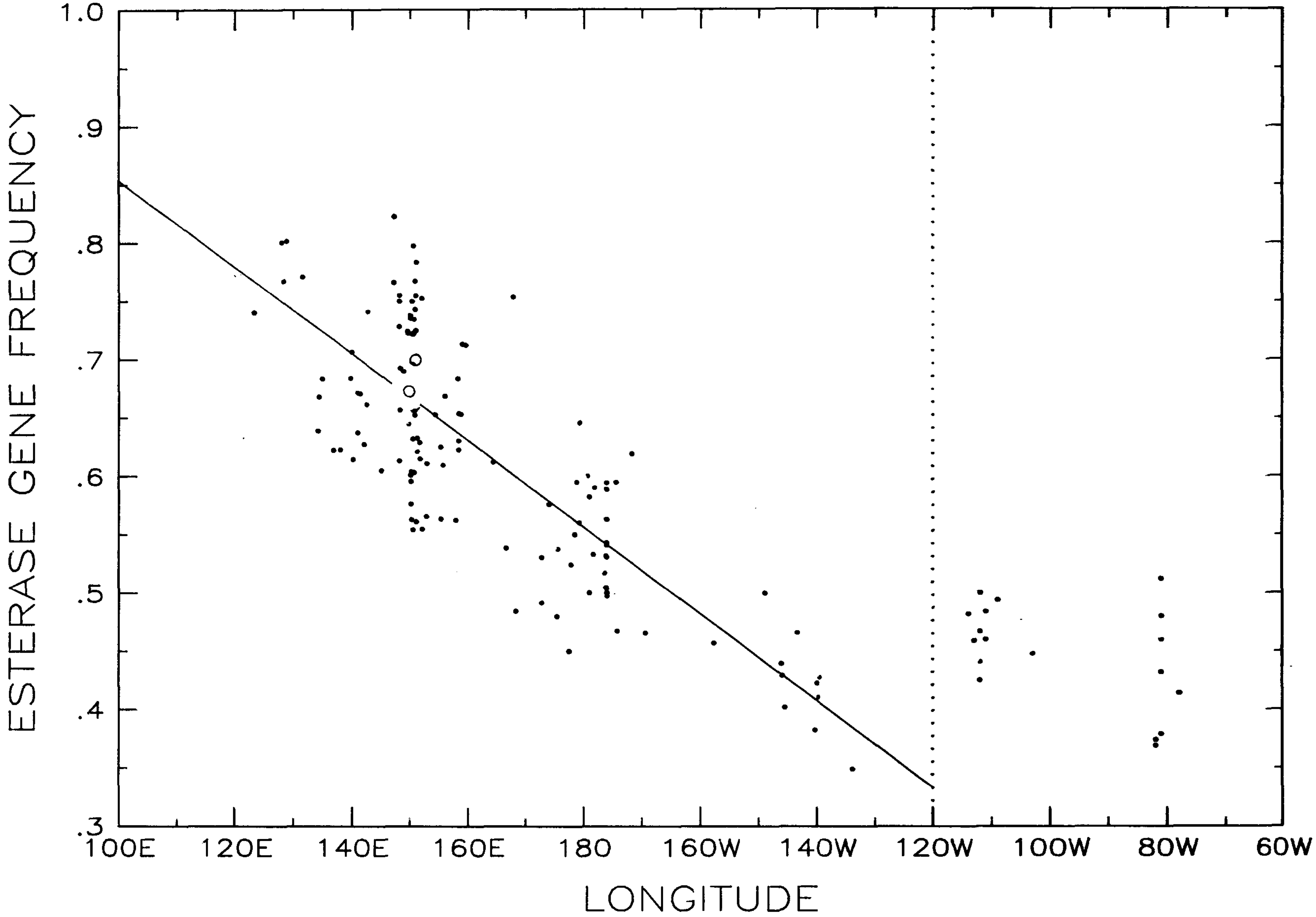


TABLE 9. CATCH OF MAJOR BAITFISH SPECIES IN BOUKI-AMI HAULS DURING TWO VISITS TO PAPUA NEW GUINEA

	October 1977		October 1977 (less one large haul)*		May-June 1979		Both Visits	
	Catch (kg)	% of Total	Catch (kg)	% of Total	Catch (kg)	% of Total	Catch (kg)	% of Total
<u>Stolephorus heterolobus</u>	1,011	42	432	32	1,217	28	2,228	33
<u>Stolephorus devisi</u>	616	25	352	26	1,162	26	1,778	26
<u>Sardinella sirm</u>	0	-	0	-	550	12	550	8
<u>Stolephorus buccaneeri</u>	331	14	172	13	27	1	358	5
<u>Spratelloides gracilis</u>)** <u>Spratelloides lewisi</u>)	96	4	96	7	215	5	313	5
<u>Gymnocaesio gymnopterus</u>	0	-	0	-	210	5	210	3
<u>Herklotsichthys quadrimaculatus</u>***	16	1	16	1	183	4	199	3
<u>Sardinella clupeoides</u>	0	-	0	-	189	4	189	3
<u>Spratelloides delicatulus</u>	60	2	60	4	66	1	126	2
<u>Thrissina baelama</u>	8	1	8	1	91	2	99	1
<u>Rastrelliger kanagurta</u>	0	-	0	-	72	2	72	1
Total Percentage		89		84		90		90
Number of hauls	18		17		39		57	
Total bait caught (kg)	2,418		1,368		4,425		6,843	
Catch loaded (kg)	1,546		1,261		3,776		5,322	
Bait discarded (kg)	872		107		649		1,521	
Average catch per haul (kg)	134.3		80.5		113.5		120.0	
Average quantity of bait loaded per haul (kg)	85.9		74.2		96.8		93.4	

* The columns exclude the catch from a single haul at Garua Harbour which yielded 43 per cent (1,050 kg) of the bait catch taken on the October 1977 visit.

** The two species have been grouped as they were not recognised as separate at the time (see Daly & Richardson 1980; Wongratana 1983).

*** Until recently, known as <u>Herklotsichthys punctatus</u> (Wongratana 1983).

together contributed very different amounts on the two visits (1%, 20%). Sprats (7%) and fusiliers (3%) made minor contributions. A breakdown of the contribution made by major taxonomic groups to the catch in all surveys conducted by the Skipjack Programme was given by Skipjack Programme (1981d).

TABLE 10. NUMBER OF TAXA (species of fish or higher taxa of fish or invertebrates) CAUGHT IN BOUKI-AMI HAULS, LISTED IN DECREASING ORDER, FOR THE COUNTRIES AND TERRITORIES RECORDING THE 10 MOST DIVERSE CATCHES DURING SKIPJACK PROGRAMME SURVEYS. Overall, a total of 236 bait taxa were recorded.

	Number of Sites Fished	Number of Bouki-ami Hauls	Number of Taxa Recorded	Percentage of Total Tropical Taxa Recorded in the SPC Region
Papua New Guinea	26	57	141	59.7
Solomon Islands	24	60	118	50.0
Fiji	26	71	111	47.0
New Caledonia	14	40	88	37.3
Ponape	3	36	62	26.3
Vanuatu	3	5	60	25.4
Society Islands	7	27	59	25.0
Western Samoa	5	14	56	23.7
Palau	9	34	56	23.7
Tonga	6	32	46	19.5

Estimates of species composition of the baitfish resource are in agreement with those of Lewis (1977) who found Stolephorus spp. dominant or co-dominant in catches at 37 (67%) of 55 sites surveyed throughout Papua New Guinea. The site dominance by anchovies in the Skipjack Programme's data was also 67 per cent (18 of 27 sites sampled at night, at which a measurable catch was made - Table 5). The Ysabel Pass bait fishery, which has provided most of the Papua New Guinea commercial baitfish catch in recent years, includes in addition to anchovies significant numbers of sprats, mainly Spratelloides gracilis. They contributed between 7 and 57 per cent (mean 29%) by weight of the commercial catch in the period 1976-79 (Dalzell & Wankowski 1980). In the other three countries with commercial pole-and-line fisheries surveyed by the Programme (i.e. Palau, Solomon Islands and Fiji), the contribution of anchovies by weight to the bait catch was generally lower, at 56, 43 and 22 per cent respectively (Skipjack Programme 1981d).

Five localities surveyed by the Skipjack Programme - Tonolei Harbour, Kieta Bay, Peterhaven, Bagaman Island and Kairiru Island - have been used only infrequently by commercial vessels. However, catches there were not larger than at the other 13 areas which were used by the commercial fleet. Of the five unexploited areas, only Tonolei Harbour is sufficiently large for a mothership-type of operation, with a number of vessels baiting for an extended period. Even though surveys in this locality coincided with the full-moon period, moderate bait catches were obtained.

During the two visits, average catches by the Hatsutori Maru No.1

compared favourably with catches by the commercial fleet at the time. In October 1977, the vessel averaged 173 kg per night, or 105 kg when one very large haul from Garau Harbour was excluded, as against the commercial vessel average of 117 kg per night. On the second visit, the Programme's vessel averaged 192 kg per night while the commercial vessels averaged 121 kg and 122 kg per night in May and June 1979, respectively (PNG DPI unpublished data).

The large haul of good bait obtained at Garua Harbour during the first visit, containing over 1,000 kg of Stolephorus heterolobus, S. devisi and S. buccaneeri, afforded an opportunity to investigate the applicability of the Programme's bait handling and transport techniques to these species. Two hundred and eighty-five kilograms of bait were retained and transported approximately 500 miles to the eastern Solomon Sea, where they were used successfully to fish concentrations of skipjack five days later. Medium size to large individuals (>50 mm) of S. heterolobus and S. buccaneeri suffered very little mortality, whilst smaller individuals of these two species and S. devisi of all sizes proved less robust. This confirmed the previous findings of Smith & Wilson (1975) and Smith (1977) that these delicate species could be transported long distances if handled correctly. Similar trials with Spratelloides produced equivocal results (Kearney 1977b). Most sardines and herrings, notably Herklotsichthys quadrimaculatus, were effective as bait and could be transported successfully, but rarely occur in sufficient quantities in the Papua New Guinea area to be important live-bait species.

Only one site was surveyed on both visits, offering little scope for examining temporal variation in catch. The detailed catch statistics from the Ysabel Pass fishery (Dalzell & Wankowski 1980; Wankowski & Dalzell ms.) indicate that both species composition and catch per unit effort vary considerably within and between years. There is no evidence of a consistent, seasonal pattern in the data. Argue & Kearney (1982) reported an absence of seasonality in bait fisheries in adjacent Solomon Islands. The relationship between annual catch and effort in the Ysabel Pass fishery remained approximately linear between 1970 and 1979, despite a four-fold increase in effort after 1971 (Wankowski 1980a). Substantial declines in catch rate accompanied by changes in species composition occurred in April 1978 and May - June 1979 (Wankowski 1980b), leading to the temporary abandonment of this fishery in June 1979. Stocks had apparently recovered by September 1979, when the Department of Primary Industry invoked a management policy of restricted entry to baiting vessels to prevent a recurrence of the decline. A similar collapse in the Cape Lambert bait fishery occurred in late 1980, with recovery evident by March 1981 (Anon. 1982). Such fluctuations in bait availability emphasise the need to monitor levels of effort carefully in areas subject to intensive fishing pressure.

Results obtained by Daly & Richardson (1980), using electrophoretic techniques to assess population structure, suggest that the Ysabel Pass, Manus Island and Cape Lambert fisheries for the two Stolephorus species and Spratelloides gracilis can probably be regarded as three discrete units for management purposes.

4.2 Tuna Fishing

The relatively unsuccessful fishing operations of October 1977 (Table 4) were not restricted to the Hatsutori Maru No.1; average daily catches by commercial vessels during the same period were among the lowest recorded since the Papua New Guinea pole-and-line fishery began (Table 11; see also Kearney 1977a, 1977b). Extensive searching of areas north of the Manus and New Hanover fisheries by the Programme's vessel established that this apparently low abundance was widespread. A similar paucity of skipjack was noted in the Solomon Islands fishery at the same time (Argue & Kearney 1982). However, large schools of skipjack were located by the Programme's vessel in the eastern Solomon Sea in late October. Average daily catches, adjusted by a factor of 3.47 (Kearney 1978a), indicate an estimated commercial catch rate of over four tonnes/day, considerably in excess of landings by commercial vessels fishing during October in the Bismarck Sea (Table 11), or Solomon Islands (Argue & Kearney 1982).

TABLE 11. AVERAGE CATCH (tonnes per vessel) PER FISHING DAY FOR THE PAPUA NEW GUINEA POLE-AND-LINE FLEET (operating mainly in the Bismarck Sea) IN MAY, JUNE AND OCTOBER, 1976 TO 1980, AND FOR THE SKIPJACK PROGRAMME TAGGING VESSEL IN OCTOBER 1977 AND MAY/JUNE 1979

Year	Pole-and-line Fleet			Hatsutori Maru No.1*		
	May	June	October	May	June	October
1976	3.44	4.11	3.68	-	-	-
1977	1.90	2.31	1.40	-	-	0.92
1978	4.57	4.37	5.02	-	-	-
1979	3.28	3.50	0.98	3.09	2.61	-
1980	2.26	2.78	4.51	-	-	-
Average Catch	3.09	3.41	3.12			

* Estimated by applying a conversion factor of 3.47 to daily catches (Kearney 1978a).

The second visit, after an initial period of relatively poor fishing due to bad weather, produced good catches in or adjacent to the main fishing areas of Manus Island, New Hanover-Mussau, eastern Bismarck Sea and St George's Channel. The converted catch rate for the second visit, including the initial period of poor fishing, was 2.8 tonnes/day, compared with 3.4 tonnes/day caught by commercial vessels (Table 11). This catch rate enabled large numbers of skipjack (n=7146) to be tagged and released in the commercial fishing grounds.

The differences between the daily catches recorded on the two visits to Papua New Guinea reflect the high variability in catch per unit effort experienced by the commercial fishery. Figure 3 shows that there was no consistent seasonal pattern in catch per unit effort (CPUE) between 1970 and 1981. Within-year trends differed markedly during this period; for example, compare 1971, 1973 and 1979. This result contradicts the view that CPUE in the Papua New Guinea fishery is seasonal (Lewis 1981), with higher catch rates obtained in the middle of the year. Since effort is seasonally distributed (Wankowski 1980a), it follows that there is no relationship between CPUE and effort. Such a relationship has yet to be demonstrated in any skipjack fishery (Joseph & Calkins 1969; Kearney 1979).

During the October 1977 visit, 125 schools of tuna were sighted, at an average rate of 0.69 schools per hour. Thirteen schools could not be identified to species; of the remaining 112, 28 per cent were classified as skipjack (for definitions of school composition, see Table 4), 54 per cent as yellowfin, 11 per cent as mixtures of these two species, and the remainder as "other species" apparently without skipjack or yellowfin. The frequency of skipjack schools was less than half that recorded during the whole of the Programme's activities (61%), while the relative abundance of yellowfin tuna schools was four times the average for all the surveys (13%). This was not reflected in the tagging rate for yellowfin (Table 4), due to their poor response to chumming, and commercial catches for the same period contained only a slightly higher proportion of yellowfin than normal (Wankowski 1980a). The low commercial catches of apparently abundant yellowfin may have been due to their relatively larger size (Kearney 1977b), which makes them less vulnerable to pole-and-line gear used in Papua New Guinea.

In May-June 1979, the proportion of identified schools recorded as skipjack was higher (40%) than on the previous visit, whereas the percentage of yellowfin schools was much lower (14%) and mixed skipjack and yellowfin higher (28%). Although 347 schools were sighted, at the rate of 0.84/hour, the proportion of identified schools (55%) was much less than for the first survey (90%). The overall identification rate during the Programme was 49 per cent. The rates at which schools were sighted and fish were caught in the separate areas in Papua New Guinea waters during each visit is shown in Table 12. In general, sighting rates were higher in the commercially fished areas of the eastern Bismarck Sea, New Hanover-Mussau and St George's Channel, and around Manus Island, and lower in other areas not exploited by the commercial fleet.

Despite differences in sighting rate and school composition between the two visits, the recorded chumming success rates were similar to one another and to the Programme's overall average (43, 44 and 47 per cent, respectively). However, several factors led to an overestimate of the chumming response on the first visit, so the figures are not properly comparable. Yellowfin schools dominated the sightings on the first visit but they were rarely chummed, as they were known through experience to respond poorly (Kearney 1977b). Schools of skipjack also responded less vigorously than usual (Section 3.0), so a positive reaction to chumming in many cases involved the capture of only a small number of fish.

Fourteen per cent of all schools identified in Papua New Guinea waters comprised species other than skipjack or yellowfin (Table 4). The average frequency obtained during the whole Programme was eight per cent. These schools were composed of either rainbow runner (_Elagatis bipinnulatus_), mackerel tuna (_Euthynnus affinis_), or frigate tuna (_Auxis thazard_), in decreasing frequency of occurrence, or some combination of the three. They were also the species most commonly found in mixed schools with skipjack and/or yellowfin tuna. Dolphinfish (_Coryphaena hippurus_), double-lined mackerel (_Grammatorcynus bicarinatus_, but see Lewis 1981) and bigeye tuna (_Thunnus obesus_) also occurred, usually in association with other species, rather than in monospecific schools.

Schools of "other species" also constituted a higher proportion than average of all schools identified in the waters of two countries adjacent to Papua New Guinea (Table 3 in Kearney 1983): Solomon Islands (19%) and the Federated States of Micronesia (24%). In both countries, _Euthynnus affinis_, _Auxis thazard_ and particularly, _Elagatis bipinnulatus_ were the

TABLE 12. TUNA SCHOOL SIGHTINGS PER HOUR PER FISHING DAY AND TOTAL CATCHES PER FISHING DAY FOR BOTH SURVEYS BY THE SKIPJACK PROGRAMME IN THE WATERS OF PAPUA NEW GUINEA. "Other areas" fished include the Solomon Sea, Lyra Reef waters and the western Bismarck Sea. Note that schools sighted on days classified as baiting, steaming or in port have not been included in the calculation of sighting rates.

	Days Fishing	Hours Sighting on Fishing Days	SCHOOLS SIGHTED PER HOUR			CATCH (kg) PER FISHING DAY			Kilograms of Bait Carried per Fishing Day
			Skipjack	Yellowfin	Total	Skipjack	Yellowfin	Total	
1 9 7 7									
Manus Island	3	29	0.21	0.17	0.55	3	0	3	50
New Hanover-Mussau	2	14	0.07	-	0.07	0	0	1	169
Eastern Bismarck Sea/ St George's Channel	6	55	0.11	0.87	1.22	12	14	35	239
Other areas	10	84	0.21	0.08	0.48	504	12	535	166
Overall (1977)	21	182	0.17	0.33	0.68	244	10	265	171
1 9 8 0									
Manus Island	7	62	0.24	0.02	0.93	471	134	614	153
New Hanover-Mussau	3	35	0.37	0.06	1.03	994	38	1,035	216
Eastern Bismarck Sea/ St George's Channel	25	247	0.18	0.09	0.87	847	65	920	178
Other areas	5	45	0.07	0.07	0.47	344	0	344	89
Overall (1979)	40	389	0.20	0.07	0.86	729	67	803	165
BOTH YEARS									
TOTAL	61	571	0.19	0.15	0.80	562	47	618	167

main components of these schools. The last species occurred in 11 and 28 per cent, respectively, of the identified schools from the waters of Solomon Islands and the Federated States of Micronesia, and in 11 per cent of identified Papua New Guinea schools. The biological samples also contained relatively high numbers of specimens of the three species. Similar patterns were evident from the surveys in American Samoa and Western Samoa, but the samples were too small to be discussed with confidence. The data from Papua New Guinea, Solomon Islands and the Federated States of Micronesia apparently confirm the subjective impression of Programme scientists that rainbow runner, mackerel tuna and frigate tuna are more common there than elsewhere in the South Pacific Commission region (Kearney & Hallier 1979).

On both visits to Papua New Guinea, over 90 per cent of tuna schools were detected either by their association with bird flocks, with most of the remainder detected by strikes on troll lines. On the second visit, four schools associated with whale sharks (Rhincodon typus) were fished successfully in the St George's Channel area. Such schools are commonly encountered in this area and along the New Britain south coast. Log schools were also fished on both visits, and an experimental fish-aggregation device (FAD) was fished on the second.

4.3 Skipjack Biology

4.3.1 Size

Skipjack tagged or sampled by the Programme in Papua New Guinea waters were large relative to those measured elsewhere. Other studies have found different size frequency distributions, with a smaller average size (e.g. Kearney, Lewis & Smith 1972). Moreover, results from previous surveys (Lewis 1980a, 1980b), as well as measurements made on commercial catches (Cooper & Wankowski 1980; Wankowski 1981), have shown that mean size and distribution of sizes may vary over time, in a manner indicative of growth and recruitment, although the patterns may be complex (Anon. 1980b; Lewis 1980b). Thus, it is difficult to make generalisations about size frequency distributions of skipjack from Papua New Guinea.

The size-related pricing structure of skipjack sold to canneries makes the capture of fish less than two kilograms (approximately 46 cm) unprofitable (e.g. White & Yesaki 1982). However, the paucity of small fish in the Papua New Guinea commercial catches does not appear to be solely a result of fishermen selecting larger individuals, in response to market constraints. The Programme's surveys, and others made earlier (Kearney, Lewis & Smith 1972; Lewis, Smith and Kearney 1974) did not discriminate against small individuals, yet these provided only a very small proportion of the tagged or sampled fish (Figure 5). Fish aggregation devices are thought to attract schools of small skipjack, but 195 skipjack tagged around an FAD in June 1979 were similar in size to others tagged in Papua New Guinea. On only a few occasions were fish smaller than 45 cm taken by the Programme in Papua New Guinea, in subsurface schools to the north of Manus Island and in log-associated schools near New Ireland, mainly in October 1977. The relatively common occurrence of fish of this size or smaller in waters of the Federated States of Micronesia, to the north (Kearney & Hallier 1980) and Solomon Islands to the south (Argue & Kearney 1982) makes their absence from the Bismarck Sea noteworthy.

A surface school of very small skipjack (10-20 cm) was observed in

October 1977 in the eastern Solomon Sea, where similarly small fish had previously been recorded (Kearney 1977b). Occurrences of such small individuals were rare during the Programme.

An apparently stable pattern of geographic variation in mean size of fish in the commercial catch from the Bismarck Sea has been documented by Kearney (1977a). The model proposed by Lewis (1980a, 1980b) for a clockwise migration of Bismarck Sea stocks is superficially consistent with this pattern.

4.3.2 Maturity, reproduction and occurrence of juveniles

Sex could not be determined in only 6 of the 144 skipjack sampled on the first visit and 7 of the 765 sampled on the second visit. On both occasions sex ratio did not differ significantly from unity (X^2 tests, $p>0.05$). Departures from a 1:1 ratio in either direction are not uncommon in samples of skipjack (see Forsbergh 1980). An excess of females was recorded in Papua New Guinea fish in studies by Kearney, Lewis & Smith (1972) and Lewis, Smith & Kearney (1974), in the latter case in all months of the year. Age-related differences in sex ratio have been reported by several authors (Forsbergh 1980). Wilson (1982) showed females to become relatively fewer than males as size increased from 45 to 65 cm in samples from Papua New Guinea, but no such trend was evident in the Skipjack Programme's Papua New Guinea data.

Only female skipjack were used in assessment of sexual maturity, as the condition of male gonads could not be determined reliably by macroscopic examination (cf. Wilson 1982). Criteria for the seven-stage classification of ovary development were given by Argue (1982). Only four per cent of the 447 female skipjack examined were immature (stages 1 and 2, Figure 6). This is mainly a reflection of the very few small fish captured, although at least some immature females were present in all size-classes up to 57 cm (Figure 7). Earlier studies of both condition and weight of gonads indicate that maturity (>stage 2) is rarely achieved by fish less than 45 cm long in Papua New Guinea (Lewis, Smith & Kearney 1974; Wilson 1982) or elsewhere (Forsbergh 1980). Stage 3 fish dominated the sample (Figure 6), as they did nearly all samples taken in tropical waters by the Skipjack Programme. Although no running ripe or spent fish (stages 5 and 6, respectively) were encountered, the presence of mature (stage 4) and recovering (stage 7) gonads implies that skipjack spawning occurs in Papua New Guinea waters. The infrequency of running ripe females has been noted in other studies (see Wilson 1982). Suggested explanations of this phenomenon include failure of ripe individuals to respond to chum, absence of surface schooling behaviour in ripe fish, and a very rapid transition from maturity to spawning, perhaps occurring at night.

Gonad indices[1] of both female and male skipjack from Papua New Guinea display significant seasonal differences, with maximum values occurring in summer months and minima in winter (Lewis 1981; Wilson 1982). However, the range of values encountered in any month is wide (Wilson 1982). The mean gonad index for female fish on the Programme's October

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1. Gonad index=10^7(gonad weight gm/(fish length mm)^3) (Schaefer & Orange 1956). High index values, particularly over 50, are associated with fish whose gonads have a high percentage of eggs that are ready to be spawned (Raju 1964).

1977 visit was 52.1, significantly higher than the mean of 40.8 recorded for the May-June 1979 visit (Student's t-test, $p<0.05$). Both values are larger than the average for these months recorded in the previous studies by Lewis (1981) and Wilson (1982). More detailed comparison of the results is not warranted in the absence of length data, which were not provided by Lewis or Wilson. The pattern of a summer maximum and a winter minimum in gonad indices is general to countries in tropical waters south of the Equator visited by the Programme (Figure 9), but fish in temperate waters do not achieve maturity even in summer (e.g. Argue & Kearney 1983).

Although fish with mature ovaries may be present at all times of the year in Papua New Guinea waters, indicating possible year-round spawning, they are most common between October and March (Wilson 1982). The close correlation between gonad index and mean size of ova, and the presence of fish with largely spent gonads only in November - February (Wilson 1982) corroborate evidence from maturity and gonad indices that most reproductive activity occurs in the summer months.

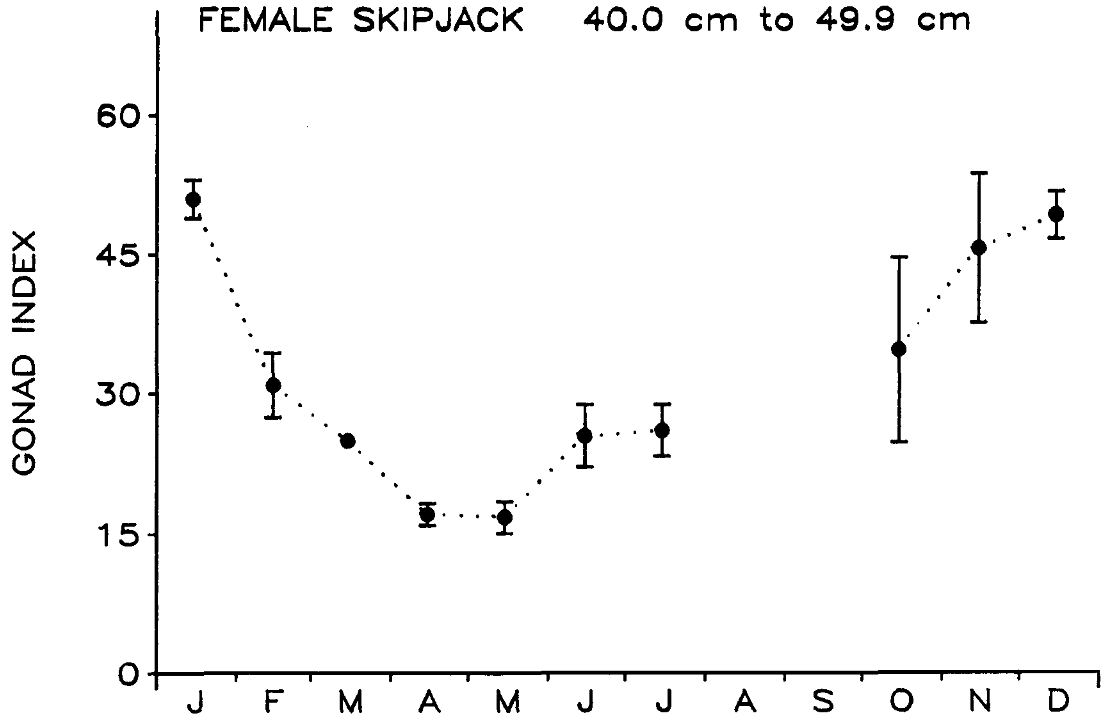
A further indicator of breeding is the incidence of juvenile skipjack in the stomachs of predators (Table 7). Skipjack juveniles were found in the stomachs of adult skipjack and yellowfin tuna in Papua New Guinea and occasionally also in the stomachs of frigate tuna and wahoo elsewhere in the Programme's study area. They were more common during the October 1977 visit (11.51 and 113.79 juveniles per hundred skipjack and yellowfin stomachs examined, respectively) than during the May-June 1979 visit (6.14 and 3.20, respectively). Analyses by Argue, Conand & Whyman (1983) indicate that the incidence of skipjack juveniles in predator stomachs is significantly higher in summer than in winter in Papua New Guinea and several other countries. The Programme's data are also consistent with observations made during earlier Papua New Guinea surveys (Lewis, Smith & Kearney 1974). Within the South Pacific Commission region during the period 1977-80, abundance of skipjack juveniles was highest in two areas, one centred approximately on Papua New Guinea - Solomon Islands - Vanuatu, and the other on the Marquesas and Tuamotu Islands, suggesting that there may be geographical localisation of spawning activity in addition to seasonal patterns.

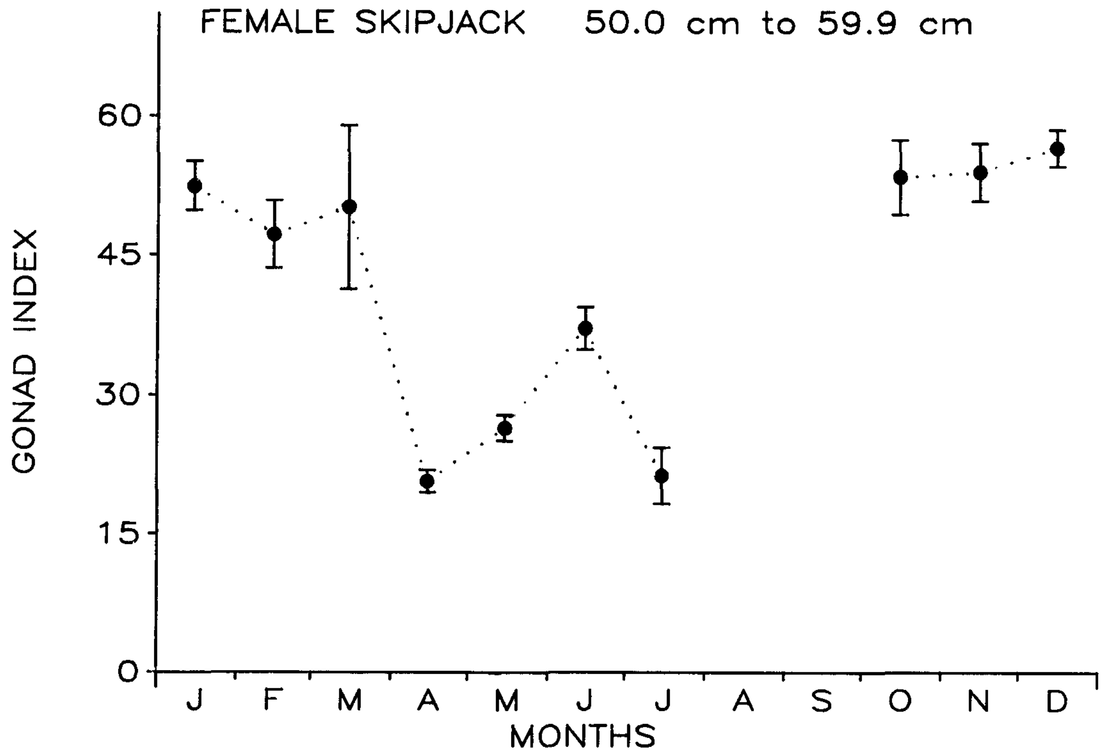
4.3.3 Skipjack diet

Apart from chum, the items most commonly encountered in skipjack stomachs from Papua New Guinea were unidentified fish remains, squid, acanthurids (surgeonfish) and alima stages of stomatopod crustaceans (Table 8). Representatives of four other fish families, triggerfish (Balistidae), lizardfish (Synodontidae), flyingfish (Exocoetidae) and soldierfish (Holocentridae) and three crustacean orders were also found in more than 10 per cent of stomachs examined. A full list of items occurring in stomachs of skipjack sampled in Papua New Guinea waters is given in Appendix C.

Assessments of the diet of Papua New Guinea skipjack by abundance (i.e. volume) rather than frequency of food items may be found in Lewis, Smith & Kearney (1974) and Wilson (1982). All studies done in Papua New Guinea indicate the importance of fish to the diet, but also emphasise the opportunistic nature of skipjack feeding. This can lead to major differences between the diets of fish from different geographic regions (see Forsbergh 1980); variations in diet composition within the South Pacific Commission area are the subject of continuing analyses.

FIGURE 9. AVERAGE GONAD INDICES(± two standard errors), BY MONTH, FOR FEMALE SKIPJACK SAMPLED BY THE SKIPJACK PROGRAMME FROM TROPICAL WATERS SOUTH OF THE EQUATOR BETWEEN 1977 AND 1980. Standard errors have been omitted from one small sample (n<5) in March, top graph; other sample sizes were at least 8 and most exceeded 100.





4.3.4 Blood genetics and population structure

Studies of genetic variation may be used to infer the breeding structure of populations. To complement tagging and other data, between 1978 and 1980 the Skipjack Programme collected 5,812 blood specimens from approximately 100 individuals in each of 58 schools, for analysis of electrophoretically detectable protein polymorphisms (indicators of genetic variation). Two hundred and seventeen specimens were from two schools fished in Papua New Guinea in May and June 1979. Results from approximately 50 schools sampled in Papua New Guinea's waters by Lewis (1980b, 1981) and Richardson (1983) were also available to the Programme.

Only one of the 42 active loci detected in the analyses of skipjack blood was suitable for detailed study (Anon. 1981; Richardson 1983). The frequency of an allele ($E_{SJ}1$) of the gene which codes for serum napthyl esterase was found to vary significantly along a longitudinal gradient, its average value increasing from 0.37 at 130°W to 0.78 at 120°E (Figure 8). The mean values from two schools sampled by the Programme in Papua New Guinea waters fell well within the 95 per cent confidence limits of the regression line of gene frequency against longitude.

The gradient in $E_{SJ}1$ indicates that it is unlikely that the western Pacific contains a "panmictic" population of skipjack, in which all individuals have an equal probability of interbreeding. Several other models of population structure were considered at two workshops convened by the Skipjack Programme (Anon. 1980a, 1981), all of which incorporate the concept of "isolation-by-distance", such that the probability of mating between any two fish is an inverse function of the distance between them. They eschew any requirement for geographic or other barriers separating genetically isolated subpopulations of skipjack, as proposed by Fujino (1972, 1976) and Sharp (1978). Tagging and recovery data (Figure B, inside back cover) also suggest that there are no barriers to movement. In particular, fish tagged in Papua New Guinea migrated across the putative boundary between eastern and western Pacific subpopulations of skipjack (Section 4.4.4.1).

One model considered by the second workshop (Anon. 1981) views the $E_{SJ}1$ gradient as a continuous cline, maintained by unknown selective pressures and/or isolation-by-distance, with an even distribution of spawning along its length. An alternative model considers the gradient to be a product of the "overlap" of skipjack from two or more centres of higher spawning activity, at the extremes of the study area or beyond. The similarity between eastern Pacific $E_{SJ}1$ frequencies (east of 120°W; Figure 8) and those from French Polynesia suggests that skipjack from these areas may have the same genetic origin, and collectively may represent a spawning group at the eastern extreme of the study area. The geographic pattern of occurrence of juvenile skipjack in predator stomachs (Section 4.3.2), together with gonad maturity data, tentatively supports the "breeding subgroups" model. However, the simpler "continuous cline" model cannot be rejected by the available data.

Variation in $E_{SJ}1$ frequency over time within the New Hanover sector of the Papua New Guinea commercial fishery was characterised by Lewis (1981). Average values were consistent with those from the Programme's studies. The periodic, apparently seasonal presence of groups of skipjack with lower gene frequencies characteristic of areas to the east suggested influxes to the fishery from other areas (Lewis 1981). This pattern may be the source of much of the variance in Papua New Guinea samples (many of which were provided to the Programme by Lewis), plotted at 151°E in Figure 8.

The Programme's blood genetics data have been complemented by studies of growth, migration and parasite fauna in investigations of population structure. Growth appears to be variable in space and time (Section 4.4.2) and thus offers little assistance in elucidating population structure. The migration data do not point to the existence of barriers to genetic exchange in the central and western Pacific (Section 4.4.3). A multivariate analysis of parasite records (Lester, Barnes & Habib ms.) showed that the parasite faunas of widely separated tropical areas were similar, and that skipjack caught in New Zealand carried many tropical parasites. These data suggest that further analyses of parasite fauna will not result in greater clarification of skipjack population structure. The various limitations of all these data have confounded the choice between different population structure hypotheses (Anon. 1981; Argue, Kleiber, Kearney & Sibert ms.). The consensus of the evidence is that, theoretically, there is scope for interaction across the whole of the Programme's study area, but in the short-term interactions between fisheries at the extremes of this area should be minimal. The potential for interaction increases as the distance between adjacent fisheries decreases, and as fishing effort becomes greater.

4.4 Skipjack Tagging

4.4.1 Tagging and recapture statistics

During the two visits by the Skipjack Programme to Papua New Guinea, 9,386 fish were tagged and released, of which 8,550 were skipjack (Table 13). All fish were single-tagged with the exception of four skipjack and two yellowfin double-tagged in 1977. Most fish were released in May (3,428) and June (5,040) of 1979, mainly in the commercial fishing areas of the eastern Bismarck Sea, including St George's Channel. The few 1977 releases (918 tuna) were concentrated in the eastern Solomon Sea.

Until 20 November 1981, when the last known recovery was made, 1,116 tagged skipjack were recaptured, mostly in local waters (959 or 86%). Eighty-eight recaptures were by vessels fishing outside the Papua New Guinea 200-mile zone, while 69 skipjack tags were returned with insufficient information to allow their place of recovery to be ascertained (Table 13). Tagged yellowfin were recaptured in Papua New Guinea waters at a much lower rate than were skipjack, but outside the DFZ the two species were recovered at similar rates.

Tags released in 1979 were recovered at a much higher rate than those released in 1977 (13.45% vs 0.6%). Two factors which may have contributed to this striking difference can be inferred from Table 14, which shows skipjack tag return rates for various displacement and time-at-liberty categories. Most skipjack were recaptured at a point relatively close (50-100 nautical miles) to the release position after a short time at liberty (1-4 months). Similar patterns are evident in all recoveries notified to the Programme (Kearney 1983). The 1977 releases were mainly in areas more than 150 nautical miles from the commercial fishing grounds, strongly reducing their probability of recovery. Moreover, in the three months following the 1977 release of tags, the commercial catch of skipjack was about one-third that taken in the same period following the 1979 releases (Figure 2).

TABLE 13. RELEASES AND RECOVERIES OF TUNA TAGGED BY THE SKIPJACK PROGRAMME IN PAPUA NEW GUINEA. Numbers of tuna tagged during 1977 and 1979 within Papua New Guinea's Declared Fishing Zone (DFZ), and the numbers of local recoveries (from within the DFZ), external recoveries (from international waters or the 200-mile zones of other countries and territories) and recoveries from unknown locations. Percentage of tags recovered is given in brackets. SJ=skipjack, YF=yellowfin, OT=other tuna species.

		October 1977	May/June 1979	Species Totals	Total
Fish tagged	SJ	900	7650	8550	9386
	YF	18	816	834	
	OT	0	2	2	
Local recoveries	SJ	3(0.3)	956(12.5)	959(11.2)	978
	YF	0	19(2.3)	19(2.3)	
External recoveries	SJ	3(0.3)	85(1.1)	88(1.0)	46
	YF	0	8(1.0)	8(1.0)	
Position indeterminate recoveries	SJ	1(0.1)	68(0.9)	69(0.8)	75
	YF	0	6(0.7)	6(0.7)	
					1149

TABLE 14. RECOVERIES OF TAGGED SKIPJACK RELEASED IN PAPUA NEW GUINEA, BY TIME-AT-LARGE AND DISPLACEMENT (straight-line distance between points of release and recovery, equal to minimum distance travelled). Data from both visits are combined.

Displacement (nautical miles)	Days at Large							
	0-10	11-30	31-60	61-120	121-180	181-360	>360	TOTALS
<50	156	115	106	65	10	3	4	459
50-100	37	68	64	42	13	5	9	238
100-200	11	57	28	36	7	2	6	147
200-400	0	0	1	7	5	3	3	19
400-800	0	0	1	5	6	20	12	44
800-1200	0	0	0	2	0	2	2	6
1200-2400	0	0	0	0	0	5	15	20
>2400	0	0	0	0	0	0	3	3
TOTALS	194	240	200	157	41	40	54	936*

* This number is fewer than shown in Table 13, which included recoveries made at an indeterminate time.

As might be predicted from Table 14, recovery rates were highest for fish released within the areas most actively exploited by the commercial fleet, such as the eastern Bismarck Sea, New Hanover-Mussau and St George's Channel (Table 15). Ninety per cent of recoveries of fish released in these areas were "local", that is, from within the Papua New Guinea DFZ. Other areas experienced a much lower proportion of local recoveries (averaging approximately 20%), reflecting both the absence of an intensive local fishery and proximity to other fisheries outside of Papua New Guinea waters. In particular, the low recovery rate and high proportion of external recoveries of the many fish tagged near Manus Island is a result of the decline of the local fishery in the months immediately after the Programme's visit, due to closure of the local baiting grounds (PNG DPI unpublished data; Anon. 1980b). There were no recoveries from releases in the western Bismarck Sea, northern Solomon Sea, southern Solomon Sea and north of New Ireland, where few releases were made and little fishing effort is expended.

TABLE 15. NUMBERS OF SKIPJACK TAGGED BY THE SKIPJACK PROGRAMME IN SEVERAL AREAS OF PAPUA NEW GUINEA AND PERCENTAGE SUBSEQUENTLY RECOVERED. The first three areas are those in which operations of the locally based pole-and-line fleet were concentrated.

Area	Number of Releases	Number of Local Recoveries	Number of External Recoveries	Total Number of Recoveries*	Overall Recovery Rate(%)
Eastern Bismarck Sea	4145	583	26	654	15.8
New Hanover-Mussau	759	71	6	80	10.5
St George's Channel	1154	292	14	318	27.6
Manus Island	978	5	27	37	3.8
North of New Ireland	1	0	0	0	0
Western Bismarck Sea	135	0	0	0	0
Northern Solomon Sea	2	0	0	0	0
Southern Solomon Sea	22	0	0	0	0
Eastern Solomon Sea	872	2	3	6	0.7
Western Solomon Sea	482	6	12	21	4.3
Totals and Averages	8550	959	88	1116	13.1

* Recoveries of tagged fish from indeterminate locations have been included in this column.

The distribution of recoveries among the various vessel types operating in Papua New Guinea is consistent with the geographical pattern of recaptures. Most tags were recovered by the locally based pole-and-line fleet (Table 16), operating in the area in which most tags were released. The few recaptures by other commercial operators were in areas away from the release points, principally north-west of Manus Island.

TABLE 16. RECOVERIES WITHIN PAPUA NEW GUINEA WATERS, BY VESSEL TYPE, OF SKIPJACK TAGGED IN PAPUA NEW GUINEA

Vessel Type	Time of Release		
	1977	1979	Total
Papua New Guinea pole-and-line	1	935	936
Japanese distant water pole-and-line	0	3	3
SPC tagging vessel	1	4	5
Other pole-and-line	1	1	2
Japanese purse-seine	0	4	4
United States purse-seine	0	1	1
Papua New Guinea artisanal	0	5	5
Unknown capture vessel	0	3	3
Totals	3	956	959

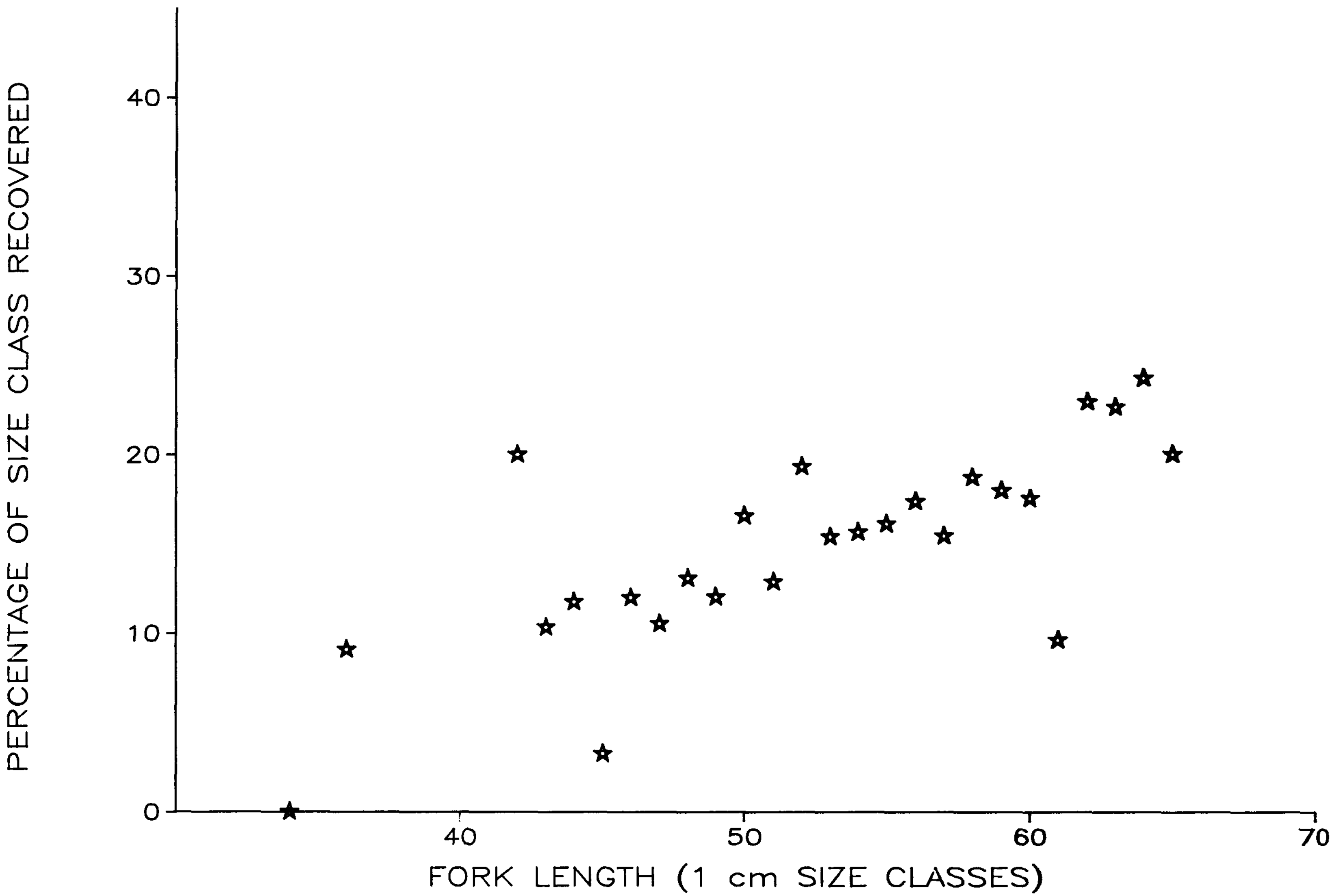
Figure 10 shows the recovery rates for skipjack released in Papua New Guinea waters by one centimetre size classes at time of release. A slight increase in recovery rate with size-at-release is evident, suggesting a small change in vulnerability to the pole-and-line fishery as fish grow or a lower natural mortality rate in larger fish. The latter explanation is unlikely (Kleiber, Argue & Kearney 1983). The trend towards higher recovery rates with greater size at release was found in the tag recapture data of only one other country (Fiji) and was not evident in the Programme's overall results (Kearney 1983). A pattern of higher recoveries of medium-sized fish (approximately 50 cm) and low recoveries of smaller and larger fish was evident in the data from three areas, Solomon Islands, New Zealand and Federated States of Micronesia (Argue & Kearney 1982, 1983; Tuna Programme ms.), but the basis of this pattern is not understood.

4.4.2 Growth

Of the 1,109 recoveries of skipjack tagged in Papua New Guinea during the 1979 visit (Table 13), 825 were included in analyses of growth. The remainder failed to meet criteria for reliability of recovery date or measurement records (see Sibert, Kearney & Lawson 1983). Most recoveries (788) were from within Papua New Guinea's 200-mile zone, where they were at liberty for an average of 41 days. Over half these fish (55%) did not increase in length, while of the 37 fish recovered outside Papua New Guinea waters, on average 198 days after tagging, four showed no growth.

The merits of skipjack growth determinations based on tag recapture studies, relative to those based on other methods, have been discussed by Josse et al. (1979). Analytical techniques for estimating growth of skipjack from the Programme's tag recapture data were developed by Sibert, Kearney & Lawson (1983) and Lawson, Kearney & Sibert (ms.). The application of these data to growth studies is complicated by the deterministic growth of skipjack (Joseph & Calkins 1969), in which growth

FIGURE 10. RECOVERY RATES OF SKIPJACK TAGGED IN PAPUA NEW GUINEA, BY ONE CENTIMETRE LENGTH-AT-RELEASE CLASSES



rates (measured as increase in length) decline as fish become larger. Thus, length increments of Papua New Guinea skipjack may be expected to differ according to both the size of the fish when tagged and the duration of the period at liberty until recapture. The effects of both factors are evident in the summary of length increases for fish in two size classes, 30-49 cm and 50-70 cm, at large for various time periods (Table 17). The average growth rates of fish in the former group were about ten times those of fish in the latter group (which was on average 9 cm longer at release). However, differences in growth rate became much less marked in fish recaptured after longer periods (e.g. 366-730 days), probably because individuals tagged in the smaller size class grew into the larger size class within a year, experiencing progressively decreasing growth.

Exact comparisons of the length increment data in Table 17 with results from other studies cannot be made, since the continuously changing growth rate during the life of a skipjack dictates that valid comparisons exist only between data sets comprising fish tagged when at the same size, and recaptured after the same period at liberty. Josse et al. (1979) using data from earlier tagging work in Papua New Guinea (see Lewis, Smith & Kearney 1974; Lewis 1980a, 1980b), and Lawson & Kearney (ms.) using the Skipjack Programme's data, provided crude estimates of annual growth rates for fish of various sizes, by extrapolation from increments recorded over shorter periods at liberty. This procedure, though imprecise, has enabled approximate comparisons of growth of fish from different regions (e.g. Forsbergh 1980; Argue and Kearney 1982).

4.4.2.1 Standardised growth increment

To facilitate more exact comparisons between data sets, such as those from different countries or from different release times in the same country, Sibert, Kearney & Lawson (1983) derived a "standardised increment" of growth. They employed a linear approximation of the von Bertalanffy growth model in an analysis of covariance, to determine the growth increment for a "standard" fish measuring 50 cm when released, and at large for 90 days before recapture within the 200-mile DFZ. Only fish at large for periods between 10 and 365 days were used (n=646).

The standardised increment of length is listed in Table 18, separately for fish recovered inside or outside Papua New Guinea waters, and for fish recaptured from tagging in 1972-74 (Lewis 1980a, 1980b). Also included are the standardised increments for fish tagged on Skipjack Programme visits to six other countries, from which tag recoveries were sufficient for analysis. Growth rate was variable within the South Pacific Commission region, with the Papua New Guinea figures in the middle of the range shown in Table 18. Increments of fish tagged through 1972-74 and in May-June 1979 were similar, though this comparison between a set comprising taggings over several years and a set comprising tags released all at one time has inherent limitations. Fish tagged in Papua New Guinea in 1979 but recovered outside the 200-mile zone had a smaller increment than those which ostensibly did not migrate. The analysis by Sibert, Kearney & Lawson (1983) revealed that significant differences in growth may exist between country data sets, between data sets from different visits to a country, and between data sets for "migrating" and "residential" fish. Thus, while significant geographical differences in fish growth can be identified, they cannot be regarded as stable, because equally significant differences can occur between data sets subsequently obtained within particular countries.

TABLE 17. SUMMARY OF LENGTH INCREMENTS FOR FISH TAGGED IN PAPUA NEW GUINEA IN MAY-JUNE 1979. Results are given for different size classes at time of tagging for seven time-at-liberty classes and for fish recaptured inside and outside Papua New Guinea's 200-mile declared fishing zone.

Release Length Range (cm)	Days at Liberty Range	Sample Size	Release Length (cm) Mean	Release Length (cm) SD	Recapture Length (cm) Mean	Recapture Length (cm) SD	Days at Liberty Mean	Days at Liberty SD	Growth (cm) Mean	Growth (cm) SD	Per cent Non-Growers
			Within Papua New Guinea 200-mile zone								
30.0-49.0	0 - 9	16	47.7	1.5	51.1	4.6	6.6	2.4	3.44	4.59	50.0
	10 - 29	17	45.9	3.6	47.8	4.7	21.4	6.2	1.82	2.13	29.4
	30 - 89	15	45.9	3.5	51.0	5.9	56.7	18.9	5.07	5.42	0.0
	90 - 179	3	44.7	2.3	53.7	4.7	125.7	46.4	9.00	7.00	0.0
	180 - 365	3	44.7	4.2	55.0	3.0	198.0	17.8	10.33	2.89	0.0
	366 - 730	1	46.0	0.0	58.0	0.0	412.0	0.0	12.00	0.00	0.0
	10 - 365	38	45.7	3.4	50.1	5.5	57.5	53.5	4.34	4.89	13.2
50.0-70.0	0 - 9	163	54.6	3.2	54.6	4.0	5.3	2.7	.05	3.04	66.3
	10 - 29	210	54.6	2.2	54.5	2.3	19.9	5.8	-.10	1.87	69.0
	30 - 89	271	55.3	2.6	55.7	3.1	48.8	17.6	.34	2.39	50.2
	90 - 179	82	56.0	2.8	57.5	5.1	115.2	19.3	1.44	5.08	37.8
	180 - 365	8	56.0	3.3	60.3	3.8	288.5	54.4	4.25	2.76	12.5
	366 - 730	15	54.3	3.1	62.7	5.4	441.7	27.4	8.33	5.35	6.7
	10 - 365	571	55.2	2.5	55.6	3.4	51.1	44.6	.39	2.87	54.8
			Outside 200-mile zone								
30.0 - 49.0	10 - 365	12	46.3	2.3	52.3	5.0	160.6	93.8	6.00	4.90	8.3
50.0 - 70.0	10 - 365	25	54.0	1.6	59.0	5.0	215.6	89.4	5.00	4.48	12.0

TABLE 18. STANDARDISED INCREMENT OF LENGTH (cm) FOR A FISH TAGGED WHEN 50 CM LONG AND AT LIBERTY FOR 90 DAYS, FOR PAPUA NEW GUINEA AND OTHER COUNTRIES VISITED BY THE SKIPJACK PROGRAMME. Fish recaptured inside and outside Papua New Guinea's 200-mile zone were analysed separately; only fish from inside the respective 200-mile zones were analysed for the other countries. The 1972-1974 Papua New Guinea data were from studies by the PNG DPI (see Lewis 1980a, 1980b).

Country	Survey Date		Increment (cm)	95% Confidence Interval
Papua New Guinea	1979	inside	3.2	± 1.5
		outside	2.2	± 1.2
Papua New Guinea	1972-74		2.6	± 1.5
Fiji	1978		3.7	± 6.9
Fiji	1980		5.6	± 1.3
Kiribati	1978		1.4	± 1.2
Palau	1980		8.5	± 6.4
Ponape	1980		4.1	± 4.1
Solomon Islands	1977		2.5	± 1.4
New Zealand	1979		1.5	± 5.2

The great variability in skipjack growth implied by the analysis of covariance had been recognised previously (e.g. Josse et al. 1979). However, the previous, less rigorous analyses failed to identify statistically significant differences between data sets from different regions, since the factors contributing to the high variability could not be discriminated. The approach by Sibert, Kearney & Lawson (1983), by successfully apportioning the variance between different sources, provides a partial test of hypotheses which seek to explain skipjack growth. Though the effects of environment or genotype on skipjack growth are not yet understood, Sibert, Kearney & Lawson (1983) concluded that genetically based differences in growth are less manifest than environmentally induced differences. Consequently, the utility of growth rate data for studies of phenomena such as population structure (e.g. Kearney 1978b) is not great.

4.4.2.2 Von Bertalanffy growth model

The von Bertalanffy model was fitted to data from fish at large for periods of 1-720 days (Sibert, Kearney & Lawson 1983) to provide estimates of the parameters L_∞ (theoretical average maximum size) and K (instantaneous rate of change in growth), which conventionally are used to describe growth of fish (Fabens 1965). The parameter estimates are summarised in Table 19 for the 1979 Papua New Guinea data set, and for six other countries from the South Pacific Commission region. The parameters derived for other data sets from Papua New Guinea, by Josse et al. (1979) using tag recapture records from 1972-74 surveys, and by Wankowski (1981) using modal progressions in length-frequency distributions of 1977-79 commercial catches, are also listed. Among the three analyses of growth in

TABLE 19. SUMMARY OF PARAMETERS OF THE VON BERTALANFFY MODELS FOR THREE STUDIES OF GROWTH OF SKIPJACK IN PAPUA NEW GUINEA, AND FOR DATA FROM SKIPJACK PROGRAMME VISITS TO SIX OTHER COUNTRIES

Country	Date	L_∞	K (per year)	Variance Explained (%)	Reference
Papua New Guinea	1979	60.2	1.55	44.4	Sibert, Kearney & Lawson (1983)
	1972-74	65.5	0.95	-	Josse et al. (1979)
	1977-79	74.8	0.52	-	Wankowski (1981)
Fiji	1978	53.5	2.67	71.8	Sibert, Kearney & Lawson (1983)
	1980	79.3	0.48	63.5	"
Kiribati	1978	52.2	3.63	44.5	"
Palau	1980	54.2	3.91	55.4	"
Ponape	1980	76.9	0.54	72.5	"
Solomon Islands	1977	60.2	1.23	44.6	"
New Zealand	1979	46.6	5.88	53.1	"

Papua New Guinea the value of K varies by a factor of three, and L_∞ by 14 cm. The model fitted by Sibert, Kearney & Lawson (1983) explained only 44 per cent of the variance in the data, indicating the model provides an incomplete description of growth of fish tagged in 1979. The models by Josse et al. (1979) and Wankowski (1981) were similarly inexact. Moreover, simulation modelling by Sibert, Kearney & Lawson (1983) showed the parameter estimates to be significantly affected by even small errors in measurement at time of release, indicating inherent difficulties in deriving a robust model. The disparities among the parameter estimates from the three studies emphasise that it is statistically improbable that any single data set will yield a definitive model of fish growth, even in a fishery as geographically restricted as that of Papua New Guinea. Thus, the management applications of the von Bertalanffy parameter estimates presently available must be approached with caution.

4.4.3 Local movements

The elucidation of skipjack dispersal patterns within Papua New Guinea's DFZ was constrained by the uneven distribution of fishing effort in both space and time. Most local recoveries of tagged skipjack occurred in the relatively small commercial fishing area of the eastern Bismarck Sea, New Hanover-Mussau and St George's Channel (Table 15). The majority of these were within 100 nautical miles of their respective points of release and within one month of being released (Table 14), thus yielding little information about movement. The lack of fishing activity in the western and northern Bismarck Sea, and in all sectors of the Solomon Sea except the northwest, determined that dispersal to those areas would remain undetected. Similarly, the generally low catch rates in the Papua New Guinea-Solomon Islands region in late 1977 and early 1978 resulted in few recoveries of the tags released in October 1977 in the eastern Solomon Sea (Section 4.4.1), precluding a detailed assessment of dispersal from that area.

Tagged skipjack released in the eastern Bismarck Sea and the New Hanover-Mussau area dispersed south into St George's Channel, west along the northern coast of New Britain, and north through the northeastern Bismarck Sea (Figures 11 and 12). A few fish were captured north and west of Manus Island. Recoveries of fish tagged and released in St George's Channel were mostly from the eastern and northern Bismarck Sea (Figure 11). These data are generally consistent with the model of movement of skipjack within the Bismarck Sea proposed by Lewis (1980b, 1981), although they are insufficient to test it rigorously, partly because of the absence of fishing effort in large parts of the Bismarck Sea. Lewis' model proposed that movement from the commercial fishery occurs in two directions : strongly and persistently to the southwest, providing a group of skipjack largely "resident" in the Bismarck Sea and moving around it in a clockwise direction, and weakly and seasonally to the northwest through the New Hanover area and eventually out of the Bismarck Sea into more northerly waters.

The lack of recoveries in the Solomon Sea prevents any assessment of a further aspect of Lewis's model, that of seasonal migration between the Bismarck and Solomon Seas. However, the recapture in Solomon Islands of seven fish tagged in St George's Channel implies movement southward through the Solomon Sea. Conversely, the recovery near Kavieng in New Ireland of one fish tagged near Bougainville suggests possible movement northwards through the Solomon Sea (Figure 12). Also, four fish tagged in the western Solomon Sea subsequently were recaptured in the eastern Bismarck Sea.

FIGURE 11. STRAIGHT-LINE REPRESENTATIONS OF MOVEMENTS OF SKIPJACK TAGGED IN THE EASTERN BISMARCK SEA AND ST GEORGE'S CHANNEL, AND RECOVERED IN PAPUA NEW GUINEA WATERS. Releases and recoveries have been selected to show no more than two migrations between any pair of one-degree squares. Tick marks on the arrows represent 30-day periods at large.

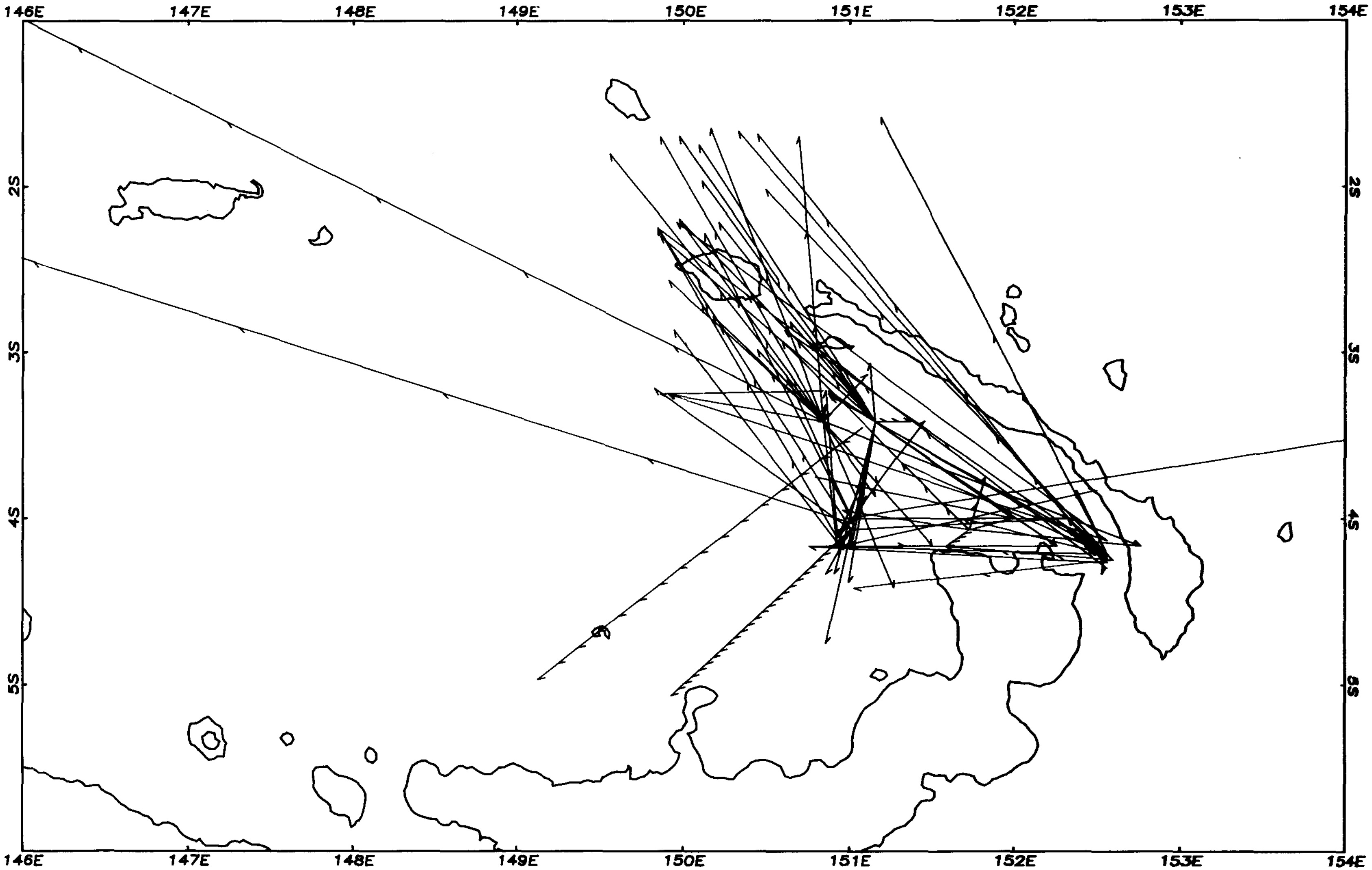
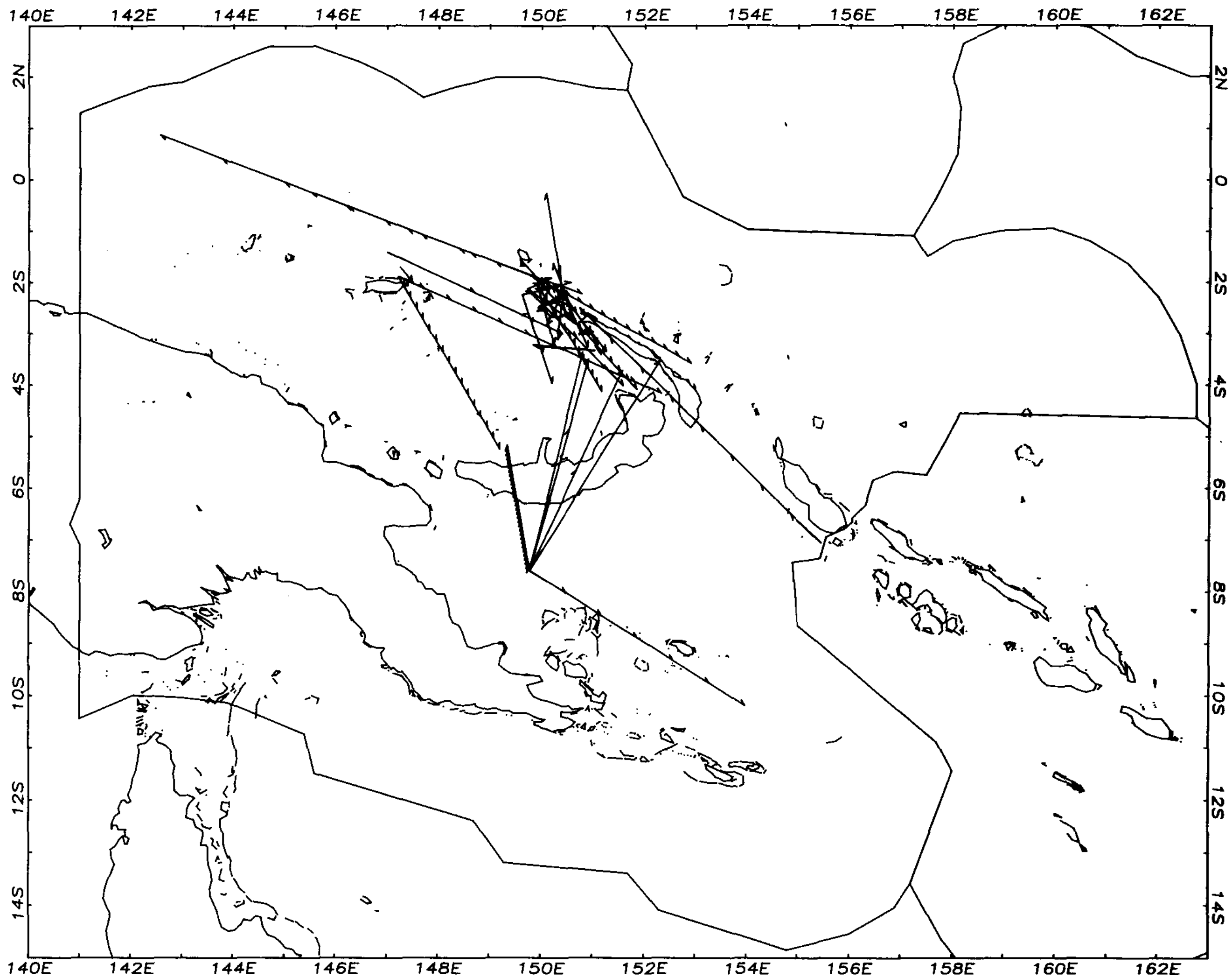


FIGURE 12. STRAIGHT-LINE REPRESENTATIONS OF MOVEMENTS OF SKIPJACK TAGGED IN THE NEW HANOVER-MUSSAU AREA, NEAR MANUS ISLAND AND IN THE SOLOMON SEA, AND RECOVERED IN PAPUA NEW GUINEA WATERS. Releases and recoveries have been selected to show no more than two migrations between any pair of one-degree squares. Tick marks on the arrows represent 30-day periods at large.



Cooper & Wankowski (1980) reported movements into the Bismarck Sea of fish tagged in the northern Coral Sea. In these instances of northward migration, it is not known whether the Vitiaz Strait, St George's Channel, or the New Hanover area provided the conduit into the Bismarck Sea.

Thus, there is qualified support for the model postulated by Lewis (1980b, 1981). However, several data emphasise the unpredictability of skipjack movements in Papua New Guinea. The releases made in the western Solomon Sea (from a single school) resulted in recoveries to the northwest (Indonesia), northeast (Phoenix Islands), east (Solomon Islands) and south (Queensland), as well as those in the Bismarck Sea mentioned above. Fish tagged near Manus Island were recaptured at points in an arc of 180° to the north, as well as in the eastern and southern Bismarck Sea (Figure 12).

4.4.4 Long distance movements

The capacity of skipjack to undertake long migrations is well known (Joseph, Klawe & Murphy 1980). The maximum displacement recorded by the Skipjack Programme was 3,470 nautical miles; many of the migrations over long distances are displayed in Figure B. The longest period at liberty was 1,070 days. A few migrating fish achieved minimum average velocities of almost 60 nautical miles per day. However, displacements of more than 200 nautical miles were reported for only 19 per cent of the skipjack tagged between 1977 and 1980, and less than one per cent were recovered 2,000 nautical miles or more from their release points.

4.4.4.1 Movements from Papua New Guinea

External recaptures of skipjack are summarised in Table 20 by month of release and month and area of recapture. Full details of each recovery made outside Papua New Guinea's 200-mile zone are provided by Appendix D. The greatest displacement was 3,470 nautical miles, for a fish tagged in St George's Channel when 52 cm long, and recaptured 173 days later in international waters east of Line Islands, when it was 54.1 cm long. The maximum period at liberty was 903 days for a fish tagged in the western Solomon Sea when 51.1 cm long, and recaptured in the same area, 148 nautical miles away, when it was 66.5 cm long. A selection of individual movements from Papua New Guinea is illustrated as straight-line trajectories in Figure 13.

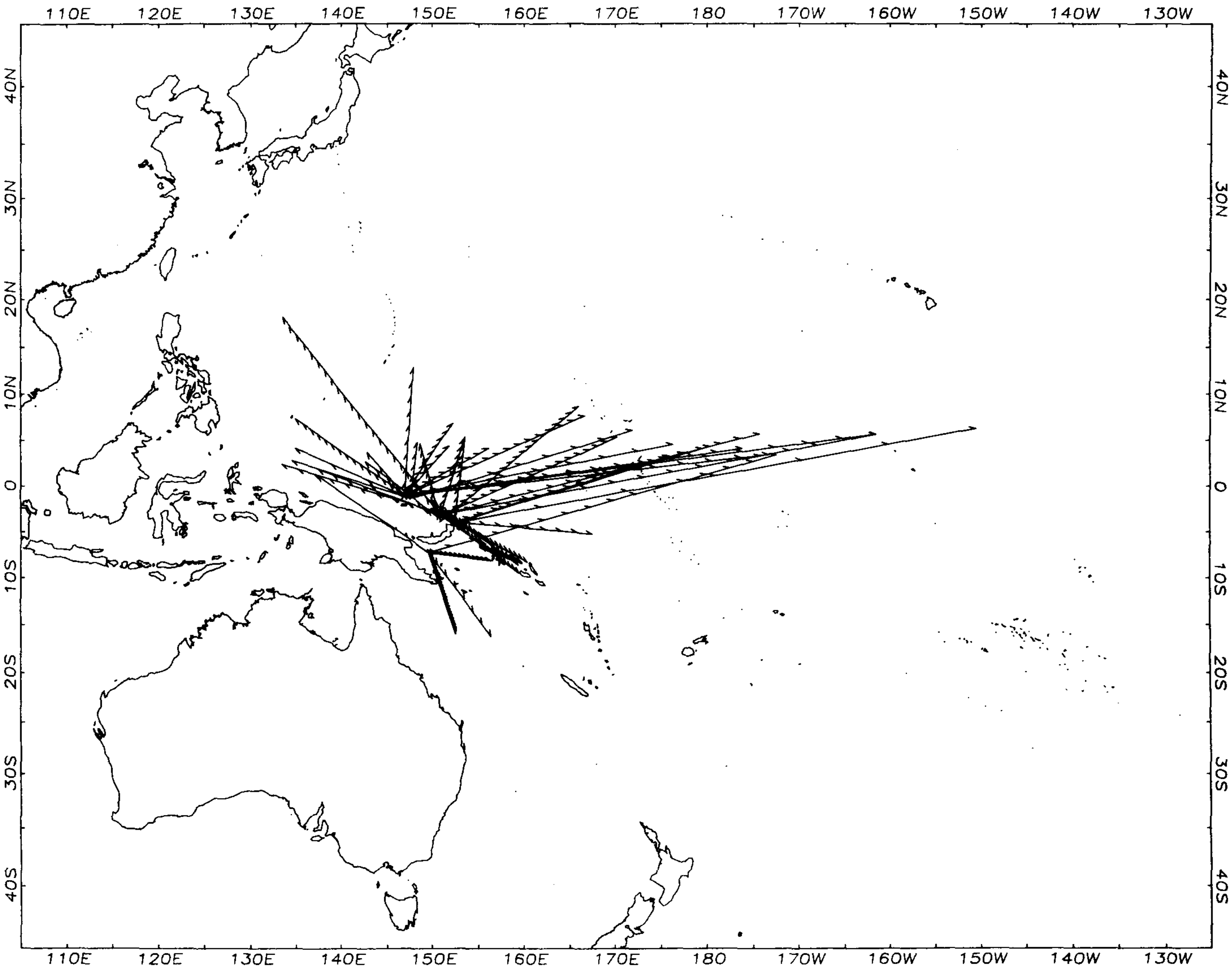
Analysis of skipjack movement into waters external to Papua New Guinea's DFZ seeks to determine whether movement occurs essentially randomly or whether it occurs in preferred directions, implying migration pathways. The distinction is important to understanding the type and degree of interaction with neighbouring fisheries. However, it is often difficult to discriminate between the two patterns; the distribution of tag recaptures, from which movement patterns must be inferred, is a function of several factors other than simply random or directed dispersal. For example, the relative abundance of tagged fish in an area is influenced by the decline in fish numbers over time (and therefore with distance from release point) because of natural or fishing mortality. More significantly, the distribution of fishing effort, through which tagged fish are located, affects perception of movement patterns.

It is not possible to integrate these factors in a single analysis of patterns of dispersal from Papua New Guinea waters, since the necessary catch data are mostly unavailable, particularly since 1979. Rough estimates of fishing effort and catch may be made from knowledge of the

TABLE 20. RECOVERIES, BY AREA AND MONTH, OF TAGGED SKIPJACK RELEASED IN PAPUA NEW GUINEA BY THE SKIPJACK PROGRAMME. For explanation of area abbreviations see Appendix E.

			AREA OF RECAPTURE														
Release Date	No. of Releases	Month of Recapture	INT	GUM	HOW	IND	KIR	KOS	MAS	PAL	PAM	PON	QLD	SOL	TRK	YAP	PNG
77/10	900	77/10															1
		78/06															1
		78/09												2			
		78/12												1			
		unknown															1
79/05	3227	79/05															22
		79/06				1											224
		79/07												1			80
		79/08	1											1			97
		79/09															30
		79/10												4			11
		79/11	1														5
		79/12	1														1
		80/01												2			
		80/02	1			1		1									
		80/03													1		
		80/04	1												2		4
		80/06															2
		80/07												3			1
		80/08	1				1				1			1			3
		80/09															3
		80/10	1														
		80/11												1			1
		80/12							1					2			
		81/04	1														
		81/08											1				1
		81/11															1
		unknown												1			42
79/06	4423	79/06															173
		79/07															131
		79/08															56
		79/09	1			1				1						2	28
		79/10				1										1	16
		79/11	1												2		2
		79/12															5
		80/01	2			1											1
		80/02				1			1						1		1
		80/03		1								2			2		1
		80/04	2			1						1			1		2
		80/05												1	2		2
		80/07	2		3									1			2
		80/08			2						1			1			4
		80/09												1			3
		80/10							3	1							
		80/12	2											1			
		81/01												1			
		81/02							2								
		81/07															1
		unknown												1			
		TOTALS	18	1	5	7	1	1	7	2	2	3	1	26	11	3	959

FIGURE 13. STRAIGHT-LINE REPRESENTATIONS OF MOVEMENTS OUT OF PAPUA NEW GUINEA WATERS OF SKIPJACK TAGGED BY THE SKIPJACK PROGRAMME. Recoveries have been selected to show no more than one within any five degree square. Tick marks on the arrows represent 30-day periods at large.



fisheries prior to 1979-1980, and from partial catch statistics (Tuna Programme unpublished data), in order to evaluate tag recovery distributions and so infer the probable patterns of skipjack movement.

Solomon Islands provided the largest number of external returns (26), with an additional one located immediately to the east in international waters (Table 21). These tags originated mainly in the commercially fished area of the Bismarck Sea, but there was also a relatively high number (7) from the few releases made in the western Solomon Sea. The high recovery rate in Solomon Islands is undoubtedly a reflection of both its proximity to Papua New Guinea and the very active fishery it supports. During 1979-1981, when almost all tag returns were received, the Solomon Islands pole-and-line fishery yielded over 20,000 tonnes of skipjack annually (Argue & Kearney 1982).

TABLE 21. EXTERNAL RECOVERIES OF SKIPJACK TAGGED IN PAPUA NEW GUINEA BY THE SKIPJACK PROGRAMME, BY AREA OF RECAPTURE. Areas are listed according to geographic position, going approximately clockwise from Solomon Islands.

Time of Release	Area of Recapture	Number Recovered	Average Displacement (nautical miles)	Average Days at Large	Average Minimum Velocity (nautical miles/day)
October 1977	Solomon Islands	3	240	360	0.7
May/June 1979	Solomon Islands	23	485	350	1.4
	International waters east of Solomon Islands	1	901	265	3.4
	Queensland (Australia)	1	549	807	1.5
	Coral Sea	1	668	200	3.3
	Indonesia	7	778	147	5.3
	Philippine Sea	1	1646	682	2.4
	Palau	2	853	282	3.0
	Guam	1	- *	266	- *
	Yap (FSM)	3	503	115	4.3
	Truk (FSM)	11	533	280	1.9
	Ponape (FSM)	3	583	287	2.0
	Kosrae (FSM)	1	744	263	2.8
	International waters between Papua New Guinea and FSM	4	596	130	4.2
	Marshall Islands	7	1314	488	2.7
	Kiribati (Gilbert Is)	1	1471	440	3.3
	International waters east of Kiribati	10	1970	393	5.0
	Howland Island	5	2073	407	5.1
	Palmyra Island	2	3002	432	6.9
	International waters east of Line Islands	1	2274	450	5.0
	Total Number of Recoveries	88			

* Exact position of recovery indeterminate.

Other areas in which recaptures were made were mainly to the north, between approximately 2°N and 10°N in the region which includes the Equatorial Counter Current, from the Philippines and Palau in the west to Palmyra Island in the east (Figure 13 and Table 21). Most recoveries were from Indonesia, the Federated States of Micronesia and the international waters between them and Papua New Guinea, the Marshall Islands, the international waters east of Kiribati, and Howland Island waters. Large fisheries, mainly purse-seine but also pole-and-line, operated in each of these areas in 1979-81 (Tuna Programme unpublished data).

In an earlier study of movements of tagged fish out of Papua New Guinea waters, Lewis (1980b) illustrated a distribution of tag recoveries similar to that recorded by the Programme. For recoveries to the north of Papua New Guinea (from a smaller geographic area than the recoveries of Skipjack Programme tags, most notably including very few east of 170°E), Lewis derived a relationship between fishing effort and tag recovery rate. This implied that dispersal to the north of Papua New Guinea may be random rather than directed. The recoveries of Skipjack Programme tags could be interpreted in a similar manner; among the areas to the north of Papua New Guinea, there is no conspicuous evidence of differences in recovery rates from which directed migration may be deduced. However, the possibility of directed migrations must still be considered, as the information on catch and effort remains incomplete and the Programme's data are equivocal. In particular, it may be significant that a large number of recoveries (almost half of those to the north of Papua New Guinea) were made east of 170°E, despite the great distances from their points of release, possibly indicating influence of the east-flowing Equatorial Counter Current (see also Tanaka & Yao 1980). These migrations from Papua New Guinea detract from the merit of Fujino's (1976) hypothesis that there is a boundary between eastern and western Pacific subpopulations of skipjack at 170°E longitude (Section 4.3.4).

Apart from the Solomon Islands recoveries and a single one from Queensland, no fish tagged in Papua New Guinea was recaptured to the southeast or south, despite the existence at that time of commercial fisheries in Fiji and New Zealand, and Japanese pole-and-line operations in the Coral Sea. Several, possibly complementary explanations may be invoked. The physical barriers presented by the land masses of New Britain, New Ireland and Solomon Islands may have limited the scope for southward and eastward migration. The small size of the Fiji fishery (<5,000 tonnes annually; Anon. undated) and the great distance to the New Zealand fishery (approximately 2,500 nautical miles) would have reduced the probability of recapturing migrants from Papua New Guinea. Consequently, dispersal to the south cannot be rejected on the basis of the Programme's results.

4.4.4.2 Movements to Papua New Guinea

Ninety-nine skipjack tagged in other countries were recaptured within Papua New Guinea's DFZ (Table 22). Full details of each recovery are included in Appendix D. Selected individual movements are represented as straight-line trajectories in Figure 14.

Palau was the origin of the majority (78%) of the migrations into Papua New Guinea waters. Sixty-three of the Palauan-tagged skipjack were recaptured by Japanese purse-seiners operating at the northwestern limits of the Papua New Guinea DFZ, on average 750 nautical miles from the points at which the tagged fish were released. Only 12 skipjack originating from

Palau were taken by locally based pole-and-line vessels fishing in the eastern Bismarck Sea, an average of 1,214 nautical miles from the release points in Palau. The Papua New Guinea pole-and-line fishery also accounted for most of the external recoveries of fish tagged in Solomon Islands, the only other significant source of migrations into Papua New Guinea waters (Table 22).

TABLE 22. NUMBER OF SKIPJACK TAG RECOVERIES IN PAPUA NEW GUINEA WATERS, BY AREA OF ORIGIN. Areas are ordered in increasing distance from Papua New Guinea.

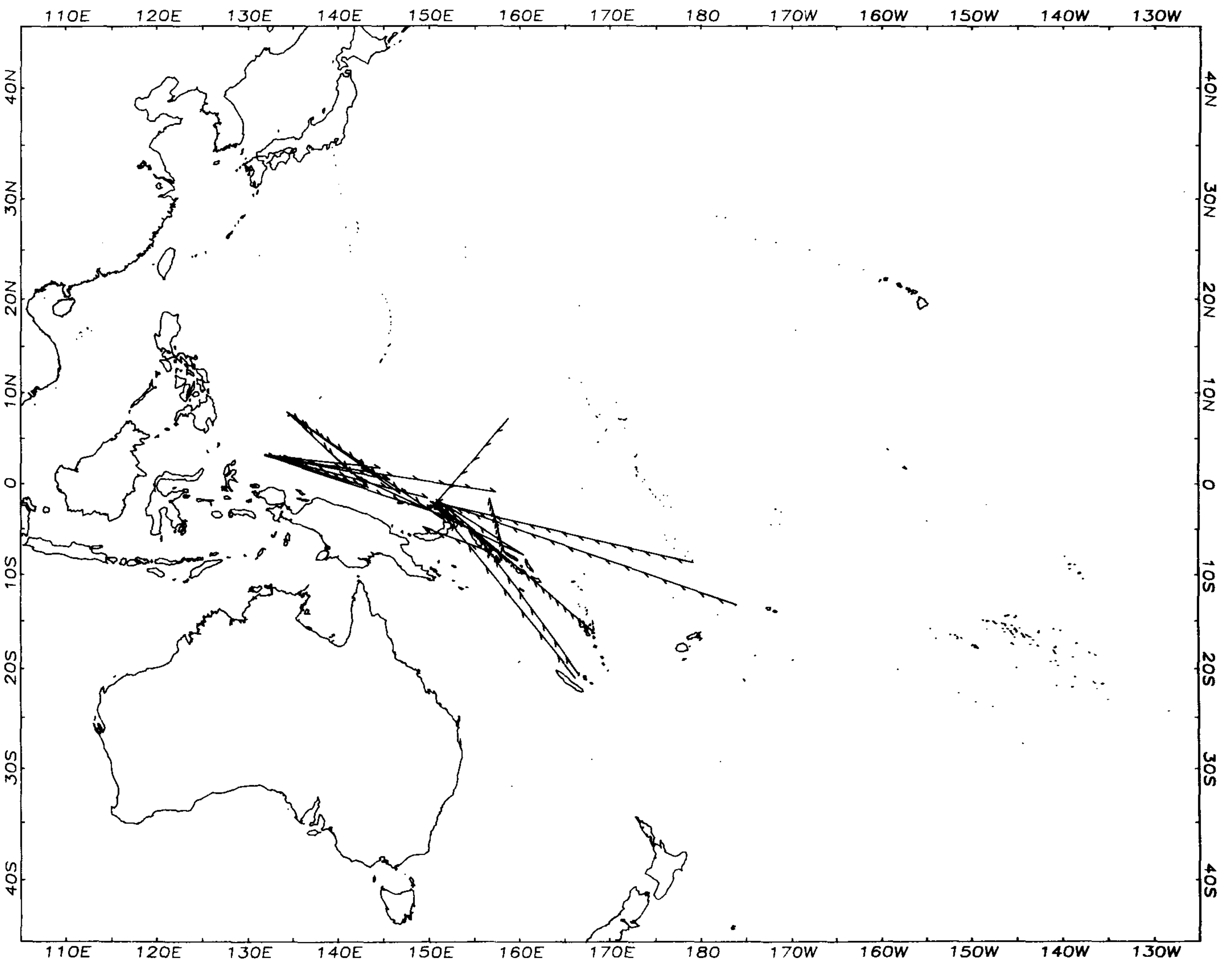
Area of Origin	Number of Releases	Number of Recoveries	Recovery Rate (%)
Solomon Islands	6221	15	0.241
Ponape (FSM)	5518	1	0.018
Palau	7233	77	1.064
New Caledonia	10219	2	0.019
Vanuatu	1254	1	0.080
Tuvalu	2904	1	0.034
Wallis and Futuna	16065	2	0.012
TOTALS		99	

There was a notable lack of recoveries of tags originating from other countries in which the Skipjack Programme tagged and released a large number of fish (e.g. the Federated States of Micronesia and Kiribati to the north, and Fiji, New Zealand, New Caledonia and Queensland to the south). In particular, the high rate of recovery in Solomon Islands of fish tagged in Queensland (Argue & Kearney 1982), when none was recovered in Papua New Guinea, is noteworthy. The absence of migration from areas south of Papua New Guinea mirrors the apparently low rate of movement in the opposite direction (Section 4.4.4.1).

A lack of movement from the north into Papua New Guinea waters was also evident in tagging studies conducted by Japanese workers in 1970-1974 (see Lewis 1980a, 1980b). Only 6 of 8,003 fish tagged north of the Equator were recovered within Papua New Guinea's DFZ, and none of these was taken in the area of the commercial fishery in the eastern Bismarck Sea. All six were released northwest of Papua New Guinea, near the Palau Islands or in the western part of the Federated States of Micronesia, northwest and southwest of Yap Island. Their recovery therefore provides a pattern consistent with the dominance of Palauan tags in the recoveries of Skipjack Programme tags in Papua New Guinea waters.

Although the data are insufficient to be conclusive, they are strongly suggestive of migration from the northwest into Papua New Guinea waters. There are good reasons, therefore, to consider the possibility of a significant interaction of fisheries operating in or between these areas. The present data permit only a tentative assessment of this interaction, because the catch and effort statistics for Palauan waters between 1979 and 1981 are unavailable (Section 4.6).

FIGURE 14. STRAIGHT-LINE REPRESENTATIONS OF MOVEMENTS INTO PAPUA NEW GUINEA WATERS OF SKIPJACK TAGGED ELSEWHERE BY THE SKIPJACK PROGRAMME. Recoveries have been selected to show no more than one release within any five degree square. Tick marks on the arrows represent 30-day periods at large.



4.5 Resource Assessment

The Programme's tag recapture data provide a basis for assessing the magnitude of the skipjack resource and its resilience to fishing pressure. A model formulated by Kleiber, Argue & Kearney (1983) was used to analyse tag attrition rates (the frequency of tag returns as a function of time) to derive estimates of various parameters of skipjack stock dynamics. Separate analyses were performed for the whole study area covered by the Programme and for the fished areas in the waters of Papua New Guinea, Solomon Islands, the Gilbert Group of Kiribati, Fiji, New Zealand, and the Society Islands of French Polynesia, for each of which there were sufficient tag recapture statistics, as well as data on catch and/or effort by fishing fleets.

4.5.1 Tag attrition model

The generalised equation of the model is given in Appendix F. The model was fitted to data on monthly tag returns and catches, using a non-linear, iterative regression procedure (Conway, Glass & Wilcox 1970). The best estimates of the parameters were obtained when the sum of squares of differences between observed and predicted tag return rates was minimised. The parameters of the skipjack stock estimated by the model were

- standing stock (P, in tonnes), for a given area, of fish which are of a size vulnerable to the fishery,

- attrition (A, in tonnes per month), which is the rate of loss of fish through natural mortality, fishing mortality and emigration, as well as other factors related to the experimental procedures. Assuming steady-state conditions for standing stock, attrition rate is the same as renewal rate (recruitment, growth, immigration) and may be termed turnover,

- throughput (T), which is the product of standing stock and turnover, and is thus a measure of flux of the standing stock. Since it has the same units as catch rate (tonnes per unit time) it allows ready comparisons between the resource and the harvest,

- harvest ratio (H), which is the ratio of catch rate to throughput (and is equal to the ratio between fishing mortality and attrition). It gives an indication of the impact of the fishery on the resource.

A variant of the model utilises effort rather than catch data from a fishery (Kleiber, Argue & Kearney 1983) to calculate these parameters, and yields a further parameter

- catchability coefficient (Q), the fraction, usually very small, of the standing stock which may be harvested by a unit of effort (e.g. one pole-and-line vessel operating for one day).

Simulation modelling has been used to test the response of the model to violations of its assumptions (Kleiber, Argue & Kearney 1983; Kleiber, Sibert & Farman ms.), particularly that of steady-state conditions in the stock. In general the model is not sensitive to either cyclical or unidirectional changes in the attributes listed above, with large changes resulting in relatively small differences in estimates provided by the model. In some circumstances, such as when P or T are changing rapidly, the relationship between estimates of attrition calculated from the catch and the effort forms of the model indicates that the stock is out of equilibrium and that parameter estimates may be incorrect (Kleiber, Sibert & Farman ms.).

4.5.2 Papua New Guinea stock estimates

The catch and effort data supplied to the tag attrition model were those from the local pole-and-line fleet, and all the parameters estimated by the model apply to only the stock existing in the area fished by this fleet. The tag recapture data set was therefore adjusted to include only the tags recovered by Papua New Guinea pole-and-line vessels. Releases made in areas outside the fishing grounds of the eastern Bismarck Sea, St George's Channel and New Hanover-Mussau also were excluded from the set. The analyses were conducted using recoveries of tags released in May-June 1979, since the October 1977 releases were outside the commercial fishing grounds. Recoveries were grouped into calendar months, but the releases were treated as a single set, not separated into calendar months, because tagging in the area of the fishery was limited to 32 days commencing on the 27 May 1979 (Table 4).

The revised data set, containing 838 tag recoveries over 32 months, is shown in Table 23, along with catch and effort statistics for each month. Mean monthly catch and effort over the period in which tag recoveries were made are also shown. Recoveries made in May and June 1979 (411 tags) were not included in the analyses, on the assumption that, as tagging was continuing in the area, there was incomplete mixing of tagged fish with the untagged population. Figure 15 shows the monthly tag returns through time, compared to return rates predicted by the model.

Other inputs into the model are correction factors for the various ways in which tags may be lost between their application to the fish and their eventual return with full documentation to the Skipjack Programme. The first factor, α, corrects for short-term loss of tags through mortality resulting from applying or carrying the tag, and shedding immediately after tagging (the Type 1 tag losses). Kleiber, Argue & Kearney (1983) and Kearney (1983) cited evidence from earlier studies, from the Programme's double tagging results, and from an experiment performed in aquarium facilities in Hawaii, which suggests that short-term mortality and shedding occur only infrequently, and that at most 10 per cent of tags are lost in these ways. Thus, a value of 0.9 (i.e. 1.0 minus 0.1) was assumed for α in the tag attrition model.

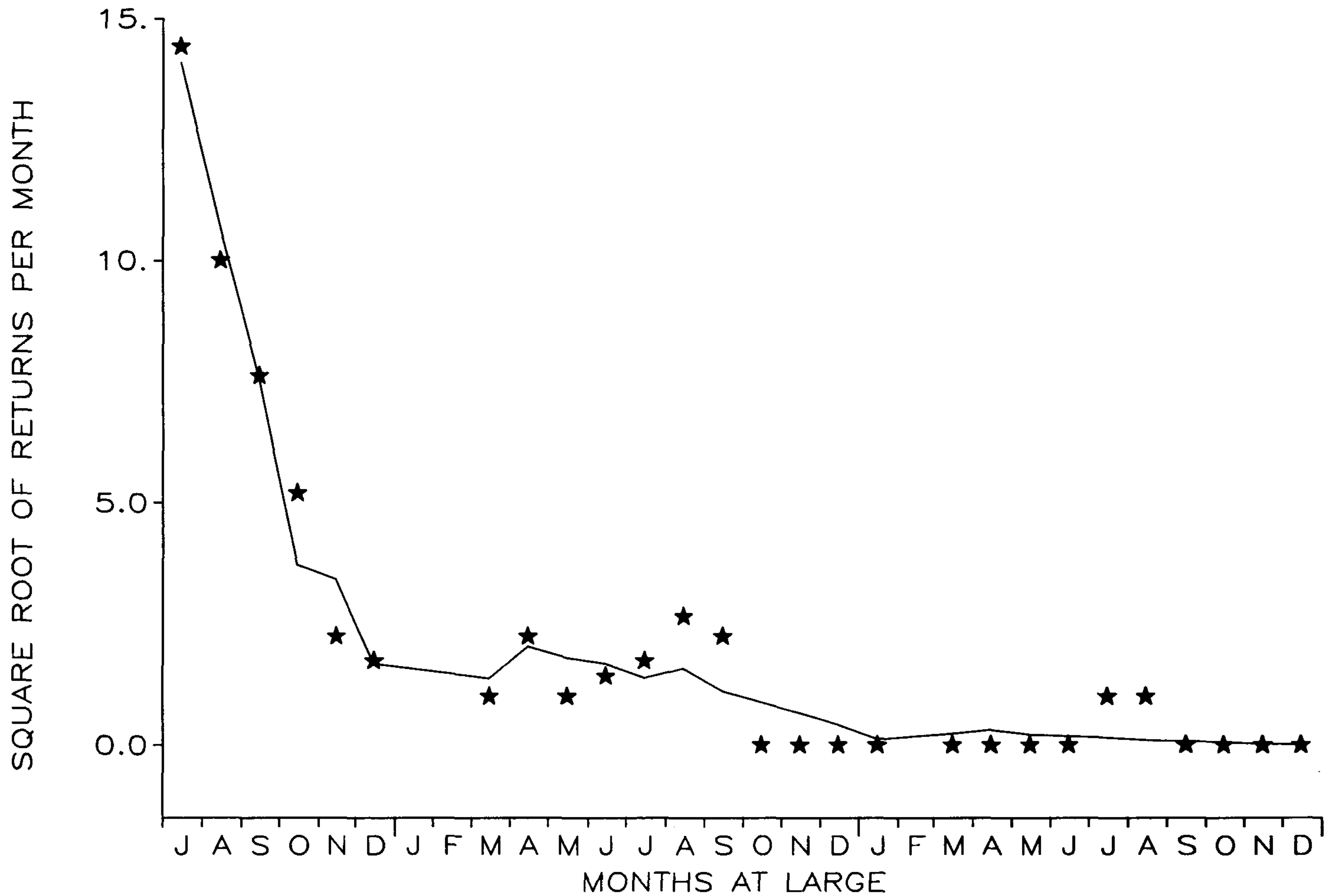
The second factor, β, accounts for non-detection of recaptured tags and non-return of detected tags by fishermen or processors, as well as the proportion of returns rendered unusable by lack of information on time and location of recovery. The calculation of β is complicated by the different probabilities of detection by and return from, for example, pole-and-line and purse-seine fisheries. The formula for calculating β is given in Kleiber, Argue & Kearney (1983), and results in lower and upper estimates of 0.62 and 0.90 for Papua New Guinea. These values are overestimated by an imprecisely known but small amount, because they do not take account of 60 tag recoveries from indeterminate locations, detected by

TABLE 23. TAG RECAPTURE AND CATCH/EFFORT DATA USED TO ESTIMATE PARAMETERS OF THE SKIPJACK STOCK EXPLOITED BY THE LOCALLY BASED POLE-AND-LINE FISHERY IN THE EASTERN BISMARCK SEA. Only releases and recaptures made in the commercially fished area by locally based pole-and-line vessels are included.

Date/ Month	Tags Released	May and June Releases Recovered	Skipjack Catch (tonnes)	Fishing Effort (boat days)
79/05	2718	20	379*	114*
79/06	3291	391	2153	598
79/07		208	2972	1035
79/08		100	2492	913
79/09		58	1840	899
79/10		27	654	614
79/11		5	811	706
79/12		3	286	212
80/01		0	0	0
80/02		0	9	10
80/03		1	609	440
80/04		5	1956	802
80/05		1	2243	985
80/06		2	2860	1005
80/07		3	2878	1068
80/08		7	5514	1100
80/09		5	3982	988
80/10		0	3697	850
80/11		0	3055	831
80/12		0	1800	553
81/01		0	222	99
81/02		0	0	0
81/03		0	1814	447
81/04		0	4675	918
81/05		0	3085	977
81/06		0	3340	962
81/07		1	3421	1077
81/08		1	2100	964
81/09		0	1660	805
81/10		0	1435	626
81/11		0	426	185
81/12		0	77	42
TOTALS	6009	838	Average 1997	670

* Indicates only the portion of total monthly catch (2,349 tonnes) and effort (709 boat days) occurring after tagging commenced.

FIGURE 15. FIT OF THE TAG ATTRITION MODEL (line) TO MONTHLY RETURNS (stars) OF TAGS RELEASED IN MAY AND JUNE 1979. The model explained 96 per cent of the variance in the data. The y-axis units are square roots of the number of tag returns because the model utilised this transformation. Only tags released in the area of the commercial fishery in the eastern Bismarck Sea, and recovered by locally based pole-and-line vessels operating there, were used.



cannery operators. Nine recoveries were known to be by foreign vessels, but the proportion recaptured by Papua New Guinea pole-and-line vessels was unknown. In the very unlikely event that a maximum possible 51 recoveries should be assigned to the locally based pole-and-line fleet, values for β of 0.54 and 0.86 would result. The effect of these changes in β values on stock parameter estimates was found to be small, between 5 and 14 per cent. Therefore, without information to allow more accurate determination of β, the values of 0.62 and 0.90 were retained. Simulation modelling by Kleiber, Argue & Kearney (1983) provided further insights into the effects of various values of β on some stock parameter estimates.

The product of α and β (called "p" in early publications, e.g. Argue and Kearney 1982, 1983), was used in preliminary estimates of Papua New Guinea stock parameters by Kleiber, Argue & Kearney (1983). They took a value of $\alpha\beta$ of 0.68, midway between the values that can be calculated using the upper and lower estimates of β above. Both values of β are used in the present calculations for Papua New Guinea stock, resulting in $\alpha\beta$ values of 0.56 and 0.81.

Estimates of standing stock, turnover, throughput, catchability coefficient and harvest ratio are shown in Table 24, based on the Programme's tag recapture data and fleet catch statistics from 1979. Other estimates, using data from 1972 and 1973 tag releases (Lewis 1980a, 1980b) are also shown. For these, a value of 0.8 was assumed for β.

A goodness-of-fit statistic, G, is also included in Table 24. It shows that the tag attrition model fitted the 1979 tag recapture data very closely, explaining 96 per cent of the variance in the data (see also Figure 15). This was the closest fit achieved for any of the data sets examined by the Skipjack Programme (Kleiber, Argue & Kearney 1983). The fit was not as good to the 1973 data, and was poor to the 1972 data (73% and 51% of variance explained, respectively). All these fits were of models using catch data; when effort data were used instead, the model fitted almost as well to the 1979 and 1973 tag recapture data, but very poorly to the 1972 data. For those fisheries with both catch and effort statistics, catch models generally fitted the tag recapture data better than effort models (Kleiber, Argue & Kearney 1983), possibly because catch statistics are more objective than those for effort. In Papua New Guinea, the trend in the goodness-of-fit figures may be explained by two possible processes : increasingly reliable catch and effort statistics as the fishery developed between 1972 and 1979, and more diligent efforts to notify returns as awareness of the existence of tagged fish grew. Alternatively, the increasingly good descriptions of the data by the model over time may also reflect the progressively more discrete area of operations of the fishery in later years (Section 1.1.2).

Using the 1979 tag recapture data, the model estimated the standing stock in the commercially fished area of Papua New Guinea to be either 28,000 or 41,000 tonnes, depending on which value was taken for β. The confidence limits of each estimate overlap (Table 24). In comparison, the standing stock for the whole study area in the western Pacific was estimated to be three million tonnes (Kleiber, Argue & Kearney 1983). The monthly turnover rate of 0.377/month in Papua New Guinea was high; turnover values for other stocks fished by pole-and-line in Solomon Islands and Fiji were much lower (Argue & Kearney 1982; Kleiber, Argue & Kearney 1983) but in Kiribati they were similar (Kleiber & Kearney 1983). Of the many factors which contribute to turnover (Section 4.5.1; Appendix F), growth beyond vulnerability to the fishery and possibly increased natural

TABLE 24. ESTIMATES OF PARAMETERS OF THE PAPUA NEW GUINEA SKIPJACK STOCK EXPLOITED BY THE POLE-AND-LINE FISHERY, USING DATA FROM TAG RELEASES IN 1972, 1973 (Lewis 1980a, 1980b) AND MAY-JUNE 1979. The estimates are derived from the catch form of the tag attrition model of Kleiber, Argue and Kearney (1983), except where indicated. Ninety-five per cent confidence limits of the estimates are given in brackets.

Year	Number of Releases	β	Standing Stock (tonnes)	Turnover Rate (per month)	Throughput (tonnes/month)	Catchability Coefficient*	Harvest Ratio	Goodness of Fit
1979	6009	0.62	28454	0.377	10738	0.109	0.186	0.964
			(21979-36693)	(0.317-0.459)	(9146-12787)	(0.073-0.175)	(0.156-0.219)	
		0.90	41157	0.377	15532	0.768	0.129	0.964
			(31791-53073)	(0.317-0.459)	(13228-18495)	(0.05-0.121)	(0.108-0.151)	
1973	4864	0.80	72534	0.483	35034	0.058	0.071	0.728
			(50178-107970)	(0.346-0.671)	(27386-46317)	(0.038-0.085)	(0.054-0.091)	
1972	4942	0.80	79082	0.239	18873	0.026	0.097	0.512
			(45056-149920)	(0.171-0.317)	(13088-29007)	(0.012-0.049)	(0.063-0.139)	

* Per 1,000 boat days. Derived from effort form of the tag attrition model.

mortality with age (~ size) (Kleiber, Argue & Kearney 1983) are important. Therefore, a stock of fish which are, on average, large when tagged may turn over at a higher rate than a stock of small fish. The Papua New Guinea fish were relatively large (Section 4.3.1).

The harvest ratio, H, shows the impact of fishing on the stock. A low harvest ratio is evidence, though not proof, of minimal depletion of the resource. Between 1972/1973 and 1979 the harvest ratio doubled (Table 24) suggesting increasingly efficient fishing operations. The even more marked increase in catchability coefficient over the same period further supports this view. The values in Table 24 (0.129 and 0.186, depending on the value of β) indicate that about one-tenth to one-fifth of the throughput was being caught in mid-1979. A similar harvest ratio for the equally intensive pole-and-line fishery in Solomon Islands, and a higher one for the New Zealand purse-seine fishery were calculated by Kleiber, Argue & Kearney (1983). Lower ratios obtained in less intensive fisheries in Fiji, Kiribati and the Society Islands, as well as in the South Pacific Commission area as a whole. Analyses based on the Beverton-Holt yield per recruit model (Kleiber, Argue & Kearney 1983) suggest that harvest ratios up to 0.5-0.7 would provide the maximum sustainable yield in western Pacific skipjack fisheries. Therefore, the estimates of present harvest ratios suggest that much greater catches are possible throughout the western Pacific. The scope for increased catches in the Papua New Guinea fishery, which was already well developed in 1979, is not as large, though it is still considerable.

The estimates of standing stock for 1972 and 1973 are higher than those for 1979 (Table 24), but have much wider confidence intervals which overlap with those of the higher of the 1979 estimates, indicating that the differences between the estimates are in most cases not significant. The differences may be due to two factors : area occupied by the fishery and times at which tags were released. Kleiber, Argue & Kearney (1983) showed that the estimates of standing stock were approximately proportional to the fished area. Since the Papua New Guinea fishery contracted eastwards in the late 1970s (Section 1.1.2), the reduced area would imply lower estimates of standing stock in 1979. Kleiber, Argue & Kearney (1983) also showed that the tag attrition model estimates of standing stock most accurately reflected the situation at the time the tags were released, or shortly thereafter. In 1979, the estimate would apply to the middle of the year, whereas the results for 1972 and 1973 are based on recoveries of tags released throughout each of those years. These differences in the duration over which tags were released may have been responsible for the different estimates of standing stock, if factors which affect the tag attrition model were not the same during the release periods. There is much temporal variability in catch rates (CPUE) in the Papua New Guinea fishery (Figure 3), implying differences in the mortality and catchability of skipjack which can affect the stock estimates from the tag attrition model (Kleiber, Sibert & Farman (ms.). Thus, the 1979 estimate may have been susceptible to short-term variation in mortality or catchability of skipjack in the months after tags were released. With the 1972 and 1973 estimates, variations would have been averaged over time.

For these reasons, the decrease of the estimated standing stock from 1972 to 1979 should not be assumed to result from over-exploitation. The absence of an inverse relationship between effort and catch per unit effort (Section 4.2) and the estimates of harvest ratios are also evidence against any decline in the fishery. Differences in attrition estimates derived from either the catch form or the effort form of the tag attrition model provide a further means of identifying such trends (Kleiber, Argue & Kearney 1983; Kleiber, Sibert & Farman ms.). A declining stock is likely to be characterised by effort-based turnover estimates which are higher than those based on catch data. This was not the case for the 1972 and 1973 estimates, although it was so for the 1979 estimates. Further tagging studies would be useful in resolving these contradictions about the effects of fishing, and in establishing the existence of any long-term trends.

Another inference of relevance to stock management can be drawn from turnover estimates. The very high rates estimated from the 1979 tag recapture data indicate that within a short period of time, approximately six months, 90 per cent of the catchable skipjack would have left the stock, to be replaced by other fish if steady-state conditions prevailed. Notwithstanding the possibly very high early growth rates of skipjack (e.g. Sibert, Kearney & Lawson 1983) and the postulated existence of a zone of high spawning activity centred around Papua New Guinea (Section 4.3.2), it seems improbable that stock renewal could have been accomplished principally by reproduction and growth. More likely, considerable immigration would have been required to maintain the high renewal rates of the Papua New Guinea stock. If so, the implications of the rapid expansion of western Pacific fisheries for skipjack may be relatively great for the Papua New Guinea resource.

4.6 Fishery Interactions

With increasing fishing activity and changing gear technology, catches from the area served by the South Pacific Commission have grown remarkably in recent years, leading inevitably to greater scope for interaction between fisheries (Kearney 1983). These may occur, for example, between various types of fishery within a particular country (e.g. artisanal vs commercial), between fisheries based on different gear types (e.g. purse-seine vs longline for yellowfin) or between fisheries operating in different countries. It is of the last type of interaction that the data of the Skipjack Programme provide some measure.

Tag recapture data enable assessment of interaction only within one generation of fish. However, within-generation assessments are most appropriate for skipjack, since the absence of any relationship between catch per unit effort and effort, even within intense fisheries (Joseph & Calkins 1969; Kearney 1979), suggests that between-generation interactions are not significant. Within-generation interactions between fisheries may be construed in various ways, such as the change in catch in one fishery resulting from catches in another, or the fraction of recruitment (throughput) in a fishery attributable to migration from another fishery. The methods developed by the Skipjack Programme measure interaction in the latter way, that is, as a function of throughput.

4.6.1 Measurement of interaction

A parameter, the "immigration coefficient" I, was derived to express interaction as the percentage of the throughput in a "receiver" country which could be ascribed to migration from another, "donor" country (Kleiber, Sibert & Hammond ms.). An earlier version of I expressed interaction as the contribution of migrants to standing stock of the receiver country (Skipjack Programme 1981b). The present coefficent is computed from the number of tag releases in the donor country and the number of recoveries of those tags in the receiver country, together with various parameters of the two stocks, estimated by the tag attrition model of Kleiber, Argue & Kearney (1983).

The equation for calculating I is given in Appendix G. Two values of I exist for any pair of fisheries, one for each of the directions in which interaction may occur. It should be emphasised that, as with the parameters derived from the tag attrition model, the immigration coefficient measures only the interaction between stocks exploited by particular fisheries operating in defined areas (Section 4.5.2). It does not provide a measure of the migration of fish from all parts of a country's fishing zone to the whole fishery zone of another country, and is therefore a minimum estimate of interaction. It must be regarded as a minimum estimate for another reason: it is calculated only from the migrations of large (usually >45 cm) skipjack, since these were the sizes that were caught and tagged by the Programme (Sections 3.0 and 4.3.1). Migrations by smaller fish were not generally taken into account, even though they may migrate in large numbers into the area occupied by a particular commercial fishery, and recruit to that fishery.

4.6.2 Interactions with the Papua New Guinea fishery

The tag recapture data (Tables 21 and 22) show that there is movement between the skipjack stock fished by Papua New Guinea pole-and-line vessels and stocks exploited in several other areas, indicating potential interactions between the fisheries. To quantify these interactions, several parameters of the stocks must be known (Appendix F), but these were available for only Papua New Guinea and Solomon Islands. However, approximations of the parameters were obtained for several other fisheries (Tuna Programme ms.), enabling estimates of the interaction between them and the Papua New Guinea fishery to be made.

Table 25 shows interactions with fisheries to which skipjack migrated from Papua New Guinea. Interactions resulting from migrations into Papua New Guinea are listed in Table 26. The closest fishery to Papua New Guinea, the Solomon Islands pole-and-line operation, received about two to four per cent of its throughput from the Papua New Guinea fishery area. There was a similar degree of interaction in the other direction, although considerable differences exist between the estimates based on returns from two separate periods of tag releases (Table 26). Recoveries of tags released in the Solomon Islands fishery in November 1977 and June 1980 yielded interaction estimates of approximately one per cent in the first instance, and 3-5 per cent in the second. This may have been a seasonal effect, since June falls within the period in which Lewis (1980b, 1981) postulated northward movement of fish from the Solomon Sea to the Bismarck Sea. In November, migrations occur in the opposite direction, according to Lewis' model. Alternatively, the lower value calculated from November 1977 tag releases may have been biased by the very low level of fishing activity in Papua New Guinea in the few months following the releases (Figure 2).

The interactions resulting from migration of skipjack from the Papua New Guinea fishery to areas fished by Japanese or locally based pole-and-line vessels in Palau, the Federated States of Micronesia, and Marshall Islands are also shown in Table 25. The level of interaction in each case was around one per cent.

The largest interaction due to fish migrating into Papua New Guinea's fished area was with Palau. The estimated proportion of throughput in the Papua New Guinea locally based pole-and-line fishery attributable to migrants from Palau was about 1-2 per cent. Overall, the seven areas

TABLE 25. INTERACTIONS BETWEEN FISHERIES DUE TO MOVEMENT OF SKIPJACK FROM PAPUA NEW GUINEA. For calculation of the immigration coefficient, I, see Appendix G.

Receiver Country[1]	Fishery	Number of Tags Returned[2]	β[3]	Average Monthly Catch[4] (tonnes)	I (%)[5]
Solomon Islands	Local pole-and-line	15	0.60	1,917	2.6 - 3.7
Palau	Local pole-and-line	1	0.76	380	0.7 - 1.0
Federated States of Micronesia	Japanese pole-and-line	10	0.76	2,330	1.1 - 1.6
Marshall Islands	Japanese pole-and-line	2	0.76	1,320	0.4 - 0.6

1 Interactions with fisheries in other countries in which skipjack tagged in Papua New Guinea were recovered (Table 21) could not be calculated since catch data were not available and could not be estimated.

2 Returns from the receiver country of tags released in Papua New Guinea's commercial fishing area in May-June 1979 (n=6,009).

3 Correction factor for undetected, unnotified or unusable tag returns (see Appendix F). Value for Solomon Islands from Kleiber, Argue & Kearney (1983); for other areas from Tuna Programme (ms.).

4 The Solomon Islands figure is from Argue & Kearney (1982). For all other areas catch estimates were prorated on the basis of 1978 and 1979 statistics (Tuna Programme unpublished data) using total 1978-1981 catch data in Iizuka & Watanabe (1983); for details see Tuna Programme (ms.).

5 Upper and lower values depend on the range of values of throughput in Papua New Guinea stock of 10,738 or 15,532 tonnes per month (Table 24).

TABLE 26. INTERACTIONS BETWEEN FISHERIES DUE TO MOVEMENT OF SKIPJACK FROM OTHER AREAS INTO PAPUA NEW GUINEA. For calculation of the immigration coefficient, I, see Appendix G.

Donor Area[1]	Number of Tags Released	Throughput in Donor (tonnes/month)[2]	Number of Tags Recovered[3]	Average Catch (tonnes)[4]	I (%)[5]
Solomon Islands 1977	1,709	11,000	4	3,340	1.0 - 1.4
Solomon Islands 1980	2,012	13,000	9	2,240	3.2 - 4.7
Palau	6,515	14,000	12	2,217	1.4 - 2.1
Federated States of Micronesia	7,647	69,000	1	1,812	0.6 - 0.9
Wallis and Futuna	13,513	4,368	1	1,545	<0.04
New Caledonia	6,572	22,308	1	1,344	0.3 - 0.5
Tuvalu	1,766	13,363	1	1,344	0.7 - 1.0
Vanuatu	1,203	14,768	1	1,344	1.1 - 1.6

1 The two tag release periods in Solomon Islands were treated separately because of different seasons and different catch rates in subsequent months. The Palau data are for the Skipjack Programme visit in 1980 only.

2 Data for Solomon Islands are calculated from Kleiber, Argue & Kearney (1983). For Palau and the Federated States of Micronesia, the figures are approximations prorated on an area basis from the throughput calculated for the once Trust Territory of the Pacific Islands (Tuna Programme ms.). For all other areas the figures are approximations, prorated from the total throughput of the Programme's study area (520,000 tonnes per month; Kleiber, Argue & Kearney 1983), using the area of the DFZ for each state.

3 Recoveries by Papua New Guinea pole-and-line vessels operating in the commercial fishing area of eastern Bismarck Sea, New Hanover-Mussau and St George's Channel.

4 By the Papua New Guinea pole-and-line fishery. In each instance, for the period over which the recoveries were made (see Appendix G).

5 Upper and lower values depend on the range of values of β for the Papua New Guinea fishery of 0.62 and 0.90 (Section 4.5.2).

listed in Table 26 provided up to 10 per cent of the throughput of skipjack in the Papua New Guinea commercial fishery. Since this is a measure only of recruitment due to relatively large fish (except in the case of Palau) migrating from a limited part of the fishing zones of the donor countries (Section 4.6.1, above), it is necessarily a minimum value.

A further factor may have resulted in underestimation of the interaction due to fish moving from Palau to New Guinea. Over 80 per cent of the skipjack tagged in Palau and recaptured in Papua New Guinea were taken by Japanese purse-seiners operating in waters in the northwest of Papua New Guinea's DFZ, that is, directly between Palau and the area in the eastern Bismarck Sea occupied by the Papua New Guinea pole-and-line fishery. Catches by the purse-seine fleet during the period Palauan tags were at large were very high (Tuna Programme unpublished data). Therefore, it is reasonable to speculate that recoveries by the Papua New Guinea pole-and-line fishery would have been significantly higher had there not been the "filter" of purse-seiners through which the fish migrated. If so, the interaction between Palauan and Papua New Guinea locally based fisheries is potentially greater than the present figures indicate.

5.0 CONCLUSIONS

5.1 Baitfish Resources

The Skipjack Programme found baitfish to be very abundant at most of the 18 localities surveyed in Papua New Guinea. Average catches were among the highest recorded by the Programme in any of the countries surveyed, and overall, the catch was the most diverse. It was dominated by several species of anchovy which are highly regarded as live bait for tuna fishing. Other effective bait common in the Programme's catch were sardines, herrings and sprats, which occasionally have been more abundant than anchovies in baitfish catches by the Papua New Guinea commercial fleet.

Future demands on the baitfish resource will depend on the magnitude of any revival of the live-bait, pole-and-line fishery. If an operation similar in organisation to that existing before 1982 is re-established, previous experience suggests that skipjack catches of up to 46,000 tonnes per year can be supported by the baiting grounds of Ysabel Pass and Cape Lambert, provided management regimes at least the equal of those previously instituted are maintained. After indications of overexploitation of baitfish at the two locations on several occasions between 1978 and 1980, restrictions were placed on effort, leading to recovery of the stocks within a few months. This suggests that yields from the Ysabel Pass and Cape Lambert grounds may have been near the maximum sustainable, and if higher annual pole-and-line catches are envisaged, baitfishing effort will need to be more widely distributed. To achieve this, changes to the structure of the fleet may be required, since there are few large areas like Ysabel Pass and Cape Lambert capable of supporting the concentration of baitfishing effort involved in a mothership-type operation. Fishing vessels which are capable of operating independently of a mothership would be able to work alone and exploit smaller, less extensive areas of baitfish habitat, of which Papua New Guinea's long coastline provides many.

The viability of renewed pole-and-line fishing in Papua New Guinea may ultimately depend upon factors other than the magnitude of the baitfish resource. Purse-seining now offers a highly efficient means of harvesting tuna free of dependence upon live bait. The ability of pole-and-line operations to compete economically with purse-seining in Papua New Guinea has yet to be resolved.

5.2 Skipjack Resources

School sightings and catches during the Skipjack Programme surveys support the view that Papua New Guinea's resources of skipjack are most abundant in the area of the eastern Bismarck Sea in which the commercial pole-and-line fishery has operated, although large numbers of fish were found at times in other parts of Papua New Guinea's waters. Markedly different catch rates were recorded on the two surveys, and these were apparently directly related to differences in the relative abundance of skipjack in the area. This difference was unlikely to have been simply a seasonal effect, since data from the locally based pole-and-line fleet show that catch per unit effort fluctuates widely, without consistent seasonal patterns.

The standing stock of skipjack in the area of the Papua New Guinea commercial fishery in May and June 1979 was estimated to be between 28,000 and 41,000 tonnes. The stock had a very high turnover rate of 0.377 per month, which may have been due more to very high migration rates than local recruitment, growth and mortality, but further data are required to test this hypothesis. Estimates of standing stock were approximately twice as high for the early 1970s as for 1979, but it is probable that these differences were due to natural fluctuations in abundance rather than a long-term effect of fishing. Several indicators which afford insights into the nature of long-term changes yielded contradictory conclusions. These would best be resolved by further tagging studies.

The marked increases in harvest ratio and catchability coefficient during the 1970s suggest improved efficiency of operations in the locally based fleet. The harvest ratio of 0.129 - 0.186 in 1979 was high compared to those of other pole-and-line fisheries in the South Pacific Commission region, and was much higher than that for the entire study area (0.037). This suggests that there is relatively less scope for expansion of the eastern Bismarck Sea fishery above the levels of the late 1970s than there is in other countries, even though the resource still appears capable of supporting a total catch perhaps two or three times larger than in previous years. Because the high harvest ratio applies only to the area of the 1979 commercial fishery, future expansion could also be achieved by extending operations into other parts of Papua New Guinea's waters not included in the present stock assessments.

Movements of tagged fish and genetic analyses of blood indicate that skipjack in Papua New Guinea are not isolated from those elsewhere in the Programme's study area, confuting previous hypotheses of discrete skipjack subpopulations in the central and western Pacific. The pattern of genetic differentiation identified by the Programme is most likely attributable to reproductive isolation-by-distance.

Only a small percentage of the tagged skipjack undertook long, international migrations. A relatively large number of these movements occurred between Papua New Guinea and the closest country, Solomon Islands. Evidence for distinct migratory pathways between Papua New Guinea and other areas, including Solomon Islands, was not conclusive, although there is some evidence of directed migration into Papua New Guinea waters from the northwest (Palau, Yap) and from Papua New Guinea towards the north (Truk) and northeast (Marshall Islands).

The low number of tag returns from other fisheries is indicative of a generally low level of interaction between them and the Papua New Guinea fishery. Only a few per cent of the throughput in the stock fished by the Papua New Guinea pole-and-line fleet was attributable to migration from elsewhere (mainly Solomon Islands and Palau). Contributions by eastern Bismarck Sea skipjack to throughput in other fisheries, mainly in Solomon Islands and the Federated States of Micronesia, were similarly low. However, the method of assessing interaction was based on movements of skipjack sufficiently large to be vulnerable to pole-and-line gear (usually >45cm), and did not take account of migrations by pre-recruit fish. It is likely that total interactions are larger than presently indicated.

Therefore, revival of the fishery in the eastern Bismarck Sea, whether utilising pole-and-line or other gear, would necessitate close monitoring of its interaction with other fisheries, particularly as catches in the region are now much greater than in the 1970s. All interactions assessed so far have been with fisheries in waters external to Papua New Guinea's DFZ, but closer fisheries, operating for instance within the DFZ, will probably have even greater interaction. For example, the purse-seine fishery by foreign vessels operating under licence in the northwest sector of Papua New Guinea's DFZ since the late 1970s probably interacted strongly with the eastern Bismarck Sea pole-and-line fishery, but the degree of this interaction could not be estimated because the appropriate catch and effort statistics were lacking. This fishery has expanded more than tenfold in the last few years, creating a need for detailed information on its dynamics and interactions. To evaluate this and other interactions accurately, further tagging studies designed specifically for this purpose will be required. The potential complexities of future interactions make the need for full fishery statistics and complementary tagging programmes more pressing than ever.

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APPENDIX A. SCIENTISTS, OBSERVERS AND CREW ON BOARD THE HATSUTORI MARU NO.1 ON BOTH SURVEYS OF PAPUA NEW GUINEA

Scientists

A.W. Argue	1979, May 14 - June 4
Charles Ellway	1979, June 4 - July 2
Robert Gillett	1977, October 5 - 31
	1979, May 14 - June 4
Jean-Pierre Hallier	1977, October 5 - 31
	1979, June 4 - July 2
James Ianelli	1979, June 10 - July 2
Robert Kearney	1977, October 5 -31
Antony Lewis	1977, October 5 - 31
Desmond Whyman	1979, May 14 - June 9

Observers

Shogo Sugiura, Japan Fishery Agency
Masakazu Yao, Tohoku Regional Fisheries Research Laboratory, Japan
Molean Chapau, Fisheries Division, Department of Primary Industry
Aufa Eko, " "
Ponchon Lili, " "
Barney Smith, " "
Charles Tenakanai, " "
Jacek Wankowski, " "
Andrew Wright, " "

Vessel Crew

Sakae Hyuga*
Yoshio Kadohno
Koshihiro Kondoh*
Yoshio Kosuka
Masahiro Matsumoto, Captain*
Akio Okumura
Yoshikatsu Oikawa*
Nozomu Origuchi
Tsunetaka Ono*
Kohji Wakasaki*
Mikio Yamashita*

Fishing Crew

Lui Andrews*
Vonitiese Bainamoli*
Mosese Cakau*
Samuela Delana
Eroni Dolodai
Veremalua Kaliseiwaga
Kitione Koroi
Jone Manuka
Eroni Marawa*
Joshua Raguru
Jona Ravasakula
Isoa Rodan
Peni Tamakina
Ravaele Tikovakaca*
Samuela Ue*

* crewed on both survey visits

APPENDIX B. CATCH AND FREQUENCY OF OCCURRENCE OF ALL TAXA (species of fish or higher taxa of fish or invertebrates) IN BOUKI-AMI HAULS DURING BOTH VISITS TO PAPUA NEW GUINEA. Juveniles are indicated by (j).

Species	Percent Occurrence in Hauls	Estimated Catch (kg)
Stolephorus heterolobus	72	2253
Stolephorus devisi	70	1796
Sardinella sirm	40	551
Stolephorus buccaneeri	25	368
Spratelloides gracilis	60	321
Gymnocaesio gymnopterus	51	219
Sardinella leiogaster	9	192
Herklotsichthys quadrimaculatus*	53	133
Spratelloides delicatulus	49	132
Thrissina baelama (j)	4	82
Rastrelliger kanagurta	47	74
Dussumieria sp.	37	54
Hypoatherina ovalaua	30	47
Sp. of Siganidae	26	40
Stolephorus sp. (j)	9	25
Apogon(Rhabdamia) cypselurus	54	24
Thrissina baelama	32	19
Stolephorus bataviensis	42	18
Pterocaesio sp.	16	14
Atherinomorus lacunosa**	33	14
Apogon sp.	4	9
Pterocaesio pisang	37	8
Spratelloides lewisi	11	3
Sp. of Holocentridae	54	1
Sp. of Lutjanidae	11	1
Stolephorus indicus	19	0
Siphamia sp.	5	0
Sp. of Chaetodontidae	33	0
Saurida gracilis	4	0
Trichiuris haumela	9	0
Sp. of Synodontidae	30	0
Pterocaesio tile	4	0
Gazza minuta	39	0
Lestidium nudum	2	0
Sardinella sp.	11	0
Runula rhinorhynchus	2	0
Saurida sp.	11	0
Saurida undosquamis	4	0
Decapterus maruadsi	5	0
Bregmaceros neeta	4	0
Ptereleotris tricolor	2	0
Pempheris vanicolensis	4	0
Fistularia villosa	4	0
Sp. of Atherinidae	2	0
Apogon fragilis	4	0
Centriscus scutatus	2	0
Hypoatherina barnesi	12	0
Dactyloptera orientalis	2	0
Leiognathus sp.	2	0
Caranx sp.	12	0
Sp. of Chaetodontidae	2	0
Lutjanus sp.	2	0
Apogon(Rhabdamia) gracilis	23	0
Scomberomorus commersonii	9	0
Lutjanus vitta	2	0
Mullodichthys sp.	16	0
Priacanthus sp.	21	0
Cheilodipterus macrodon	12	0
Decapterus sp.	5	0
Gastrophysus sp.	12	0
Sp. of Sphyraenidae	63	0
Archamia zosterophora	9	0
Acanthurus sp.	2	0
Lactarius lactarius	2	0
Mullodichthys samoensis	5	0
Bregmaceros sp.	16	0
Selar boops	30	0

Archamia lineolata	30	0
Leiognathus bindu	30	0
Secutor sp.	19	0
Secutor rucornis	4	0
Sp. of Acanthuridae	42	0
Pranesus sp.	4	0
Leiognathus elongatus	14	0
Scomberoides tol	7	0
Sp. of Centriscidae	2	0
Secutor insidiator	5	0
Sardinella zunasi	7	0
Sp. of Reptilia	4	0
Sp. of Elasmobranchii	2	0
Caranx sexfasciatus	7	0
Sp. of Nemipteridae	2	0
Selaroides leptolepis	2	0
Sardinella melanura	5	0
Sp. of Aluteridae	2	0
Sp. of Paralepidae	4	0
Decapterus macrosoma	5	0
Sp. of Crustacea	23	0
Grammatorcynus bicarinatus	4	0
Sp. of Carangidae	14	0
Sp. of Crustacea	18	0
Sp. of Polychaeta	2	0
Epinephelus sp.	2	0
Sp. of Scaridae	2	0
Siphamia tubulata	4	0
Sp. of Scombridae	2	0
Sp. of Hemirhamphidae	2	0
Sardinella clupeiodes	2	0
Caesio coerulaureus	2	0
Sp. of Pempheridae	2	0
Parapriacanthus sp.	7	0
Sp. of Anthiidae	4	0
Sp. of Bothidae	2	0
Sp. of Pomacentridae	4	0
Sp. of Caesiodidae	7	0
Dipterygonotus leucogrammicus	2	0
Pterocaesio diagramma	2	0
Sp. of Myctophidae	9	0
Apogon leptacanthus	2	0
Upeneus sulphureus	2	0
Sp. of Exocoetidae	11	0
Sphyraena barracuda	4	0
Pranesus duodecimalis	2	0
Aeoliscus strigatus	2	0
Platax sp.	2	0
Selar crumenophthalmus	23	0
Myripristis pralinius	2	0
Synodus variegatus	2	0
Megalops cyprinoides	2	0
Mullodichthys auriflamma	2	0
Sp. of Thaliacea	5	0
Scomberoides sp.	14	0
Pellona ditchela	19	0
Atule mate	5	0
Sp. of Anguillidae (j)	7	0
Sp. of Priacanthidae	5	0
Xiphasia sp.	2	0
Sp. of Tetrodontidae	12	0
Fistularia sp.	11	0
Sp. of Crustacea (j)	11	0
Sp. of Diodontidae	4	0
Sp. of Balistidae	9	0
Sp. of Cephalopoda (Octopoda)	7	0
Sp. of Cephalopoda (Decapoda)	47	0
Sp. of Apogonidae	11	0
Thrissocles setirostris	7	0
Sp. of Mullidae	28	0
Rastrelliger sp.	4	0
Sp. of Syngnathidae	5	0
Sp. of Trichiuridae	5	0
Sp. of Leiognathidae	2	0

Totals : 141 taxa 6398

* Until recently, known as Herklotsichthys punctatus (Wongratana 1983).

** Until recently, known as Pranesus pinguis (Whitehead & Ivantsoff 1983).

APPENDIX C. ITEMS OCCURRING AT LEAST TWICE IN SKIPJACK STOMACHS EXAMINED IN PAPUA NEW GUINEA. Juveniles are indicated by (j).

Item No.	Diet Item	Number of Stomachs	Percentage Occurrence
1	Chum from *Hatsutori Maru*	246	60.89
2	Fish remains (not chum)	212	52.48
3	Cephalopoda (squid)	121	29.95
4	Acanthuridae	94	23.27
5	Stomatopoda (alima stage)	77	19.06
6	Balistidae	56	13.86
7	Synodontidae	46	11.39
8	Euphausiacea	45	11.14
9	Decapoda (shrimp)	45	11.14
10	Stomatopoda	42	10.40
11	Exocoetidae	41	10.15
12	Holocentridae	41	10.15
13	Gempylidae	31	7.67
14	Unidentified fish	29	7.18
15	Scombridae (j)	27	6.68
16	Chaetodontidae	27	6.68
17	Decapoda (megalopa stage)	27	6.68
18	*Stolephorus buccaneeri* (Engraulidae)	26	6.44
19	Gastropoda	25	6.19
20	Mullidae (blue goatfish)	23	5.69
21	*Dactylopterus orientalis* (Dacylopteridae)	20	4.95
22	Aluteridae	20	4.95
23	Decapoda (oxystomatid larva)	14	3.47
24	Carangidae	12	2.97
25	Amphipoda	11	2.72
26	Siganidae	11	2.72
27	*Decapterus* sp. (Carangidae)	9	2.23
28	Empty stomach	9	2.23
29	Engraulidae (j)	8	1.98
30	*Xiphasia* sp. (Xiphasiidae)	7	1.73
31	Bramidae	7	1.73
32	Decapoda (phyllosmoa stage)	7	1.73
33	Priacanthidae	6	1.49
34	Paralepidae	6	1.49
35	Sternoptychidae	5	1.24
36	Leiognathidae	5	1.24
37	Unidentified fish (j)	5	1.24
38	Crustacean remains	5	1.24
39	Crustacea (Decapoda)	4	0.99
40	Tetrodontidae	4	0.99
41	Mollusca	3	0.74
42	Ascideacea	3	0.74
43	Fistulariidae	3	0.74
44	*Argonauta* sp. (Cephalopoda)	3	0.74
45	Scaridae	3	0.74
46	Gonostomidae	2	0.50
47	Hemirhamphidae	2	0.50
48	Syngnathidae	2	0.50
49	Decapoda (penaeid shrimp)	2	0.50
50	Anguilliformes (leptocephalus larva)	2	0.50
51	Platycephalidae	2	0.50
52	Polychaeta	2	0.50
53	*Selar* sp. (Carangidae)	2	0.50
54	Crustacea	2	0.50
55	Engraulidae	2	0.50
56	Istiophoridae (j)	2	0.50
	Total Stomachs Examined	404	

APPENDIX D. TAG AND RECOVERY INFORMATION FOR EACH TAGGED SKIPJACK WHICH MADE A MIGRATION OUT OF OR INTO PAPUA NEW GUINEA'S 200-MILE DECLARED FISHING ZONE. A list at the end of this appendix gives the meanings of the codes used. The inset lines present release data as follows: country abbreviation (see Appendix E); school number; year/month/day of release; time of release; latitude of release; longitude of release; numbers of tagged skipjack released; numbers of tagged yellowfin released; numbers of species other than skipjack and yellowfin that were tagged and released. Line(s) following that for release data present the following data for each tag recovery: species, S for skipjack, Y for yellowfin; recovery country abbreviation (see list); year/month/day of recovery; days at large; recovery latitude; recovery longitude; great circle distance in nautical miles between release and recovery location; fork length in millimetres at time of tagging and length credibility code (see list); fork length at recovery and credibility code (see list); tag number; nationality of recapture vessel (or country chartering vessel), and tag recovery gear (see list). Date or position of recovery was excluded if the range of possible values was more than half the span from the release date or release position to the midpoint of the range of possible recovery dates or positions. If the range was less than half of this span, the information was included and the date or position of recovery was taken to be the midpoint of the range.

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**Migrants from the waters of Papua New Guinea to other areas**

      PNG  10 771026 1400 0707S 15530E  134    0    0
S SOL 781219 419 0830S 15900E 0224 550M 590B AB05755 SOLPOL

      PNG  11 771026 1500 0706S 15525E  122    0    0
S SOL 780928 337 0910S 15910E 0255 541B 560W AB05783 SOLPOL

      PNG  13 771026 1600 0705S 15522E   64    0    0
S SOL 780914 323 0900S 15858E 0243 520M 560W AB06825 SOLPOL

      PNG 547 790520 1700 0736S 14947E  482    0    0
S IND 790615 026 0050N 13725E 0896 520M 510W SK35653 JAPPOL
S SOL 790724 065 0835S 15700E 0433 490M 540W SK35668 SOLPOL
S INT 790809 081 0254N 13852E 0908 530M 549W SK35667 JAPSEN
S SOL                             490M    U SK35657 SOLPOL
S SOL 791016 149 0730S 15630E 0400 550M    U SK35736 SOLPOL
S SOL 791018 151 0930S 15930E 0588 520M 530W SK35698 SOLPOL
S INT 791206 200 1636S 15630E 0668 511B    U SK36093 JAPPOL
S SOL 800712 419 0830S 15930E 0580 511B 620W SK36067 SOLPOL
S SOL 800715 422 0830S 15630E 0403 490M 620W SK35646 SOLPOL
S INT 800805 444 0308N 17221W 2357 500M 618J SK35779 JAPPOL
S SOL 800825 463 0800S 15600E 0370 511B 620W SK35824 SOLPOL
S QLD 810804 807 1618S 15240E 0549 511B 750W SK36019 JAPPOL

      PNG 550 790527 1500 0325S 15110E  434    0    0
S PAM 800811 442 0523N 16127W 2888 550M 637W SK36256 JAPPOL

      PNG 551 790527 1600 0330S 15105E   95    0    0
S INT 801019 511 0525N 17414W 2146 560M 624W SK36820 JAPPOL
S SOL 801203 556 0952S 15935E 0634 564B 600B SK36854 SOLPOL
S MAS 801221 574 0502N 17022E 1264 560M 690C SK36773 JAPPOL

      PNG 552 790527 1715 0327S 15105E  322    0    0
S TRK 800404 313 0451N 15335E 0520 550M 620J SK36875 JAPPOL
S INT 810408 682 1753N 13335E 1646 530M 710W SK36981 JAPPOL

      PNG 553 790528 0640 0325S 15051E  550    8    0
S IND 800205 254  130N 13730E 0853 548B    U SK37284 JAPSEN
S KOS 800215 263 0335N 16106E 0744 550M 608W SK36505 JAPPOL
S SOL 800711 410 0830S 15630E 0455 530M 600W SK36507 SOLPOL

      PNG 554 790528 1745 0328S 15053E  135    6    0
S SOL 801202 554 0840S 16032E 0655 520M 630B SK37700 SOLPOL

      PNG 558 790530 1450 0413S 15234E   96   19    0
Y TRK 800810 438 0400N 15400E 0500 580M 060W SK37947 JAPLON

      PNG 559 790530 1525 0415S 15236E  163    3    0
S SOL 800106 221 0945S 16025E 0570 530M 540W SK39243 SOLPOL
S SOL 801102 522 0940S 16120E 0613 510M 610B SK37958 SOLPOL

      PNG 560 790530 1600 0418S 15234E  117  117    0
S TRK 800403 309 0438N 15410E 0545 440M 574W SK39502 JAPPOL
S KIR 800812 440 0258N 17600E 1471 530M 600W SK39540 JAPPOL

      PNG 561 790530 1710 0421S 15231E   68    0    0
S INT 791115 170  600N 15030W 3470 520M 541W SK39194 JAPPOL
S INT 800406 312 0403N 17933W 1749 530M 575J SK39570 JAPPOL

      PNG 562 790531 0805 0416S 15234E  143    1    0
S SOL 791018 140 0930S 15930E 0519 540M 510B SK39629 SOLPOL
S SOL 791023 145 0830S 16030E 0537 530M 600W SK39345 SOLPOL
S TRK 800324 298 0500N 15340E 0560 560M 596J SK39357 JAPPOL

      PNG 563 790531 0855 0408S 15234E  121    9    0
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      PNG 566 790531 1045 0416S 15233E  169   12    0
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      PNG 572 790601 1600 0410S 15234E   48  99   0
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U SOL 800624 389 0800S 15800E 0397 497B 580W SK40179 SOLPOL

      PNG 573 790603 1115 0402S 15102E   50  17   0
S TRK 800507 339 0418N 14849E 0517 490M 650W SK40458 JAPPOL

      PNG 574 790603 1340 0407S 15056E   70   0   0
S TRK 800420 322 0503N 15042E 0550 500Q 586W SK40499 JAPPOL

      PNG 575 790603 1500 0404S 15101E  904  12   0
S YAP 791024 143 0409N 14651E 0553 510M 552W SK40847 JAPPOL
S TRK 800221 263 0543N 15407E 0616 560M 630W SK40627 JAPPOL
S TRK 800329 300 0530N 15220E 0579 530M 700C SK41110 JAPPOL
S INT 800423 325 0300N 18000E 1789 540M 640W SK41039 JAPPOL
S SOL 800918 473 0830S 15800E 0494 550M 630W SK40397 SOLPOL

      PNG 576 790603 1640 0400S 15059E  208   0   0
S INT 800703 396 0426N 17905W 1864 540B 600W SK41776 JAPPOL

      PNG 580 790606 1700 0403S 15058E   17   2   0
S TRK 800324 292 0507N 15254E 0562 540M 570W SK41934 JAPPOL

      PNG 581 790607 0840 0405S 15101E   75   3   0
S     810813 799                      552B    U SK41993 JAPPOL

      PNG 582 790607 1145 0415S 15100E  119  49   0
S MAS 810212 616 0821N 16603E 1176 510M 660W SK44156 JAPPOL

      PNG 587 790608 1120 0345S 15048E  231   0   0
S INT 800106 212 0221N 14246E 0605 570M 650W SK44232 JAPSEN
S SOL 800715 403 0830S 15630E 0444 550M 630W SK41618 SOLPOL

      PNG 591 790609 1230 0406S 15233E  187   4   0
S IND 800205 242  130N 13730E 0963 520M    U SK44347 JAPSEN
S SOL 800508 334 0730S 15830E 0410 540M 570W SK44614 SOLPOL

      PNG 594 790615 1040 0125S 14700E  513 220   1
S INT 790905 082 0322N 14257E 0376 460M 490W SK38247 JAPSEN
Y IND 790906 083 0227N 13440E 0775 515M 540W SK38659 JAPSEN
Y IND 790906 083 0227N 13440E 0775 470M 495W SK44499 JAPSEN
S PAL 790909 086 0348N 13501E 0784 480M 485W SK38158 JAPSEN
Y INT 790915 092  300N 14100E 0447 505M 513W SK38450 JAPSEN
S YAP 790921 098 0432N 14149E 0473 460M 480W SK38661 JAPSEN
Y YAP 790927 104 0447N 14153E 0482 470M 565W SK38169 JAPSEN
S YAP 790927 104 0447N 14153E 0482 445M 509W SK38631 JAPSEN
S IND 791005 112 0135N 13726E 0601 550M 560W SK44784 JAPSEN
Y IND 791019 126 0022S 13754E 0550 560M 548W SK38177 JAPSEN
Y YAP 791114 152 0516N 14316E 0459 475M 537W SK38499 JAPPOL
Y INT 791123 161 0150N 14211E 0349 465M 530W SK38490 JAPSEN
S TRK 791129 167 0402N 15159E 0443 410M 515W SK38161 JAPPOL
S INT 800130 229 0414N 17624E 1795 525M 612J SK44761 JAPPOL
S GUM 800307 266 1230N 14800E 0837 550M 600W SK38034 JAPUUU
S PON 800329 288 0404N 15630E 0658 550M 552J SK44964 JAPPOL
S PON 800401 291 0348N 15613E 0635 530M 600W SK44792 JAPPOL
S INT 800707 388 0308N 17312W 2403 520M 634W SK38136 JAPPOL
S HOW 800803 415 0346N 17607W 2234 485M 540C SK38474 JAPPOL
S PAM 800811 423 0523N 16127W 3116 560M 635J SK38176 JAPPOL
S HOW 800827 439 0125N 17636W 2190 520M 604W SK44937 JAPPOL
S MAS 801028 501 0628N 16604E 1236 520M 626J SK44471 JAPPOL
S MAS 801031 504 0721N 16642E 1291 500M 622W SK38154 JAPPOL
S MAS 810205 602  700N 16630E 1272 515M 645W SK44919 JAPPOL

      PNG 597 790617 1030 0142S 14741E  184   0   0
S IND 790906 081 0227N 13440E 0820 475M 491W SK38762 JAPSEN
S TRK 791108 144 0425N 14830E 0370 560M 569W SK38785 JAPPOL
S MAS 800210 238 0544N 17200E 1524 550M 630W SK38748 JAPPOL
S PON 800325 282 0132N 15438E 0460 530M 614W SK38316 JAPPOL
S PAL 801008 479 0700N 13500E 0922 550M    U SK38756 TPIPOL
S MAS 801025 496 0643N 16925E 1396 515M 645W SK38814 JAPPOL
S INT 801211 543 0424N 17913E 1926 560M 680C SK38803 JAPPOL

      PNG 599 790618 1750 0125S 14605E   91   0   0
S INT 791111 146 0148N 14218E 0298 460M 501W SK38351 JAPSEN
S IND 800131 227 0214N 13849E 0488 475M 559W SK38881 JAPSEN

      PNG 601 790619 1640 0145S 14644E   99  38   0
S TRK 800515 331 0630N 15220E 0598 530M 620W SK38088 JAPPOL

      PNG 603 790621 1600 0215S 15023E   97   0   0
S INT 800407 291 0435N 17818W 1922 575M 640C SK42217 JAPPOL
S INT 801210 538 0427N 17850E 1752 560M 670W SK42244 JAPPOL

      PNG 607 790623 0730 0315S 15053E  106  35   0
S IND 800409 291 0202N 13333E 1087 540M 589W SK42389 JAPSEN

      PNG 609 790623 0945 0320S 15102E   93   3   0
S HOW 800730 403 0203N 17716W 1928 565M 618W SK42706 JAPPOL
S SOL 800829 433 0850S 15840E 0562 540M 590W SK38548 SOLPOL

      PNG 610 790623 1015 0319S 15058E   47  18   0
S SOL 801215 541 0910S 15810E 0554 570M 560B SK42772 SOLPOL

      PNG 614 790626 0915 0221S 15026E   39   0   0
S SOL                                650M     SK42830

      PNG 617 790626 1540 0203S 14955E   98   3   0
S HOW 800712 382 0315N 17626W 2043 550M 594J SK42879 JAPPOL
S HOW 800729 399 0142N 17725W 1973 550M 650W SK42188 JAPPOL

      PNG 618 790627 1115 0153S 14950E  133  11   0
S SOL 810103 556 0900S 15930E 0718 440M 560B SK43037 SOLPOL
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Migrants from other areas to the waters of Papua New Guinea .

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      SOL  30 771109 1715 0857S 15846E  482   0   0
S PNG 780604 207 0230S 15045E 0615 503B 580W AY02276 PNGPOL

      SOL  35 771114 1415 0854S 15830E  301  13   0
S PNG 780603 201 0230S 15045E 0601 500M    U AY03041 PNGPOL

      SOL  36 771114 1530 0859S 15830E  183  24   0
S PNG 780529 196 0330S 15050E 0563 525M 580W AY03381 PNGPOL

      SOL  43 771125 1054 0841S 15821E  132   0   0
S PNG 780615 202 0300S 15000E 0604 530M 580W AY03939 PNGPOL

      SOL 882 800611 1115 0744S 15811E  288  18   0
S PNG 810226 260 0153S 15632E 0365 510M 544W 1E11080 JAPSEN
S PNG 810314 276 0342S 15126E 0470 510M 570W 1E11031 PNGPOL
S PNG 810323 285 0359S 15147E 0443 510M 580W 1E10789 PNGPOL
S PNG 810709 393 0359S 15147E 0443 525M 510W 1E11042 PNGPOL

      SOL 886 800614 1030 0737S 15616E  120 146   0
S PNG 810102 202 0420S 15124E 0351 450M 500B 1E11596 PNGPOL

      SOL 888 800615 1030 0740S 15618E   26  51   0
S PNG 801018 125 0459S 14910E 0455 570M 600B 1E12151 PNGPOL

      SOL 891 800617 1100 0831S 15928E  246   0   0
S PNG 810611 359 0355S 15157E 0526 550M 600W 1E11788 PNGPOL

      SOL 893 800618 1030 0840S 15936E 1533  26   0
S PNG 810618 365  350S 15130E 0563 460M 510W 1E12482 PNGPOL
S PNG 820830 803                     470M 617W 1E11926 JAPSEN

      SOL 901 800622 1150 0807S 16020E  204   0   0
S PNG 800817 056  158S 15038E 0687 580M 560B 1E14595 PNGPOL
S PNG 800825 064 0350S 15110E 0604 580M 620B 1E14982 PNGPOL
S PNG 800829 068 0038N 14150E 1225 600M 602W 1E14819 JAPSEN

      PON 321 781103 1000 0659N 15838E   47  57   0
S PNG 790423 171 0215S 15040E 0731 490M    U SH00508 PNGUUU

      PAL 315 781020 1300 0706N 13454E  440   0   0
S PNG 790111 083 0054N 14123E 0537 580M 616W SK30301 JAPSEN
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PAL 928 800807 0745 0421N 13218E 3 70 0
Y PNG 810430 266 0355S 15157E 1278 500M 600W 2E22286 PNGPOL

PAL 929 800809 1600 0300N 13135E 85 16 0
Y PNG 810212 187 0003N 14727E 0968 370M 494W 1B14319 JAPSEN
S PNG 810805 361 360M 480C 1B14318 JAPSEN

PAL 930 800809 1615 0300N 13136E 282 7 0
S PNG 810103 147 0012N 14534E 0854 340M 471W 2E22479 JAPSEN
S PNG 810411 245 0150S 14940E 1122 340M 550E 2E22523 PNGPOL
S PNG 810712 337 0038S 14308E 0725 360M 518W 2E22458 JAPSEN

PAL 931 800811 0715 0257N 13140E 151 123 0
S PNG 800915 036 130N 14430E 0774 530M 496W 1B14163 JAPSEN
Y PNG 801221 132 0030S 14302E 0712 370M U 2E22328 JAPSEN
S PNG 801225 136 0028S 14401E 0769 422T 503W 1B14153 JAPSEN
S PNG 810704 327 0357S 15203E 1290 422T 510W 2E22544 PNGPOL
Y PNG 810730 353 0021N 14213E 0652 400M 520W 2E22483 JAPSEN

PAL 932 800812 0710 0252N 13140E 241 77 0
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S PNG 810701 323 0027S 14202E 0653 334T 510W 1B14497 JAPSEN
S PNG 810711 333 0340S 15200E 1281 360M 520W 1B14245 PNGPOL
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S PNG 801103 083 0011S 14114E 0603 480M 500W 1B14684 JAPSEN
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S PNG 801201 111 0250S 15010E 1161 440T 400B 2E22370 PNGPOL
S PNG 801221 131 0018S 14302E 0708 440T 494W 2E23092 JAPSEN
S PNG 801224 134 0021S 14352E 0757 440T 514W 2E22358 JAPSEN
S PNG 810225 197 0016N 14534E 0848 420M U 2E22837 JAPSEN
S PNG 810307 207 0029S 14319E 0727 440T 491W 2E22361 JAPSEN
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S PNG 810730 351 0021N 14213E 0651 460M 524W 1B14734 JAPSEN

PAL 935 800813 0945 0257N 13137E 143 12 0
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S PNG 810810 362 0033N 14345E 0742 470M 515W 2E23529 JAPSEN

PAL 937 800814 0735 0253N 13138E 635 10 0
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S PNG 801120 098 0033N 14136E 0614 450M 484W SM04126 JAPSEN
S PNG 801213 121 0114N 14142E 0612 440M 476W SM04302 JAPSEN
S PNG 801221 129 0018S 14302E 0710 430M 496W SM04185 JAPSEN
S PNG 801223 131 0012S 14335E 0740 470M 474W 2E23625 JAPSEN
S PNG 810107 146 0028N 14448E 0803 460M 479W 2E23660 JAPSEN
S PNG 420M U 2E23677 PNGPOL
S PNG 810212 182 0003N 14727E 0964 410M 500W 2E23883 JAPSEN
S PNG 810507 266 0236S 14945E 1135 350M 520W 2E24009 PNGPOL
S PNG 810909 391 0126N 14134E 0602 480M 534C 2E23659 JAPSEN

PAL 938 800815 0755 0250N 13134E 13 0 0
S PNG 810225 194 0016N 14534E 0854 450M 498W 2E23764 JAPSEN

PAL 939 800818 0830 0736N 13416E 123 8 1
S PNG 420M U 2E23981 PNGPOL
S PNG 810210 176 0022N 14145E 0623 395M 494W 2E23982 JAPSEN
S PNG 810717 333 0057N 14320E 0673 400M 541J 2E24203 JAPSEN

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PAL 941 800818 1340 0741N 13410E 2347 237 4
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S PNG 810730 345 0021N 14213E 0651 380M 532W 2E27062 JAPSEN

PAL 943 800820 1035 0735N 13459E 208 0 0
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CAL 53 771215 1840 2114S 16602E 275 11 0
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CAL 83 780103 1445 2043S 16618E 130 0 0
S PNG 780924 264 0520S 15445E 1142 510M U SA05626 PNGSUB

VAN 120 780122 0920 1622S 16757E 28 0 0
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TUV 257 780628 1005 0859S 17904E 43 0 0
S PNG 791019 478 0212S 14959E 1783 530M 660B SK22715 PNGPOL

WAL 216 780518 1105 1334S 17612W 293 0 0
S PNG 790905 475 0215S 15049E 2071 550M 620W SE02658 PNGPOL

WAL 225 780521 0815 1332S 17610W 417 0 0
S PNG 0600S 15600E 1705 520M 563D SK18696 UUUUUU

CODES FOR LENGTH MEASUREMENTS, RECAPTURE GEARS AND COUNTRY ABBREVIATIONS

Release Length Credibility

M	Measured
B	Estimated from Biological Data
T	Estimated from Tagging Data
G	Guessed
U	Unknown
Q	Length Questionable

Recapture Length Credibility

A	Measured by Hatsutori Maru No.1 (SPC staff)
B	Measured by joint local ventures
C	Measured by Japanese long-range boats, or long-liners of other nationalities
D	Measured by other supposedly reliable sources
E	Measured by unreliable sources
W	Measured length verified by weight
J	Estimated from weight
K	Estimated from other sources (string, etc.)
U	Unknown

Nationality of Recapture Vessel (Country Abbreviations)

AMS	American Samoa
CAL	New Caledonia
FIJ	Fiji
IND	Indonesia
INT	International waters
JAP	Japan
KIR	Kiribati
KOR	Korea
NOR	Norfolk Island
NSW	New South Wales (Australia)
PAL	Palau
PHL	Philippines
PNG	Papua New Guinea
POL	French Polynesia
PON	Ponape (Federated States of Micronesia)
QLD	Queensland (Australia)
SOC	Society Islands (French Polynesia)
SOL	Solomon Islands
TAW	Taiwan
TOK	Tokelau
TON	Tonga
TUV	Tuvalu
USA	United States
VAN	Vanuatu
WAL	Wallis and Futuna
WES	Western Samoa
ZEA	New Zealand

Type of Recapture Vessel

SEN	Purse-seine
POL	Pole-and-line
LON	Longline
SHE	Pearl-shell trolling
ART	Artisanal
GIL	Gill net
REC	Recreational (sport fishing)
SUB	Subsistance (village)
UUU	Unknown

APPENDIX E. ABBREVIATIONS USED FOR COUNTRIES AND TERRITORIES IN THE CENTRAL AND WESTERN PACIFIC

AMS - American Samoa
CAL - New Caledonia
COK - Cook Islands
FIJ - Fiji
GAM - Gambier Islands (French Polynesia)
GIL - Gilbert Islands (Kiribati)
GUM - Guam
HAW - Hawaii
HOW - Howland and Baker Islands (U.S. Territory)
IND - Indonesia
INT - International waters
JAP - Japan
JAR - Jarvis (U.S. Territory)
KOS - Kosrae (Federated States of Micronesia)
LIN - Line Islands (Kiribati)
MAQ - Marquesas Islands (French Polynesia)
MAR - Northern Mariana Islands
MAS - Marshall Islands
MTS - Minami-tori shima (Japan)
NAU - Nauru
NCK - Northern Cook Islands
NIU - Niue
NOR - Norfolk Island
NSW - New South Wales (Australia)
PAL - Palau
PAM - Palmyra (U.S. Territory)
PHL - Philippines
PHO - Phoenix Islands (Kiribati)
PIT - Pitcairn Islands
PNG - Papua New Guinea
POL - French Polynesia
PON - Ponape (Federated States of Micronesia)
QLD - Queensland (Australia)
SCK - Southern Cook Islands
SOC - Society Islands (French Polynesia)
SOL - Solomon Islands
TOK - Tokelau
TON - Tonga
TRK - Truk (Federated States of Micronesia)
TUA - Tuamotu Islands (French Polynesia)
TUV - Tuvalu
VAN - Vanuatu
WAK - Wake Island (U.S. Territory)
WAL - Wallis and Futuna
WES - Western Samoa
YAP - Yap (Federated States of Micronesia)
ZEA - New Zealand

APPENDIX F. SUMMARY OF THE TAG ATTRITION MODEL DERIVED BY KLEIBER, ARGUE & KEARNEY (1983) TO ESTIMATE STOCK PARAMETERS FROM TAG RECAPTURE DATA

The formula for the model is :

$$r_i = \frac{\alpha \beta N_o F_i}{A} e^{-iA}\left(e^{A} - 1\right)$$

where

r_i = number of returns in the ith month.

α = proportion of tagged fish surviving Type-1 tag losses, which include short-term mortality due to the process of handling and tagging, and immediate shedding of improperly implanted tags.

β = proportion of recaptured tags which are returned within usable information. This proportion is reduced by three factors : non-detection of recovered tags, failure to return detected tags, and return of tags with insufficient or inaccurate information on recovery.

N_o = number of tagged fish released.

F_i = instantaneous rate of fishing mortality (harvest rate in the ith month).

A = instantaneous total attrition rate, which includes natural mortality, fishing mortality, emigration, tag slippage and mortality due to carrying a tag (Type-2 tag losses), and growth out of vulnerability to the fishery.

i = number of months since release.

From the number of tag releases, N_o, the model predicts the number of tag retuns per time period, r_i, as a function of fishing mortality per time period, F_i, and the attrition of tags at large, A.

Since F_i may be approximated as :

$$F_i \cong \frac{C_i}{P} \cong Q E_i$$

where C_i = catch in the i th month.

E_i = effort in the i th month.

P = standing stock, or biomass.

Q = catchability coefficient, or fraction of the standing stock harvested by one unit of fishing effort.

then the following equations may be used :

$$P = \frac{\bar{C}}{F}$$

$$Q = \frac{\bar{E}}{F}$$

In addition, harvest ratio H may be calculated as

$$H = \frac{F}{A}$$

where H = harvest ratio, or proportion of total attrition which is due to fishing.

APPENDIX G. EQUATION FOR CALCULATING THE IMMIGRATION COEFFICIENT (Kleiber, Sibert & Hammond ms.)

$$I = \frac{RT_D}{\alpha_D \beta_R N_o C_R}$$

where

R = number of recoveries in the receiver country of tags released in the donor country.

T_D = throughput (tonnes per month) of the stock in the donor country.

α_D = factor accounting for Type-1 tag losses (see Appendix F) in the donor country.

β_R = factor accounting for loss of recapture information (see Appendix F) in the receiver country.

N_o = number of tags released in donor country.

C_R = mean monthly catch rate in the receiver country during the period in which tags were recovered. A minimum period of 12 months was used, evenly bracketing the recovery period; where tags were recovered over a period longer than 12 months, the average catch was calculated for the whole period plus one month before and after it.