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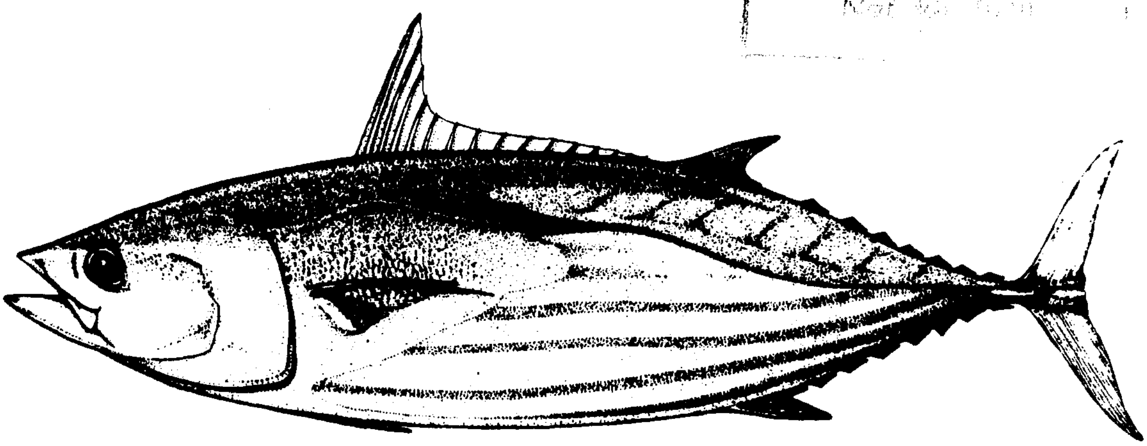
AN ASSESSMENT OF THE SKIPJACK AND BAITFISH RESOURCES OF EASTERN AUSTRALIA



Skipjack Survey and Assessment Programme
Final Country Report No. 16

South Pacific Commission
Noumea, New Caledonia
June 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 skipjack 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 is indebted to officials of Australian Fisheries, Department of Primary Industry, Canberra, New South Wales State Fisheries and the Queensland Fisheries Service. Special thanks are due for the assistance provided by Ray Walker, Australian Fisheries, Department of Primary Industry, Canberra, Dr Don Francois, New South Wales State Fisheries, Sydney, Colin McDonald, Department of Foreign Affairs, Canberra, and Kevin Williams, CSIRO Division of Fisheries Research, Cronulla, Sydney.

Tuna Programme
South Pacific Commission

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AN ASSESSMENT OF THE SKIPJACK AND BAITFISH RESOURCES OF EASTERN AUSTRALIA

1.0 INTRODUCTION

The Skipjack Survey and Assessment Programme was created in response to rapid expansion of surface fisheries for skipjack (Katsuwonus pelamis) in the waters of the central and western Pacific during the early 1970s. The objectives of the Skipjack Programme were to survey the skipjack and baitfish resources within the area of the South Pacific Commission and parts of New Zealand and the Pacific coast of Australia (Figure A, inside front cover), and to assess the status of skipjack stocks and the degree of interaction between fisheries for skipjack within this region and beyond. These assessments provide a basis for rational development of skipjack fisheries throughout the region and sound management of the resource.

The Programme's field research spanned almost three years between October 1977 and August 1980, and included 847 days of tagging and survey operations. Visits were made to all central and western Pacific member countries and territories of the South Pacific Conference (see Anon. 1983a). Forty-three days were spent in eastern Australian waters in April and May 1979, and five days were spent in waters around Norfolk Island[1] in March 1980. The survey of the east coast of Australia was of particular significance because it afforded the Programme an opportunity to study tuna and baitfish in temperate and tropical environments along a single coastline spanning 23° of latitude (approx. 1,500 nautical miles), and to examine in detail a predicted discontinuity in the distribution of surface-schooling tuna between 26°S and 32°S latitude (Kearney 1975). Preliminary results from the 1979 visit were given by Kearney & Gillett (1979) and from the 1980 visit to Norfolk Island by Kearney & Hallier (1980). This report presents the final analyses of the work by the Programme in Australian waters, compares them to previous data and to results from elsewhere in the Programme's study area, and considers their implications for skipjack and baitfish resource management.

1.1 Previous Research

The existence of a widely distributed and possibly large skipjack resource off south-eastern Australia first became apparent after extensive surface-fishing surveys between 1938 and 1942 by the Commonwealth Scientific and Industrial Research Organization (CSIRO) aboard the research vessel Warreen. A summary of these and subsequent surveys is given in Appendix A. Skipjack were sampled, using trolling gear, from the waters of

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1 At the time of the Skipjack Programme survey, Norfolk Island was a member of the South Pacific Conference, and an interim report was prepared for it. In October 1980, Norfolk Island's status as part of the Commonwealth of Australia was reaffirmed, and it ceased to hold separate membership of the Conference. Thus, the results of the survey of Norfolk Island waters are treated here with those from the survey of eastern Australian waters.

Queensland, New South Wales, Victoria and Tasmania (Blackburn 1941, 1943; Flett 1944; Blackburn & Tubb 1950; Serventy 1956). Sampling of larval skipjack by towed plankton nets was also conducted on some of these cruises. Further trolling surveys were made in the same areas during 1950 and 1951 by the CSIRO vessel Stanley Fowler (Robins 1952), while aerial surveys were made by CSIRO between 1965 and 1977 (Hynd & Robins 1967; Hynd 1968), and pole-and-line surveys by the Catriona B in 1977 and 1978 (Carrick 1977, 1978).

Data collected during the CSIRO trolling surveys were used to assess size distribution, reproduction cycles and feeding biology of skipjack, mainly from eastern Australian waters (Blackburn & Serventy 1981). There are no comparable data from Norfolk Island waters.

The southern limit of skipjack distribution appears to coincide with the position of the 15° or 16°C isotherms (Robins 1952; Hynd & Robins 1967; Blackburn & Serventy 1981). Thus, the abundance of skipjack in south-eastern Australian waters varies seasonally, with large concentrations of fish occurring as far south as Tasmania in summer. In winter, skipjack are not found in abundance south of the central New South Wales coast (Blackburn & Serventy 1981). The northern limits of skipjack distribution in coastal waters off eastern Australia were thought by Robins (1952) to coincide with the 19°C to 20.5°C isotherms, or about 30°S and 38°S latitude in winter and summer, respectively. However, during aerial and surface surveys, Hynd (1968) reported a few schools of skipjack between 17°S and 25°S, off the north and central Queensland coast, in August to November 1965 (late winter to early summer), and January to May 1967 (late summer to early winter), but they were not seen in great abundance at any time. There were no reports of skipjack occurring in coastal waters off southern Queensland and northern New South Wales, leading Kearney (1975) to predict that there was a hiatus in the distribution of skipjack along the eastern Australian coast, between approximately 26°S and 32°S. Japanese longline vessels had taken incidental catches of skipjack in waters offshore from this section of the eastern Australian coast and a subsequent survey of the southern part of this area by the Catriona B (Carrick 1977) indicated some schools of skipjack in offshore waters.

Thompson (1943) suggested that northern Pacific live-bait, pole-and-line techniques might be suitable for catching tuna under Australian conditions. Early trials aboard the Warreen (Flett 1944) demonstrated that skipjack, albacore and southern bluefin could be fished successfully by this method. There now exists a major pole-and-line fishery for southern bluefin in New South Wales and South Australia, but a sizeable fishery for skipjack has not been developed (Section 1.2). Purse-seine trials were also conducted by the CSIRO using the Warreen and the Jester (Blackburn 1943), but no skipjack were caught (Appendix A).

Live pilchards and anchovies, caught at night by lampara net, were used in the early pole-and-line trials (Flett 1944). Results of surveys of the abundance of several baitfish species, mainly anchovies, pilchards and jack mackerel, were reported by Blackburn & Tubb (1950), Blackburn & Rayner (1951) and Carrick (1977, 1978). The biology of several species was studied by Blackburn (1950a, 1950b, 1951), Webb & Grant (1979) and Richardson (1982). Further biological data and synopses of the fisheries for various pilchard and anchovy species may be found in Blackburn (1960), Humphrey (1960) and Winstanley (1979).

1.2 Previous Fisheries Development

Early research indicated both the existence of a skipjack resource off south-eastern Australia and a means by which to exploit it (Section 1.1). Subsequent exploratory fishing ventures demonstrated that it was possible to catch skipjack in quantities sufficient to support commercial operations (Temple 1963; Uchida 1975). However, the low price offered for skipjack by Australian processors has consistently hampered the development of a fishery (Peter Sloan & Company 1978; Anon. 1982). Most catches to date have been taken incidentally during fishing for southern bluefin. An inshore gill-net fishery for skipjack operated in summer off Lakes Entrance, Victoria, during the early 1960s, but after 1965, effort was redirected towards catching edible sharks, which yielded higher prices (Uchida 1975). In the best years of the gill-net fishery for skipjack, catches were around 100 tonnes, taken mainly in December and January (Peter Sloan & Company 1978). Figures for skipjack catches from all sources are not available for most years, but the highest catch appears to have been in the 1974-1975 season, when 2,375 tonnes were taken off New South Wales (Blackburn & Serventy 1981). This resulted primarily from the reintroduction of purse-seining, as about 80 per cent of the catch were by purse-seiners.

Two factors have rekindled interest in exploitation of skipjack. The first was the recognition that the stocks of skipjack in eastern Australian waters may be very high, perhaps supporting annual catches several times those currently taken of southern bluefin (Lorimer 1970; Ottesen & Grant 1982). The second has been the decline in yields from, and restrictions on access to, the southern bluefin fishery (e.g. Anon. 1982). Over 200 tonnes of skipjack were taken in nine sets during exploratory fishing in New South Wales waters by the American purse-seiner Frontier in 1979 and 1980. Moves by the Australian Government to encourage the development of purse-seining operations which target specifically on skipjack have not yet met with success.

2.0 METHODS

2.1 Vessels and Crew

Two Japanese commercial fishing vessels, the Hatsutori Maru No.1 and the Hatsutori Maru No.5, were chartered at different times by the Skipjack Programme from Hokoku Marine Products Company Limited, Tokyo, Japan. Details of both vessels are given in Kearney (1982). The 192-gross tonne Hatsutori Maru No.1 was used during the survey of eastern Australia in April and May 1979. The waters of Norfolk Island were surveyed in March 1980 using the 254-gross tonne Hatsutori Maru No.5.

The Hatsutori Maru No.1 was operated with at least three Skipjack Programme scientists, nine Japanese officers and twelve Fijian crew. For the Hatsutori Maru No.5, additional Fijian crew were usually employed. Observers from various Australian and New Zealand Government fisheries agencies, the Australian National University, the Norfolk Island Legislative Assembly and the Norfolk Island fishing community were on board at various times during the surveys of Australian waters. Names of all personnel and details of the times scientists and observers spent on board are given in Appendix B.

2.2 Baitfishing

Most baitfishing activity was carried out at night using a "bouki-ami" net set around bait attraction lights. In some countries surveyed by the Skipjack Programme, beach seining during daylight hours supplemented night catches, but it was not attempted in Australia. A lampara net was deployed during daylight hours on two occasions in New South Wales. Details of bouki-ami and beach-seine techniques employed by the Skipjack Programme are given in Hallier, Kearney & Gillett (1982); the use of a lampara net is described in Nedelec (1975).

2.3 Fishing, Tagging and Biological Sampling

Both vessels used by the Skipjack Programme were designed for commercial, live-bait pole-and-line fishing, and the basic strategy of approaching and chumming schools normally employed by such vessels was not changed. 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 numbers of crew on the Hatsutori Maru No.1 and No.5 were fewer than either of these vessels carry 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 tuna 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-18 February, 28 March-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 1978). It was assumed that the same ratio of 3.47 applied to the operations of the Hatsutori Maru No.5.

Since tagging was the primary research tool, attempts to tag large numbers of skipjack usually dominated the fishing strategy. The tagging techniques and alterations to commercial fishing procedures were described in detail by Kearney & Gillett (1982).

Specimens of tuna and other pelagic species which were poled or trolled, but not tagged and released, were routinely analysed. Data collected included 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 Programme. 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 the methods described by Fujino (1966) and Sharp (1969), and were frozen and packed on dry ice for air freighting to the Australian National University, Canberra, Australia, where they were electrophoretically analysed (Richardson 1983).

Beginning in December 1979, body cavities of skipjack were examined for the presence of macro-parasites. Complete sets of gills and viscera were taken from five fish from each school (up to a maximum of three schools per day), frozen, and subsequently air freighted to the University of Queensland, St Lucia, Australia, for detailed examination.

2.4 Data Compilation and Analysis

Five separate logbooks were used for compiling data accumulated during the fieldwork outlined in Sections 2.2 and 2.3. The techniques used to enter data from these logs into computer files and to process data were discussed by Kleiber & Maynard (1982). Electrophoretic data from blood samples and parasite identifications from skipjack viscera were also coded and entered into computer files. Data processing was carried out on the Programme's Hewlett Packard 1000 computer in Noumea.

Assessment of the skipjack resource and possible interactions among skipjack fisheries required several different approaches. Records of the migration of tagged skipjack formed the basis of the investigations of movement patterns and fishery interactions, using analytic techniques described in Skipjack Programme (1981a) and Kleiber, Sibert & Hammond (ms.). Evaluation of the magnitude of the skipjack resource and its dynamics, based on tag recapture data, are described by Kleiber, Argue & Kearney (1983). Methods employed in studies of growth are described by Sibert, Kearney & Lawson (1983) and Lawson, Kearney & Sibert (1984), and of juvenile abundance, in Argue, Conand & Whyman (1983). Procedures used to compare fishing effectiveness of different baitfish families are described in Argue, Williams & Hallier (ms.). Evaluation of population structuring across the whole of the western and central Pacific was based on a comparison of the tagging results with the blood genetics analyses (Anon. 1980, 1981; Skipjack Programme 1981b), and analyses of the occurrence and distribution of skipjack parasites (Lester, Barnes & Habib ms.).

3.0 SUMMARY OF FIELD ACTIVITIES

Figure 1 shows the areas surveyed for surface-schooling tuna in Australian waters. The eastern Australian coast was surveyed between Cape Howe, at the New South Wales-Victoria border, to the northernmost part of Queensland. In New South Wales and southern Queensland, searching and fishing was concentrated approximately along the 200-metre depth contour. In central and northern Queensland the vessel worked mainly within 10 nautical miles of the outer edge of the Great Barrier Reef, as well as surveying large areas of the Coral Sea (Figure 1). However, some time was spent within the Great Barrier Reef lagoon north of Cairns. The survey of Norfolk Island waters involved a circumnavigation of the island at a distance of approximately 40 nautical miles, and searching and fishing in areas to the north-east, south and south-east of the island.

Daily field activities are summarised in Table 1. Twenty-three days, of which 14 involved fishing, were spent in the waters of New South Wales, 20 days were spent in Queensland waters (15 fishing days) and 5 days were spent in waters surrounding Norfolk Island (4 fishing days). Non-fishing days were spent steaming, in port, or daybaiting. A total of 362 hours were spent searching and fishing, for an average of 10 hours per day on which these activities occurred. Almost 35.6 tonnes of tuna (90% skipjack, 10% yellowfin, with a few albacore) were caught and 8,418 tuna, including 8,086 skipjack, were tagged and released. Yellowfin constituted a significant proportion of the catch and tag releases only around Norfolk Island.

FIGURE 1. THE AREA OF EASTERN AUSTRALIAN WATERS SURVEYED BY THE SKIPJACK PROGRAMME

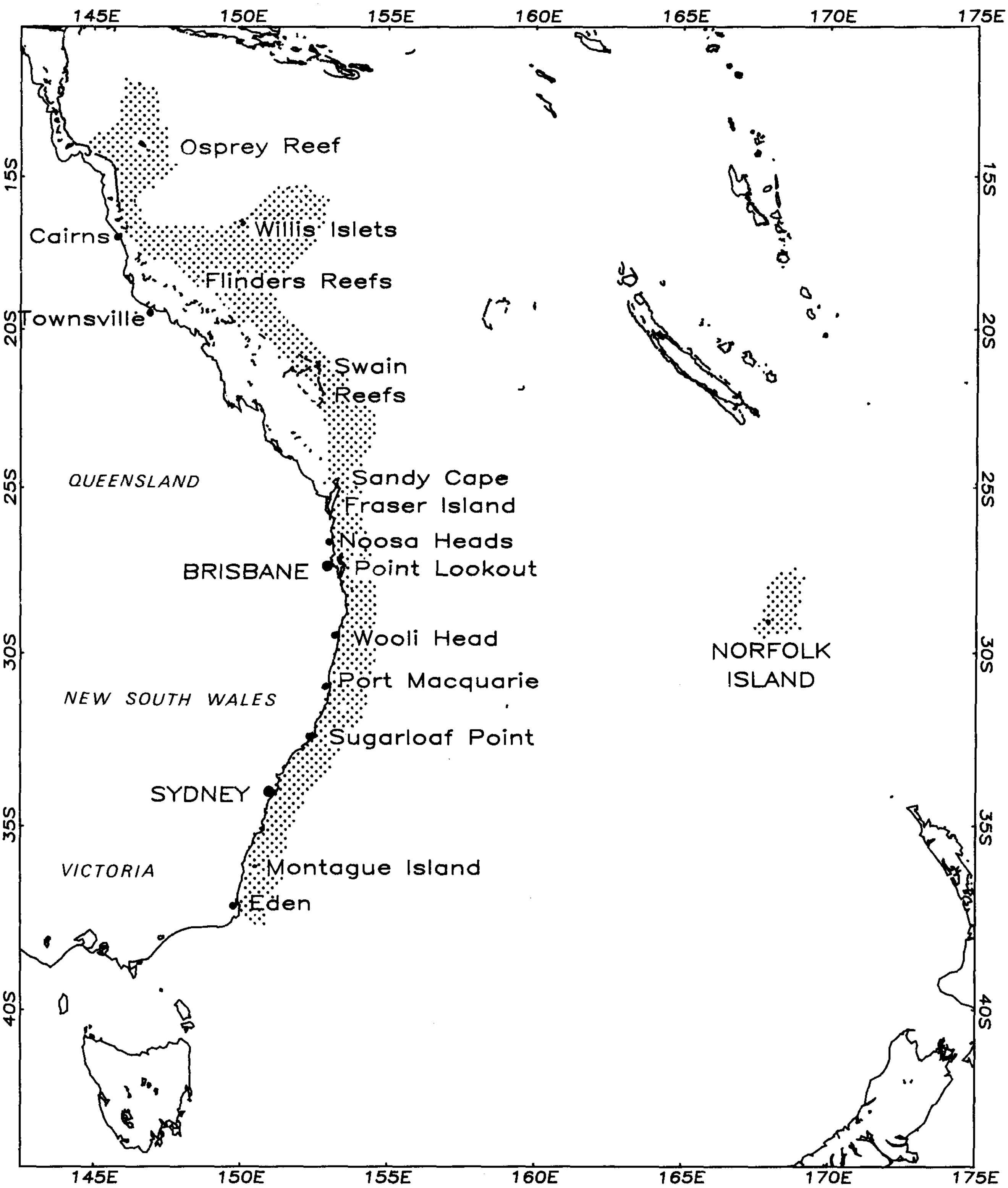
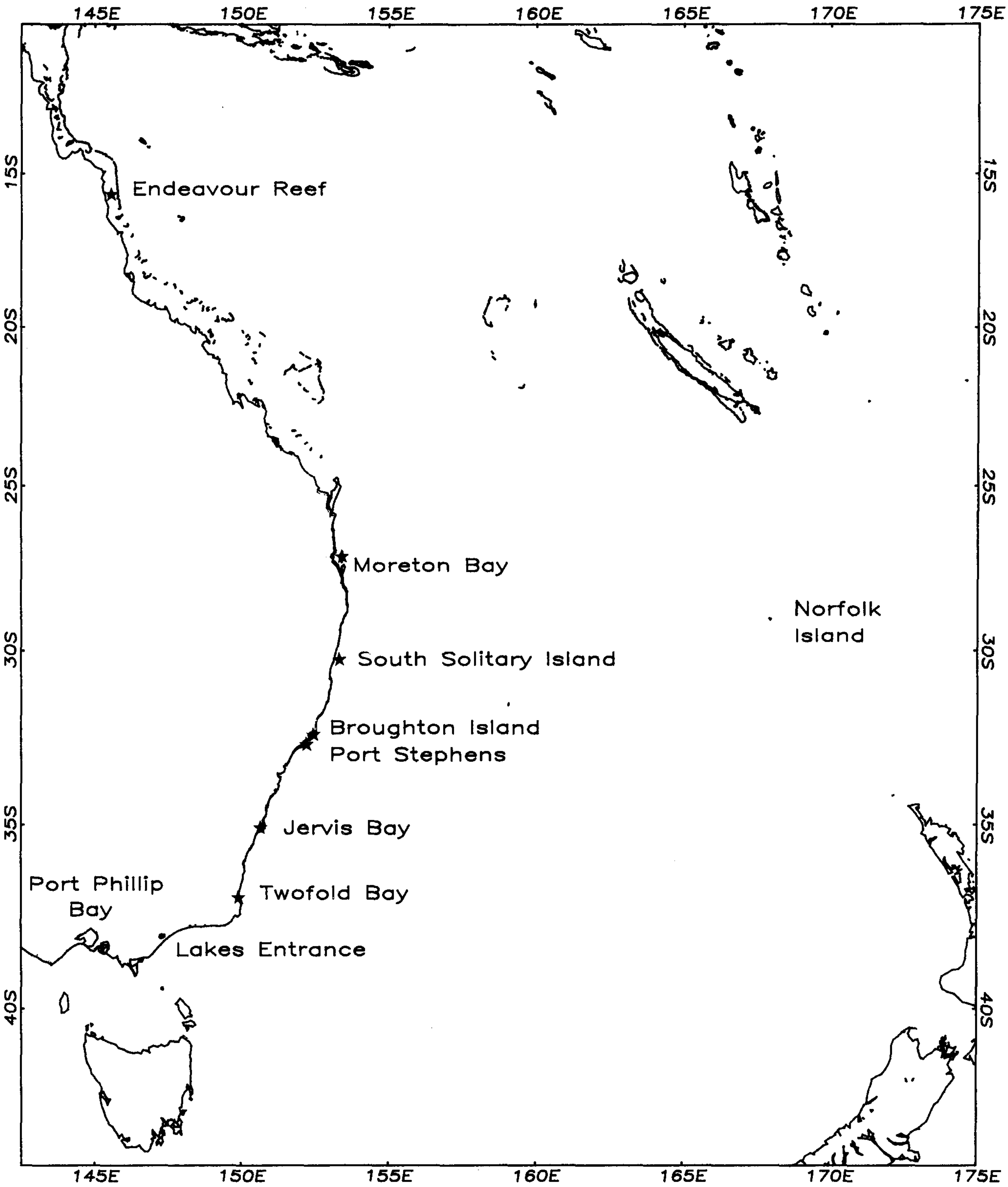


TABLE 1. SUMMARY OF DAILY FIELD ACTIVITIES IN AUSTRALIAN WATERS. Schools sighted are identified by species: SJ = skipjack or skipjack with other species except yellowfin, YF = yellowfin or yellowfin with other species except skipjack, S+Y = skipjack with yellowfin or skipjack with yellowfin and other 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) SJ	YF	S+Y	OT	UN	Fish Tagged (numbers) SJ	YF	OT	Fish Caught (kg) SJ	YF	Total Catch (kg)
01/04/79	E of Eden	Steaming	1311	3	0	0	0	0	0	0	0	0	0	0	0
02/04/79	Eden	Steaming	1310	0	-	-	-	-	-	-	-	-	-	-	-
03/04/79	Eden	Fishing	1719	8	5	0	0	0	1	145	0	1	479	0	481
04/04/79	Eden-Montague Is	Fishing	1656	11	2	0	0	0	0	68	0	12	189	0	269
05/04/79	Montague Is	Fishing	1611	12	10	0	1	1	1	537	8	3	1616	70	1718
06/04/79	Jervis Bay	Fishing	1367	11	13	0	0	0	0	637	0	0	2527	0	2527
07/04/79	Jervis Bay	Fishing	1428	11	11	0	0	0	0	143	0	0	443	0	443
08/04/79	Jervis Bay	Fishing	1241	11	7	0	1	0	1	1334	0	0	3592	0	3594
09/04/79	N of Jervis Bay	Fishing	1626	12	7	0	0	0	1	1030	0	0	2676	0	2680
10/04/79	N of Jervis Bay	Fishing	1188	9	5	0	0	0	2	317	0	0	1137	0	1137
11/04/79	N of Jervis Bay	Fishing	1031	12	1	0	0	0	1	15	0	0	34	0	34
12/04/79	Sydney	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
13/04/79	Sydney	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
14/04/79	Sydney	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
15/04/79	S of Sydney	Steaming	0	0	-	-	-	-	-	-	-	-	-	-	-
16/04/79	Jervis Bay	Steaming	0	12	3	0	0	0	1	-	-	-	-	-	-
17/04/79	Port Stephens	Baiting	0	0	-	-	-	-	-	-	-	-	-	-	-
18/04/79	Port Stephens	Baiting	6	0	-	-	-	-	-	-	-	-	-	-	-
19/04/79	Port Stephens	Fishing	818	3	1	0	0	0	0	0	0	0	10	0	10
20/04/79	Port Stephens	Fishing	815	11	5	0	0	1	6	63	0	0	258	0	268
21/04/79	Sugarloaf Point	Fishing	683	11	6	0	0	0	1	33	0	0	93	0	93
22/04/79	Port Macquarie	Fishing	572	11	1	0	0	0	1	0	0	0	5	0	5
23/04/79	Wooli Head	Fishing	1086	11	0	0	0	0	0	0	0	0	0	0	0
24/04/79	Point Lookout	Fishing	1059	10	0	0	0	0	0	0	0	0	0	0	0
25/04/79	Brisbane	In Port	1055	0	-	-	-	-	-	-	-	-	-	-	-
26/04/79	Moreton Bay	Steaming	1055	0	-	-	-	-	-	-	-	-	-	-	-
27/04/79	Noosa Heads	Fishing	1104	10	1	0	0	0	0	0	0	0	0	0	0
28/04/79	Sandy Cape	Fishing	1100	11	0	0	1	0	1	0	0	0	0	0	0
29/04/79	Swain Reefs	Fishing	1088	11	0	1	0	0	3	0	0	0	0	0	0
30/04/79	E of Townsville	Fishing	1070	11	0	0	0	0	1	0	0	0	0	0	0
01/05/79	Flinders Reefs	Fishing	1064	10	7	0	0	0	0	911	0	0	5951	0	5951
02/05/79	Flinders Reefs	Fishing	786	11	7	0	0	0	1	304	0	0	1481	0	1481
03/05/79	Willis Islets	Fishing	716	11	6	0	2	0	2	1177	3	0	4298	22	4323
04/05/79	Willis Islets	Fishing	485	11	3	1	0	1	2	215	0	0	1637	0	1639
05/05/79	Flinders Reefs	Fishing	462	11	8	0	0	0	3	0	0	0	0	0	0
06/05/79	E of Cairns	Fishing	414	9	2	0	3	0	3	1	1	0	11	24	37
07/05/79	Cape Flattery	Fishing	416	10	3	1	6	1	3	39	50	0	138	278	462
08/05/79	Osprey Reef	Fishing	233	11	2	2	1	0	7	4	0	0	21	6	27
09/05/79	Cape Flattery	Fishing	165	12	2	1	6	0	2	0	0	0	9	43	54
10/05/79	Cairns	In Port	38	0	-	-	-	-	-	-	-	-	-	-	-
11/05/79	Cairns	In Port	33	0	-	-	-	-	-	-	-	-	-	-	-
12/05/79	E of Cairns	Steaming	29	0	-	-	-	-	-	-	-	-	-	-	-
13/05/79	Osprey Reef	Fishing	24	11	0	1	0	0	2	0	0	0	0	2	2
26/03/80	S of Norfolk Is	Fishing	1697	13	1	0	0	0	2	239	0	0	1670	0	1670
27/03/80	Norfolk Island	Fishing	1394	7	0	1	1	0	2	456	161	0	1389	1887	3276
28/03/80	Norfolk Island	Fishing	770	7	0	0	1	0	2	151	93	0	523	1165	1688
29/03/80	Norfolk Island	Fishing	516	11	2	0	0	0	2	267	0	0	1719	0	1719
30/03/80	N of Norfolk Is	Steaming	125	5	0	0	0	0	0	0	0	0	0	0	0
TOTALS	Days 48			362	121	8	23	4	54	8086	316	16	31906	3497	35588

FIGURE 2. LOCATION OF SKIPJACK PROGRAMME BAITFISHING SITES IN EASTERN AUSTRALIA



The catches and tag releases in eastern Australia were concentrated in two areas: off southern New South Wales, between Eden and Jervis Bay, and in the Coral Sea, northeast of Townsville, in the vicinity of the Flinders Reefs and Willis Islets. A large part of the coastline between Sugarloaf Point (32°S) and Sandy Cape (24°S) was apparently devoid of surface-schooling tuna. Only three schools were sighted in 42 hours of searching (Table 1), and only one fish, a 5 kg skipjack, was caught (by trolling).

Baitfishing using a bouki-ami net was carried out on 10 occasions, at five locations in New South Wales and two in Queensland (Figure 2, Table 2). Two unsuccessful attempts to capture bait using a lampara net during daylight hours were also made in New South Wales. The composition of the bait catches in eastern Australia is summarised in Tables 3 and 4.

TABLE 2. SUMMARY OF BAITFISHING EFFORT AND CATCH BY THE SKIPJACK PROGRAMME IN THE WATERS OF EASTERN AUSTRALIA

Anchorage	Time of Hauls	Number of Hauls	Major Species	Estimated Average Catch per Haul (kg)	Mean Length (mm)	Other Common Species
New South Wales						
Twofold Bay			*Sardinops neopilchardus*	325	145	Sp. of Sphyraenidae
37°04′S	Night	1	*Trachurus* spp.	111	81	*Decapterus* sp.
149°55′E			*Hyperlophus vittatus*			*Pomatomus saltator*
Jervis Bay			*Sardinops neopilchardus*	88	150	*Trachurus* spp.
35°06′S	Night	6	*Scomber australasicus*	76	235	*Pomatomus saltator*
150°44′E			*Etrumeus jacksoniensis*	55	152	*Engraulis australis*
Port Stephens			*Etrumeus jacksoniensis*	3	140	*Pomatomus saltator*
32°42′S	Night	1	*Trachurus* spp.	2	118	Sp. of Coelenterata
152°05′E			*Hyperlophus vittatus*			Sp. of Squid
Broughton Island			*Trachurus* spp.	390	124	*Etrumeus jacksoniensis*
32°37′S	Night	2	*Hyperlophus vittatus*	4		*Decapterus leptosoma*
152°17′E			*Sardinops neopilchardus*	4		*Scomber australasicus*
South Solitary Is			*Etrumeus jacksoniensis*	258	95	*Trachurus* spp.
30°11′S	Night	1	*Engraulis australis*	216	85	Sp. of Sphyraenidae
153°16′E			*Sardinops neopilchardus*	47	104	
Queensland						
Moreton Bay			*Antherinomorus ogilbyi**	78	74	*Lethrinus fletus*
27°15′S	Night	1	*Trachurus* spp.	6		*Polydactylus* sp.
153°22′E			*Decapterus russelli*			Sp. of Squid
Endeavour Reef			*Sardinella leiogaster*	37	186	*Archamia lineolata*
15°45′S	Night	1	*Stolephorus indicus*		40	*Sardinella* sp.
145°35′E			*Stolephorus devisi*			*Spratelloides delicatulus*

* Previously known as *Pranesus ogilbyi* (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.

TABLE 3. CATCH AND FREQUENCY OF OCCURRENCE OF BAITFISH SPECIES IN BOUKI-AMI HAULS IN NEW SOUTH WALES

Species	Catch (kg)	Per cent of Total Catch	Frequency in Hauls (%)
Trachurus spp.	916	29	91
Sardinops neopilchardus	899	28	55
Etrumeus jacksoniensis	590	18	55
Scomber australasicus	453	14	36
Engraulis australis	217	7	55
Sp. of Sphyraenidae	+ *		73
Sp. of Cephalopoda (squid)	+		45
Pomatomus saltator	+		36
Decapterus leptosoma	+		27
Hyperlophus vittatus	+		27
Decapterus sp.	+		9
Sp. of Apogonidae	+		9
Sp. of Synodontidae	+		9
Sp. of Coelenterata	+		9
Sp. of Ctenophora	+		9

Number of Hauls	11
Total Bait Caught (kg)	3205
Catch loaded (kg)	2997
Bait discarded (kg)	208
Average Catch per Haul (kg)	291
Average Quantity of Bait Loaded per Haul (kg)	272

* Catches given as (+) are of species present in hauls as indicated by column 3, but always in amounts recorded as numerically less than one per cent of the haul; thus the aggregate catch for these species is not accurately known.

TABLE 4. CATCH AND FREQUENCY OF OCCURRENCE OF BAITFISH SPECIES IN BOUKI-AMI HAULS IN QUEENSLAND

Species	Catch (kg)	Per cent of Total Catch	Frequency in Hauls (%)
Atherinomorus ogilbyi	78	59	50
Sardinella leiogaster	37	28	50
Trachurus spp.	7	5	50
Sp. of Cephalopoda (squid)	+ *		100
Sardinella sp.	+		100
Sardinella sirm	+		50
Stolephorus devisi	+		50
Stolephorus indicus	+		50
Spratelloides delicatulus	+		50
Spratelloides gracilis	+		50
Dussumieria sp.	+		50
Pterocaesio diagramma	+		50
Archamia lineolata	+		50
Atherinomorus sp.	+		50
Decapterus russelli	+		50
Polydactylus sp.	+		50
Lethrinus fletus	+		50
Sp. of Leiognathidae	+		50
Sp. of Holocentridae	+		50
Sp. of Priacanthidae	+		50
Sp. of Platycephalidae	+		50
Sp. of Cephalopoda (octopus)	+		50

Number of Hauls	2
Total Bait Caught (kg)	132
Catch loaded (kg)	132
Bait discarded (kg)	0
Average Catch per Haul (kg)	66
Average Quantity of Bait Loaded per Haul (kg)	66

* Catches given as (+) are of species present in hauls as indicated by column 3, but always in amounts recorded as numerically less than one per cent of the haul; thus the aggregate catch for these species is not accurately known.

A large quantity of bait captured in New South Wales survived very well in the bait tanks and was transported to Queensland, reducing the need to fish for bait during the early part of the Queensland survey. Baitfishing was not attempted at Norfolk Island. All live bait used there had been transported from New Zealand.

A summary of school sightings and chumming response is given in Table 5. Numbers of fish sampled for biological data in each of New South Wales, Queensland and Norfolk Island are listed in Table 6. The length frequency distributions of skipjack tagged or sampled in each area are given in Figure 3. The fork length of skipjack from New South Wales ranged from 38 to 68 cm, and the distribution was apparently unimodal with a mean around 49.3 cm, quite similar to the mean size (50.4 cm) of all skipjack tagged or sampled during the entire Skipjack Programme. The range of sizes encountered in Queensland was larger (38 to 77 cm) and their distribution was strongly bimodal, with modes around 47-48 cm and 61-62 cm. Skipjack from Norfolk Island ranged in fork length from 41 to 67 cm, with a mode around 50 cm and another around 63 cm. The former group of fish was caught north of the island, while the latter group was taken south of the island.

TABLE 5. TUNA SCHOOL SIGHTINGS PER HOUR PER FISHING DAY AND CHUMMED SCHOOL RESPONSES FOR SKIPJACK PROGRAMME SURVEYS OF AUSTRALIAN WATERS

	New South Wales	New South Wales*	Queensland	Queensland*	Norfolk Island
Number of Schools Sighted					
Skipjack	77	76	41	40	3
Skipjack and Yellowfin	2	2	19	19	2
Yellowfin	0	0	7	7	1
Other tuna	2	2	2	2	0
Unknown species	16	15	30	30	8
Total	97	95	99	98	14
Number of Hours Searching/ Fishing	159	137	160	140	43
Sighting Rate	0.61	0.69	0.62	0.70	0.33
Number of Schools Chummed	81	80	85	84	12
% Positive Response	63.0	63.7	28.2	28.6	50.0

* Excluding days spent in waters between 32°S and 26°S.

Maturity data are summarised in Figures 4 and 5. Diet items are listed in Tables 7, 8 and 9, and the occurrence of juvenile tuna in the stomachs of sampled skipjack and other tuna is shown in Table 10. The results of genetic analyses of blood samples from six schools in eastern Australian waters and one school from Norfolk Island are included in Figure 6. Parasite samples from four schools near Norfolk Island were included in analyses by Lester et al. (ms.) (Section 4.3.4).

TABLE 6. NUMBERS OF FISH FROM AUSTRALIAN WATERS SAMPLED FOR BIOLOGICAL DATA

Species	Number Measured	Number Weighed	Number Examined for Sex	Number Examined for Stomach Content	Number Examined for Tuna Juveniles	Number Sampled for Blood Analysis
New South Wales						
Skipjack *Katsuwonus pelamis*	1007	554	598	313	595	332
Yellowfin *Thunnus albacares*	3	3	3	3	3	
Albacore *Thunnus alalunga*	32	32	32	16	32	
Frigate Tuna *Auxis thazard*	12	12	12	9	12	
Dolphin Fish *Coryphaena hippurus*	2	2	0	2	2	
Kingfish *Seriola lalandii*	3	3	0	3	3	
Totals	1059	606	645	346	647	332
Queensland						
Skipjack *Katsuwonus pelamis*	637	252	270	117	270	317
Yellowfin *Thunnus albacares*	35	35	35	25	35	
Mackerel Tuna *Euthynnus affinis*	1	1	0	1	1	
Frigate Tuna *Auxis thazard*	1	0	0	0	0	
Rainbow Runner *Elagatis bipinnulatus*	24	1	1	1	1	
Totals	698	289	306	144	307	317
Norfolk Island						
Skipjack *Katsuwonus pelamis*	197	99	89	30	84	72
Yellowfin *Thunnus albacares*	119	43	39	14	43	
Totals	316	142	128	44	127	72
Grand total	2073	1037	1079	534	1081	721

FIGURE 3. LENGTH FREQUENCY DISTRIBUTIONS OF SKIPJACK TAGGED OR SAMPLED BY THE SKIPJACK PROGRAMME IN EASTERN AUSTRALIA

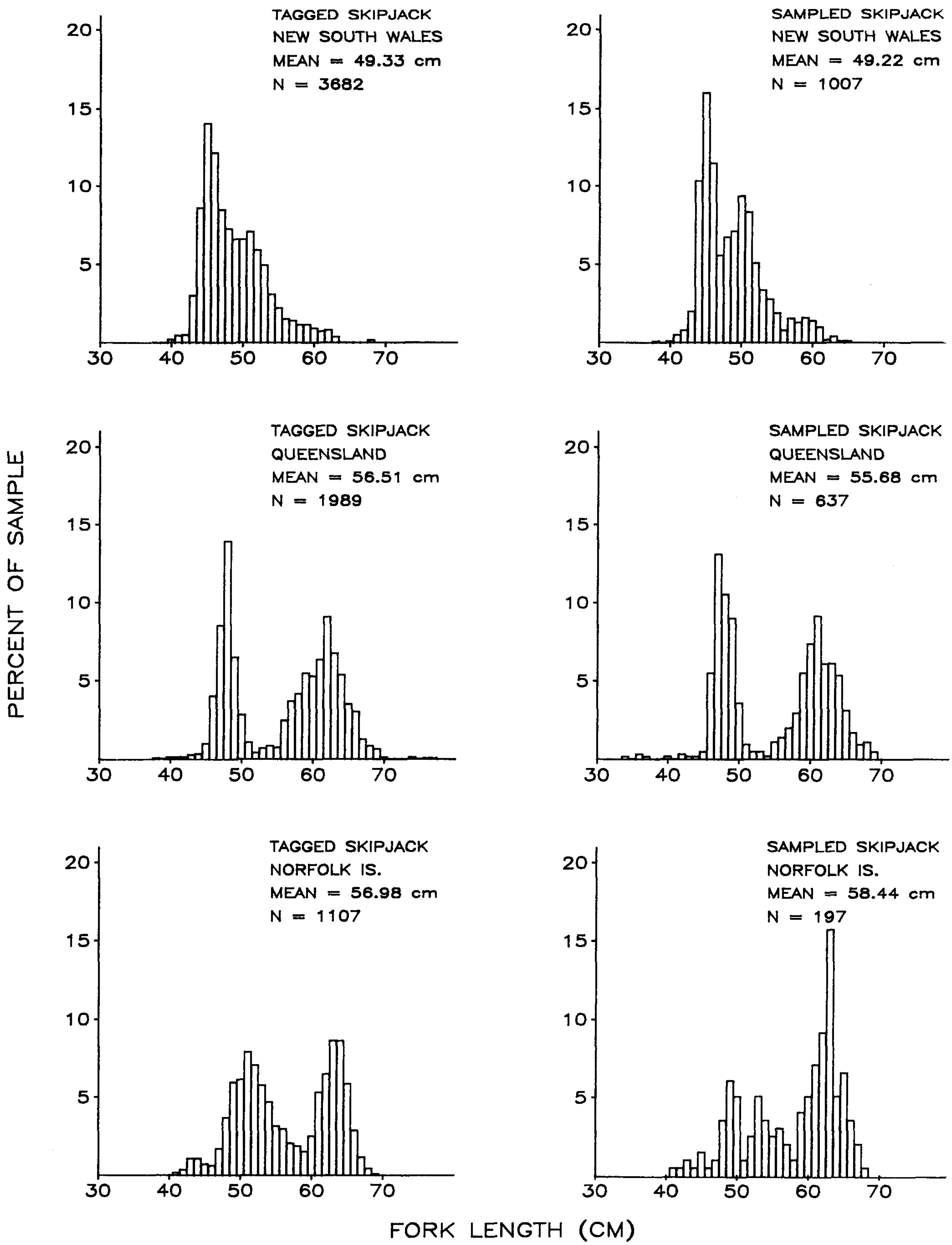


FIGURE 4. DISTRIBUTION OF FEMALE SKIPJACK BY MATURITY STAGE FOR SAMPLES FROM NEW SOUTH WALES, QUEENSLAND, NORFOLK ISLAND AND TROPICAL AREAS SURVEYED BY THE SKIPJACK PROGRAMME

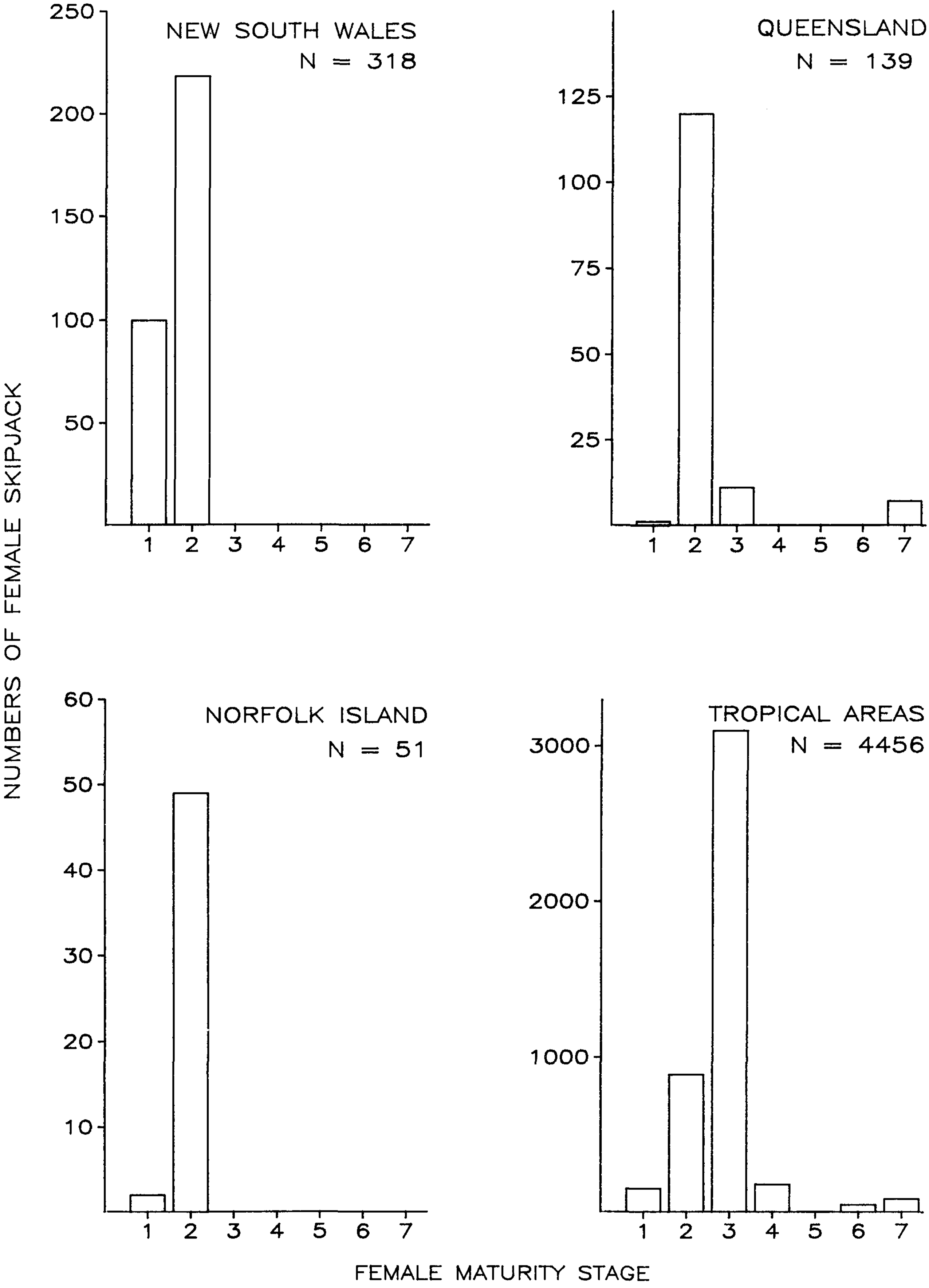
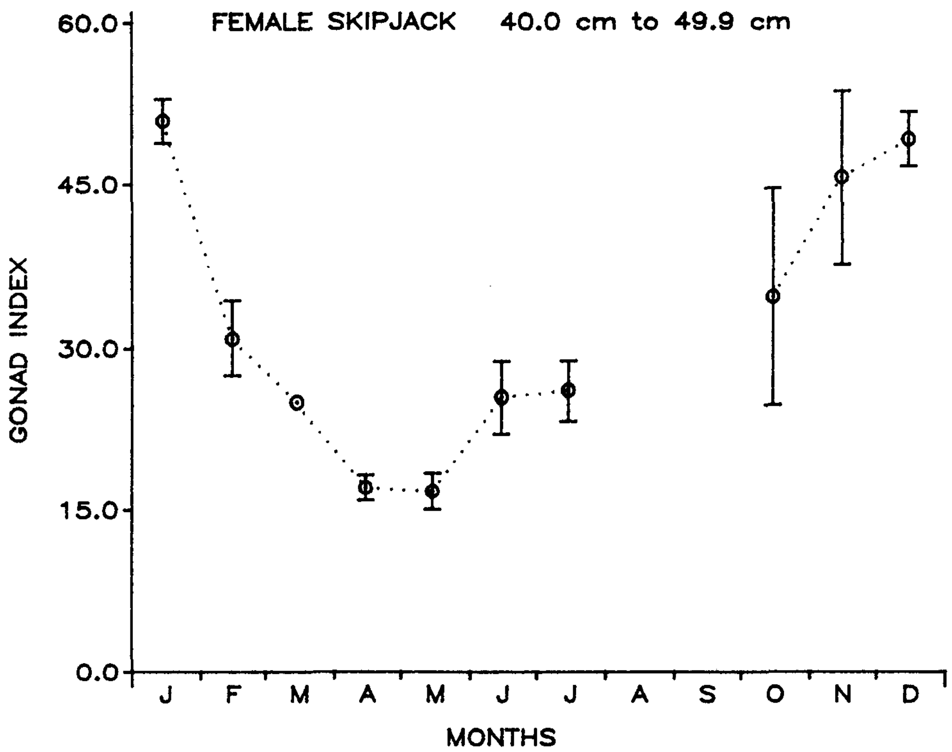


FIGURE 5. AVERAGE GONAD INDICES (± two standard errors), BY MONTH, FOR FEMALE SKIPJACK SAMPLED BY THE SKIPJACK PROGRAMME FROM TROPICAL WATERS SOUTH OF THE EQUATOR BETWEEN 1977 AND 1980. Standard errors omitted for one small (<5)sample (upper graph, March); other sample sizes were at least 8 and most exceeded 100. No samples for August and September.



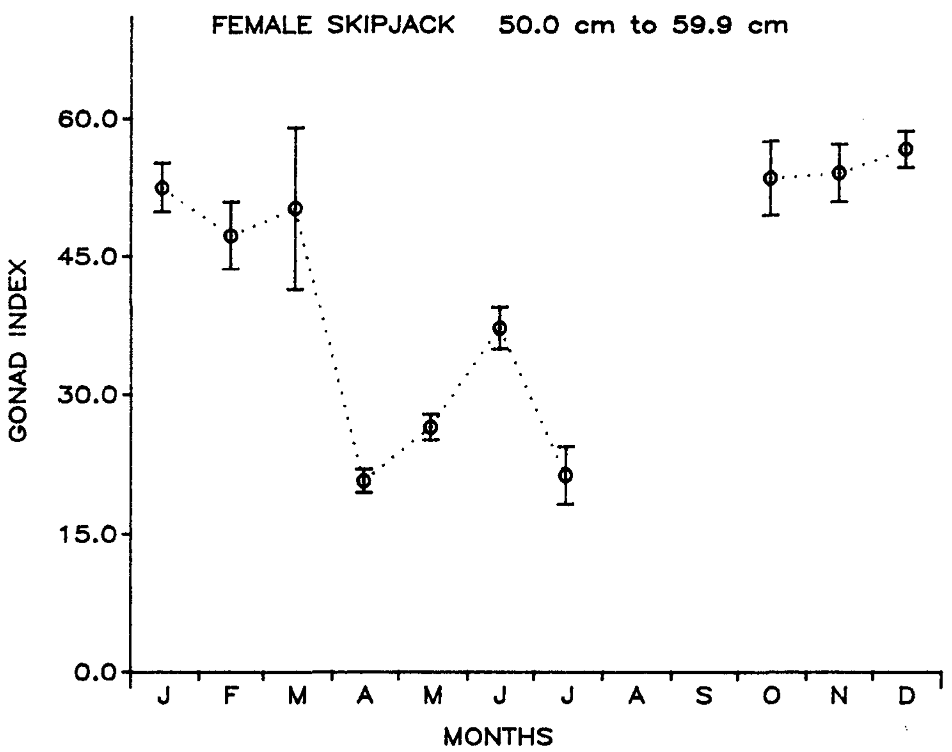


TABLE 7. ITEMS OCCURRING IN STOMACHS OF SKIPJACK CAPTURED IN NEW SOUTH WALES WATERS

Item	Number of Stomachs	Percentage Occurrence
Chum from Hatsutori Maru No.1	130	41.53
Fish remains (not chum)	122	38.98
Cephalopoda (squid)	53	16.93
Amphipoda	51	16.29
Empty stomach	51	16.29
Stomatopoda	41	13.10
Decapoda (megalopa stage)	39	12.46
Decapterus sp. (Carangidae)	31	9.90
Stomatopoda (alima stage)	22	7.03
Euphausiiacea	20	6.39
Myctophidae	14	4.47
Clupeidae	13	4.15
Trachurus sp. (Carangidae)	10	3.19
Ostraciidae	10	3.19
Crustacean remains	9	2.88
Gastropoda	9	2.88
Tetrodontidae	8	2.56
Decapoda (shrimp)	7	2.24
Aluteridae	7	2.24
Carangidae	6	1.92
Gempylidae	6	1.92
Chaetodontidae	5	1.60
Diodontidae	5	1.60
Sphyraenidae	5	1.60
Unidentified fish	4	1.28
Decapoda (phyllosoma stage)	4	1.28
Unidentified fish (j)	4	1.28
Anguilliformes (leptocephalus stage)	3	0.96
Priacanthidae	3	0.96
Balistidae	2	0.64
Apogonidae	2	0.64
Bramidae	2	0.64
Mollusca	2	0.64
Synodontidae	2	0.64
Lutjanidae	1	0.32
Crustacea	1	0.32
Lophiidae	1	0.32
Acanthuridae	1	0.32
Invertebrate remains	1	0.32
Argonauta sp. (Cephalopoda)	1	0.32
Mullidae	1	0.32
Plastic material	1	0.32
Cephalopoda (octopus)	1	0.32
Serranidae	1	0.32
Total Stomachs Examined	313	

TABLE 8. ITEMS OCCURRING IN STOMACHS OF SKIPJACK CAPTURED IN QUEENSLAND WATERS

Item	Number of Stomachs	Percentage Occurrence
Chum from Hatsutori Maru No.1	61	52
Fish remains (not chum)	54	46.15
Cephalopoda (squid)	25	21.37
Engraulidae (j)	22	18.80
Gempylidae	10	8.55
Decapoda (phyllosoma stage)	8	6.84
Empty stomach	8	6.84
Unidentified fish (j)	8	6.84
Aluteridae	6	5.13
Synodontidae	6	5.13
Scombridae (j)	5	4.27
Unidentified invertebrate	4	3.42
Decapoda (megalopa stage)	4	3.42
Stomatopoda	4	3.42
Exocoetidae	4	3.42
Decapoda (shrimp)	4	3.42
Invertebrate remains	3	2.56
Gastropoda (Heteropoda)	3	2.56
Amphipoda	3	2.56
Acanthuridae	3	2.56
Chaetodontidae	3	2.56
Unidentified fish	3	2.56
Stomatopoda (alima stage)	3	2.56
Anthiidae	2	1.71
Dactylopterus orientalis (Dacylopteridae)	2	1.71
Anguilliformes (leptocephalus stage)	2	1.71
Cephalopoda (octopus)	2	1.71
Gastropoda	2	1.71
Holocentridae	1	0.85
Diodontidae	1	0.85
Stolephorus buccaneeri (Engraulidae)	1	0.85
Nomeidae	1	0.85
Xiphasia sp. (Xiphasiidae)	1	0.85
Trash material	1	0.85
Bramidae	1	0.85
Ostraciidae	1	0.85
Decapoda (carid shrimp)	1	0.85
Crustacean remains	1	0.85
Priacanthidae	1	0.85
Engraulidae	1	0.85
Decapterus sp. (Carangidae)	1	0.85
Total Stomachs Examined	117	

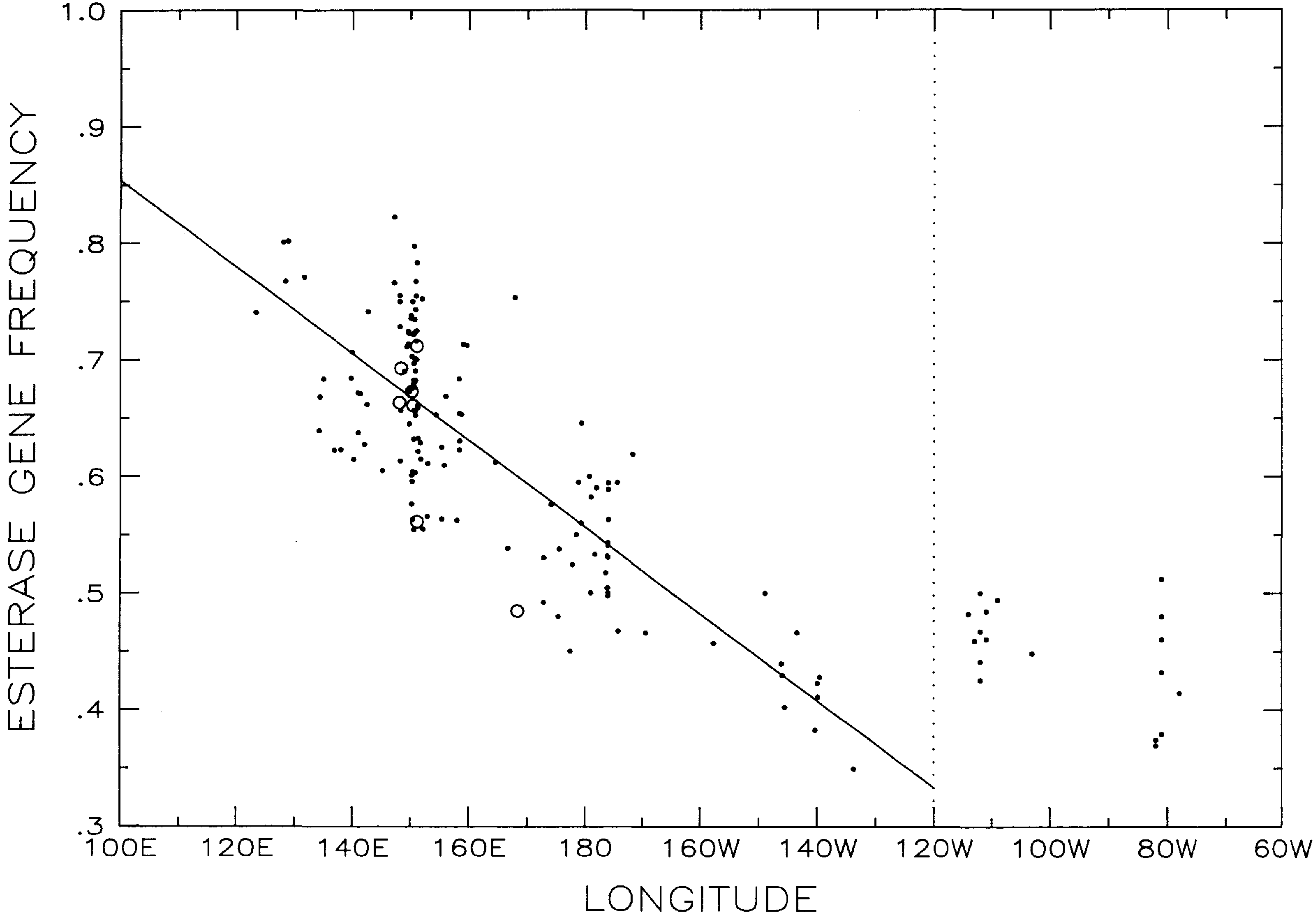
TABLE 9. ITEMS OCCURRING IN STOMACHS OF SKIPJACK CAPTURED IN NORFOLK ISLAND WATERS

Item	Number of Stomachs	Percentage Occurrence
Chum from Hatsutori Maru No.1	19	63.33
Fish remains (not chum)	9	30.00
Empty stomach	4	13.33
Unidentified fish (j)	3	10.00
Decapoda (megalopa stage)	1	3.33
Euphausiacea	1	3.33
Total Stomachs Examined	30	

TABLE 10. OCCURRENCE OF PREY TUNA IN STOMACHS OF PREDATOR TUNA IN AUSTRALIAN WATERS

Predator	Predators Examined	Prey Species	No. of Prey	No. of Predators with Prey	Prey per 100 Predators	Percentage of Predators with Prey
New South Wales						
Skipjack	595	No prey tuna found				
Yellowfin	3					
Frigate Tuna	12					
Albacore	32					
Dolphinfish	2					
Kingfish	3					
Total	647					
Queensland						
Skipjack	270	Skipjack	10	5	3.70	1.85
		Auxis	1	1	0.37	0.37
		Albacore	1	1	0.37	0.37
Yellowfin	35	Skipjack	1	1	2.86	2.86
Rainbow Runner	1					
Mackerel Tuna	1					
Total	307		13	8		
Norfolk Island						
Skipjack	84	No prey tuna found				
Yellowfin	43					
Total	127					

FIGURE 6. SKIPJACK SERUM ESTERASE GENE FREQUENCY FOR 163 SAMPLES VERSUS THE LONGITUDE OF THE SAMPLE LOCATION. Each point is the average of approximately 100 specimens sampled from a single school on the same day. The Eastern Australian samples are shown as circles.



4.0 RESULTS AND DISCUSSION

4.1 Baitfishing

The use of a bouki-ami net to capture live bait in Australia was novel, although previously the technique had been successfully used in other temperate regions, such as Japan and New Zealand (e.g. Ben-Yami 1980; Webb 1972). Most live bait used in the Australian southern bluefin tuna fishery is captured by lampara net or small purse-seines, for which the vessel is not anchored and sea conditions need not be as benign as for bouki-ami fishing. The bouki-ami technique requires protected environments with little wind, current and wave action. Habitats most favourable to baitfish are in coastal areas with freshwater inflows supplying nutrients to maintain high productivity, and mud or muddy-sandy bottoms (Hallier et al. 1982). Consultations with Australian fisheries officers and examination of navigation charts indicated a number of areas apparently suitable for baitfishing along the New South Wales and southern Queensland coast. There are extensive, suitable areas in central and north Queensland in the Great Barrier Reef lagoon.

Baitfishing was conducted at five sites in New South Wales and two sites in Queensland (Table 2). A total of 3,337 kg of live bait was caught in 13 hauls, and most (93.8%) was loaded into holding tanks aboard the *Hatsutori Maru No.1*; 5.4 per cent were released alive, being excess to carrying capacity, and 0.8 per cent was discarded dead. No baitfishing was attempted at Norfolk Island, as there are no areas suitable for bouki-ami operations, and very little habitat favourable to baitfish species.

4.1.1 New South Wales

Eleven bouki-ami hauls were made on eight different nights in New South Wales (Table 2). Adverse sea conditions prevented baitfishing on two other occasions, at Port Stephens and South Solitary Island. An estimated total of 3,205 kg of bait was caught, with an average catch per haul of 291 kg (Table 3). This is much higher than the average catch of 121 kg per haul made by the Skipjack Programme in tropical waters (Skipjack Programme 1981c), but is lower than the average catch of 489 kg for 23 hauls made by the Skipjack Programme in temperate waters of northern and central New Zealand in 1979 and 1980 (Argue & Kearney 1983). Average catches were high at four of the five localities (Table 2); only at Port Stephens was the average catch low, because strong tidal currents interfered with the operations of the bouki-ami. However, at the two localities at which more than one haul was made (Jervis Bay and Broughton Island), there was considerable variation in the sizes of the catches. Three of the six hauls made at Jervis Bay yielded only 1 kg of bait each, and another yielded only 29 kg. No baitfish were captured in one of the two hauls made at Broughton Island, perhaps due to problems when deploying the net.

Table 3 lists the total catch and frequency of occurrence of the most common species taken by bouki-ami in New South Wales. The most commonly captured species were the jack mackerel, *Trachurus* spp., and the pilchard, *Sardinops neopilchardis*, which together accounted for 57 per cent of the catch. Two species of *Trachurus*, *T. novaezealandae* and *T. declivis*, are abundant in temperate Australian coastal waters (Williams 1981; Phillips 1982) but they are commonly confused, particularly at juvenile stages. Skipjack Programme scientists used criteria described in Stephenson &

Robertson (1977), principally the length of the dorsal accessory lateral line and the curvature of the main lateral line, but there were many apparently intermediate forms not attributable to either species. Accordingly, the catches listed in Tables 2 and 3 are combined figures for all Trachurus species. Only three other species contributed significantly to baitfish catches in New South Wales waters (Table 3): the maray Etrumeus jacksoniensis (18% of total catch), the Australian mackeral Scomber australasicus (14%) and the southern anchovy Engraulis australis (7%). The last two species were each abundant in only a single haul, at Jervis Bay and South Solitary Island respectively.

An extensive survey of baitfish at 14 localities in New South Wales waters by the Catriona B in 1977 and 1978, sponsored by CSIRO and private interests, also found catches to be dominated by jack mackerel, designated as T. mccullochi (syn. T. novaezealandae; Stephenson & Robertson 1977). Pilchard, maray, anchovy and sprat (Hyperlophus vittatus) were caught only occasionally (Carrick 1977, 1978; Anon. 1978). In the 1977 survey by the Catriona B, effort was concentrated in areas south of Sydney, since little bait was observed at localities as far north of Sydney as Byron Bay. In 1978, hauls were made mainly between Sugarloaf Point and Eden, but the two localities surveyed on the northern New South Wales coast both had large quantities of Trachurus (Carrick 1978).

The anchovies and pilchards proved to be very effective as live bait for skipjack during the Skipjack Programme's survey of south eastern Australia. The families to which they belong, the Engraulidae and Clupeidae respectively, also were found to contain the most effective bait species throughout the Skipjack Programme's entire study area (Skipjack Programme 1981d; Argue et al. ms.). The mackerels Trachurus spp. and Scomber australasicus were useful as bait when small, but frequently were too large to be effective for skipjack fishing. They also exhibited undesirable behavioural characteristics, such as sounding or failing to school after being chummed, further limiting their utility as live bait. The performance by the Catriona B also emphasised the superiority of pilchards and anchovies over jack mackerel for chumming skipjack. During the 1977 survey by the Catriona B, only one school of 88 chummed with Trachurus gave a positive biting response, whereas three of eight schools chummed with pilchards responded positively. During its 1978 survey, only Trachurus were available; but small specimens were used successfully to chum skipjack schools. Large specimens were not effective.

The major baitfish species captured in New South Wales proved to be very hardy, with almost zero mortality during loading or transport in the bait wells. Trachurus caught near Broughton Island on 18 April 1979 remained in the bait wells on the Hatsutori Maru No.1 with negligible mortality for over one month, despite exposure to low salinity water in the Brisbane River and to warm tropical waters in north Queensland and Papua New Guinea, as well as a transfer to the bait receiver for two days in Cairns. A large haul of Engraulis australis from South Solitary Island was loaded onto the research vessel in rough and difficult conditions with negligible mortality. Early trials (Fowler 1942) demonstrated that E. australis and S. neopilchardus can be maintained in bait pens for up to five months; such a procedure was recommended by Thompson (1943) to overcome fluctuations in bait availability. Only Etrumeus jacksoniensis was found to suffer considerable mortality during handling and in the baitwells. A large catch of this species was made near South Solitary Island on 22 April 1979, but about 50 per cent mortality was recorded over the next three days on board the research vessel.

The hardiness of the Trachurus spp., and E. australis resulted in ample bait supplies during the survey period in northern New South Wales. Consequently, baitfishing was done on only one occasion between 32°S and the Queensland border, with the result that the Skipjack Programme is able to make only a limited assessment of baitfish resources in the northern part of the state. The number of suitable baitfishing localities in this area is, however, limited. The Catriona B surveys, which provided extensive coverage of the coast north to the Queensland border (Carrick 1977, 1978), identified several apparently suitable locations but found only limited concentrations of baitfish, particularly of the sought-after anchovies and pilchards. Although availability of these species apparently varies seasonally (Blackburn 1950b), it may also fluctuate unpredictably from year to year Carrick 1978), limiting the scope for development of live-bait fisheries for tuna in northern New South Wales waters.

4.1.2 Queensland

The ample supplies of bait transported from New South Wales, together with a negligible requirement for bait in southern Queensland waters because of an absence of surface tuna schools, meant there was little need to fish for bait along the southern Queensland coast. A haul made in Moreton Bay yielded only 87 kg of bait, mainly the hardyhead Antherinomorus ogilbyi (Table 2). Most species taken in this haul have a tropical distribution, though a few Trachurus, which occur mainly in temperate waters, were also caught.

A second haul yielding 45 kg was made at Endeavour Reef, north of Cairns. The catch was dominated by the sardine Sardinella leiogaster, and included small numbers of anchovies (Stolephorus) and sprats (Spratelloides) (Table 2). The three genera were a significant component of baitfish catches by the Skipjack Programme in tropical areas (Kearney 1983), and are each regarded as very effective live bait for skipjack (Argue et al. ms.). The twenty-two species captured in the two bouki-ami hauls made in Queensland are listed in Table 4.

The limited coverage of the Skipjack Programme survey in Queensland waters provides little basis for assessing the baitfish resources there. However, in north and central Queensland there are extensive areas of habitat suitable to the major tropical baitfish species, suggesting that a resource capable of supporting a live bait skipjack fishery could be found. The coastline of southern Queensland is more exposed, but there are sufficient localities with baitfish habitat and suitable conditions for baitfishing to suggest that a small live-bait skipjack fishery could be supported. However, in many parts of Queensland, particularly the central and north areas, the distance between the coastal baiting grounds and skipjack fishing grounds outside the Barrier Reef may impose constraints on any future live-bait pole-and-line fishery.

4.1.3 Norfolk Island

Suitable conditions for bait fishing with bouki-ami gear do not exist at Norfolk Island, so no baitfishing was done there by the Skipjack Programme. The underwater lights were set on one night but attracted only a small number of blue sprats (Spratelloides delicatulus), a species which occurred in approximately half of the Skipjack Programme's catches from tropical waters. The virtual absence of habitat suitable for baitfish species suggests that other methods are unlikely to yield quantities of baitfish sufficient for pole-and-line operations.

All bait used during the Skipjack Programme survey of waters around Norfolk Island was transported from New Zealand. It consisted mainly of relatively large specimens of S. neopilchardus and T. novaezealandae. The hardiness of both species allowed relatively large quantities to be transported by crowding the bait wells beyond their usual capacity. These quantities proved to be necessary during the Norfolk Island survey; perhaps because the specimens were large, they elicited a relatively poor biting response from the tuna, and a low tuna/bait ratio resulted.

4.2 Skipjack Fishing

A total of 210 schools of tuna were sighted during 362 hours spent searching and fishing in Australian waters (Table 1), at an average rate of 0.58 schools per hour. This is lower than the average of 0.75 schools sighted per hour during the entire Skipjack Programme, which was conducted mainly in tropical waters. It is similar to the school sightings rate of 0.54 schools/hour recorded by the Programme in surveys of temperate waters of northern and central New Zealand. However, the low Australian figure was not solely a result of the time spent in temperate waters off New South Wales; the rates at which schools were sighted in Queensland and New South Wales waters were only slightly different (Table 5), although the rate at which schools were sighted during the short time spent in subtropical waters near Norfolk Island was much lower (0.32 schools/hour). Rather, the Australian figure was low because of the absence of tuna schools in the area between 32°S and 26°S (approximately from Sugarloaf Point to southern Fraser Island) on the east coast of the Australian continent. Only three schools were sighted during 42 hours of searching in this area. This result was predicted by Kearney (1975), but reasons for this hiatus in the distribution of skipjack along the eastern Australian coast are not known. Kearney (1975) postulated that the apparent dearth of skipjack extended eastward to 160°E, but the survey by the Catriona B in 1977 located many schools of skipjack in oceanic waters off the continental shelf in the southern part of this area between 29°S and 31°S. It is probable that the location of the gap in skipjack distribution varies seasonally.

Most schools were detected through their association with bird flocks, particularly in Queensland where only one of the 99 schools sighted was not accompanied by birds. The Queensland schools tended to be relatively small and mobile, a feature of skipjack schools in other tropical regions surveyed by the Skipjack Programme. In New South Wales a few subsurface schools were present in all areas, and were detected by strikes on troll lines. No schools were seen associated with logs or floating debris as occurs in other areas in the western Pacific. In southern New South Wales a spotter aircraft made available by H.J. Heinz Company was used to seek surface tuna schools. However, there was no evidence that the aerial support enhanced the Programme's fishing operations, and it was felt that aerial observations of surface tuna schools in conditions similar to those prevailing during April 1979 may substantially underestimate abundance. Similar problems of relating aerial sightings of skipjack to availability had previously been reported in Papua New Guinea (Kearney 1977). This is in strong contrast to the Skipjack Programme's experience in New Zealand, when spotter planes greatly assisted in locating fishable aggregations of tuna (Argue & Kearney 1983). The very low number of tuna schools sighted during aerial surveys of central and northern Queensland by Hynd (1968) may also warrant re-evaluation, given the rate at which schools were sighted in those areas by the Skipjack Programme.

Table 5 shows the number of schools that were approached and chummed, and the proportion of them that responded positively to the chum. The figure for New South Wales is higher than the average response of 47 per cent recorded during the entire Skipjack Programme, while that for Queensland is lower. The chumming response during the Norfolk Island survey was comparable with the Programme's average. Notwithstanding the different rates of response by schools in New South Wales and Queensland, catch rates in the two states were very similar, at 946 kg and 932 kg per fishing day respectively. This may in part reflect the greater mean size of Queensland fish (Figure 3). Calculations based on the conversion ratio of 3.47 (Section 2.3) indicate that catches of about 3.25 tonnes per day would have been made if the vessel had been fishing commercially at the time. Excluding the days spent between 32°S and 26°S from the calculations, the commercial catch rate would have been almost four tonnes per day. The average commercial catch rate achieved by the Skipjack Programme throughout the entire study area between 1977 and 1980 was 3.45 tonnes per day, while the Japanese pole-and-line fleet, which carries live bait from Japan and is thus not limited by bait supplies, caught an average of 4.55 tonnes per boat per day in the tropical central and western Pacific between 1972 and 1978 (Skipjack Programme 1980). At Norfolk Island, the daily catch averaged 2,088 kg, giving an estimated daily catch under commercial conditions of 7.25 tonnes. This high value is partly a result of the great number of relatively large yellowfin caught (Kearney & Hallier 1980), but it also reflects the good catches of large skipjack.

Best catches by the Skipjack Programme in Australia were recorded off the southern New South Wales coast, between Eden and Jervis Bay, and in the Coral Sea off Townsville. The area near Port Stephens and Sugarloaf Point, in which a great abundance of skipjack had previously been recorded (Carrick 1978), yielded only small catches during the Skipjack Programme surveys. However, the school sighting rate near Port Stephens was only slightly lower than that for the more southerly waters and some of the schools observed were very large. Therefore, the poor catches probably do not accurately reflect abundance. The poor quality of the bait, which was mostly relatively large specimens of Trachurus spp., may have contributed to the poor catches.

In New South Wales waters, 96 per cent of identified schools contained skipjack. Only two schools contained yellowfin in association with skipjack, and two schools of albacore (Thunnus alalunga) were sighted. In contrast, yellowfin were present in 38 per cent of identified schools in Queensland, mostly in association with skipjack, but in seven instances they formed pure schools. Nevertheless, skipjack were the dominant species, occurring in 87 per cent of identified schools. Frigate tuna (Auxis thazard) and dolphinfish (Coryphaena hippurus) were seen occasionally in both New South Wales and Queensland, while kingfish (Seriola lalandi) were present in small numbers in New South Wales, and mackerel tuna (Euthynnus affinis) and rainbow runner (Elagatis bipinnulatus) were recorded in several schools from Queensland.

4.3 Skipjack Biology

4.3.1 Diet

Apart from chum from the Hatsutori Maru No.1, fish remains and squid were the items most commonly encountered in the stomachs of skipjack from eastern Australian waters surveyed by the Skipjack Programme (Tables 7 and 8). A further 40 items were found in skipjack sampled in New South

Wales (Table 7), of which more than half were identical or closely related to items among the 37 found in skipjack stomachs sampled in Queensland (Table 8). Many of the differences between stomach contents of skipjack from the two areas were in items occurring only infrequently, except for the common occurrence of juvenile tropical anchovies in skipjack sampled in north Queensland. There were only four items, excluding chum, identified from the 30 skipjack stomachs examined in Norfolk Island waters, and fish were again the most important (Table 9).

These results, in common with those obtained elsewhere by the Skipjack Programme or by other researchers (see Forsbergh 1980), indicate the importance of fish to the diet of skipjack. They also emphasise the opportunistic nature of skipjack feeding, which leads to great diversity in skipjack diet items and at times to major differences in diet composition between sampling locations and sampling periods. This is well exemplified by the results of previous studies of skipjack diet in Australia (Robins 1952, Blackburn & Serventy 1981). They found euphausiids to be overwhelmingly dominant in skipjack stomachs sampled from eastern Australian waters south of Sydney, including areas of southern New South Wales surveyed by the Skipjack Programme. In waters north of Sydney where euphausiids rarely occur, Robins (1952) and Blackburn & Serventy (1981) found that fish were the major component of the diet of skipjack.

4.3.2 Maturity and recruitment

Female gonad maturity stages for skipjack samples from Australia are shown in Figure 4. Seven stages of gonad maturity were recognised during the Skipjack Programme's survey using criteria given in Argue (1982), representing a progression of reproductive condition from immature (stage 1) to post-spawning (stages 6 and 7). Maturing gonads were classified as stages 2 and 3, mature gonads as stage 4 and ripe gonads as stage 5. In the Programme's samples from all parts of eastern Australia, stage 2 gonads were predominant. The distribution of maturity stages in 4,456 female skipjack examined by the Programme, mainly from tropical waters (Figure 4) was dominated by stage 3 gonads. In New South Wales and Norfolk Island stage 1 was the only other represented in the samples. The absence of advanced maturing or mature gonads, which was also a feature of the New Zealand sample, suggests that reproduction does not occur in southern Australian waters. In Queensland, a small proportion of the sample was at stage 3, and a few recovering ovaries (stage 7) were identified. This implies that some spawning may occur off the Queensland coast. The absence of running ripe female gonads (stage 5) is not unusual; only two were sampled during the entire Programme. Suggested explanations of this phenomenon include failure of ripe individuals to respond to chum, absence of schooling behaviour in ripe fish, or a very rapid transition from maturity to spawning, perhaps occurring at night.

Seasonal changes in female gonad index[2] for all Skipjack Programme samples from tropical waters suggest that skipjack spawning is most intense south of the Equator between October and March (Figure 5). This trend is very similar to that presented by Naganuma (1979) for samples collected

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

from a wide area of the tropical south Pacific waters, and by Lewis (1981) for samples from the Papua New Guinea fishery, a few degrees south of the Equator. Skipjack samples from New South Wales and Norfolk Island had low average gonad indices, of 7.35 and 9.51 respectively. Queensland fish had a mean gonad index of 15.89. The higher Queensland figure does not simply reflect the larger average size of the fish; those in the 40-49 cm size range had gonad indices of 14.52, similar to the average value of 16.53 for fish larger than 50 cm.

Since sexual maturity is achieved when skipjack are about 45 cm long, the immature condition and size of the gonads sampled in New South Wales and Norfolk Island is not a result of sampling fish that were too small to be mature (Figure 3). There were no significant differences in mean sizes of the fish at each gonad maturity stage in each area, except that in Queensland the single stage 1 fish was only 34.5 cm long, and the stage 7 fish were all large, averaging 64.7 cm.

A further index of breeding is the incidence of juvenile skipjack in the stomachs of predators. None of the 647 fish sampled from New South Wales waters or the 127 fish sampled from Norfolk Island waters had juvenile skipjack in their stomachs. In Queensland, five skipjack and one yellowfin, of a total of 307 fish sampled, had juvenile skipjack in their stomachs (Table 10), such that the average frequency was 3.58 prey per 100 predators. This is lower than the average value of 10.8 recorded in all tropical areas surveyed by the Skipjack Programme, and much lower than the values of 25 to 50 juveniles per 100 predators found in Vanuatu, Wallis and Futuna or the Marquesas Islands. Argue et al. (1983) presented detailed analyses of the tuna juvenile data, taking into account size-selective predation by adults, time of day, distance from land and sampling season. Skipjack juveniles occurred most frequently in the stomachs of predators captured by the Programme between October and March in tropical waters south of the Equator, coinciding with the period of maximum gonad development in skipjack in these waters. The data also indicate that during the 1977 to 1980 survey period, abundance of juvenile skipjack within this region was highest in two areas, one centred approximately on Solomon Islands - Papua New Guinea - Vanuatu, and the other on the Marquesas and Tuamotu Islands.

The small size and immature condition of the gonads, and the absence of juvenile tuna from the stomachs of predators are evidence that spawning of skipjack is unlikely to occur in the waters of Norfolk Island and New South Wales, or elsewhere in southern Australia. Water temperatures in March and April, when the Skipjack Programme samples were taken, are close to the maxima recorded in the annual water temperature cycles at these latitudes (Mulhearn 1983). Samples collected off south-eastern Australia during the early 1940s and analysed by Blackburn & Serventy (1981) also had immature gonads and low gonad indices. However, it is very likely that breeding occurs in summer in waters off north Queensland, since gonad indices were relatively high, some fish were approaching a mature condition or had recovering ovaries, and juvenile skipjack were present in the stomachs of predators. Other data on the occurrence of larval skipjack (Ueyanagi 1970) and juvenile skipjack in the stomachs of predatory tuna and billfish (Mori 1972), and on seasonal variations in gonad size (Naganuma 1979) also suggest that summer breeding occurs in the Coral Sea off north Queensland.

4.3.3 Growth

Because very few of the skipjack tagged in Australian waters were recovered with reliable information on length at both the time of release and time of recapture, it has not been possible to evaluate parameters of growth for Australian-tagged fish. However, many of the findings on growth of skipjack tagged elsewhere by the Skipjack Programme are relevant to future considerations of skipjack growth in Australia.

The growth of skipjack, as in other tunas, is a function of size. Larger fish increase in length more slowly than smaller fish (Joseph & Calkins 1969). Therefore, when a tagged fish is recovered, its increase in size depends on not only the length of time it was at liberty, but also its size when released. These considerations complicate the evaluation of growth by the analysis of tagging data. Table 11 presents a summary of size and growth information for skipjack tagged and released in the Skipjack Programme study area for each size class for which there were sufficient data. Mean size-at-release varied from 41 to 55 cm, time-at-liberty from 0 to over 300 days, and growth increments from -0.3 to 12 cm. Although confounded by the possibility of between year variability in growth (discussed below), the effects of time-at-liberty are apparent in the difference in growth increment between FIJ1 and FIJ2 data sets, in which the fish were released at approximately the same size but the mean times-at-liberty were different. The effects of size-at-release (in this case possibly confounded by variability in growth in different areas) can be seen in the different growth increments in the PAL3 and PNG0 data, in which the fish were at liberty for approximately the same period of time but the mean sizes-at-release were different. Growth increments were in most instances quite small, and the proportion of fish which did not show any measurable growth was high (40%). There are several possible reasons for this apparent lack of growth. Firstly, the time-at-liberty may have been too short for detectable growth to have occurred. Secondly, skipjack may have been near their maximum size when tagged and released. Thirdly, they may have encountered conditions unfavourable for growth. Fourthly, errors in length measurement at both release and recovery may have obscured what growth occurred.

It is possible to calculate corrections for the effects of size-at-release and time-at-liberty on the observed growth increment. These calculations used analysis of covariance and a linearised version of the von Bertalanffy growth equation, to produce a standard growth increment for an arbitrary size-at-release and time-at-liberty (Sibert et al. 1983). Standardised growth increments are presented in Table 12. Growth varied considerably from country to country, and differed significantly between visits to a country and between fish recovered inside or outside the country of release (Sibert et al. 1983). Thus, skipjack growth seems to be highly variable in time and space. The growth observed in tagged skipjack was a function of where and when the fish were tagged, and where they were recovered. It may be closely coupled to environmental conditions such as temperature and the oceanographic variables that are thought to regulate the abundance of food. Variations in these parameters in space and time, though as yet largely undocumented, may explain the differences in growth rate observed throughout the Skipjack Programme study area.

Von Bertalanffy growth parameters, which conventionally are used to describe growth of fish (Fabens 1965), were estimated for fish tagged in seven countries in the central and western Pacific (Table 13). Also

TABLE 11. SUMMARY OF LENGTH INCREMENTS FOR SKIPJACK TAGGED BY THE SKIPJACK PROGRAMME IN VARIOUS COUNTRIES AND TERRITORIES IN THE SKIPJACK PROGRAMME STUDY AREA. Fish were at large for periods between 10 and 365 days. Country abbreviations are explained in Appendix D.

	RECAPTURES WITHIN COUNTRY OF RELEASE						RECAPTURES OUTSIDE COUNTRY OF RELEASE					
Country and Visit	Sample Size	Mean Size at Release	Mean Size at Recapture	Mean Days at Liberty	Increment Mean	Increment Standard Deviation	Sample Size	Mean Size at Release	Mean Size at Recapture	Mean Days at Liberty	Increment Mean	Increment Standard Deviation
FIJ1	431	48.0	48.6	23.9	0.65	2.29	3	51.3	55.3	68.7	4.00	2.65
FIJ2	208	51.2	55.3	108.7	4.09	5.34	9	51.7	61.3	237.8	9.67	11.86
KIR1	279	48.4	49.8	56.0	1.43	2.18	15	51.0	55.2	137.3	4.20	3.43
MAQ2	26	48.3	48.0	18.9	-0.27	1.31	3	48.0	60.0	273.7	12.00	3.00
PAL1	0						14	59.0	63.1	113.6	4.14	4.59
PAL3	14	40.8	47.8	85.3	7.00	5.55	143	40.6	49.3	171.0	8.71	6.49
PNG0 *	290	54.6	56.4	87.6	1.78	2.46	16	53.4	57.6	229.7	4.25	3.86
PNG2	609	54.6	55.2	51.5	0.63	3.17	37	51.5	56.8	197.8	5.32	4.58
PON1	7	53.9	57.7	84.7	3.86	2.67	12	53.9	57.6	152.4	3.67	3.37
PON3	13	51.4	57.2	168.0	5.77	2.31	43	55.4	59.9	186.0	4.47	4.30
SOL1	38	51.8	54.3	192.5	2.45	4.28	2	52.5	57.5	199.0	5.00	0.00
TRK1	1	50.0	56.0	121.0	6.00	-	10	49.7	56.7	152.6	7.00	2.79
TRK2	1	53.0	54.0	21.0	1.00	-	6	53.5	60.0	186.2	6.50	4.04
VAN1	1	52.0	52.0	0.0	0.00	-	3	50.7	57.3	261.0	6.67	2.89
WAL1	0						22	53.0	54.4	198.5	1.36	2.77
WAL2	0						7	52.9	57.1	242.7	4.29	5.22
WAL1+WAL2	0						29	53.0	55.0	209.2	2.07	3.63
ZEA1	213	45.8	46.4	37.9	0.64	2.30	11	47.5	54.2	305.7	6.64	3.41
ZEA2	1	54.0	54.0	76.0	0.00	-	3	50.3	57.7	323.7	7.33	4.51

* Results for skipjack tagged and released in Papua New Guinea from 1972 to 1974 (see Kearney, Lewis & Smith 1972; Lewis, Smith & Kearney 1974).

included are two estimates of growth parameters of skipjack in Papua New Guinea, using a 1972-1974 tag recapture data set (Josse et al. 1979) and data on modal progressions in length-frequency distributions of commercial catches (Wankowski 1981). The fits of the von Bertalanffy model to the Skipjack Programme's data explained only 44 to 72 per cent of the variance in the data. This, together with the large disparities among parameter estimates based on different data sets, even those from the same country, suggest that it is statistically improbable that a single data set will yield a definitive model of skipjack growth in a given area. There have been no studies of skipjack growth in Australia, and future investigators should be conversant with these limitations.

TABLE 12. STANDARDISED INCREMENTS OF LENGTH (cm) FOR FISH 50 CM LONG AT RELEASE AND AT LIBERTY FOR 90 DAYS. The 95 per cent confidence interval of each increment is given in parentheses. Data are for fish recaptured within the 200-mile zone of the country in which they were released. See Appendix D for abbreviations.

Country	Increment	Visits Included
FIJ	4.5 (±1.2)	FIJ1, FIJ2
KIR	1.4 (±1.2)	KIR1
PAL	8.5 (±6.4)	PAL3
PNG	3.6 (±1.9)	PNG2
PON	4.1 (±4.1)	PON3
SOL	2.5 (±1.4)	SOL1
ZEA	1.5 (±5.2)	ZEA1

TABLE 13. SUMMARY OF PARAMETERS OF THE VON BERTALANFFY MODELS FOR THREE STUDIES OF GROWTH OF SKIPJACK IN VARIOUS COUNTRIES IN THE SKIPJACK PROGRAMME STUDY AREA (from Tuna Programme 1984). L_∞=theoretical average maximum size. K=instantaneous rate of change in growth.

Country	Date	L_∞	K (per year)	Variance Explained (%)	Reference
Papua New Guinea	1979	60.2	1.55	44.4	Sibert et al. (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 et al. (1983)
	1980	79.3	0.482	63.5	"
Kiribati	1978	52.2	3.63	44.5	"
Palau	1980	54.2	3.91	55.4	"
Ponape	1980	76.9	0.539	72.5	"
Solomon Islands	1977	60.2	1.23	44.6	"
New Zealand	1979	46.6	5.88	53.1	"

The great variability in skipjack growth has several implications for fisheries management strategies. Firstly, the management applications of the von Bertalanffy growth parameter estimates presently available must be approached with caution. Secondly, the utility of growth rate and size data for elucidating such phenomena as population and stock structure, as has been previously proposed (e.g. Kearney 1975; Blackburn & Serventy 1981), is unlikely to be great.

4.3.4 Population structure

There is movement of some skipjack adults over much of the western and central Pacific (Figure B, inside back cover), suggesting that genetic exchange is possible among all parts of the Programme's study area. However, detailed examination of tag recapture data (Section 4.4) and preliminary analyses of fishery interactions (Section 4.4.3) indicate that the actual level of exchange of skipjack, at least of the size caught by pole-and-line gear, may be quite low. Analyses of the genetic variation in skipjack throughout the central and western Pacific were undertaken by the Skipjack Programme to provide additional information on migration and population structure and, ultimately, potential interactions between fisheries.

Electrophoretic analyses of skipjack blood samples reveal a gradient in esterase gene frequency, a genetic marker used to infer population structure, across the tropical Pacific between approximately 120°E and 130°W (Figure 6). The esterase gene frequencies for the samples taken in Australian waters were within the 95 per cent prediction limits for the regression line of average gene frequency on longitude. There was considerable variation in individual esterase gene frequency values along this average line, although the cause of this variability was unclear (Anon. 1981).

Several models of population structure of skipjack in the Pacific Ocean have been proposed (Fujino 1972, 1976; Sharp 1978; Anon. 1981). One of these models, suggested by the Programme's tagging and blood genetics data, is called the clinal population structure model (Anon. 1981). It has the basic premise that the probability of breeding between skipjack is inversely proportional to the distance between them. Acceptance of this model implies that there are no genetically isolated skipjack subpopulations in the study area, separated by geographical boundaries, which is contrary to hypotheses advanced by Fujino (1972, 1976) and Sharp (1978).

The gradient in esterase gene frequency is consistent with several possible distributions of skipjack spawning, one being a relatively even distribution of skipjack spawning in tropical waters across the study area. Alternatively, it may be considered a product of "overlap" of skipjack from two or more centres of higher spawner density at the approximate extremes of the study area or beyond. The similarity between eastern Pacific esterase gene frequencies (east of 130°W) 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) tentatively supports the latter view of skipjack spawning.

Parasite samples were taken over a wide range of tropical waters and from temperate and subtropical waters of New Zealand and Norfolk Island, but not from eastern Australia. A multivariate analysis presented by Lester et al. (ms.) showed that the parasite faunas from widely separated tropical areas were similar, and that skipjack caught in New Zealand carried many tropical parasites. The parasite studies did not greatly increase the information available on skipjack population structure, nor offer a means of clarifying fishery interactions.

After two workshops hosted by the South Pacific Commission to examine the question of skipjack population structure, it was concluded (Anon. 1980, 1981) that it is difficult to choose between the various population structure hypotheses, due to limitations of the extant blood genetics, tagging and ancillary data. However, it appears unlikely that discrete subpopulations of skipjack tuna exist in the central and western Pacific, as Fujino (1972, 1976) and Sharp (1978) have proposed. The genetic structure of the seven schools analysed by the Skipjack Programme is consistent with the clinal, isolation-by-distance model of population structure (Anon. 1981). However, since skipjack clearly are capable of undertaking very long migrations, it is possible that samples with genetic compositions characteristic of areas to the east may be taken in Australia. Fujino (1976) recorded one such sample.

4.4. Tag Recapture Data

As of 10 October 1983, there had been 76 recoveries of the 8,086 skipjack tagged and released in Australian waters, and one of the 316 tagged yellowfin had been recaptured. Further recoveries are not anticipated. The overall rate of recovery of tagged skipjack (0.94%) was very low, much less than the average of 4.6 per cent achieved for all tags released by the Skipjack Programme between 1977 and 1980. Table 14 shows that the recovery rate of fish tagged in Queensland was higher than those for New South Wales or Norfolk Island (1.17%, 0.67% and 0.36% respectively). All but four of the skipjack, as well as the single yellowfin, were captured in waters external to the 200-mile Australian Fishing Zone (AFZ).

TABLE 14. NUMBERS OF RELEASES AND RECOVERIES OF TUNA TAGGED BY THE SKIPJACK PROGRAMME IN AUSTRALIAN WATERS. Numbers of tuna tagged during 1979 and 1980 within Australia's Fishing Zone (AFZ) and the number of local recoveries (from within the AFZ), 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.

		New South Wales 1979 April	Queensland 1979 May	Norfolk Island 1980 March	Species Totals	Totals
Fish tagged	SJ	4,322	2,651	1,113	8,086	8,418
	YF	8	54	254	316	
	OT	16	0	0	16	
Local recoveries	SJ	2(0.05)	2(0.08)	0	4	5
	YF	0	0	1(0.39)	1	
External recoveries	SJ	29(0.67)	31(1.17)	4(0.36)	64	64
	YF	0	0	0	0	
Position indeterminate recoveries	SJ	4(0.09)	4(0.15)	0	8	8
	YF	0	0	0	0	
					Total	77

Both the low rate and the distribution of tag recoveries are a consequence of the lack of fishing effort for skipjack in Australian waters. An analysis of distances travelled and periods of liberty since release for all fish tagged by the Skipjack Programme (Figure 7) indicates that most fish were captured within 250 miles of their release point or within 180 days of release. Mortality occurring over longer periods of time results in fewer fish being available for recapture at distances far from their points of release (Section 5.2), so the low rate of recovery of Australian-tagged fish is not surprising.

There were also three recoveries in Australian waters of skipjack which had been tagged in New Zealand, and one recovery of a skipjack tagged in Papua New Guinea by the Skipjack Programme. Full details of each release and recovery of skipjack which moved out of or into Australian waters are given in Appendix C.

4.4.1 Skipjack migrations

The capacity of skipjack to make long migrations is well known (Joseph, Klawe & Murphy 1980). A maximum displacement of 3,470 nautical miles was recorded by the Skipjack Programme, for a fish tagged in Papua New Guinea and recaptured 173 days later in international waters east of Line Islands. The maximum period at liberty was 1,070 days for a fish tagged in Fiji and recaptured in Fijian waters only 62 nautical miles away. Many of the long-distance migrations recorded by the Skipjack Programme are shown in Figure B (inside back cover). Migrations represented in this figure were selected by plotting no more than one example of movement in each direction between any pair of ten-degree squares, and no more than two examples of movement occurring wholly within any ten-degree square. The presentation thus over emphasises long-distance migrations, which the data in Figure 7 show to be relatively rare.

4.4.1.1 Local migrations

The two tagged skipjack recovered in New South Wales waters were captured by an Australian pole-and-line vessel and an unknown vessel, after 262 and 284 days at liberty and 10 and 151 nautical miles from their release points, respectively. The two skipjack recaptured in Queensland were caught by the Programme's research vessel on the same day they were tagged.

4.4.1.2 Movements from Australia

The longest migration by a skipjack tagged in Australia was 3,203 km, by a fish tagged in New South Wales and recaptured in the Society Islands of French Polynesia, 290 days later. The longest period at liberty was for a fish tagged near Norfolk Island, and recaptured near New Caledonia 694 days later. The distribution of recoveries in time and space is shown in Table 15 and a selection of the movements are represented as straight-line trajectories in Figure 8. The majority of recoveries (34) were made in Solomon Islands; 25 of these tags were released in Queensland, 8 in New South Wales and one in Norfolk Island. It is noteworthy that no tags were recovered in the adjacent Papua New Guinea fishing zone, where a large locally based pole-and-line fishery operated until 1982 (Tuna Programme 1984). Eleven tags were recovered in New Caledonia. They originated from New South Wales, Queensland and Norfolk Island, and represent roughly the same proportion (approximately 0.1%) of tags released in each of these areas. The other area in which a large number of tags was recovered was New Zealand; all nine fish recaptured there were tagged in New South Wales.

FIGURE 7. NUMBERS OF SKIPJACK TAG RECOVERIES, BY DISTANCE TRAVELLED AND TIME-AT LARGE, FOR THE ENTIRE SKIPJACK PROGRAMME DATA SET. Data are for tag returns received by 10 October 1983. Recaptures for 103 fish which travelled more than 1,500 nautical miles are included in the sample sizes, but are not shown in the figure.

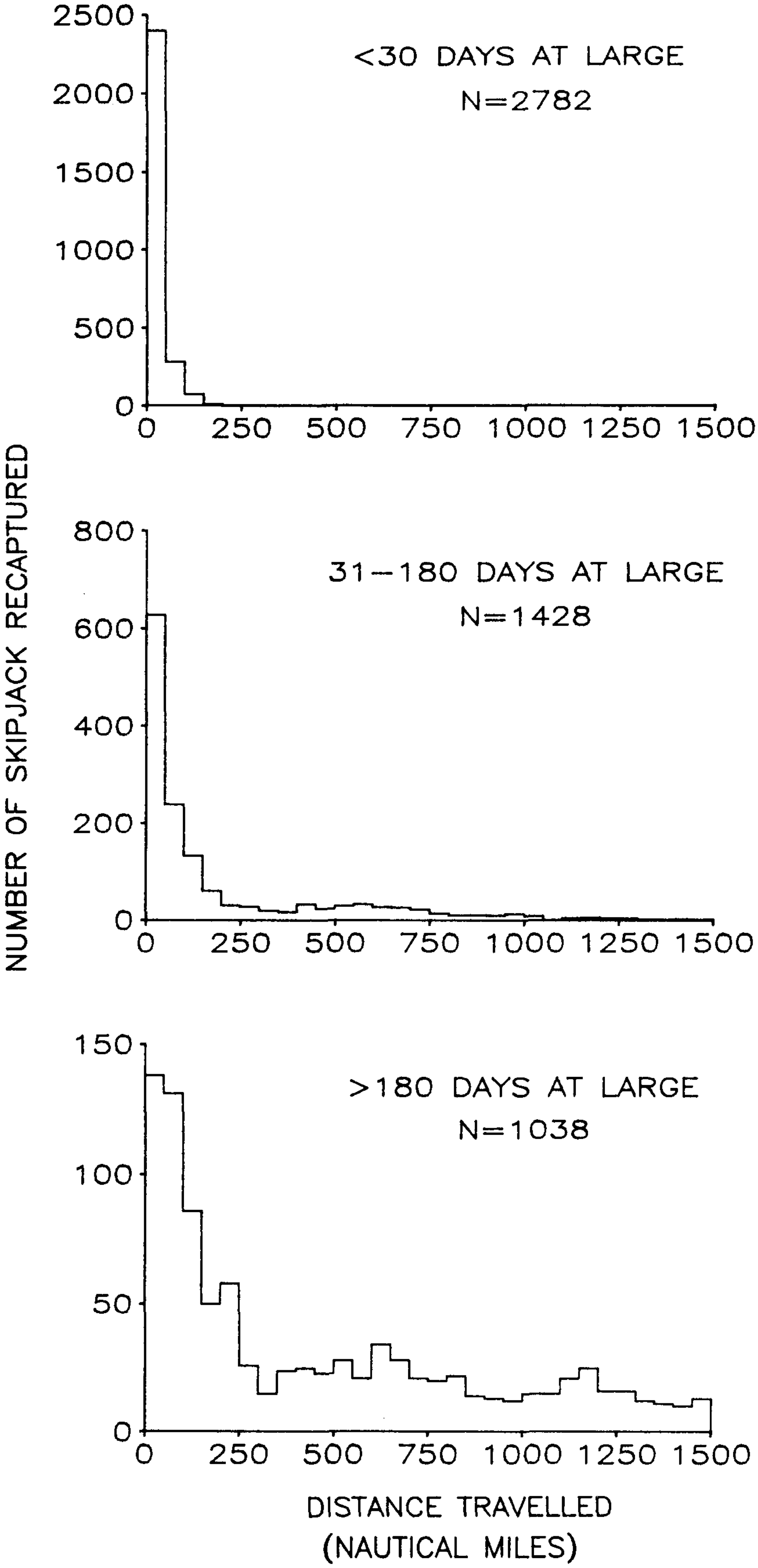
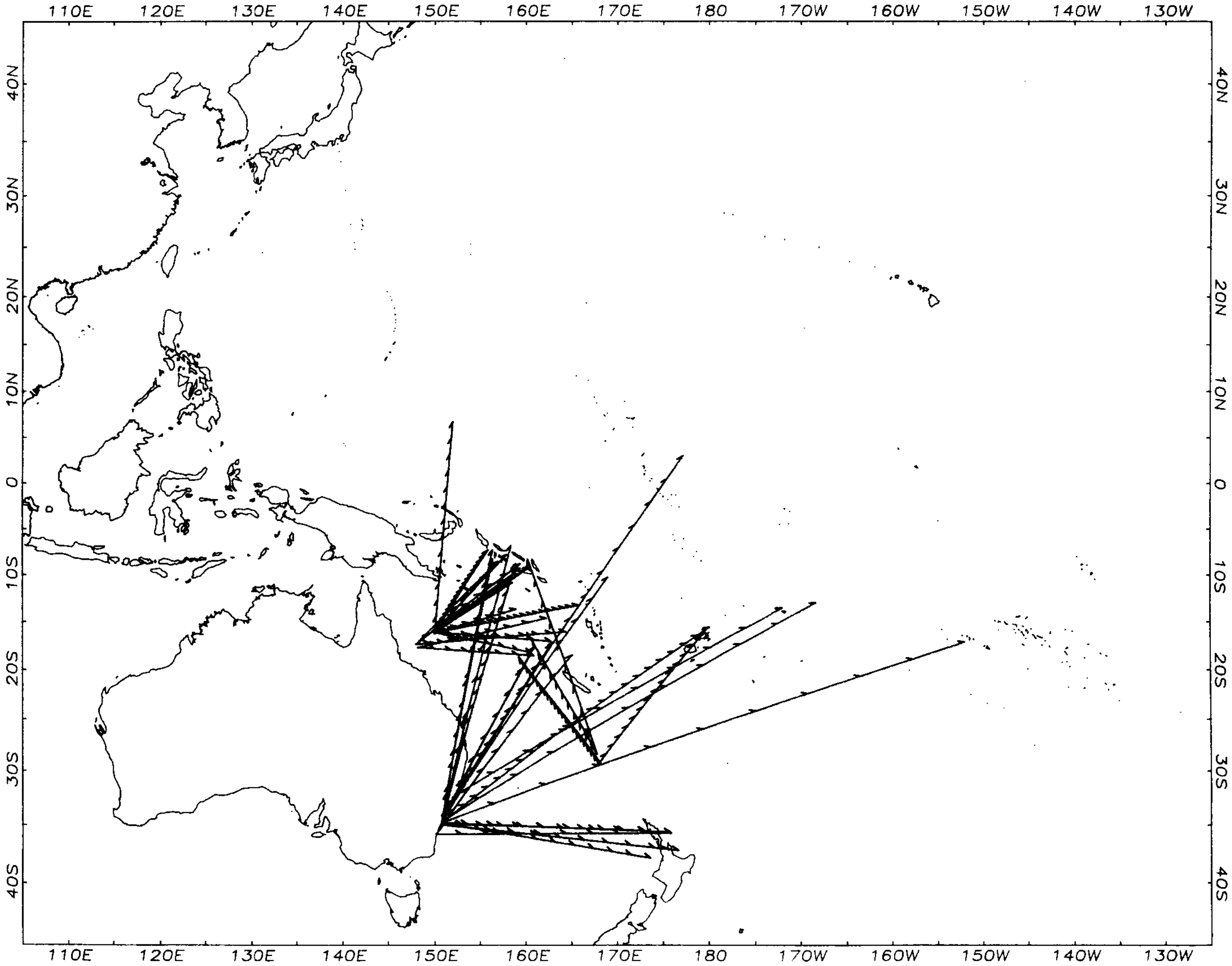


TABLE 15. RECOVERIES BY AREA AND MONTH OF TAGGED SKIPJACK RELEASED IN AUSTRALIAN WATERS BY THE SKIPJACK PROGRAMME. For explanation of area abbreviations, see Appendix D. * indicates recovery location indeterminate.

Area and Release Date	No. of Releases	Month of Recapture	COUNTRY OF RECAPTURE														
			AMS	CAL	FIJ	INT	NOR	NSW	PNG	QLD	SOC	SOL	TRK	VAN	WES	ZEA	*
New South Wales																	
79/04	4322	79/07										1					
		79/11		1								3					
		79/12		3				1				1					
		80/01		1				1			1				1	1	
		80/02	1	1								1				4	
		80/03														1	
		80/04										1					
		80/07				1											
		80/10										1					
		81/02			1												
		Unknown			1											3	4
Queensland																	
79/05	2651	79/05								2							
		79/07										2					
		79/10										4					
		79/11		1								7					
		79/12		2								6					
		80/02										1					
		80/03												1			
		80/05											1				
		80/06										1					
		80/10										1					
		80/11										1					
		80/12										2					
		81/02												1			
		Unknown															4
Norfolk Island																	
80/03	1113	80/12										1					
		Unknown		2	1												
		TOTAL	1	11	3	1	0	2	0	1	1	34	1	2	1	9	8

FIGURE 8. STRAIGHT-LINE REPRESENTATIONS OF MOVEMENTS OUT OF EASTERN AUSTRALIAN WATERS OF SKIPJACK TAGGED IN EASTERN AUSTRALIA, AND INTO EASTERN AUSTRALIAN WATERS OF SKIPJACK TAGGED ELSEWHERE BY THE SKIPJACK PROGRAMME. Only 39 of the 62 recorded migrations out of Eastern Australian waters are plotted, by choosing only one example of movement in each direction between any pair of two-degree squares. Tick marks on the arrows represent 30-day periods at large.



Movements from all three of the tag release areas were towards the east and north; none was towards the south. This is not surprising for fish released in New South Wales, because it is near the southern limit of skipjack distribution. The absence of southerly movement from Queensland or Norfolk Island at least partly reflects the low fishing effort to the south, although the effort expended in New Zealand was sufficient to recover a significant number of tags released in New South Wales. Another possible explanation is that the seasonal decline in surface-sea temperatures in the months following tagging in Queensland and Norfolk Island may have constrained southward migrations. Movement in a southerly direction usually occurs in spring and early summer, with movements in a northerly direction occurring after summer (Robins 1952; Argue & Kearney 1983).

4.4.1.3 Movements to Australia

Only four fish tagged elsewhere by the Skipjack Programme, three from New Zealand and one from Papua New Guinea, were recaptured in Australian waters. Two New Zealand fish, one tagged in February 1979 and the other tagged in March 1980, were recovered off the New South Wales coast, after 267 and 360 days at liberty respectively; that is, in the following summer. The fish were recaptured by an American purse-seiner engaged in exploratory fishing, and by an Australian pole-and-line vessel. The movements of one of these fish is represented as a straight-line trajectory in Figure 8. In all such cases (e.g. Figure B) the trajectory actually followed is likely to have been much less direct; in the case of the New Zealand fish recaptured in New South Wales, it is possible that it included a migration northwards towards the tropics and southward again in the following spring, since seasonal influence of migration has been reported (Robins 1952; Argue & Kearney 1983). The same considerations may apply to the recovery by the Skipjack Programme research vessel of a skipjack in Norfolk Island waters 390 days after it was tagged in New Zealand (Figure 8).

The single migrant from Papua New Guinea was recaptured by a pole-and-line vessel in the Coral Sea east of Cairns, 549 km from its point of release in the western Solomon Sea and after 807 days at liberty.

The low number of recoveries in Australian waters of skipjack tagged elsewhere by the Skipjack Programme cannot be taken as evidence that there is little recruitment of fish to Australian stocks from other areas. The exceedingly low fishing effort expended in Australian waters provides only a very low chance of recovery. The four tag recoveries therefore may be indicative of a significant amount of migration of fish, which have already been exposed to other fisheries, into Australian waters.

4.4.2 Resource assessment

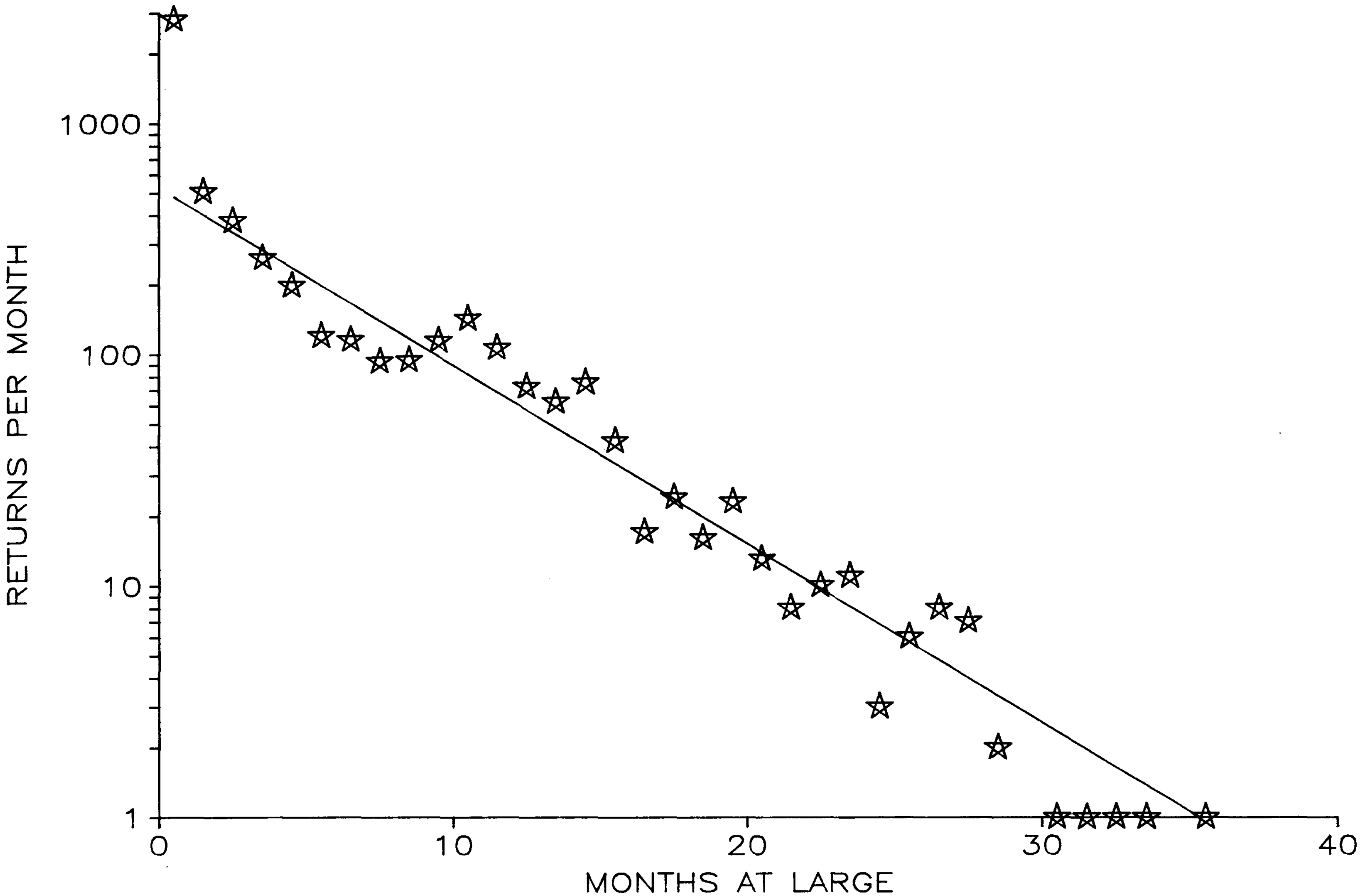
The Programme's tag recapture data provide a basis for assessing the magnitude of the skipjack resource and its resilience to fishing pressure. A model formulated by Kleiber et al. (1983) was used to analyse tag attrition rates (the frequency of tag returns as a function of time) to derive estimates of various parameters of skipjack stock dynamics. Separate analyses were performed for the whole study area covered by the Programme and for the 200-mile zones 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 either catch or effort by fishing fleets. There were insufficient local tag recoveries, due to low local fishing effort and no reliable catch and effort data, to enable such an assessment to be made of the skipjack stock in New South Wales, Queensland or Norfolk Island waters. Figure 9 shows the numbers of tag returns for the whole Skipjack Programme study area versus the numbers of months these tags were at large after release. The straight line in the figure depicts the average number of tag recoveries one would predict per month from fitting the mathematical model of Kleiber et al. (1983) to the catch and tag return data.

The data points (stars) in Figure 9 deviate little from the line predicting the average number of tag returns per month. The instantaneous rate of decrease of tag returns estimated from the fitting procedure is called the tag attrition rate, which results from natural and fishing mortality, changes in vulnerability, and emigration. An additional component, presumably small, includes both continual shedding of tags and continual mortality from the effects of tagging. The estimate of attrition rate was 0.17 per month (Kleiber et al. 1983), which is similar to the rate of 0.23 estimated for skipjack stocks from the large fished area north of the Equator in the eastern tropical Pacific (Joseph & Calkins 1969). Thus, after six months at large, close to 70 per cent of the tag releases by the Skipjack Programme were unavailable for recapture, for one or another of the reasons above, and after a year this had increased to 90 per cent. Assuming steady-state conditions in the stock, these fish were replaced by new recruits through reproduction, growth and immigration.

The model also provided estimates of several other parameters of the skipjack stock, but in doing so a correction factor was applied to account for non-return of recaptured tags, return of tags without sufficient or accurate recapture data, and loss of tags immediately after application through shedding or mortality. In the entire study area, the population size or "standing stock" that was vulnerable to surface fisheries was estimated to be approximately three million tonnes during the 1977 to 1980 study period (95% confidence range of 2.5 million to 3.7 million tonnes). Average monthly catch in the Programme's study area, 19,000 tonnes, divided by population size, provided an estimate of average monthly fishing mortality of approximately 0.006, which is only a small proportion of the monthly attrition rate. Other losses, through natural death, decreased vulnerability to fishing, and emigration are difficult to partition, but because the study area was vast and covered much of the area of skipjack distribution in central and western Pacific waters, it has been assumed that emigration is the smallest of the three.

The product of standing stock and monthly attrition rate provides an estimate of monthly "throughput" - the biomass (tonnes) of skipjack recruited to the standing stock each month. This is assumed for the duration of the tagging experiment to be matched by an equal amount leaving each month (i.e. steady-state conditions prevail). From Skipjack Programme data, throughput was estimated to be 0.46-0.59 million tonnes per month. Average monthly loss due to catch represents approximately four per cent of the estimated monthly throughput. Hence, there appears to be potential for greatly increased catches from the region as a whole before recruitment would be affected. The experience with much more mature skipjack fisheries off the coast of Japan and in the eastern Pacific, where there has been no relationship between catch per unit effort and effort over a period of 20 or more years (Joseph & Calkins 1969, Kearney 1979), supports this view.

FIGURE 9. NUMBERS OF SKIPJACK TAG RECOVERIES VERSUS MONTHS AT LARGE, FOR THE ENTIRE SKIPJACK PROGRAMME DATA SET. The Y axis has a logarithmic scale.



Assuming a uniform dispersion of skipjack in the study area, it would be possible to make a "guesstimate" of the size of the skipjack stock in eastern Australian and Norfolk Island waters, by pro-rating the total standing stock from the entire study area on the basis of the proportion of the area occupied by Australia's exclusive fishing zone. Since the eastern section of the AFZ is a relatively large part of the total Skipjack Programme study area, the skipjack resource may be expected to be large, perhaps more than 100,000 tonnes, turning over at a rate comparable to that estimated for other parts of the study area. However, such an estimate would be tenuous, since the abundance of skipjack in a significant part of the eastern part of the AFZ is known to vary seasonally. Another estimate by CSIRO suggests that the skipjack resource off south-eastern Australia alone might support annual catches of 50,000 tonnes (Ottesen & Grant 1982). Although it is not possible to make better estimates with the data presently available, it is clear that catches could be an order, or perhaps two, of magnitude greater than those taken at present.

4.4.3 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 interaction between fisheries (Kearney 1983). These may occur, for example, between various types of fishery within a particular country (e.g. artisanal vs. industrial), between fisheries based on different gear types (e.g. purse-seine vs. longline for yellowfin) or between fisheries operating in different countries. The data of the Skipjack Programme provide a measure of the last type of interaction.

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 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.

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 et al. ms.). An earlier version of I expressed interaction as the contribution of migrants to standing stock of the receiver country (Skipjack Programme 1981a). 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 et al. (1983). Two values of I exist for any pair of fisheries, one for each of the directions in which interaction may occur. It should be remembered that, as with the parameters derived from the tag attrition model, the immigration coefficient measures only the interaction between particular fisheries operating in defined areas. It does not provide a measure of migration of fish from all parts of a country's fishery zone to the whole fishery zone of another country, and is therefore a minimum estimate of interaction. Table 16 summarises the recoveries from skipjack released

TABLE 16. RELEASE AND RECAPTURE SUMMARY FOR TAGGED SKIPJACK RELEASED BY THE SKIPJACK PROGRAMME IN ALL COUNTRIES, TERRITORIES AND SUBDIVISIONS THEREOF AS OF 10 OCTOBER 1983. Releases and recoveries are arrayed by tagging or recovery location, usually a country or territory except in cases where smaller geographical divisions were more informative; abbreviations are explained in Appendix D. Not included in the table are returns for which the country or area was unknown.

COUNTRY OF RECAPTURE

NUMBER OF RELEASES BY COUNTRY

		AMS	CAL	FIJ	GIL	GUM	HAW	HOW	IND	INT	JAP	KOS	LIN	MAQ	MAR	MAS	MTS	NAU	NCK	NOR	NSW	PAL	PAM	PHL	PHO	PNG	PON	QLD	SOC	SOL	TOK	TON	TRK	TUA	TUV	VAN	WAK	WAL	WES	YAP	ZEA	TOT
775	AMS	3																																					1			4
10219	CAL		18		1					2					1											2	2			10			1									37
20094	FIJ		1	1948	1					5								1							4				1			2			6		1	2	2		3	1977
174	GAM																																									
4569	GIL	1			385			24		32		1	1			14		1					2		1		1															463
108	JAP				1				2	3	7				1	1																										15
297	KOS									3						2																										5
20282	MAQ				1			1		4				42											1				1													50
195	MAR									2	1				2		1										1						2									9
327	MAS									2						1		1																								4
1229	NCK																		1																							1
91	NIU																																									
1113	NOR		2	1																										1												4
4322	NSW	1	6	2						1											2								1	8									1		9	31
7233	PAL				3				28	69		3			1	6						108		6		77	9			2			23							31		366
367	PHO				1																																					1
59	PIT																																									
8550	PNG				1	1		5	7	18		1				7						2	2			958	3	1		26			11							3		1046
5518	PON				1			2		17	2	23			1	30								1		1	113			1			13							10		215
2651	QLD		3																									2		25			1			2						33
48	SCK																																									
1725	SOC																												36													36
6221	SOL			1	1				1	2																16				526												547
64	TOK																														1											1
1969	TON																								1				1			10							1			13
1054	TRK									4		5				5											19						16							2		51
5528	TUA																												5					25								30
2904	TUV			2	2		1	1		7		1				4		1					1		1	1				2					2				1	1		28
1254	VAN																									1				4						2						7
16065	WAL		1	14	5			5		11						3									24	2			3				1		1			66	11		6	153
1926	WES	1																											1	1									19		1	23
778	YAP				2				3	7	1				3							1					1						3							5		26
12734	ZEA		5	31						3										1	2								5		1	1			1	1			5		1003	1059
140443	TOT	6	36	1999	405	1	1	38	41	192	11	34	1	42	9	73	1	4	1	1	4	111	5	7	32	1058	149	3	54	606	2	13	71	25	10	5	1	66	41	52	1022	6235

throughout the total study area, by country/territory of release and recovery, and offers a simple index of the degree of interaction between fisheries. However, this form of presentation takes no account of tag recovery effort, that is, the catch from which the tags were recovered. Reliable catch data are necessary for quantifying the interactions. These were available to the Programme from some of the locally based fisheries during the period tags were at large, but not for catches between 1979 and 1982 by the large United States and Japanese distant-water purse-seine fisheries and the Japanese distant-water pole-and-line fishery. These fisheries operate in much of the western Pacific and over the period of tag recoveries they accounted for a significant percentage (~20%) of Skipjack Programme tag returns. Until the Programme receives catch data from these fisheries, accurate estimates of interaction between distant-water and locally based fisheries cannot be made.

The Skipjack Programme has calculated coefficients of interaction in at least one direction for as many pairs of countries and territories in the South Pacific Commission region as possible with the available data. A selection of the results is shown in Table 17, including an estimate of interaction due to fish migrating from Queensland to Solomon Islands (see Argue & Kearney 1982). Most coefficients are small, with over half of them less than two per cent, but they span a wide range, from less than 0.1 per cent for movements from Kiribati to the Federated States of Micronesia to 37 per cent for movements from the Federated States of Micronesia to the Marshall Islands. The Queensland-to-Solomon Islands estimate is relatively high, at 7.5 per cent. Most of those omitted from the selection in Table 17 were also very low, from 0.1 to 1.0 per cent (e.g. Argue & Kearney 1982; Tuna Programme 1984). Thus, with very few exceptions, interactions at the time of tagging were quite low, at least between the particular fisheries listed in Table 17. Developments in these areas since then may have already altered the levels of interaction. It should also be noted that these results apply only to skipjack of the size tagged by the Programme (mean length about 50 cm). Skipjack smaller than this could very well move large distances and contribute significantly to interactions between stocks in the fished areas.

Fishery interactions increase as the distance between fisheries decreases. If fisheries in neighbouring countries expand their areas of operation to include waters adjacent to common borderlines, the degree of interaction may increase. Furthermore, if different gear types were to operate in the same area, such as purse-seine and pole-and-line fleets working in the same or nearby fishing grounds of a country, then the degree of interaction would be much higher than present figures indicate. Since the few available tagging data indicate that there is at least some exchange of skipjack between Australia and neighbouring countries, there exists the possibility of strong interaction between fisheries in the future. If large-scale exploitation of skipjack is initiated in Australian waters, it will be advisable to closely monitor interactions with adjacent fisheries.

5.0 CONCLUSIONS

5.1 Baitfish Resources

The southern and central coasts of New South Wales provide many areas suitable for baitfishing using bouki-ami gear. Catches in these areas by the Programme's research vessel were generally very high, confirming the

TABLE 17. COEFFICIENTS OF INTERACTION BETWEEN FISHERIES OPERATING IN VARIOUS COUNTRIES AND TERRITORIES IN THE SOUTH PACIFIC COMMISSION REGION (from Kleiber, Sibert & Hammond ms.). See Appendix D for abbreviations for countries and territories. The numerals following donor country codes indicate tag release data sets from separate visits to the same country.

Donor Country	Receiver Country									
	PNG[c]	SOL[c]	PAL[c]	FSM[d]	MAS[d]	MAR[d]	FIJ[c]	ZEA[e]	WES[f]	SOC[f]
PNG	-	2.6	0.8	1.4	0.5					
SOL 77	1.1	-								
SOL 80	3.7	-								
PAL 78			-	8.6	2.2					
PAL 80	1.6	0.4	-	3.5	1.3	0.7				
FSM	0.7	0.9		-	37.0	10.8				
MAS					-					
MAR				17.4		-				
FIJ 78							-	0.6[a]		
FIJ 80							-			
ZEA							6.5	-	2.1[b]	3.6
KIR[c]				<0.1	0.1					
QLD[g]		7.5								

a Assuming β_r=0.76 and T_d=7300

b Assuming β_r=0.76

c Local pole-and-line fishery

d Japanese pole-and-line fishery

e Local purse-seine fishery

f Local artisanal and subsistence fishery

g No fishery; parameters for calculating interaction as assumed by Argue & Kearney (1982).

existence of a baitfish resource capable of supporting a commercial-scale pole-and-line fishery for skipjack or other tuna. However, catches varied considerably even at a single locality, and other authors suggest they may fluctuate from year to year. Any such inconsistencies in the availability of bait would adversely affect the development of a pole-and-line fishery for skipjack, so they should be more fully investigated.

The good bait catches in southern and central New South Wales reduced the need for baitfishing in northern New South Wales, and the conclusions that can be drawn from the Programme's work there are limited. Many localities not investigated by the Programme may prove to have suitable conditions for bouki-ami fishing and good supplies of bait species. However, there are fewer, and less sheltered, anchorages in northern New South Wales and surveys by other agencies suggest that bait resources are smaller or at least less accessible than those in central and southern parts of the state.

Baitfish catches in New South Wales were dominated by jack mackerel, pilchards and anchovies. The last two groups are very effective as live-bait for skipjack, but the mackerel are often ineffective, especially when large. Any future bait fishery should concentrate its efforts on pilchards and anchovies. A feature of the New South Wales baitfish survey was the hardiness of the major bait species to capture, transfer and transport. This suggests that fishing in offshore waters, distant from baiting sites, would be possible.

The availability of bait transported from New South Wales also reduced the need for baitfishing in Queensland waters. A single haul in southern Queensland caught relatively little bait, which comprised a mixture of temperate and tropical species. A small haul taken in North Queensland contained species typical of tropical areas in the central and western Pacific, and known to be very effective as live-bait for skipjack. There are likely to be many locations in central and northern Queensland suitable for bouki-ami fishing, and there appear to be extensive areas of habitat suitable to baitfish species. The Programme's experience in other tropical areas suggests that a large baitfish resource probably exists in North Queensland. Although baiting grounds are likely to be some distance from the fishing grounds outside the Great Barrier Reef, the application of bait-handling techniques developed by the Skipjack Programme would enable tropical bait to be transported considerable distances.

There is little habitat suitable for baitfish species at Norfolk Island, and conditions do not favour the use of bouki-ami gear. However, the hardiness of temperate bait species from both New South Wales and New Zealand suggests that bait could be transported to the Norfolk Island area for pole-and-line fishing.

5.2 Skipjack Resources

In New South Wales, both school sightings rate and catch rate indicate that skipjack are moderately abundant off the south coast near Eden and Jervis Bay. School sightings and results from other surveys indicate that skipjack are abundant northwards to the Port Stephens-Sugarloaf Point area, with a period of maximum abundance in summer. Although it was not possible to quantify the skipjack standing stock, it is likely to be large and capable of supporting catches many times greater than the highest catches recorded in the past. Furthermore, it is probable that recruitment each year would be relatively independent of fishing pressure in southern Australian waters the preceding season.

Pole-and-line and purse-seine techniques presently used in the southern bluefin fishery, or demonstrated by exploratory fishing ventures, are readily applicable to exploitation of skipjack stocks. Skipjack may represent a viable alternative to southern bluefin, catches of which are limited by both the small size and vulnerable condition of the stocks and the restricted access to the fishery. However, the seasonality of skipjack abundance and the vagaries of the weather in south-eastern Australian waters strongly suggest that vessels fishing skipjack in this area would also need access to resources of other species or of skipjack in other areas to complement catches. It is apparent that major constraints on development of a skipjack fishery are the low price presently offered by processors and the limited processing capacity of Australian plants.

The catch rate and school sightings rate in central and northern Queensland were comparable to those recorded by the Skipjack Programme in other tropical areas presently supporting commercial fisheries for skipjack. Thus, there appears to be a large resource of skipjack in tropical eastern Australian waters, although it also could not be quantified. Techniques appropriate to the exploitation of these small, relatively mobile schools have been developed throughout the central and western Pacific in recent years, and could be used under Australian conditions.

The apparent absence of skipjack off a large part of the southern Queensland and northern New South Wales coastline is presently unexplained, and warrants further investigation.

Catch rates in waters around Norfolk Island indicate that skipjack are present in abundance in summer months. Future exploitation by pole-and-line techniques would require bait to be transported from other, probably temperate areas. Purse-seine techniques would also be appropriate, but any fishery based in the area would be seasonal.

The absence of a skipjack fishery anywhere in eastern Australia meant that there were very few recaptures in Australian waters of skipjack tagged either in Australia or elsewhere. The four recoveries that were made, three from New Zealand and one from Papua New Guinea, may therefore be indicative of a significant level of migration of skipjack from adjacent areas into Australian waters. This is to be expected in view of the probable absence of skipjack spawning in temperate waters. The recovery of Australian-tagged skipjack in other countries indicates that extensive migrations occur out of Australian waters. Only one interaction could be quantified, between stocks in north-eastern Australia and Solomon Islands, and it was relatively high. It is therefore apparent that if commercial fisheries for skipjack are established in eastern Australia, interactions between them and fisheries operating in adjacent areas should be closely monitored.

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APPENDIX A. SUMMARY OF TUNA AND BAITFISH RESEARCH OR EXPLORATORY FISHING SURVEYS IN EASTERN AUSTRALIAN WATERS. Catches are shown by species: SJ = skipjack, YF = yellowfin, ALB = albacore, SBT = southern bluefin tuna, MT = mackerel tuna, DT = dogtooth tuna, JM = jack mackerel, AB = Australian bonito, ST = slender tuna. Effort is shown as line hours (l-hr), hours (hrs), or days.

Trip Date	Vessel	Gear	Mission	Area	Catch	Effort	Reference
May 1938- Dec. 1939	Warreen	Plankton nets	Larval fish sampling	NSW TAS VIC	-	-	Blackburn 1941
Sept. 1938	Warreen	Troll	Exploratory fishing	QLD South	Various pelagic school sightings	22 days	Blackburn & Tubb 1950
Oct. 1938- March 1942	Warreen	Troll	Trolling/Larval fish sampling	NSW QLD	1138 SBF	5117 l-hrs	Serventy 1956
Dec. 1938	Warreen	Pole-and-line/ troll, hoop net	Pole-and-line fishing/ trolling/baitfishing	NSW Montagu Is.	No tuna, some JM		Flett 1944
May 1939	Warreen	Troll	Exploratory fishing	QLD South	Various pelagic school sightings	8 days	Blackburn & Tubb 1950
July 1939	Warreen	Troll	Exploratory fishing	QLD North	No schools seen	4 days	Blackburn & Tubb 1950
July 1939	Warreen	Troll	Exploratory fishing	QLD South	Various pelagic school sightings	6 days	Blackburn & Tubb 1950
Feb. 1940	Warreen	Pole-and-line, troll, hoop net, lampara net	Pole-and-line fishing/ trolling/baitfishing	NSW Eden	121 SJ, 1 SBF, 1 tonne anchovies, 234 kg anchovies, 200 kg anchovies + scad		Flett 1944
May-June 1940	Warreen	Pole-and-line, troll, lampara net	Pole-and-line fishing/ trolling/baitfishing	TAS East	0 SJ, 5 SBF ~200 kg sprats ~200 kg anchovies		Flett 1944
Oct.-Dec. 1940	Warreen	Pole-and-line, troll, hoop net, lampara net	Pole-and-line fishing/ trolling, baitfishing	NSW Jervis Bay	0 SJ, 60 SBF, 35 AB ~2 tonnes pilchards		Flett 1944
April 1941	Warreen	Pole-and line, troll, lampara net	Pole-and-line fishing/ trolling/baitfishing	TAS St Patrick's Head	3 SJ		Flett 1944
June 1941	Warreen	Purse-seine net	Purse-seine trials	TAS	250 kg JM		Blackburn 1943
June-July 1941	Pasadena II		Exploratory fishing	NSW North QLD South	Various pelagic school sightings	30+ days	Blackburn & Tubb 1950
March 1942	Warreen	Troll	Exploratory trolling	TAS Cape Pillar	Some SJ	-	Robins 1952
March-April 1942	Jester	Purse-seine net	Purse-seine trials	TAS	Nil	-	Blackburn 1943
March-May 1942	Arcadiar	Lampara net	Purse-seine trials	TAS	1 tonne sprats		Blackburn 1943
May-July 1943	Mary	Purse-seine net	Exploratory fishing	TAS Adventure Bay	4 tons JM 1 ton JM	2 hauls	Blackburn 1943
Jan.-May 1947	Eden Star	Purse-seine net, air spotter plane	Fishing trials	TAS NSW	31 tons JM 2 tons AB	7 hauls	Blackburn & Olsen 1947
March-April 1947	Valetta	Lampara net	Exploratory lampara fishing	TAS	Maximum daily catches - 940, 1,112, 833 kg of sprats		Blackburn & Olsen 1947

Trip Date	Vessel	Gear	Mission	Area	Catch	Effort	Reference
Oct.-Nov. 1947	Eden Star	Purse-seine net	Fishing trials	NSW Eden-Narooma	15-22 tonnes JM	5 hauls	Blackburn & Rayner 1951
July 1948	Eden Star	Purse-seine net	Fishing trials	NSW Eden-Narooma	35 tonnes JM	3 hauls	Blackburn & Rayner 1951
March-April 1949	Eden Star	Purse-seine net	Fishing trials	TAS Southeast	60 tonnes JM	? hauls	Blackburn & Rayner 1951
1950-1951	Senibua	Pole-and-line	Exploratory tuna fishing/live bait trials	NSW South	117 tonnes tuna	70 days	Anon. 1968
Aug.-Nov. 1950	Stanley Fowler	Troll	Surface temperature collection/trolling	NSW Central and South	525 SJ		Robins 1952
Feb.-May 1951	Stanley Fowler	Troll	Surface temperature collection/trolling	TAS NSW South	1,183 SJ		Robins 1952
June, July, 1951	Stanley Fowler	Troll	Surface temperature collection/trolling	NSW Batemans Bay QLD Moreton Bay	398 SJ		Robins 1952
1957 ?	Derwent Hunter	Troll	Exploratory trolling	NSW	ALB		Robins 1957 Whitley 1964
Feb.-March 1963	Anchovette	600 m gill net	Gill netting trials	VIC Lakes Entrance	16.5 tonnes SJ		Temple 1963
Aug.-Nov. 1965	Degei	Pole-and-line, troll, spotter plane	YF tuna survey	QLD Coral Sea	4 SJ, 130 YF, 32 MT, 16 DT, 54 others, 39 YF tagged		Hynd 1968
Dec. 1966	Espiritu Santo	Purse-seine net	Exploratory purse-seine fishing	NSW Eden	29 tonnes SBT 7 tonnes SJ	2 hauls	Uchida 1975
July-Nov. 1973	Laurus	Purse-seine net, spotter plane	Exploratory purse-seine trials	TAS NSW Eden	2.5 tonnes SJ 36.5 tonnes JM 8,000 tonnes sighted	10 hauls	Anon. 1974
Dec. 1976	Nippon Maru	Purse-seine net	Exploratory tuna seine fishing	QLD Coral Sea	Nil SJ		Anon. 1977
Aug.-Oct. 1977	Catriona B	Pole-and-line	Exploratory pole-and-line fishing for SJ	NSW North	3.0 tonnes SJ		Carrick 1977
Jan.-Feb. 1978	Catriona B	Pole-and-line	Exploratory pole-and-line fishing for SJ	NSW Central	53.2 tonnes SJ 3,600 tonnes SJ sighted		Anon. 1978 Carrick 1978
April 1979	Hatsutori Maru No.1	Pole-and-line, troll and spotter plane	Skipjack tagging programme	NSW	13 tonnes SJ 4322 SJ tagged	16 days	Kearney & Gillett 1979
May 1979	Hatsutori Maru No.1	Pole-and-line, troll	Skipjack tagging programme	QLD	13 tonnes SJ 2651 SJ tagged	15 days	Kearney & Gillett 1979
Oct.-Dec. 1979	Frontier	Purse-seine net	Exploratory purse-seine trials	NSW	120 tonnes SJ	2 hauls	Barwell 1980
Dec. 1979	Denebola	Mid-water trawler	Exploratory pelagic	TAS South	60 kg SJ (10 fish)		Collins & Baron 1981
Dec. 1979-Jan. 1980	Frontier	Purse-seine net	Exploratory purse-seine trials trawling	NSW South	80 tonnes SJ 37.8 tonnes JM	7 hauls	Barwell 1980
March 1980	Hatsutori Maru No.1	Pole-and-line, troll	Skipjack tagging programme	Norfolk Is.	5 tonnes SJ 1113 SJ tagged	5 days	Kearney & Hallier 1980
Oct.-Nov. 1982	Hoyo Maru No.12	Drift net	Exploratory fishing	Norfolk Is.	73 tonnes ST	28 sets	Anon. 1983b

APPENDIX B. SCIENTISTS, OBSERVERS AND CREW ON BOARD THE RESEARCH VESSELS

Scientists

A.W. Argue	1979	April 15 - May 13
Charles Ellway	1979	April 1 - April 25
Robert Gillett	1979	April 15 - May 13
Jean-Pierre Hallier	1979	April 1 - April 15, 1980 March 26-30
James Ianelli	1979	April 1 - May 12
Robert Kearney	1979	April 17 - April 24
Desmond Whyman	1979	May 12 - May 13, 1980 March 26-30

Observers

Greg Doyle, New South Wales State Fisheries
Tony Lewis, Australian National University
Geoff McPherson, Queensland Fisheries Service
Barry Richardson, Australian National University
Gary Voss, Ministry of Agriculture and Fisheries, New Zealand
Gwiedo Kucerans, Ministry of Agriculture and Fisheries, New Zealand
Barry Evans, Norfolk Island Deep Sea Fishing Club
Bruce Mackenzie, Member of Legislative Assembly, Norfolk Island
Albert Buffet, fisherman, Norfolk Island
Colin Buffet, fisherman, Norfolk Island
Byron Burrell, fisherman, Norfolk Island
Peter Coyne, fisherman, Norfolk Island
Denis Christian, fisherman, Norfolk Island
Kerry Dourau, fisherman, Norfolk Island
R. Dourau, fisherman, Norfolk Island
Alan King, fisherman, Norfolk Island
Max Inglis, fisherman, Norfolk Island
Norman Le Cren, fisherman, Norfolk Island

Vessel Crew

Kenji Arima
Sakae Hyuga
Yoshio Kadohno
Mitsutoyo Kaneda, Captain
Koshihiro Kondoh *
Seima Kobayashi
Masahiro Matsumoto, Captain
Yoshikatsu Oikawa *
Tsunetaka Ono *
Nosumu Origuchi
Yukio Sasaya
Kohji Wakasaki *
Mikio Yamashita *

Fishing Crew

Lui Andrews *
Vonitiese Bainamoli
Mosese Cakau
Samuela Delana *
Eroni Dolodai *
Luke Kaidrokai
Veremalua Kaliseiwaga
Kitione Koroi
Metuisela Koroi
Aminiasi Kuruyawa
Eroni Marawa *
Kitione Naivaurerega
Joshua Raguru *
Jona Ravasakula *
Napolioni Ravitu
Ravaele Tikovakaca *
Samuela Ue *

* Indicates that he crewed on both research vessels

APPENDIX C. TAG AND RECOVERY INFORMATION FOR EACH TAGGED SKIPJACK WHICH MADE A MIGRATION OUT OF OR INTO AUSTRALIA'S 200-MILE 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 D); 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.

```
        NSW 483 790405 1030 3604S 15024E  218    0    0

S ZEA 800114 284 3557S 17608E 1245 450M 502D SK05367 UUUSEN

        NSW 489 790406 0735 3543S 15038E   61    0    0

S CAL 791121 229 1749S 16113E 1212 630M    U SK06288 JAPPOL

        NSW 492 790406 0955 3544S 15046E  100    0    0

S CAL 800108 277 1843S 16515E 1277 570M 682J SK06624 JAPPOL

        NSW 496 790406 1410 3520S 15059E  157    0    0

S SOL 791228 266 0830S 15630E 1638 560M 650W SK06856 SOLPOL
S                                  520M      SK06193 JAPPOL

        NSW 497 790406 1520 3514S 15105E   41    0    0

S ZEA 800131 300 3728S 17654E 1251 460M 505K SK06875 ZEASEN

        NSW 498 790406 1600 3510S 15105E   70    0    0

S CAL 791201 239 1815S 16053E 1141 610M 666J SK06881 JAPPOL

        NSW 503 790407 1605 3522S 15102E   47    0    0

S SOL 801006 548 0900S 15900E 1641 455M 520W SK06985 SOLPOL

        NSW 506 790408 0840 3508S 15104E  194    0    0

S SOL 791119 225 0830S 15900E 1656 490M 580W SK07000 SOLPOL
S ZEA 800207 305 3544S 17307E 1076 440M    U SK07016 ZEASEN
S CAL 800214 312 1800S 16152E 1178 570M 710W SK07256 JAPPOL

        NSW 507 790408 0920 3506S 15104E  745    0    0

S SOL 791125 231 0730S 15630E 1683 420M 550W SK07360 SOLPOL
S ZEA 800205 304 3523S 17236E 1053 450M 500J SK07562 USASEN
S ZEA 800310 337 3809S 17352E 1110 450M 555D SK07502 UUUSEN

        NSW 511 790408 1610 3504S 15105E  285    0    0

S ZEA 800101 268 3552S 17602E 1217 476B 511E SK08189 USASEN
S SOC 800123 290 1718S 15155W 3203 476B 510D SK07897 POLSHE
S FIJ 810211 675 1546S 17947W 1945 476B 480E SK08320 FIJPOL

        NSW 513 790409 1100 3455S 15110E  119    0    0

S SOL 791125 230 0700S 15830E 1723 475M 520W SK08452 SOLPOL
S NSW 791227 262 3457S 15058E 0010 470M 558W SK08258 AUSPOL
S NSW 800118 284 3717S 15005E 0151 480M 530W SK08464 AUSUUU

        NSW 514 790409 1325 3441S 15110E   96    0    0

S ZEA 800206 303 3526S 17240E 1055 470M    U SK08494 USASEN

        NSW 515 790409 1605 3458S 15105E  764    0    0

S SOL 790724 106 0835S 15700E 1616 459B 540W SK08999 SOLPOL
S CAL 791206 241 1737S 16259E 1220 460M 700W SK09223 JAPPOL
S ZEA 800131 297 3728S 17654E 1255 460M 505K SK08808 ZEASEN
S AMS 800208 305 1310S 16811W 2561 459B 545W SK08771 JAPPOL
S SOL 800227 324 1028S 16905E 1769 459B 531W SK08929 JAPPOL
S FIJ            1730S 17900E 1821 459B    U SK09133 FIJPOL
S SOL 800428 385 0910S 15805E 1595 459B 570W SK09156 SOLPOL
S                                  470M    U SK09096 UUUUUU
S INT 800702 450 0250N 17718E 2706 459B 640C SK09433 JAPPOL

        NSW 516 790410 0925 3456S 15105E   68    0    0

S CAL 791206 240 1750S 16042E 1147 610M 710J SK09448 JAPPOL

        NSW 517 790410 1010 3459S 15108E  143    0    0

S                                  539B    U SK09512 JAPPOL
S                                  580M 662W SK09492 JAPPOL

        NSW 518 790410 1050 3502S 15112E  106    0    0

S ZEA 800205 302 3523S 17236E 1047 450M 500J SK09396 USASEN

        NSW 522 790421 1020 3227S 15246E   33    0    0

S WES 800112 266 1344S 17150W 2237 460M 510E SK09902 WESSUB

        QLD 523 790501 0800 1756S 14822E  457    0    0

S QLD 790501 000 1756S 14822E 0000 660M 660A SK32431 SPCPOL
S QLD 790501 000 1756S 14822E 0000 635M 640A SK09637 SPCPOL
S                                  639B 718W SK09947 JAPPOL
S SOL 791126 209 1455S 16225E 0828 580M 700W SK09891 JAPPOL
S SOL 791127 210 1450S 16227E 0831 639B 695W SK09659 JAPPOL
S                                  630M 662W SK32291 JAPPOL
S CAL 791127 210 1846S 16106E 0727 660M 676J SK32265 JAPPOL
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QLD 529 790502 1510 1736S 14809E 152 0 0

S SOL 790708 067 0845S 15705E 0744 604B 455B SK32617 SOLPOL
S SOL 791227 239 0900S 15930E 0839 620M 690W SK32893 SOLPOL
S VAN 800318 321 1616S 16431E 0943 580M 700W SK32870 JAPPOL

QLD 531 790503 1105 1622S 15012E 725 3 0

S SOL 790706 064 0800S 15730E 0659 480B 580B SK34843 SOLPOL
S SOL 791011 161 0915S 15920E 0684 480B 530W SK34733 SOLPOL
S SOL 791014 164 0930S 15930E 0682 480B 520W SK34231 SOLPOL
S SOL 791019 169 0800S 15800E 0679 470M 550B SK34185 SOLPOL
S SOL 791021 171 460M 519E SK34608 SOLPOL
S SOL 791101 182 0900S 15700E 0595 490M 520B SK34529 SOLPOL
S SOL 791129 210 1102S 15838E 0586 480B 500W SK32981 JAPPOL
S CAL 791204 215 1827S 16047E 0619 480B 600W SK34752 JAPPOL
S SOL 791205 216 0825S 15930E 0724 480B 530B SK34721 SOLPOL
S SOL 791219 230 0830S 15900E 0699 480M 520W SK34557 SOLPOL
S SOL 791221 232 0830S 15900E 0699 480B 530W SK34759 SOLPOL
S TRK 800513 376 0633N 15211E 1380 480M 600W SK34612 JAPPOL
S SOL 801018 534 0900S 15930E 0701 480B U SK34728 SOLPOL
S SOL 801114 561 0920S 16037E 0741 480B 570B SK34844 SOLPOL
S 470M U SK34443
S SOL 801203 580 0730S 15600E 0631 490M 620W SK34137 SOLPOL
S VAN 810226 665 1327S 16554E 0927 480M 670W SK34121 JAPPOL

QLD 532 790503 1200 1621S 15010E 71 0 0

S SOL 791111 192 0830S 15730E 0637 620M 650W SK34881 SOLPOL

QLD 533 790503 1250 1620S 15008E 135 0 0

S SOL 801202 579 0840S 16032E 0763 620M 640B SK35030 SOLPOL

QLD 534 790503 1310 1620S 15007E 171 0 0

S SOL 791124 205 0730S 15700E 0666 480M 560W SK35303 SOLPOL
S 490M U SK35112
S SOL 791127 208 0835S 15940E 0727 500M 570B SK34693 SOLPOL
S CAL 791210 221 1716S 16258E 0740 490M 490W SK35049 JAPPOL
S SOL 800625 419 0800S 15830E 0701 480M 580W SK34997 SOLPOL

QLD 539 790504 1722 1627S 15008E 212 0 0

S SOL 791209 219 1353S 15904E 0540 630M 670W SK35177 JAPPOL
S SOL 791231 241 0900S 15930E 0707 590M 680W SK35242 SOLPOL
S SOL 800227 299 1052S 15916E 0629 600M 710W SK35240 JAPPOL

NOR 797 800326 1520 2928S 16820E 239 0 0

S CAL 820218 694 1855S 15922E 0800 640M 816W 1B19650 JAPPOL

NOR 798 800327 1425 2837S 16757E 456 123 0

S SOL 801219 267 0830S 16020E 1281 450M 540W 2B22480 SOLPOL
S CAL 810317 355 1621S 16019E 0848 500M 620W 2B22461 JAPPOL

NOR 801 800329 1000 2930S 16814E 136 0 0

S FIJ 810613 441 1546S 17955W 1052 640M U 2B22575 FIJPOL

ZEA 431 790222 1835 3520S 17448E 967 C 0

S NSW 791116 267 3650S 15105E 1151 480M U SB02965 USASEN

ZEA 441 790302 1645 3525S 17453E 326 0 0

S NOR 800326 390 2928S 16820E 0487 500M 621A SK01585 SPCPOL

ZEA 796 800323 1230 3531S 17450E 1058 0 0
S NSW 810318 360 3510S 15100E 1164 540M U 1B18585 AUSPOL

PNG 547 790520 1700 0736S 14947E 482 0 0
S QLD 810804 807 1618S 15240E 549 511B 750W SK36019 JAPPOL

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 <u>Hatsutori Maru No.1</u> (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	Subsistence (village)
UUU	Unknown

APPENDIX D. 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)
KIR - Kiribati
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