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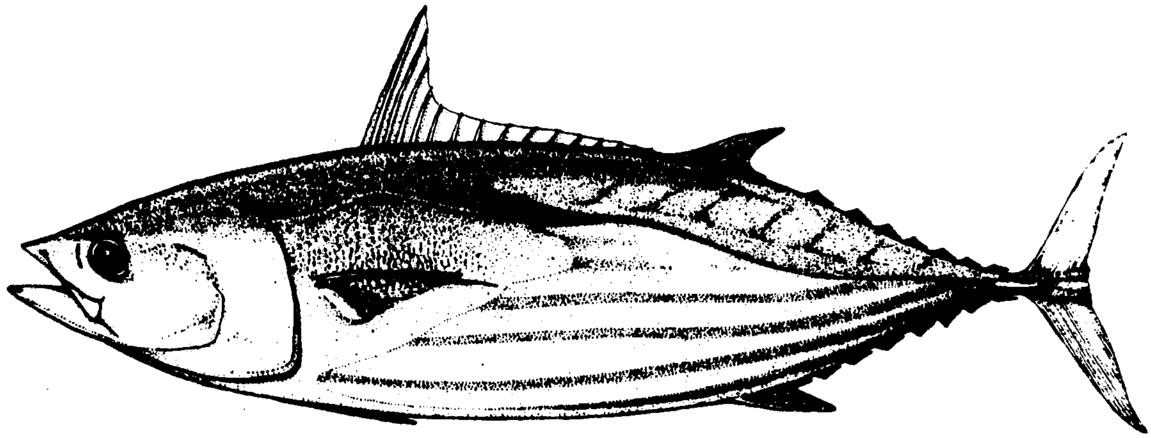
AN ASSESSMENT OF THE SKIPJACK AND BAITFISH RESOURCES OF AMERICAN SAMOA



Skipjack Survey and Assessment Programme
Final Country Report No. 17

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, and the generosity of these governments is gratefully acknowledged.

The Skipjack Programme has been succeeded by the Tuna and Billfish Assessment 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 Programme's investigation of yellowfin tuna resources of the region, is continuing under the Tuna Programme. Reports for each of the countries and territories for which the South Pacific Commission works have been prepared in a final country report series. Most of these reports have been co-operative efforts involving all members of the Tuna Programme staff in some way.

The staff of the 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 Skipjack Programme is grateful for the assistance provided by officials of the Government of American Samoa, in particular Henry Sesepasara, Director of the Office of Marine Resources, Pago Pago.

Tuna Programme
South Pacific Commission

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

AN ASSESSMENT OF THE SKIPJACK AND BAITFISH RESOURCES OF AMERICAN SAMOA

1.0 INTRODUCTION

The Skipjack Survey and Assessment Programme was created in response to rapid expansion of surface fisheries for skipjack (*Katsuwonus pelamis*) during the 1970s in the waters of the central and western Pacific. The objectives of the Skipjack Programme were to survey the skipjack and baitfish resources within the area of the South Pacific Commission, and to assess the status of skipjack stocks and the degree of interaction between fisheries for skipjack within the Commission 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 countries and territories in the area of the South Pacific Commission (Figure A, inside front cover) as well as New Zealand and Australia. Fifteen days were spent in the waters of American Samoa from 1 to 5 and 15 to 21 June 1978, and 20, 21 and 27 February 1980. Preliminary results from the 1978 visits were given by Kearney & Hallier (1978). This report presents the final analyses of the work by the Programme in the waters of American Samoa, 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 Historical Background

In American Samoa, as in other islands of Polynesia, skipjack fishing traditionally was carried out by groups led by masterfishermen, using specialised canoes and pearl-shell lures (Hiroa 1930). Local tuna fishing in American Samoa in the early 1950s was described by van Pel (1954) as "very small scale", mainly conducted by partly decked canoes trolling outside the fringing reef. In 1971, a project was initiated to build eight-metre, Oregon-style fishing dories (Anon. 1973). Twenty-five were built in the early 1970s, but only one was still fishing in 1978 (Wendler 1980). The total catch of pelagic species, mainly tuna, by local fishermen in 1978 was reported by Crossland & Grandperrin (1979) to be about 20 tonnes.

In American Samoan waters, unlike many other parts of the South Pacific Commission region, there has been very little fishing by the Japanese distant-water pole-and-line fleet. The only activity reported between 1972 and 1978, the most recent years for which figures are available, was four boat-days in 1975 and five boat-days in 1976, yielding a total catch of 67 tonnes of skipjack (Skipjack Programme 1980a).

By virtue of its magnificent harbour, one of the best in the Pacific, and the favoured status enjoyed by American Samoa under U.S. tariff regulations, Pago Pago has become the site of two large cannery operations, and subsequently, a major centre for supplying fuel to and provisioning fishing vessels operating in the central Pacific. The first cannery was established by the government in 1949 but soon failed (Kent 1980). It was reopened by the Van Camp Company in early 1954 (van Pel 1954), processing the catch of Japanese longline vessels based in Pago Pago. The Starkist Company began operating a second cannery in 1963, but plans in the early 1970s by the Bumble Bee Company for a third cannery were thwarted by the lack of adequate supplies of water (Kent 1980). In the late 1960s and early 1970s the canneries were supplied by more than 250 Japanese, Korean and Taiwanese longline vessels (Baldwin 1977), which took all but a few per cent of their catch in waters further than 200 miles from American Samoa (Kent 1980). Catches in various years between 1962 and 1977 by Japanese, Korean and Taiwanese longliners operating within the 200-mile zone of American Samoa were summarised by Klawe (1978) and Skipjack Programme (1981a). There are now fewer longline vessels operating, and a large proportion of the tuna supplied to the canneries comes from United States purse-seiners operating in the central Pacific. The canneries possess large freezer facilities to cope with excess short-term supplies, particularly from super-seiners, which commonly may carry approximately 1,000 tonnes of fish. In 1978, each cannery was reported to have 3,000 tonnes of freezing capacity (Crossland & Grandperrin 1979). About 70,000 tonnes of tuna, with a landed value of around US$100 million was processed in 1980 (Simiki, Ratcliffe & Sorrensen 1981).

Other facilities of significance to the development of Pago Pago as a fleet centre include the marine railway and dry dock, built by the government in 1958, and the availability of fuel at prices significantly lower than elsewhere in the Pacific (Simiki et al. 1981).

The development of canning operations has limited the development of local fisheries (Wendler 1980). The availability of employment has led to a decline in traditional lifestyles, including involvement with fishing. As well, cheap fish became readily available, both through the domestic marketing of canned wahoo, and the development of a blackmarket in fish from vessels supplying the canneries (Simiki et al. 1981). The government's "Economic Development Plan for American Samoa : FY 1979-1984" (in Wendler 1980) recognised the need to re-establish locally based, small-scale commercial fisheries, as well as to promote industrial-scale operations in territorial waters.

1.2 Previous Research

Early investigations of fisheries in American Samoa by American authorities and by the South Pacific Commission (van Pel 1954) concluded that tuna was an abundant but underexploited resource. Preliminary data on abundance were obtained by the United States Bureau of Commercial Fisheries, which spent 26 hours sighting for tuna schools and bird flocks in the general area of the Samoa Islands between 1951 and 1960 (Waldron 1964). A visit by the United Nations Development Programme/Food and Agriculture Organization (UNDP/FAO) South Pacific Tuna Mission (Anon. 1969) concluded that Hawaiian techniques could be used to catch skipjack if adequate bait supplies could be caught. Subsequent surveys by the U.S. National Marine Fisheries Service (NMFS) in 1970, using the *Charles H. Gilbert* (Hida 1970) and in 1972 using the *Anela* (Uchida & Sumida 1973) failed to catch quantities of bait adequate to the needs of a pole-and-line operation. Using bait from Hawaii as well as locally captured wild bait, the *Charles H. Gilbert* survey tagged 840 skipjack and 91 yellowfin (Hida 1970), none of which has since been recovered (Shomura pers. comm.). The *Anela* also made good catches of tuna, mostly skipjack, taking an average of 4.0 tonnes per day, using bait transported from the Marshall Islands. Research by American Samoa government agencies between 1970 and 1975, using the Alofaga and a number of smaller vessels, obtained school sightings data and catches which further indicated that the tuna resource was large, but inadequate bait resources were again encountered (Swerdloff 1972; Sesepasara undated). The Alofaga cruises also indicated that the skipjack resource was relatively evenly dispersed around Tutuila Island, and that it peaked in abundance in the summer months.

Recognition of the inadequacy of the baitfish resource of American Samoa led to the establishment in 1973 of a project to culture mollies (also called top minnows), *Poecilia mexicana* and *P. vittata* (Baldwin 1977). Fishing trials were conducted in conjunction with the Pacific Tuna Development Foundation (PTDF) aboard the Alofaga in 1975 (Sesepasara undated) and aboard the J-Ann in 1978 (Vergne, Bryan & Broadhead 1978). The trials indicated that cultured mollies could be used successfully as bait, but that the culture techniques were not cost effective.

Other surveys of skipjack in American Samoan waters have been by surface-trolling by the PTDF in 1975, using the Alofaga (Anon. 1975) and by the NMFS in 1979 using the Townsend Cromwell (Anon. 1979). The French research organisation, Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), collected some data on tuna ecology and thermoclines during three cruises spent partly in American Samoan waters between 1970 and 1977 (Cremoux 1980), and conducted aerial spotting for tuna in an area northwest of Pago Pago in October 1979 (Marsac 1981).

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 (1982a). The 192-gross tonne Hatsutori Maru No.1 was used during the survey of American Samoa in May-June 1978, and the Hatsutori Maru No.5 of 254 gross tonnes was used during the second, in February 1980.

The Hatsutori Maru No.1 was operated with at least three Skipjack Programme scientists, nine Japanese officers and twelve Fijian crew. Up to three additional Fijian crew were employed on the Hatsutori Maru No.5. Names of all personnel and details of the times scientists and observers spent on board are given in Appendix A.

2.2 Baitfishing

Baitfishing was carried out at night using a "bouki-ami" net set around bait attraction lights. In some countries, beach-seining during daylight hours supplemented night catches, but it was not attempted in American Samoa. Night baiting procedures were similar to those used by commercial vessels, but were modified where necessary to meet the Programme's special requirements. Details of techniques and modifications employed are given in Hallier, Kearney & Gillett (1982).

2.3 Skipjack Fishing and Tagging

Both the vessels used by the Skipjack Programme were designed for commercial, live-bait pole-and-line fishing, and the basic strategy of spotting, 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.

The numbers of crew on the Hatsutori Maru No.1 and No.5 were fewer than either of these vessels carry under commercial fishing conditions. The effective number of fishermen was further reduced, because at least one crew member was required to assist each scientist in the tagging procedures. Furthermore, the need to pole skipjack accurately into the tagging cradles reduced the speed of the 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.

As tagging was the primary tuna research tool, attempts to tag large numbers of fish usually dominated the fishing strategy. The tagging technique and alterations to normal fishing procedures are described in detail in Kearney & Gillett (1982).

2.4 Biological Sampling

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 ratio, gonad weight, stage of sexual maturity, and a record of stomach contents. In addition, a record of all fish schools sighted throughout the survey was maintained. Where possible the species composition of each school was determined and 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 in dry ice for air freighting to the Australian National University, Canberra, Australia, where they were electrophoretically analysed (Richardson 1983).

After December 1979, skipjack body cavities were examined for the presence of macro-parasites. Five complete sets of gills and viscera from each school were frozen and subsequently shipped to the University of Queensland, St Lucia, Australia, for detailed examination.

2.5 Data Compilation and Analysis

Five separate logbook systems were used for compiling data accumulated during the fieldwork. The techniques used to enter data from these logs onto computer files and to process data are discussed in Kleiber & Maynard (1982). Data from blood samples and parasite identifications were also coded and entered onto 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 between fisheries for skipjack in American Samoa and those in other countries 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 (1981b) and Kleiber, Sibert & Hammond (ms.). Evaluation of the magnitude of the skipjack resource and its dynamics, based on tag recapture data, are described in Kleiber, Argue & Kearney (1983). Methods employed in studies of growth are described in 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 1981c) and analyses of the occurrence and distribution of skipjack parasites (Lester, Barnes & Habib ms.).

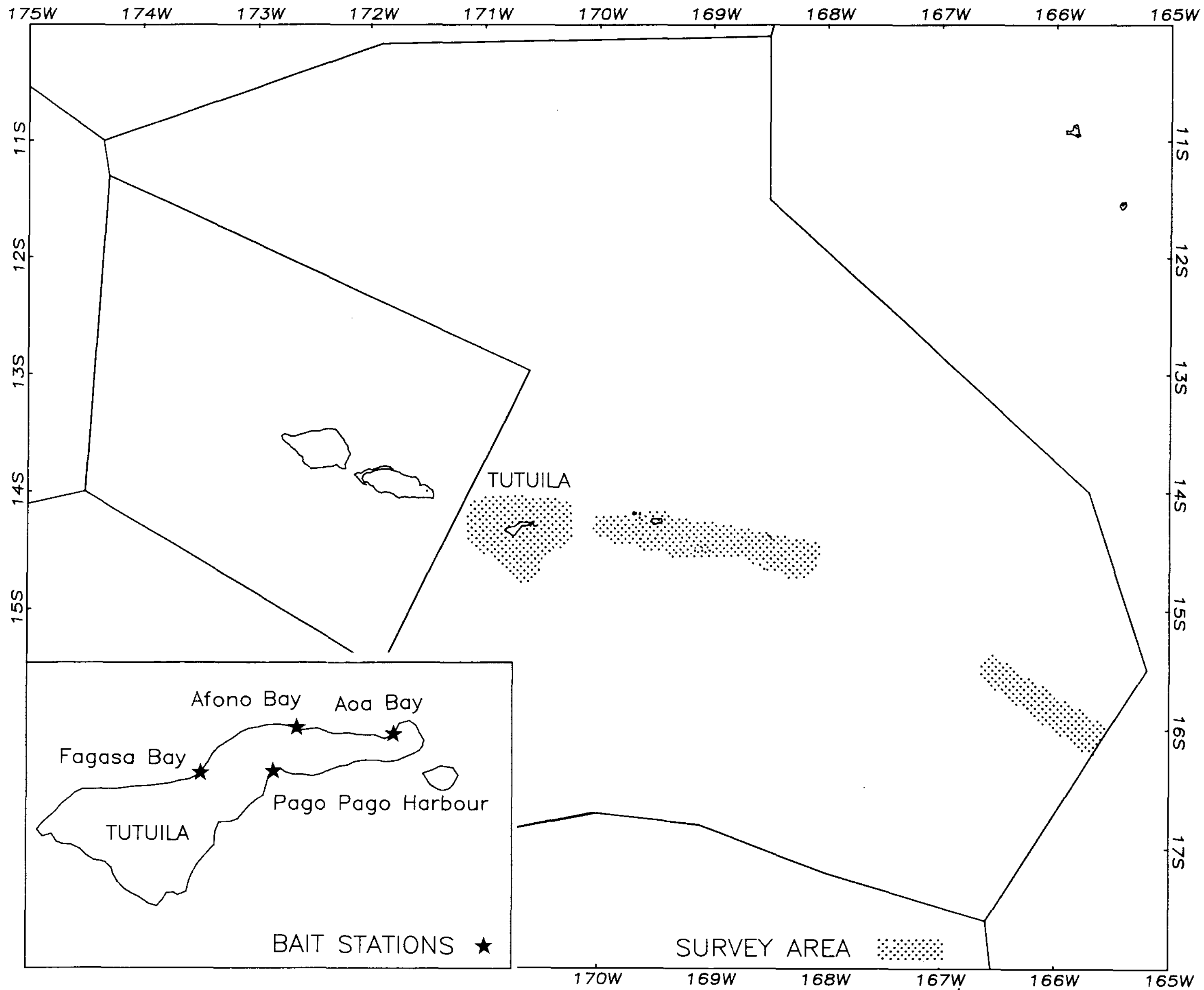
3.0 SUMMARY OF FIELD ACTIVITIES

Seven days were spent fishing, three days steaming and five days in port during the Skipjack Programme surveys of American Samoa (Table 1). Unloading 10 tonnes of skipjack accumulated in the ship's freezers and loading cultured baitfish necessitated the long period in port. Figure 1 shows the areas covered by the surveys, and the four localities at which baitfishing was conducted.

TABLE 1. SUMMARY OF DAILY FIELD ACTIVITIES BY THE SKIPJACK PROGRAMME IN THE WATERS OF AMERICAN SAMOA. Schools sighted are given 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. * Steaming through American Samoan waters in transit between Cook Islands and Western Samoa.

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)
01/06/78	Pago Pago	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
02/06/78	Pago Pago	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
03/06/78	N. Tutuila	Steaming	0	2	0	0	0	0	3	-	-	-	-	-	-
04/06/78	N. Tutuila	Steaming	0	7	3	0	0	0	10	0	0	0	20	0	20
05/06/78	Pago Pago	In Port	0	0	-	-	-	-	-	-	-	-	-	-	-
15/06/78	Pago Pago	In Port	155	0	-	-	-	-	-	-	-	-	-	-	-
16/06/78	Pago Pago	In Port	509	0	-	-	-	-	-	-	-	-	-	-	-
17/06/78	N. Tutuila	Fishing	509	9	2	1	0	1	5	0	0	0	2	6	10
18/06/78	N. Tutuila	Fishing	480	10	0	0	3	1	2	1	0	0	5	10	43
19/06/78	S. Tutuila	Fishing	459	10	3	0	0	3	2	73	0	0	303	0	311
20/06/78	S. Tutuila	Fishing	399	9	0	0	0	0	3	0	0	0	0	0	0
21/06/78	W. Tutuila	Fishing	519	5	1	0	0	0	3	0	0	0	0	0	0
20/02/80	E. Am. Samoa	Fishing	125	12	0	0	0	0	0	0	0	0	0	0	0
21/02/80	Manua Is.	Fishing	123	11	3	2	0	0	3	701	0	0	2381	0	2381
27/02/80	S. Am. Samoa	Steaming*	294	3	0	0	0	0	0	0	0	0	0	0	0
TOTALS	Days 15			78	12	3	3	5	31	775	0	0	2789	16	2765

FIGURE 1. AREAS SURVEYED FOR SKIPJACK AND LOCALITIES FISHED FOR BAIT BY THE SKIPJACK PROGRAMME IN THE WATERS OF AMERICAN SAMOA



On fishing days, an average of 9.4 hours were spent searching and fishing. Fifty-four schools were sighted, at an average rate of 0.72 schools per hour. Approximately three tonnes of tuna (98% skipjack) were caught, and 775 fish, all skipjack, were tagged (Table 1). The results of baitfishing activities carried out on four nights are summarised in Tables 2 and 3. Five hauls were made at four different locations around Tutuila Island in June 1978.

TABLE 2. SUMMARY OF BAITFISHING EFFORT AND CATCH BY THE SKIPJACK PROGRAMME IN THE WATERS OF AMERICAN SAMOA

Anchorage	Time	Number of Hauls	Dominant Species*	Est. Av. Catch per Haul (kg)	Mean Length (mm)	Other Common Species
Afono Bay 14°15′S 170°39′W	Night	1	No Catch			
Fagasa Bay 14°16′S 170°43′W	Night	1	Atherinomorus lacunosa*	1	100	Spratelloides delicatulus
			Bregmaceros sp.		24	Parapriacanthus sp.
			Spratelloides gracilis		34	Sp. of Acanthuridae
Aoa Bay 14°15′S 170°35′W	Night	1	Spratelloides gracilis	20	37	
			Fistularia sp.			
Pago Pago Bay 14°16′S 170°41′W	Night	2	Stolephorus devisi	78	53	Rastrelliger kanagurta
			Sp. of Carangidae			Archamia lineolata
			Gazza minuta			Stolephorus indicus

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

Explanatory Notes

Anchorage	: Recorded positions are truncated to the nearest minute. For large bays there may be more than one position tabulated.
Time of Hauls	: Day hauls - 0600-1759 hrs inclusive Night hauls - 1800-0559 hrs inclusive
Number of Hauls	: Number of hauls at the anchorage position, either day or night as specified. A haul is defined as any time the net was placed in the water.
Species	: Those species that made up at least one per cent of the numbers caught from one or more bait hauls at a particular location.
Average Catch (species)	: Total catch includes bait loaded, bait discarded alive and bait discarded dead at the location. The average catch in kilograms per haul is the product of total catch in kilograms and weighted numerical percentage of the catch for a particular species, divided by the total number of hauls at the location. The weighted numerical percentage is the product of numerical percentage, a constant, and the cube of the species′ average standard length. (In the absence of a mean SL for the species, the numerical percentage itself is used.) The sum of the weighted percentages equals the sum of the total of the numerical percentages. In this way the smaller (numerically abundant) fish are suppressed in their contribution to the catch while the less common, larger fish are proportionally enhanced in their representation. Catches are expressed in kilograms for the dominant three species; thus, the sum of the average species catches will often be less than the average location catch.
Mean Length	: Weighted by numerical abundance when there were multiple hauls at the same location.

TABLE 3. CATCH AND FREQUENCY OF OCCURRENCE OF ALL TAXA (species of fish or higher taxa of fish or invertebrates) IN BOUKI-AMI HAULS MADE BY THE SKIPJACK PROGRAMME IN AMERICAN SAMOA. Juveniles are indicated by (j).

Species	Percent Occurrence	Catch (kg)
Stolephorus devisi	40	157
Spratelloides gracilis	60	21
Antherinomorus lacunosa*	20	1
Sp. of Synodontidae	40	0
Sp. of Mullidae	20	0
Sp. of Stolephorus (j)	20	0
Sp. of Anguillidae (j)	20	0
Sp. of Apogonidae	20	0
Leiognathus elongatus	20	0
Sp. of Lutjanidae	40	0
Sp. of Syngnathidae	20	0
Sp. of Pomacentridae	40	0
Spratelloides delicatulus	40	0
Sp. of Acanthuridae	40	0
Sp. of Gobioidei	20	0
Herklotsichthys quadrimaculatus*	20	0
Sp. of Chaetodontidae	20	0
Sp. of Balistidae	40	0
Sardinella sirm	20	0
Caranx sexfasciatus	20	0
Sp. of Sphyraenidae	20	0
Fistularia sp.	20	0
Sardinella melanura	20	0
Sp. of Holocentridae	20	0
Gazza minuta	40	0
Archamia lineolata	20	0
Rastrelliger kanagurta	20	0
Sp. of Carangidae	40	0
Stolephorus indicus	20	0
Sp. of Thaliacea	20	0
Sp. of Cephalopoda (Decapoda)	20	0
Stolephorus buccaneeri	20	0
Sp. of Myctophidae	20	0
Sp. of Cephalopoda (Octopoda)	20	0
Bregmaceros sp.	20	0
Parapriacanthus sp.	20	0
Sp. of Crustacea	20	0
Sp. of Crustacea	20	0
Total Catch		179

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

TABLE 4. NUMBERS OF FISH SAMPLED FOR BIOLOGICAL DATA BY THE SKIPJACK PROGRAMME IN AMERICAN SAMOA

Species	Number Measured	Number Weighed	Number Examined for Sex	Number Examined for Stomach Content	Number Examined for Tuna Juveniles	Number Sampled for Blood Analyses
Skipjack _Katsuwonus pelamis_	158	60	59	40	59	117
Yellowfin _Thunnus albacares_	5	5	5	5	5	0
Mackerel Tuna _Euthynnus affinis_	1	1	1	1	1	0
Rainbow Runner _Elagatis bipinnulatus_	16	16	16	11	11	0
Dolphinfish _Coryphaena hippurus_	2	2	2	2	2	2
Totals	182	84	83	59	78	119

A summary of numbers of fish sampled for biological data is given in Table 4. The length frequency distributions of tagged and sampled skipjack are shown in Figure 2. The fork length ranged from 39 to 64 cm; the small sample from June 1978 appeared to be bimodal, with peaks around 45 cm and 60 cm, whereas the large February 1980 sample was unimodal, with a mode and mean length of about 51 cm. The Skipjack Programme's overall sample averaged 50.4 cm. Maturity data are summarised in Figures 3 and 4, diet items in Table 5, and the incidence of tuna juveniles in the stomachs of sampled skipjack and other tuna species in Table 6. Blood samples were taken from 117 skipjack from a school east of Tutuila Island on 21 February 1980; results of blood genetics analyses are included in Figure 5 (Section 4.3.3). Two schools were sampled in February 1980 for examination for parasites (see Lester et al. ms.).

4.0 RESULTS AND DISCUSSION

4.1 Baitfishing

The Skipjack Programme made five bouki-ami hauls at four locations in American Samoa in June 1978 (Table 2). Strong east-southeast winds restricted the baitfish survey to the north Tutuila Island and Pago Pago Harbour. A total of 180 kg of baitfish was caught; 138 kg were loaded aboard the research vessel, while the remainder died during hauling and loading operations, and consequently was discarded.

The catch per haul was consistently low (Table 3), averaging only 36 kg. The average bait catch by the Skipjack Programme in tropical waters between 1979 and 1980 was 121 kg. Hauls at three localities in American Samoa yielded only 2 kg of bait, but two hauls made on the same night in Pago Pago Harbour produced 71 and 53 kg respectively. These catches, although small, were unexpected since conditions were thought to be unfavourable for baitfishing, with much bright light from dockside facilities.

FIGURE 2. LENGTH FREQUENCY DISTRIBUTIONS OF SKIPJACK TAGGED OR SAMPLED BY THE SKIPJACK PROGRAMME IN AMERICAN SAMOA

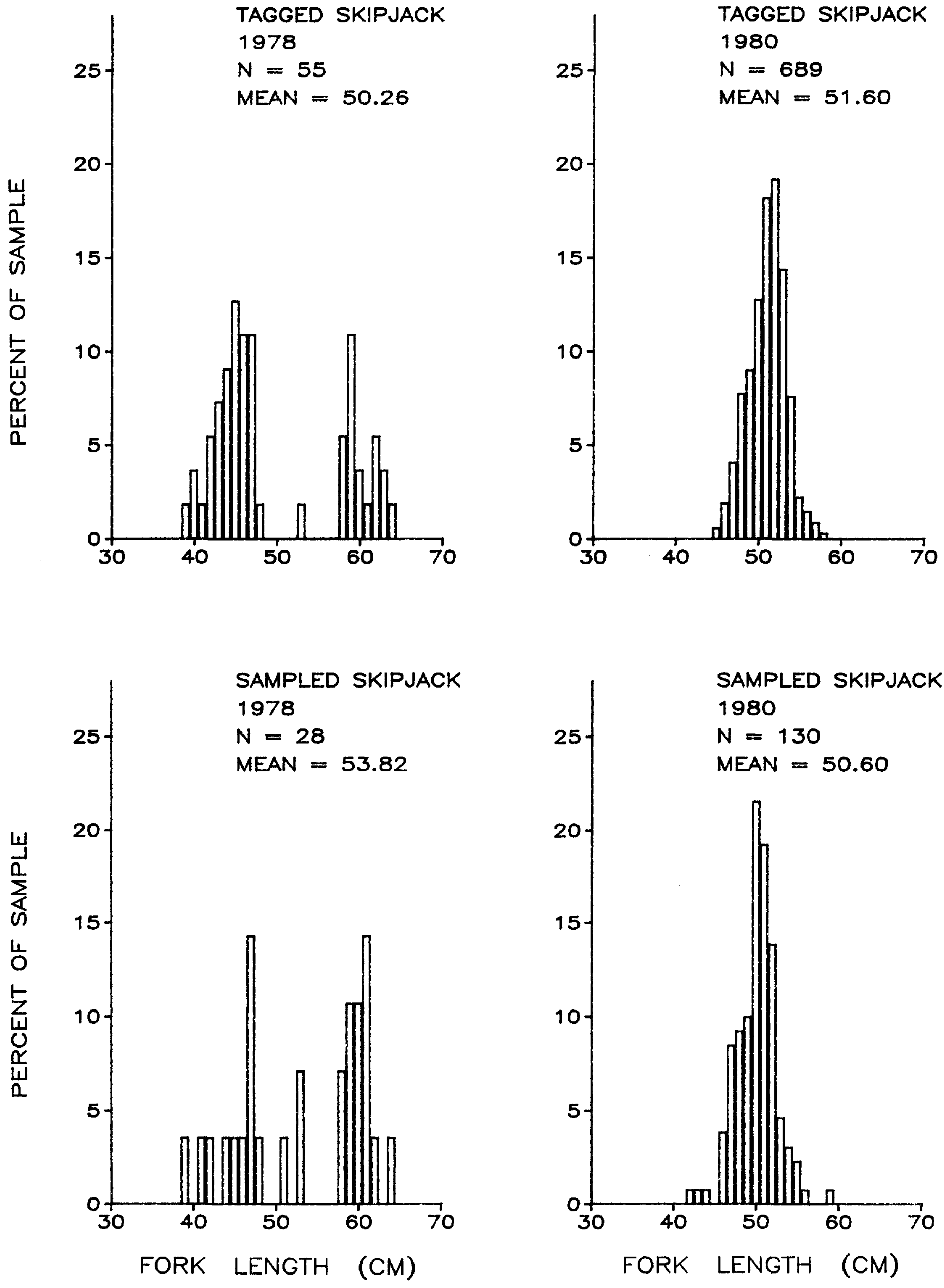


FIGURE 3. DISTRIBUTION OF FEMALE SKIPJACK BY MATURITY STAGE FOR SAMPLES FROM (a) AMERICAN SAMOA AND (b) FROM THE ENTIRE SKIPJACK PROGRAMME STUDY AREA

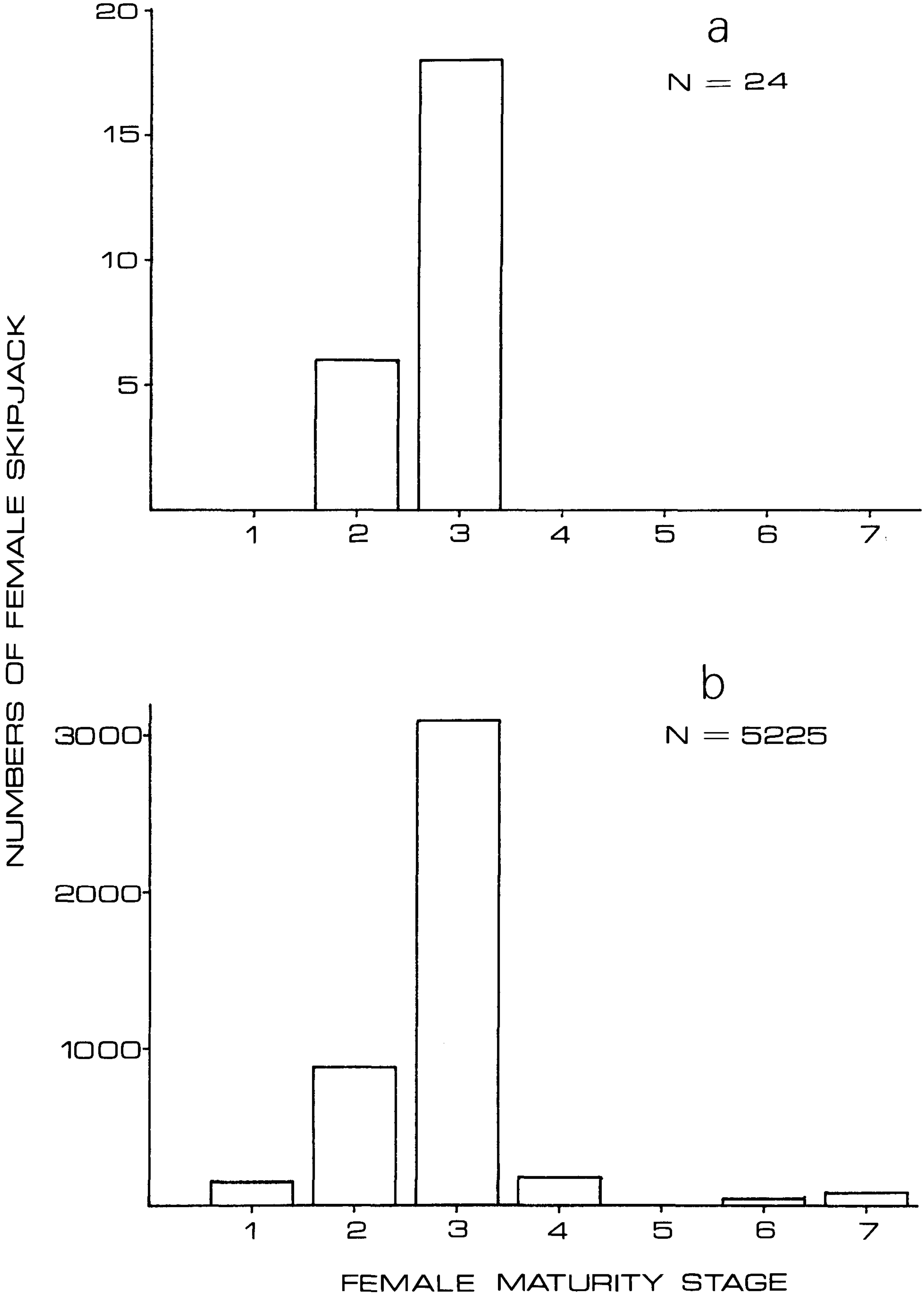


FIGURE 4. AVERAGE GONAD INDICES ($\pm$ two standard errors), BY MONTH, FOR FEMALE SKIPJACK SAMPLED BY THE SKIPJACK PROGRAMME FROM TROPICAL WATERS SOUTH OF THE EQUATOR. Standard errors omitted for one small (<5) sample (top graph, March); other sample sizes were at least 8 and most exceeded 100. No samples for August and September.

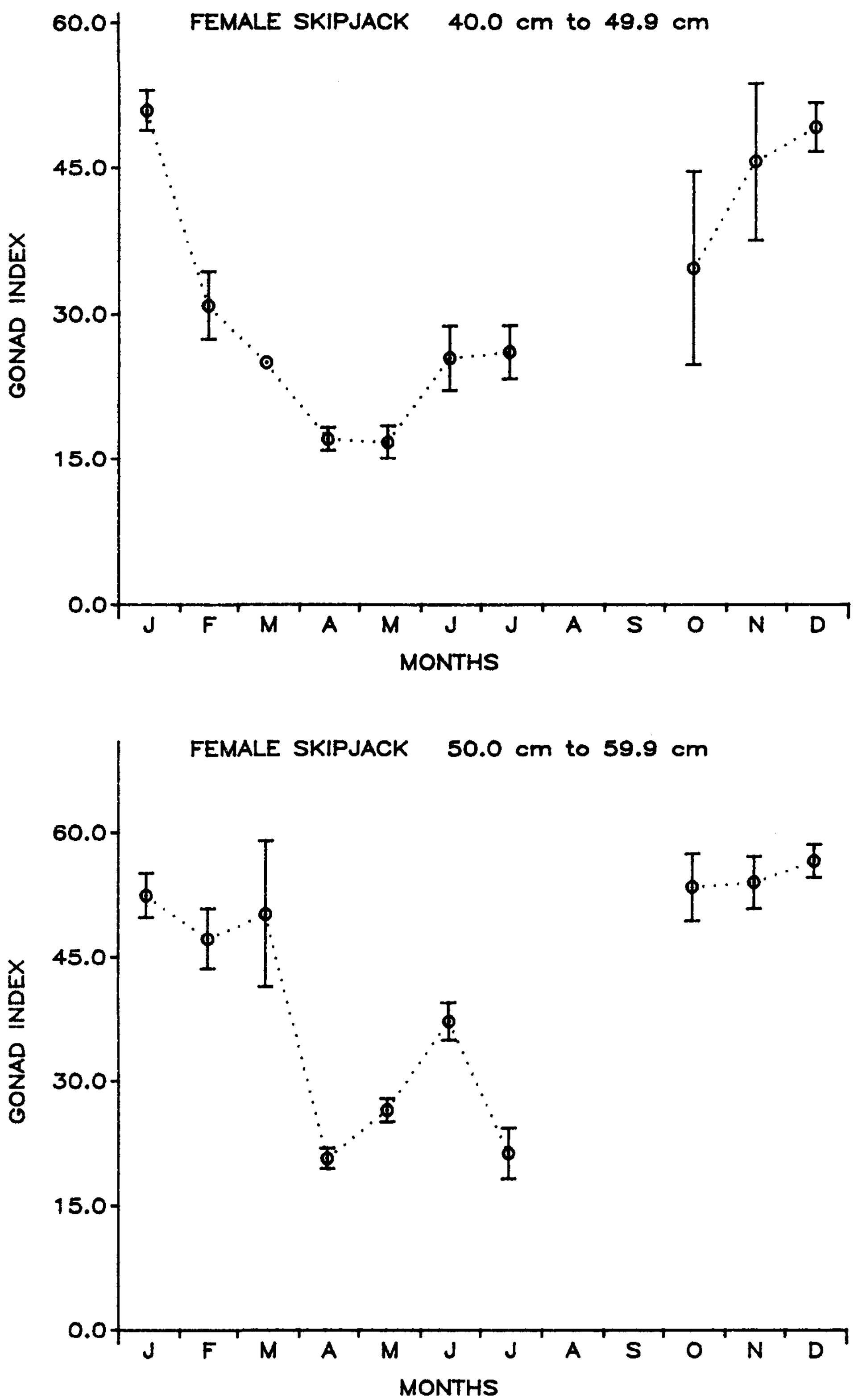


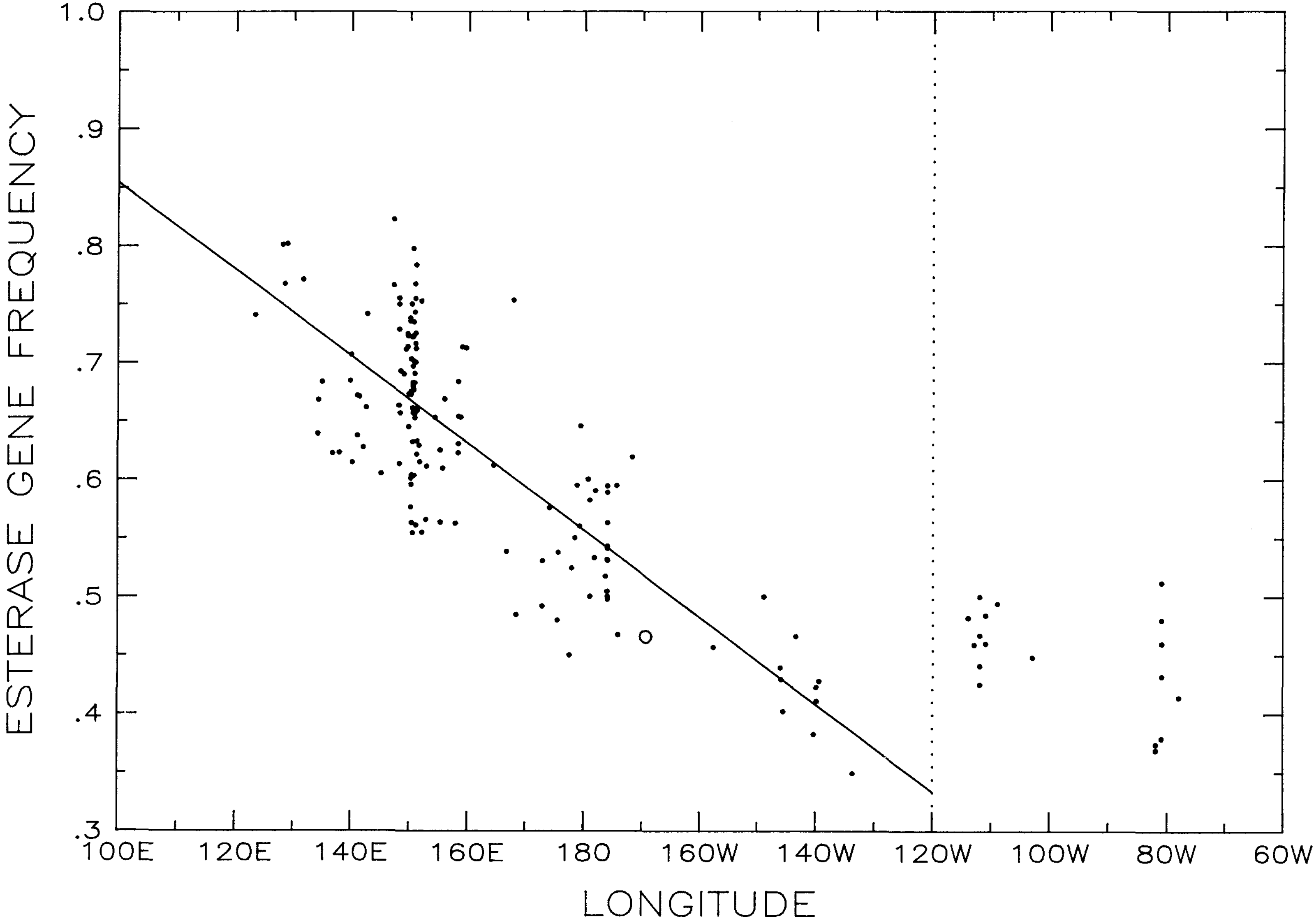
TABLE 5. ITEMS FOUND IN STOMACHS OF SKIPJACK SAMPLED IN AMERICAN SAMOA

Item No.	Diet Item	Number of Stomachs	Percentage Occurrence
1	Chum from _Hatsutori Maru_	29	72.50
2	Fish remains (not chum)	21	52.50
3	Acanthuridae	12	30.00
4	Holocentridae	6	15.00
5	Balistidae	5	12.50
6	Cephalopoda (squid)	4	10.00
7	Aluteridae	3	7.50
8	Unidentified fish	3	7.50
9	Empty stomach	2	5.00
10	Gempylidae	2	5.00
11	Scombridae (j)	2	5.00
12	_Xiphasia_ sp. (Xiphasiidae)	2	5.00
13	Decapoda (megalopa stage)	2	5.00
14	Stomatopoda	1	2.50
15	_Dactylopterus orientalis_ (Dacylopteridae)	1	2.50
16	Diodontidae	1	2.50
17	Cephalopoda (octopus)	1	2.50
18	Crustacea	1	2.50
19	Bramidae	1	2.50
20	Hemirhamphidae	1	2.50
21	Engraulidae (j)	1	2.50
	Total Stomachs Examined	40	

TABLE 6. INCIDENCE OF TUNA JUVENILES IN STOMACHS OF PREDATOR TUNA SAMPLED IN AMERICAN SAMOA

Predator	Predators Examined	Prey Species	No. of Prey	No. of Predators with Prey	Prey per 100 Predators	Percentage of Predators with Prey
Skipjack	59	Skipjack	4	2	6.78	3.39
Yellowfin	5	Skipjack	1	1	20.00	20.00
Rainbow Runner	11	-				
Mackerel Tuna	1	-				
Dolphinfish	2	-				
Totals	78		5			

FIGURE 5. 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 American Samoa sample is shown as a circle.



The bait catch from Pago Pago Harbour was dominated by one species of anchovy, Stolephorus devisi. Other hauls were dominated by the sprat Spratelloides gracilis. Both species are very effective as live bait for tuna (Argue et al. ms.). The relative abundances of baitfish species captured during all surveys undertaken by the Programme throughout the central and western Pacific are given in Skipjack Programme (1981d).

Published results of other baitfish surveys in American Samoa have been similarly low. In 1970 the Charles H. Gilbert caught only 280 kg of bait in eight sets of a lampara net in Pago Pago Harbour at night, and only 308 kg in 31 sets of a beach seine during daylight hours (Hida 1970). Catches were dominated by the mackerel, Rastrelliger kanagurta, the sardine Sardinella melanura and the herring Herklotsichthys punctatus (synonymous with H. quadrimaculatus; Wongratana 1983). The last two species are usually considered to be good live bait for tuna, but specimens of S. melanura were too big to be effective. Daytime visual surveys and night sets of bait attraction lights by the Anela in 1972 revealed insignificant quantities of bait in Pago Pago Harbour or around the coast of Tutuila (Uchida & Sumida 1973). During fishing trials by the research vessel Alofaga between 1972 and 1975, an average of less than 8 kg of bait was taken in several hundred sets of either a beach seine, a lift net or a "blanket net" (Sesepasara undated). The J-Ann crew were unable to capture significant quantities of live bait during surveys in 1978 (Vergne et al. 1978). The Townsend Cromwell made observations of bait around attraction lights at six stations during 1979, but reported only minor quantities (Anon. 1979).

The paucity of the baitfish resource can be largely attributed to the absence of suitable habitat. In general, baitfish require extensive shallow areas, usually within reef lagoons, adjacent to freshwater inflows which carry nutrients to support high local productivity. Exploitation of such a resource by bouki-ami techniques requires anchorages protected from the wind, with little current and between 25 and 40 metres depth to allow deployment of the net (Hallier et al. 1982). Few such areas exist in American Samoa except for Pago Pago Harbour, but it has not proved to be a good baiting ground. The poor results obtained by the Skipjack Programme and by previous surveys, which have tended to concentrate on what were thought to be the best available grounds, suggest that other areas are unlikely to contain extensive baitfish resources.

The culture of mollies (Poecilia mexicana and P. vittata) as an alternative source of bait was initiated in American Samoa in 1973 (Baldwin 1977; Pacific Tuna Development Foundation 1982). Preliminary fishing trials aboard the Alofaga (Sesepasara undated) led to an expansion of the project in 1977 (Pacific Tuna Development Foundation 1982), with major fishing trials conducted aboard the J-Ann in 1978. Almost 18 tonnes of tuna were caught, with an average tuna to bait ratio of 9.6:1 (Vergne et al. 1978); Pacific Tuna Development Foundation 1982). Similar results were reported by the Skipjack Programme (1980b, 1981e) during trials conducted at various times between June 1978 and February 1980. However, production costs are a major factor in the viability of a pole-and-line fishery relying on the culture of bait. Vergne et al. (1978) reported that bait costs were twice the value of the tuna catches, and that significant improvements in culture techniques were required to achieve cost effectiveness. Further discussion of economic aspects of baitfish culture to supply commercial-scale operations may be found in Kearney & Rivkin (1981).

4.2 Skipjack Fishing

A total of 2.8 tonnes of skipjack and yellowfin were captured in seven fishing days during the two Skipjack Programme surveys of American Samoa, an average catch of 0.4 tonnes per day. Using the conversion ratio of 3.47 (Section 2.3), the Skipjack Programme catches under commercial conditions would have been approximately 0.2 tonnes per day for the June 1978 survey and 4.0 tonnes in February 1980. The 1980 figure reflects very good fishing on one day (estimated commercial catch: 8.1 tonnes), using cultured milkfish (*Chanos chanos*) transported from Rangiroa, French Polynesia, as live bait. The result during the first survey might be attributed to the live-bait characteristics of mollies, which were used almost exclusively, but the tuna schools also responded poorly to wild bait at the time. The estimated average commercial catch during the entire period of the Skipjack Programme throughout the central and western Pacific was 3.5 tonnes per day. Fishing operations in American Samoa by the *Anela* in 1972, using bait transported from the Marshall Islands and Fiji, produced an average of 4 tonnes per day during 3 fishing days (Uchida & Sumida 1973). The Japanese pole-and-line fleet, using live bait transported from Japan, caught 7.4 tonnes of tuna per day during 9 boat days spent in American Samoan waters in 1975 and 1976 (Skipjack Programme 1980a).

Since the Programme's fishing success in American Samoa was strongly affected by the poor biting response of tuna schools chummed during June 1978, the rate of sighting tuna schools is probably more informative of the abundance of surface tuna than is catch rate. Fifty-four schools of tuna were sighted by the Skipjack Programme in the waters of American Samoa on both surveys. During the first survey 0.88 schools were sighted per hour, and during the second, the rate was 0.31 per hour. The figure for the first survey was slightly higher than the average sighting rate of 0.75/hour during the entire Skipjack Programme. Very high school sighting rates were recorded during the same periods in nearby waters of Western Samoa (Tuna Programme 1984). Most of the 23 schools identified to species contained skipjack (Table 1). Yellowfin occurred in six schools and there were occasional schools of other species, mainly rainbow runner (*Elagatis bipinnulatis*) and dolphinfish (*Coryphaena hippurus*). A large proportion (57%) of schools were not identified, and may have contained species less commercially valuable than skipjack or yellowfin.

During 26 hours of searching for tuna schools in the Samoa area in the 1950s and early 1960s, the U.S. Bureau of Commercial Fisheries spotted only one tuna school (Waldron 1964). From February to April 1970, the crew of the NMFS vessel *Charles H. Gilbert* observed 144 schools in the general area of Samoa in 31 days of spotting, an average rate of 4.6 schools per day. In 4 days in March and April of 1972 the crew of another NMFS vessel *Anela*, sighted an average of 6.2 schools per day. Surveys around Tutuila by the *Alofaga* and various smaller vessels between 1972 and 1978 (Swerdloff 1972; Sesepasara undated) produced similar school sighting rates. Most schools were of skipjack.

The Skipjack Programme surveys, and those by other agencies, demonstrate that surface tuna may be abundant in American Samoa. Differences between the Skipjack Programme results and those from previous surveys undoubtedly are due to differences between spotters, vessels and weather conditions as well as variations in the numbers of tuna schools. While tuna are present year-round, there appears to be a peak in skipjack abundance in summer (Swerdloff 1972; Sesepasara undated). Other areas at similar latitudes in the South Pacific, such as Fiji and French Polynesia, report abundance and catches peaking in summer (Kearney 1982b; Gillett & Kearney 1983).

4.3 Skipjack Biology

4.3.1 Diet

Table 5 lists 20 food items found in the 40 skipjack stomachs examined by the Skipjack Programme in American Samoa. The stomach contents were typical of those from skipjack from other tropical waters in the South Pacific Commission area. Apart from chum from the research vessel, unidentified fish remains and surgeonfish (Acanthuridae) were the most common food items, occurring in over 15 per cent of the stomachs examined. The results in Table 5 indicate the importance of fish to the diet, but also emphasise the opportunistic nature of skipjack feeding. Analyses based on contents of all skipjack stomachs sampled throughout the entire region are currently in progress.

4.3.2 Maturity and reproduction

Female gonad maturity stages for skipjack samples from both visits to American Samoa are shown in Figure 3. During the Skipjack Programme's work, seven stages of gonad maturity were recognised using criteria in Argue (1982), representing a progression in 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. On both visits to American Samoa, stage 3 gonads were predominant, with no mature fish. Notwithstanding the limited sample size, this distribution of maturity stages is similar to that found for 5,225 female skipjack examined by the Programme between 1977 and 1980 (Figure 3).

Seasonal changes in female gonad index[1] for all Skipjack Programme samples from tropical waters suggest that skipjack spawning is most intense south of the Equator between October and March (Figure 4). This trend is very similar to that presented by Naganuma (1979) for samples collected 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 sampled from American Samoa in June 1978 and February 1980 had mean gonad index values of 21.1 and 24.9 respectively. The former figure is similar to winter averages in Figure 4, but the latter value is considerably lower than average summer values. However, the February 1980 figure for American Samoa is based on a sample of only 11 skipjack, which renders close comparison unreliable. Evidence from the skipjack surveys of other countries at the same latitude as American Samoa, including Western Samoa, suggests that breeding is likely to occur in summer in American Samoa.

A further index of breeding is the incidence of skipjack juveniles in the stomachs of predators (Table 6). Only three of the 78 predators examined from American Samoa (two skipjack and one yellowfin) had skipjack juveniles in their stomachs. They contained five skipjack juveniles,

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

giving a frequency of 6.41 per 100 predator stomachs. This was among the lowest figures recorded during the entire Skipjack Programme, and may be compared to values of 25-50 juveniles per 100 predator stomachs found in Vanuatu, Wallis and Futuna or the Marquesas Islands (Argue et al. 1983). The frequency of juvenile skipjack in predator stomachs was also low (4.55) in adjacent waters of Western Samoa (Tuna Programme 1984). The overall average for the Programme was 10.8 in tropical waters. 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 skipjack 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. As virtually nothing is known about the movements of juvenile skipjack, the relative contributions of spawning in these areas or in local waters to recruitment in American Samoa cannot be established.

4.3.3 Blood genetics and 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 fisheries interactions.

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 5). The esterase gene frequency for the sample taken in the waters of American Samoa was 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, including those of American Samoa, and from subtropical and temperate waters of Norfolk Island and New Zealand. 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 improve definition of skipjack population structure, nor offer a means of clarifying fishery interactions.

After two workshops hosted by the Skipjack Programme 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, the genetics data supported the conclusions that there should be minimal short-term interactions between fisheries at the extremes of the Programme's study area, and that interaction should increase as the distance between fisheries decreases.

4.3.4 Growth

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 7 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. The effects of time-at-liberty can be seen by noting 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 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 much 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 little 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

TABLE 7. 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 B.

	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	.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).

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 8. 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.

TABLE 8. STANDARDISED INCREMENTS (cm) OF LENGTH 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. Country abbreviations are explained in Appendix B.

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

Only four of the skipjack released in American Samoa were recovered with reliable information on time-at-liberty and size-at-release and -recapture. Thus, there are insufficient data on which to make a general assessment of the growth of fish in American Samoan waters.

4.4 Tag Recapture Data

As of 10 October 1983, four recoveries of the 775 tagged skipjack (1.2%) released in the waters of American Samoa had been notified to the Skipjack Programme. Three were recovered locally, that is, in American Samoan waters, and one was recovered in Western Samoan waters. All of the local recoveries were by the Skipjack Programme research vessel on the same day they were released.

4.4.1 Skipjack migrations

The one skipjack which migrated to Western Samoan waters was recaptured after a period of 54 days at liberty, 120 nautical miles from its release point. There was also one record of a migration in the opposite direction: one skipjack released in Western Samoa was recaptured in American Samoa after 224 days at liberty, 76 nautical miles from its point of release. A migration of 2,561 nautical miles was made by a skipjack tagged in New South Wales (Australia) and recaptured in American Samoa by a Japanese pole-and-line vessel after 305 days at liberty.[2] Straight-line representations of these three international migrations into or out of American Samoan waters are shown in Figure 6.

The low number of recoveries in American Samoan waters of fish tagged either in American Samoa or elsewhere by the Skipjack Programme is undoubtedly a reflection of the low fishing effort in American Samoa. There is only a low level of local fishing for tuna (Crossland & Grandperrin 1979), while most industrial-scale operations at the time the tags were at liberty used longlining techniques (Section 1.1), to which surface-schooling skipjack are rarely vulnerable.

The capacity of skipjack to undertake long migrations is well known (Joseph, Klawe & Murphy 1980). The longest migration recorded by the Skipjack Programme was 3,740 nautical miles; many of the migrations over long distances are shown in Figure B (inside back cover), which presents a selection of Skipjack Programme tag returns from throughout the central and western Pacific. Returns were selected by plotting no more than one example of a migration in each direction between any pair of ten degree squares and no more than two examples of a migration wholly within any ten degree square. The impression from this figure is one of considerable mixing of skipjack, with little evidence of barriers to movement within the study area. The lack of apparent movement to the east, north and south beyond the area surveyed reflects poor chances for recovery as a result of low fishing effort, as well as the presence of unsuitable habitats at the latitudinal extremes (skipjack are seldom encountered polewards of 40 degrees latitude or in waters less than 16°C).

However, the impression of many wide-ranging international migrations gained from Figure B does not accurately reflect the average over all the tag recoveries. The figure overemphasises long distance, relatively rare migrations, due to the procedure used to select recoveries for the figure. The majority (86%) of tag recoveries were made less than 250 nautical miles from their release site and within 180 days of tagging (Figure 7). Long-distance migrations are prevalent only within the group of skipjack that were at large for more than 180 days.

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,

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2 Previous release-recapture summaries (e.g. Kleiber et al. 1983) included a tag released in Kiribati and recovered in American Samoa. The recovery position had been erroneously located; the tag was recovered in Western Samoan waters and is considered in that country's report (Tuna Programme 1984).

FIGURE 6. STRAIGHT-LINE REPRESENTATIONS OF MOVEMENTS OUT OF AMERICAN SAMOAN WATERS OF SKIPJACK TAGGED IN AMERICAN SAMOA, AND INTO AMERICAN SAMOAN WATERS OF SKIPJACK TAGGED ELSEWHERE BY THE SKIPJACK PROGRAMME. Tick marks on the arrows represent 30-day periods at large.

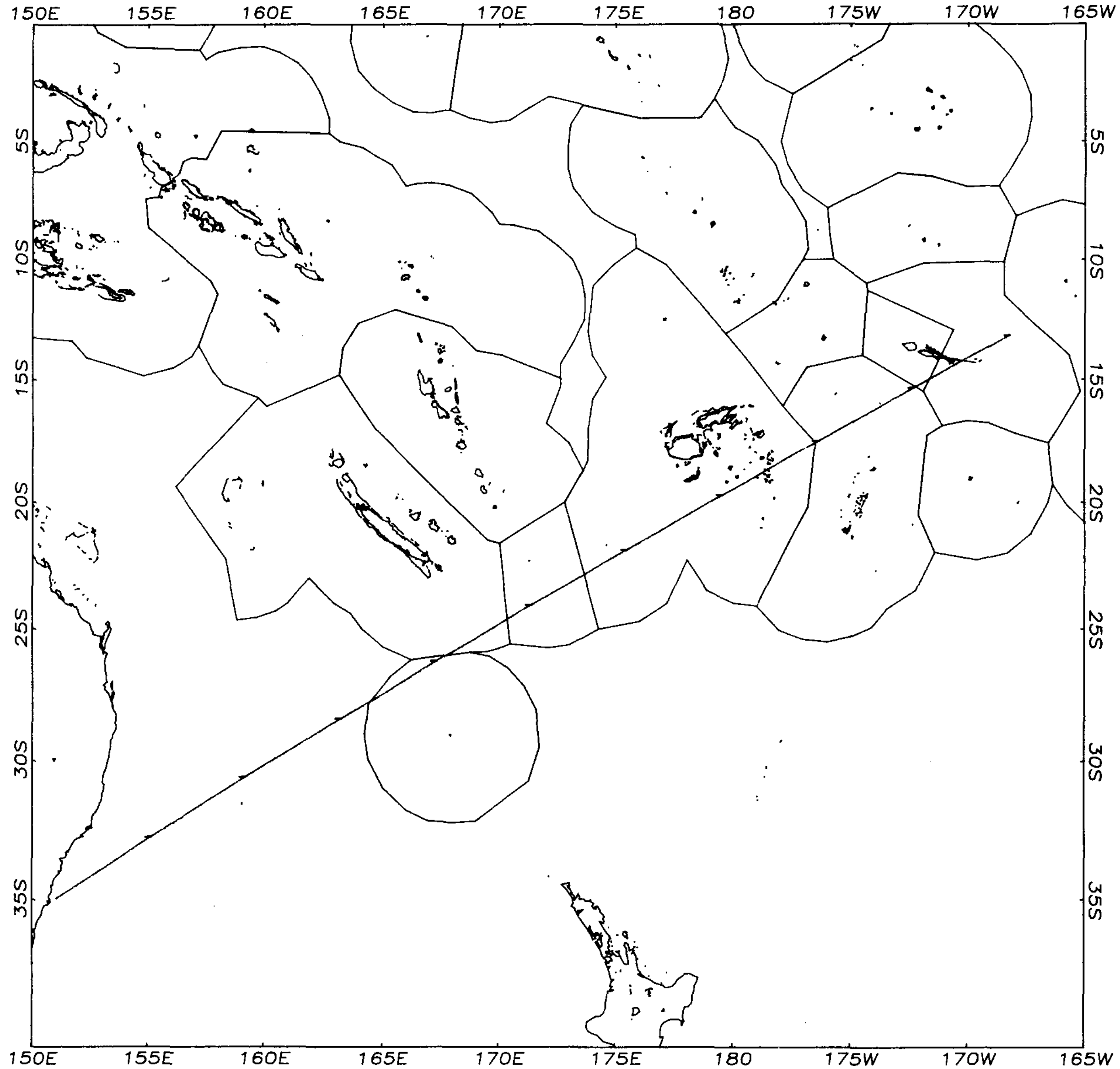
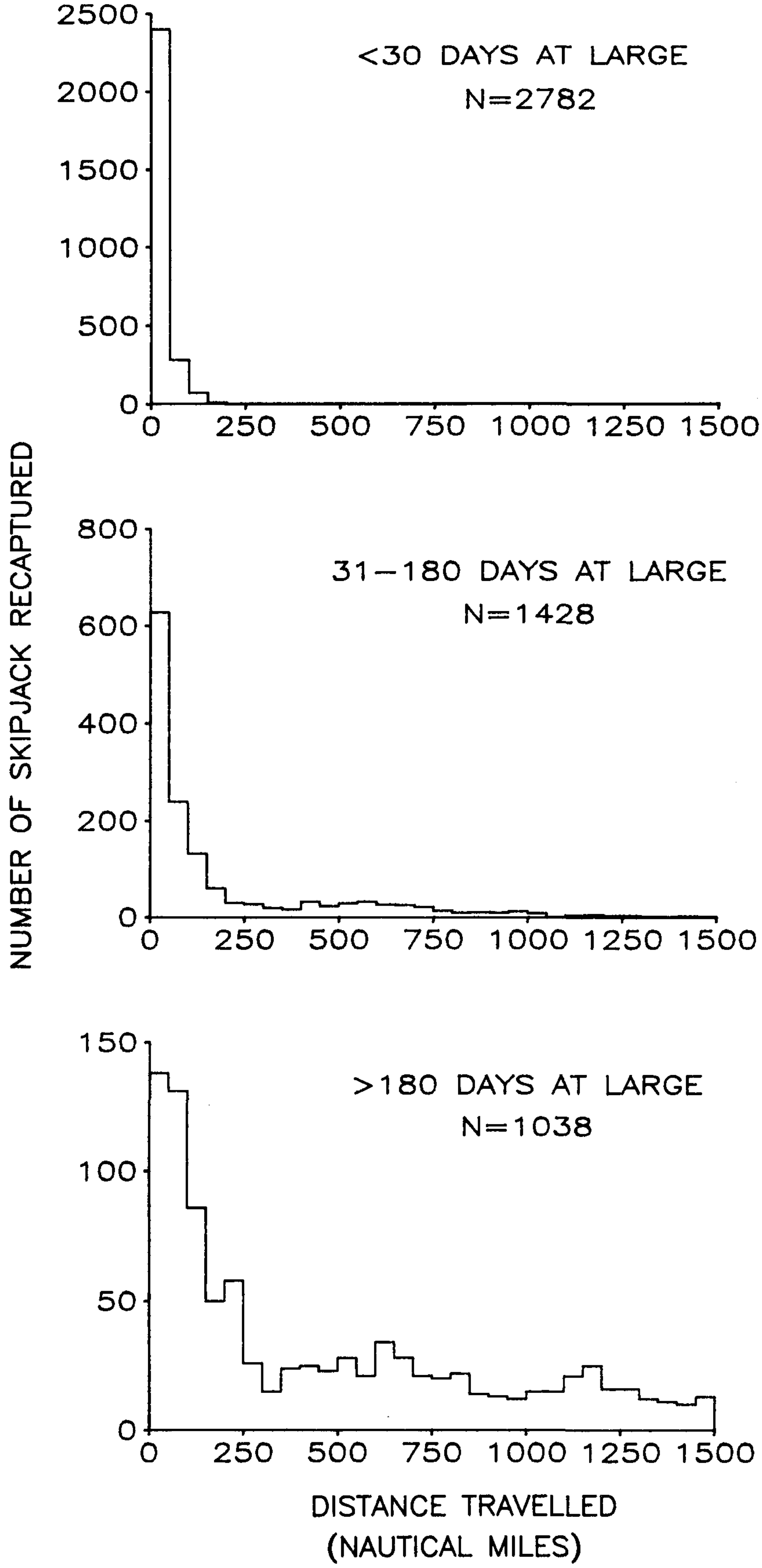


FIGURE 7. NUMBERS OF SKIPJACK TAG RECOVERIES, BY DISTANCE TRAVELLED AND TIME-AT-LARGE, FOR THE ENTIRE SKIPJACK PROGRAMME DATA SET. Data are for tag returns received by 10 October 1983. Recaptures for 103 fish which travelled more than 1,500 nautical miles are included in the same sizes, but are not shown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



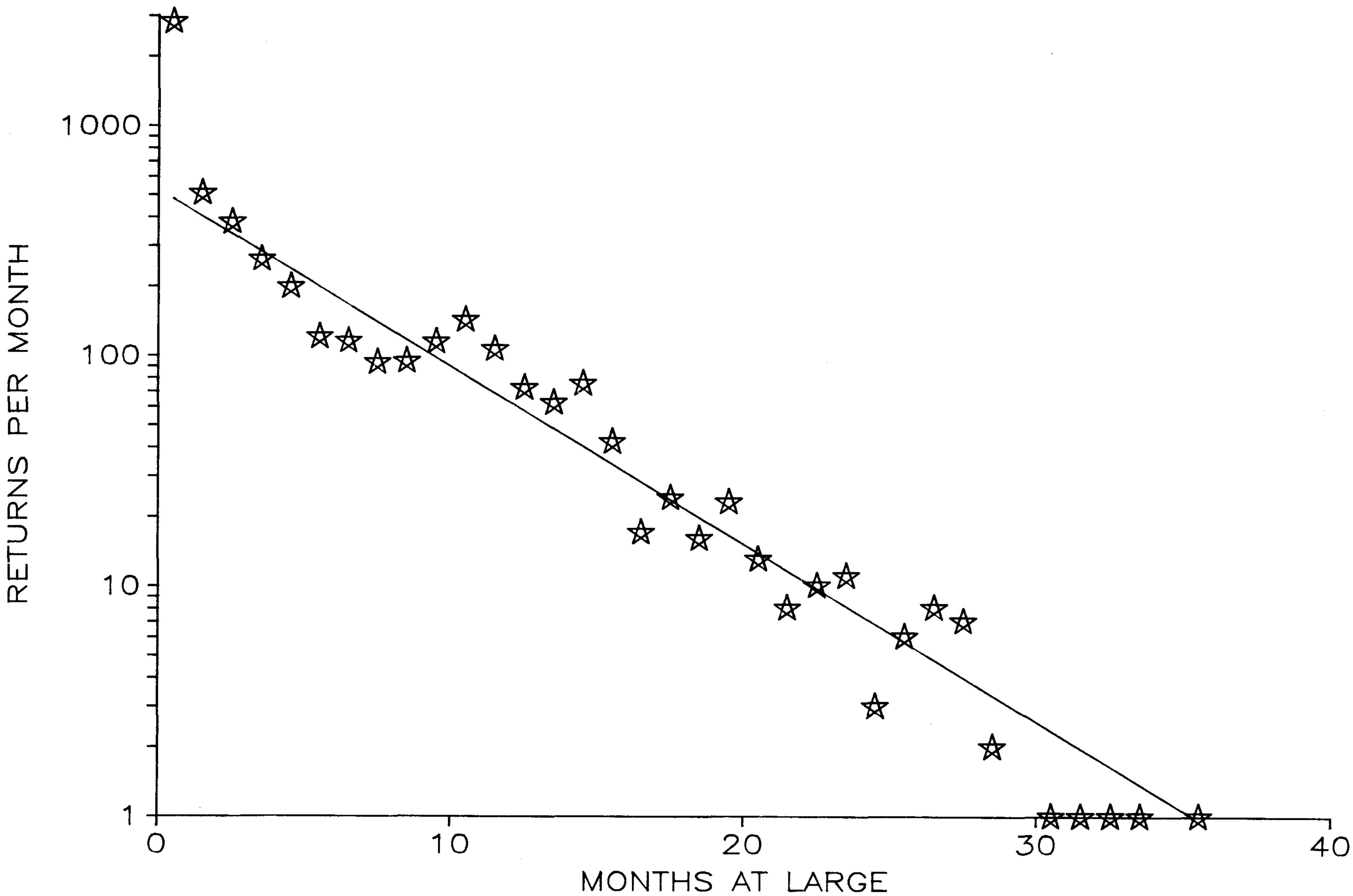
the Gilbert Group of Kiribati, Fiji, New Zealand, and the Society Islands of French Polynesia, for each of which there were sufficient tag recapture statistics, as well as data on either catch or effort by fishing fleets. The lack of local tag returns precludes an assessment of American Samoa's skipjack stock. Figure 8 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 8 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" which 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 (Kleiber et al. 1983). 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 8. NUMBERS OF SKIPJACK TAG RECOVERIES VERSUS MONTHS AT LARGE, FOR THE ENTIRE SKIPJACK PROGRAMME DATA SET. The Y axis has a logarithmic scale.



The resource of skipjack in the waters of American Samoa is obviously a small fraction of the total standing stock in the study area. Although the data for American Samoa are insufficient to estimate the size of the local skipjack resource quantitatively, because of the lack of tag returns from a well-documented, locally based fishery, it is likely that the catch of skipjack in the waters of American Samoa could increase greatly without significantly impairing recruitment. However, a large increase in skipjack fisheries in neighbouring countries could have a detrimental impact on the quantity of skipjack available in American Samoa (see Section 4.4.3).

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 1981b). The present coefficent is computed from the number of tag releases in the donor country and the number of recoveries of those tags in the receiver country, together with various parameters of the two stocks, estimated by the tag attrition model of Kleiber 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 9 summarises the recoveries from skipjack released 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

TABLE 9. SUMMARY OF SKIPJACK RELEASE AND RECOVERY DATA FOR THE ENTIRE SKIPJACK PROGRAMME, 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 B. 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
18065	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

the Programme for some 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 10. 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. Most of those omitted from the selection in Table 10 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 10. 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 (mostly >45 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.

5.0 CONCLUSIONS

Bouki-ami catches by the Skipjack Programme confirm that the live bait resources of American Samoa are small, and probably inadequate to support operations by pole-and-line vessels. Similar conclusions may be drawn from the results of previous baitfish surveys by other agencies.

Skipjack catches by the Skipjack Programme were low in American Samoa, perhaps because of a period of poor biting response by skipjack schools and lack of good quality bait. However, surface schooling tuna apparently are abundant in American Samoan waters. Both the school sighting rate and, occasionally, the catch rate during the Skipjack Programme surveys were comparable to results achieved by the Skipjack Programme in other areas presently supporting commercial tuna fisheries. The lack of local tag returns precluded an assessment of the size of the skipjack resource in American Samoan waters. However, extrapolating from analyses for the entire Skipjack Programme study area in the central and western Pacific, American Samoa's 200-mile zone is likely to support much larger catches than presently are being made.

TABLE 10. COEFFICIENTS OF INTERACTION BETWEEN FISHERIES OPERATING IN VARIOUS COUNTRIES AND TERRITORIES IN THE CENTRAL AND WESTERN PACIFIC (from Kleiber et al. ms.). The numerals following country codes indicate tag release data sets from separate visits to the same country. Abbreviations for countries and territories are explained in Appendix B.

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					

a Assuming $\beta_r=0.76$ and $T_d=7300$

b Assuming $\beta_r=0.76$

c Local pole-and-line fishery

d Japanese pole-and-line fishery

e Local purse-seine fishery

f Local artisanal and subsistence fishery

Techniques such as trolling and gill-netting around FADs, such as have been tested in Western Samoa, may be effective alternatives to live-bait pole-and-line operations for subsistence or small-scale, locally based commercial operations. Another technique which does not depend on live bait is purse-seining, which has become a very efficient method of harvesting tuna in the central and western Pacific in the last few years. The availability of relatively cheap fuel and the cannery and port facilities at Pago Pago would favour the exploitation of American Samoan skipjack stocks by purse-seiners, whether locally or foreign based. However, purse-seiners would almost certainly need access to more than just the waters of American Samoa if they are to maintain economically viable year-round activities.

No estimates of interaction between skipjack stocks in American Samoan waters and those in other areas could be made, but tag recapture studies confirm that there is exchange with adjacent areas. Since interactions are likely to increase as catches increase and distance between fisheries decreases, future fisheries in American Samoa and adjacent regions should be monitored closely for evidence of interaction.

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

South Pacific Commission Scientists

A.W. Argue	20-21 February 1980
Charles Ellway	31 May, 1-5 and 14-21 June 1978
Jean-Pierre Hallier	31 May, 1-5 and 15-21 June 1978 20-21 February 1980
James Ianelli	20-21 February 1980
Desmond Whyman	31 May, 1-5 and 15-21 June 1978

Observers

Patrick Bryan Baitfish Project Manager Marine Resources Office Pago Pago	17-20 June 1978

Japanese Crew Cruise One	Japanese Crew Cruise Two
Masahiro Matsumoto, Captain	Mitsutoyo Kaneda, Captain
Ryoichi Eda	Kenji Arima
Sakae Hyuga	Seima Kobayashi
Yoshihiro Kondoh	Yoshihiro Kondoh
Yoshio Kozuka	Yoshikatzu Oikawa
Yoshikatsu Oikawa	Tsunetaka Ono
Akio Okumura	Yukio Sasaya
Kohji Wakasaki	Kohji Wakasaki
Mikio Yamashita	Mikio Yamashita

Fijian Crew Cruise One	Fijian Crew Cruise Two
Eroni Marawa	Ravaele Tikovakaca
Lui Andrews	Lui Andrews
Vonitiese Bainimoli	Samuela Delana
Mosese Cakau	Eroni Dolodai
Samuela Delana	Luke Kaidrokai
Lui Diva	Veremalua Kaliseiwaga
Kitione Koroi	Metuisela Koroi
Jone Manuku	Aminiasi Kurugawa
Jona Ravasakula	Kitione Naivaurerega
Ravaele Tikovakaca	Jona Ravasakula
Samuela Ue	Napolioni Ravitu
Taniela Verekila	Samuela Ue

APPENDIX B. 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