A PARAMETER FOR ESTIMATING POTENTIAL INTERACTION BETWEEN FISHERIES FOR SKIPJACK TUNA (*Katsuwonus pelamis*) IN THE WESTERN PACIFIC

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Tuna and Billfish Assessment Programme
Technical Report No.12

South Pacific Commission
Noumea, New Caledonia
November 1984

Original text: English

Prepared for publication at
South Pacific Commission headquarters, Noumea, New Caledonia
and printed at System Press Pty Ltd, Sydney, 1984

PREFACE

The Skipjack Survey and Assessment Programme, which commenced in August 1977 and concluded in September 1981, was an externally funded part of the work programme of the South Pacific Commission. The governments of Australia, France, Japan, New Zealand, United Kingdom and the United States of America provided funding for the Programme, which worked in the waters of all of the countries and territories within the area of the South Pacific Commission and in New Zealand and Australia.

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 is continuing under the Tuna Programme.

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 Assistant, Veronica van Kouwen; and Programme Secretary, Carol Moulin. Most staff were involved to some extent in the fieldwork from which this report resulted and/or in the analysis of the data and preparation of the manuscript.

Tuna Programme
South Pacific Commission

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1.0 INTRODUCTION

The annual catch of skipjack tuna (*Katsuwonus pelamis*) in the central and western Pacific Ocean has increased from approximately 5,000 tonnes in the early 1960s to over 300,000 tonnes in 1983. This spectacular growth has been characterised by continuous change in both the nature of the fishery and the distribution of effort (Kearney 1983a, 1983b). The most significant change has been the recent expansion of the purse-seine fleets of distant-water fishing nations (principally United States, Japan, Korea and Taiwan) to a level where they now account for the majority of the catch taken in the region (Tuna Programme unpublished data).

Prior to the Skipjack Survey and Assessment Programme of the South Pacific Commission, the potential for interaction between different fisheries was recognised (Anon. 1975). Although subsequent work indicated that the resource was much larger than had previously been anticipated, and that only a small fraction of it was harvested (Kleiber, Argue & Kearney 1983), it was emphasised that the uneven distribution of fishing effort, with areas of heavy, localised exploitation, could lead to significant interactions between fisheries. The potential for such interactions has been heightened by the rapid changes in the nature and intensity of the fisheries.

The principal research effort of the Skipjack Programme between 1977 and 1980 was the tagging of over 140,000 skipjack (Kearney & Gillett 1982). To mid-1983, over 6,000 tags had been recovered, indicating extensive movement by at least a portion of the population between many areas of the western Pacific (Kearney 1983c). These tag recapture data provide a basis for assessing exchange of fish between areas, and thus also the potential for interaction between fisheries.

2.0 MEASUREMENTS OF INTERACTION

2.1 Types of Interaction

Kearney (1983b) identified several types of interactions which resource managers may find it necessary to evaluate. Interactions may occur between various types of fisheries operating within the waters of single countries, such as large-scale commercial, artisanal and subsistence fisheries. There also may be interaction between gear types, of which an example is that between purse-seiners and longliners harvesting yellowfin. The type of interaction receiving most attention to date, however, is that between fisheries operating in different national jurisdictions based on the possibility that catch in one jurisdiction may affect the availability of fish in another. It is of this last type of interaction that the data presently available to the Tuna Programme provide some measure.

There are several ways to conceptualise interactions between fisheries, necessitating development of different analytical techniques or models to express the interactions. Tag recapture data, such as those generated by the Skipjack Programme, permit assessment of interactions occurring within a single generation. Within-generation assessments are the most appropriate for skipjack, since the absence of any relationship between catch per unit effort and effort (Joseph & Calkins 1969; Kearney 1979) implies that between-generation interactions are not significant, or are not detectable at current stock levels.

The method developed in this paper assesses interaction as a function of the throughput or the rate at which the stock in an area exploited by a fishery is renewed. A stock is defined here as the group of fish in a given area exploited by a given fishery. An index is derived to express interaction as the percentage of the throughput in a "receiver" stock which may be attributed to migration from a "donor" stock. Thus, interactions are essentially between stocks, and the index is only indirectly a measure of interaction between fisheries. However, for conciseness in discussion, interactions are referred to as "fishery interactions", since they may be considered to index the potential for interactions between the separate fisheries.

2.2 Derivation of a Coefficient of Interaction

The coefficient of interaction (I) expresses interaction as the arrival rate of skipjack from a donor country to a receiver country (biomass per unit time), divided by the throughput in the receiver country (also biomass per unit time). Thus, I is a measure of the proportion of total biomass inputs to the receiver country resulting from migration from the donor country. The coefficient has a directional component, in that the interaction may be different depending on the direction for which it is calculated.

The derivation commences with a known number of tags released (N_o) in the donor country. The number of tagged fish at large in the donor country (N_d), and therefore available to migrate to the receiver country, as a function of time (t) is given by

$$N_d = \alpha_d N_o \, e^{-A_d t} \qquad (1)$$

where α_d = proportion of fish surviving type I tag losses

A_d = instantaneous attrition rate in the donor country, due to all sources of loss from the stock.

Allowing M to be the proportion of fish at large in the donor country which migrate to the receiver country per unit time, the number of tagged fish doing so per unit time will be MN_d. If an attrition rate A_r applies to the stock in the receiver country, the rate of change in the number of fish tagged in the donor country, but at large in the receiver country (N_r), is given by

$$\frac{dN_r}{dt} = MN_d - A_r N_r$$

$$= \alpha_d M N_o \, e^{-A_d t} - A_r N_r \qquad (2)$$

which may be solved to give

$$N_r = \frac{\alpha_d M N_o}{A_r - A_d}\left(e^{-A_d t} - e^{-A_r t}\right) \tag{3}$$

The instantaneous rate at which tags from the fish represented by N_r are returned is represented by

$$\frac{dR}{dt} = \beta_r F_r N_r \tag{4}$$

where β_r is a factor which takes into account non-detection, non-return or inaccurate reporting of recovered tags, dR/dt is the rate at which tags are recovered in the receiver country, and F_r is instantaneous rate of fishing mortality, which may be estimated as

$$F_r = \frac{C_r}{P_r} \tag{5}$$

where C_r is the catch rate (biomass per unit time) in the receiver country and P_r is the standing stock in the receiver country. Substituting 3 and 5 into 4 and integrating over time from zero to infinity gives

$$R = \frac{\alpha_d \beta_r M N_o C_r}{A_r A_d P_r} \tag{6}$$

where R is the total number of tags recovered in the receiver country. Solving for M gives

$$M = \frac{R A_r A_d P_r}{\alpha_d \beta_r N_o C_r} \tag{7}$$

If P_d is the standing stock in the donor country, then the migration rate from donor to receiver is MP_d (biomass per unit time). It follows that the coefficient of interaction,

$$I_{d \to r} = \frac{MP_d}{T_r} \tag{8}$$

where T_r, the throughput of fish in the receiver country, is equal to

$$T_r = A_r P_r \tag{9}$$

After substitution and rearrangement,

$$I_{d \to r} = \frac{R A_d P_d}{\alpha_d \beta_r N_o C_r} \tag{10}$$

$$= \frac{R T_d}{\alpha_d \beta_r N_o C_r}$$

This equation may be evaluated using values of R and N_o recorded by the Skipjack Programme, known values of C_r from the catch statistics of the receiver country, and estimates of T_d from the tag returns to the donor country (Kleiber et al. 1983). Values of α_d and β_r are also required, but these are poorly known. The value of α_d is also used in estimating T_d, and if the same value is used the calculation of $I_{d \rightarrow r}$ is unaffected by inaccuracy in α_d. This result is found by defining T_d^* to be the estimate of T_d from the tag attrition model of Kleiber et al. with the assumption that both α_d and β_d are equal to one. To the extent that these parameters differ from unity, T_d^* is a biased estimator of T_d such that

$$T_d = \alpha_d \beta_d T_d^* \qquad (11)$$

which when substituted into 11 yields

$$I_{d \rightarrow r} = \left(\frac{\beta_d}{\beta_r}\right) \frac{RT_d^*}{N_o C_r} \qquad (12)$$

The coefficient of immigration is thus insensitive to α_d but depends on the ratio of the non-return coefficients in the donor and recipient countries.

3.0 RESULTS

Interaction can be assessed between those fisheries for which there was an exchange of tags, in at least one direction, and for which there are catch statistics. Table 1 is a matrix showing numbers of skipjack tagged by the Skipjack Programme in one country and recovered in the waters of another (R). Only tags released within, or recovered by vessels operating within, defined fisheries in each of the countries are included. Also shown in Table 1 are the relevant catch statistics spanning the period during which tags were recovered (C_r), numbers of tags released (N_o), turnover in the donor country (R_d), and β in the receiving country (r).

Table 2 is a matrix of interaction coefficients between fisheries estimated from the data in Table 1. Most coefficients are small, with over half of them less than 2 per cent, but they span a wide range, from less than 0.1 per cent for movement from Kiribati to Federated States of Micronesia to 37 per cent for movement from Federated States of Micronesia to Marshall Islands.

4.0 DISCUSSION

The proportion of throughput in a stock due to migrants from another area is a measure of importance of exchange of stock between the two areas. It is possible under certain conditions, such as high stock sizes and low fishing effort, that there would be little fishery interaction despite a high rate of exchange. Therefore, the statistic developed in this paper is effectively an index of the potential for fishery interaction.

Most coefficients calculated for fisheries in the central and western Pacific are low, indicating that under the conditions prevailing when these

TABLE 1. DATA USED IN CALCULATION OF INTERACTION COEFFICIENTS. Numbers in columns headed by country codes are numbers of tags caught in that country but released in the country indicated in first column of row. The number immediately following the slash in each column is the average catch during the period that tags were recovered. Abbreviations for countries and territories are explained in the Appendix.

Donor Country and Year	N_o	T_d	β_r	Number of Tags Recaptured/Average Catch by Receiver Country									
				PNG	SOL	PAL	FSM	MAS	MAR	FIJ	ZEA	WES	SOC
PNG 79	6009[a]	13000[a]	.79[a]	-	15/1917[b]	1/380[b]	10/2331[b]	2/1320[b]					
SOL 77	1709[a]	11000[a]	.71[a]	4/3340[b]	-								
SOL 80	2012[a]	13000[a]	.60[a]	9/2240[b]	-								
PAL 78	718[d]	14000[d]	.76[d]			-	7/2330[d]	1/1320[d]					
PAL 80	6515[d]	14000[d]	.76[d]	12/2220[d]	2/1830[d]	-	25/2220[d]	5/1230[d]	1/460[d]				
FSM	7647[d]	69000[d]	.76[d]	1/1800[d]	1/1760[d]		-	37/1320[d]	4/490[d]				
MAS	327[d]	47000[d]	.76[d]					-					
MAR	195[d]	18000[d]	.76[d]				3/2330[d]		-				
FIJ 78	7570[f]									-	3/748[e]		
FIJ 80	11646[a]	7300[a]	.89[a]							-			
ZEA	6298[a]	5000[a]	.41[a]							19/291[e]	-	2/62[e]	4/108[e]
KIR	4403[a]	380[a]	.91[a]				2/2230[d]	13/1320[d]					
WES					1/1748[c]							-	
SOC	896[a]	5700[a]	.91[a]										-

Data sources:

a Kleiber, Argue & Kearney (1983)

b Tuna Programme (1984)

c Argue & Kearney (1982)

d Tuna Programme (1984b)

e Argue & Kearney (1983)

f Kearney (1982)

TABLE 2. COEFFICIENTS OF INTERACTION BETWEEN FISHERIES OPERATING IN VARIOUS COUNTRIES AND TERRITORIES IN THE CENTRAL AND WESTERN PACIFIC. All values calculated assuming α_d=0.9. 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 the Appendix.

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 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 data were gathered, there was generally little potential for within-generation fishery interactions. Most cases of exchange greater than two per cent were between adjacent countries. Thus, there may be potential for fishery interaction between Papua New Guinea and Solomon Islands and between Federated States of Micronesia, Palau, Marshall Islands, and Northern Mariana Islands. The only case of a relatively high rate of exchange between widely separated areas is that due to migration from New Zealand to Fiji. This case may be an artifact of the timing of tag releases into the highly seasonal New Zealand fishery (Argue & Kearney 1983).

Because of the distribution of tag releases and fishing effort, the analyses presented here provide a measure of the interaction due to fish migrating from a part of a country's territory to a part of the territory of another country. Thus, they do not express the potential for interaction between the total resources of the two countries. Moreover, the immigration coefficients represent only a portion of the total skipjack population since they were calculated from the migrations of large individuals (usually 40 to 60 cm when tagged), the size vulnerable to pole-and-line gear.

The expansion of the purse-seine fleets in the years since 1978-1980 undoubtedly has increased levels of interaction between fisheries, particularly those operating in areas shown to have a high potential for interaction. Total skipjack catches are much higher and distance between fishing grounds has decreased substantially because areas of operation are no longer restricted by the proximity of baiting grounds.

There are several ways in which these estimates of interaction could be improved. Further tagging in the regions of intense purse-seine activity would provide information on current conditions in the fishery and enable calculation of interaction between several gear types. Development of models of tag attrition which implicitly include migration between fisheries would provide more direct measures of interaction (Sibert 1984).

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APPENDIX. 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