

# INFLUENCE OF PURSE-SEINE FISHERIES ON LONGLINE FISHERIES FOR YELLOWFIN TUNA (*THUNNUS ALBACARES*) IN THE WESTERN INDIAN OCEAN

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## INTRODUCTION

In 1982, France started a large-scale industrial purse-seine (PS) fishery in the western Indian Ocean. In 1983, Mauritius and Japan also started PS fisheries. During 1982-83, operations were more or less on a trial basis, and the total catch was about 4,500 t and 24,000 t, respectively, which was about 2% and 9% of the total tuna catch in the FAO's F51 area of the western Indian Ocean in (Figure 1). Due to the success of these trials, Spain, Ivory Coast, Panama and the United Kingdom started to join the PS fishing operations in 1984, as did other countries (Cayman Islands, Malta, USSR/Russia and Seychelles) in later years. Total catch increased significantly, to 103,000 t in 1984 (about 32% of the total tuna catch in the F51 area), and has been continuously increasing to 291,000 t in 1992 (about 40% in the F51 area). Among many PS fishing countries, France and Spain are the two most dominant, exploiting about 80% of all PS catches on average in the FAO F51 area in the 1984-1992 period). Average species compositions of PS catches in that period are skipjack 52%, yellowfin 43%, bigeye 4%, and other species 1%. Among these species, yellowfin tuna (YFT) is a highly

productive and commercially important resource and is commonly exploited by both PS and the Asian industrial longline fisheries (LL) of Korea, Japan and Taiwan in the common fishing grounds (Figure 2).

Hence, it is a matter of course that LL fishing nations started to be concerned about the possible impact of PS. It is also a matter of course that artisanal fisheries (AF) of developing nations (Maldives, Sri Lanka, Pakistan, and others in the western Indian Ocean) started to be worried about the possible impact of PS. Logically, there are six types of fisheries interactions:  $PS \leftrightarrow LL$ ,  $PS \leftrightarrow AF$  and  $AF \leftrightarrow LL$ . Among them, it has been reported that  $PS \Rightarrow LL$  is predicted as the most serious by simulation studies and review papers (see next section, **Review**). Hence, it is essential to investigate such interaction. In this paper, descriptive analyses based on the accumulated fisheries information are conducted for the investigation.

In conducting studies of fisheries interactions, the stock structure needs to be defined in advance for meaningful analyses. This paper assumes that the YFT stock structure is formed by two major stocks (west and east) and possibly two minor stocks (far west and far east (or Pacific) stock) as depicted in Figure 3 (upper).

This assumption is based on (a) past studies of stock structure by Hirano and Tagawa (1956), Kurogane and Hiyama (1958), Mimura (1958), Kurogane and Hiyama (1958), Kurogane (1960), Morita and Koto (1960) and Nishida (1992), and also (b) results of tagging experiments in the Indian Ocean by Yano (1991), Cayre and Ramcharrun (1990) and Waheed and Anderson (1993). This study concerns mainly the western YFT stock.

Figure 1. Area of competence of IPTP in terms of FAO statistical areas.

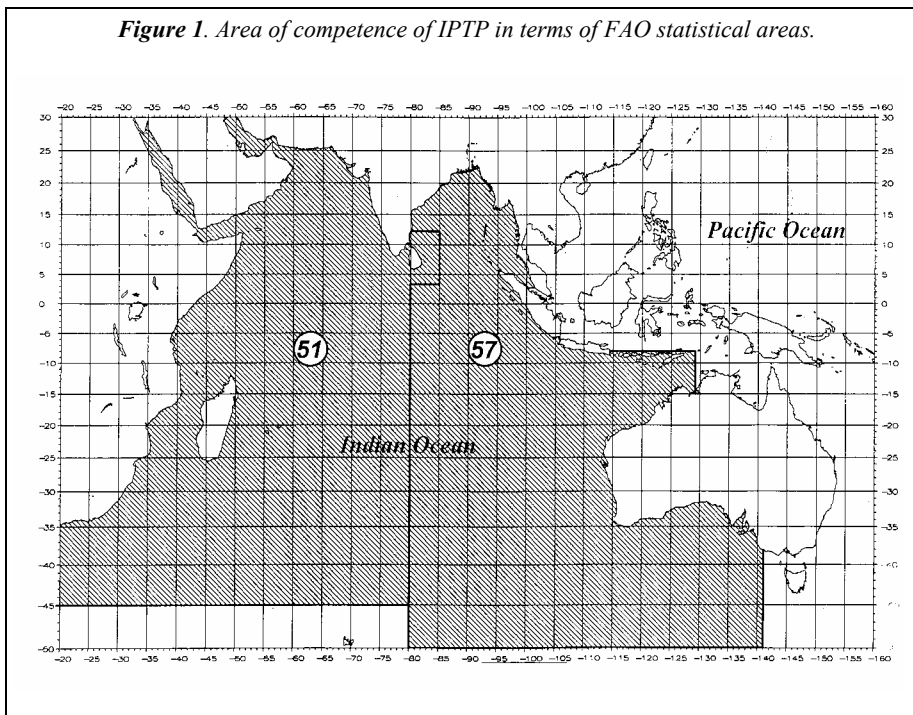


Table 1. Papers and reports on fisheries interactions for YFT in the Indian Ocean.

Type	Method	Author	Year	Conclusion
Quantitative analyses	Ricker type simulation model for Y/R	Marsac & Hallier	1987	Increasing PS catches generate a moderate negative effect on LL and no effect on AF.
	Ricker type simulation model for Y/R	Bertignac	1993	Reduction of PS fishing effort could result in 20-30% increase of LL catch. But, impact of PS on LL was not observed in reality. If fishing effort by PS(log) is reduced, PS(free), LL and AF catch could increase from 15-25%. Oman type fisheries impact PS and LL.
Quantitative analyses	Review	Marcille	1985	PS affects LL; LL catch could fall by 30-50% in next few years.
	Review	Suzuki	1987	Total YFT catch will be increased by the development of PS with reduction of LL catch.
	Analysis of CPUE/size	Nishida	1988	PS impacts LL within same fishing grounds. No conclusion on interactions between PS $\Rightarrow$ AF.

LL: longline fisheries; PS: purse-seine fisheries; AF: artisanal fisheries.

Table 2. Catch/effort and size data (by month and 5° x 5° area) used for the analyses.

Data type	Fishery	Country	Year	Unit	Source
Catch/Effort	LL	Korea	1975-87	number/hooks	IPTP
		Japan	1954-91	number/hooks	NRIFSF
	PS	Taiwan	1980-87	number/hooks	IPTP
		France	1982-91	t /boat-days	IPTP
Size(fork length)	LL	Spain	1984-90	t /boat-days	IPTP
		Japan(*)	1975-91	1cm/2cm class interval	NRIFSF
	PS	Taiwan	1985-88	2cm class interval	IPTP
		Spain	1984-90	2cm class interval	IPTP

\* Data based on month/1° x 1° area are also available and used.

Figure 4 shows the trend of YFT annual catch by three types of fisheries in the western Indian Ocean, based on statistics of the FAO F51 area (Nishida, 1993). According to Figure 4, YFT catch by PS is about 2-5 times the LL catch during the major PS operation period from 1984-91. LL catches in the western Indian Ocean are more or less constant, ranging from 17-38,000 t before and after the major PS started (1984-91).

Under the above situation, this paper attempts to investigate the possible impact of PS on LL for the western Indian Ocean YFT stock. First past research works on fisheries interactions are initially reviewed, then descriptive (spatial and temporal) analyses are attempted for basic fisheries statistics (catch, CPUE and size).

## REVIEW

Table 1 summarizes papers and reports relating to fisheries interactions for YFT in the Indian Ocean in the past, classified into two categories, quantitative and qualitative analyses. All the papers predict moderate impacts of PS on LL. Marsac and Hallier (1987) and Bertignac (1993) showed this by conducting the Ricker type of simulations. In their studies, Yields per Recruit (Y/R) were simulated as indices of the impact of one fishery on the other fishery by

changing fishing mortality (F). Both papers concluded that PS moderately impacted LL, but such an impact was not observed in reality. Review papers by Marcille (1986) and Suzuki (1987) also predicted effects of PS on LL by referring to similar cases in the Atlantic and the Pacific Oceans, respectively. Nishida (1988) found local impacts of PS on LL in the common fishing grounds of PS and LL and also found positive impact (*i.e.*, PS increases LL CPUE) in the surrounding waters of the affected areas. It is further commented that positive and negative impacts make the LL CPUE unchanged (constant) overall. However, in that paper data for only 4 years after PS started were used, thus the long-term effect needs to be re-investigated. Tsuji (1994) made similar comments about local impacts of PS on LL in the case of western Pacific YFT fisheries. Bertignac (1993) suggested developing a model with spatial structure for the interaction studies because his simulation work was not based upon the spatially aggregated model, which might mask the real situation. Taking these comments and suggestions into account, descriptive analyses for spatial and temporal changes in CPUE and size frequencies with updated information are conducted in this paper. It is hoped to be able to find out the reasons why the impacts of PS on LL predicted by the simulation studies are not seen in reality.

Table 3. Analyses conducted in this study.

Section (Indicator)	Analysis for	Time period analyzed(*)	Area analyzed	Purpose
3.1 CPUE	Comparison of spatial changes	Short period (4 yrs) before and after PS	Whole PS fishing ground	To investigate long term effect
		Long period (8 yrs) before and after PS		
3.2 Size frequency	Comparison of time series trend	Annual basis(1954-91)	Whole vs. heavy PS fishing ground	Whole vs. heavy PS fishing ground
		8 years before and after PS started		
3.3 LL(CPUE) vs. PS(catch)	Relationship	10 years after PS fishing started (1982-91)	Whole PS fishing ground	immediate effect

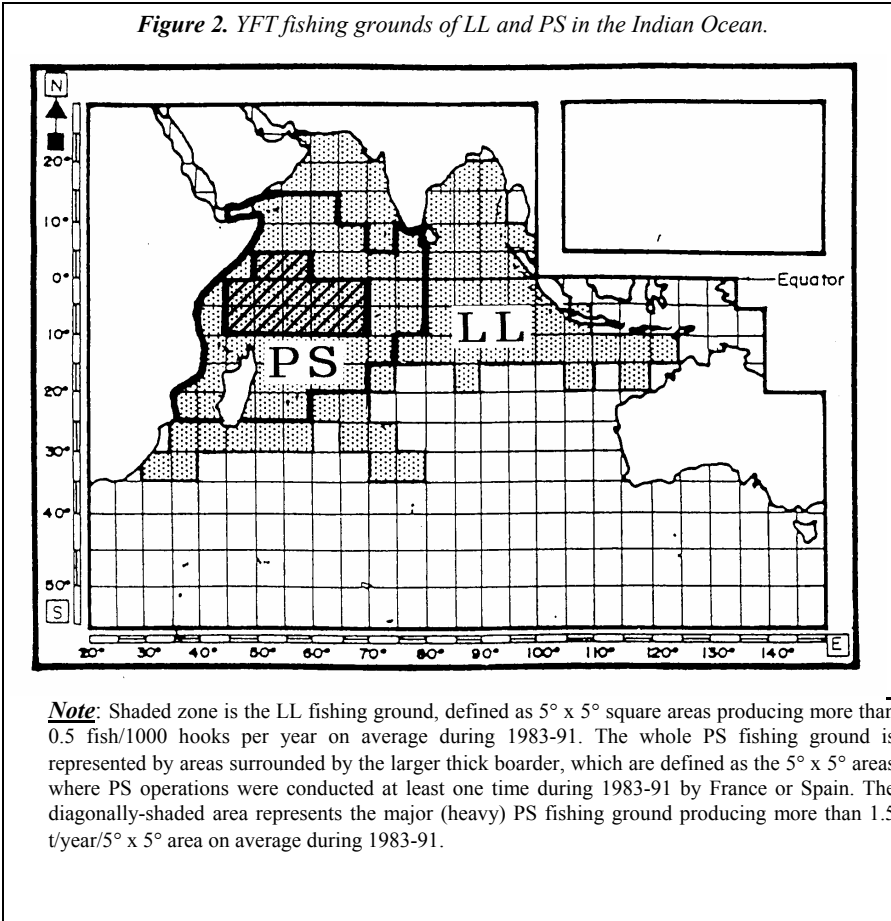
\* The starting year of PS fisheries is defined as 1983 in the analyses, although the actual year was 1982. This is because the total PS catch in 1982 was negligible (2% of the total tuna catch in the whole western Indian Ocean/FAO F51 area).

## DATA AND ANALYSES

With historical fisheries data (catch, effort and size) available at ITP and NRIFSF, spatial and temporal changes of LL CPUE and size frequency, distributions before and after PS started, are investigated in the PS fishing ground, in order to check the long-term effects. In addition, the relationships between LL (CPUE) and PS (Catch) are investigated, to check the immediate effects. Table 2 summarizes the information used in the analyses, and Table 3 summarizes the types of analyses to be

conducted in this study.

In this type of analysis, caution needs to be emphasized in interpreting the results, *i.e.*, decreases of LL CPUE or changes in size-frequency distributions do not simply imply impacts of PS on LL. This is because other different factors (environmental conditions, strong cohort, availability of fish, *etc.*) might be the major or partial causes of such decreases or changes. However, if consistent changes in different analyses or relatively stronger changes are observed in a particular area (*e.g.*, heavy PS fishing ground), it might be a possible real impact of PS on LL. With these cautions in mind, the analyses were carried out.



### CPUE:(long-term influence)

#### (1) Spatial analyses

To see the PS effects on LL globally, spatial analyses based on 5°x 5° area were conducted. These analyses are performed by comparing distribution maps of annual average CPUE (LL) in two periods (before and after PS started in 1983) and also by looking at distribution maps for differences in CPUE between these two periods. Figure 5 shows the short-term situation (4 years before and after PS), which is taken from Nishida (1988), while Figure 6 shows the long-term case (8 years before and after PS). Both short- and long-term situations show decreases of CPUE in a majority of the 5° squares in and around the heavy (major) PS fishing ground. On the other hand, increases of CPUE are observed in a majority of the 5° squares in the

Table 4. Sample size(n), its proportion (%), mean LL (CPUE) and range of LL (CPUE) for four clusters (A-D) of scatter plots by PS (catch) interval

	<i>Range of PS(catch)</i>	<i>n (%)</i>	<i>Mean LL(CPUE)</i>	<i>Range of LL(CPUE)</i>
A	0 <= PS(catch) < 1	911 (90%)	6.6 fish/1000hooks	0<=LL(CPUE)<=31.2
B	1 <= PS(catch) < 3	77 (8%)	5.8 "	0<=LL(CPUE)<=21.1
C	3 <= PS(catch) < 5	21 (2%)	4.4 "	0<=LL(CPUE)<=14.1
D	5 <= PS(catch)	5 ( 0%)	2.8 "	0<=LL(CPUE)<= 4.2
Total		1014 (100%)		

Table 5. Summary of LL (CPUE) analyses for annual trends

<i>Area analyzed</i>	<i>LL countries</i>	<i>B: Average LL (CPUE) Before PS (1975-82)</i>	<i>A: Average LL (CPUE) After PS (1983-91)</i>	<i>Rate of change (%) from B to A =(A-B)*100/B</i>
Whole PS fishing ground	Korea	8.2 fish/1000 hooks	7.5 fish/1000 hooks	9 %
	Japan	8.2	7.6	7 %
	Taiwan	2.8	3.0	7 %
Heavy PS fishing ground	Average of 3 countries	4.7	2.9	38 %

surrounding waters of the heavy PS fishing grounds.

### (2) Trend of annual CPUE (whole PS fishing ground)

Historical annual CPUE data for LL (Korea, Japan and Taiwan) in the PS fishing ground were compiled. Trends of these CPUE from 1954 to 1991 are depicted in Figure 7 (upper), while those for 1975-91 are magnified in Figure 7(lower). The whole PS fishing ground is defined as 5°x 5° areas where PS operations were conducted at least once during 1983-91 (Figure 2).

Based on Figure 7, average LL (CPUE) decreased drastically from a maximum of about 90 fish/1000 hooks in the mid 1950s to less than 10 after 1973, with a few exceptions. Based upon Figure 7 (lower), average CPUE trends in recent years (1975-91), before and after PS started, are almost constant at the low level, ranging from 3 to 9 fish/1000hooks, except in 1977-78. The patterns of CPUE trends for Korea, Japan and Taiwan are almost identical; however, CPUE values of Taiwan are lower than those of Korea and Japan. This is probably because Taiwan targets mainly albacore, hence its fishing efficiency is probably lower than those of the other two countries.

### (3) Annual CPUE trend (heavy PS fishing ground)

As observed in the spatial analyses, LL CPUE decreased in a majority of the 5° squares of the heavy PS fishing ground after PS started. In this connection, annual CPUE trends in the heavy PS fishing grounds are secondarily investigated. The heavy PS fishing ground is defined as the 5°x 5°-square areas from which the French and Spanish fleets together produced more than 4,500 t of YFT catch per year. Figure 8 shows the LL annual average CPUE trend

for Korea, Japan and Taiwan from 1955-91 (top), with the trend for 1975-1991 magnified (bottom). The general trend of the whole period is similar to the one for the whole PS fishing ground in Figure 8 (top). However, the time series in recent years in Figure 8 (bottom) indicates the moderate decreasing trend after PS started in 1983. The overall average CPUE before PS (1975-82) is 4.7 fish/1000 hooks, while the one after PS is 2.9, a 36% decrease on average after PS operations initiated.

### Size frequency distribution:(long-term influence)

CPUE analyses proved that there are almost no changes in LL CPUE in the whole PS fishing ground, while there are moderate decreases in the heavy PS fishing grounds. Similar analyses for size for both whole and heavy PS fishing grounds were conducted to discover fluctuations of size-frequency distributions before and after PS.

LL size data for Japan and Taiwan are combined and standardised into 2-cm class interval data by 5° x 5° area, then processed to create percent size-frequency distributions. In these analyses, data for 8 years before and after PS are used, pooled by period (1975-82 for before PS, and 1983-90 for after PS).

During processing of the Japanese size data, it was suspected that some of the measurements were originally by 5 cm or 10 cm class interval, even though they were classified as 1 cm or 2 cm intervals in the database. This was noticed because of sharp pulses in the size-frequency distributions when they are depicted. This is probably caused by the fact that some Japanese LL fishermen measured size data roughly, by 5 cm or 10cm interval, because it is an easy way to measure fish even in rough weather or under busy working conditions (Shiohama, NRIFSF, pers. comm.). This problem was eased by

smoothing frequencies with a moving average of five class intervals.

PS size data were processed in the same way as the LL size data, and will be used to compare with LL distributions. In the PS fisheries, larger YFT (80-160 cm) are caught mainly in free-swimming schools, while smaller YFT (20-80 cm) are mainly from log-associated schools. Hence, the same size of YFT (80-150 cm) are exploited by both PS (free-swimming schools) and LL, while PS (log schools) and LL rarely catch the same sizes of YFT.

Figure 9 (top) shows three different types of percent size-frequency distributions for PS and LL (before and after PS started) in the whole PS fishing ground, while Figure 9 (bottom) shows those in the heavy PS fishing ground. Sample sizes are adequate for all distributions except LL (before) in the heavy fishing ground, for which  $n = 306$ . In this case, the distribution is assumed to be similar to the real one. With this assumption, the results will be explained. The distributions of LL (before and after) in the whole PS fishing ground form similar shapes, while in the heavy PS fishing ground the distribution of LL (after PS) is located in a larger size than that of LL (before PS).

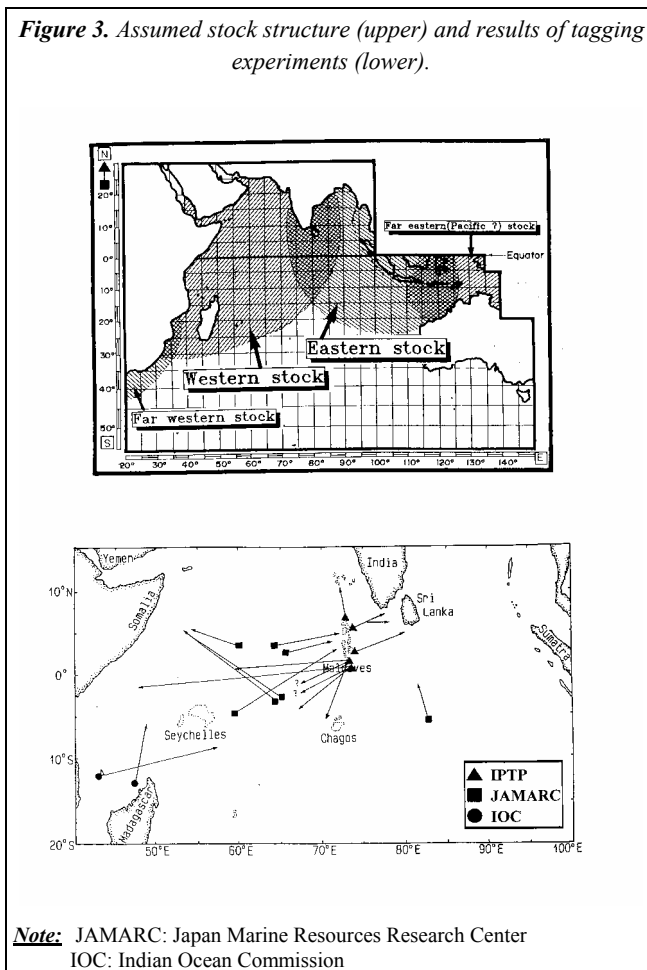
Hence, the difference in average sizes for LL between the two periods (before and after PS) in the heavy PS fishing ground are large (122 cm vs. 110 cm, respectively), while those in the whole PS fishing ground are small (116 cm vs. 120 cm). PS size-frequency distributions in the two PS fishing grounds form similar shapes, with two modes, the large mode located around 50 cm and the small one at 125 cm. The means are slightly different between two PS fishing grounds: 73 cm for the whole PS fishing ground and 80 cm for the heavy PS fishing ground.

### Relationship between LL (CPUE) and PS (catch): (immediate influence)

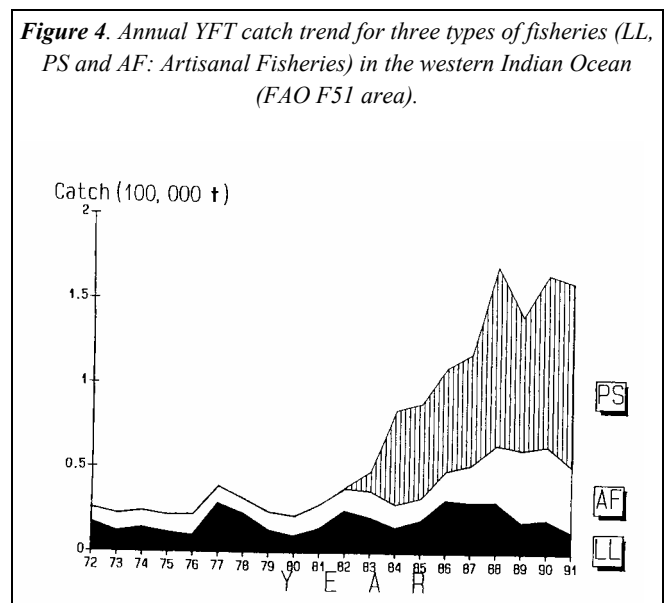
For the last analysis, a relationship between LL (CPUE) and PS (catch) is investigated. This analysis is conducted by plotting monthly and  $5^\circ \times 5^\circ$ -based LL CPUE (fish/1000 hooks) vs. PS catch (t). Pairs of the data are compiled from LL monthly average CPUE (Korea, Japan and Taiwan combined) and PS monthly catch in the whole PS fishing grounds (France and Spain combined) during 1982-91. Figure 10 (top) shows the original scatter plot. It clearly shows that all plots are located within the diagonal border drawn between the two outermost points. This implies that the relationship between LL (CPUE) and PS (catch) is inversely proportional.

Scatter plots are classified into four clusters by PS (Catch) ranges, as in Figure 9 (bottom). Table 4 summarizes various statistics according to the range of PS (catch). Cluster A, which includes 90% of the total points, dominates the relationship between LL (CPUE) vs. PS (catch), which implies almost no relationships within these ranges.

**Figure 3.** Assumed stock structure (upper) and results of tagging experiments (lower).



**Figure 4.** Annual YFT catch trend for three types of fisheries (LL, PS and AF: Artisanal Fisheries) in the western Indian Ocean (FAO F51 area).



## DISCUSSION

Crude descriptive analyses for spatial and temporal fluctuations of LL CPUE (all ages pooled) and size-frequency distributions in response to PS (catch) were conducted to examine the possible impact of PS on LL. In this type of analysis, careful interpretations for changes of CPUE and size frequencies are needed, because other

different factors (temporal-spatial specific environmental conditions, strong cohort, availability of fish, *etc.*) might be partial or major causes of such changes. However, if consistent changes in different types of analyses or relatively stronger changes are commonly observed in some particular area (*e.g.*, heavy PS fishing grounds), these are more likely to be evidence that PS influences LL. With these cautions in mind, discussion will follow.

It was discovered that the general trends of LL CPUE are more or less constant in the whole PS fishing ground before and after PS started, while those in the heavy PS fishing grounds show a moderate decrease. Table 5 summarizes the analyses of CPUE trends. It clearly demonstrates that there are relatively larger decreases in the heavy PS fishing ground than in the whole PS fishing ground.

These phenomena were also observed in the CPUE distribution maps: the CPUE of adult YFT in the majority of 5° x 5° areas indicate that decreases of CPUE occur in the heavy PS fishing grounds after PS started, while CPUEs in the majority of surrounding areas show increase trends. This makes the time series of CPUE trend constant in the whole PS fishing ground because the increased and decreased CPUEs cancel each other out.

Why the moderate decrease of LL (CPUE) in spite of the large PS catch?

This will be discussed for two cases: (a) the long-term situation and (b) the immediate situation:

### (a) Long-term situation

In the case of the long-term influence, the reason for the moderate decrease of LL (CPUE) of adult YFT instead of large PS (catch) might be the existence of a cryptic adult biomass, as defined by Fonteneau (1994). LL gear is deployed at a depth of 50-300m, depending on the target species. However, tuna move horizontally and vertically beyond this range; in fact, images of tuna have been found at even 500-2,000-m depths with echosounders (Yamada, 1990; Kawamura, 1994). Hence, LL cannot catch some of tuna located out of reach of the gear. Such resources are defined as cryptic biomass for LL fisheries.

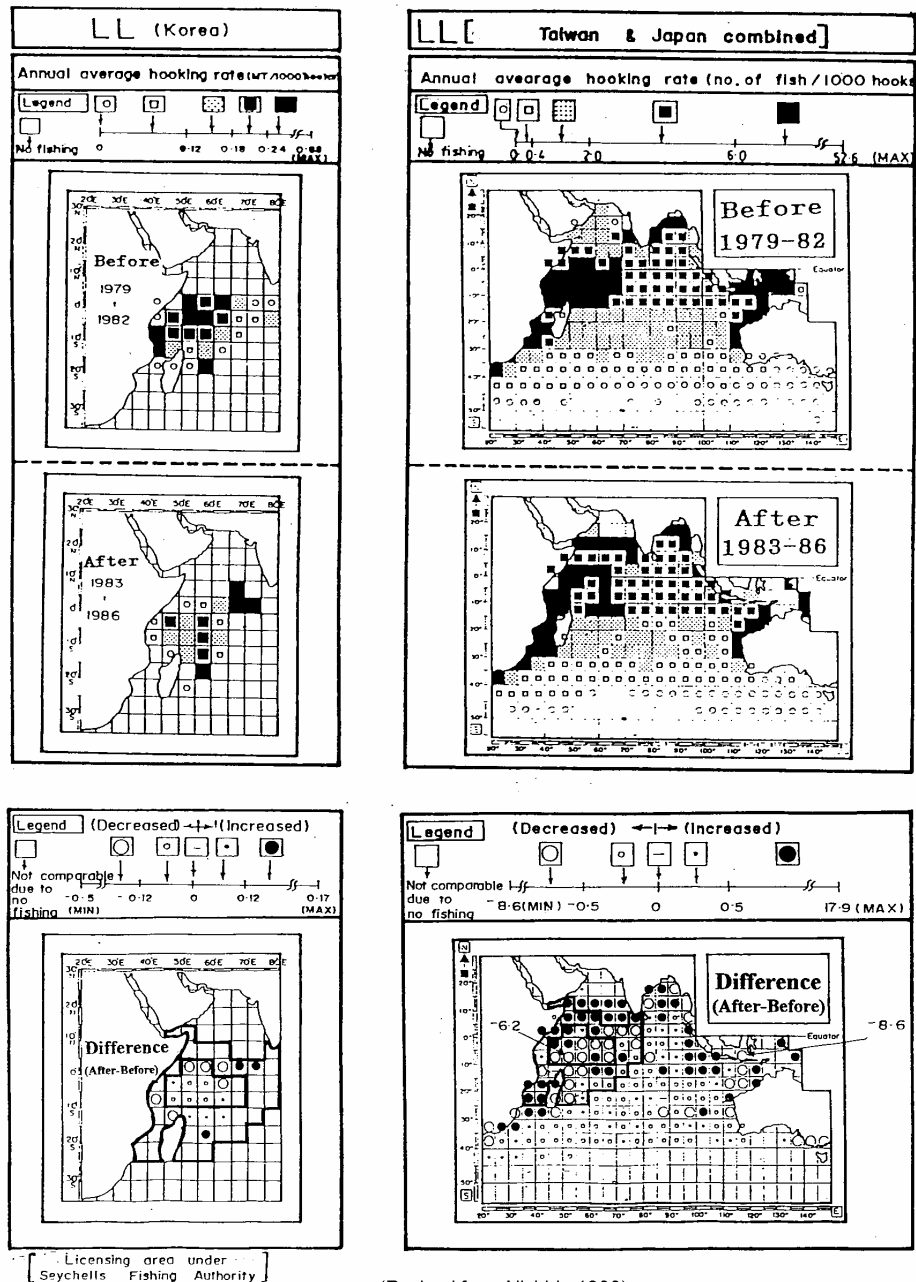
In considering the cryptic biomass, it is further assumed that recruitment to adult YFT will become a part of the cryptic biomass for LL fisheries. The proportion of the recruitment that becomes cryptic biomass depends upon the YFT abundance: when YFT abundance is low, a large part of the recruitment will become cryptic biomass, and vice versa. If this assumption is true, when the population level is not high, the cryptic biomass will be more dominant, hence LL (CPUE) will not reflect the real recruitment and abundance. Therefore, there will be a slight response of LL (CPUE) to recruitment and real population will become and LL (CPUE) will become more or less constant (Nishida, 1995). This is the reason why LL (CPUE) remains constant, even when there are large PS (catch) for a long period. On the other hand, when YFT abundance is high, the non-cryptic biomass will be dominant and LL (CPUE) will be roughly affected by the real (dominant non-cryptic) recruitment and population abundance.

In the western Indian Ocean, LL (CPUE) of adult YFT is currently at 20-25% of the level in the 1950s when LL started. Hence, at present, the adult YFT population is apparently at a low level because of the low LL (CPUE) values. However, the real population is probably much higher because of the influence of the cryptic biomass. This is again the major reason why LL (CPUE) is apparently not influenced by large PS (catch) when only LL (CPUE) values are looked at. Hence, in reality, LL is probably influenced as predicted by the simulation studies by Marsac and Hallier (1987) and Bertignac (1993).

### (b) Immediate situation

In the case of the immediate situation, the monthly and 5°x 5°-based relationships between LL (CPUE) and PS (catch) in Figure 10 provide interesting insights into the reasons for the moderate increase of LL (CPUE) in the heavy PS fishing grounds and no changes in the whole PS fishing ground. According to Figure 10 (bottom), each cluster has its own upper limit of LL (CPUE). About 90% of the total data points are in cluster A. Within this range, it is not clear if PS (catch) affects LL (CPUE) because of the wide range of LL (CPUE). On the other hand, in the other clusters (B-D) there are clear upper limits of LL (CPUE). Thus, it is obvious that PS (catch) affects LL (CPUE) when PS exploits large catches (more than 1 t/month/5°x 5° area). However, only 5% of the total data points are in these three clusters. Hence, it can be concluded that in general there is no serious immediate influence of PS (catch) on LL (CPUE) at the current catch levels, but if PS (catch) is large (more than 1 t/month/5°x 5° area), LL (CPUE) will be affected negatively according to the intensity of the PS (catch). This immediate effect is mainly caused by PS (catch from free schools) because the common size range of YFT (80-160 cm) are exploited by both PS (catch from free schools) and LL. However, the real influence is expected to be larger than the results

Figure 5. Short-term spatial fluctuations (4 years before and after PS) of LL CPUE of Korea (left) and Japan and Taiwan combined (right).

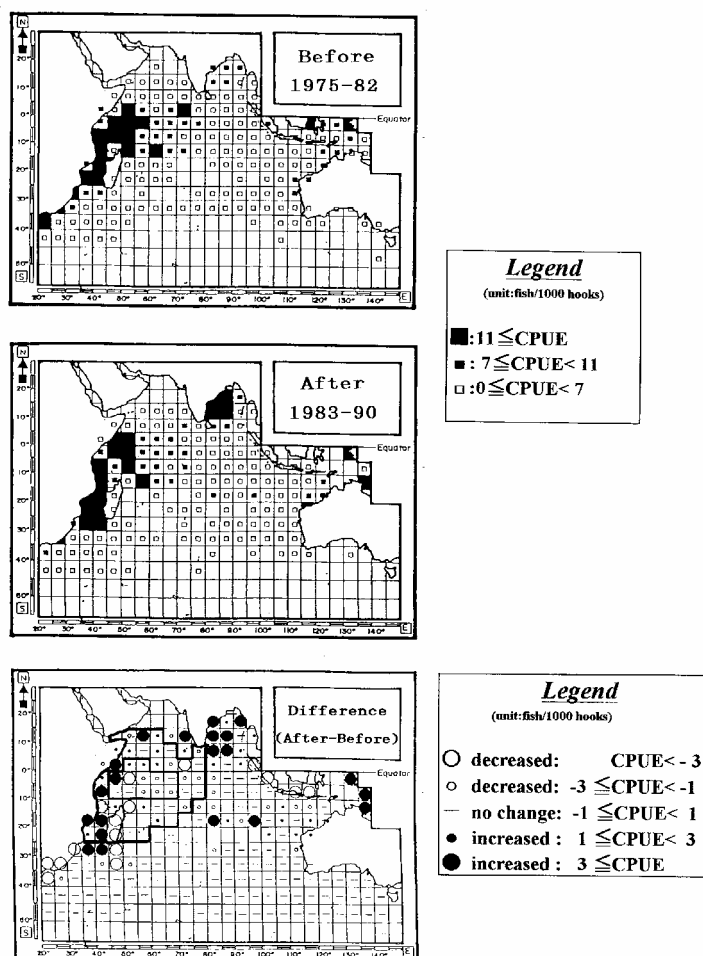


**Note:** Top 5° x 5°-basis maps show CPUE distributions before PS started in 1983, while the middle maps depict those after PS. The bottom maps represent differences of CPUE between these two periods. The outside border on the bottom map represents the whole PS fishing ground, while the inside one is for the major (heavy) PS fishing ground (see Figure 2).

obtained in this study because true LL (CPUE) values are possibly masked by the cryptic biomass, as discussed above.

#### FURTHER STUDY

**Figure 6.** Long-term spatial fluctuation (8 years before and after PS) of LL CPUE of Japan.



**Note:** Top 5° x 5°-basis map shows CPUE distributions before PS started in 1983, while the middle map depicts those after PS. The bottom map shows the differences of CPUE between these two periods. The outside border on the bottom map represents the whole PS fishing ground, while the inside one is for the major (heavy) PS fishing ground (see Figure 2).

The first priority is to investigate the cryptic biomass, using archival and/or sonic tags, to elucidate at what depth and for how long adult YFT move, and also to elucidate the proportion of the cryptic biomass to the real population. Then, it is necessary to estimate unbiased LL (CPUE) by adjusting the cryptic biomass, which is reflected in the real adult YFT population.

If unbiased (CPUE) is estimated, it will be necessary to cross-check the results of this study and the above-mentioned simulations by quantitative analyses in the future. The General Linear Model (GLM) analyses are effective for assessing the influence of the PS on LL quantitatively in the whole vs. heavy PS fishing ground,

including the environmental factors. This examination can be conducted with the following model:

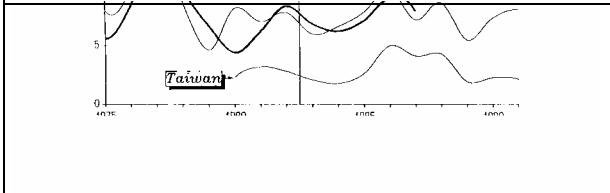
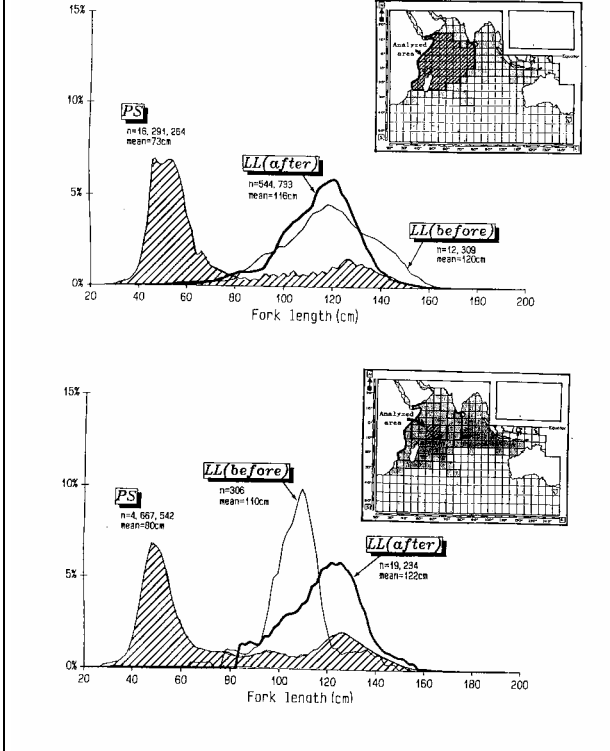
$$LL(CPUE) = \mu(\text{mean}) + \text{year} + \text{season} + \text{area} + \text{PS}(\text{catch}) + \text{environmental factors}$$

where the 'area' term includes the whole and the heavy PS fishing ground.

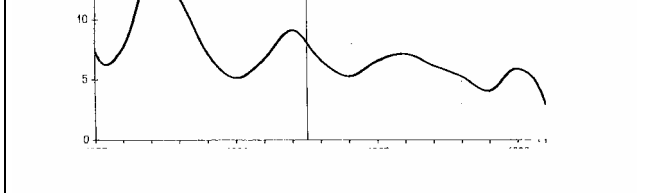
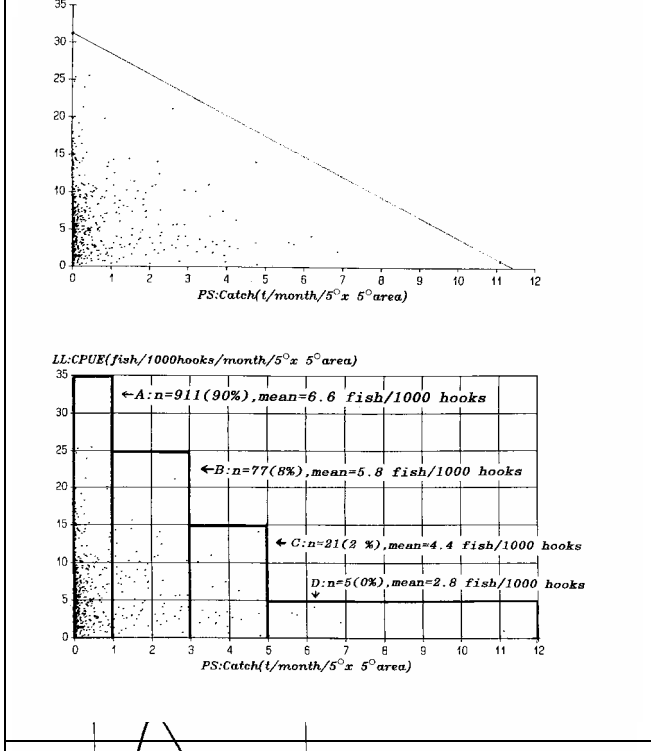
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**Figure 7** Trends of the annual CPUE in the whole PS fishery and comparison of the frequency distribution of fork length (before and after PS) and the heavy PS (before and after PS) (being ground) and the heavy PS which is being ground).



**Figure 8** Trends of the annual average CPUE in the heavy PS fishery and comparison of the frequency distribution of fork length (before and after PS) and the heavy PS (before and after PS) (being ground) and the heavy PS which is being ground.



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