Recent trend of Japanese longline fishery in the Indian Ocean with special reference to the targeting

Is the target shifting from bigeye to yellowfin?

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Abstract

Since the late 1990s, yellowfin ratio in the total of bigeye and yellowfin catch has been increased in the Indian Ocean. This increasing trend of yellowfin ratio is obvious in the western Indian Ocean where this trend started around early 1990s. Distribution of catch by species, species composition, CPUE and their historical change were analyzed by area in order to know whether the target species has been changing.

Increasing trend in yellowfin ratio seems to have been brought by 1) shift of fishing ground (distribution of effort concentration) to yellowfin dominant region in the western Indian Ocean, 2) an introduction of NHF (the Number of Hooks Between Floats) larger than 17 incorporating with Nylon materials in around 1990, which can catch yellowfin more effectively than ordinary deep longline, NHFCL3 and 4, and 3) decrease of bigeye abundance (CPUE) and increasing or flat level in yellowfin CPUE in recent 10 years in the tropical Indian Ocean. Some Japanese longliners appeared to take a different tactic that attempts to catch abundant yellowfin as well as some catches of bigeye in the western Indian Ocean rather than fishing on bigeye in the main fishing ground in the tropical area.

1. Introduction

In the Indian Ocean, about 10-30% of total global effort has been used by Japanese longline boats (Fig. 1), and 100 – 400 thousand individuals of bigeye and about similar number of yellowfin are caught annually (Fig. 2). Changes in catch amount of these species depended mainly on the fishing effort which has greatly fluctuated between 50 million and 130 million hooks per year in the past three decades. During the middle 1970s, target species for Japanese longliners was rapidly shifted from yellolwfin, which was important as the material of tuna sausage (Suda and Schaefer, 1965), to bigeye (Suzuki et al. 1977). This shift of targeting was accompanied by the introduction of deep freezer that enhanced the value of bigeye as the Sashimi material (Miyabe and Bayliff, 1987). According to the shift of the targeting, the number of hooks between floats (NHF), which was mainly 4 to 6 (conventional longline) had changed to 10 or more (deep longline) in order to catch bigeye, which inhabits at deeper water than yellowfin, more effectively (Suzuki, 1977, Suzuki and Kume, 1982). This target shifting was reflected in the species composition in the longline catch in the Indian Ocean. Bigeye ratio in the total catch of bigeye and yellowfin, which was about 40% before the shift in the middle 1970s, increased up to 50-60% in 1977 and was kept in the same level until around 1996 (Fig. 2). Thereafter, the bigeye ratio decreased and the catch of yellowfin exceeded that of bigeye again in 1999 (Matsumoto et al., 2000), and the bigeye ratio decreased to about 45% in 2000 through 2002. In 2003, bigeye ratio went down further to nearly 30 %, as adult yellowfin was extraordinary good for longline and this was even more so in the purse seine fishery (IOTC, 2004).

If this change in the species composition of the Japanese longline catch is interpreted simply, targeting shift from bigeye to yellowfin is appeared to be occurring in the Indian Ocean, especially, in the tropical area. This paper studies the distribution of catch by species, species composition, fishing gear specific CPUE and their historical change in order to know why the increase of yellowfin ratio occurred and to clarify whether the target species has been changing or not.

2. Materials and methods

GLM (Generalized Linear Model):

CPUEs based on the number of catch was used;

The number of fish caught / the number of hooks * 1000

The model used for GLM analyses (CPUE-LogNormal error structured model) includes environment factors (SST and MLD) as follows.

Model (CPUE-LogNormal error structured model):

$$\text{Log}(CPUE_{ijkl} + const) = \mu + YR_{(i)} + MN_{(j)} + AREA_{(k)} + NHFCL_{(l)} + SST(m) + MLD(n) + YR(j)*NHFCL(l) + AREA(k)*SST(m) + AREA(k)*MLD(n) + SST(k)*MLD(n) + e_{(ijkl....)}$$

Where Log : natural logarithm,

CPUE : catch in number of bigeye per 1000 hooks,

Const : 10% of overall mean of CPUE

μ : overall mean (i.e. intercept),

$YR_{(i)}$: effect of year,

$MN_{(j)}$: effect of fishing season (month),

$AREA_{(k)}$: effect of sub-area,

$NHFCL_{(l)}$: effect of gear type (class of the number of hooks between floats),

$SST_{(m)}$: effect of SST,

$MLD_{(n)}$: effect of MLD,

AREA(k)*SST (m) : interaction term between sub-area and SST,

AREA(k)*MLD(n) : interaction term between sub-area and MLD,

SST(m)*MLD(n) : interaction term between SST and MLD,

$e_{(ijkl..)}$: error term.

The number of hooks between float (NHF) was divided into 6 classes (NHFCL 1: 5-7, NHFCL 2: 8-10, NHFCL 3: 11-13, NHFCL 4: 14-16, NHFCL 5: 17-19, NHFCL 6: 20-21) as later explanation. Gear (NHFCL) specific CPUE or gear specific CPUE by year was obtained by LSMEANS option of GLM procedure.

Area and sub-area definition used in this study:

Area and sub-area definition used in the CPUE study is shown in Fig. 3. Main fishing ground of Japanese longline fishery except that of southern bluefin tuna was divided into seven sub-areas, which were used only for the standardization of CPUE. Five main areas, Western Tropical (sub-areas 1 and 3), Central Tropical (sub-areas 2 & 4), Eastern Tropical (sub-area 5), Western Temperate (sub-area 6) and Central and eastern Temperate (sub-area 7) Indian Ocean were used to describe regional trend of fishery (catch, effort and CPUE).

Catch and effort data used:

The Japanese longline catch (in number) and effort statistics from 1960 up to 2002 were used. 2002 data is preliminary. The catch and effort data aggregated by month, 5-degree square and the number of hooks between floats (NHF) was used for the analysis.

Environmental factors:

SST (Sea Surface Temperature) data from 1946 to 2002 was downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA, http://goos.kishou.go.jp/rrtdb/database.html). MLD (Mixed Layer Depth) data from 1960 to 2002 was downloaded from JEDAC (Joint Environmental Data Analysis Center) website of Scripps Institution of Oceanography (http://jedac.ucsd.edu/DATA_IMAGES/index.html). Each data whose original resolution are 2-degree latitude and 2-degree longitude by month for SST and 2-degree latitude and 5-degree longitude (corner of grid) by month for MLD were re-stratified into 5-degree latitude and 5-latitude longitude by month from 1991to 2002 using the procedures described in Okamoto et al. (2001), and used in the analyses.

Termes "bigeye ratio" and "yellowfin ratio" used in this paper means the ratio of bigeye (BET) or yellowfin (YFT) catch in number in the total catch of these two species (BET+YFT). That is, Bigeye ratio = BET/ (BET+YFT), and yellowfin ratio=YFT/(BET+YFT).

3. Results and discussion

Catch distribution by species:

Fig. 4 shows the distribution of effort and catch by species averaged over five years starting from 1985, 1990, 1995 and four years from 2000. In general, bigeye is more predominant than yellowfin in the Japanese longline catch in the Eastern Indian and opposite is true, dominant yellowfin catch in the western Indian Ocean. Off Somalia, 50°E-70°E and 10°S-10°N, and region from Mozambique Channel (West off Madagascar) to off Cape Town are the main fishing ground for Japanese longliners in the western tropical and temperate Indian Ocean excluding fishing ground for southern bluefin which distribute south of 35°S. In the fishing ground off Somalia, yellowfin ratio tends to be higher in the southern and western part of the area. The region from Mozambique Channel to off Cape Town is known as good fishing ground for yellowfin rather than bigeye. In the eastern Indian Ocean, relatively dense fishing effort is distributed in the regions from the Equator to 15°S and from 25°S to 35°S of 80°E-115°E where bigeye is almost always the most major species followed by albacore in the higher latitude around 25°S -30°S.

Bigeye catch in the western tropical area, off Somalia, was about the same as that of yellowfin until around 1990 (Fig. 5). Thereafter the effort at the north (5°N-10°N) of fishing ground off Somalia decreased and that in its African offshore increased (Fig. 4). As a result of these shift of the effort distribution yellowfin ratio has increased rapidly in this area up to over 70% in 2000 (Fig. 5).

In the eastern tropical area, bigeye ratio was increased by the target shift in middle 1970s from less 40% to 70% in 1980. After 1989, fishing effort in the offshore of Indonesia where yellowfin is abundant, decreased, and effort from Equator to 15°S of 80°E-115°E increased. Accordingly, bigeye ratio has been increased to about 80% after 1991 (Fig. 5). Bigeye ratio in central tropical area has not shown remarkable change after middle 1980s.

In the western temperate area, the number of hooks used which was less than 5 million before 1990, increased steeply up to over 18 million hooks after 1993 with maximum 28 million hooks in 1998 (Fig. 5). According to this increase in the effort, the catch in number of three main tunas (albacore, bigeye and yellowfin) increased dramatically from less than 100 thousand to 200 – 300 thousand fishes (Fig. 5). Because yellowfin ratio in this area is about 70% in average, such a large increase of total catch in this area should affect considerably on the yellowfin ratio of the whole Indian Ocean.

Time and special regulation of southern bluefin tuna fishing ground was introduced by Japanese government in 1989 (Itoh and Miyauchi, 2004). As the allowable fishing season for each fishing ground differs slightly by year, that of off Cape Town is normally from May to July (August) and that of south-western waters off Australia is from September to December (November). These restrictions of fishing season mean that no fishing for southern bluefin tuna is allowed to Japanese longliner from January to April. Waiting for the open of the off Cape Town fishing ground in April, longliners seems to have concentrated to the region from Mozambique Channel to offshore of Cape Town in the first quarter and have caught the yellowfin dominant catch (Fig. 6). In spite of the drastic increase in fishing effort and catch, yellowfin ratio in western temperate has generally been kept in the same level, about 70%, and has not shown remarkable change in the recent decade (Fig. 5).

In the central and eastern tropical areas, fishing effort was not so many at the region, 25°S -30°S and 80°E-115°E in 1980s, after when it have increased with the catch in which albacore and bigeye were major species (Fig. 4). Although yellowfin dominant operations were made around north-western off Australia in 1980s, it was almost disappeared in 1990s. Followed by those change in effort and catch distribution in 1980s-1990s, the effort which was less than 5 million hooks increased up to 15 – 35 million hooks and bigeye ratio increased from 60% to over 80% (Fig. 5).

The change in the effort distribution followed by change in the species composition of the longline catch in each area as described above, brought 1) steep increase of yellowfin ratio (decrease of bigeye ratio) in the western tropical Indian, 2) increase of total catch in which yellowfin ratio is high, about 70%, in the western temperate, and 3) increase of bigeye ratio and bigeye abundant total catch in the eastern Indian Ocean. Recent high yellowfin ratio in the Japanese longline catch in the Indian Ocean is, at least partially, explained by decrease of effort in the bigeye abundant area (northern part of Somalia fishing ground) and increase of effort at the yellowfin abundant area (African coastal and offshore area from Equator to 35°S including western part of Somalia fishing ground). Why has the fishing effort been concentrated to the yellowfin abundant region in the western Indian Ocean? Although this shift of effort distribution might be shift of target species, the shift of this time is quite different from the shift from yellowfin to bigeye that occurred in the middle 1970s, in the respect that the price of bigeye is still quite higher, about 1.5 times higher than that of yellowfin.

Change in gear configuration:

If target species was changed in fact from bigeye to yellowfin, not only fishing ground but also fishing method would be changed, for example, from deep longline to shallower (conventional) longline gear. Fig. 7 shows the historical change in the ratio of the number of hooks between float (NHF) classified into six (NHFCL1 - 6) used in each year from 1970. The ratio of NHFCL3 (NHF11-13), which is most major gear after the former shift of targeting in the middle 1970s in the tropical area decreased steeply since early 1990s and replaced to NHFCL5 – 6 (Fig. 7). NHFCL5 and 6 was introduced around 1990 and spread rapidly, especially in the western tropical area, where the ratio of NHFCL5 and 6 reached to 50% in 1992, and about 80% in 1996. This shift to laeger number of NHF was obvious in western than eastern tropical. In the recent five years, the ratio of NHFCL6 (NHFCL20 – 21), the largest NHF, is about 10% in eastern, 20% in central tropical area, and reach up to 40% in the western tropical Indian Ocean. The change in the gear configuration with relation to the targeting shift in the middle 1970s was aiming to set the longline gear at deeper water to catch bigeye which inhabit deeper than yellowfin, effectively. However, in the latest decade when the yellowfin ratio has increased, NHF used has been shifting to larger NHF, and this trend is more obvious in the western tropical area where increasing trend of yellowfin ratio is more remarkable. How can this apparent contradiction be explained?

CPUEs for bigeye and yellowfin estimated by GLM by NHFCL were shown for each area in Fig. 8 in which the catch rate of NHFCL5 and 6 for yellowfin should be paid attention. It is natural that the yellowfin CPUE of NHFCL3 and 4 were lower than that of NHFCL1 and 2 because of deeper gear setting of former NHFCL. However, yellowfin CPUE of NHFCL5 was higher than that of NHFCL3 and 4, and the CPUE of NHFCL6 was higher than even NHFCL1 and 2. In the case of bigeye CPUE, although the CPUE of NHFCL6 was slightly lower than that of NHFCL5, level of CPUE is similar among NHFCL4, 5 and 6, and NHFCL6 showed highest CPUE in the eastern tropical area as that for yellowfin. That indicates that NHFCL5 and 6 is the most effective gear to catch either of yellowfin and bigeye in the tropical Indian Ocean. It means that NHFCL 5 and 6 are set at deep enough to catch bigeye and at shallow enough to catch yellowfin. Although author can not find explanation which is scientifically reasonable enough, at present yet, the following possibility can be thought.

Fig. 9 showed the historical change in the ratio of Nylon as the materials of main line by NHFCL. The Nylon seems to start to be used as the material of main line (branch line as well) around late 1980s (Okamoto and Bayliff, 2003). The materials of main and branch line have been recorded in logbook since 1994 as two categories, Nylon or other. About 100% and 80% of material for NHFCL6 and NHFCL5 were already Nylon in 1994, and Nylon material for NHFCL5 increased and became to nearly 100% in 2003. NHF greater than 18 was not existed before 1992. It is said that Nylon material made the NHF larger than 18 possible to be use, because the NHF18 or more made of former material, Cremona, was too heavy to suspend by normal float at each side of a basket (Okamoto et al., 2004). Material of other NHFCL1 to 4, 10% to 60% of which were made of Nylon has increased over 90% in 2003. Specific gravity of Nylon is 1.14, lighter than Cremona whose specific gravity is 1.30. And the water resistance of Nylon main line is smaller than Cremona main line because former is thinner than latter one. These characteristics of Nylon material may bring the characteristic of mainline (and maybe branch line as well) that it is easy to sink deep enough to catch bigeye, but also easy to be blown up to shallow enough to catch yellowfin. This hypothesis, which the Nylon material would be easily blown up and this may bring high yellowfin CPUE, has not been proved. It would be necessary to compare fishing gear movement under the water between the gear materials, Nylon material and other material.

If the yellowfin CPUE has increased in the recent decade simultaneously with the rapid spread of NHFCL5 and 6, the effects of NHFCL5 and 6 might be estimated to be higher than the actual CPUE even if NHFCL did not have any effect on the CPUE trend. Yellowfin and bigeye CPUEs from 1991 to 2003 was standardized for all and each tropical area by using GLM which the NHFCL factor and any interaction with the NHFCL were not included in the model, and the year trend was shown in Fig. 10 with nominal CPUE. In any tropical area, yellowfin CPUE did not show increasing trend, or show rather slightly decreasing trend in eastern tropical area. Furthermore, the higher yellowfin CPUEs of NHFCL5 and 6 were observed not only in western tropical but also in central and eastern areas where yellowfin ratio has not shown increasing trend. Therefore, higher CPUE of NHFCL5 and6 seems not to be derived from other factors which may affect on the CPUE of each NHFCL. On the other hand, bigeye CPUE showed declining trend in all tropical areas (Fig. 10). Declining trend of bigeye CPUE and increasing or flat in level of yellowfin CPUE would be one reason for increasing yellowfin ratio in the recent years.

Finally, some consideration on the targeting by economic aspect will be made. In Table 1, relative CPUE of bigeye and yellowfin in early 1990s and 2000s are estimated by nominal CPUE shown in Fig. 10 (top table) Assuming that relative price of Bigeye caught in tropical area would be 1.5 and that of Yellowfin would be 1.0, relative incomes for both species were estimated by period and area (middle table of Table 1). Adding the relative income of both species, total relative income was estimated by period and area (bottom table of Table 1). By decrease in Bigeye CPUE, the income from bigeye decreased in all area, while the large increase in the income of yellowfin derived from jumping up of CPUE from 8.0 to 14.0, was observed in the western tropical. As a result, in early 1990s, highest income (19.5) could be expected in the eastern tropical area from bigeye abundant catch while the income expected in the western tropical was lowest (17.0) lowest in the same period. In the early 2000s, the expected income in the western area (18.5) became higher than that in the eastern tropical (14.0), being pushed up by the high yellowfin CPUE.

Declining trend of bigeye CPUE has been remarkable not only in the Indian but also in the other Oceans since around late 1980s. Possibly, the same type of change in longline operation as in the western Indian Ocean might have been occurring at the Pacific and Atlantic Oceans and the similar analyses would be needed for these Oceans.

Conclusion:

In summary, increase of yellowfin ratio since early 1990s has been brought by the following three factors.

1. Shift of fishing ground (distribution of effort concentration) to yellowfin dominant region in western Indian Ocean.

2. Introduction of NHFCL5 and 6 incorporating with Nylon materials, which can catch yellowfin more effectively than ordinary deep longline, NHFCL3 and 4. Bigeye CPUEs of NHFCL5 and 6 are almost same as that of NHFCL3 and 4.

3. Decrease of bigeye abundance (CPUE) and flat level in yellowfin CPUE in recent 10 years in the tropical Indian Ocean.

However, it might not be adequate to interpret simply that the increasing yellowfin ratio means targeting change from bigeye to yellowfin, mainly because the price of bigeye is still significantly (about 1.5 times) higher than that of yellowfin. Then it is hard to suppose that Japanese longliners would abandon the bigeye catch. NHFCL5 and 6 made of Nylon were effective to catch both of yellowfin and bigeye although it is not clear if the longliners could expect the high CPUE for yellowfin by this gear. Moreover, bigeye abundance in the Indian Ocean has continuously decreased and lowest CPUE has been recorded every year (Okamoto et al., 2004). Under these situations, author supposes that Japanese longliners would dare select the yellowfin abundant fishing ground to get more and stable catch of yellowfin with less but still considerable amount of bigeye catch rather than adhere to the fishing ground of bigeye, the high price but quite low CPUE target species.

4. Acknowledges

I appreciate Mr. Y. Warashina and Dr. Y. Nishikawa for providing useful information on Japanese longline fishery and Mr. S. Sawadaishi for the information of longline fishing gear. I also thank Drs. Z. Suzuki, Y. Uozumi and N, Miyabe for critically reviewing the manuscript.

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Table 1. Bigeye and yellowfin CPUEs in early 1990s and early 2000s in each tropical area, and relative income estimated using the CPUEs and relative price of each species, 1.5 and 1.0 for bigeye and yellowfin, respectively.

	Bigeye			Yellowfin		
Nominal CPUE	Early 1990s		Early 2000s	Early 1990s		Early 2000s
Western Tropical	6.0	→	3.0	8.0	→	14.0
Central Tropical	8.0	→	5.0	6.0	→	4.0
Eastern Tropical	11.0	→	8.0	3.0	→	2.0

↓

	Bigeye			Yellowfin		
Relative income	Early 1990s		Early 2000s	Early 1990s		Early 2000s
Western Tropical	9.0	→	4.5	8.0	→	14.0
Central Tropical	12.0	→	7.5	6.0	→	4.0
Eastern Tropical	16.5	→	12.0	3.0	→	2.0

↓

Total	Bigeye & Yellowfin		
relative income	Early 1990s		Early 2000s
Western Tropical	17.0	→	18.5
Central Tropical	18.0	→	11.5
Eastern Tropical	19.5	→	14.0

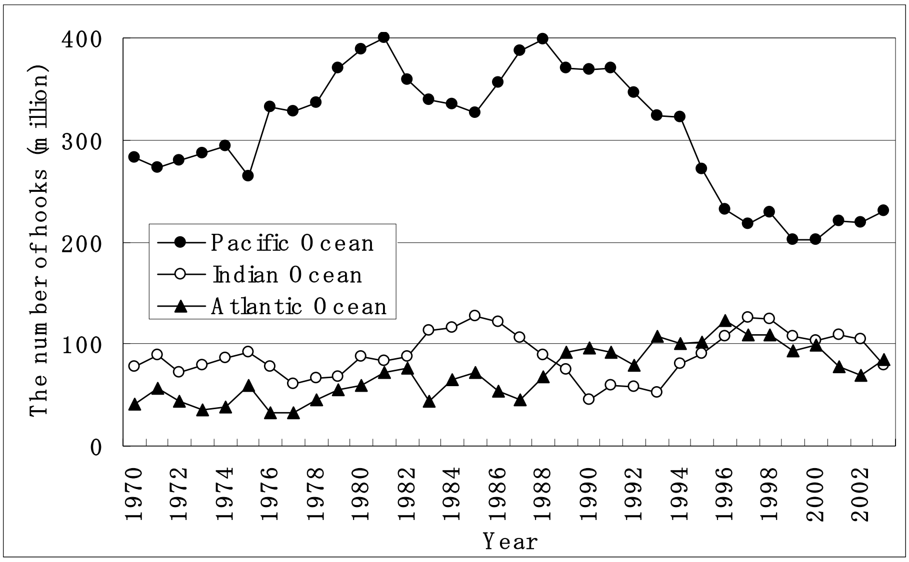


Fig. 1. Historical change in the number of hooks used by Japanese longline boats in each Ocean.

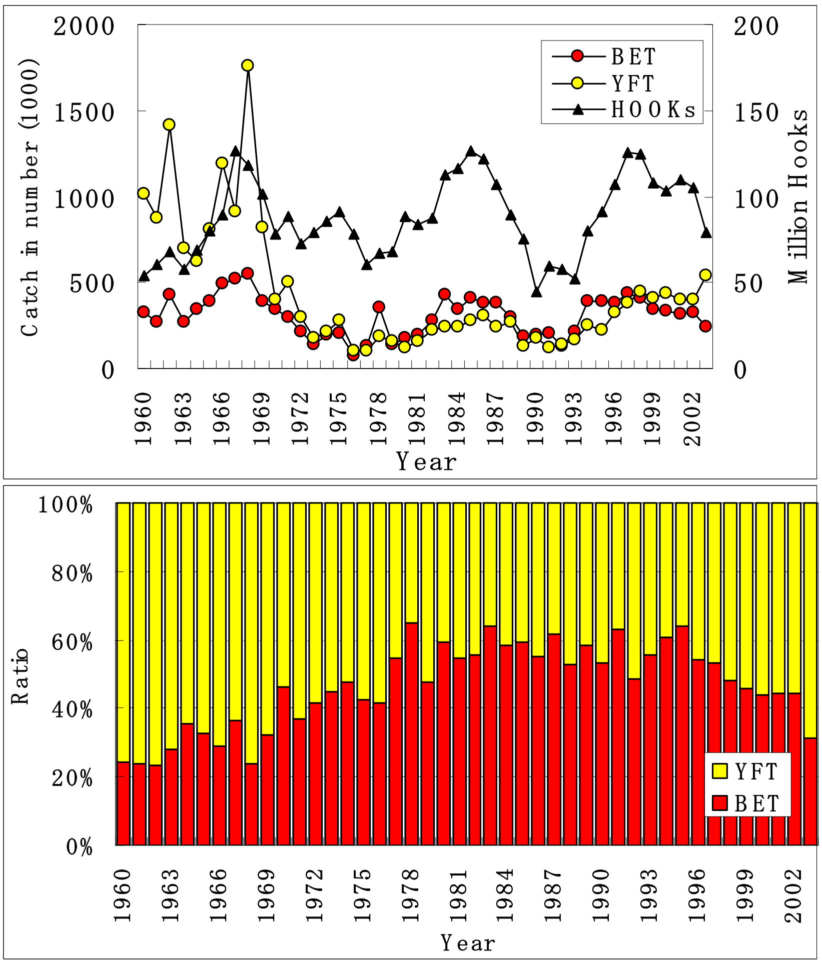


Fig. 2. Change in the number of hooks, catch in number of bigeye and yellowfin (top) and yellowfin – bigeye ratio (bottom) in the Indian Ocean from 1960 to 2003.

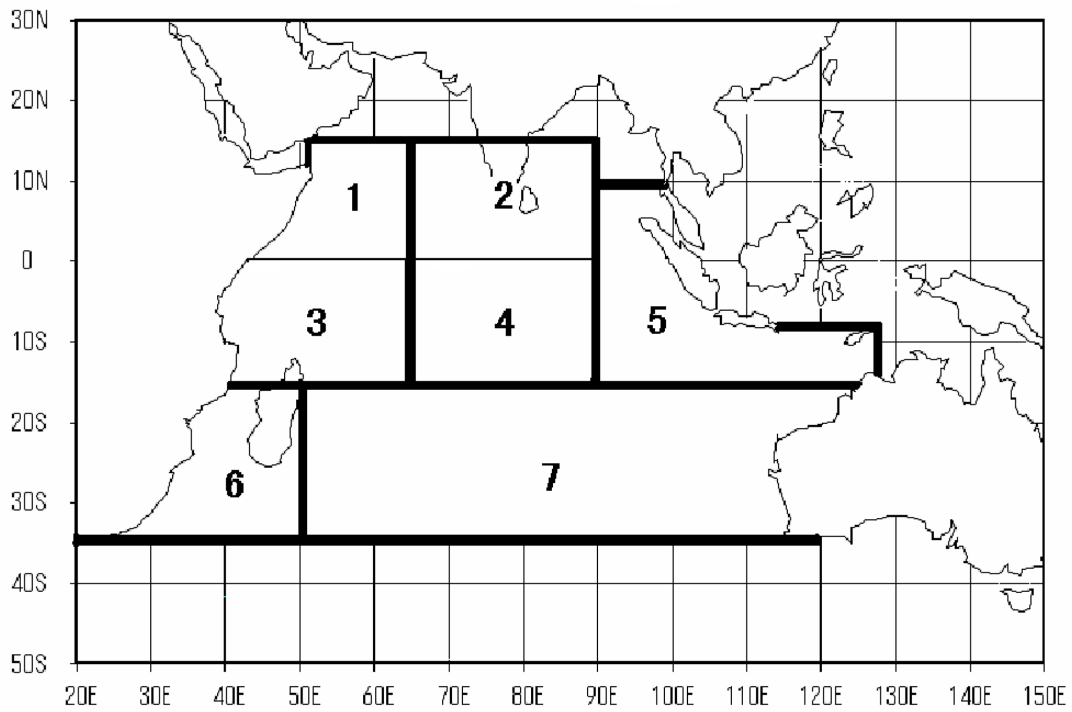


Fig. 3. Seven sub-areas (1-7) definitions and five main areas, Western Tropical (sub-areas 1 and 3), Central Tropical (sub-areas 2 & 4), Eastern Tropical (sub-area 5), Western Temperate (sub-area 6) and Central and eastern Temperate (sub-area 7) Indian Ocean used in this study.

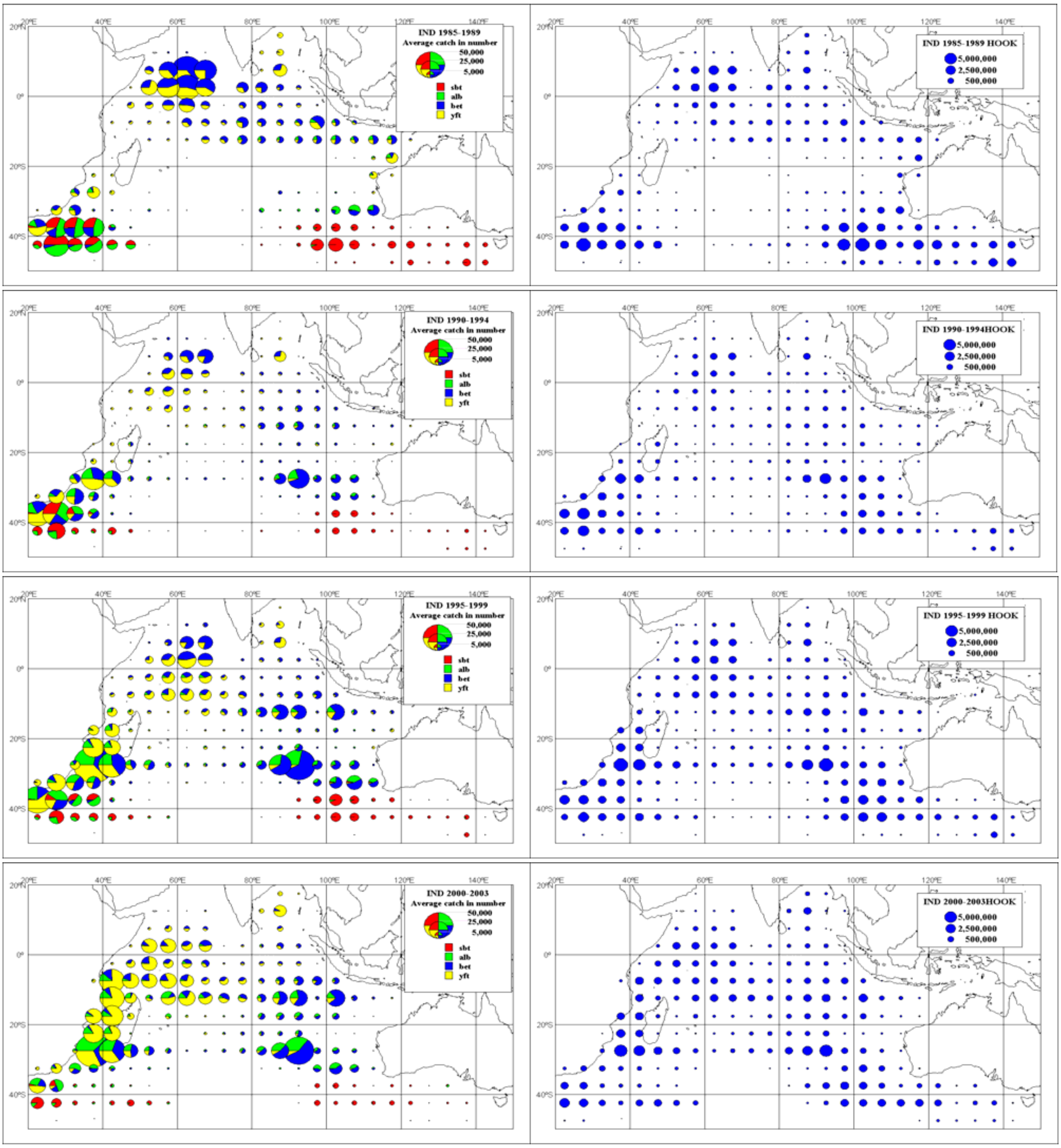


Fig. 4. Distribution of average catch by species (right) and effort (left) in each five years from 1985, 1990, 1995 and four years from 2000.

Tropical Areas

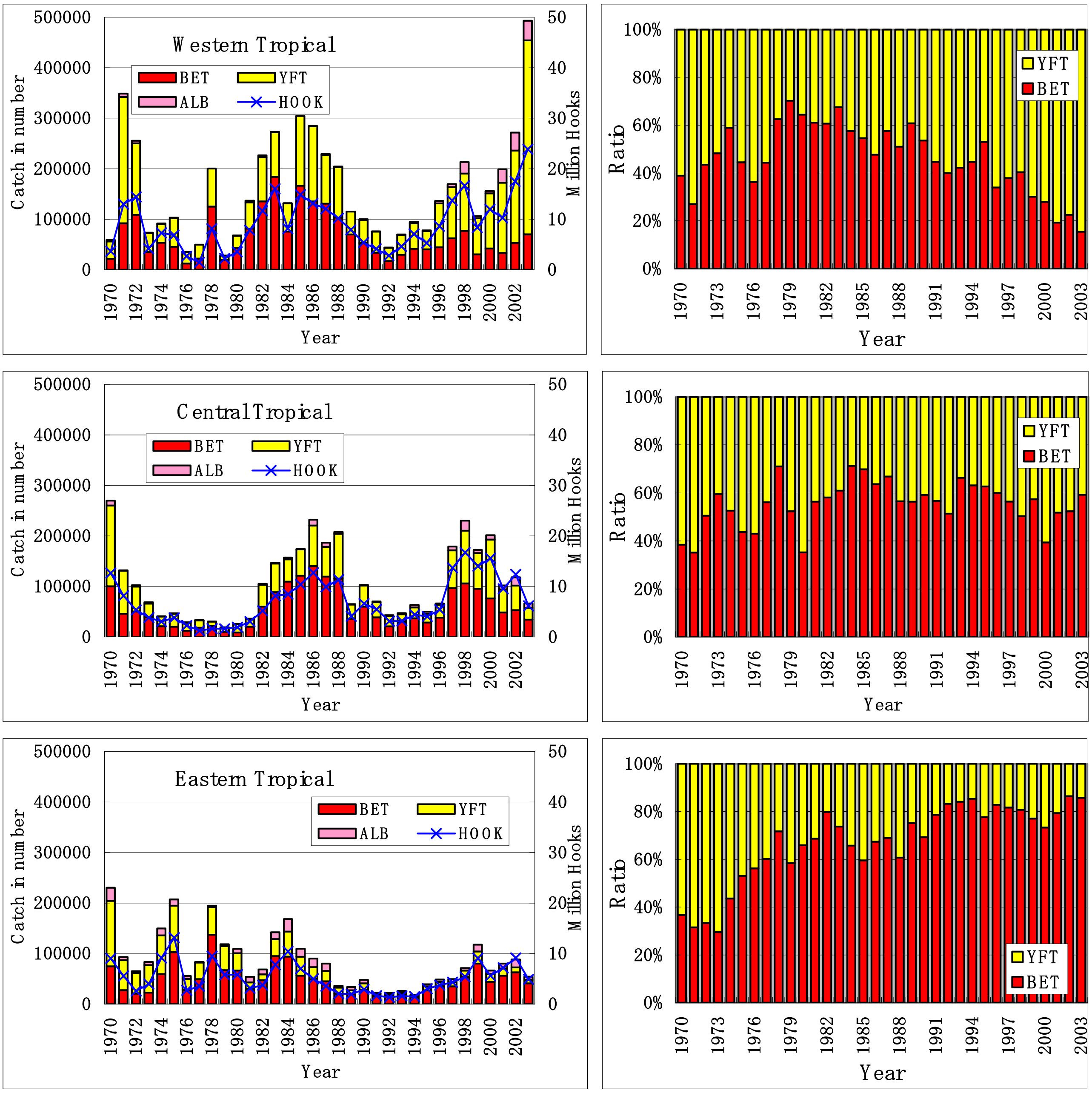


Fig. 5. Historical change in the number of hooks used, catch in number of three major tunas, albacore, yellowfin and bigeye (left figures) and bigeye-yellowfin ratio (right figures)

Temperate Areas

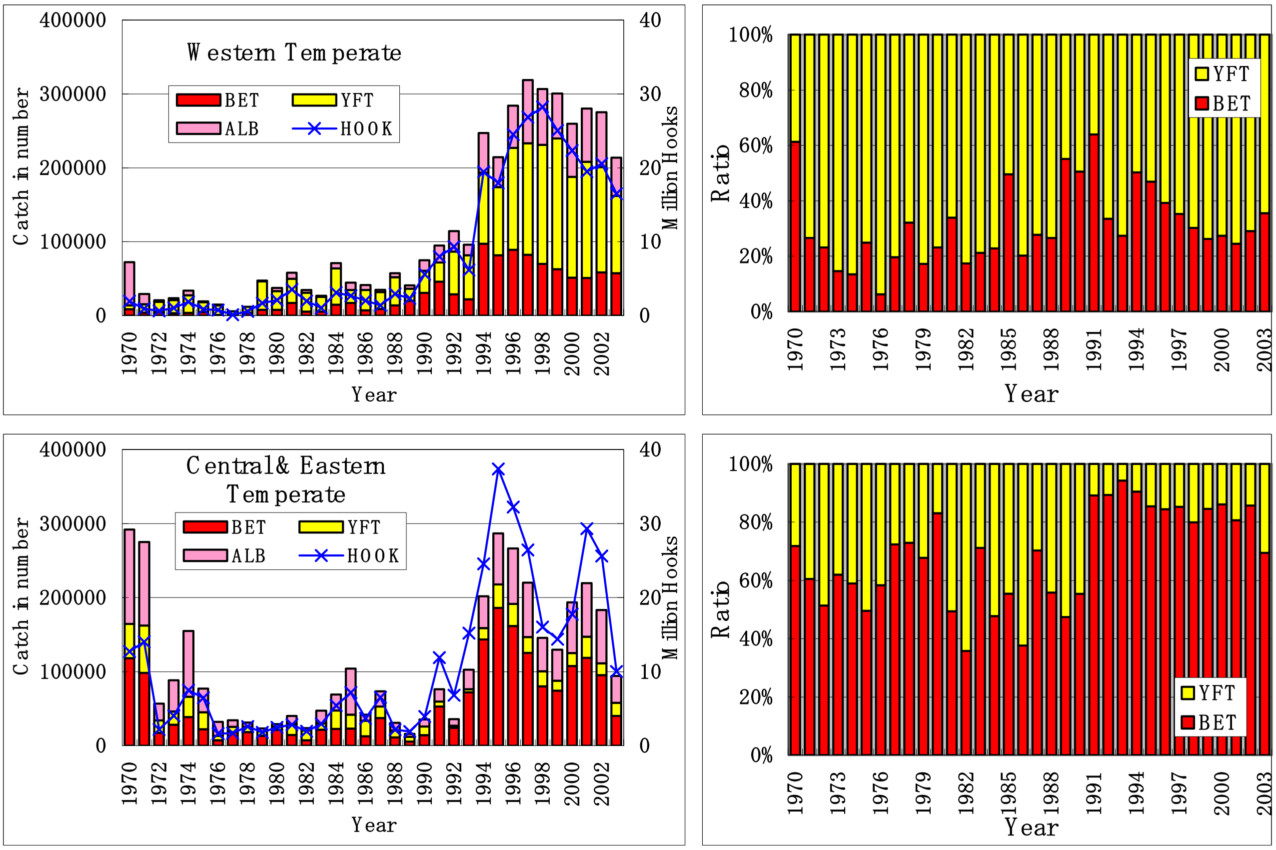


Fig. 5. Continued.

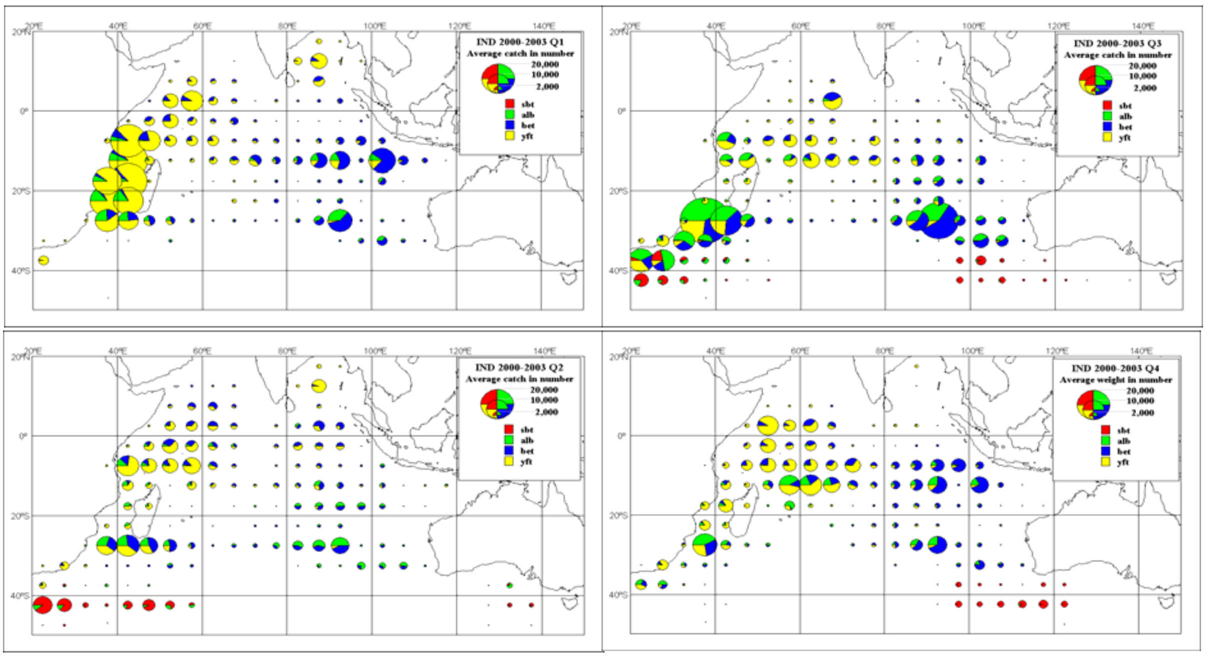
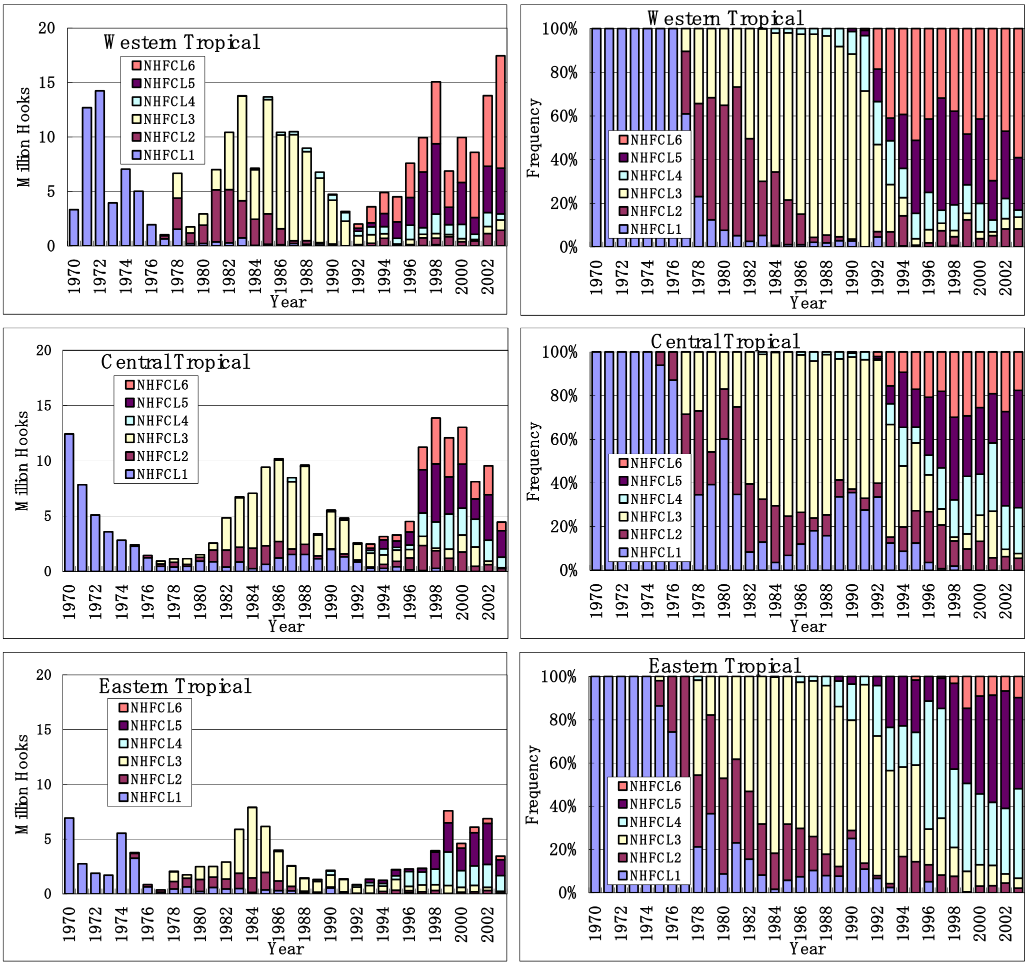


Fig. 6. Quarterly distribution of catches by species by Japanese longline fishery averaged for four years from 2000 to 2003

Tropical Areas



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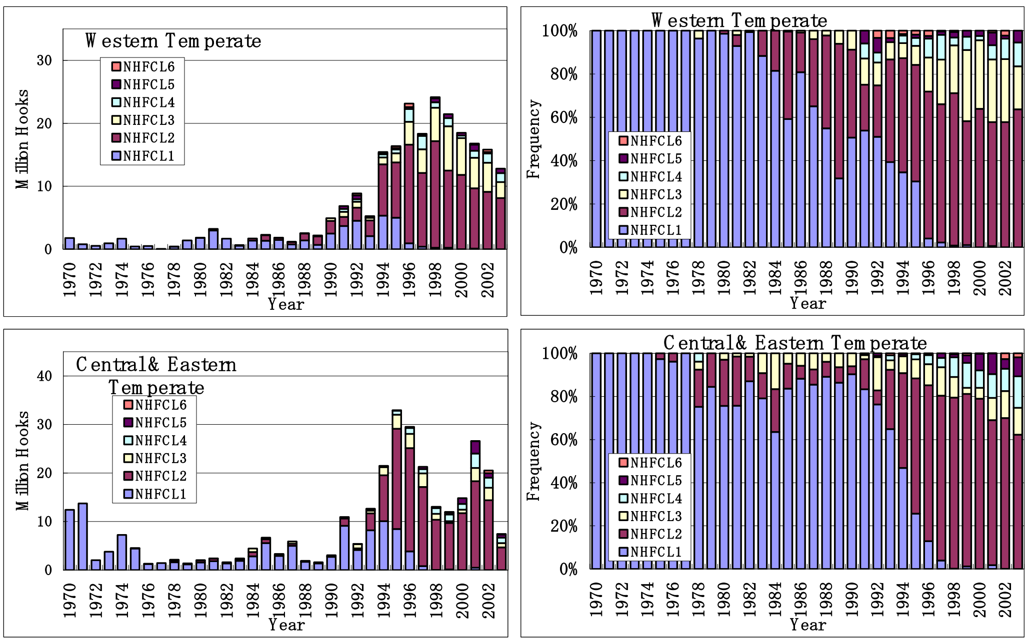
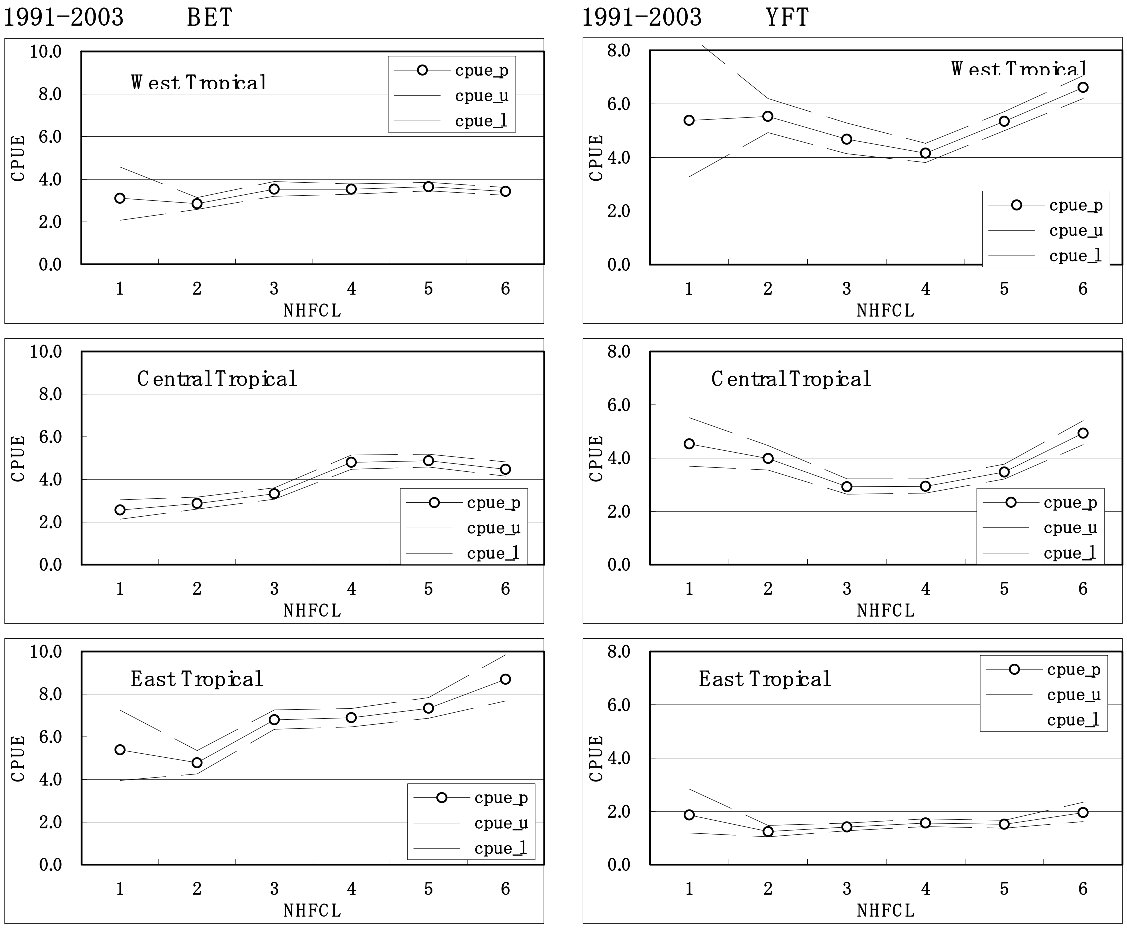


Fig. 7. Chanage in the gear configuration (the number of hooks between floats) classified into six classes (NHFCL 1: 5-7, NHFCL 2: 8-10, NHFCL 3: 11-13, NHFCL 4: 14-16, NHFCL 5: 17-19, NHFCL 6: 20-21) in each areas.

Tropical Areas



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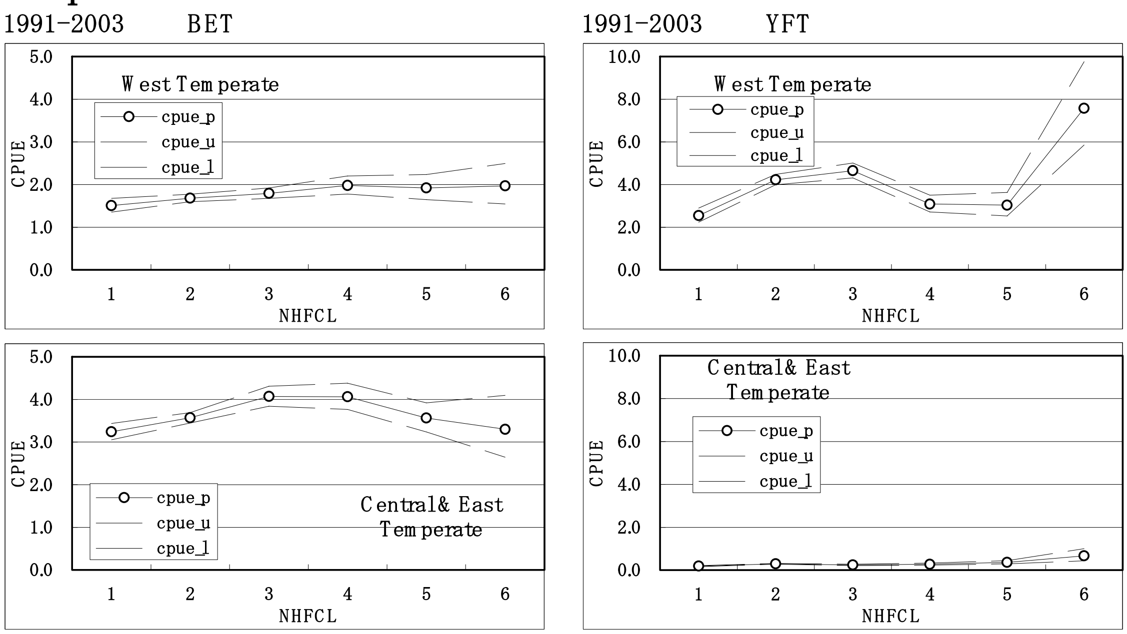

Fig. 8. Standardized CPUE of bygeye (left figures) and yellowfin (right) by six NHFCL (NHF classes) in each areas.

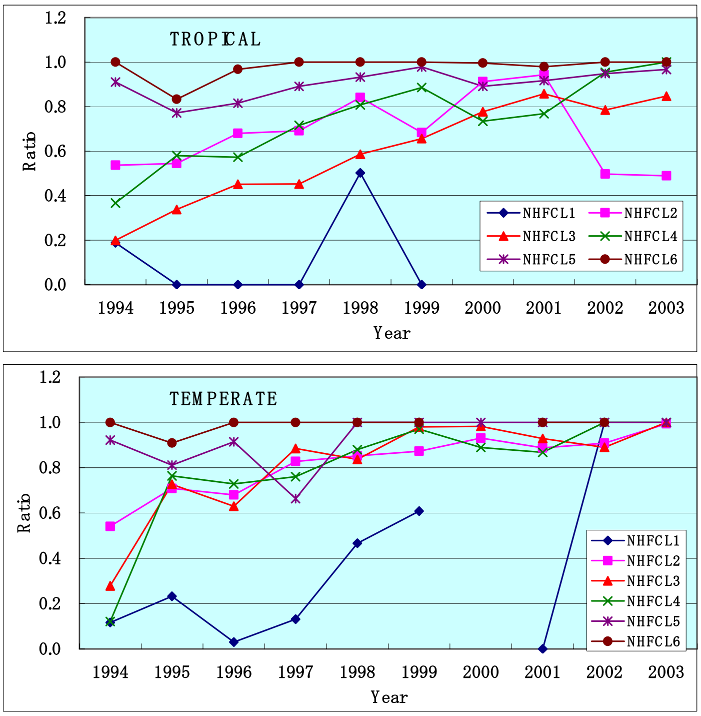

Fig. 9. Change in ratio of Nylon material mainline by six NHFCL (NHF classes) in tropical (top figure) and temperate (bottom figure) areas.

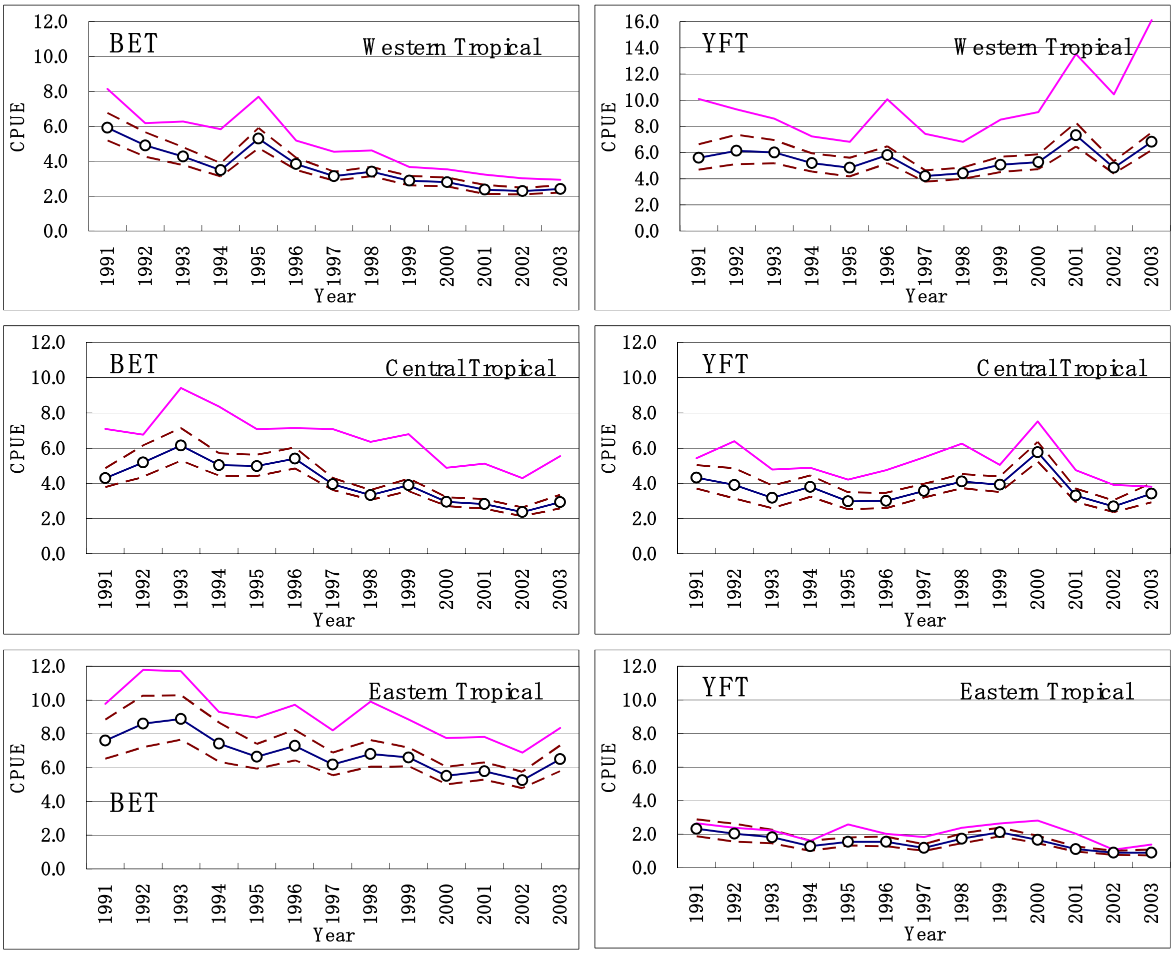

Fig. 10. Standardized CPUE of bygeye (left figures) and yellowfin (right) by year from 1991 to 2003 with 95% confidence limit with nominal CPUE (pink line). Unit of CPUE is catch in number per 1000 hooks.