Estimation of longline gear configuration using species composition in the operations of which the gear structure are already known

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Abstract

Method to estimate unrecorded gear configuration of longline operations in the tropical Indian Ocean was devised. In this study, tentatively, gear configuration of half of Japanese longline fishing data from 1975 to 2002 were estimated by comparing species configuration of remained half of fishing data. In the four sorts of species combinations tested, combination of six species (BET, YFT, ALB, SWO, MLS and BUM) resulted in the highest correct estimation ratio. By substitution of the strata whose species composition could not determined for one or both gear types, the ratio of un-judged observation decreased from 0.464 to 0.300. In the estimation using composition of six species and applying the substitution, the correct estimation ratio was about 63% in average. When the estimated and actual gear configurations were applied into GLM, both of estimated and actual NHFCLs showed significant effect on the bigeye CPUE standardization, although the difference of effects between estimated NHFCLs (regular and deep longlines) was smaller than that observed between actual gear types.

Introduction

In order to observe the trend of abundance of tuna and billfish species, standardized CPUE has often be used as the abundance index (Miyabe, 1991; Punsly and Nakano, 1992; Hsu, 1997; Yokawa, 2000; Okamoto et al., 2001; Mejuto et al., 2002, Meneses et al., 2004). In this standardization, effects of season, area, oceanographical factors, gear configuration are usually included in GLM or other statistical models. The information of gear specific CPUE (Yoshihara, 1951; Nakano et al., 1997) and observation of catch depth using hook timer (Boggs, 1992) and small Temperature-Depth Recorder (Matsumoto et al., 2001), have indicated that the each species of tunas and billfishes has its specific vertical distribution pattern. Therefore, the gear depth, or gear configuration that been used in GLM modeling, is considered as an important factor in the CPUE standardization.

As an indicator for longline fishing gear depth and target species, NHF (the Number of Hooks between Float) has often been used (Yokawa et al., 2001; Okamoto et al., 2004a; Uosaki, 2004). NHF used in the operation of Japanese distant-water longliners has historically changed. In the tropical Pacific, NHF was mainly 5 or 6 before middle 1970s, and has been increased to NHF of 10 or more thereafter (Suzuki et al., 1977), to be more effective in catching bigeye tuna whose commercial value was much higher when it was used as sashimi material. Furthermore, coupling with the introduction of Nylon material for main and branch lines in around 1990s, operations with larger number of NHF (18-21) has been rapidly increased. This historical change of NHF is highly correlated with the depth coverage of longline gear, and as a result is also correlated with the target species of operations. Therefore, accurate estimation of the effect of NHF in the standardization of CPUE of longline fisheries such as Japanese distant-water longliners, which the value of NHF changed drastically since the early 1950's, is quite important for the reliable estimation of the historical trends of tuna abundance index. For Japanese longline fishery, NHF data of each operation has been recorded in the logbook since 1975 and is available for the CPUE standardization. But for Taiwanese longline fishery which is another main distant-water longline country in all Oceans, NHF data was not available until 1994. In order to standardize Taiwanese longline catch, its gear configuration before 1994 has been attempted to be estimated by some indicators as catch ratio (Lee and Nishida, 2002; Chang, 2004) or catch rate of some species (Lee and Liu, 2000; Chang, 2003). However, including catch ratio or catch rate of some species in the model as explanatory variables might not be adequate because the difference of historical trends of abundance/biomass of the target species of the analysis from those of other comparing species would cause unpredictable biases in the results of the CPUE standardization.

Moreover, take bigeye as an example, high bigeye ratio or CPUE in the aggregated data is always judged as the deep longline operation targeting bigeye in spite of the situation that many operations of low bigeye catch, even zero catch, and failed deep longline operations in the set by set data series may be classified into shallower setting targeting fishes other than bigeye. If gear configuration estimated by this type of criteria, that is high bigeye catch or CPUE = deep and low bigeye catch or CPUE = regular, is used in the model for the bigeye CPUE standardization, the historical up and/or down trend of bigeye abundance index would be diminished and come to be flattened because bigeye CPUE itself is included as explanatory variable in the model.

In this paper, a new method to estimate longline gear configuration in the tropical Indian Ocean was developed in order to apply, in the future, mainly for the Taiwanese longline data in the periods before 1994. Data of the Japanese distant-water in the comparable area and periods were used to develop and verify the reliability of the methods because general operations styles of Japanese and Taiwanese longliners are quite similar with each other and data of Japanese longliners has more reliable information about species composition and gear configuration since 1975. The main difference of this method from those used previously is as follows.

1) Gear configuration was estimated not by each operation but by each vessel, year, quarter, and area. We expected that this would be effective in the reduction of biases caused by data of unusually succeeded/failed operations and also in the increase of the reliability of the results, because one particular Japanese and Taiwanese longline vessel generally use the same or similar gear configuration and seldom change it operation by operation from deep to regular or vice versa.

2) Gear composition was estimated by similarity between gear specific species compositions of reference data and species composition of sample data whose gear configuration is unknown. Therefore, the species composition was not ranked to judge the gear configuration.

Materials and methods

1) Datasets used for analyses

Japanese longline catch and effort data by each operation in the tropical Indian Ocean from 1975 to 2003 was used in this study. The data contains license number for the identification of vessels, and operation/catch information. Operation information includes fishing date, fishing location, total number of hooks used and NHF. Catch information includes catch in number of albacore, bigeye, yellowfin, swordfish, striped marlin and blue marlin for calculation of catch ratio. All the data with NHF information was divided randomly into two data set, DATA1 and DATA2, and gear configuration of DATA2 is masked and to be estimated by DATA1. In this paper, fishing gear of DATA 2 as a sample data was estimated by DATA1 as a reference data to develop the method. However, final destination of this study is to estimate gear configuration of longline data of other country for the period without NHF information. When the method is applied into the foreign data, their longline data will be treated as the same manner as DATA 2.

2) Area definition

Tropical Indian Ocean north of 15°S was divided into six areas and used in this study (Fig. 1). This area definition was modified slightly from the area definition used in 2004 for the bigeye CPUE standardization of Japanese longline fishery (Okamoto et al 2004b). Temperate areas south of 15°S which was included in the original definition were not used in this study.

3) Procedure for estimating gear configuration

Class of gear configuration (regular longline and deep longline) which was used by each vessel in each stratum (each year, quarter, and area) was estimated as the following procedures.

STEP 1: Species combination in each stratum of reference data

All catch and effort data of each operation in which NHF data was recorded, were divided randomly into two data sets, reference data (DATA 1) and sample data (DATA 2). Catch in number of each species of DATA 1 was aggregated by year, quarter, 5 degree square and two classes of NHF, NHFCL1 (NHF 5-10) and NHFCL2 (NHF11-21). In this study, NHFCL1 and NHFCL2 were regarded as regular and deep longline, respectively. Using aggregated catch by species, species composition was calculated. For example, species compositions of three species, BET, YFT and ALB are calculated as BET/(BET+YFT+ALB), YFT/(BET+YFT+ALB), ALB/(BET+YFT+ALB).

STEP 2: Species composition in each strata for each vessel

Using remained half data, DATA 2, the species composition for four species combinations and the number of operation were calculated by year, quarter, 5 degree square and each vessel identified by each license number. Although NHF data was included in DATA 2, NHF data was not referred in this step.

STEP 3: Judge of gear configuration in each stratum by similarity of species composition

By comparing similarity of species composition between each vessel and that of each NHFCL in each stratum, the NHFCL which was used by the vessel was determined. As the index of similarity, Pianka's α index (1973) was used as follows.

$$\alpha = \frac{\sum_i p_i \cdot q_i}{\sqrt{\sum_i (p_i)^2} \cdot \sqrt{\sum_i (q_i)^2}}$$

Where, pi is the ratio of species i calculated in the stratum using all data in DATA 1, and qi is the ratio of species i calculated in the same stratum for the vessel using DATA 2. The α value was multiplied by the number of operation in order to weight it, and resulted value calculated for each NHFCL was regarded as the point of each NHFCL in the stratum for the vessel.

STEP 4: Judge of gear configuration in the area basing on that estimated in each stratum

Obtained points in each stratum for each vessel was summed up by area, year, quarter and NHFCL, and NHFCL with higher total point was determined as the NHFCL which was used by this vessel in this area, year and quarter.

In order to know which species composition can reflect the representative species composition for each NHFCL in the strata more really, species compositions of four sort of species combinations (1: BET = bigeye and YFT = yellowfin, 2: BET, YFT and ALB = albacore, 3: BET, YFT, ALB and SWO = sword fish, 4: BET, YFT, ALB, SWO, MLS = striped marlin and BUM =blue marlin) were tested and the correct estimation ratio of them were compared.

In the case of that the species composition of both or one NHFCL in the stratum could not be referred, following two methods were applied.

CASE 1: NHFCL of the vessels was not estimated in the stratum.

CASE 2: averaged species composition in the area in the year and quarter for each NHFCL was referred. If average species composition could not be referred, NHFCL was not determined in this stratum for this vessel.

4) Comparison of effect of gear configuration for bigeye CPUE applying recorded and estimated gear classes into GLM

Actual and estimated NHFCL was applied as the explanatory variables in the GLM (CPUE-LogNormal error structured model) to compare the effect of them. Used model was as follows.

$$\text{Log}(CPUE_{ijkl} + const) = \mu + YR_{(i)} + QT_{(j)} + AREA_{(k)} + NHFCL_{(l)} + QT_{(j)}*AREA_{(k)} + YR_{(i)}*NHFCL_{(l)} + QT_{(j)}*NHFCL_{(l)} + AREA_{(k)}*NHFCL_{(l)} + e_{(ijkl....)}$$

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,

$QT_{(j)}$: effect of fishing season (quarter),

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

NHFCL(l) : effect of gear type (class of the number of hooks between floats),
QT (j)*AREA (k) : interaction term between quarter and sub-area,
YR (i)*NHFCL (l) : interaction term between year and gear type,
QT (j)*NHFCL (l) : interaction term between quarter and gear type,
AREA (k)*NHFCL (l) : interaction term between sub-area and gear type,
e(ijkl..) : error term.

Results

1) Historical trend of effort by NHF in each area

The historical change in the effort by NHF and ratio of used NHF was shown in Fig. 2. From Area 1 to 5, the trends of ratio of NHF used were basically similar. That is, NHF less than 7 was major until 1977 when it was replaced quickly by NHF 8-10 and NHF11-13 and the ratio of the large NHFs reached to 80-90% of total observations already in 1978. NHF 11 -13, the major NHF from early 1980s decreased dramatically in early 1990s and has replaced to NHF of 14 or more. This shift to larger number of NHF was obvious in western than eastern tropical. In the recent five years, the ratio of NHFCL20 – 21, the largest NHF, is about 10% in Area 5, 20% in Area 4, and reach up to 40% in the western areas, Area 1 and 3. Historical NHF change in Area 0 was a little bit different from other areas in term of relatively high ratio of NHF 5-7 till 1995.

2) Test of uniformity of gear configuration in each stratum by each vessel

In this study, it was assumed that gear configuration used by the same vessel would not be changed so much in the stratum (year, quarter and area). If gear is changed frequently from deep longline to regular longline or vice versa in the same stratum, concept of the method in this study would utterly be collapsed. Then, how many vessels changed their NHFCL in the same quarter and area was observed by each of five periods of year (Table 1). Ratio of the vessel which changed their NHFCL in the same stratum in the tropical Indian Ocean was not so high, ranged from 1.3 % to 8.1 % and about 5% in average, and was considered to be low enough to accept the assumption.

3) Determine of species combination to be used

In Fig. 3, historical change of species composition in each area from 1975 to 2002 was shown for each NHFCL. The species composition of even same gear category has considerably changed. Species compositions of different gear categories (NHFCL1 and 2) seem to be similar in area1, 4 and 5, and relatively different in area 0 and 2.

Ratio of correct estimation for NHFCL of DATA2 by applying four sorts of species composition was shown in Fig. 4 through the analyzed years. This ratio means the ratio of correct estimation in the observation whose NHFCL was judged to be NHFCL 1 or 2, that is, when NHFCL was not judged (unknown) they were not included in the observation. In this case, any substitution was not made for the lack of species composition to be referred. The average ratio of correct estimation was lowest (0.579) for the composition of two species combination (BET and YFT) and highest (0.615) for that of six species combination (BET, YFT, ALB, SWO, MLS and BUM). Basing on this results, it was determined that species composition of six species combination should be used.

4) Substitution of missing criteria

When there is not species composition to be referred for one or both NHFCL in the strata, two methods were applied, CASE1 without substitution and CASE2 with substitution, as described in the materials and methods. Ratio of correct estimation in all observations was shown in Fig. 5 for both cases in each year. Average of the ratio of correct estimation in CASE 1 (without substitution) was 0.615 in average, while that in CASE 2 (with substitution) were 0.629, a little bit higher than CASE 1. Abrupt decline in correct ratio of CASE1 observed in 1983, and 2000 and 2001, was almost disappeared in that of CASE 2. Correct ratio of CASE 2 was kept to be higher than 60% except about 50% from 1982 to 1986. The ratio of unknown, the observation whose NHFCL was not estimated, was high before 1977 and after 1990 (Fig. 6). This unknown ratio was 0.464 and 0.300 in CASE 1 and CASE 2, respectively. This means that about 47% of unknown observation in CASE 1 could be estimated by substitution in CASE 2.

In Fig. 7, ratios of NHFCL1 and 2 estimated for DATA 2 using above method of CASE 1, and ratios of real NHFCL recorded in the logbook were compared. Actual NHFCL ratio shows that the regular longline (NHFCL 1), which was more than 90% in 1975 and 1976, has quickly been replaced by NHFCL2 and decreased into about 10% after 1987. Whereas, although the estimated NHFCL 1 also showed declining trend from 1975 to 1990, the ratio was already low, about 65% in 1975, and the ratio about 30-40% in 1990s was higher comparing to the ratio of real gear configurations. That is, the large change in actual gear configuration was weakened in the estimated one.

5) Application of actual and estimated gear configurations into GLM for bigeye CPUE standardization

Actual and estimated gear configurations (NHFCL 1 and 2) were applied into GLM and effects of each NHFCLs on the bigeye CPUE were compared (Fig. 8). ANOVA table for each GLM run was shown in Table 2. In the both of estimated and actual NHFCLs, the effect NHFCLs, and interactions between NHFCL and year, quarter and area were significant in the GLM results. Basically, trends of effect of the both NHFCLs were similar between estimated and actual NHFCLs. However, difference of CPUE between estimated NHFCL 1 and 2 seems to be smaller than that between actual NHFCLs.

Discussion

The ratio of correct estimation of NHFCLs was 0.629 in average with substitution for lack of species composition to be referred (CASE 2), and was 0.619 in average without substitution (CASE 1). Ratio of unknown (not judged) in the all observation was 50-90% in CASE1 and 50-70% in CASE2. Most of these unknown judgments were caused by the lack of species composition for one of two NHFCLs. As indicated by Fig. 6, regular longline (NHFCL 1) which was more than 90% before 1977 decreased into less than 20% in 1987, about 10%, thereafter. Therefore before 1977 and after 1987, each area often contained only one NHFCL in the year and quarter. In this case, another NHFCL can not be estimated by the substitution used in this study.

Effect of each NHFCL on the bigeye CPUE derived from GLM showed that the effect of estimated NHFCLs was similar trend to that of the actual NHFCLs although difference of effects (CPUEs) between estimated NHFCL 1 and 2 was smaller than that between actual NHFCLs. Because about 30-40% of estimated NHFCL was mis-judged to another NHFCL, the difference of their effect would naturally become fainter and less contrastive than actual one. Nevertheless, effect of NHFCL, and each interaction between NHFCL and year, quarter and area were all significant according to the ANOVA table of GLM although SS (Sum of Square) of estimated NHFCL in all SS was only 0.7%, quite smaller than 4.4% of the actual NHFCL. Therefore, as far as there is not other reasonable indicator for the gear configuration in the tropical area, NHFCL estimated by the method in this paper would be worthy to apply for CPUE standardization.

In this paper, the most critical assumption while estimating gear configuration was that the gear configuration used by a vessel would be the similar in a stratum (year, quarter and area). Therefore the area definition used is very important for the precise estimation of the gear configuration. If heterogeneous fishing grounds are included in the same area, different gear configurations would possibly be included together in the quarter. In this study, the area definition used in the bigeye CPUE standardization was tentatively used. This area definition would be possible to be improved so as to reflect more uniformity of the gear composition by using statistical method like tree model or neural network.

Acknowledgement

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Table 1. The number and ratio of the vessel which change their gear configuration (from deep longline to regular longline, or vice versa) in the same year, quarter and area in reach period.

		No. of obdservation		Ratio of			No. of obdservation		Ratio of
Area	Year	Total	Variable	Variable	Area	Year	Total	Variable	Variable
0	1975-1979	144	2	0.014	3	1975-1979	127	2	0.016
0	1980-1984	271	10	0.037	3	1980-1984	223	19	0.085
0	1985-1989	402	17	0.042	3	1985-1989	320	1	0.003
0	1990-1994	164	3	0.018	3	1990-1994	127	5	0.039
0	1995-2002	346	28	0.081	3	1995-2002	614	46	0.075
1	1975-1979	194	5	0.026	4	1975-1979	153	2	0.013
1	1980-1984	453	28	0.062	4	1980-1984	256	18	0.070
1	1985-1989	557	13	0.023	4	1985-1989	473	21	0.044
1	1990-1994	171	5	0.029	4	1990-1994	192	10	0.052
1	1995-2002	440	14	0.032	4	1995-2002	774	35	0.045
2	1975-1979	114	3	0.026	5	1975-1979	699	17	0.024
2	1980-1984	483	30	0.062	5	1980-1984	622	29	0.047
2	1985-1989	715	35	0.049	5	1985-1989	505	28	0.055
2	1990-1994	274	20	0.073	5	1990-1994	231	14	0.061
2	1995-2002	507	41	0.081	5	1995-2002	775	54	0.070

Table 2. ANOVA table of GLM for the standardization of Japanese longline CPUE for bigeye using actual (left of table) or estimated (right of table) NHFCL in the model.

	Model (lognormal): Actual NHFCL					Model (lognormal): Estimated NHFCL				
Source	D. F.	S. S.	M. S.	F Value	Pr > F	D. F.	S. S.	M. S.	F Value	Pr > F
Model	86	964.63	11.22	37.05	<.0001	86	942.24	10.96	37.16	<.0001
	R-square=0.3970					R-square=0.3971				
Year	27	269.29	9.97	32.94	<.0001	27	272.81	10.10	34.27	<.0001
Quarter	3	26.04	8.68	28.67	<.0001	3	45.62	15.21	51.57	<.0001
Area	5	83.61	16.72	55.23	<.0001	5	71.83	14.37	48.73	<.0001
NHFCL	1	33.39	33.39	110.28	<.0001	1	8.58	8.58	29.08	<.0001
QT*Area	15	51.54	3.44	11.35	<.0001	15	75.14	5.01	16.99	<.0001
YR*NHFCL	27	15.29	0.57	1.87	0.0041	27	29.43	1.09	3.70	<.0001
QT*NHFCL	3	2.91	0.97	3.21	0.0221	3	4.25	1.42	4.80	0.0024
Area*NHFCL	5	35.70	7.14	23.58	<.0001	5	23.31	4.66	15.81	<.0001

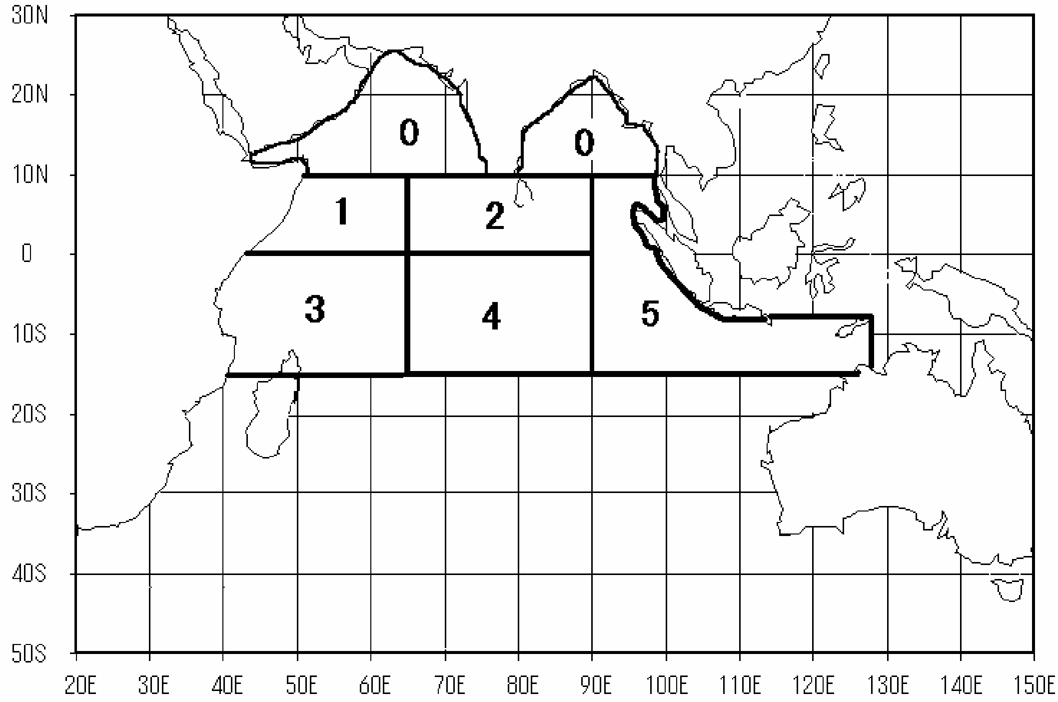


Fig. 1. Area definition used in this study.

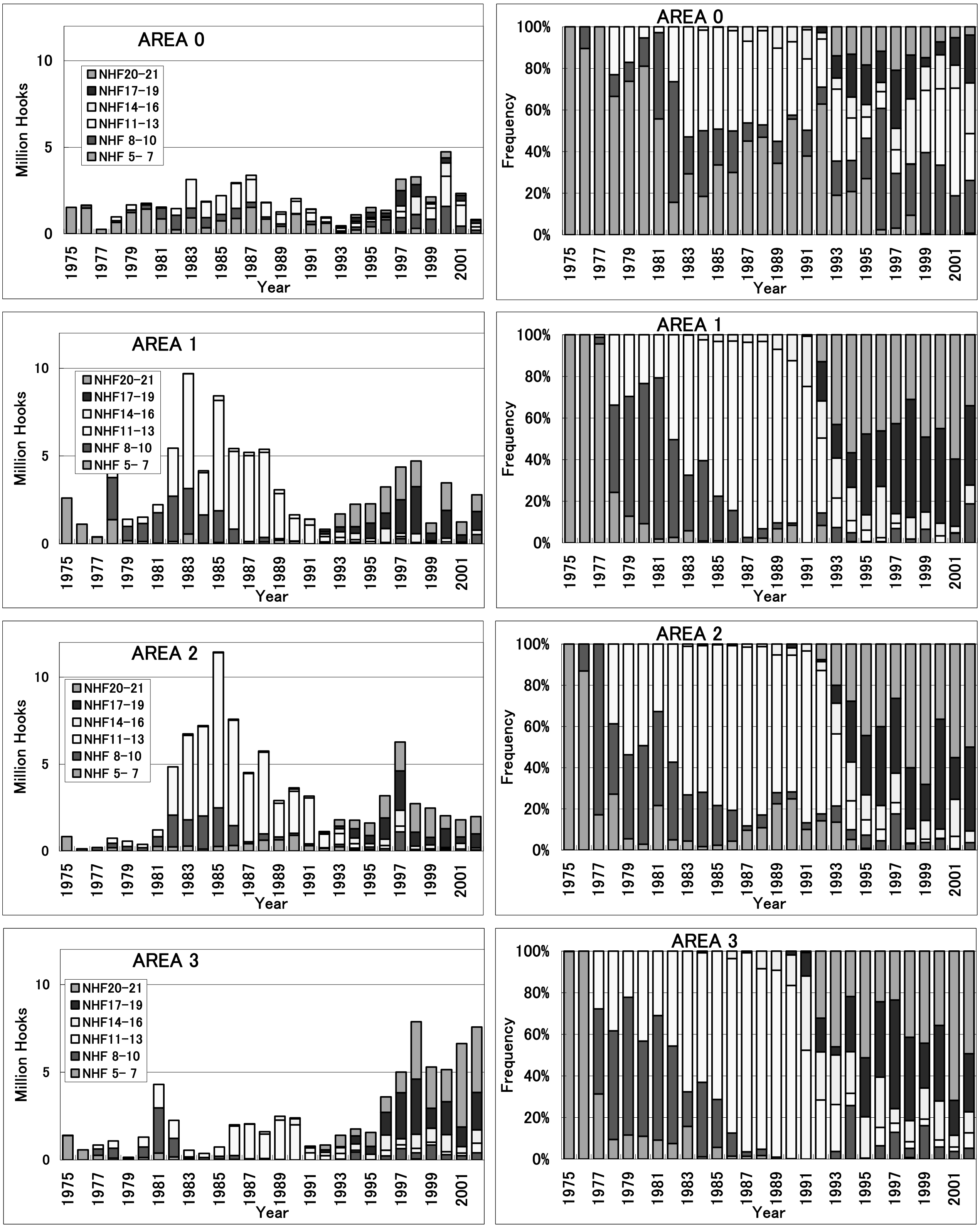


Fig. 2. Historical change of NHF used in each area in the tropical Indian Ocean from 1975 to 2002.

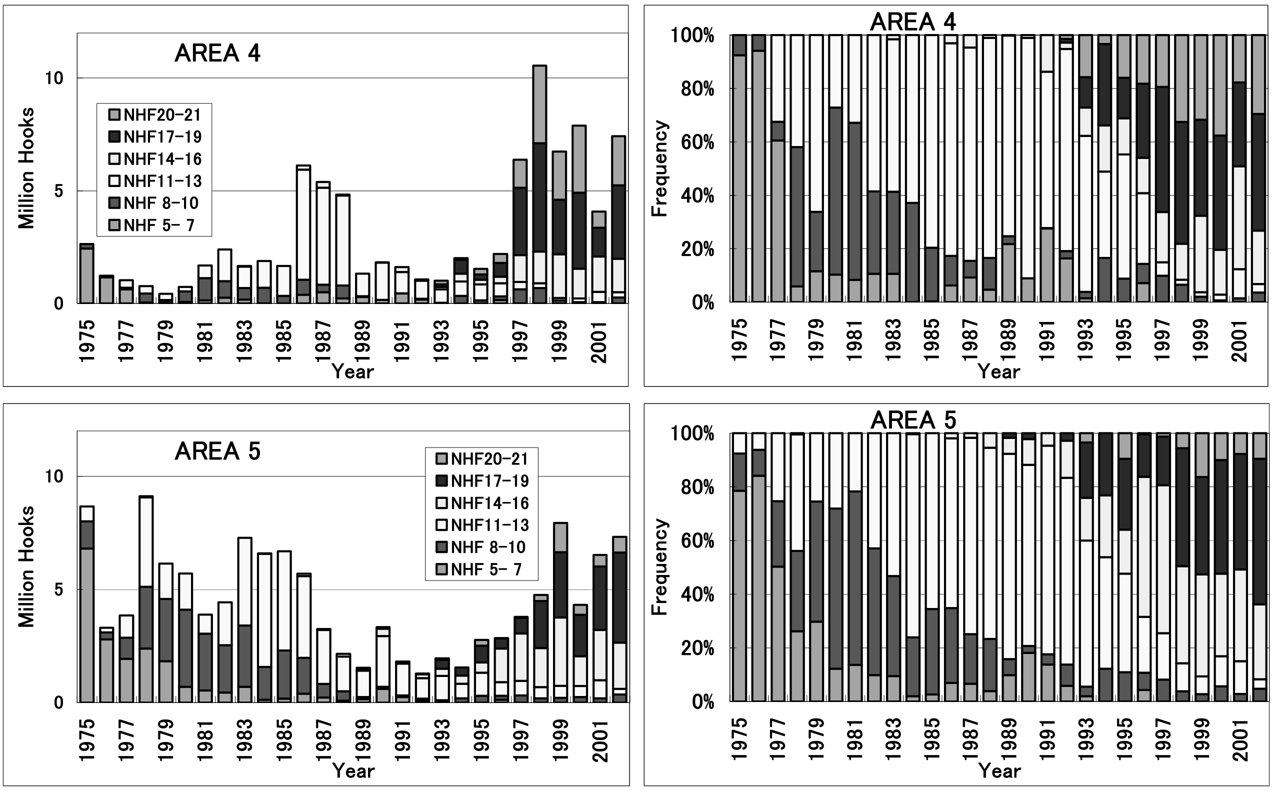


Fig. 2. Continued.

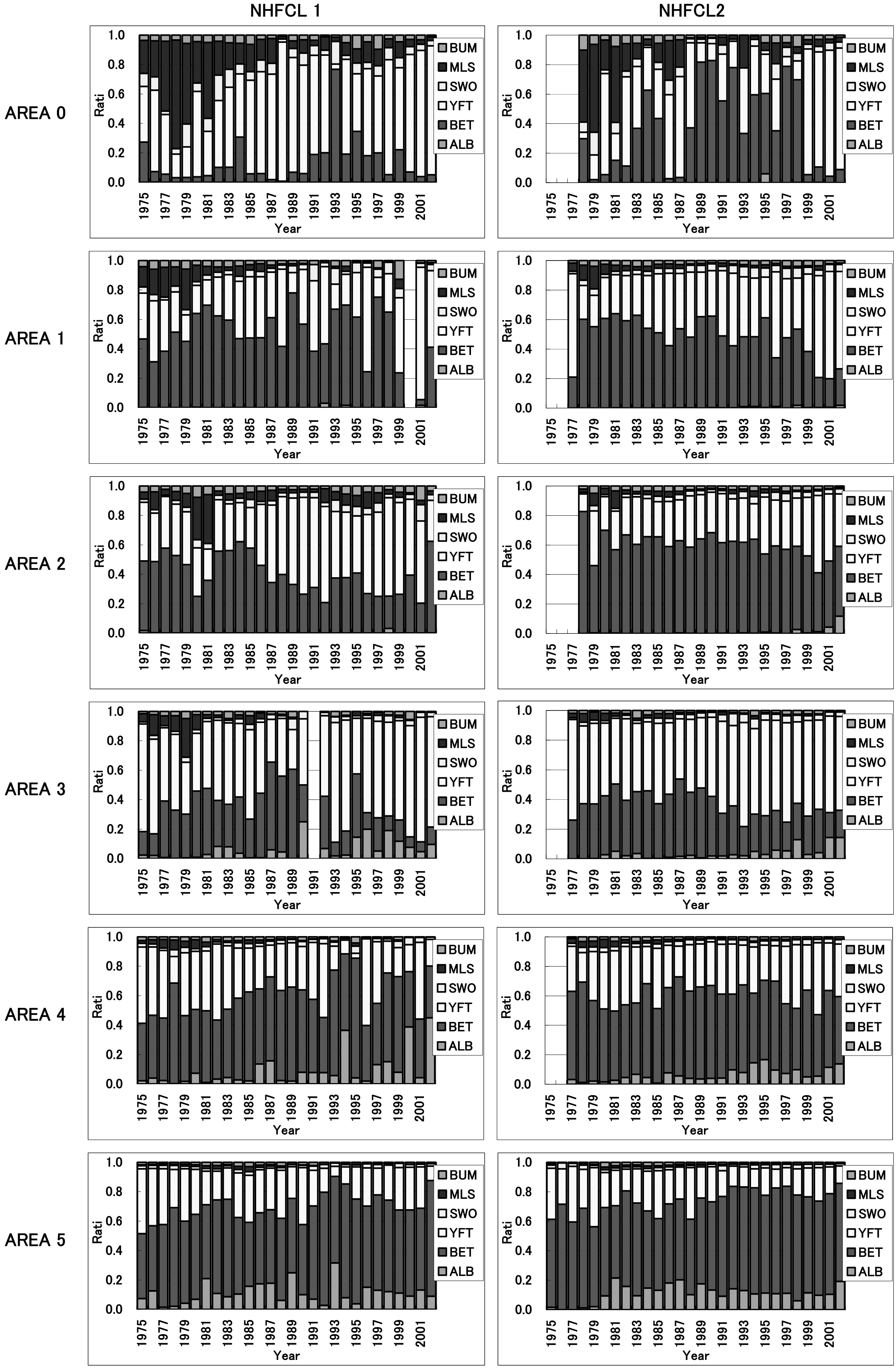


Fig. 3. Historical change in the species composition of longline catch by area in the tropical Indian Ocean from 1975 to 2002

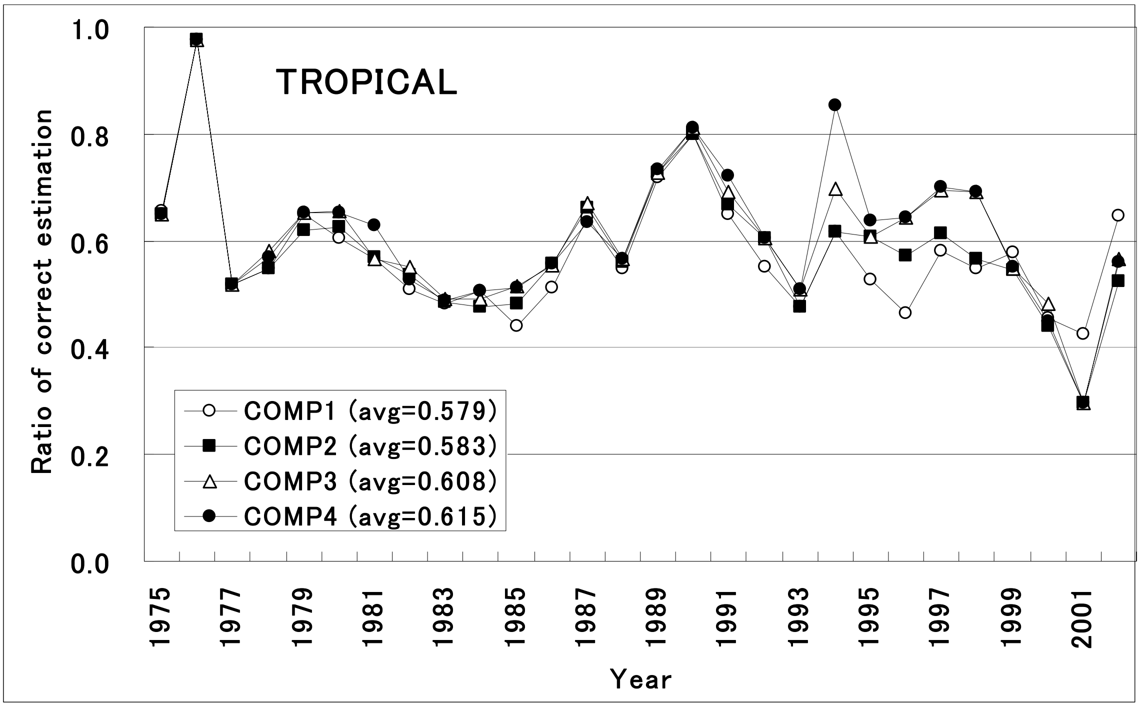


Fig. 4. Comparison of correct estimation ratio between four sorts of species composition used for estimation of NHFCL.

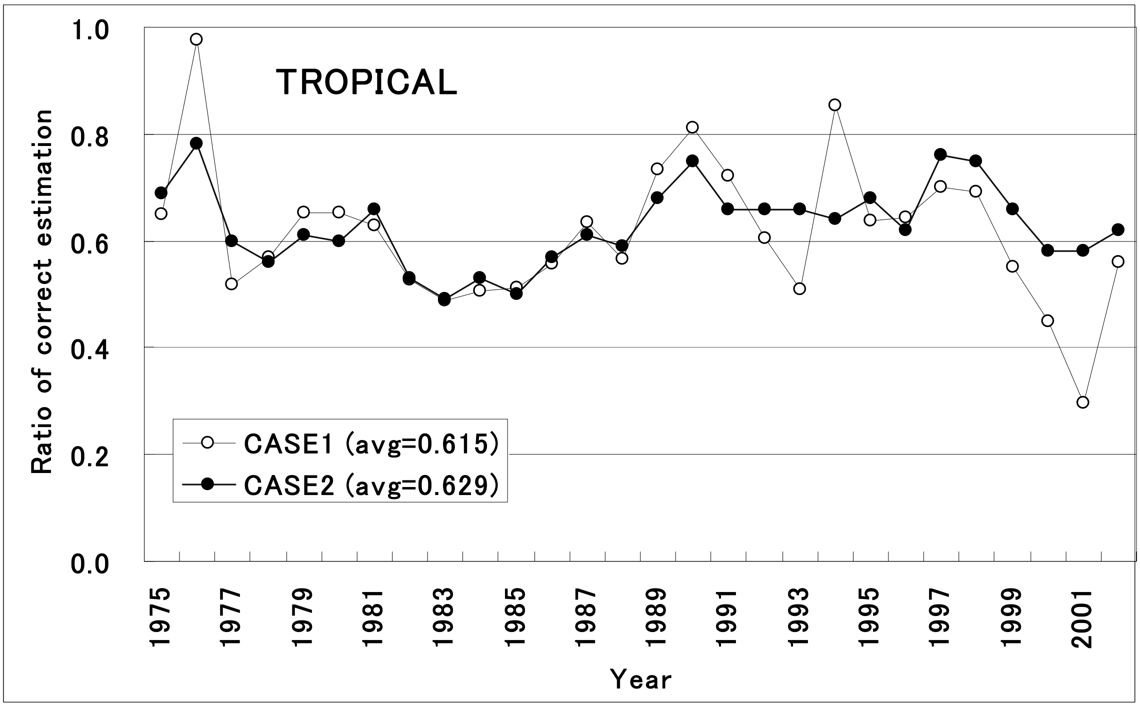


Fig. 5. Comparison of correct estimation ratio between two cases, without (CASE 1) and with (CASE 2) substitution for the lack of species composition to be referred for one or both NHFCL in the strata.

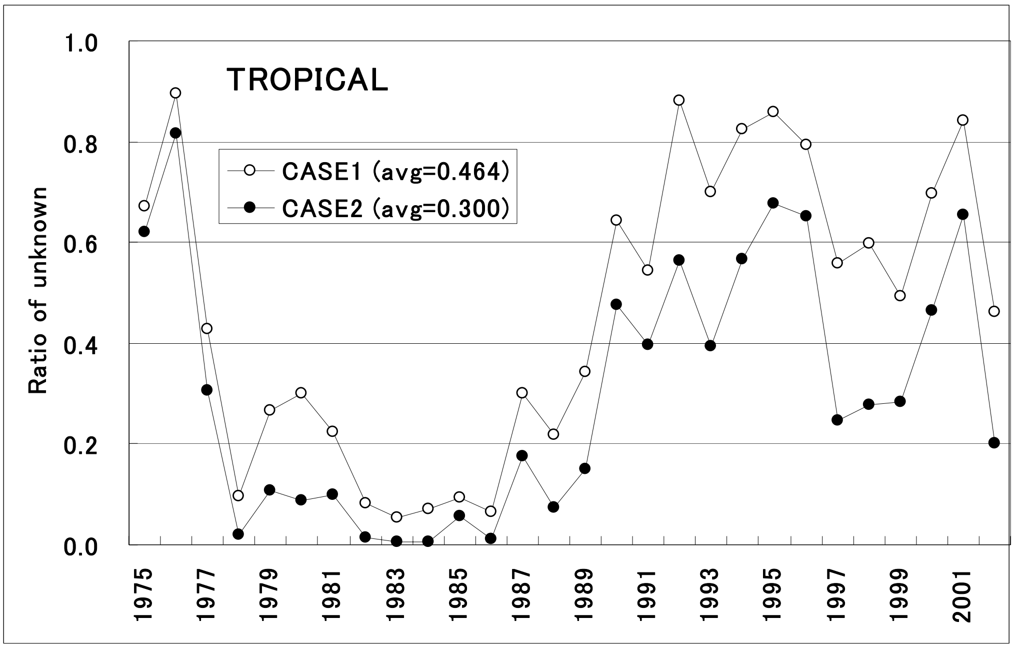
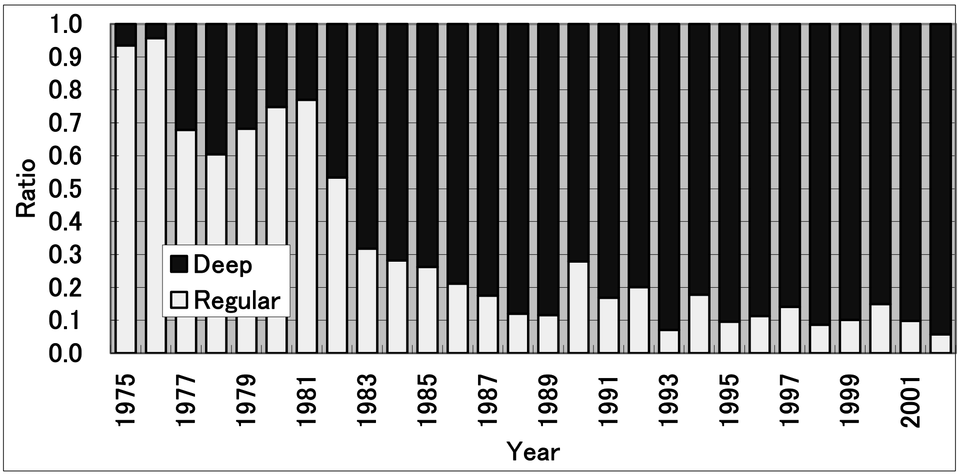


Fig. 6. The ratio of observations in DATA 2, whose gear configuration could not be determined.



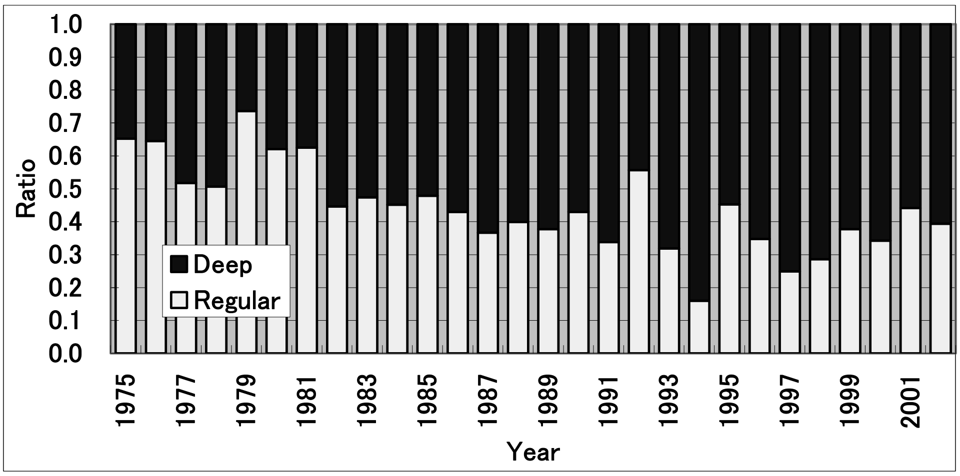


Fig. 7. Ratios of actual (top) and estimated (bottom) NHFCLs (Regular = NHFCL 1 and deep = NHFCL 2) for the DATA 2.

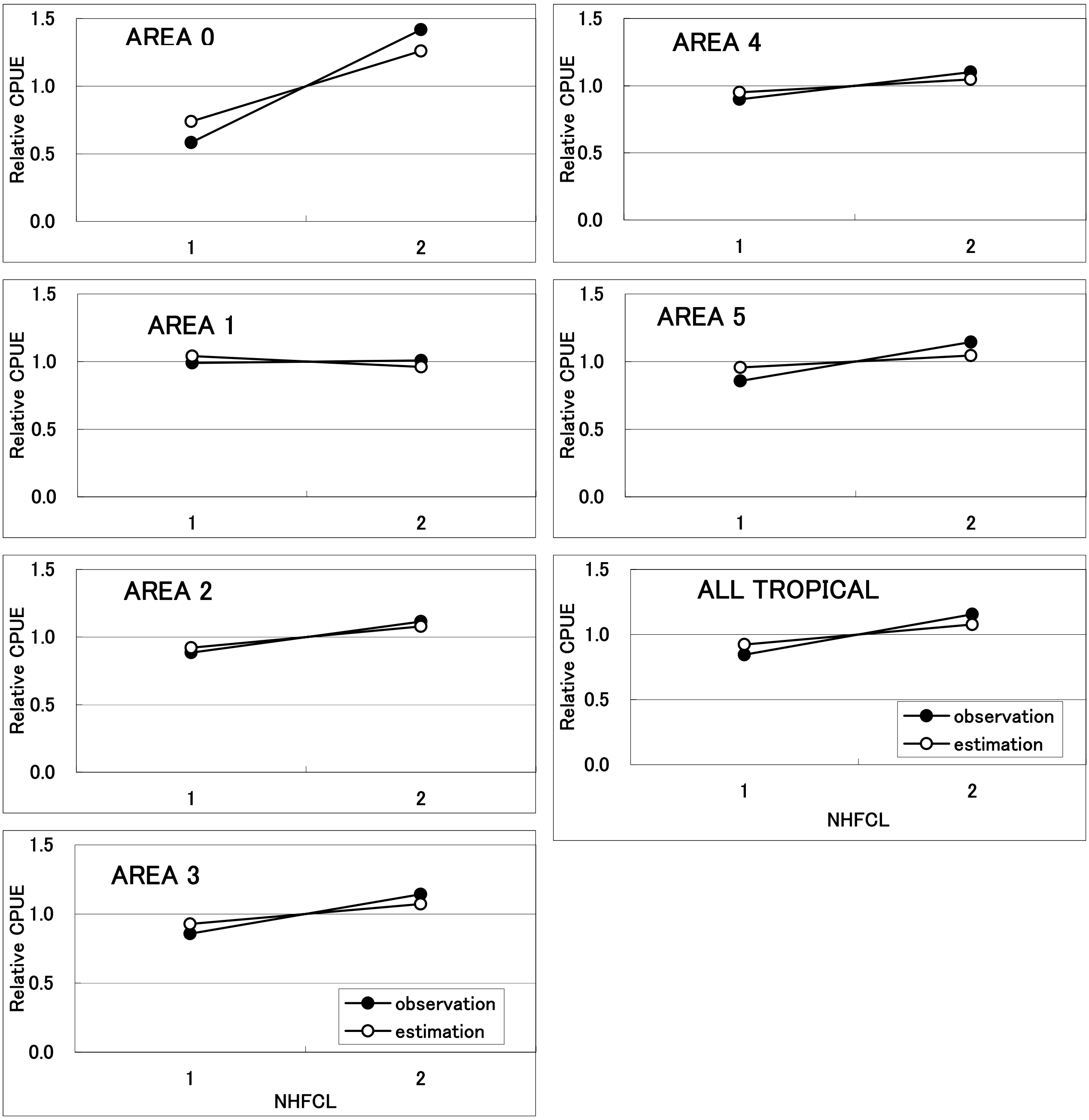


Fig. 8. Comparison of the effects of actual and estimated NHFCL 1 and 2 in the standardization of Japanese longline CPUE for bigeye estimated by GLM.