MODELING OF BYCATCH OCCURRENCE RATE OF SEABIRDS FOR JAPANESE LONGLINE FISHERY OPERATED IN SOUTHERN HEMISPHERE

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SUMMARY

We modeled the bycatch occurrence rate in consideration of factors of year and season and examined longitudinal changes in the rate across years. We used operational data obtained by scientific observers from 1997 through 2015. As a preliminary analysis, differences in species composition of seabirds bycaught between northern and southern regions of waters south of 20^{0}S were examined through hierarchical cluster analysis. Bycatch species composition was changed at the boundary of 40^{0}S, 35^{0}S and 40^{0}S, off Cape, in Indian Ocean and in the Tasman Sea, respectively. Presence/absence of seabird bycatch data by set was modeled with the generalized additive model (GAM). The data for the GAM analysis were split in two by a boundary dividing the data into northern and southern areas. Estimated bycatch occurrence rate varied at relatively low level in the model of the northern area, while that varied at relatively high level in the model of the southern area. Bycatch occurrence rates in an east-west direction differed not only among year periods but also among seasons in both waters north and south of 35^{0}S. It was suggested the importance of consideration of longitudinal variation of bycatch occurrence rate among year and season to estimate total bycatch number.

KEYWORDS generalized additive model, seabird bycatch occurrence rate, latitude, longitude

1 Introduction

Strengthen seabird bycatch mitigation measure has been required in the southern hemisphere where some vulnerable albatross species occur (IUCN 2015). Regulations to implement two of three mitigation technics such as tori line, night setting and branch line weighting had been implemented since July 2013 in the ICCAT conventional area and since July 2014 in the IOTC and WCPFC conventional areas. The regulations covers the waters south of 25^{0}S and 30^{0}S in the ICCAT and IOTC conventional areas and the WCPFC conventional area,

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respectively (ICCAT Rec11-09, IOTC Res12/06, WCPFC CMM 2012-07). Evaluation of effectiveness of the regulations is required within few years after implementation in ICCAT and IOTC. This evaluation should be carried out with bycatch number and/or bycatch rate obtained from integrated data contributed by countries and members concerned. Therefore, it is required to model bycatch number or bycatch rate precisely. Inoue et al. (2016) examined the factors affecting bycatch occurrence rate in the light of interactions potentially existing among factors using random forest. As a result, they found that variables of latitude, year, season and species group played an important roles to estimate the bycatch occurrence rate. In this paper, we modeled the bycatch occurrence rate in consideration of factors of year and season and examined longitudinal changes in the rate across years.

2 Materials and methods

2.1 Data preparation and processing

We used operational data obtained by scientific observers from 1997 through 2015. These data included two types of information. The former was information on operation including time and position of start and end of line setting, climate, hydrographic condition, gear configuration, species of bait and seabird bycatch mitigation measures applied. The latter was information including time at loading on board, species, length and body weight for each catch or bycatch. In addition, the scientific observers took photos of catch and bycatch and gathered samples of otolith and muscles. In CCSBT fishery, the scientific observers boarded randomly-selected distant water longline vessels, which operated in the Atlantic, Indian and Pacific Oceans with targeting southern bluefin tuna (Yamasaki et al. 2016). In the ICCAT conventional waters, 1564 sets of 30 trips and 1076 sets of 20 trips were observed in 2013 and 2014, respectively (Japan 2016). Those coverage rates for total number of sets were 7.0% and 12.1%, respectively. In the IOTC conventional waters, the scientific observers covered 360, 557, 472, 420 sets from 2010 through 2013, respectively, of which the coverage rates were 7.5%, 6.3%, 4.9% and 4.6% (NRIFSF and Fisheries Agency 2015). Japan Observer Program required the on-board scientific observers to take photos of specific regions and whole bodies of seabirds bycaught. Species identification were conducted with the photos of seabirds bycaught through a collaboration of NRIFSF and Birdlife International.

The data derived from longline sets carried out south of 20^0S were used for statistical analysis in this study. These data were divide into two periods corresponding to breeding period (season 1) of albatross and petrels and their non-breeding periods (season 2). The season 1 and 2 are staring from October and April and ending to March and September, respectively. Based on knowledges that age at first maturity for albatrosses is around ten years-old and, moreover, total egg production per maturity was one, resulting in nature of low productivity for albatrosses, it was supposed that there were small annual variations of overall population size for albatrosses in a term less than around five years. Hence, year factors were converted into the following periods, 1997-1999, 2000-2004, 2005-2009, 2010-year of pre-implementation of the regulations for seabird bycatch mitigation (2010-pre-impl.), and years of post-implementation of those up to 2015 (post-impl.-2015).

2.2 Cluster analysis

As a preliminary analysis, differences in species composition of seabirds bycaught between northern and southern regions of waters south of 20^0S were examined through hierarchical cluster analysis. The data for number of bycatch by species and by set were aggregated into the grids mentioned as follows. Three areas of the waters off Cape (70^0W-60^0E), the Indian Ocean (60-120^0E) and the Tasman Sea (120-180^0E) were defined. Each of areas were separated into latitude classes at an interval of 5 degree such as 20-25^0S, 25-30^0S, 30-35^0S, 35-40^0S, 40-45^0S and 45-50^0S. Information on individual species included in albatrosses were classified into species groups such as wandering albatrosses, black-browed albatrosses, yellow-nosed albatrosses, shy-type albatrosses, Grey-headed albatrosses. Northern and southern giant petrels were included into giant petrels. Species other than those mentioned above were treated as individual species. Number of bycatch by group by area were converted into bycatch rate (number of bycatch per 1000 hooks) by dividing by a sum of hooked by area observed by the scientific observers. Cluster analysis were conducted for each area. Functions of 'hclust' and 'dplyr' of R package (Wickham and Francois 2016) were applied for this statistical analysis.

2.3 GAM for bycatch occurrence rate

Inoue et al. (2016) indicated that factors of year, longitude and season had effects on seabird bycatch occurrences through the analysis using random forest. Based on this result, presence/absence of seabird bycatch data by set were modeled using those factors as explanatory variables with generalized additive model (GAM). Smoothing spline was fitted only to an effect of longitude and rest of explanatory variables were used as categorical variables.

The data for the GAM analysis were split in two by a boundary dividing the data into northern and southern areas because of definite differences in species composition between two areas (See results). Latitudes of the boundary were set at 30^0S, 35^0S and 40^0S and optimal one was determined by BIC. Moreover, number of knots for the smoothing spline were changed from 1 to 10 through the GAM calculations and, finally, optimal one was determined by BIC.

3 Results

3.1 Cluster analysis

Bycatch rates tended to increase to south expect for that in 25-30^0S latitude class in Indian Ocean (**Fig. 1**). There were obvious differences in species compositions among the latitude classes in each area. In the waters off Cape, definite differences in species composition were found in the latitude classes north and south of 40^0S. The bycatch rates for white-chinned petrels were the highest in the latitude classes south of 40^0S, although the bycatch rates for grey-headed albatrosses recorded the highest in the latitude classes south of 40^0S. In the Indian Ocean, the bycatch rate for yellow-nosed albatrosses were dominant in the northernmost latitude class and decreased to south. In contrast, the catch rate for grey-headed albatrosses, which increased to south, was dominant in the latitude classes of 35-40^0S and 40-45^0S. In the Tasman Sea, wandering albatrosses occurred in all the latitude classes. The bycatch rates for shy-type albatrosses and Buller's albatrosses increased to south, which were the second highest and the highest in the latitude class of 40-45^0S, respectively.

3.2 Bycatch occurrence rates by latitude

BIC touched bottom when, using the data split at 35^0S, 1 to 3 knots and 8 knots were applied for estimation of smoothing splines for the longitude effects in northern and southern areas in the GAM analysis, respectively (**Fig. 2**). We employed the 3 and 8 knots for northern and southern area, respectively. Total number of observations of zero/positive bycatch data was 1,922 and 11,721 for the waters north and south of 35^0S, respectively (**Table 1**). There were no observations in season 1 of post-impl.-2015 in the waters north of 35^0S. Small numbers of observations of 19 and 10 were recorded in season 1 of 1997-1999 and the latest year period in north and south of 35^0S, respectively.

3.3 Bycatch occurrence rate by longitude

Bycatch occurrence rates varied among longitude. In general, bycatch occurrence rates in an east-west direction differed not only among year periods but also among seasons in both waters north and south of 35^0S (**Figs 3 (A) and (B)**). Moreover, the bycatch occurrence rates from the waters south of 35^0S were lager than those from the waters north of 35^0S, where most of the bycatch occurrence rates were estimated to be less than 0.25.

In the waters north of 35^0S (**Fig 3 (A)**), the longitudes where high bycatch occurrence rates over 0.25 changed among seasons. In season 1, there were no observations at the latitudes west of 20^0E in all year periods. A bump of the rate appeared between 50^0E and 100^0E in 2000-2004. In addition, in 2010-pre-impl., the bycatch occurrence rate increased in waters east of 150^0E corresponding to Tasman Sea. In season 2, the bycatch occurrence rate increased at the latitudes east of 150^0E in 1997-1999. A peak appeared at the latitudes around 75^0E in 2000-2004, although there were no observations of positive bycatch in this region.

In the waters north of 35^0S (**Fig. 3(B)**), overall bycatch occurrence rates in season 1 were estimated to be higher than those in season 2. Multiple peaks of the rate were found in all combinations of year periods and seasons due to 8 knots applied for estimation on the smoothing splines. In season 1 of all year periods, no observation at longitudes west of 20^0E or 30^0E was deemed to cause plateau of 1.0 of the bycatch occurrence rate. In season 1, the by catch occurrence rate showed the peak at the longitudes around 150^0E, corresponding to the Tasman Sea, in 2010 and after. In season 2, overall rates before 2005 were smaller than those in 2005 and after. The latitudes around 150^0E (Tasman Sea) had a peak of the rate in 2005 and after.

4 Discussion

4.1 Differences in bycatch occurrence rate between northern and southern part of study area

It was shown that the optimal latitude of the boundary dividing the data into northern and southern areas was 35^0S through the GAM analysis. The models of lowest BICs were the ones that the knots were 1-3 in north, the knot was in south and boundary was 35^0S (Fig 2). The model of second lowest BIC was the model that the knot was 10, and other values were same as lowest model, and the lowest BIC was 14797 and second lowest BIC was 14820 thus, there is not large but concrete difference between lowest and second lowest BIC. The cluster analysis revealed that bycatch rate for grey-headed albatrosses was dominant in the waters south of 40^0S and 35^0S in off Cape and the Indian Ocean, whereas yellow-nosed albatrosses occurred frequently in the waters north of those latitudes. Species-specific distribution pattern of seabirds changed in a north-south direction depending on changes in oceanographic environment by latitude (Pinaud and Weimerskirch 2007). Differences in species compositions between northern and southern waters might affect bycatch occurrence, resulting in construction of the model for the bycatch occurrence rate for the data divided into north and south of 35^0S.

Overall bycatch occurrence rates in the waters south of 35^0S were larger than those in the water north of 35^0S. In particular, higher bycatch rates were recorded for grey-headed and black-browed albatrosses in the waters of south of 35^0S. Grey-headed albatrosses are one of the susceptible species to bycatch and, indeed, the number of bycatch is the most in albatrosses. In addition, black-browed albatrosses is also susceptible to bycatch. It is thought that frequent occurrence of bycatch for these species contribute the higher bycatch occurrence rate estimated by the model for the waters of south of 35^0S. This result is consistent with that derived from the random forest analysis conducted by Inoue et al. (2016).

4.2 Longitudinal changes in bycatch occurrence rate

Smoothing spline was seemed to be successfully fitted to observed bycatch occurrence rate. The knot of south model was 8 and it indicated that the bycatch occurrence rate would have high variation among longitude. It predicted the peaks of the rate occurring at the latitudes around 100^0E and between 120^0E and 150^0E. The longitudinal changes in the bycatch occurrence rate estimated in this study were not similar to those estimated through random forest conducted by Inoue et al. (2016). As a reason for this difference, it is thought that the bycatch occurrence rate was estimated for each year period in detail. In this study, the bycatch occurrence rate was predicted differently among years and through east – west direction.

In the waters south of 35^0S, the bycatch occurrence rates in season 2 decreased after implementation of the regulations (Fig. 3, post-impl.-2015). The implementation of the regulation might reduce chances of bycatch. The rate, however, did not change before and after the implementation of the regulation in season 1. In order to verify the reason, further analysis on changes in the occurrence of bycatch after the implementation with accumulation of the data in future.

In the waters south of 35^{0}S, the bycatch occurrence rates in season 1 were estimated to be higher than those in season 2, consistent with the result from Inoue et al. (2016). Season 1 overlaps breeding period for bycatch-susceptible species of albatrosses and petrels. Albatrosses and petrels are inferred that they tend to aggregate around longline vessels engaging line setting to have easier feeding during their breeding period due to their increase of forage requirements.

4.3 Availability and limitation of GAM and future study

In this study, the bycatch occurrences were predicted by year period and by season through the GAM analysis. A Procedure in this study is considered to have a potential to apply the data of countries and members concerned. As a first step, the bycatch occurrence rates could be compared within the longitudes where the data are available for several countries and members concerned.

In our model, the bycatch occurrence rate was predicted differently among years, season and through longitude direction, thus it is suggested the importance of consideration of longitudinal variation of bycatch occurrence rate among year and season to estimate total bycatch number.

In 2010-pre-impl., higher bycatch occurrence rate were predicted at the longitudes of 50-90^{0}E where there were no observations. And Bycatch occurrence rate before 2010 in the Tasman Sea supposed to be low from raw data, but a strong peak of bycatch occurrence rate in the Tasman Sea was predicted. This result is thought to be caused by constraint of fixed number of knots on the smoothing spline. In this model, it requires attention that the peak is sometimes too extreme. One of resolution for the problem, it would be effective to estimate bycatch rate with using zero-inflated GAM.

At this stage, application of GAM is limited in estimation of the bycatch occurrence rate. We need bycatch rate if total number of bycatch is calculated. Further modification of modeling technics and accumulation of observations are required to estimate the bycatch rate through the GAM analysis.

References

Inoue Y, Kanaiwa M, Yokawa K, Oshima K (2016) Examination of factor affecting to bycatch occurrence rate of seabirds in southern hemisphere by Japanese pelagic longline fisheries with using Random Forest. ///////

IUCN (2015) http://www.iucnredlist.org/

Japan (2016) Report of Japan's scientific observer program for tuna longline fishery in the Atlantic Ocean in the fishing years 2013 and 2014. SCRS/ 2015/152. Collect. Vol. Sci Pap ICCAT 72: 2328 – 2338.

National Research Institute of Far Seas Fisheries, Fisheries Agency (2015) Japan National Report to the scientific committee of the Indian Ocean tuna commission, 2015. IOTC-2015-SC18-NR12[E].

Pinaud D and Weimerskirch H (2007) At-sea distribution and scale-dependent fraging behavior of petrels and albatrosses: a comparative study. Journal of Animal Ecology 76: 9 – 19.

Yamasaki I, Ito T, Oshima K, Matsunaga H (2016) Report of Japanese scientific observer activities for southern Bluefin tuna fishery in 2014 and 2015. CCSBT-ERS/1609/20.

Table 1. Number of observations of zero bycatch and positive bycatch by year period and by season.

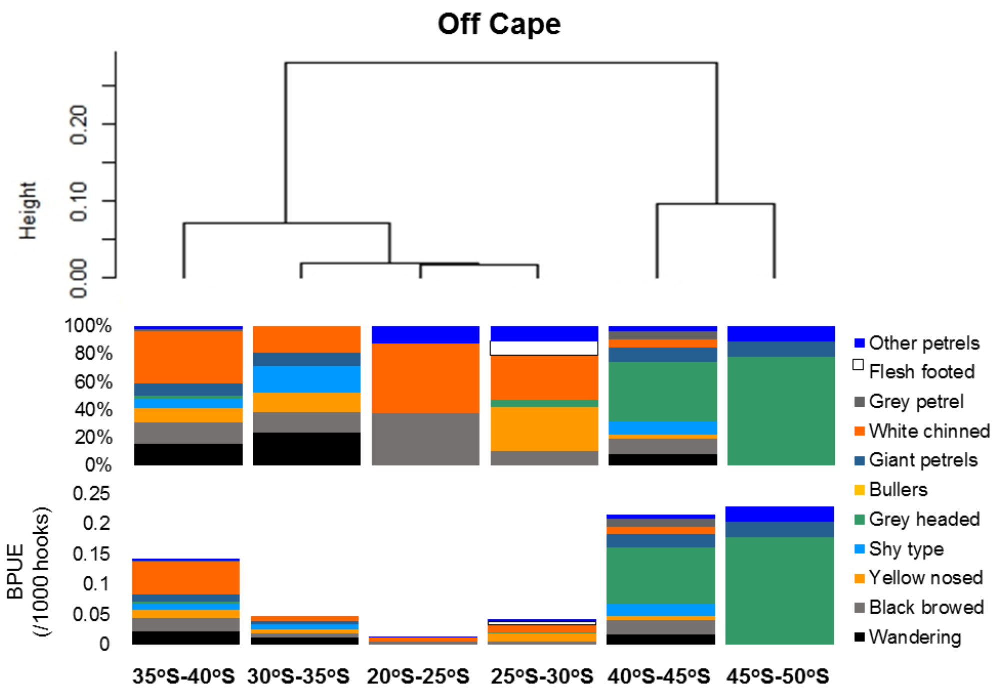
North of 35^0S

Year period	Season 1		Season 2		Combined		Total
	Zero bycatch	Positive bycatch	Zero bycatch	Positive bycatch	Zero bycatch	Positive bycatch	
1997-1999	19	0	97	20	116	20	136
2000-2004	151	26	39	11	190	37	227
2005-2009	76	5	198	43	274	48	322
2010-pre-impl.	83	5	716	90	799	95	894
post-impl.-2015	0	0	293	50	293	50	343
Total	329	36	1,343	214	1,672	250	1,922

South of 35^0S

Year period	Season 1		Season 2		Combined		Total
	Zero bycatch	Positive bycatch	Zero bycatch	Positive bycatch	Zero bycatch	Positive bycatch	
1997-1999	349	185	2,361	784	2,710	969	3,679
2000-2004	486	330	2,055	509	2,541	839	3,380
2005-2009	205	112	1,097	394	1,302	506	1,808
2010-pre-impl.	47	94	1,068	413	1,115	507	1,622
post-impl.-2015	2	8	711	511	713	519	1,232
Total	1,089	729	7,292	2,611	8,381	3,340	11,721

(A)



(B)

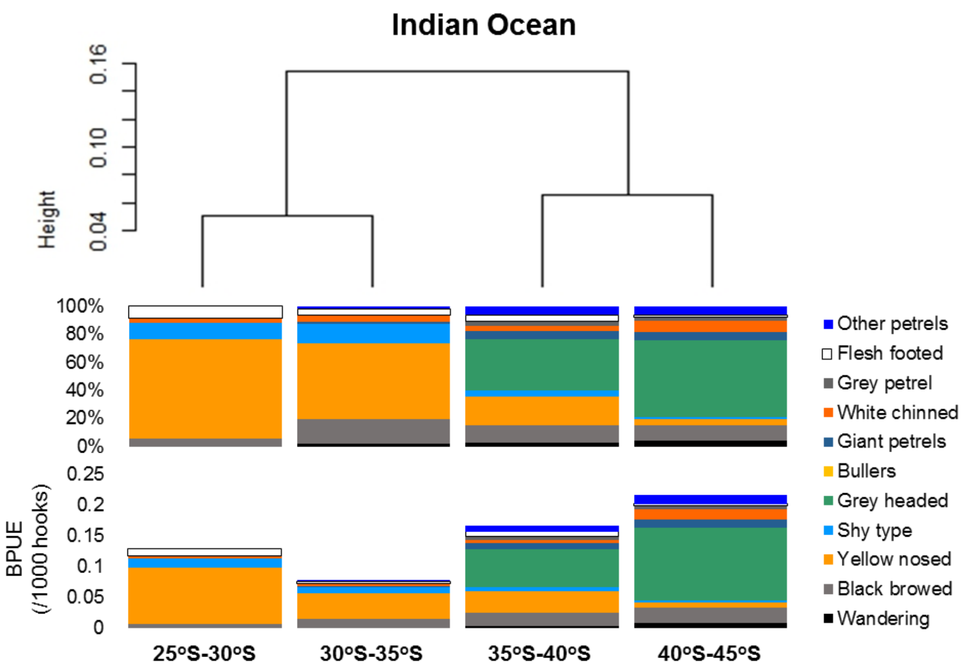


Figure 1. Dendrogram, species composition and species-group specific bycatch rate (BPUE) by latitude class for waters of Cape (A), Indian Ocean (B) and Tasman Sea (C).

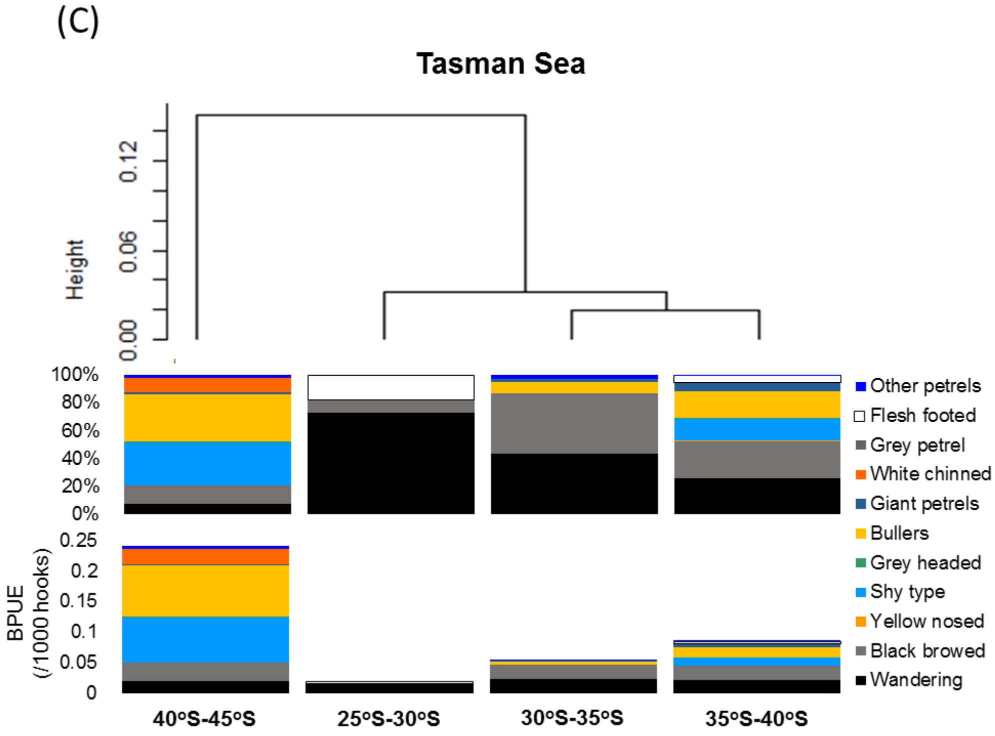


Figure 1. *Continued*.

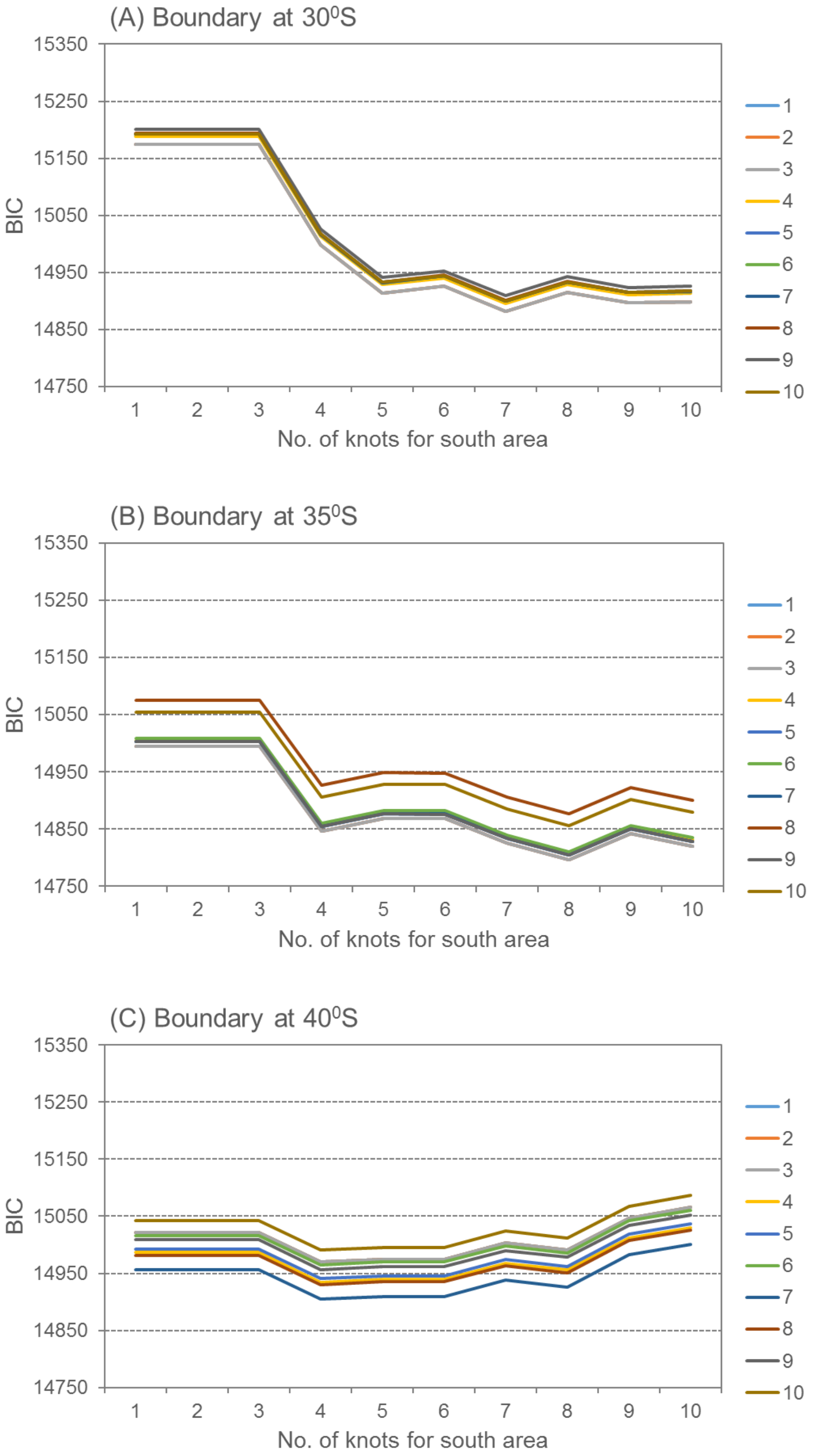


Figure 2. Variation in BIC in case of data split at boundary set at 30^0S, 35^0S and 40^0S. In each panel, BIC were calculated for all combinations of sequence of number of knots from 1 through 10 for north and south areas.

(A) North of 35^0S

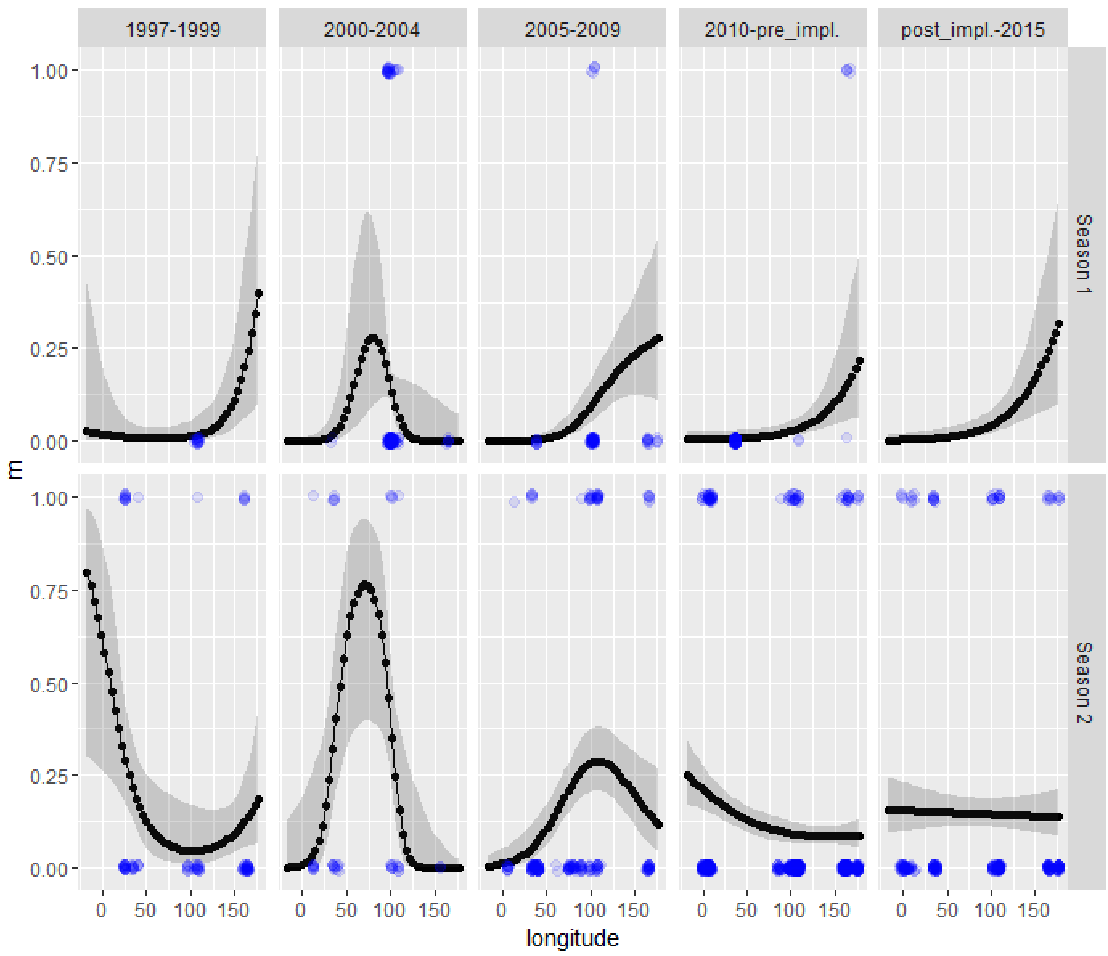


Figure 3. Longitudinal change in bycatch occurrence rate in the waters north (A) and south (B) of 35^0S. Blue circles indicate individual observations of zero/positive bycatch by operation.

(B) South of 35^0S

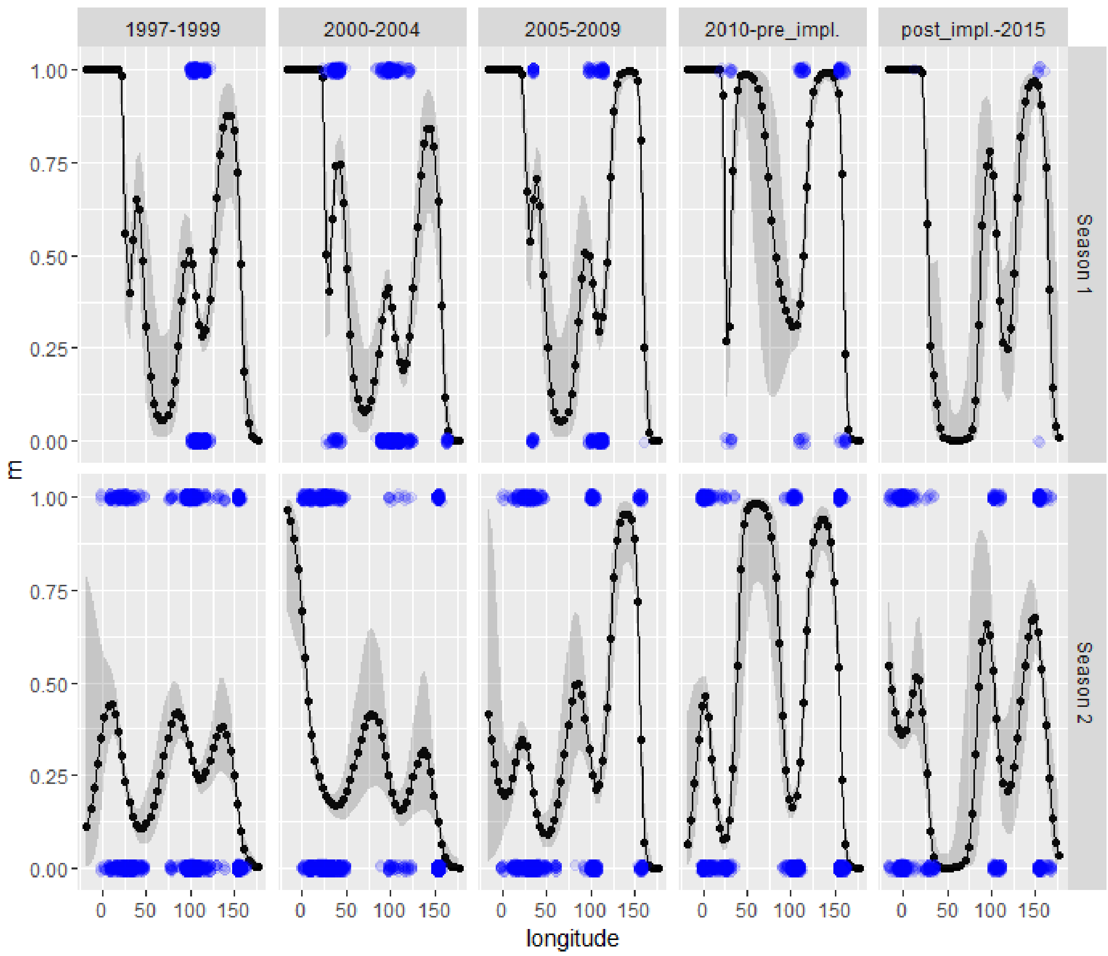


Figure 3. *Continued*.