Examination of factors affecting seabird bycatch occurrence rate in southern hemisphere in Japanese longline fishery with using random forest

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SUMMARY

We analyzed the factor affecting bycatch occurrence rate. Random forest was applied to analyze. We constructed four models examining effect of species group, season, year, environmental factors, distance from the colonies, a lunar phase, and catch of fish. Our model was likely to be a statistically appropriate model because out of bags is an acceptable range though a little high. Dominant variables in common with analyzed four models were latitude, longitude, elapsed days from the first day of the year, number of observed hooks, species group, sea surface temperature in this study. Also year, cruise ID and lunar phase were dominant variables in common with two to three models. Those variables would have the large impact on bycatch occurrence rate. Thus, it was suggested that those variables should be considered in the comparison between CPCs and in the collaboration work.

KEYWORDS random forest, bycatch occurrence rate, seabird species group

1. Introduction

Particular seabird bycatch mitigation measure has been required in the southern hemisphere because some vulnerable albatross species occur here (IUCN 2015). Regulation was introduced from July 2013, south of 25S in ICCAT conventional area, from July 2014, south of 25S in IOTC conventional area, from July 2014, south of 30S in WCPFC area, which is to choose two from three mitigation measure, Tori line, night setting and branch line weighting (ICCAT Rec11-09, IOTC Res12/06, WCPFC CMM 2012-07). Validation of effect of the regulation is required within few years in ICCAT and in IOTC. It is examined by bycatch number or/and bycatch rate with using combined data of related member country. In this time, it is required to consider what factor affecting bycatch rate and bycatch number is and what kind of framework is needed for the analysis.

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We had tried the preliminary analysis with using Japanese seabird bycatch data of high latitude in the southern hemisphere. It was found that seabird bycatch rate in that area could be affected not only by seabird distribution area where longline fisheries were operated but also by several factors such as oceanic condition, seabird species composition, techniques to use as bycatch mitigation measures. In this document, we made the model adding the factor affecting the bycatch occurrence rate per a set, as many as possible. And to find the dominant factor from those factors, we analyzed the model which divided into the species group. Briefly, we analyzed the factor affecting bycatch occurrence rate including species group, season, year, environmental factors, distance from the colonies, which supposed to affect seabird distribution, a lunar phase which supposed to affect seabird activity, and catch of fish which supposed to reflect targeting.

2. Material and method

Not only seabird abundance in fishing ground but also other several factors would be related to seabird bycatch occurrence. Random forest was applied to analyze the factor affecting seabird bycatch occurrence. Random forest is a developed version of regression tree and it could consider uncertainty in parameters and input data with resampling both of them. Though interactions among variables, sometimes having strong effect, have to be considered in Generalized Linear Model (GLM) analysis, amount of data used in this study was not enough to consider the interactions. For example, in the GLM analysis, it is needed that data is required in all combination of level between the interaction variables when considering the interactions between season and year, or year and species group. However, the random forest does not require data in all combination of the level between interaction variables and also it could consider interaction term automatically.

2.1 Data

2.1.1 Data from observer program

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 of catch or bycatch, species, body length and body weight. In addition, the scientific observers took photos of catch and bycatch and gathered samples of otolith and muscles. In longline operations relevant to CCSBT, 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 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 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.

2.2 Modeling of bycatch occurrence rate with using the random forest

2.2.1 Response variables

The data derived from longline sets carried out south of 20^0S were used for statistical analysis in this study. Occurrence or not-occurrence of bycatch among species group in operations covered by observers was used for the response variable. Bycatch of albatrosses and giant petrels include two types of cases. One case is direct attacks to a bait and another case is secondary attacks to the bait obtained by petrels. In this way, since the factor of bycatch occurrence of albatrosses and giant petrels is different from that of petrels, we divided the bycatch occurrence rate models into the model of albatrosses and giant petrels group and that of petrels and shearwaters group (hereafter, albatross model and petrel model). Also, since information of use of bycatch mitigation measure is available from 2011 in the observer data, we made the other models which included information of use of mitigation measure as explanatory variables (hereafter, albatross mitigation model and petrel mitigation models, **Table 1**).

2.2.2 Explanatory variables

As factors having spatial temporal effect, we used latitude, longitude, year, elapsed days from the first of the year (hereafter, the day of the year) for explanatory variables. As variables giving characteristic of fishing effort or fishing vessel, we used a number of observed hooks, cruise ID, observer ID, fishing master ID as explanatory variables. Fisherman change gear configuration and bait depending on target species and some of that information such as the specification of fishing gears is unknown in present data. Thus, we used catch number of butterfly tuna, slender tuna, albacore, yellowfin tuna, southern bluefin tuna, bigeye tuna, swordfish, shortfin mako, porbeagle, blue shark for explanatory variables, as a reflection of fisherman's intents. We used sea surface temperature at noon, wind speed, distance from a colony, rate of night time during setting, lunar phase for explanatory variables as a factor related to seabird distribution and bycatch. And to consider the interaction between diving petrels and/or shearwaters, and albatrosses and giant-petrels which cause a secondary attack, we used bycatch number of white-chinned petrels, grey petrels, flesh-footed shearwaters and other petrels for explanatory variables in albatross model and petrel model. Also, we used use of weighted branch line, number of tori line, use of blue-dyed bait, use of underwater setting, use of combination of side setting, bird curtain and weighting branch line (hereafter, bird curtain), use of bait caster for explanatory variables in albatross mitigation model and petrel mitigation model.

Species group was employed for explanatory variables to explain a difference of bycatch occurrence rate among species groups. Because, provided species identification in detail, the bycatch occurrence rate must be extremely low and then model performance decrease, we used species group rather than individual species. We employed general grouping, such as wandering albatross group (WAA), black-browed albatross group (BBA), yellow-nosed albatross group (YNA), shy-type albatross (SYA), grey-headed albatross (GHA), Buller's albatross (BLA), giant-petrels (GP) (**Table 2**). Bycatch occurrence rate for petrels is further lower than that for albatross, and we examined bycatch occurrence rates of white-chinned petrels(WCP), grey petrels(GRP), flesh-footed shearwaters(FFS) and other petrels.

Movement from colony during breeding season is different from that during the non-breeding season. General colonies of albatrosses are Falkland Islands, South Georgia, Islas Diego Ramirez, Tristan da Cunha, Prince Edward Islands, Crozet, Kerguelen, Campbell Island, Macquarie Island, Auckland Island and Antipodensis Island. We calculated a direct distance from nearest colony among those colonies.

Night setting, one of the seabird bycatch mitigation measures, means line setting in the night time when seabirds are non-active. Not all night setting, however, are not practically completed before sunrise. Hence, we calculated ratio of night time against whole line setting time as follows. We calculated sunrise time and sunset time by the R package RAtmosphere with information of date, latitude, longitude and start time of line setting obtained from each opearation. It is known that moonlight has an influence on the shearwater's activity during the night (Yamamoto et al. 2008). To consider the effect of moonlight, we calculated lunar phase from date when line setting started by the R package lunar (Lazaridis 2014). 0 refers to the new moon, $\pi/2$ refers to the first quarter, π refers to the full moon, $3\pi/2$ refers to the last quarter in lunar phase.

2.2.3 Configuration of the model

'Mtry', corresponding to number of variables randomly sampled as candidates at each split, was set at 4 in random forest model. Values of sample size in positive catch and in zero catch for random sampling was set at 1000, 1500 for albatross model respectively, 270, 340 for albatross mitigation model respectively, 250, 360 for petrel model respectively and 90, 130 for petrel mitigation model respectively. This value was set to equalize percentage of error at positive catch to zero catch data. 'ntree' was number of iterations and set at 2000.

All analyses were conducted with R version 3.3.1 (R core team 2016). For the random forest analysis, we used a function of 'randomForest' in R package of 'rondomForest' (Liaw and Wiener 2002).

2.2.4 Variable selection

Indicators of degree of 'importance' and 'variation' were applied to determine impacts of each variable on response veriables. We regarded the variables with high importance and high variation as dominant variable.

We showed degrees of importance measured by the Mean Decrease Accuracy and the Mean Decrease Gini (hereafter, Gini coefficient) (see **Fig. 2** in results). In this study, we employed importance from Mean Decrease

Gini as an indicator of the impacts of variables, because importance from the Gini coefficient was generally used for analysis. Also, it showed appropriate importance when one uses data, which does not have observations in all possible combination of level under a condition where many interaction effects were possible. We regarded the variables of top 10, 15 and 20 of importance from Gini coefficient as high impact and dominant variables (see model diagnosis).

In addition, variation, an another indicator, were defined as a range of variation of partial dependence (hereafter, variation) estimated for each explanatory variable. This is because if the range of variation of partial dependence was small, the variable would not have a large impact on bycatch occurrence rate, even though importance from mean decrease Gini is high. In this study, if the variation was higher than 0.08, it was regarded as large impact and dominant variables and if the variation was higher than 0.2, it was regarded as strongly large impact and dominant variables (**Table 3**).

3. Result

3.1 Model diagnosis

Out of bag (OOB) were 0.269, 0.265, 0.188 and 0.193 in albatross model, albatross mitigation model, petrel model and petrel mitigation model, respectively (**Fig. 1**). OOB became stable by 2000 iterations in all 4 models (**Fig. 1**). In all models, since a large number of zero catch was recorded, TRUE of data was very few (**Table 4**). Also, since positive catch in petrel model and petrel mitigation model was fewer than that in albatross model and albatross mitigation model, TRUE of data was extremely few (**Table 4**).

Variables were selected from those in top 10, top 15, top 20 or top 25 in the degrees of importance based on the Gini coefficient calculated from the albatross model, albatross mitigation model, petrel model and petrel mitigation model. The model was constructed with these selected variables by 2000 iterations and then OOBs were calculated. OOBs were the smallest at top 10, 0.247 and 0.249 in albatross model and albatross mitigation model, respectively (**Table 5**). OOB was the smallest at top 15, 0.184, in petrel model. In petrel mitigation model, there is little difference between OOB at top 20 and OOB at top 25 (**Table 4**). From these result, variables in top 10 in the albatross model and the albatross mitigation model, variables in top 15 in the petrel model and variables in top 20 in the petrel mitigation model were regarded as dominant variables.

3.2 Albatross model

The importance of variables of the random forest is indicated in Fig 2. Variables at top 1-10 in importance from mean decrease Gini (variation) were species group (0.3), a day of the year (0.2), latitude (0.25), sea surface temperature (0.15), longitude (0.05), number of observed hooks (0.06), distance from the colony (0.03), lunar phase (0.08), observer ID (0.2), cruise ID (0.22) (**Fig. 2** and **Table 6**).

Partial dependence for each variable showed at **Fig3** indicate a variation of predicted value against variation of the individual variable. Partial dependence is an indicator of bycatch occurrence rate and bycatch occurrence rate increase when partial dependence decrease and bycatch occurrence rate decrease when partial dependence increase.

We focused on partial dependent of the variables, of which variation was higher than 0.08. In the species group variable, bycatch occurrence rate of Buller’s albatrosses and giant petrels were lower than that of other species groups. In the variable of elapsed days from the first day of the year, bycatch occurrence rate increased during January to March. Bycatch occurrence rate increased when latitude increased. Bycatch occurrence rate was high at the sea surface temperature of 9 to 11^0C. When lunar phase was a new moon, bycatch occurrence rate was low. Bycatch occurrence rate varied among observer IDs. Bycatch occurrence rate was high at particular cruise ID and it did not vary in other cruise ID.

3.3 Albatross mitigation model

Variables in top 10 of importance from mean decrease Gini (variation) were elapsed days from the first day of the year (0.2), latitude (0.23), species group (0.2), distance from the colony (0.1), longitude (0.08), sea surface temperature (0.12), number of observed hooks (0.1), lunar phase (0.4), catch of southern bluefin tuna (0.1), catch of blue shark (0.1) (**Fig. 2**, **Table 6**).

Partial dependence for each variable showed at **Fig. 4**. We focused on partial dependent of the variables, of which variation was higher than 0.08. Bycatch occurrence was high around 20W and around 150E in longitude. Bycatch occurrence increased when latitude increased and the variation range of partial dependence was high 0.23. Bycatch occurrence was high from January to March and the variation was high 0.2. Bycatch occurrence increased when the number of observer hooks increased. In black-browed albatross group, bycatch occurrence was high and in Buller’s albatrosses and giant petrels bycatch occurrence was low. Bycatch occurrence rate was high at the sea surface temperature of 9 to 11^oC. Bycatch occurrence rate was high at near the colony, around 1000km from the colony. When catch of the southern bluefin tuna and blue shark increased, bycatch occurrence rate increased.

3.4 Petrel model

Variables in top 15 of importance from the Mean Decrease Gini (variation) were elapsed days from the first day of the year (0.6), longitude (0.3), latitude (0.14), cruise ID (0.25), observer ID (0.2), distance from the colony (0.07), species group (0.25), number of observed hooks (0.1), sea surface temperature (0.09), fishing master ID(0.1) lunar phase (0.07), year (0.15), wind speed(0.08), catch number of southern bluefin tuna (0.07), catch number of blue shark (0.05) (**Fig.2**, **Table 6**).

Partial dependence for each variable showed at **Fig. 5**. We focused on partial dependent of the variables, of which variation was higher than 0.08. Bycatch occurrence rate was high around 20W while bycatch occurrence rate was low around 150E, and the variation range of partial dependence of longitude was 0.3. Bycatch occurrence rate was higher in the south than in the north, especially around 35S and 45S. Bycatch occurrence rate was high in 2015. Bycatch occurrence was high from November to March, and the variation range of the partial dependent was high 0.6. Bycatch occurrence was high when the number of observed hooks was 2500-3000. Bycatch occurrence rate of the white-chinned petrel was high, that of the grey petrel was middle and that of the flesh-footed shearwater was low. Bycatch occurrence rate varied among cruise ID and though it was high in particular IDs, it was similar level in other IDs. Bycatch occurrence rate varied among observer ID and fishing master ID. Bycatch occurrence rate was high at the sea surface temperature of 8 to 13^{o}C. Bycatch occurrence rate was high at a wind speed of 2 – 5 m/s.

3.5 Petrel mitigation model

Variables in top 20 of importance from the Mean Decrease Gini (variation) were elapsed days from the first day of the year (0.35), latitude (0.25), number of observed hooks (0.18), observer ID(0.25), sea surface temperature (0.15), longitude (0.1), cruise ID (0.1), fishing master ID (0.12), lunar phase (0.1), distance from the colony (0.05), wind speed (0.07), albacore (0.12), southern Bluefin tuna (0.05), species group (0.06), porbeagle (0.13), rate of night setting (0.07), blue shark (0.07), year (0.12), weighting branch line (0.1), butterfly tuna (0.07). (**Fig. 2**, **Table 6**).

Partial dependence for each variable showed at **Fig. 6**. We focused on partial dependent of the variables, of which variation was higher than 0.08. The bycatch occurrence rate was high around 100E and 150E. The rate was higher in the south than in the north, especially the highest at 45S and the variation range of the partial dependence was 0.25. The rate was high in 2015. The bycatch occurrence rate was high from February to April and the variation range of the partial dependence was 0.35. When the number of observed hooks increased, the bycatch occurrence rate increased, especially at 2500-3000 hooks. The bycatch occurrence rate varied among cruise IDs, observer IDs, and fishing master IDs. The bycatch occurrence rate was high at the sea surface temperature of 8-16^{o}C. The bycatch occurrence rate was high at the new moon and low at the full moon. When catch number of albacore is high, bycatch occurrence rate was low. When catch number of porbeagle was high, bycatch occurrence rate was high. When weighting branch line is used, bycatch occurrence rate decreased.

4. Discussion

4.1 Response variable: bycatch occurrence rate

Although the SC-ECO recommended to examine factors affecting bycatch rate, we used bycatch occurrence rate as a response variable. We decide to use bycatch occurrence rate as a response variable, which is simpler structure, because zero catch is too many and thus too small information to use bycatch rate, and distribution of the bycatch rate is skewed. On the other hand, because the bycatch number per a set was 1 in most cases, accounting for 68-94% of total number of observation for positive catch (**Table 7**), bycatch occurrence rate is enough reliable for examination of dominant factor affecting seabird bycatch and general description of seabird bycatch occurrence pattern in high latitude area of the southern hemisphere. In future, we will examine estimation of total seabird bycatch number from bycatch occurrence rate, and will examine estimation of bycatch rate with using random forest by the accumulation of the data.

4.2 Model diagnosis

TRUE (1 of 0-1) in our model has very small since positive catch was small and zero catch is very large. However, OOB of FALSE was similar to that of TRUE, and OOB of TRUE was low level such as 0.20-0.28 (**Fig. 1**). Our model was likely to be a statistically appropriate model because OOB is an acceptable range though a little high.

Factors affecting to bycatch occurrence rate in petrel model was more than these in albatross model. And factors affecting to bycatch occurrence rate in petrel mitigation model was more than these in petrel model. These might be related to the fact that positive catch in petrel model was smaller than albatross model. Also, these might be related to the fact that data of petrel mitigation model is smaller than petrel model. It should be paid attention to that number of dominant variables vary in the collaboration work.

4.3 Dominant factor affecting bycatch occurrence rate

Dominant variables in common with analyzed 4 models were latitude, longitude, elapsed days from the first day of the year, number of observed hooks, species group, sea surface temperature in this study. Those variables would have the large impact on bycatch occurrence rate. Thus, those variables should be considered in the comparison between CPCs and in the collaboration work.

Also, dominant variables in common with 2 or 3 models of albatross model, albatross mitigation model, petrel model and petrel mitigation model were year, cruise ID, observer ID and lunar phase. In these variables, observer ID was not appropriate because it traced year effect (see below). It is agreeable that year, cruise ID, lunar phase are considered in the analysis of observer data.

Other dominant variables were master ID, wind speed, catch number of albacore, southern bluefin tuna and blue shark, use of weighting branch line. We would like to discuss the validity of these variables in below.

4.4 Dominant factor in spatial and temporal factors

4.4.1 Longitude

Longitude affected bycatch occurrence rate in albatross mitigation model, petrel model and petrel mitigation model (**Table 6**, **Figs. 4**, **5** and **6**). Bycatch occurrence rate was high off Cape and in the Tasman Sea. In the Tasman Sea. This high occurrence rate would reflect the fact that bycatch occurrence rate increase in 2014 and in 2015, while off Cape, it would reflect the fact that occurrence rate was relatively high level through analysis year. The result from albatross model was different from the result from albatross mitigation model. This is because, data from 1997 to 2015 was used for albatross model while data from 2011-2015 was used for albatross mitigation model, thus, the area where bycatch occurrence rate increased during 1997 to 2010 were not reflected in the albatross mitigation model. In other words, the distribution pattern of bycatch occurrence rate from 1997 to 2010 is thought to be different from that from 2011 to 2015.

4.4.2 Latitude

When latitude increased in the southern hemisphere, bycatch occurrence rate increased (**Table 6**, **Figs. 3**, **4**, **5** and **6**). This is likely to be related to following reason; 1) this is caused by variation of number of operations, 2) this is caused by the distribution pattern of albatross and petrels, 3) this is caused by both 1) and 2). Sometimes the number of sets increase in high latitude in some year, so it might cause the variation of bycatch occurrence rate by latitude. And also, the distribution pattern of albatross and petrels might cause that. For example, distribution of grey-headed albatross, of which bycatch number is larger than other albatrosses, is located around 45S (ACAP 2012b). Thus, number of sets and distribution of seabirds might cause the pattern. The relationship between seabird distribution and bycatch occurrence rate in each seabird species group discuss in **Appendix 1**.

4.4.3 Year

Bycatch occurrence rate increased in 2014 and 2015 (**Table 6**, **Figs. 5** and **6**). This result is relevant to increase of the bycatch occurrence rates in the Tasman Sea in 2014 and 2015.

This would be caused by data increasing of 2014 and 2015 in the area where bycatch occurrence rate was relatively high, such as the water in the south of the Tasman Sea in first quarter.

4.4.4 Elapsed days from the first day of the year

Bycatch occurrence rate increased from 1 to 100 days, or from January to March in all model (**Table 6**, **Figs 3**, **4**, **5** and **6**). Data used in our study covered the foraging range of breeding albatrosses. Albatrosses and petrels are in breeding season during January to March (ACAP, 2012a, 2012b, 2012c, 2012d, 2012e, 2012f and 2012g). Most albatrosses increase their food demand during the breeding season. This might affect increase of bycatch occurrence.

4.4.5 Number of observed hooks

When the number of observed hooks increased, bycatch occurrence rate increased (**Table 6**, **Figs. 4**, **5** and **6**).

The chance of bycatch would increase, when the number of observed hooks increase. Bycatch occurrence rate decreased before 1500 hooks and after 3000 hooks. This is thought to be caused by data limitation before 1500 and after 3000 hooks, where observation was rare. It is difficult to discuss those situations because of data limitation.

4.5 Effect of Cruise ID, observer ID and fishing master ID

Cruise ID, observer ID and fishing master ID affected bycatch occurrence rate (**Table 6**, **Figs. 3**, **4**, **5** and **6**). Effect of cruise ID and fishing master ID would be related to fishing gear, target species, a specification of mitigation measure and use of mitigation measure by each vessel. Early Observer ID tended to be high bycatch occurrence rate. Small values of observer ID correspond to the ID registered in recent year and simultaneously bycatch occurrence rate was increased in 2014 and 2015. Thus, it is possible that effect of observer ID trace year effect.

4.6 Oceanographic environment effect

4.6.1 Sea surface temperature

The bycatch occurrence rate increased when the sea surface temperature is 9 – 11^{o}C or 8 – 13^{o}C (**Table 6**, **Figs. 3**, **4**, **5** and **6**). Several albatross use current of the southern sea for a foraging area. For example, it is known that foraging range of the wandering albatross was related to Antarctic Polar front (Xavier et al. 2003). The grey-headed albatross utilize Antarctic Circumpolar Current, the Southern extent of Sub-tropical Front, Sub-Antarctic Front, Antarctic Polar front, which is located in 40S-50S and high bycatch area (Nel et al. 2001). Also, the white-chinned petrel uses Antarctic water, Polar Front and Polar Frontal Zone, which are a temperature of 0 -10^{o}C (Catard et al. 2000). Polar front is located at around 45S which is high bycatch occurrence area in this study. Thus, it is indicated that temperature of foraging area in albatrosses and petrels relate to bycatch occurrence rate. The area where Japanese longline bycatch seabird is suggested to be north edge of the foraging area of many albatross species.

4.6.2 Wind speed

Bycatch occurrence rate decrease when wind speed is high (**Table 6**, **Fig. 5**). It is indicated that optimal wind speed varies according to wind direction in past paper (Spear and Ainley 1997). Since too high wind speed is not optimal for flight, albatrosses and petrels could not approach around stern of longline vessel. Variation range of partial dependent in petrel model is higher than that in albatross model. This is because body size of petrel is small and thus petrel is more easily influenced by wind speed.

4.6.3 Lunar phase

Bycatch occurrence rate decreased in the new moon in albatross mitigation model (**Table 6**, **Fig. 3**). This result agreed with past findings (Jimenez et al. 2009, Melvin et al. 2014). On the other hand, bycatch occurrence rate decreased in the full moon and increased in the new moon in petrel mitigation model (**Table 6**, **Fig. 6**). This result did not agree with past knowledge that shearwater flew for longer periods and landed on the water more frequently on the night with a full moon (Yamamoto et al. 2008). This requires investigating the reason in the future.

4.6.4 Distance from the colony

Bycatch occurrence rate was high when distance from the colony is close (**Table 6**, **Fig. 4**). This would be because adult breeders forage around colony during breeding season and utilize fishing vessel. Bycatch rate of adult is relatively high around colony while bycatch rate of juvenile and immature is relatively high in Inoue (unpubl. data). Thus, bycatch occurrence rate of immature and juvenile would not increase at near the colony and this reflect small variation range of partial dependence in effect of distance from the colony.

4.7 Effect of fish species

When catch number of albacore increased, bycatch occurrence rate in petrels decreased (**Table 6**, **Fig. 6**). Habitat of albacore ranges from subtropical area to temperate area in temperatures of 10-25^{o}C (Fishbase 2016b), which is different from sea surface temperatures of bycatch occurrence area in petrels. And thus they related negatively.
When catch number of the southern bluefin tuna increase, bycatch occurrence rate in albatrosses increased (**Table 6**, **Fig. 4**). Temperatures of habitat of southern bluefin tuna range from 5^{o}C to 20^{o}C (Fishbase 2016c), which (partially) overlap sea surface temperatures of the bycatch occurrence area of albatrosses.

When catch numbers of porbeagle and blue shark increased, bycatch occurrence rate increased (**Figs. 4** and **6**). The bycatch occurrence rate in albatrosses and petrels was estimated to be relatively high around 35S-45S (**Appendix1 Fig. 7**), while catch of porbeagle and blue shark increased around 35S-45S (**Fig. 4**) (Matsunaga and Nakano 1996, Semba et al. 2013 and Kai et al. 2015). It would be caused that the distribution of porbeagle and blue shark overlap the distribution of albatrosses and petrels was relevant to bycatch occurrence.

4.8 Effect of bycatch mitigation measure

When weighting branch line were used, bycatch occurrence rate was decreased (**Table 6**, **Fig. 6**). Since bait sinks quicker by weighting branch line, chance of attack on baits by petrels is decreased. This leads decline of bycatch occurrence rate. In the albatross model, weighting branch line was not dominant variables but it decreases bycatch occurrence (**Fig. 4**). It is possible that the effect of weighting branch line against petrel worked as a significant one in the petrel mitigation model because of deep-diving nature of petrels.

4.9 Effectiveness and limit of random forest model

This study indicated that random forest worked effectively to examine the factors affecting seabird bycatch occurrence rates, even though many variables with their interactions should be considered in the light of complicated mechanism of bycatch occurrence and coverage rate of the observer for total fishing effort was not so high in high latitude of southern hemisphere.

In addition, it was indicated that the effectiveness of each variable, such as year effect and bycatch mitigation measure effect, could quantified with using partial dependence. In future, data accumulation after implementation of the current regulations and integration of data across countries and member concerned might contribute to analyze the bycatch occurrence rate/bycatch rate further in detail.

Random forest model could not estimate the area of interaction, where data does not cover. Thus, final evaluation of effectiveness of regulation would need to be evaluate with combination of other analysis. For example, by regulation analysis with using the GAM, estimation of bycatch occurrence rate could be done by compensating the area where data does not cover.

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Table 1. Data sources and applied explanatory valiables used in each model.

model	examined species	data	Appled explanetory valiables	Added explanetory valiables
Albatross model	albatrosses and giant-petrels	1997-2015	CruiseID observer ID, masterID, longitude, latitude, year, day of the year, species group, catch number of fish species, environmental variables, number of observed hooks, night setting rate	Bycatch number of petrels
Albatross mitigation model		2011-2015		Bycatch number of petrels, use of mitigation measure
Petrel model	shearwaters and petrels	1997-2015		
Petrel mitigation model		2011-2015		Use of mitigation measure

Table 2. Seabird species included in each group and the number of bycatch.

Group name	Species name	1997-1999	2000-2004	2005-2009	2010-2014	2015
Wandering albatross group	Wandering albatross Tristan albatross Antipodean albatross Gibson's albatross	56	134	89	114	45
Black-browed albatross group	Black-browed albatross Campbell albatross	143	166	150	163	80
Yellow-nosed albatross group	Atlantic yellow-nosed albatross Indean yellow-nosed albatross	68	154	164	90	18
Shy-type albatross	Shy albatross White-capped albatross	67	98	135	115	164
Grey_headed albatross		525	269	272	288	168
Buller's albatross		1	47	6	158	129
Giant petrel group	Southern giant-petrel Northern giant-petrel	60	111	88	76	11
White_chinned petrel		15	251	106	35	76
Grey petrel		44	38	41	35	11
Flesh footed shearwater		18	16	29	26	4
Other petrel		36	54	20	61	28
Number of observed hooks		7846135	7699110	6673402	7844876	2105996

Table 3. Valiations of the partial importance in each explanatory variable.

Albatross model		Albatross mitigation model	
Explanatory variables	Variation	Explanatory variables	Variation
Species group	**0.3**	**Latitude**	**0.225**
White-chinned petrel	**0.28**	**Species group**	**0.2**
Latitude	**0.25**	**Day of the year**	**0.2**
CruiseID	**0.22**	**Observer ID**	**0.15**
Day of the year	**0.2**	**Porbeagle**	**0.14**
Observer ID	**0.2**	**Sea surface temperature**	**0.12**
Sea surface temparature	**0.15**	**Nuber of observed hooks**	**0.1**
Porbeagle	**0.12**	**Distance from the colony**	**0.1**
Year	**0.08**	**Southern bluefin tuna**	**0.1**
Lunar Phase	**0.08**	**Blue shark**	**0.1**
Rate of night setting	0.07	**Bigeye tuna**	**0.09**
Blue shark	0.07	**Longitude**	**0.08**
Number of observed hooks	0.06	**Year**	**0.08**
Yellowfin tuna	0.06	**Butterfly tuna**	**0.08**
Longitude	0.05	Wind speed	0.06
Wind speed	0.05	Cruise ID	0.05
Master ID	0.05	Master ID	0.05
Grey petrel	0.05	Rate of night setting	0.05
Bigeye tuna	0.04	White-chinned petrel	0.05
Distance from the colony	0.03	Lunar phase	0.04
Southern bluefin tuna	0.03	Flesh-footed shearwater	0.04
Flesh-footed shearwater	0.03	Yellowfin tuna	0.03
Albacore	0.02	Weighted blanch line	0.03
Butterfly tuna	0.01	Bird curtain	0.03
Swordfish	0.01	Bait caster	0.03
Slender tuna	0.01	Albacore	0.02
Shortfin mako	0.01	Swordfish	0.02
Other petrel	0.01	Shortfin mako	0.02
		Grey petrel	0.02
		Other petrel	0.02
		Tori line	0.02
		Slender tuna	0.004
		Underwater setting	0.004
		Blue dyed bait	0.0005

Table 3. Continued.

Petrel model		Petrel mitigation model	
Explanatory variables	Variation	Explanatory variables	Variation
Day of the year	**0.6**	**Day of the year**	**0.35**
Longitude	**0.3**	**Latitude**	**0.25**
Species group	**0.25**	**Observer ID**	**0.25**
Cruise ID	**0.25**	**Nuber of observed hooks**	**0.175**
Observer ID	**0.2**	**Sea surface temperature**	**0.15**
Porbeagle	**0.2**	**Porbeagle**	**0.13**
Year	**0.15**	**Year**	**0.12**
Latitude	**0.14**	**Master ID**	**0.12**
Number of observed hooks	**0.1**	**Albacore**	**0.12**
Master ID	**0.1**	**Longitude**	**0.1**
Rate of night setting	**0.1**	**Cruise ID**	**0.1**
Albacore	**0.1**	**Lunar phase**	**0.1**
Sea surface temperature	**0.09**	**Bigeye tuna**	**0.1**
Wind speed	**0.08**	**Weighted blanch line**	**0.1**
Butterfly tuna	**0.08**	Wind speed	0.07
Lunar phase	0.07	Rate of night setting	0.07
Distance from the colony	0.07	Butterfly tuna	0.07
Southern bluefin tuna	0.07	Blue shark	0.07
Slender tuna	0.05	Species group	0.06
Blue shark	0.05	Distance from the colony	0.05
Bigeye tuna	0.03	Yellowfin tuna	0.05
Yellowfin tuna	0.02	Southern bluefin tuna	0.05
Swordfish	0.02	Swordfish	0.03
Shortfin mako	0.02	Underwater setting	0.02
		Shortfin mako	0.009
		Bird curtain	0.008
		Bait caster	0.008
		Slender tuna	0.005
		Tori line	0.004
		Blue dyed bait	0.0003

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Table 4 Cross varidation table obtained using test data in four model.

Albatross model		
	FALSE	TRUE
FALSE	21625	7985
TRUE	277	773

Albatross mitigation model		
	FALSE	TRUE
FALSE	5924	2141
TRUE	80	241

Petrel model		
	FALSE	TRUE
FALSE	13946	3336
TRUE	49	189

Petrel migation model		
	FALSE	TRUE
FALSE	3840	883
TRUE	17	52

Table 5. Out of bags estimate of error rates of top 10, 15, 20, and 25 using the Importance from Mean Decrease Gini in Albatross model, Albatross mitigation model, Petrel model and Petrel mitigation model.

out of bags	Albatross model	Albatross mitigation model	Petrel model	Petrel mitigation model
top 10	0.247	0.249	0.187	0.223
top 15	0.256	0.252	0.184	0.209
top 20			0.194	0.192
top 25				0.191
Full model	0.270	0.265	0.192	0.189

Table 6. The explanatory variables which affected occurrence rates of bycatch and detailed outlines of effects.

		Effect											
category	Explanatory variables	Albatross model			Albatross mitigation model			Petrel model			Petrel mitigaiton model		
		Importance	Variation	Direction	Importance	Variation	Direction	Importance	Variation	Direction	Importance	Variation	Direction
Basic information	Longitude	5	0.05		5	0.08	High at -20 and 150	2	0.30	High at -20 Low at 150	6	0.10	High at 100-150
	Latitude	3	0.25	Strongly negative	2	0.23	Strongly negative	3	0.14	Strongly negative	2	0.25	Strongly negative
	Year							12	0.15	High in 2015	18	0.12	High in 2015
	Day of the year	2	0.20	High in Jan.-Mar.	1	0.20	High in Jan.-Mar.	1	0.60	High in Nov.-Mar.	1	0.35	High in Feb.-Apr.
	Number of observed hooks	6	0.06		7	0.10	Positive	8	0.10	High at 2500-3000 hooks	3	0.18	High at 2500-3000hooks
	Species group	1	0.30	Highly variable	3	0.20	Highly variable	7	0.25	Highly variable	14	0.06	
Recording condition	Cruise ID	10	0.22	Highly variable				4	0.25	Variable	7	0.10	Variable
	Observer ID	9	0.20	Variable				5	0.20	Variable	4	0.25	Highly variable
	Master ID							10	0.10	Variable	8	0.12	Variable
Environment	Sea surface temperature	4	0.15	High at 9-11°C	6	0.12	High at 9-11°C	9	0.09	High at 8-13°C	5	0.15	
	Wind speed							13	0.08	Hight at 2-5m	11	0.07	
	Lunar phase	8	0.08	Low at new moon	8	0.04		11	0.07		9	0.10	High at newmoon Low at fullmoon
	Distance from colony	7	0.03		4	0.10	High near the colony	6	0.07		10	0.05	
	Rate of setting at night										16	0.07	
Catch	Slender tuna												
	Butterfly tuna										20	0.07	
	Albacore										12	0.12	Negative
	Yellowfin tuna												
	Southern bluefin tuna				9	0.10	Positive	14	0.07		13	0.05	
	Bigeye tuna												
	Sword fish												
	Shortfin mako												
	Porbeagle										15	0.13	Positive
	Blue shark				10	0.10	Positive	15	0.05		17	0.07	
Impact of secondary attack	White-chinned petrel												
	Grey petrel												
	Flesh-footed shearwater												
	Other petrel												
Mitigation measure	Weighted blanch line										19	0.10	Negative
	Tori line												
	Blue dyed bait												
	Under water setting												
	Bird curtain												
	Bait caster												

Table 7. Frequency distribution table for the bycatch number of each seabird species group.

Catch	0	1	2	3	4	5	6	7	8	9	10	>10
Wandering albatross	12777	319	30	7	3	1	2	0	0	1	0	0
Black-browed albatross	12532	536	55	13	3	1	0	0	0	0	0	0
Yellow-nosed albatross	12826	236	42	18	7	5	0	1	0	2	0	3
Shy-type albatross	12697	361	49	19	10	2	1	1	0	0	0	0
Grey-headed albatross	12348	540	133	46	19	13	10	7	4	5	3	12
Buller's albatross	12899	178	45	8	3	5	2	0	0	0	0	0
Giant-petrel	12818	304	14	3	0	1	0	0	0	0	0	0
White-chinned petrel	12811	243	50	21	7	4	0	3	1	0	0	0
Grey petrel	12989	135	14	2	0	0	0	0	0	0	0	0
Flesh-footed shearwater	13065	64	5	5	1	0	0	0	0	0	0	0
Other petrel	12989	116	25	8	1	1	0	0	0	0	0	0

Table 8 Number of set in each year

Year	Number of set
1997	690
1998	918
1999	1543
2000	548
2001	619
2002	524
2003	772
2004	695
2005	890
2006	804
2007	472
2008	250
2009	287
2010	119
2011	550
2012	542
2013	786
2014	1172
2015	959

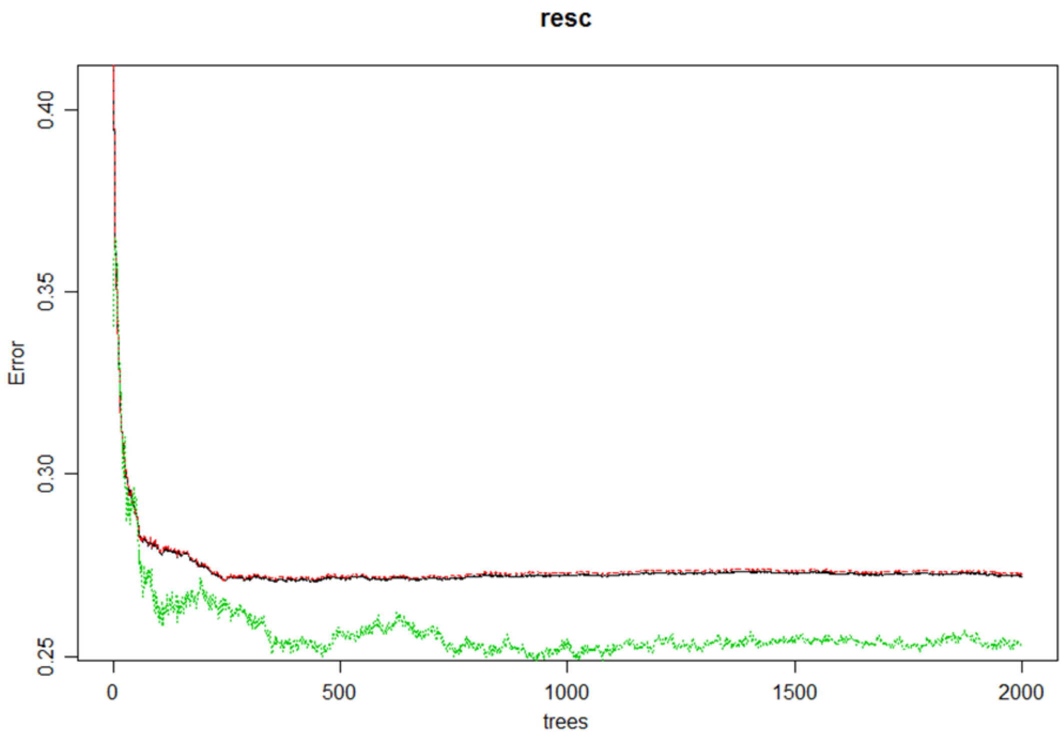
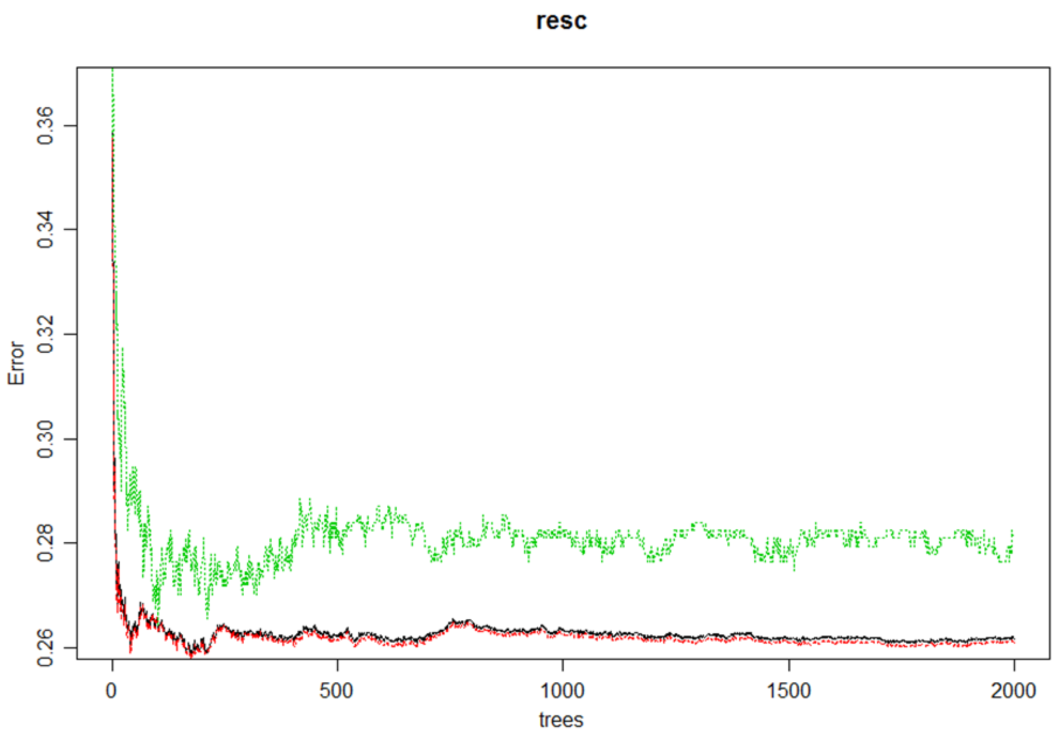


Fig. 1-a Albatross model



Fif. 1-b Albatross mitigation measure model

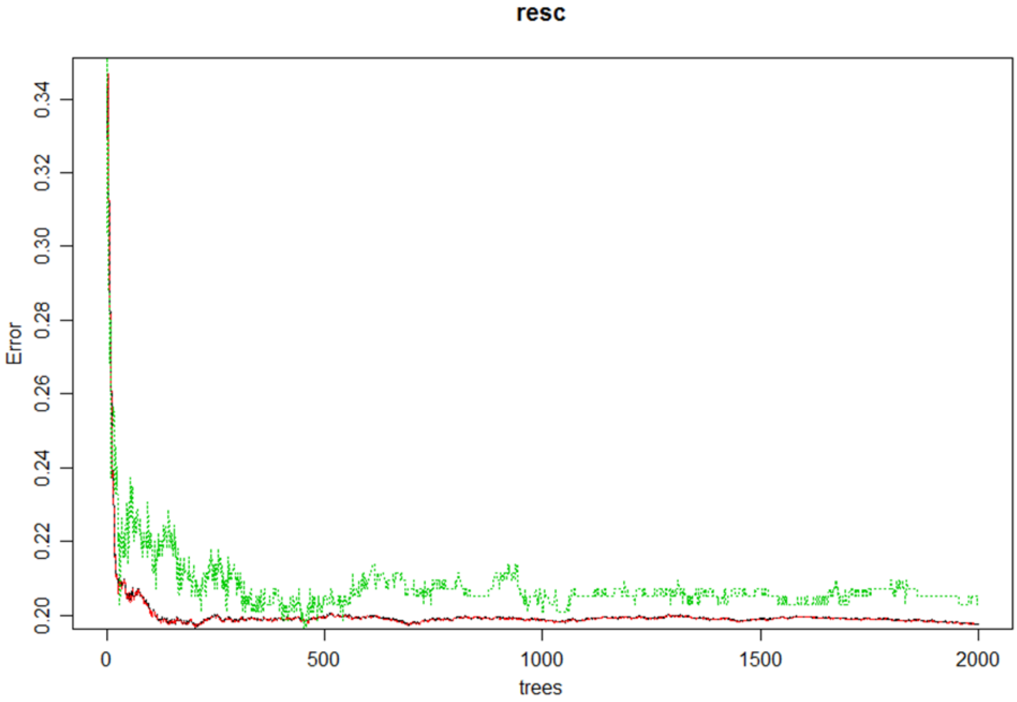


Fig. 1-c Petrel model

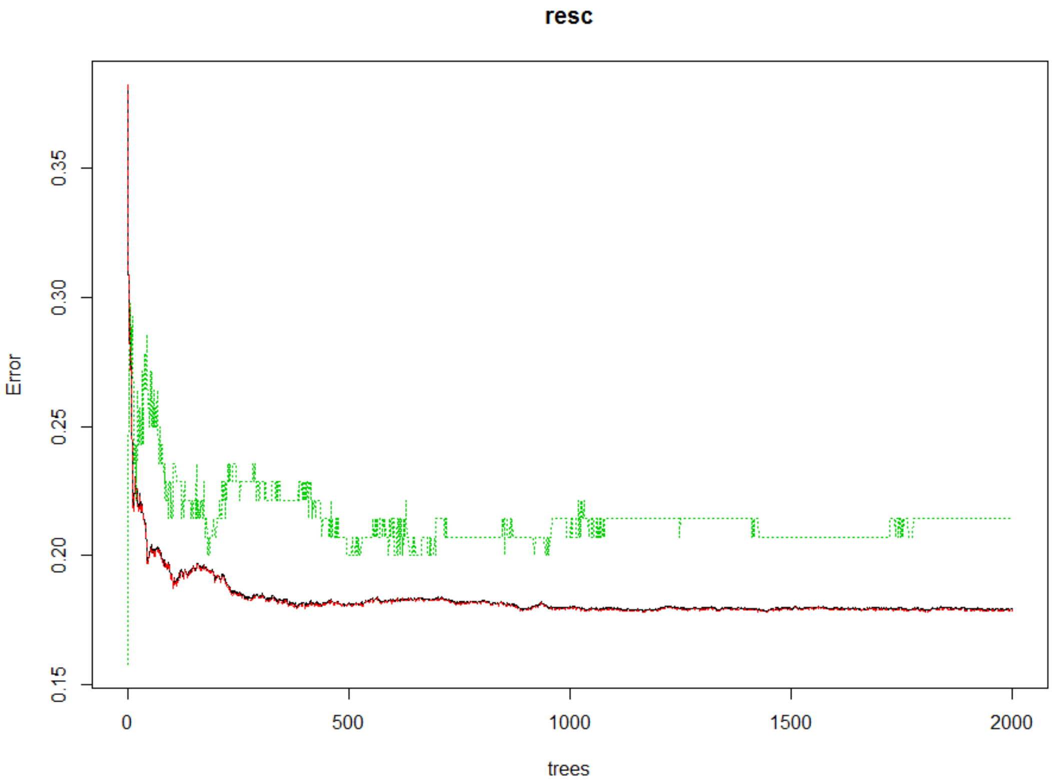


Fig. 1-d Petrel mitigation measure model

Fig. 1 The number of trees for out of bags error estimates (OOB). Green and red plots mean error estimate which is TRUE and FALSE, respectively. The X axis indicates the number of trees.

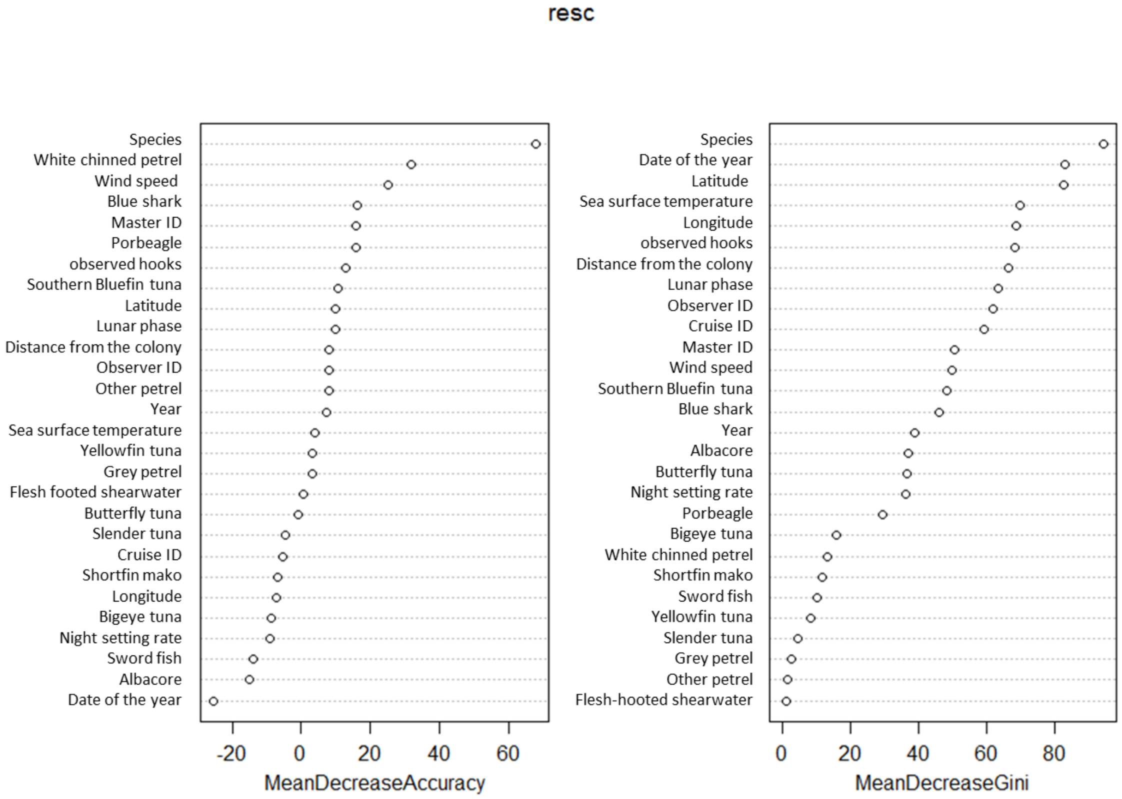


Fig. 2-a Albatross model

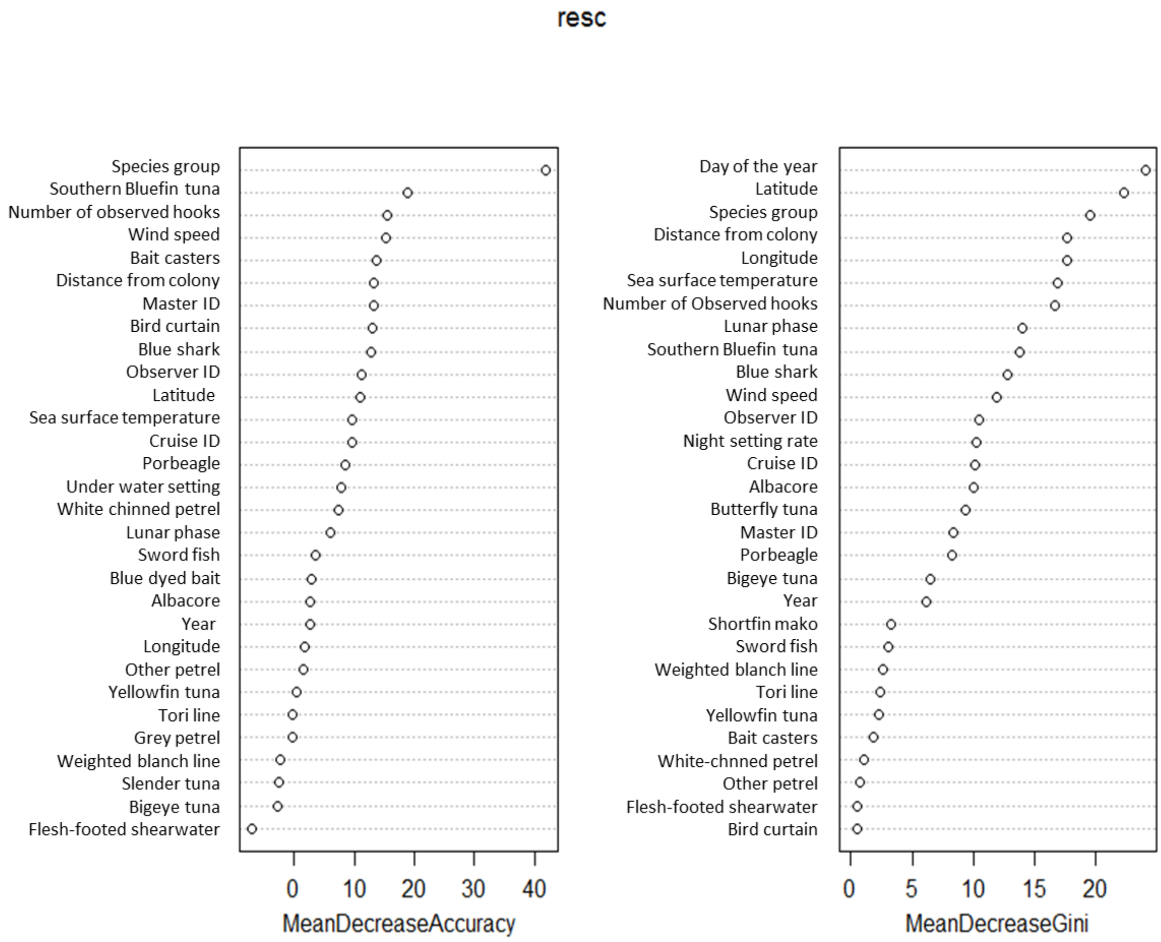


Fig. 2-b Albatross mitigation model

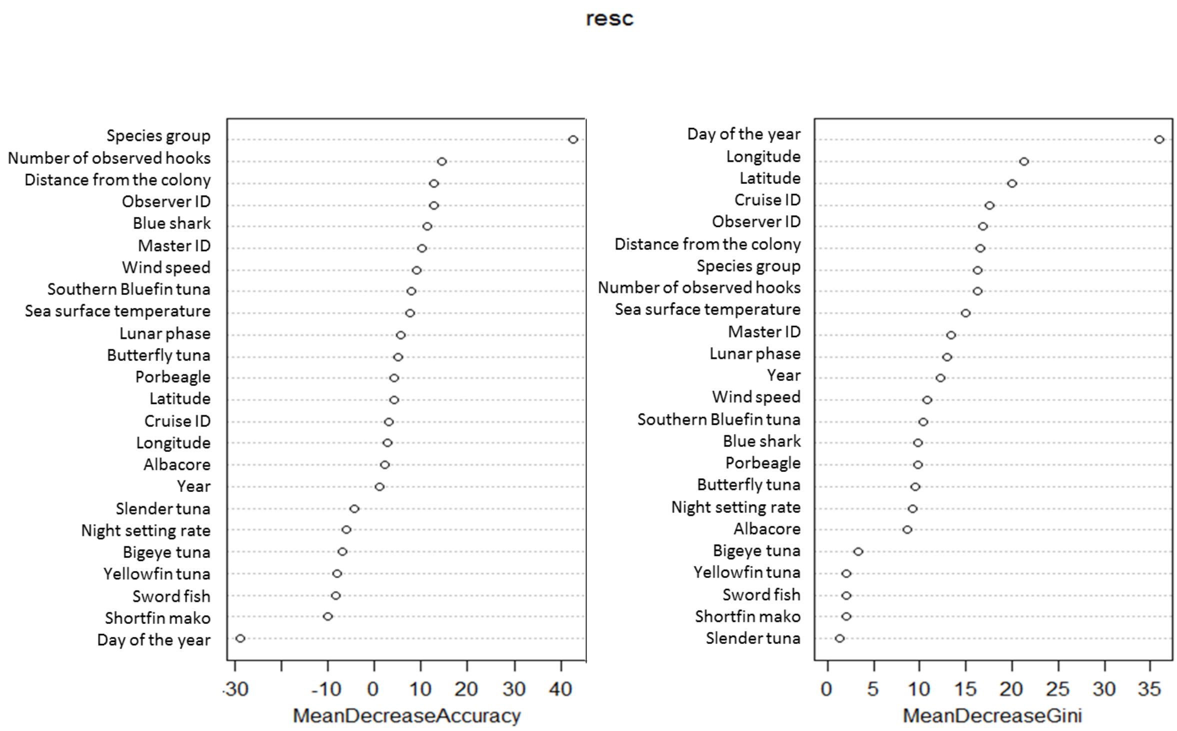


Fig. 2-c Petrel model

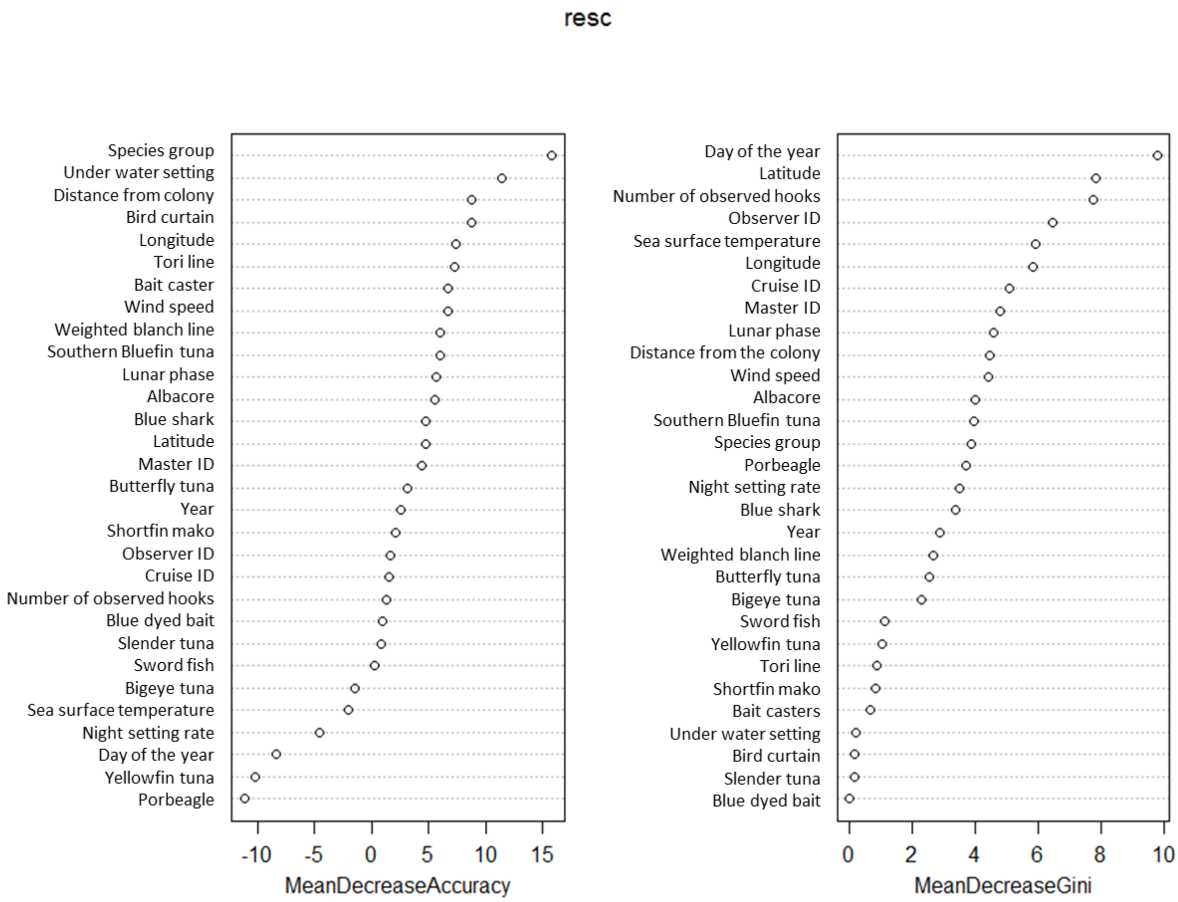


Fig. 2-d Petrel mitigation model

Fig. 2 Importance of the value. The each graph on the left shows Importance from Mean Decrease Accuracy and graph on the right shows Importance from Mean Decrease Gini.

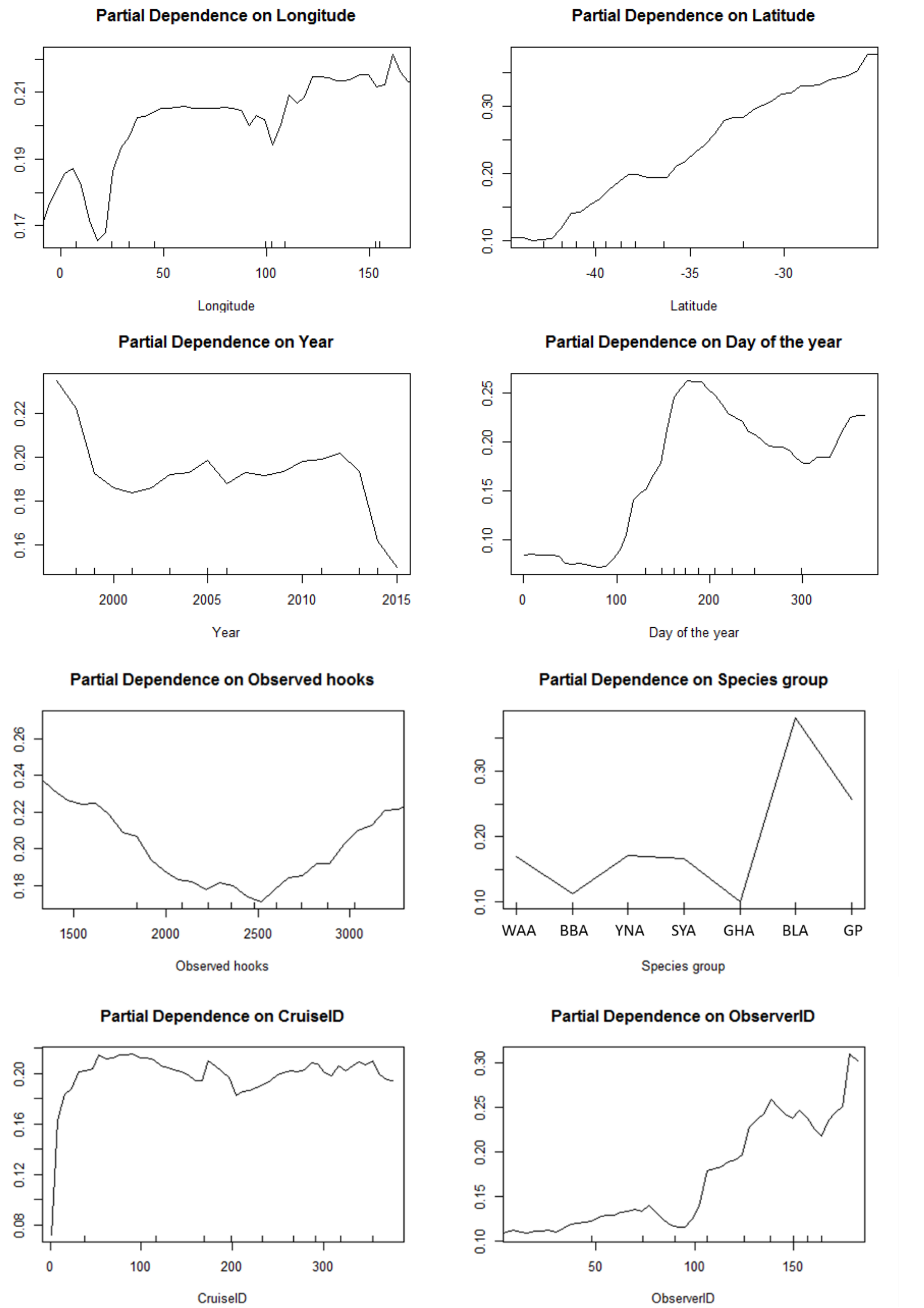


Fig. 3 Albatross model. Figures show that the partial dependences associated with changes of each variation. The Y axis indicates the partial dependence. The larger value means lower probabilities of bycatch.

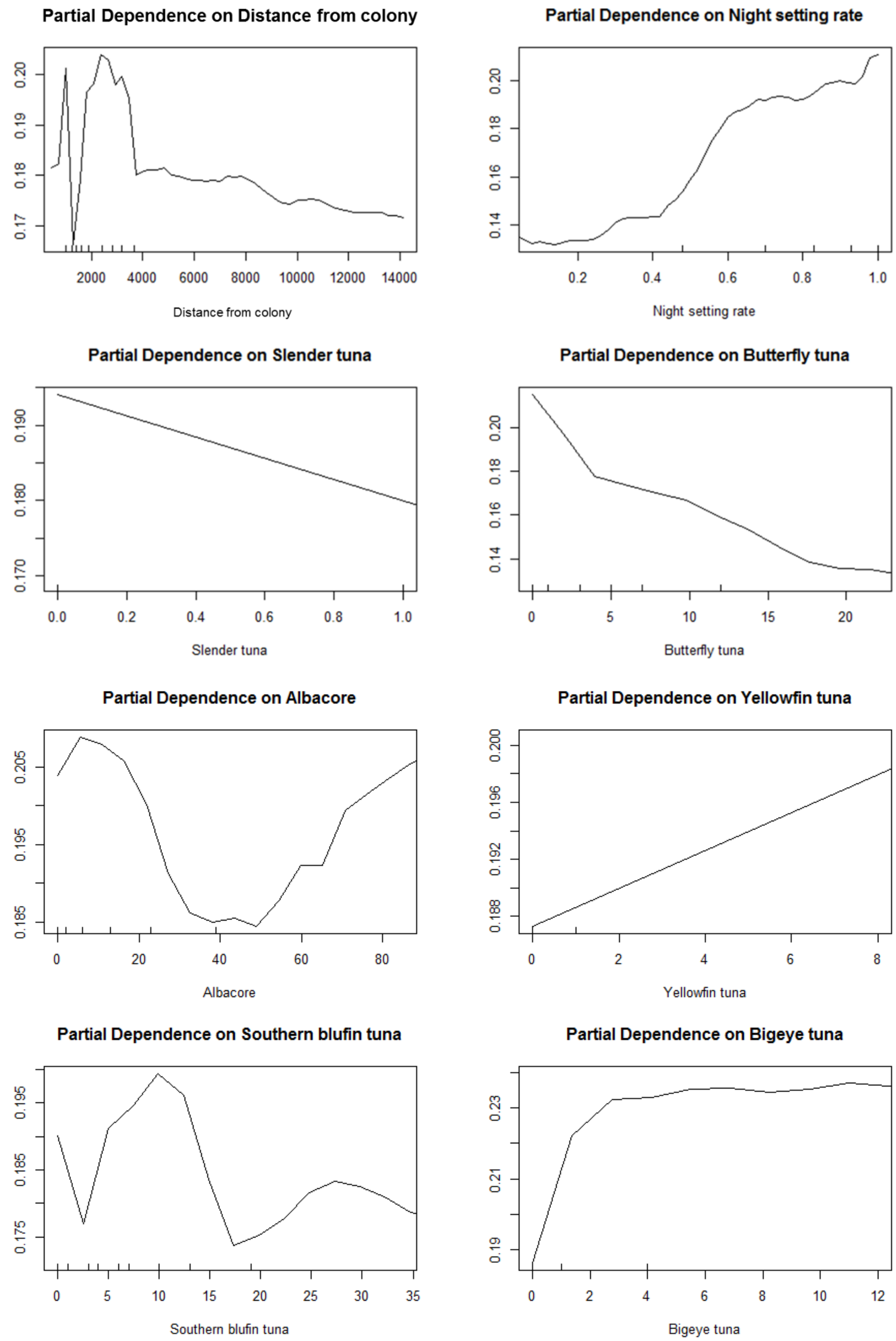


Fig. 3 Continued.

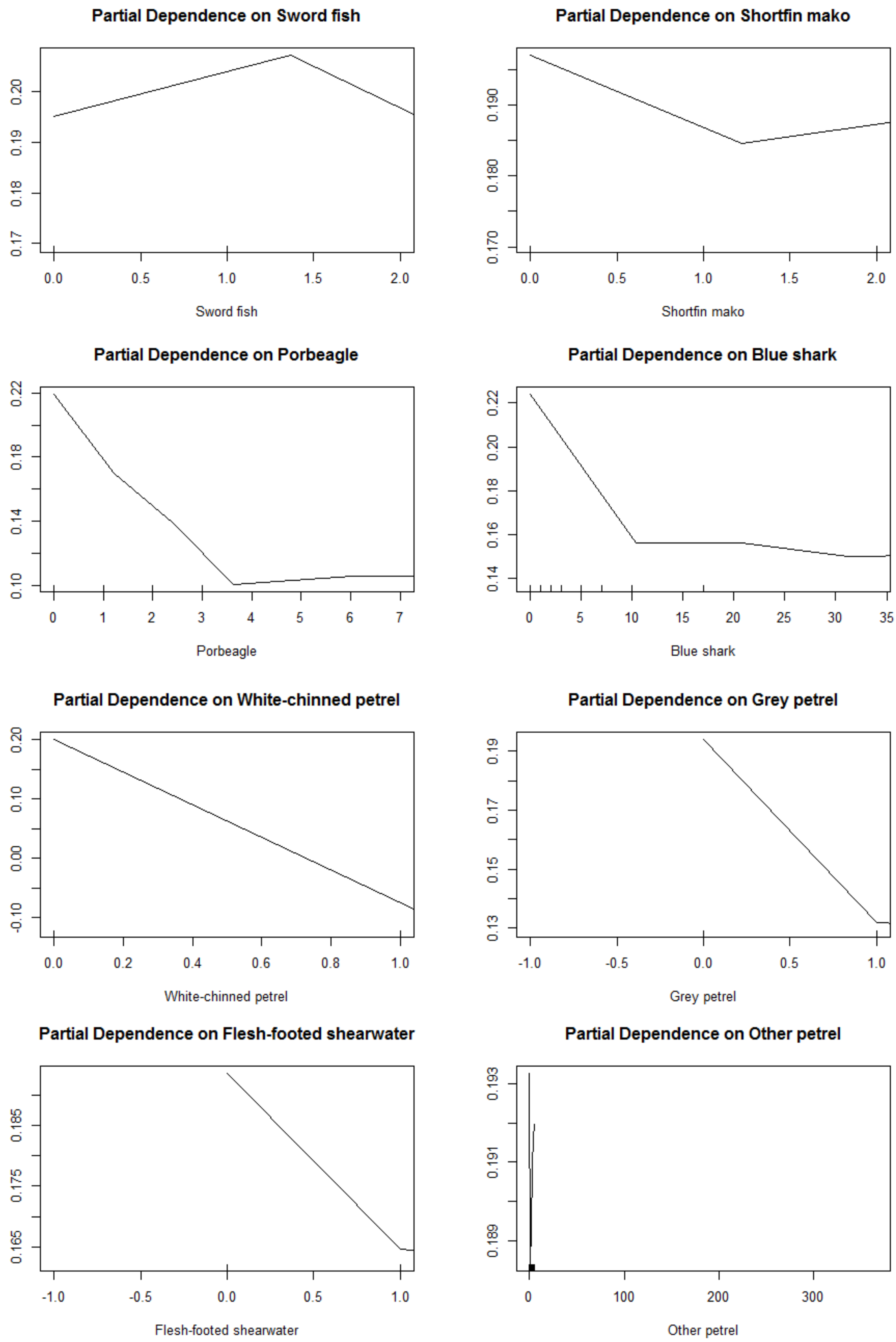


Fig. 3 Continued.

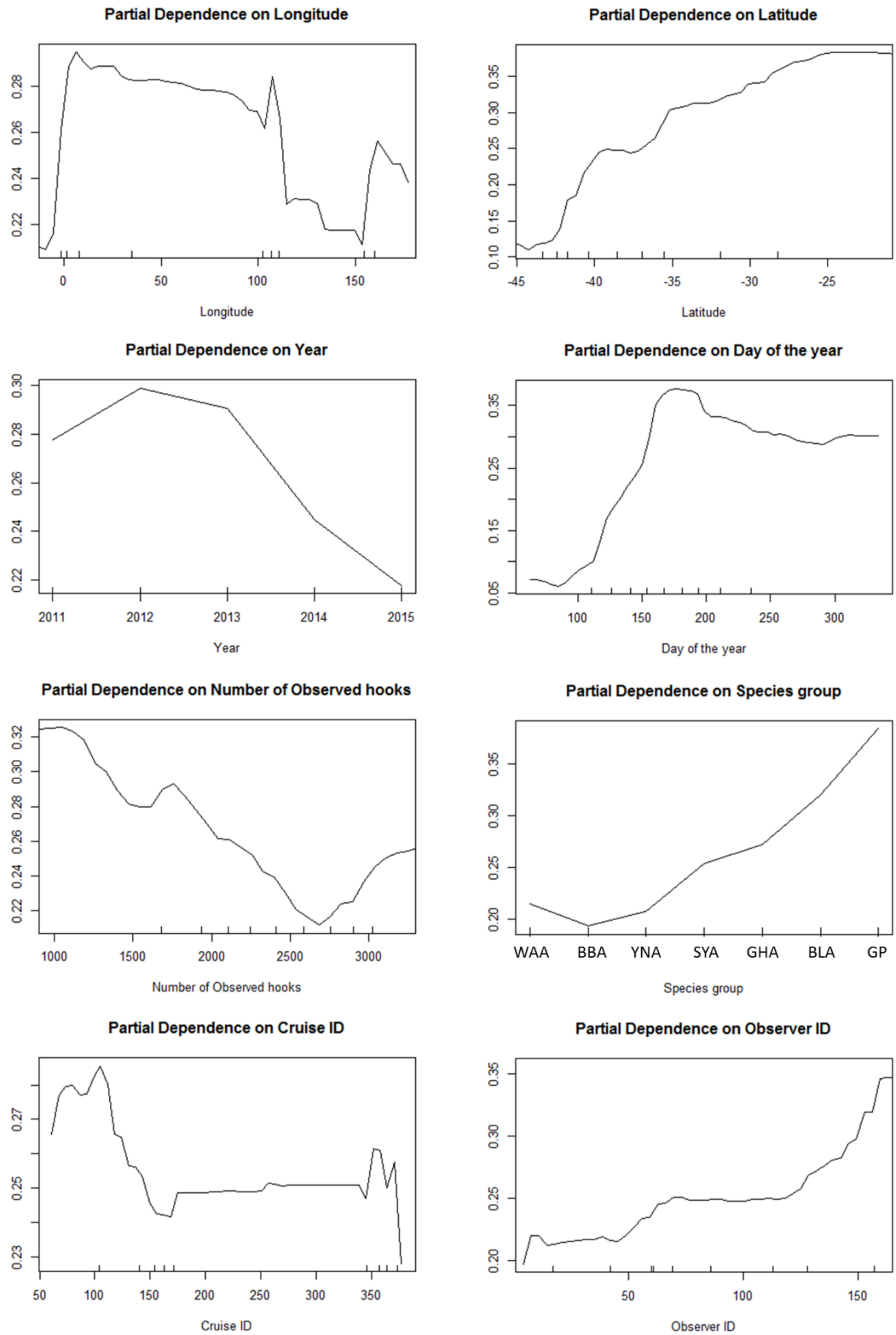


Fig. 4 Albatross mitigation model. Figures show that the partial dependences associated with changes of each variation. The Y axis indicates the partial dependence. The larger value means lower probabilities of bycatch.

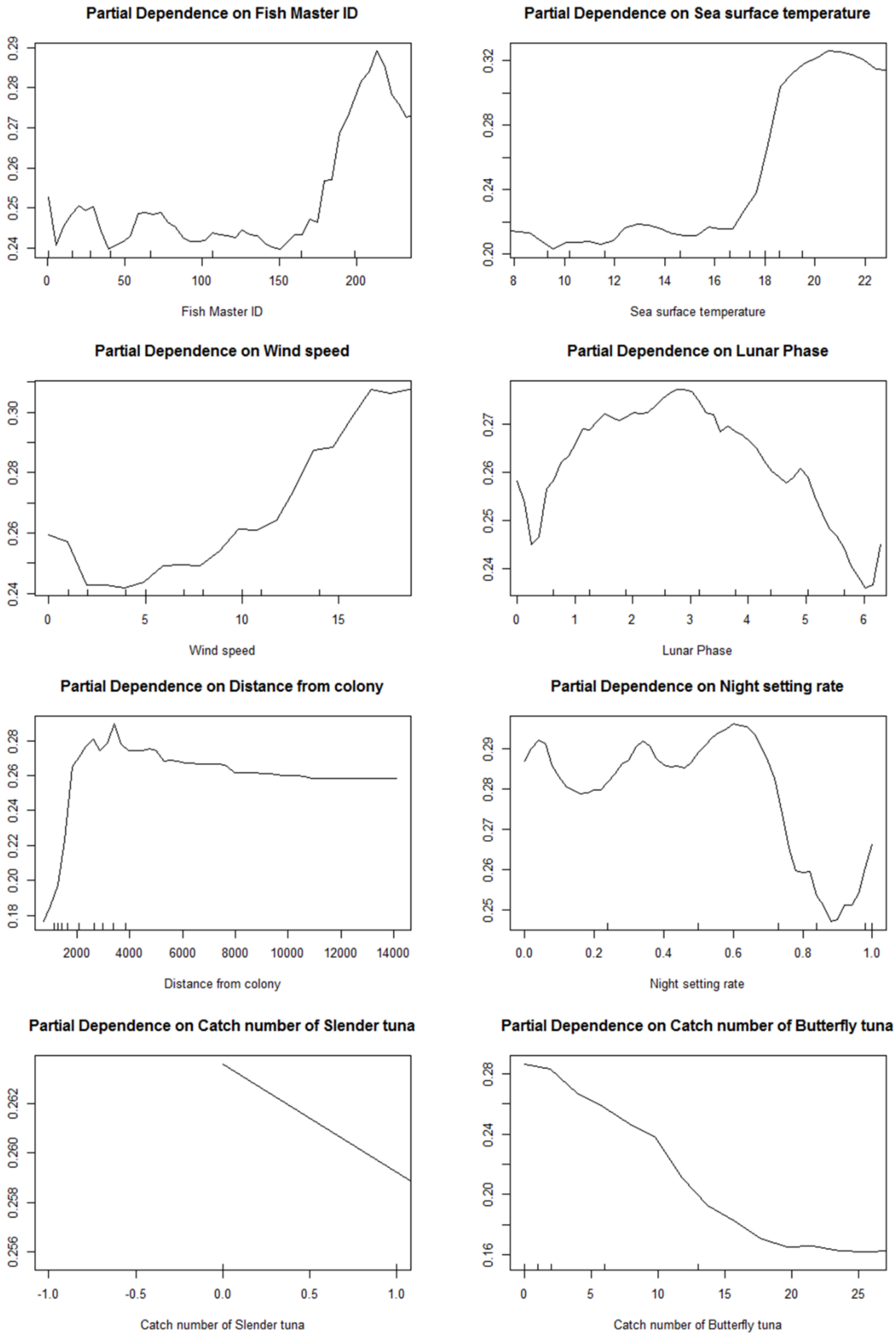
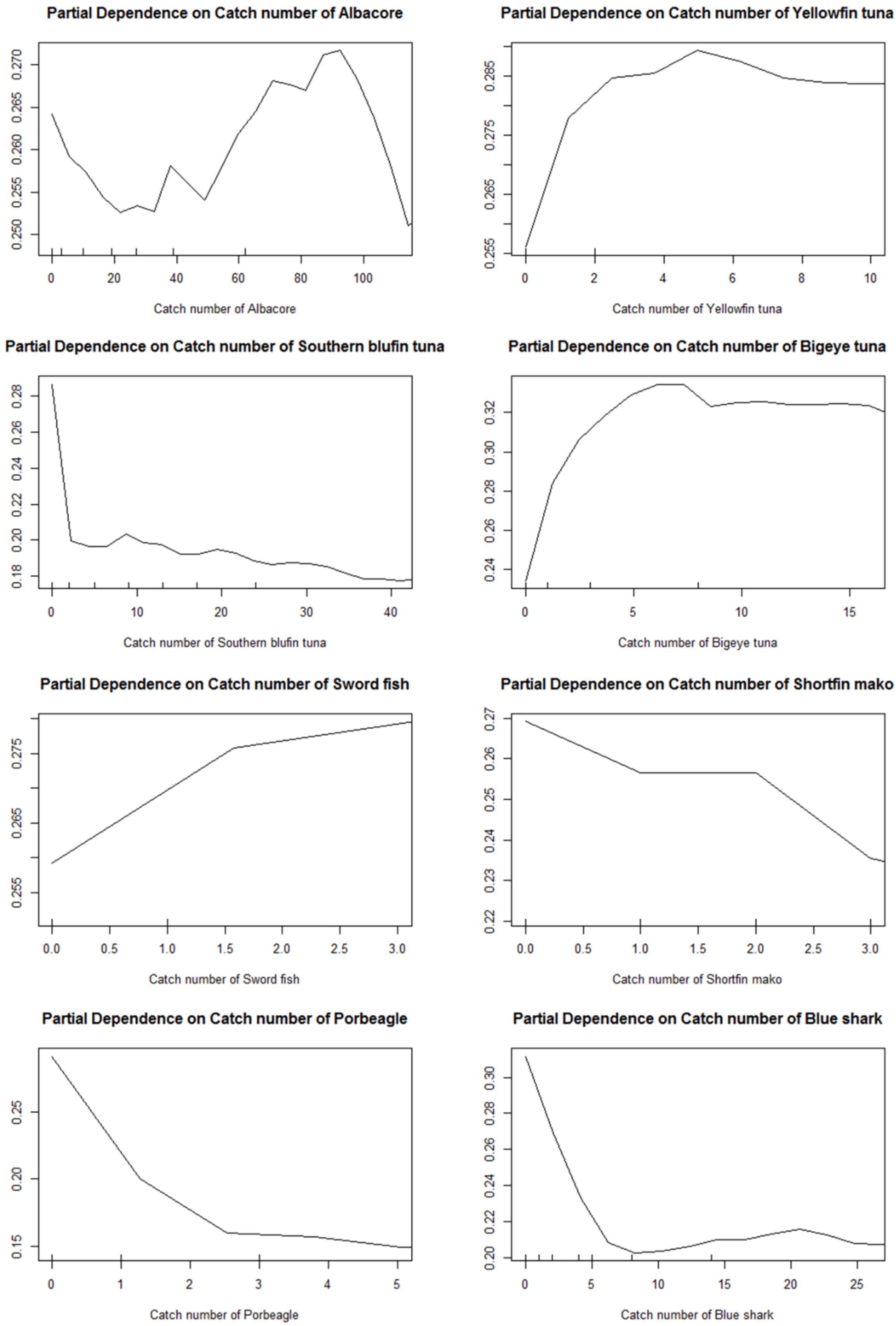


Fig. 4 Continued.



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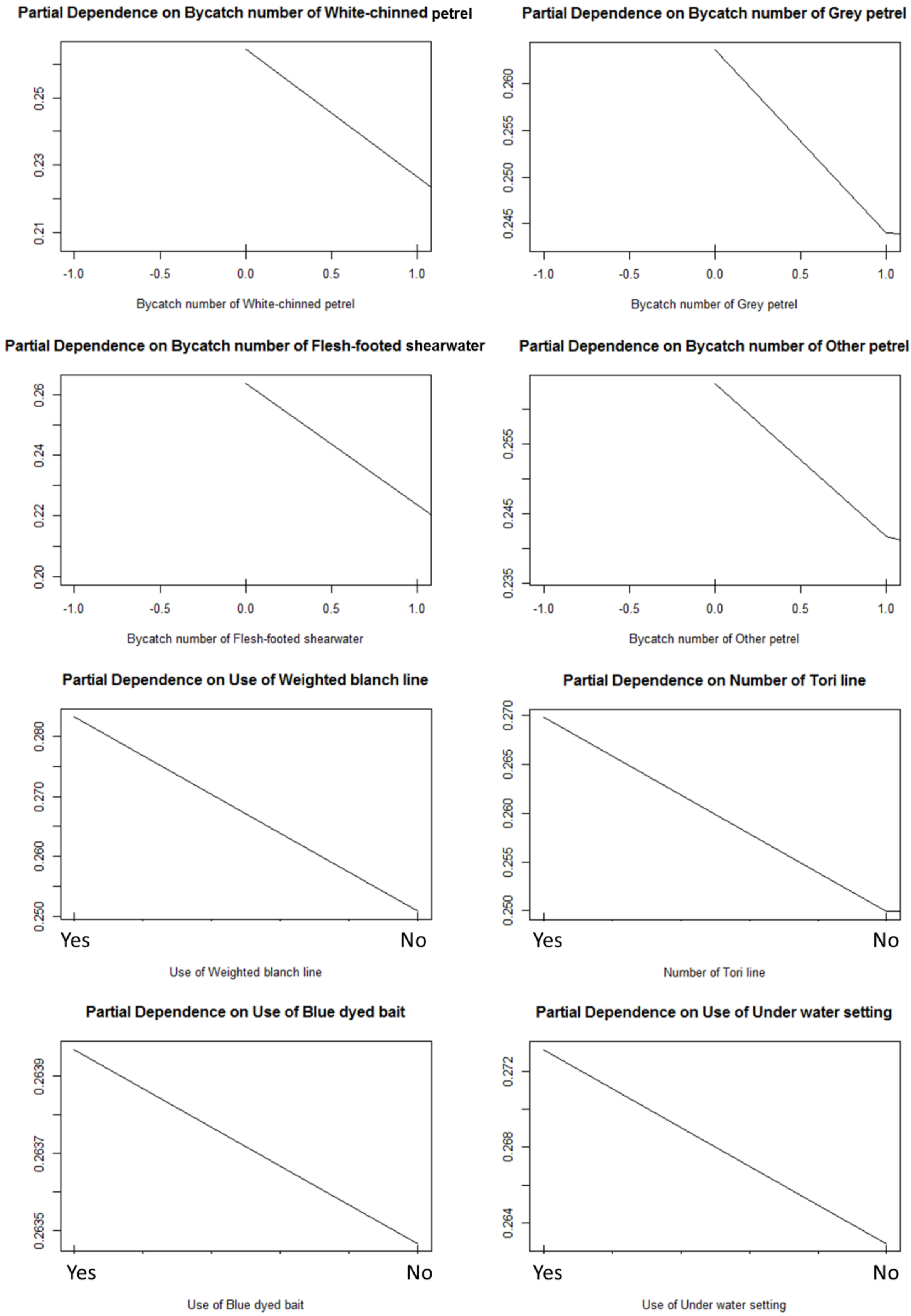

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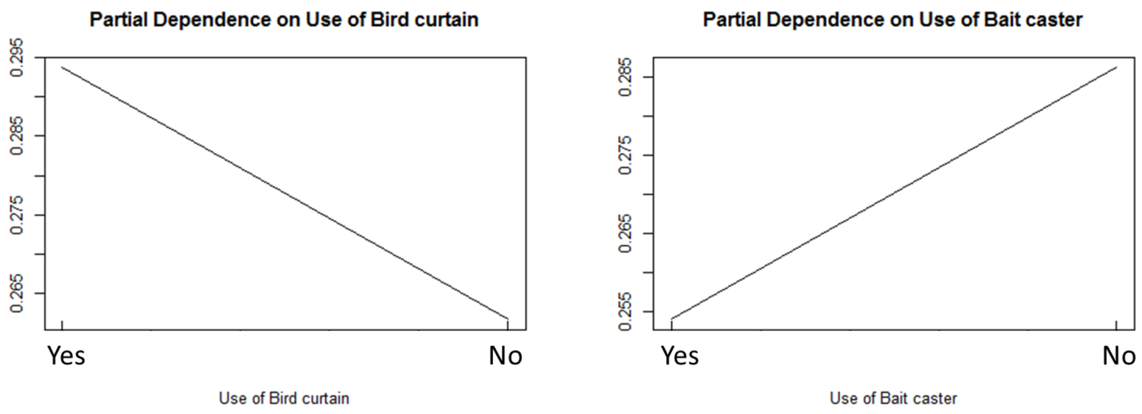


Fig. 4 Continued.

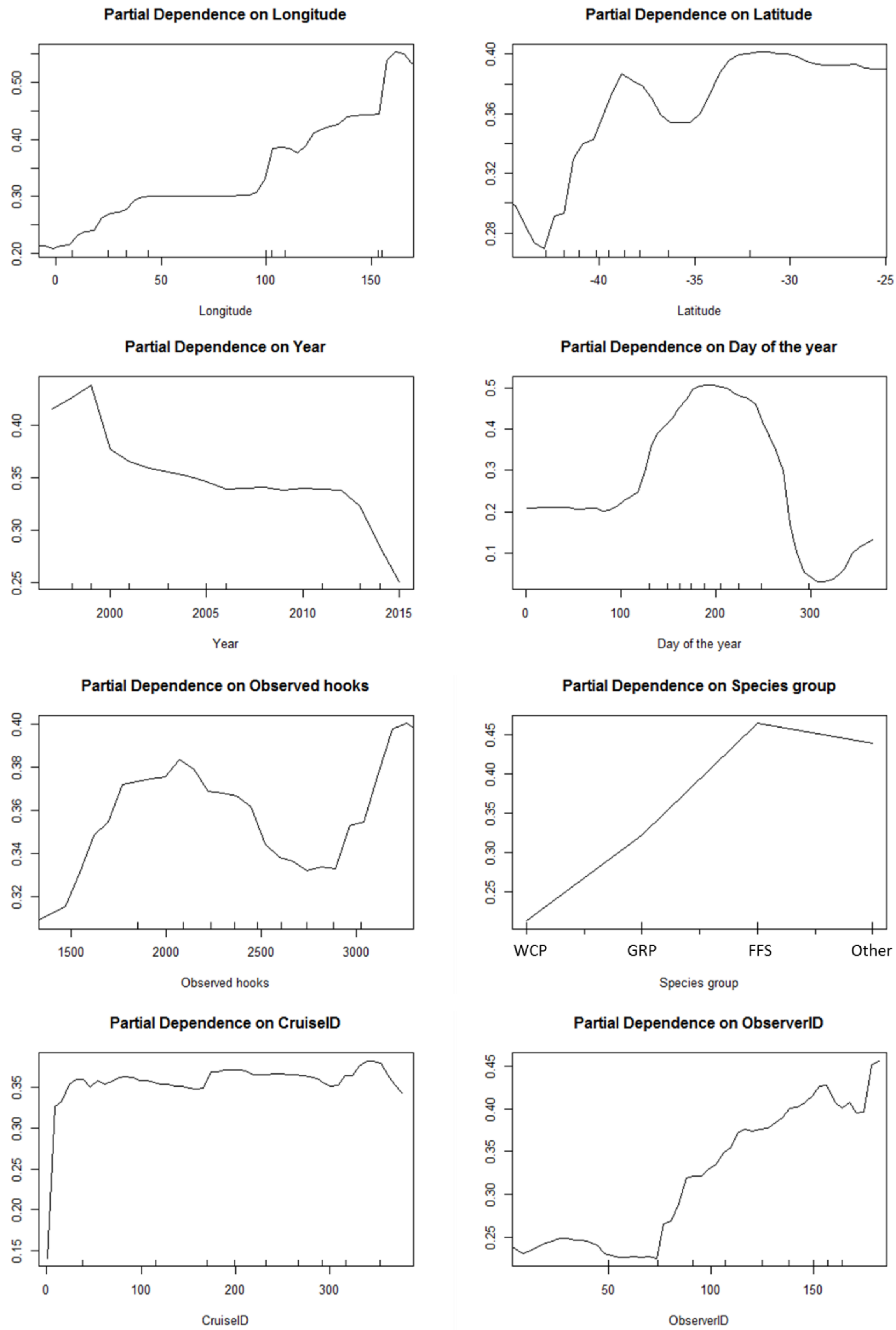


Fig. 5 Petrel model. Figures show that the partial dependences associated with changes of each variation. The Y axis indicates the partial dependence. The larger value means lower probabilities of bycatch.

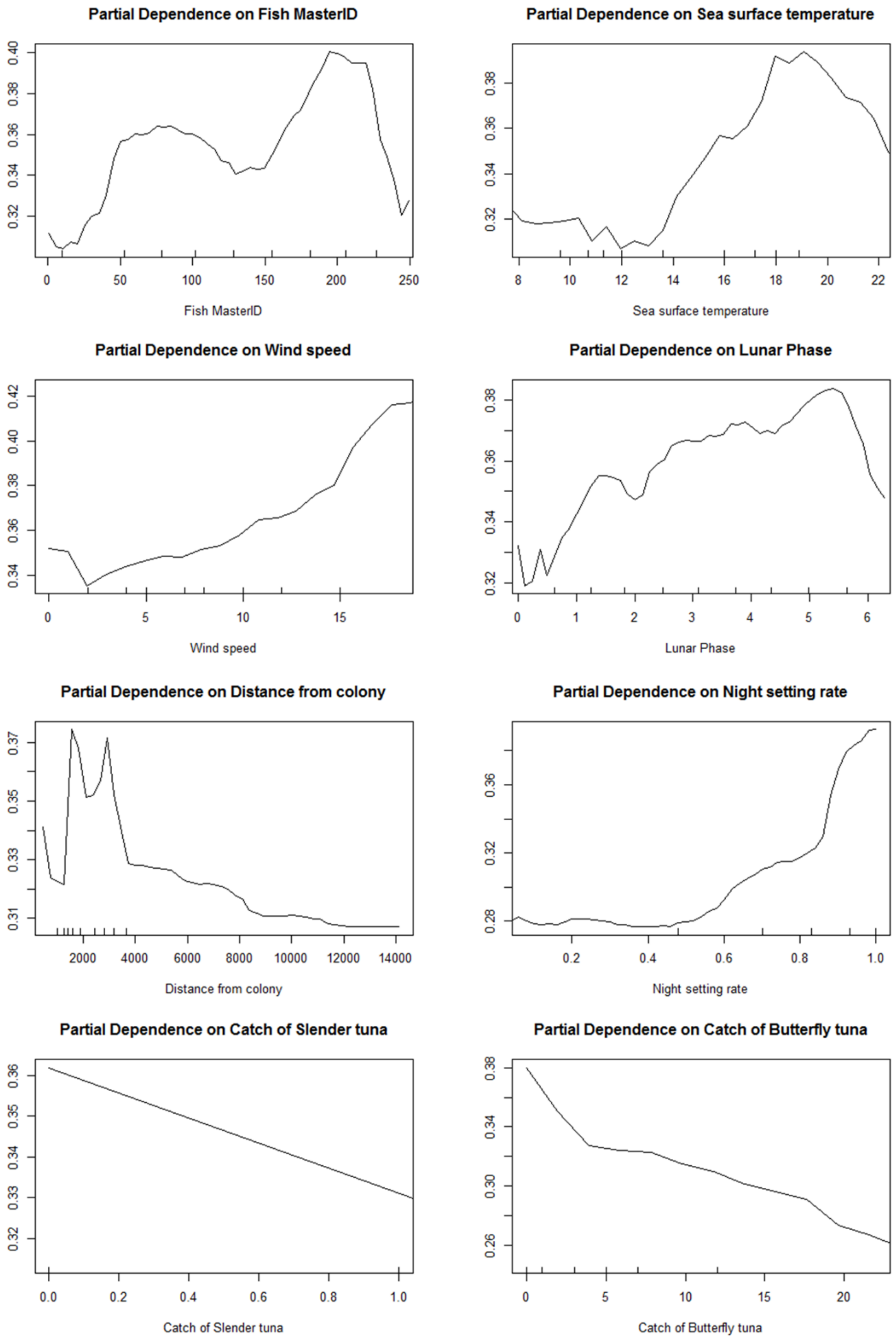


Fig. 5 Continued

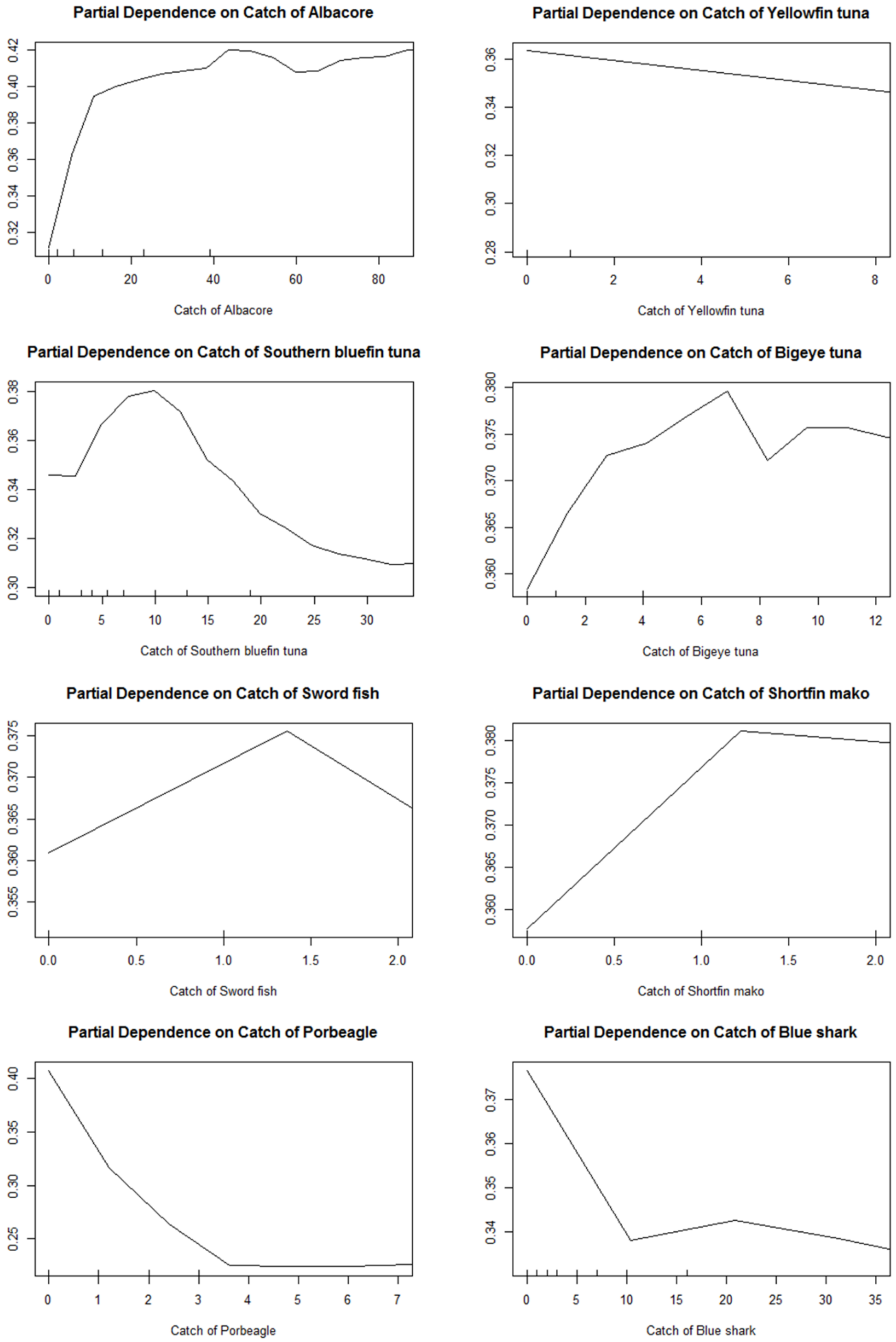


Fig. 5 Continued.

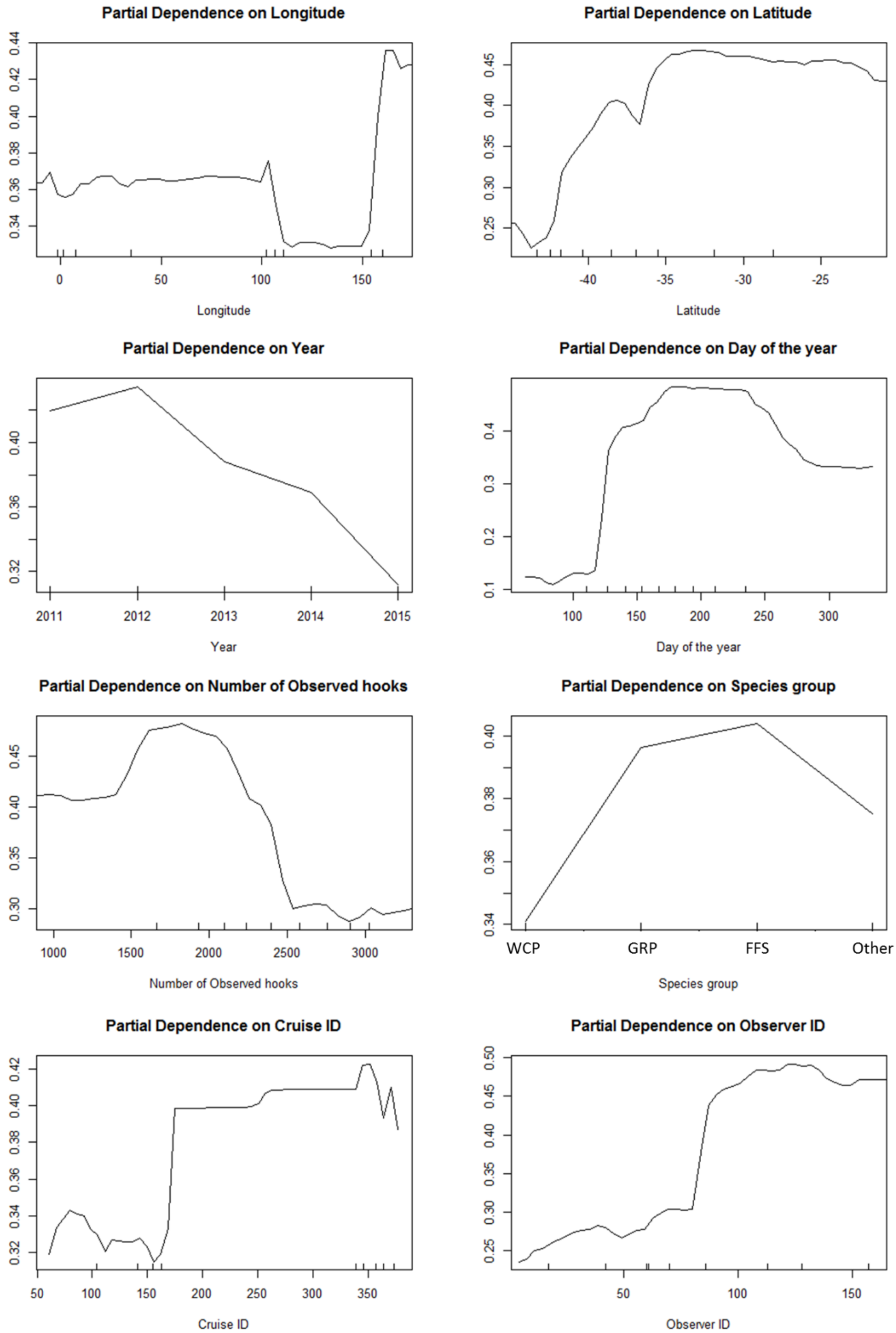


Fig. 6 Petrel mitigation model. Figures show that the partial dependences associated with changes of each variation. The Y axis indicates the partial dependence. The larger value means lower probabilities of bycatch.

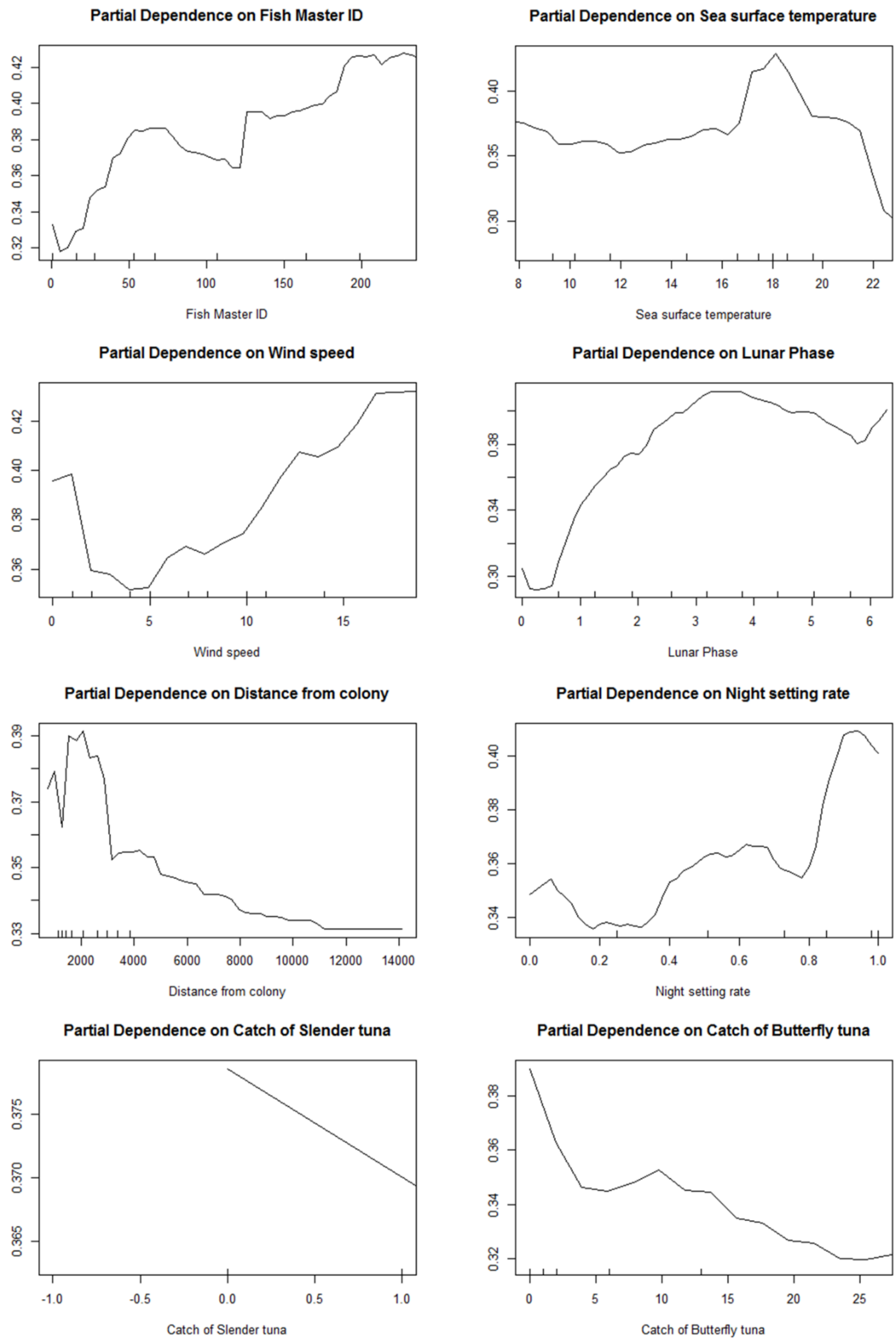


Fig. 6 Continued.

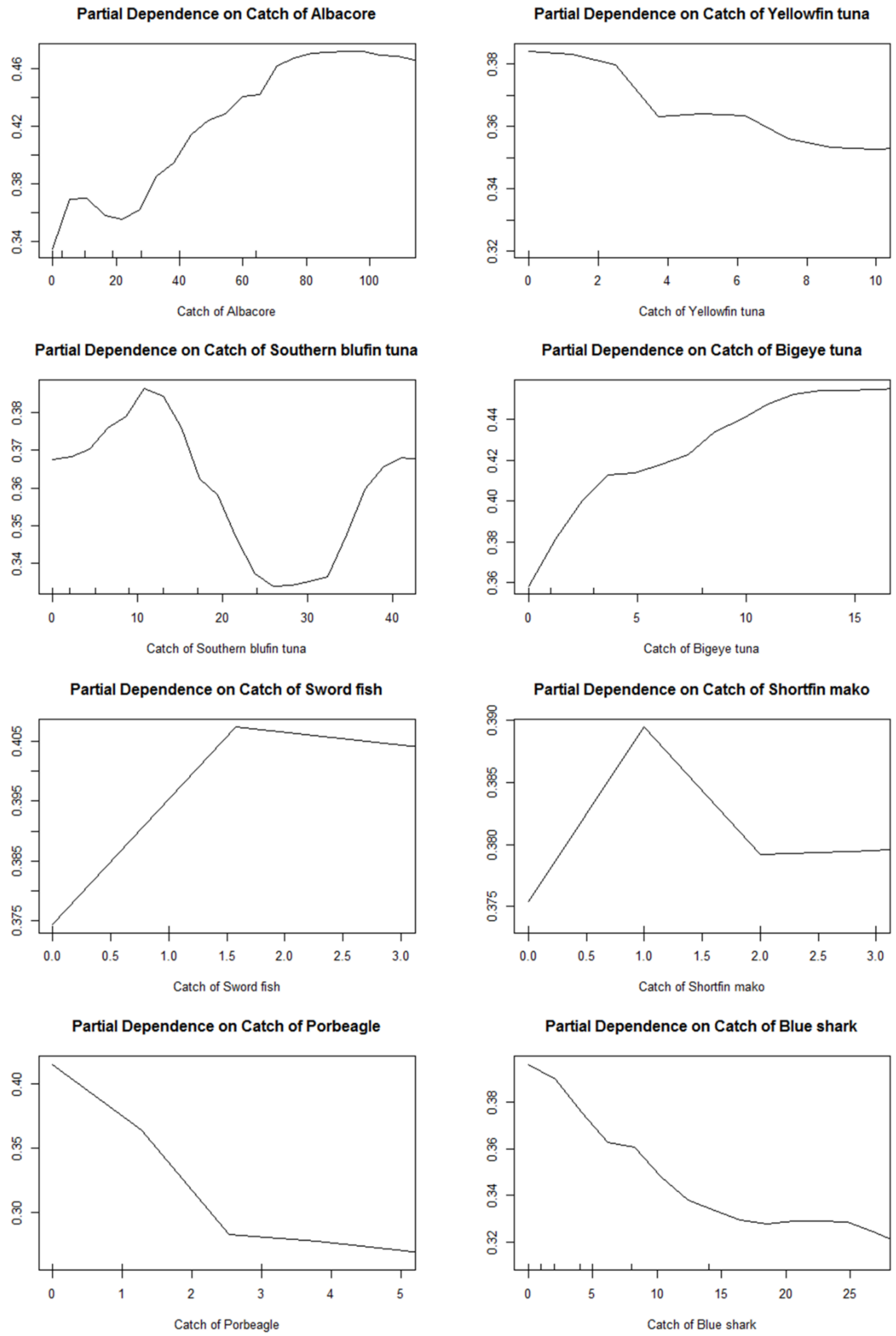


Fig. 6 Continued.

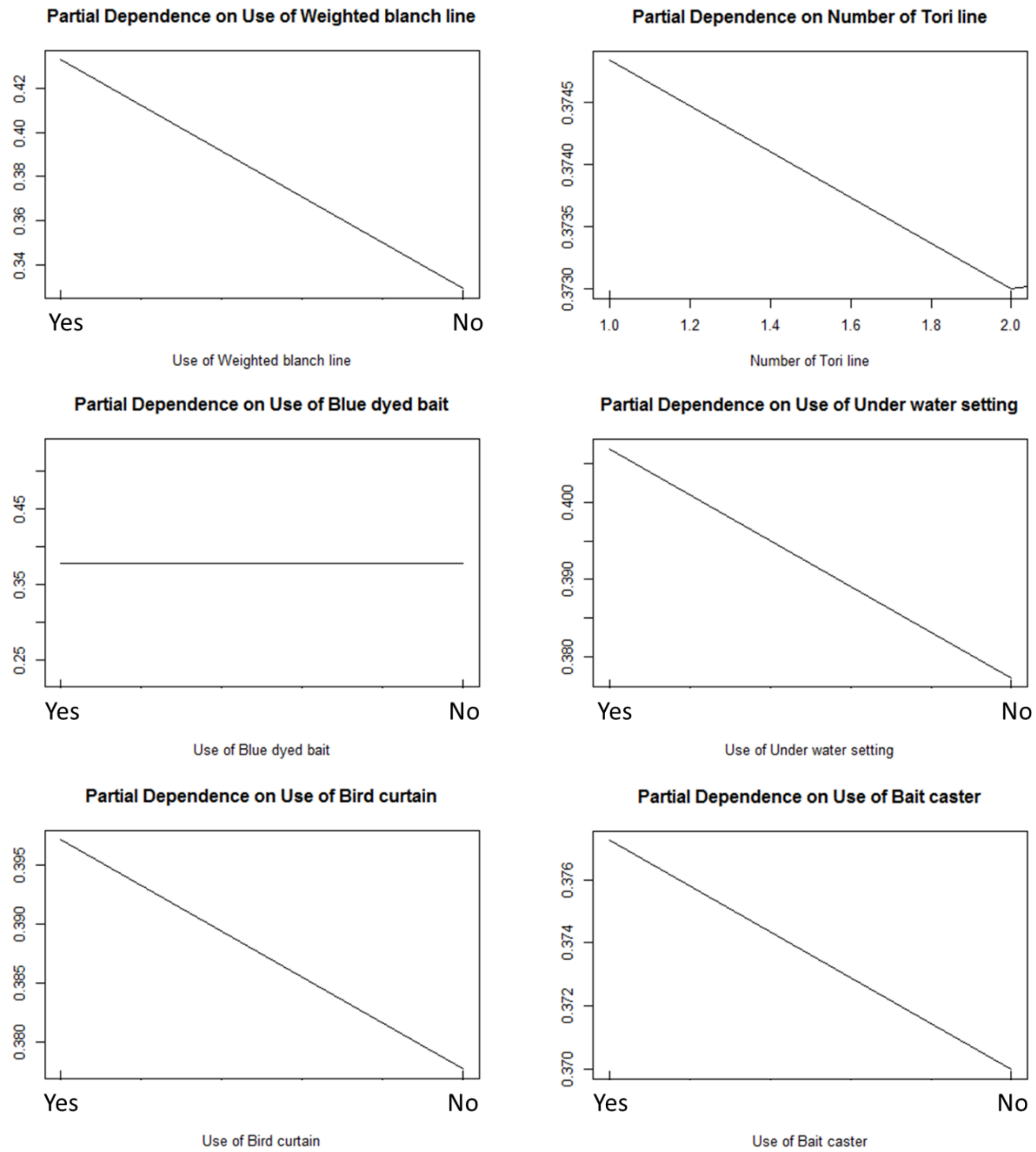


Fig. 6 Continued.

Appendix 1

Material and Methods

Estimation of distribution of bycatch occurrence rates in seabird species group using the random forest model.

The bycatch occurrence rates of each seabird species group was estimated using Albatross model and Petrel model created in this study. We estimated the distribution of bycatch occurrence rates by conducting procedures; as input data of the explanatory variables of the latitude, the longitude, seabird species, and year, we created all possible data and as input data of the rest of explanatory variables, we put the median. And we used the “Predict” function of R for the estimation.

Results

Distribution of bycatch occurrence rates in each seabird species predicted by Albatross model and Petrel model.

We estimated the distribution of bycatch occurrence rates by Albatross model and Petrel model (**Appendix 1 Fig. 7**). Wandering albatross group, black-browed albatross group, and yellow-nosed albatross group were recorded relatively high bycatch occurrence rates from not only southern area but also the northern area, meanwhile shy-type albatross and grey headed albatross were recorded the higher rates towards the south. Yellow-nosed albatross group was recorded relatively high rates off the west coast of Australia. Area shown relatively high rates for grey-headed albatross and Buller’s albatross was the south of 40°S off Cape Town and the southward of 150°E, respectively. The estimated bycatch occurrence rate of black-browed albatross group was the highest and that of Buller’s albatross was the lowest in all the analyzed albatross species groups. In the petrel model, giant petrel group was recorded relatively high bycatch occurrence rate in the south of 45°S in the Indian and the Atlantic (**Appendix 1 Fig. 7**). White-chinned petrel, grey petrel and flesh-footed shearwater showed similar distribution pattern of the rates, which was the higher occurrence rate in the lower latitude and towards the west.

Discussion

Bycatch occurrence rate and the distribution in each seabird species

Adequacy of grouping:

The results of random forests (i.e. Albatross model, Petrel model, Albatross mitigation model and Petrel mitigation model) indicated that bycatch occurrence rate varies widely among species groups (**Figs. 3**,**4**,**5**, and **6**, **Table 3**). Therefore, it is preferable to estimate in the level of species group. In this study, the low bycatch occurrence rate in rare species makes the estimation impossible when the seabirds were classified at specific level, so they are grouped at the level of species group. This processing prevented bycatch occurrence rate to be too low and caused an increase in the number of variables to assess. The species which belongs to the same species group breed during almost same season, therefore annual life cycles are also similar between the species of the same group. In addition, these also have an almost same ecological niche such as prey items, behaviors and life cycles.

Distribution of bycatch occurrence rates will be discussed according to each species group.

Wandering albatross group: This group showed moderate bycatch occurrence rate in comparison to the other groups (**Fig. 3**). The region recorded relatively high rates was around 35°S and 45°S across the Indian and Atlantic Oceans (**Appendix1 Fig. 7**). ACAP (2012a) introduced that wandering albatross has a wider distribution in this species group. The author also indicated that the juveniles and non-breeders of this species occur in latitude belt of the 35°S and the breeders distribute to the area around colonies located on the south of the 35°S. The distribution patterns or densities of two regions where was estimated to be high bycatch occurrence rate may reflect on those of two different developmental stages.

Black-browed albatross group: This group showed higher bycatch occurrence rate in comparison with the other groups (**Fig. 3**). The population size of black-browed albatross which is a species included in this group is larger than the other albatross species groups (ACAP 2012b). Consequently, the bycatch occurrence rates of this group may be increased. Distributions of higher bycatch occurrence rates in this species group were ranged around 35°S and 45°S in the Indian and the waters off Cape Town as well as wondering albatross group does (**Appendix 1 Fig. 7**). Black-browed albatross shows a relatively wide distribution in this group. This species lives near the colonies in the period of chick provisioning whereas moves to 35°S in the incubation period (Wakefield et al. 2011). Additionally, the non-breeders have wide distribution in the Southern Ocean ranged from 30°S to 60°S (ACAP 2012b). It is supposed that the distributions of non-breeders and breeders will be reflected those of bycatch occurrence rates in 35°S and 45°S, respectively.

Yellow-nosed albatross group: This group showed moderate bycatch occurrence rate in comparison to the other groups (**Fig. 3**). In this study, most of bycatch individuals in this group are thought as Indian yellow-nosed albatross judging from the distributions of bycatch position and this species. Areas for higher bycatch occurrence rates located in the approximately 35°S off the west coast of Australia (**Appendix 1, Fig. 7**). In the breeding period, yellow-nosed albatross is known to distribute in subtropical waters which is north of wandering and black-browed albatrosses (Pinaud and Weimerskirch 2007). The aggregated distribution of the bycatch incidents may be caused by that behavior of the breeders.

Shy-type albatross: This group showed moderate bycatch occurrence rate in comparison with the other groups (**Fig. 3**). Little is known about the oceanic distribution of this group (see Petersen et al. 2008 for the coastal waters). In this study, this group showed wide distribution of bycatch occurrence rate from 35°S to 45°S in the waters off Cape Town to the Indian Ocean (**Appendix 1, Fig. 7**). However, information about the oceanic distribution of this species is limited, therefore it will be needed to review in the future.

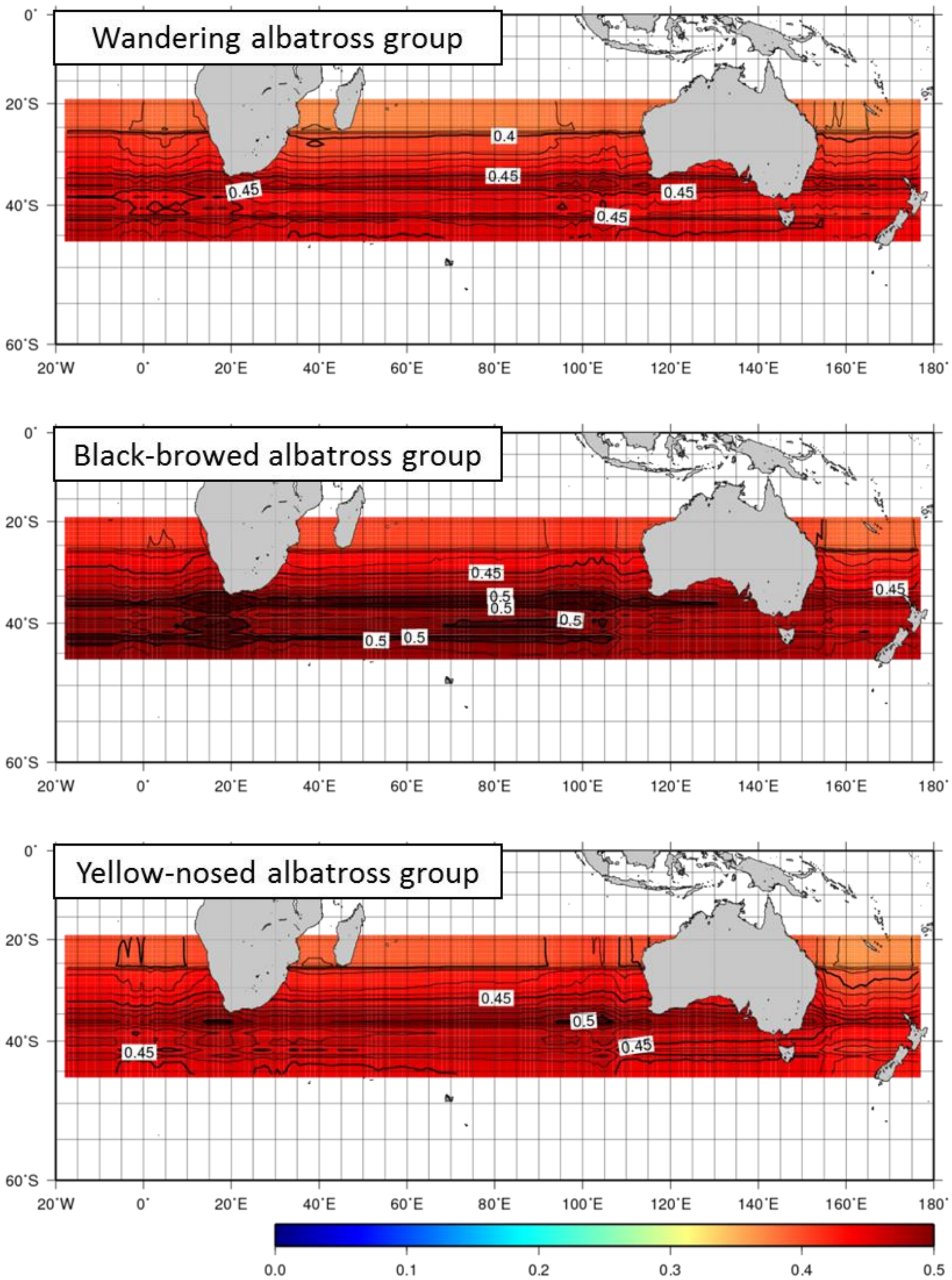
Grey-headed albatross: This species showed much higher bycatch occurrence rate than the other groups (**Fig. 3**). The population size of this species is third-largest in the southern hemisphere after the black-browed albatross and the white-capped albatross. Bycatch occurrence rate was higher than that of wandering albatross group and consequently it is considered that this species is easy to be bycaught (**Fig. 3**). The bycatch positions of this species distributed mainly in the 45°S which is south of distribution of the other species (**Appendix1, Fig. 7**). Grey-headed albatross shows wide distribution in the whole of Southern Ocean (Croxall et al. 2005), and it lives in the south of 45°S around the area from the waters off Cape Town to the Indian Ocean (ACAP 2012c). It is likely that the higher bycatch occurrence rates reflected on the distributional patterns and densities.

Buller's albatross: This group showed much lower bycatch occurrence rate than the other groups (**Fig, 3**). This is because this species mainly distributes in the east of the Tasman Sea (ACAP 2012d) where there is low overlapping with observer effort. There are only a few bycatch records except for the cases from the Tasman Sea in 2014 and 2015. It is supposed that the record of higher bycatch occurrence rate shown in the southward Tasmania reflects on the distributional patterns indicated by the tracking data in ACAP (2012d) (**Appendix 1, Fig. 7**).

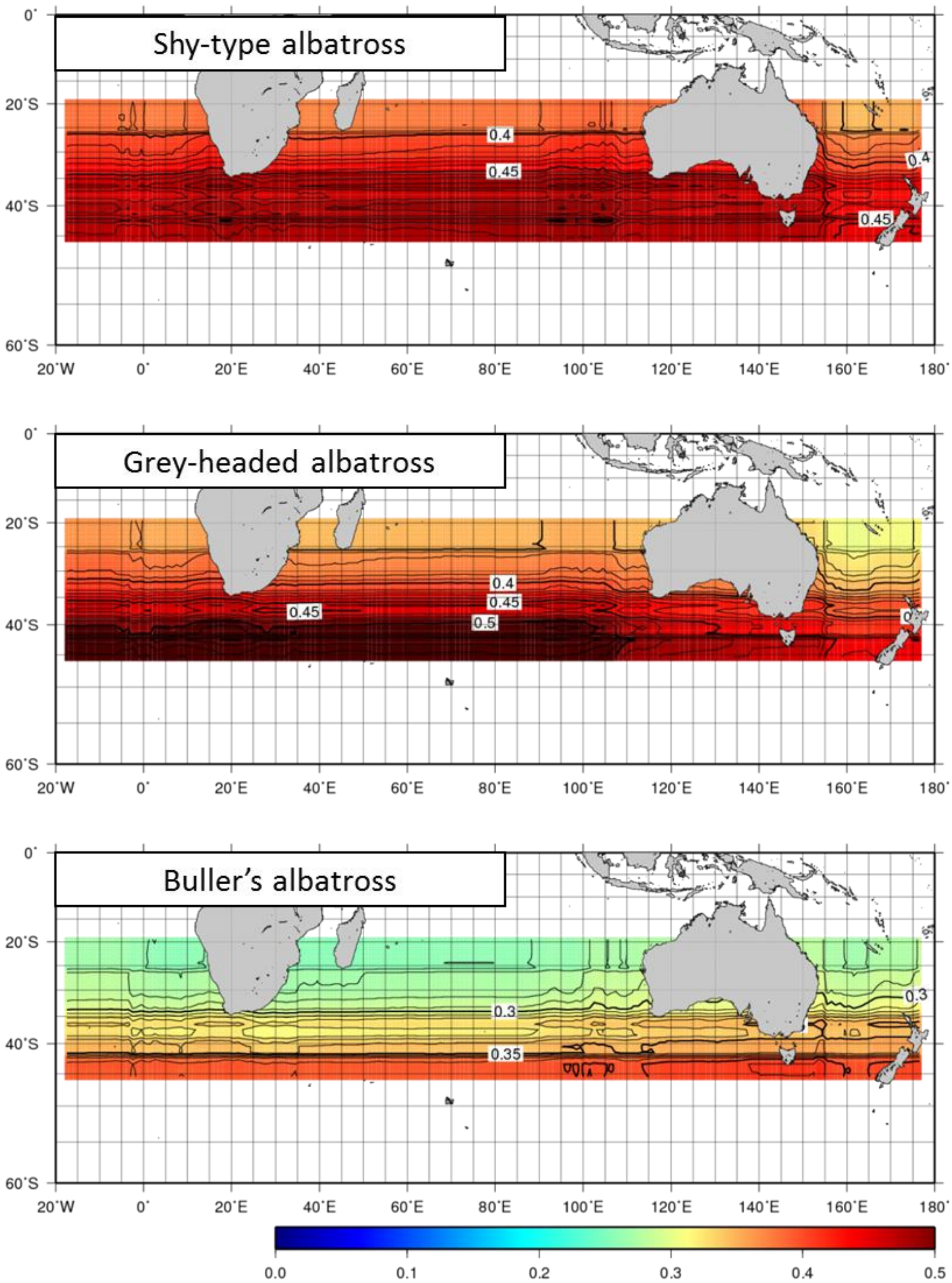
Giant petrels: This group showed lower bycatch occurrence rate in comparison to the other groups (**Fig. 3**). This is possibly because that the population of this species group is larger than that of black-browed albatross group and grey-headed albatross. Bycatch occurrence rate of giant petrels was recorded high in the south of 40°S through the Southern Sea (**Appendix 1, Fig. 7**). It is known that the southern and northern giant petrels have distributions in the whole of the Southern Sea (ACAP 2012e, f). Although distributional maps in ACAP (2012e, f) indicate that these species live in the area from 30°S to 60°S, it was supposed that the bycatch occurrence rates and distribution densities are relatively high in the southern area in this study.

White-chinned petrel: This species showed higher bycatch occurrence rate in comparison with the other groups of the petrels (**Fig. 5**). The population size of this species is larger than those of grey petrel and flesh-footed shearwater (this species: 3,000,000 individuals, grey petrel: 400,000 individuals, flesh-footed shearwater: 650,000 individuals, IUCN 2016). The high rate would be caused by the large population. Bycatch occurrence rate of this species was recorded as high level in the area from 40°S to 45°S (**Appendix1 Fig. 7**). It was also high in the Atlantic and decreased with going eastward. It is difficult to make a comparison between estimated bycatch occurrence rate and actual distribution patterns or densities of this species due to lack of information about the number of individuals and distribution of breeding population in each Island (ACAP 2012g). Although a previous study indicated that the foraging ground is located at the continental shelf and its slope distant from their colonies (>2000km, Phillips et al. 2005), it is supposed that the number of bycatch is recorded as high level in southern oceanic area away from the continental shelf.

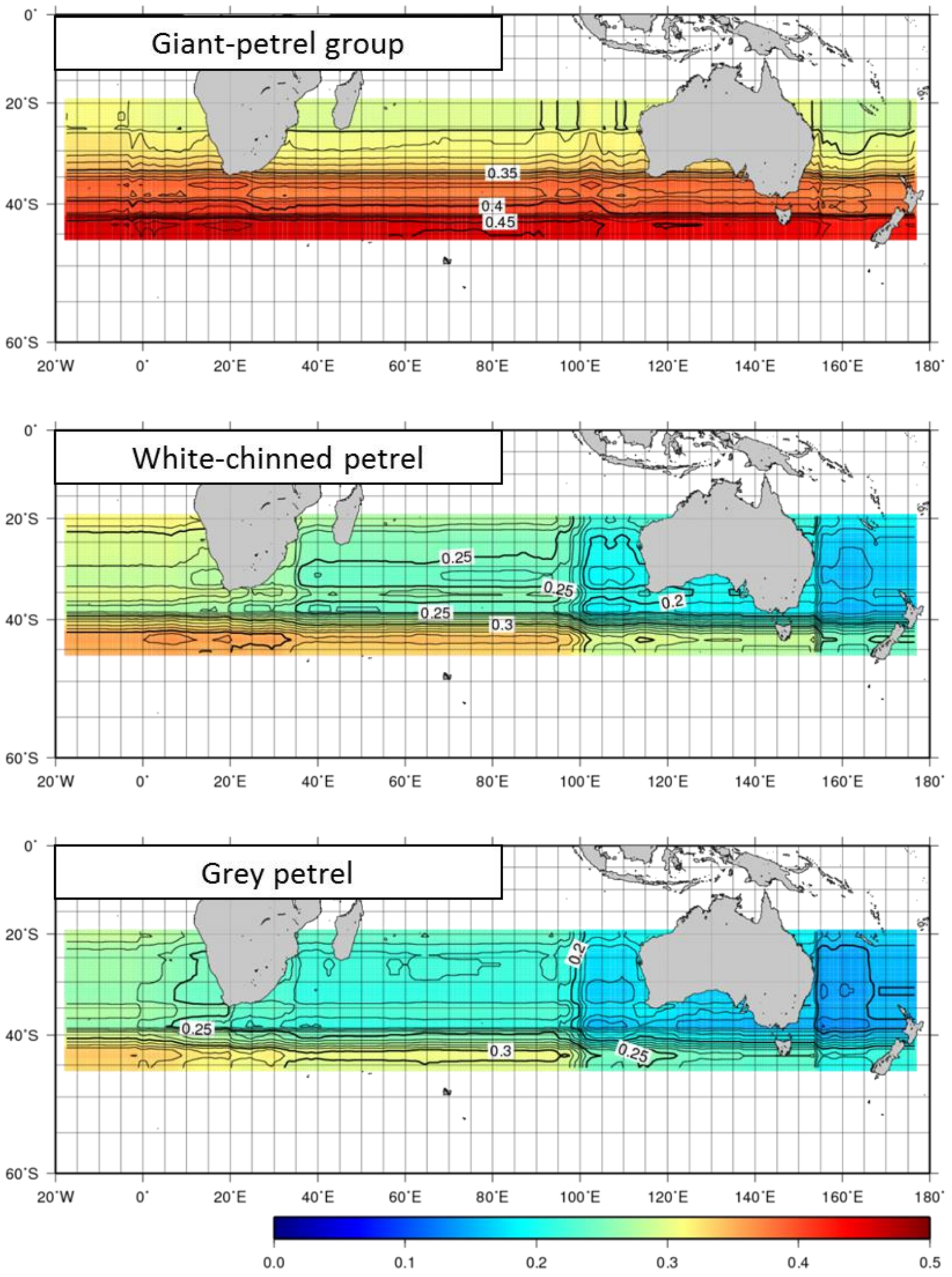
Grey petrel, flesh-footed shearwater, and the other petrels: These groups showed lower bycatch occurrence rates than the other groups (**Fig. 5**). The grey petrel and the flesh-footed shearwater are smaller sizes of population than that of the white-chinned petrel as mentioned above, therefore it is considered to affect the low bycatch occurrence rate. Although the rates of these species group are relatively high in the area from 40^{o}S to 45^{o}S in the Atlantic and decreased with going eastward like as white-chinned petrel, bycatch occurrence rates of these groups are wholly recorded at low levels (**Appendix1 Fig. 7**). ACAP (2012h) indicates the range of grey petrel extends to the area from 32^{o}S to 58^{o}S, but our result indicates that bycatch occurrence rate of this species is high in the south of the area of ACAP (2012h). Flesh-footed shearwater breeds in the Indian and Pacific and has a wide distribution across the two ocean basins (IUCN 2016), but our result indicates that the bycatch occurrence rate of this species is high in the south of the area shown in IUCN (2016). There is discrepancy between our results and previous report of distribution of those species, so it will be necessary to be investigated their actual distributions.



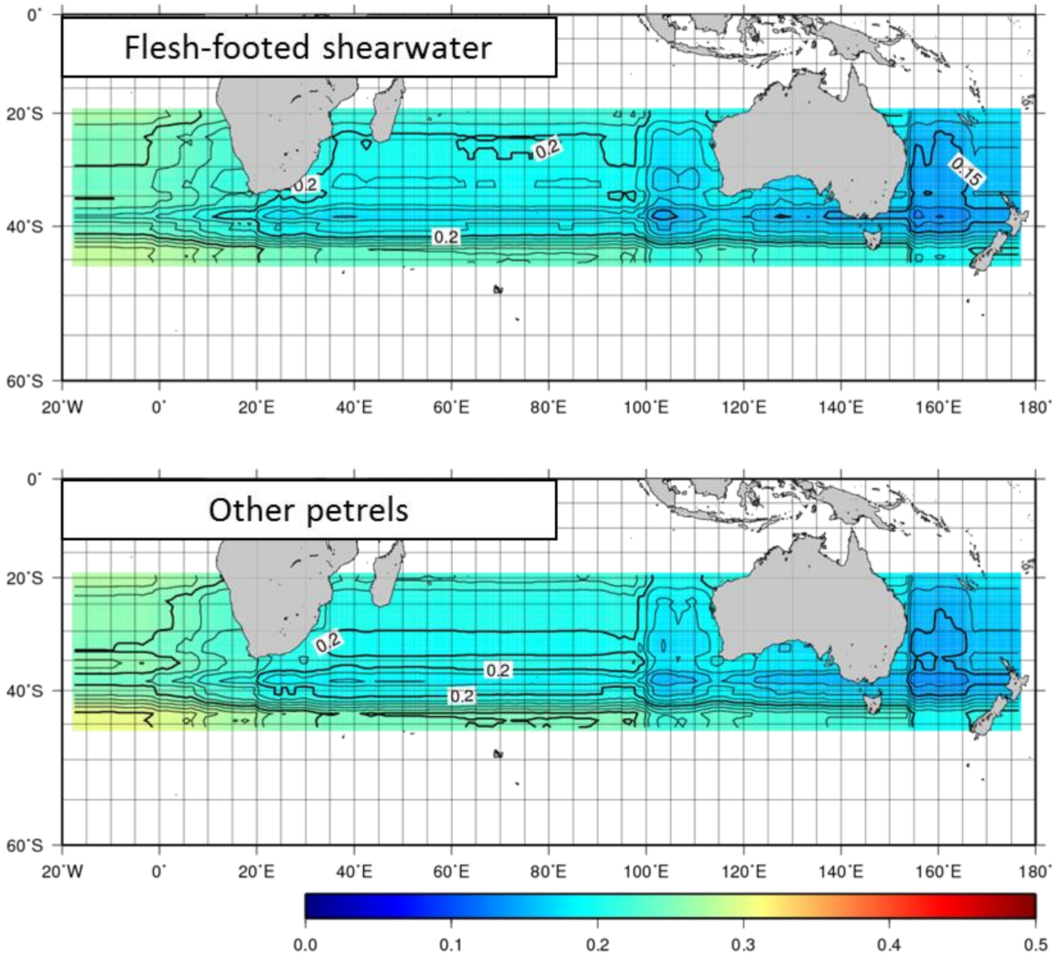
Appendix1 Fig. 7 Distribution of bycatch occurrence rate predicted by albatross model or petrel model. Color shows the degree of bycatch occurrence rate with indicating that red is high rate.



Appendix 1, Fig. 7 Continued.



Appendix 1, Fig. 7 Continued.



Appendix 1, Fig. 7 Continued.