海鳥混獲回避措置評価に関する統計的考察

Statistical consideration on sea-bird mitigation measure evaluation

辻　祥子
Sachiko TSUJI
国立研究開発法人水産研究・教育機構　国際水産資源研究所
National Research Institute of Far Seas Fisheries,
Japan Fisheries Research and Education Agency

要旨

1997-2015 年に収集した南緯 35 度以南の日本船オブザーバデータを用いて、延縄操業における海鳥混獲の統計的特性に関する解析を行った。 操業毎にみても航海単位で見ても混獲率の出現はゼロに近い側に偏っており、約 10%の混獲率の高い操業が混獲の約半分の原因となっている。航海毎の混獲率のバラツキは用いている回避措置の有効性の違いに起因することが示唆されており、多くの漁業者が混獲を一定の範囲内に抑えることに成功している。解析から BPUE が観察鈎数の影響を受けていることが明らかであり、混獲率の指標としては操業毎の平均混獲尾数を用いるほうが望ましい。

Summary

The document examined the statistical characteristics of the occurrence of seabird bycatch in the longline fisheries using the data collected through the Japan's onboard observer program in the period of 1997 to 2015. Only the data on the operations conducted in the south of 35S was utilized. The distribution of occurrence of seabird bycatch, both by operations as well as at the level of cruises, indicated a strong skewedness toward lower values with a long tail in the upper end. Around 10 percent of efforts with high seabird bycatch accounted for about half of the total bycatch. The variability in average bycatch rate among the cruises was considered to reflect a range of effectiveness of the mitigation measures that the fishers had applied. The shape of distribution indicated that a substantial portion of fishers succeeded to suppress an extent of seabird bycatch under a certain level. The analysis revealed a positive relation between the BPUE and the amount of hooks observed. It considered the average seabird captured per operation, showing more consistency that the BPUE against the number of hooks observed, to be more preferable as a standard indicator of referring the bycatch rate.

Introduction

The incidental mortality of seabirds in pelagic longline fisheries has raised a serious global concern, which has led to various efforts of international coordination toward implementing the effective mechanisms of reducing such mortality. The effort included the adoption of obligatory mitigation measures by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in 1992 to reduce the incidental seabird mortality in commercial fisheries in the Southern Ocean. In 1999 the FAO established the International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (IPOA-SEABIRDS) as a voluntary instrument and encouraged all nations engaged in longline fisheries to assess the existence of the problem and adopt national plan of action including procedures for national reviews and reporting requirements, with a strong emphasis on the harmonization and collaboration with relevant international organizations.

For the tuna longline fisheries, the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) adopted a recommendation relating to ecological related species, including the incidental mortality of seabirds by longlines and made the use of bird scaring lines (tori poles) mandatory in the fisheries targeting on southern bluefin tuna in 1997. The five tuna RFMOs have established conservation and management measures which require or recommend their pelagic longline vessels to use a combination of seabird bycatch mitigation measures. The CCSBT currently has a non-binding recommendation that CCSBT fleets comply with the seabird CMMs of the IOTC, WCPFC and ICCAT. The ICCAT Recommendation 11-09 and the IOTC Resolution 12-06 are the most recent relevant CMMs.

The seabird by-catch component of FAO's GEF-funded Common Oceans Tuna Project is progressing toward the integrated global assessment of effectiveness of seabird bycatch mitigation measures, accumulating the considerations on the potential methods for measuring and monitoring the effectiveness of tuna RFMO seabird CMMs.

So far, two standard indicators, the rate of mortality expressed as number of bird taken per 1,000 hooks, i.e. so-called Bird per Unit Effort (BPUE), and the total number of seabird caught, usually estimated by multiplying BPUE with total relevant efforts, are commonly accepted to describe the seabird incidental mortality by tuna longliners.

Japan has dispatched scientific observers onboard the longline vessels targeting on southern bluefin tunas since 1992 and has collected the information on incidental seabird take together with other information. The Japan's longline fleet has been one of the largest among those operating in the higher latitude of the southern hemisphere, the area subject to the seabird bycatch mitigation CMMs of the CCSBT and IOTC. The data assembled more than 20 years with a relatively consistent quality provided the best opportunity to examine the characteristics of seabird bycatch observed in the longline fisheries. As an initial step to examine the historical changes of the seabird bycatch, the statistical characteristics of the event were examined in order to determine the suitable procedure to treat the data, which was the original start of preparing this document.

The analysis raised concerns on the statistical reliability of those two accepted standard indicators of seabird mortality, in particular of the BPUE. Since the total mortality is usually derived as a simple or stratified extrapolation of the BPUE, the credibility of the BPUE in fact would determine the quality of assessments based on those two indicators as a whole.

Due to a constraint in time and available information, the document still remains as its preliminary stage mainly based on a quick and rough examination the data derived from one source, the Japan's onboard observer data and including still indicative information. The author wish that the sharing this preliminary information would stimulate the interests of the relevant researchers, managers and the information owners and become a trigger to collaborate toward the better understandings on the seabird mortality occurrences. The document also tried to cover some speculations on a conceptual relevance, feasibility and cost-efficiency in monitoring and evaluations, and indication in seabird mortality management, in addition to the statistical characteristics.

Data used in the analysis

The analysis was based on the observer data set that was prepared by the National Institute of the Far Seas Fisheries. The data set contained the seabird bycatch information collected through the Japan's onboard observer program for tuna longline fisheries during 1997 and 2015. The contents included the starting and ending times and locations of setting and hauling of individual operations, the number of individuals taken aboard by species, including seabirds, during the observation, vessel and cruise identifications, and other supplementary information including details of mitigation measures implemented. The recordings of all species taken aboard during the observation were obligatory in this period. Some of other recording requirements, in particular for those on the mitigation measures implemented, have been modified mainly in 2011 and 2015, with minor adjustments in between years. Then, both the reporting practices and quality of onboard observers were considered to remain relatively consistent, at least in regards to the reports on seabird bycatch.

For the purpose of the analysis, only the data operating in the area of high risk in terms of seabird bycatch. Although initially extracted the data operating in the south of 25S, corresponding with the ICCAT and IOTC CMMs, the preliminary examination indicated that in the area between 25 S and 35 S, the fishing occurred less consistently and that the observed seabird bycatch tended to be lower than those observed in the south of 35 S. Therefore, the analysis in this document only utilized the operation data occurred in the south of 35 S. Total 12,113 records was used and Table 1 gave a quick summary.

By aggregating the data of multiple years and from the whole operating areas, the analysis assumed that the pooled data set could provide a good representation of overall seabird bycatch situation integrating both temporal and spatial variances. In the other words, the extracted pooled data set was treated as a pseudo population of longline seabird bycatch in the analysis here. This pseudo population is supposed to represent the situation in the area of high risk in the seabird bycatch.

It should be noted that the data set used here corresponded the period when the CCSBT binding measure of requiring mandatory use of tori-pole with longline operations is effective. The data is also subject to the various additional efforts for improving the effectiveness of mitigation measures, including the progress in technical development and strengthening of regulations. Therefore, the pseudo-population would reflect the situation under the influence of a range of mitigation measures already implemented, not a virgin status of seabird bycatch against an introduction of mitigation measures.

The impacts of temporal change of mitigation measure implementation as well as of fishing operation were quickly examined without detecting any conclusive signals, which were not included in this document.

Results and discussion

Seabird bycatch occurrence in operations

This section examined the statistical characteristics of seabird bycatch occurred at individual operations, treating each operation as independent.

Figure 1 showed a probability distribution of seabird bycatch in the BPUE. Red bold line indicated the pooled result of 1997 to 2015, with thin lines corresponding to the individual years that did not show fundamental differences from the pooled result. Some statistics of indicating the shape of distribution were in Table 2.

No seabird bycatch was observed in 71 percent of the operations, 8,593 out of 12,113 operations. The average and standard deviation of the observed BPUEs by operation were 0.26 and 0.71, and those for seabird positive operations were 0.91 and 1.06. The highest BPUE observed was 13.7, with the median of 0.49 within the seabird positive operations. In addition to the large occurrence of zero, the difference between average and median BPUEs within the seabird positive operations indicated that seabird bycatch distribution was skewed toward the lower values with a long tail. Due to a difficulty to identify a proper statistical model to approximate such distribution, the analysis here stayed with rather primitive non-parametric statistics, including ranks and percentiles and focused to reveal general characteristics of the event.

When referring the number of seabirds captured per operation, the operations with the seabird bycatch of two or less accounted for 93.6 percent of total operations, including the no bycatch operations of 71 percent. The highest number of seabird bycatch observed was 32 in one operation (Table 2). Fifty-three operations, 0.4 percent of total operations, captured 10 or more seabirds, accounting for 10.5 percent of total seabird bycatch. Similarly the 288 operations, 2.4 percent of total operations, were with 5 or more seabird bycatch, and contributed 30.5 percent of total seabird bycatch.

The Figure 2 visualized the same thing by plotting the accumulated seabird bycatch corresponding to the number of hooks used. The top 1 percent, 5 percent, and 10 percent of the observed efforts explained 17 percent, 45 percent and 64 percent of total seabird bycatch, respectively. The BPUEs corresponding to the top 1 percent, 5 percent and 10 percent of the efforts were 2.87, 1.20 and 0.74, respectively.

The occurrence of seabird bycatch is characterized with a large occurrence of zero with a long tail of positive values. The first important indication is that the mean value has no statistical representativeness, neither a central value nor most common value, and is highly sensitive to the values sampled from the high end. The same distribution pattern was observed consistently throughout the times and areas examined.

It is important not to forget that the data utilized here would reflect the situation of longline fisheries with certain mitigation measures already implemented. The distribution of large zero observations with a long tail in the high end could be partially attributed to the effects of the mitigation measures.

Seabird bycatch at the cruise level

While the analysis in the previous section treated the seabird bycatch of each operation to be independent, a certain level of vessel dependency was well recognized. Accordingly, Japan treated the observer data on seabird bycatch as a two-stage sampled data, with the first stage sampling on the cruises and sampling operations as the second level (e.g. Takeuchi, 1998). This section examined the extent of dependency of seabird bycatch on the cruises and speculated their indication.

The probability distribution of average BPUE of individual cruises was shown in Figure 3, together with those based on the operations for a comparison. Table 2 and Figure 2 also showed the distribution pattern of average BPUE at the cruise level and the accumulated seabird bycatch in accordance with the number of hooks used, in comparison with those based on individual operations.

The proportion of the cruises with no seabird captured were 22 out of the 302 cruises, accounting 7.3 percent of the total cruises, and 5.0 percent of the total fishing efforts in the number of hooks. Considering that the cruise was consisted with the average of around 40 operations, this proportion was significantly higher than the value expected from a random selection of 70 percent probability event, i.e. $(0.7)^{40}$, that is negligible, almost zero. The average and standard deviation of the mean BPUEs of the cruises were 0.27 and 0.41, with the median of 0.12 and the highest value of 3.44.

The major characteristics of the seabird bycatch occurrence at the level of the cruises were quite similar to those observed at the level of operations. The distribution of mean BPUE by cruises was skewed toward the lower end, with a quite long tail in the upper end, though the extent of skewedness became less obvious due to a smearing effect of combining multiple operations data. Still, the minor portion of the top end cruises with high bycatch rate contributed substantially to the total seabird bycatch. The cruises with the top bycatch rate, corresponding to 1 percent, 5 percent, and 10 percent of fishing efforts in the number of hooks, accounted for 9 percent, 28 percent, and 44 percent of total seabird caught, respectively (Figure 2).

If a smearing effect would provide a reasonable explanation of the differences between the BPUE distributions by operations and by cruises, a 'cruise' can be considered as a random sampling process of individual operations, and then it would be most appropriate to treat the individual operations as independent, as shown in the previous section. The occurrence of the cruises with no seabird bycatch contradicted against the hypothesis of randomness as indicated above. Similarly, when comparing the expected and observed occurrences of the operations with the BPUE within the top 5 percentiles, the 51 cruises, 17 percent, carried the operations of the high bycatch rate more than expected from a random selection, while the 177 cruises, 59 percent, indicated the occurrence of the operations of the high bycatch being less than expected. Figure 4 showed the result of comparison of mean BPUE distribution between the observed one with the simulated distribution based on random sampling process. The simulation randomly extracted the BPUEs of 40 operations from the whole data set utilized here with bootstrapping for mimicking a cruise and repeated a process for 300 times, make it comparable to the number of observed cruises of 302. The result indicated that the cruise could not be considered as a random selection process of individual BPUEs, implying the importance of cruise effects in understanding and interpreting the seabird bycatch. The cruises worked to disperse the population expected from random smearing into two directions, one with more operations with low bycatch rate than average expectation and the other carrying more operations with high bycatch rate.

<u>Indication of the differences in seabird bycatch among cruises/vessels</u>

The seabird bycatch rate could be considered to depend on at least two factors: i) the seabird abundance at the time of line setting and ii) the effectiveness of applied mitigation measures in reducing the seabird bycatch. This section examined the data after dividing into the time-area strata for further investigating the indication of seabird bycatch data. The strata were defined with the year and the three areas defined based on the longitude, west of 60E, between 60E and 120 E, and east of 120E. The first two roughly corresponded to the CCSBT Areas 9 and 8, whereas the last one a combination of areas surrounding the south coast of Australia and around New Zealand. Considering that the actual operation tended to occur in the concentrated way within a limited time and area, the size of stratum was considered small enough to assume the homogeneity in bycatch risk in a sense of seabird abundance or risk of encounter. In fact, the dimension of the strata would be roughly equivalent with that utilized in the extrapolation of seabird bycatch, which indicatively assumed the consistency in risks and operations within a stratum. Then, the major part of the remaining differences could be attributed to the second factor, i.e. the variation in effectiveness of mitigation measures among cruises.

First, one example of the details of seabird bycatches observed among the cruises operating in the same time-area were shown in Table 3. In the assumption of relatively consistent bycatch risk within a given time-area stratum, this example alone could provide a good counter evidence against the hypothesis placing a heavy dependence on time-area component in explaining the bycatch occurrence, and supporting the consideration to regard the variations in average bycatch rate as a reflection of the variation in the effective of implemented mitigation measures among cruises.

Though the choice of this specific example was not random, high bycatch cruises and low bycatch cruises were commonly found within the same stratum. In all of the 14 strata that contained the minimum five cruises including at least one cruises of high bycatch rate (defined as 0.65 BPUE and higher, corresponding roughly to the top 10 percent), the cruises with the low bycatch rate of 0.1 BPUE and lower always coexisted.

So far, the pooled observer data was regarded as a mother population of representing an overall longline bycatch event. Taking this as a true distribution, it would be possible to examine whether the observed occurrence of high bycatch cruise could be statistically explained as a random sample from the same mother population. The cruises with no bycatch observation were eliminated from this analysis, due to a difficulty in distinguishing between the zero bycatch and no recording, in particular for the early years. The null hypothesis was no difference from the original population and the exercise assumed that the 30 cruises consistently operating in a stratum and identified the top 10 percent high bycatch cruise with the mean BPUE of 0.65 and higher. The results rejected the null hypothesis only for five strata out of 55 with the 10 percent significance, with the four of them indicating the higher bycatch than the mother population. The remaining 50 strata could not reject the null hypothesis. This indicated that the bycatch distribution pattern among cruises was common throughout years and areas examined, though the method utilized have only a limited statistical power to detect temporary and spatial differences.

The number of observers dispatched in the past varied according the years and areas ranging from one to 24 cruises by the strata identified above. Figure 5 was a graphical summarization of the occurrence of high bycatch events in accordance with the number of observed cruises within a stratum. One data corresponded to each stratum observed in the stacked bars and yellow was assigned to the strata where the high bycatch cruises were found. The line and blue dots indicated the theoretical and observed probabilities that the high bycatch cruises of 10 percent probability would be found in a given stratum when assuming total 30 cruises operating in each stratum. It seemed that the existence of high bycatch cruises could be picked up reasonably well when five or more cruises were observed out of 30 cruises. The observation was consistent with the preliminary bootstrap simulation results, not included here.

Nature of Bird per Unit Effort (BPUE)

The number of bird taken per 1,000 hooks, so-called Bird per Unit Effort (BPU) is commonly accepted as the standard indicator for seabird incidental capture rate. The same procedure, i.e. standardizing the longline effort with the number of hooks used, was broadly applied to the longline catch rate standardization, often with further sophistications and adjustments by introducing the stratifications and modeling to accommodate the influences of the temporal, spatial, operational and environmental factors, depending on the availability of additional information. The procedure assumes a linear regression of catch with the number of hooks used. This section would speculate whether this underlying assumption still hold its validness even in the situation of rare events such as seabird bycatch.

The information available through the onboard observer data represents what occurred during the observation period by observers. Observers do not necessarily observe a complete process of a haul but often truncate their observations to attend the other required tasks such as preparation of daily report. While the majority of observers attended around 80 percent of hauling operation, the data set indicated a variation in the observed efforts per operations ranging from few hundred hooks to around 3,500. This variance would be caused from the combination of two the effects, a) the variation of gear configurations adopted by fishing vessels, and b) the variation of the coverage rate, the proportion of hooks observed in a given date, among observers. Whatever the reason of variation, if the seabird bycatch would occur in accordance with the number of hooks, the BPUE would remain constant regardless the amount of efforts observed, while the seabird captured per operation would increase as the observed efforts would increase.

Table 4 showed a comparison of a range of statistics describing the seabird bycatch distribution, stratified with the number of hooks observed per. Because of a large proportion of zero catch event, this analysis utilized the percentiles of BPUE within the operations only with seabird bycatch to better capture the shape of BPUE distribution. For a reference, the average BPUEs calculated from the whole operations in a given stratum were also included in the table. The first block were the observed BPUEs, while in the second block, the value was standardized with that observed with the stratum of the 3,000 and more hooks observed, in order to examine a possible impact of the denominator, i.e. the number of hooks. The figures in the middle were a reference to a denomination effect, a reversed figure of the mid point of number of hooks in a given stratum (e.g. 1,250 for the stratum of 1,001 – 1500 hooks) and again standardized with that of the last one (i.e. 3,300).

The result suggested a contradiction against the testing hypothesis. The BPUEs showed a declining tendency according to the increase of the observed efforts. The rates of the decline of BPUE in accordance with the observed efforts were comparable with the reversed value of observed efforts, suggesting a direct influence of the denominator.

On the other hand and interestingly, the occurrence of seabird capture per operation shown in the last block of Table 4 remained quite stable. The practices of truncating observation time for each haul seemed not introducing a substantial deterioration in detecting seabird bycatch.

In summary, the Japan's tuna longline observer data could not provide an evidence to support the hypotheses of the longline seabird bycatch to be dependent to the number of hooks used. Needless to say, this issue would require further investigation with additional information. Having said that, in a lack of clear evidence to support, it would be safer and more appropriate to remain with the statistics closer to the nature of the targeted event, in this case seabird bycatch, from the statistical viewpoint.

Summary conclusion

The ultimate objective of the seabird bycatch mitigation efforts is to reduce the overall mortality incidentally caused during the process of the longline fisheries operations. In that sense, the author believes that the statistics of primary importance is a robust and reliable estimate of total seabird incidental mortality. While the extrapolation of observed mortality into the estimate of total is unavoidable, it is still important to choose a reference indicator, adequately sensitive to the target event and least sensitive to noises as possible.

Currently, the mean BPUE had been adopted as a standard indicator of such reference of ratio to be used for extrapolation to the total value. With the observed distribution of BPUE, the utilization of mean does not provide any statistical representativeness. Although it is possible to utilize this as a reference for an extrapolation, it would induce a substantial uncertainties and instability of resulted estimates. Considering the existing BPUE distribution under the influence of effectiveness of the mitigation measures implemented, the more the mitigation measures would become effective, the more the distortion in the bycatch distribution pattern exaggerated and the less the credibility of the estimates derived from a mean value. It is important to urgently explore alternative indicators and the procedures of obtaining a robust and less-biased estimate of total bycatch.

The examination of historical observer records onboard the Japan's longline vessels indicated the seabird bycatch per operation to be more robust against the amount of hooks observed. More importantly, the average number of seabirds caught by operation is directly linked to the actual event and easy to understand. For example, the fishers can easily grasp the indication, for example of their operations with the mitigation target required through the regulations by themselves, which would be great benefits. By separating the indicator into the occurrence of events and its magnitude, there might be a possibility to apply the procedure utilized in assessment and prediction the disease outbreaks and disastrous events. From those reasons, the seabird by catch per operation would be one possible option of alternative indicators for worth further pursuing in the future work.

The analysis revealed that the existing observer data reflects a range of effectiveness of mitigation procedures that the individual fishing masters applied to their fishing operations. The results also indicated that a substantial component of the cruises observed in fact succeeded well to suppress an extent of seabird bycatch under a certain level. This would imply first that with proper implementation, it would be practically possible to suppress under a certain level quite effectively, which was in accordance with the evidences provided in the process of development and evaluation of various mitigation measures (e.g. Melvin et al. 2014).

Even there is a wide variation, statistically, as long as the pattern and extent of the effectiveness of mitigation measures applied are consistent between the sampled and mother populations, the estimates for the mother population could be derived from the samples without a serious distortion. However, in principle, the random sampling is neither really powerful nor suitable to capture the events with a large variation induced by multiple factors of different magnitude of impacts, such as the cases indicated here. Introducing stratification is a most commonly utilized solution that would substantially improve both the cost-efficiency and the reliability of resulted statistics.

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Table 1. Summary of data utilized in the analysis, extracted all operations occurred south of 35S from the Japan's onboard observer data.

Year	Number of cruises involved	Number of sets involved	Number of observed Hooks (000 hks)	Observed sea-bird bycatch
1997	15	684	1737	242
1998	25	915	2370	501
1999	51	1376	3348	756
2000	14	560	1357	267
2001	17	643	1575	360
2002	20	544	1251	466
2003	16	758	1879	393
2004	14	679	1709	199
2005	17	762	1847	236
2006	16	819	2063	538
2007	10	423	1087	186
2008	5	235	560	173
2009	7	257	608	110
2010	8	275	642	286
2011	11	568	1385	390
2012	12	419	984	120
2013	13	455	1077	362
2014	19	812	1991	764
2015	22	929	2059	922
Total	**312**	**12113**	**29529**	**7271**

Table 2. Distribution of seabird incidental capture.

	Bycatch per operation		Bycatch per cruise	
Percentiles	**BPUE**	**Birds caught per operation**	**Average BPUE**	**Average birds caught per operation**
Min. value	0	0	0	0
5%	0	0	0	0
10%	0	0	0.01	0.04
25%	0	0	0.05	0.13
50% (Median)	0	0	0.12	0.29
75%	0.36	1	0.32	0.72
90%	0.77	2	0.65	1.60
95%	1.30	3	0.90	2.06
99%	3.14	7	2.12	4.53
Max value	13.70	32	3.44	7.75
Mean	*0.26*	*0.6*	*0.27*	*0.62*

Table 3. Example of the difference in the seabird bycatch observed among the cruises operating within one time area stratum, define with the time in year and the area with the similar dimension as the CCSBT Area 9.

			BPUE			Seabird positive set	
Total operations	**Total seabirds caught**	**Max. # captured per set**	**Mean**	**Max.**	**%**	**Average birds per operation**	**Average BPUE**
21	1	1	0.02	0.33	5	1	0.33
28	5	1	0.08	0.51	18	1	0.43
17	5	2	0.13	0.85	24	1.3	0.57
52	59	4	0.39	1.40	63	1.8	0.62
10	11	5	0.39	1.69	60	1.8	0.64
51	55	9	0.66	3.85	47	2.3	1.40
31	171	32	2.01	11.90	84	6.6	2.40

Table 4. Comparison of seabird bycatch distributions according to the number of hooks observed.

	Number of hooks observed					
Percentiles	**-1000**	**1001-1500**	**1501-2000**	**2001-2500**	**2501-3000**	**3001-**
Sample size	171	461	1255	4329	4604	1293
% sets w/o bycath	71.9	63.3	75.3	72.3	68.7	72.6
BPUE Distribution in seabird positive operation						
50% (Median)	2.16	1.35	0.61	0.47	0.39	0.33
75%	3.40	2.67	1.50	0.89	0.78	0.66
90%	7.08	4.45	2.16	1.46	1.46	1.31
95%	8.49	6.41	3.13	2.30	2.10	1.95
99%	11.68	10.68	4.54	4.42	4.17	2.94
Max value	13.70	12.00	7.24	6.89	11.90	5.27
Mean BPUE (all sets)	*0.86*	*0.78*	*0.28*	*0.23*	*0.24*	*0.18*
Standardized with the value in the last stratum						
50% (Median)	6.54	4.10	1.87	1.42	1.19	1
75%	5.17	4.05	2.28	1.36	1.19	1
90%	5.39	3.39	1.65	1.11	1.11	1
95%	4.34	3.28	1.60	1.18	1.08	1
99%	3.98	3.48	1.55	1.51	1.42	1
Average	*5.08*	*3.66*	*1.79*	*1.31*	*1.20*	*1*
Mean BPUE	*4.87*	*4.41*	*1.59*	*1.27*	*1.37*	*1*
1/central hooks in the stratum	*6.6*	*2.64*	*1.89*	*1.47*	*1.20*	*1*
Distribution of seabird bycatch in seabird positive operation						
50% (Median)	2	2	1	1	1	1
75%	3	3	3	2	2	2
90%	5.3	6	4	3	4	4
95%	6.65	9	6	5	6	6
99%	8.53	15.3	9	10	11.6	8.94
Max value	9	18	12	17	32	17
Average	0.69	1.11	0.52	0.51	0.66	0.55

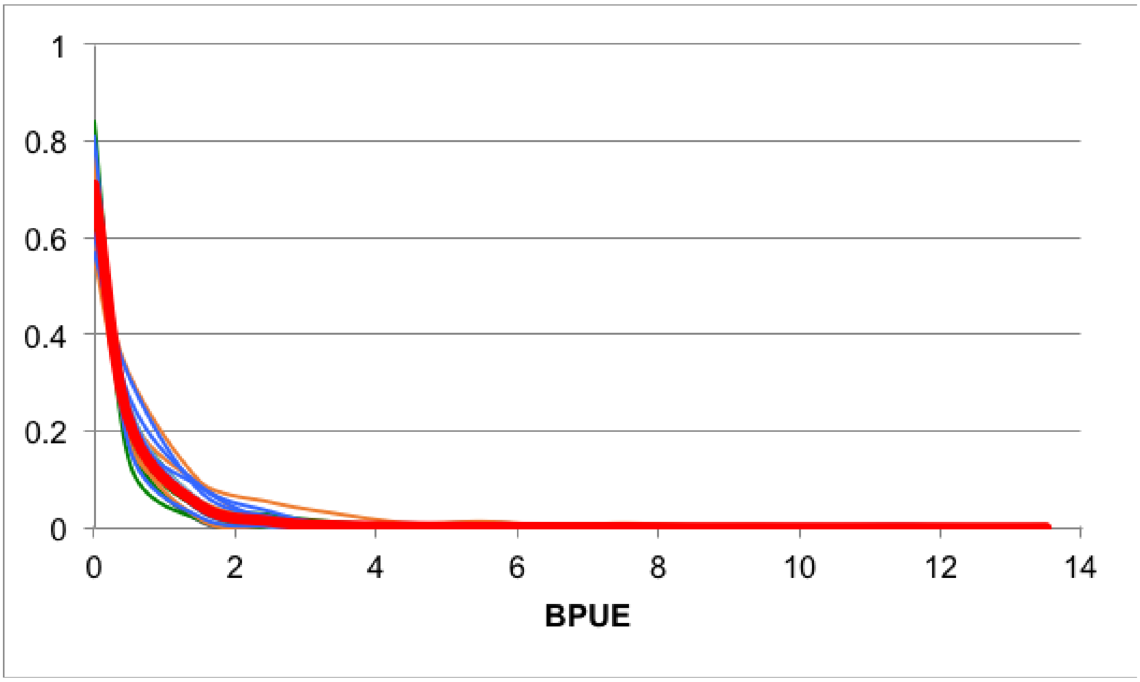

Figure 1 Probability distribution of seabird bycatch indicated as BPUE of individual operation observed in the south of 35S during 1997 and 2015. Red bold line indicated the pooled result of the whole years, with thin lines corresponding to the individual years.

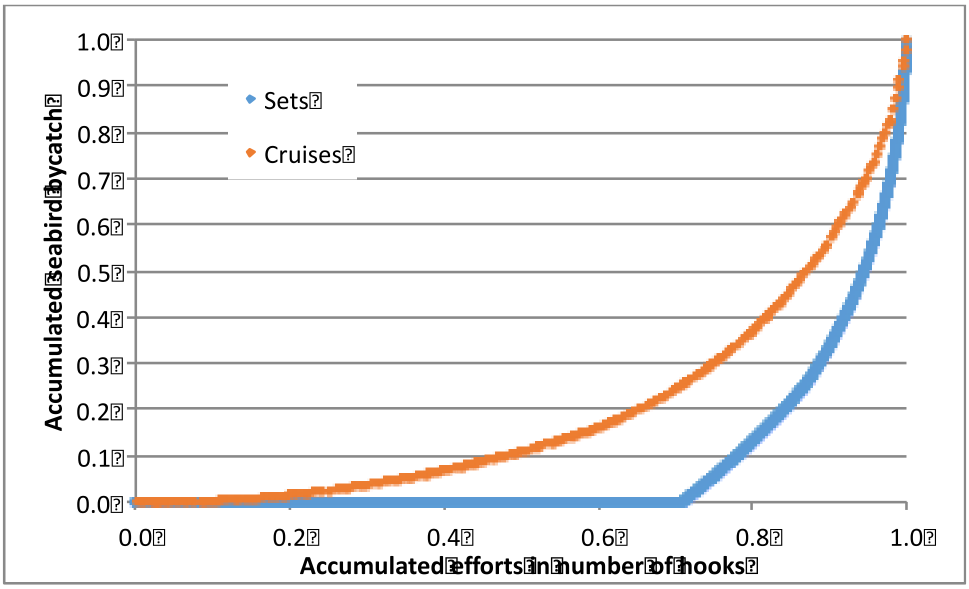

Figure 2 Accumulated seabird bycatch in accordance with the accumulated fishing efforts defined with the number of hooks. Blue indicated the results based on individual operations, while orange based on the cruises.

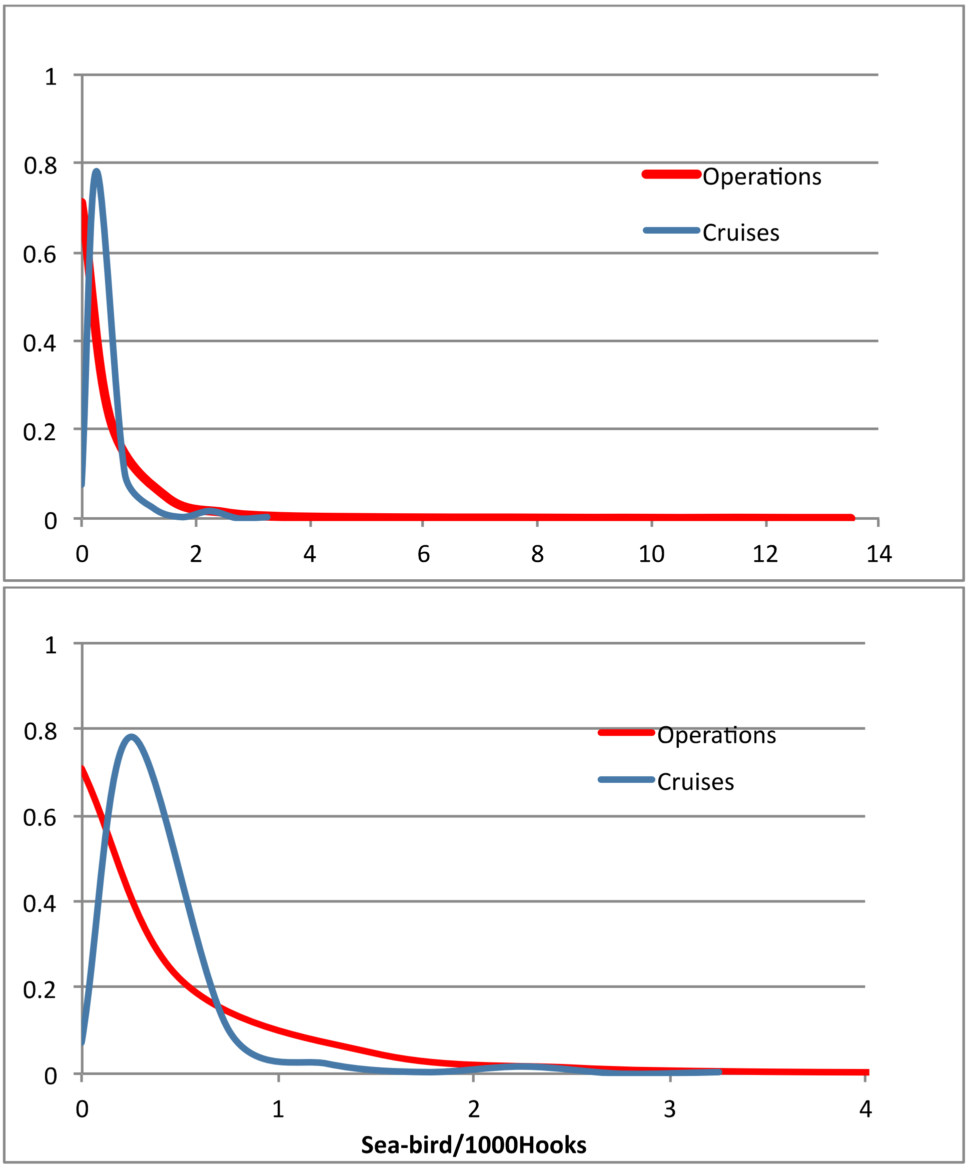

Figure 3 Probability distribution of seabird bycatch indicated as BPUE observed through the Japan's onboard observers for the operations in the south of 35S during 1997 and 2015. Red line indicated the pooled result based on the individual operations, while blue showed the distribution of average BPUE by cruises. The lower figure was a simple extraction up to the BPUE value of 4.

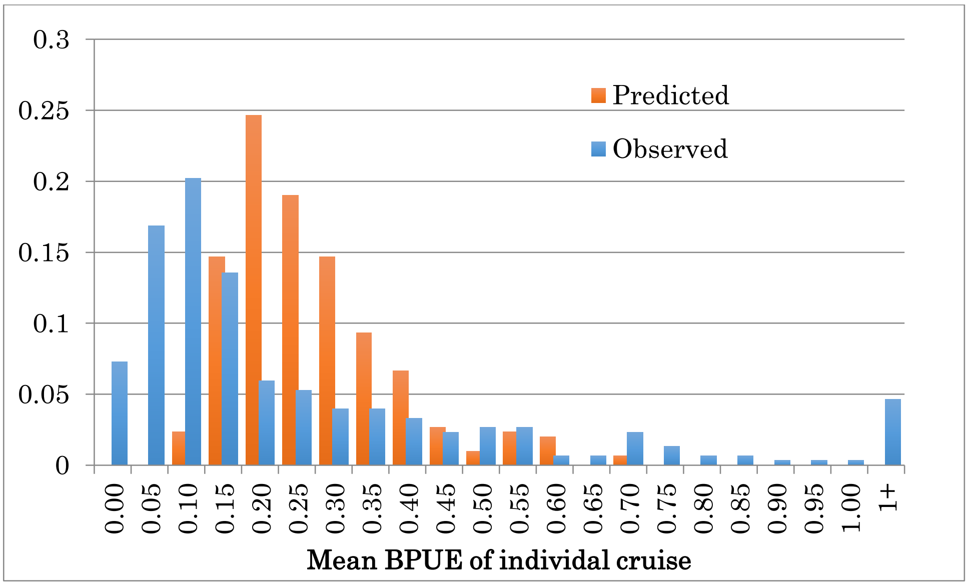

Figure 4 Comparison of the distribution of observed mean BPUE of individual cruises (blue bars) against the simulated distribution with random bootstrapping of 40 operations for 300 times (orange bars).

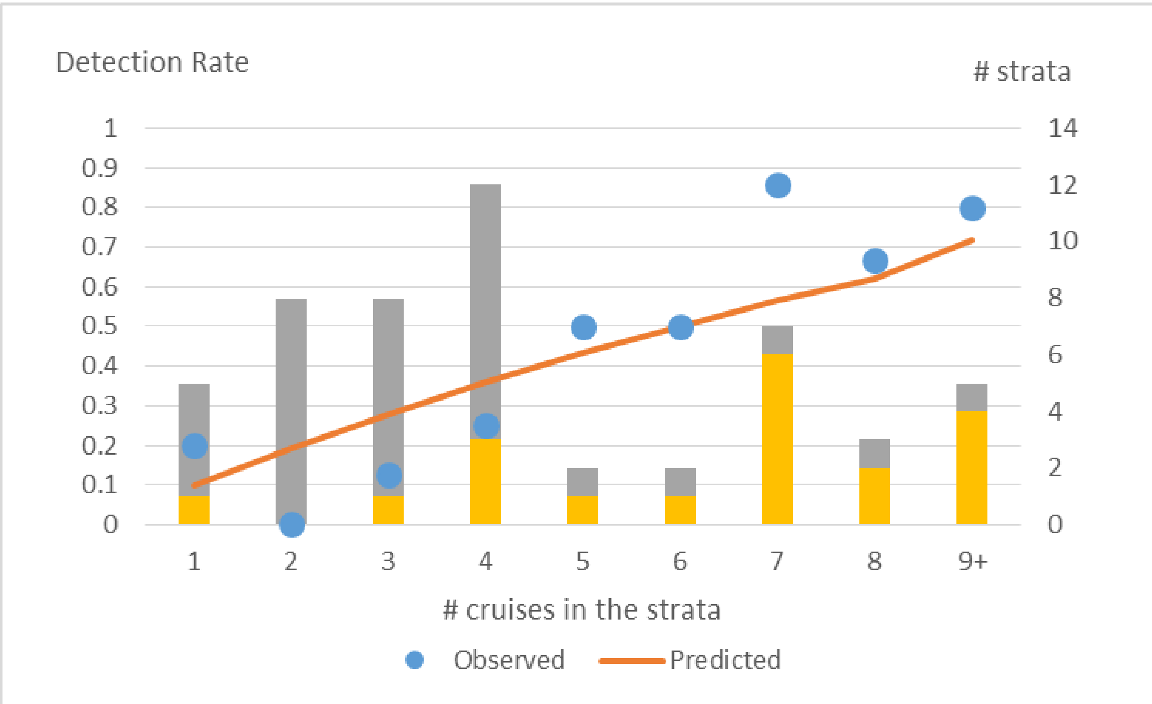

Figure 5. The comparison of detectability of the cruises with high seabird bycatch (average BPUE 0.65 and higher), corresponding to the number of observed cruises in a stratum. Each stratum represented one data in the stack bars. Yellow bars indicated the number of strata where the cruises of high seabird bycatch were found. The line and blue dots indicated the theoretical and observed probabilities of detecting the existence of high bycatch rate cruises, with a given number of observed cruises against the total 30 cruises in operation.