Australian Government
Bureau of Rural Sciences

Estimation of seabird bycatch rates in the Eastern Tuna and Billfish Fishery

E. Lawrence, F. Giannini, N. Bensley and J. Crombie

Postal address:
Bureau of Rural Sciences
GPO Box 858
Canberra, ACT 2601

Copies available from:
BRS Publication Sales
GPO Box 858
Canberra ACT 2601

Ph: 1800 020 157
Fax: 02 6272 2330
Email: salesbrs@brs.gov.au
Internet: http://www.brs.gov.au

Executive Summary

Monitoring seabird bycatch rates in the Eastern Tuna and Billfish Fishery (ETBF) is critical to determine the effectiveness of bycatch mitigation measures and whether management objectives are being met. Estimating seabird bycatch rates, however, is challenging as seabird bycatch is a comparatively rare event and there are strong variations in catch rates between fishing areas and time of year.

To improve estimates of seabird bycatch rates in the ETBF this report compares two methods of calculating estimates using both AFMA observer and logbook data (from the years 2001 to 2007):

- design-based inference, where a mean bycatch rate is generated from observer data, *versus*
- model-based inference, where a statistical model is used to generate the mean bycatch rate.

To assist with interpreting the management application of the results, the estimates produced are based around the reporting and compliance criteria defined by the *Threat Abatement Plan 2006 for the incidental catch (or bycatch) of seabirds during oceanic longline fishing operation* (TAP). The TAP specifies that in the ETBF all seabird bycatch rates should be below 0.05 birds per 1000 hooks in all fishing areas and seasons.

The design-based estimates are constrained by the coverage of the observer effort across the fishery. Observer coverage is not distributed randomly across the fishery due to operational constraints. Likewise, not all shots undertaken by vessels have an equivalent chance of being covered by an observer. Therefore, basing estimates on design-based inference (i.e. the observer data only) will result in heavily biased estimates.

A model was developed based on the observer data and applied to the logbook data to estimate bycatch rates. The model incorporates the factors: latitude, longitude, season, length of mainline, depth of set, whether lightsticks were used, bait type (live, dead or mixed), sea surface temperature and distance of setting from the nearest coastline.

The results show model-based estimates provide a more robust method of assessing the performance of management measures. The design-based estimates have wider confidence intervals and fluctuate far more through time. This is due to the influence of the changes in the spatial distribution and rate of observer coverage through time. The model-based approach can better account for these biases. The model-based estimates also show that while seabird bycatch rates have generally decreased over time, it is evident that the level of seabird bycatch is still likely to exceed 0.05 birds per 1000 hooks in some areas and seasons. The fishing areas where this is most likely are between latitudes 30° S and 40° S and the fishing season when this is most likely is summer.

The model-based methods can assist fishery managers improve the design and implementation of observer programs. For example, in areas where the seabird bycatch rate is consistently low, the model estimates a low bycatch rate with small standard errors. Increasing observer coverage in these areas would have little effect on the standard errors (confidence) of the estimates. In areas where the seabird bycatch rate is variable, an increase in coverage would provide estimates with improved levels of confidence and thus facilitate more informed management decisions. It is likely to be more cost effective to calculate model-based estimates for rarely caught species, such as seabirds, than to develop and maintain the species-specific observer programs required to obtain adequate design-based estimates.

Acknowledgements

We are grateful for the comments and support provided by the Eastern Tuna and Billfish Fishery (ETBF) Resource Assessment Group. We would also like to thank Drs Peter Ward, Ilona Stobutzki and Gavin Begg (BRS) for their input on the method and draft report.

Contents

Tables

Figures

Introduction

The incidental catch (or bycatch) of seabirds during oceanic longline fishing operations is listed as a key threatening process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and a Threat Abatement Plan (*Threat Abatement Plan 2006 for the incidental catch (or bycatch) of seabirds during oceanic longline fishing operation* **-** TAP) is in place to manage this threat. The TAP also contributes to Australia meeting its obligations under the *International Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries*.

The TAP aims to significantly reduce the bycatch of seabirds during oceanic longline operations in the Australian Fishing Zone (AFZ) (Department of the Environment and Heritage, 2006). The TAP applies to all longline fisheries under Commonwealth jurisdiction. In longline fisheries known to impact seabirds, the TAP sets maximum bycatch rates ranging from 0.01 to 0.05 birds per thousand hooks in all fishing areas and seasons[1] as criteria to measure the effectiveness of bycatch mitigation measures. The bycatch rates are based on the levels of fishing effort occurring in fisheries prior to the introduction of the current TAP in 2006.

A number of longline fisheries operate in Australian waters, using both pelagic and demersal longline fishing gear. The majority of longlining effort in Australian fisheries takes place in Australian Government managed fisheries; longlining only occurs on a small scale in State and Territory managed fisheries. There are two main pelagic longline fisheries in Australia, which are managed by the Australian Government—the Eastern Tuna and Billfish Fishery (ETBF) and the Western Tuna and Billfish Fishery.

The ETBF is the fishery of most concern due to the level of fishing effort in the fishery and significant annual seabird bycatch rates (Baker and Finley, 2008). The seabird groups most affected are the albatrosses and petrels because of their limited population sizes and low reproduction rates (Baker and Finley, 2008). These species are also typically large seabirds which naturally feed on fish and squid found on or close to the surface, similar to the baits in pelagic longline fisheries (Baker and Finley, 2008). Smaller species cannot swallow large food items and hence are rarely caught on longlines (Baker et al., 2002).

The TAP specifies that in the ETBF all seabird bycatch rates should be below 0.05 birds per 1000 hooks in all fishing areas and seasons. Monitoring of seabird bycatch rates in the ETBF is critical to determine whether these criteria are being met and whether current bycatch mitigation measures are effective. The TAP requires that longline observer programs be used to validate seabird bycatch data collected by the logbook system. Data on the number of seabirds caught during longline operations in the ETBF have been collected by Australian Fisheries Management Authority (AFMA) observers since 2001. Comparisons between logbook and observer data indicate that the logbook reporting rate is poor. Consequently, seabird bycatch rates based on logbook information are largely underestimated. For this reason observer data are critical in calculating estimates of seabird bycatch. However, for operational reasons observer effort is not necessarily representative of fishing effort. Therefore, estimates of seabird bycatch based solely on observer data are unlikely to be representative of seabird bycatch across the fleet. Given the international concern and the national protected status of the seabirds involved, management requires the most accurate and scientifically robust estimates of bycatch rates.

[1] For the purposes of the TAP in the ETBF, 'fishing areas' are defined as 5 degree latitudinal bands within the Australian Fishing Zone, with the area between 30° S and 35° S further divided into two zones by the meridian of longitude 156° E, and 'fishing seasons' are 'Summer' (1 September to 30 April) and 'Winter' (1 May to 31 August) only.

Objective

To improve estimates of seabird bycatch rates in the ETBF this report compares two methods of calculating estimates using the AFMA observer and logbook data:

- design-based inference, where a mean bycatch rate is generated from observer data, *versus*
- model-based inference, where a statistical model is used to generate the mean bycatch rate.

To assist with interpreting the management application of the results the estimates produced are based around the reporting and compliance criteria defined by the TAP, although annual estimates at the TAP fishing area and season scales have been produced for 2007 only.

Data Sources

AFMA logbook and observer data were used from the years 2001 to 2007. The ETBF observer data are recorded under four 'Type' categories; data from the three AFMA seabird mitigation trials and the ongoing observer data routinely collected since 2003 . The trial types are as follows:

- ***Underwater line setting chute trial*** – the trial was designed to test the effectiveness of an underwater line setting chute device.
- ***38 gram swivel in combination with double tori-lines trial*** – the trial was designed to test the effectiveness of the use of 38 gram swivels in conjunction with double tori-lines.
- ***60 gram swivel in combination with double tori-lines trial*** – the trial was designed to test the effectiveness of the use of 60 gram swivels in conjunction with double tori-lines.

Of the observer data collected, approximately 60% are part of AFMA's ongoing observer program (2003-2007), while the remainder were collected as part of three mitigation device trials (2001-2004). The data include seabird catch numbers, geographical position, fishing gear and environmental information (for more information refer to Lawrence *et al*., 2006).

Preliminary modelled seabird bycatch estimates were presented to a meeting of the ETBF Resource Assessment Group in November 2007. At this meeting the group agreed that the seabird data collected as part of the 'Underwater line setting chute trial' may not be indicative of typical seabird bycatch rates. This was due to the number of gear failures that occurred during the trial and also because the mitigation method is not typically used in the ETBF. Given this, a trial term was included in the model indicating each of the three trials, as well as, 'ongoing observer data'. As there were some problems distinguishing between trial and ongoing observer data in the AFMA database (approximately 700 observations had been incorrectly recorded as forming part of a trial), a rule was determined based on the knowledge from a number of people involved in the trials. For the purposes of this project 'ongoing observer data' has been classified as all observer data with a trial type of 'ECTBF' or observer data collected after 1 September 2004 (when all of the mitigation trials were considered to be complete).

Methods and Results

Design-based inference is the simplest method of obtaining estimates of a population mean from a sample of the population. However, design-based sampling and inference depend on the principle of randomisation and the assumption that every unit in the population has a chance of being selected in the sample (Cochran, 1977). For operational reasons, the ETBF observer effort is not distributed randomly across the fishery (see Figures 1 and 2). Likewise, not all shots undertaken by vessels have a chance of being covered by an observer. Therefore, basing estimates on design-based inference (i.e. the observer data) will result in heavily biased estimates. For example, if the observer data are concentrated in areas of high seabird bycatch, catch rates will be over-estimated (e.g. 2002) and vice versa. Observer coverage in the ETBF between September 2001 and September 2007 was 3.5% of shots recorded in logbooks. Annual coverage rates and the spread of coverage show an increasing trend over this period.

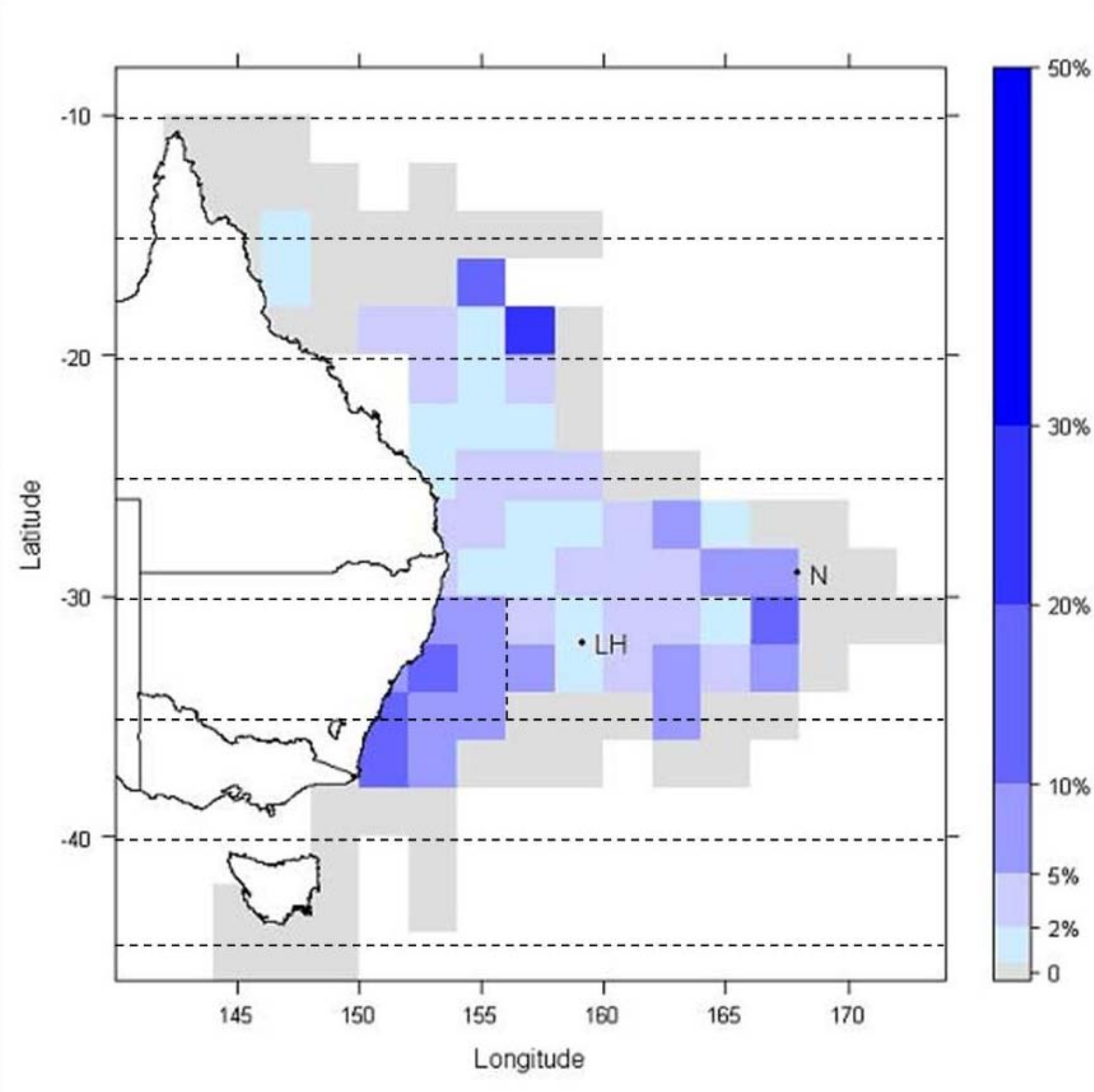

Figure 1 Distribution of logbook effort in the ETBF 2001-2007 aggregated by 2-degree squares. Squares are coloured depending on percentage of shots observed with the darker colours representing a higher number of observed shots. Dashed lines indicate TAP 'fishing areas'. Note: 'LH' indicates Lord Howe Island and 'N' indicates Norfolk Island.

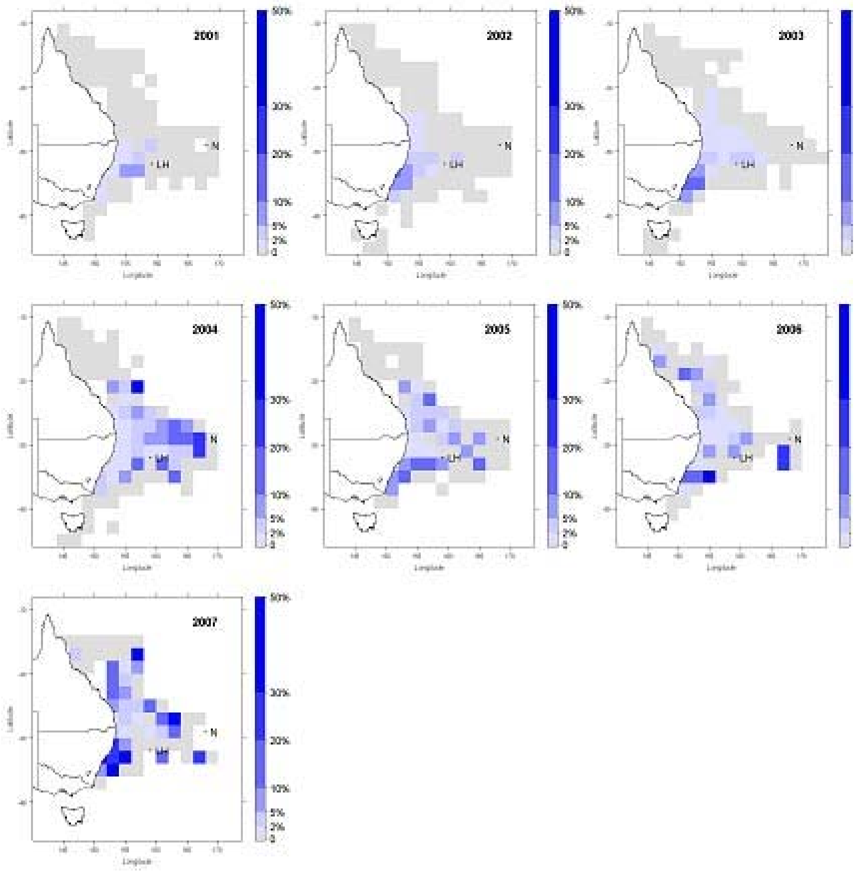

Figure 2 Distribution of logbook effort in the ETBF for each year (2001-2007) aggregated by 2-degree squares. Squares are coloured depending on percentage of shots observed with the darker colours representing a higher number of observed shots. Note 'LH' indicates Lord Howe Island and 'N' indicates Norfolk Island.

An alternative to design-based inference is model-based inference. Model-based inference has an advantage over design-based inference when the data are skewed because it allows the best possible inference for the sample observed (Royall, 1970). However, this method can be very susceptible to model mis-specification and so it is critical to select an appropriate model. This type of inference is appropriate to use in the case of the seabird data, provided an appropriate model can be found.

To produce estimates of seabird bycatch across the ETBF at the scales defined by the TAP (fishing area and season), it is essential that there is an appropriate spatial and temporal coverage of observer data and that this is representative of total effort in the fishery (as measured by the logbook data). As demonstrated in Figure 1, the logbook data for the ETBF is distributed between 10° S and 45° S, while the observer data have a smaller latitudinal range extending between 15° S and 38° S. While it would be possible to produce estimates for the areas of low or no observer coverage (based on modelling the observer data), these estimates would rely heavily on the assumption that seabird bycatch in these areas follow the model generated from the observer data collected in other areas and would have very large standard errors. For these reasons, estimates have not been produced for latitudes above 20° S and below 40° S in this report.

Model-based estimation of seabird bycatch rates

To determine a model based on observer data and apply this model to the logbook data, only those factors available in both datasets can be considered. These factors were latitude, longitude, season, length of mainline, depth of set and whether lightsticks were used. Type of bait (live, dead or mixed), sea surface temperature and distance of setting from the nearest coastline were derived for both the observer and logbook datasets. Based on previous work (Lawrence et al., 2006), seabird abundance counts, time of setting and details of any mitigation devices in use would also be good predictors of the rate of seabird bycatch, however, inconsistent or a lack of recording of these variables in the logbook data prevented their use.

The seabird data are 'zero-inflated' which means that a large proportion of the longline sets did not catch any seabirds (approximately 93% of the observer data). This means that the data contain more instances of zero seabird captures than would be predicted using a standard Generalized Linear Model (GLM) with a Poisson error model, which would usually be applied to count data such as this. An appropriate modelling technique often used with this type of data is the delta model, which involves modelling the chance of a non-zero catch and the number caught separately. This methodology was used here to model seabird captures (i.e. presence or absence of seabirds in an observed shot) followed by modelling the number of seabirds caught, conditional on at least one seabird being caught in a shot. A combined prediction was then calculated from these two models by multiplying the predictions from each model, giving an estimate of the number of seabirds caught per 1000 hooks for each logbook entry. Predictions were not calculated for those observations with a trial type of 'underwater line setting chute' for the reasons outlined earlier (see Data Sources).

As mentioned above, initial model investigations revealed problems with some of the explanatory factors. Length of mainline and depth of set were not available for a significant proportion of the observer data, which prevented their inclusion in the final models. Longitude and distance from nearest coastline were found to be highly correlated ($r = 0.92$), which caused problems with model fitting. Distance from the nearest coastline was determined to have a stronger relationship with seabird bycatch than longitude, so longitude was not considered in the final set of models. In addition, latitude was included in the model as a categorical variable (i.e. latitude band) as the relationship of this variable with seabird bycatch was found to be non-linear.

The probability of obtaining a non-zero catch was modelled using a GLM with Binomial response. The significant explanatory variables in this model were trial type, latitude band, season, sea surface temperature and type of bait (live, dead or mixed). The number of seabirds caught, given that the catch rate was non-zero, was modelled using a GLM with a Truncated Poisson error distribution. The significant explanatory variables were trial, distance from coastline, season and the number of lightsticks used. A term for the total number of hooks set was also included in the model as an offset (rather than estimated) to account for the number of hooks set which is known for each shot. Due to the small number of non-zero observations in the observer data, it was necessary to exercise caution in determining the number of parameters estimated by the non-zero catch model. Therefore, in the absence of additional observer data, the addition of new terms in the model (e.g. mitigation device used, time of day) may be at the expense of existing terms.

Other models that were fitted to the seabird data were a Generalized Additive Mixed Model (GAMM), a Generalized Linear Mixed Model (GLMM) and a Generalized Additive Model (GAM). Both of the mixed models resulted in a poor fit and general convergence problems. The GAM with a quasipoisson error distribution resulted in an improved fit, however, it was still inferior to the fit obtained using the delta modelling approach. These results are not surprising given the large proportion of zero values in the data.

The effect of adding a year term to the model was investigated. The year term was very highly correlated with the trial type term and so only one of these terms was included in the final model. As the trial term was found to explain a greater amount of variation in the data, the trial term was chosen. This finding enables a simpler model estimation process (if it was determined a year effect was necessary in the seabird bycatch model the parameters would have to be re-estimated each year).

The bait term was not available for a small percentage of the logbook records (less than 1%). For the purposes of producing estimates of seabird bycatch those records not containing information on the type of bait used were removed from the analysis. This method was chosen over dropping the bait term from the models due to the highly significant nature of the term.

The uncertainty around the mean predicted rates was calculated using a parametric bootstrap. For each bootstrap sample, a presence-absence random variable was generated from a Bernoulli distribution and a catch variable was generated from a Truncated Poisson distribution for each logbook data record. The two sets of simulated predictions were multiplied together for each bootstrap sample to give the uncertainty around the predicted seabird bycatch rates.

The mean seabird bycatch rates produced for the 2002-2007 ETBF logbook data are presented below (Tables 1 to 3). The 'lower confidence bound' and 'upper confidence bound' columns represent the 2.5 and 97.5 percentiles of the bootstrap estimates respectively.

As shown in Table 1, the estimated mean seabird bycatch rate for each year falls below the target rate of 0.05 birds per 1000 hooks specified by the TAP, however, the upper confidence bound exceeds the target rate from 2002-2006. Table 2 provides the estimated seabird bycatch rates segregated by TAP area. The mean rate exceeds the TAP level in both areas between 30° S and 35° S. The lower confidence interval exceeds 0.05 birds per 1000 hooks in the 30° S to 35° S (≤ 156° E) area while the upper confidence intervals exceed the TAP level in all areas except 25° S to 30° S. Table 3 indicates that 0.05 birds per 1000 hooks is exceeded by the mean rate in summer.

Table 1 Model-based estimates of annual mean seabird bycatch rates (birds per 1000 hooks) and 95% confidence intervals between 20° S and 40° S for 2002-2007.

Year	Mean Rate	Lower Confidence Bound	Upper Confidence Bound
2002	0.0416	0.0281	0.0683
2003	0.0368	0.0255	0.0550
2004	0.0389	0.0256	0.0590
2005	0.0334	0.0217	0.0508
2006	0.0330	0.0203	0.0574
2007	0.0248	0.0146	0.0383

Table 2 Model-based estimates of mean seabird bycatch rates (birds per 1000 hooks) and 95% confidence intervals between 20° S and 40° S by TAP fishing area for 2002-2007.

TAP Band	Mean Rate	Lower Confidence Bound	Upper Confidence Bound
20° S - 25° S	0.0240	0.0000	0.0582
25° S - 30° S	0.0169	0.0078	0.0305
30° S - 35° S (<=156° E)	0.0997	0.0620	0.1499
30° S - 35° S (>156° E)	0.0553	0.0267	0.1168
35° S - 40° S	0.0482	0.0238	0.0732

Table 3 Model-based estimates of mean seabird bycatch rates (birds per 1000 hooks) and 95% confidence intervals between 20° S and 40° S by TAP seasons for 2002-2007.

TAP Season	Mean Rate	Lower Confidence Bound	Upper Confidence Bound
Summer	0.0501	0.0334	0.0773
Winter	0.0133	0.0081	0.0218

Tables 4 and 5 refer to the 2007 fishing season only (1 September 2006 to 31 August 2007). The results in these tables show that although we are 95% confident the overall estimated mean rate of seabird bycatch in 2007 is below 0.05 seabirds per 1000 hooks, the areas of 30° S to 40° S and the Summer TAP season do not fall into this category. This suggests that although the majority of fishing in 2007 did not occur in the areas of higher seabird bycatch, the fishing that did occur in these areas may have been associated with high (≥ 0.05) seabird bycatch rates.

Table 4 Model-based estimates of mean seabird bycatch rates (birds per 1000 hooks) and 95% confidence intervals between 20° S and 40° S by TAP fishing area for 2007.

TAP Band	Mean Rate	Lower Confidence Bound	Upper Confidence Bound
20° S - 25° S	0.0155	0.0000	0.0419
25° S - 30° S	0.0106	0.0043	0.0192
30° S - 35° S (<=156° E)	0.0788	0.0428	0.1245
30° S - 35° S (>156° E)	0.0393	0.0180	0.0736
35° S - 40° S	0.0606	0.0278	0.0957

Table 5 Model-based estimates of mean seabird bycatch rates (birds per 1000 hooks) 95% confidence intervals between 20° S and 40° S by TAP seasons for 2007.

TAP Season	Mean Rate	Lower Confidence Bound	Upper Confidence Bound
Summer	0.0398	0.0246	0.0590
Winter	0.0123	0.0061	0.0241

Design-based estimation of the observer data

Although the inadequacy of design-based estimation in the calculation of seabird bycatch rates was discussed earlier in this report, some estimates based on this method are presented in Table 6 to give an indication of the differences between using this method and a model-based method. The estimates are based on simple ratio estimation with no stratification. Stratification would improve precision for the fishery-wide seabird bycatch estimate provided it is possible to divide the fishery into relatively homogeneous strata. This is likely given the distribution of seabird bycatch. However, the estimates would still be heavily biased due to the limitations of the observer data.

Table 6 Design-based estimates of annual mean seabird bycatch rates (birds per 1000 hooks) and confidence intervals between 20° S and 40° S for 2002-2007.

Year	Mean rate	Lower Confidence Bound	Upper Confidence Bound
2002	0.1555	0.0911	0.2198
2003	0.1175	0.0726	0.1623
2004	0.0694	0.0322	0.1065
2005	0.0219	0.0088	0.0350
2006	0.0487	0.0242	0.0732
2007	0.0261	0.0020	0.0501

When the design-based estimates (Table 6) are compared to the model-based estimates, it is clear that the design-based estimates have wider confidence intervals and fluctuate far more through time (see Figure 3). This is due to the influence of the changes in the spatial distribution and rate of observer coverage through time. For example, in 2002 observer coverage was concentrated in a small area and correlated with a high observed seabird bycatch rate, yet in 2007 the spatial distribution of observer coverage was much wider and associated with a much lower rate of seabird bycatch. Comparatively, much less change has occurred in the spatial distribution of fishing effort over the same period.

The model-based approach can better account for the biases in the observer data. This is best demonstrated by the differences in the trends in mean annual seabird bycatch rates between the two methods from 2002 to 2007. The declining trend and improved confidence in the design-based estimates are driven by both declining observed catch rates and improvements to the spatial distribution and annual rate of observer coverage. However, the model-based approach shows a much more gradual decline in the estimated mean annual seabird bycatch rate as it is less influenced by the biases in the observer data.

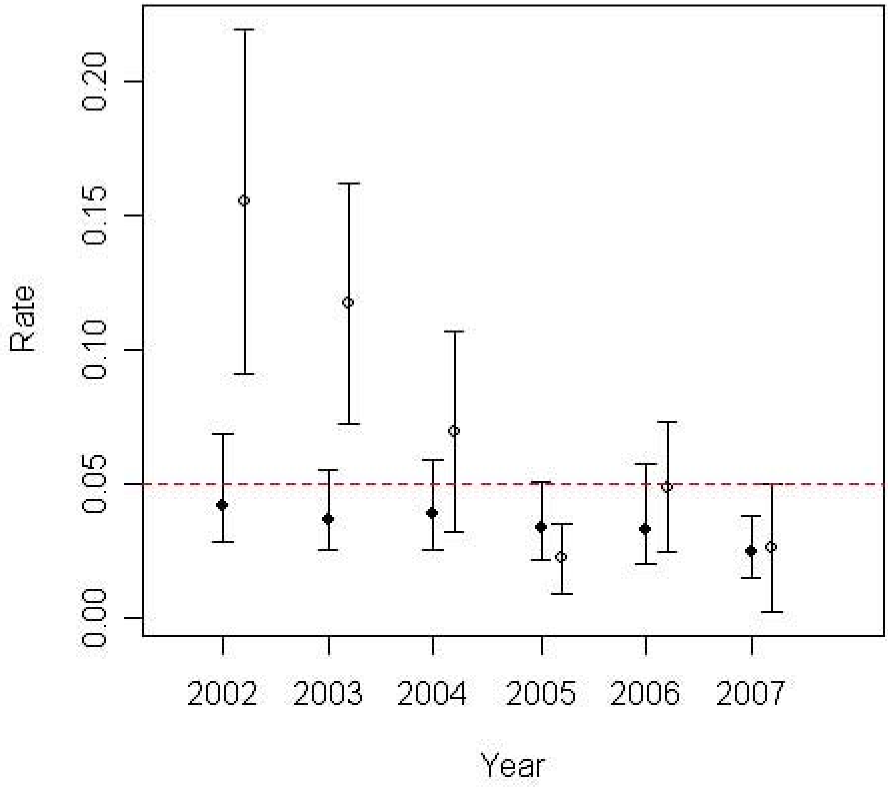

Figure 3 Comparison of design-based (open circle) to model-based (solid circle) estimates of the annual mean rate of seabird bycatch between 20° S and 40° S in the ETBF (2002-2007). The bars correspond to the 95% confidence intervals. The dashed line indicates 0.05 seabirds per 1000 hooks.

Conclusions

It is possible to estimate seabird bycatch rates across the ETBF from observer and logbook data. However, when doing so it is critical that the appropriate method of estimation is used. The consequences of not doing so may result in an over or under estimation of bycatch rates which could result in an inappropriate management or policy response.

The model-based estimation method is recommended as it provides a substantial improvement over using simple observed seabird bycatch rates (design-based estimates), as the effect of spatial and temporal bias in observer coverage is catered for in the modelling process. Model-based estimates therefore also provide a more robust method of assessing the performance of management measures. However, it should be noted that this modelling approach relies on the assumption that the observer data are representative of the logbook data with respect to the probability of catching seabirds (i.e. the same factors affect the capture of seabirds whether an observer is on board or not).

The model-based results show that while seabird bycatch rates have generally decreased over time, seabird bycatch is still likely to exceed 0.05 birds per 1000 hooks in some areas and seasons. The fishing areas of greatest concern are between latitudes 30° S and 40° S and the fishing season of most concern is summer. However, note it was not feasible to include several important explanatory variables in the model and it is likely that the models could be improved through the addition of these (e.g. use of tori poles, seabird abundance counts, time of day). As more comprehensive seabird bycatch observer data becomes available more confidence in the models will be obtained. However, even without these additional explanatory variables the model results are more robust than those produced using the design-based method.

The results also show model-based methods can assist fishery managers improve the design and implementation of observer programs. For example, in areas where the seabird bycatch rate is consistently low, the model estimates a low bycatch rate with small standard errors. Increasing observer coverage in these areas would have little effect on the standard errors (confidence) of the estimates. In areas where the seabird bycatch rate is variable, an increase in coverage would provide estimates with improved levels of confidence and thus facilitate more informed management decisions. If this method was to be adopted the data requirements to build an effective model would need to be taken into consideration when designing observer programs.

Specific modelling expertise is required to support model-based approaches. However, investing in this approach is likely to be more cost effective and more practical than the investment (human and financial) required to obtain similar confidence in results from design-based observer programs alone. Decision-makers must therefore weigh up the costs and benefits of improved levels of confidence against the consequences of potentially making poor decisions due to ambiguous information.

It would be equally valid to use model-based methods to estimate bycatch rates for other rarely caught species in this and other fisheries and similar results would be expected. In particular, it is likely to be more cost effective to calculate model-based estimates for rarely caught species than to develop the species-specific observer programs required to obtain adequate design-based estimates. However, to reiterate, the method relies heavily on the determination of an appropriate model. This method would not be appropriate in the absence of an adequate dataset (in terms of the number and quality of records) that details the factors that explain the catch rates of a rare species (e.g. environmental, fishing practices, spatial and/or temporal factors).

References

Baker, G.B. and Finley, L.A. (2008) *National Assessment Report for Reducing the Incidental Catch of Seabirds in Longline Fisheries (2008 Assessment Report)*, unpublished report to Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

Baker, G. B., Gales, R., Hamilton, S., Wilkinson, V. (2002) *Albatrosses and petrels in Australia: a review of their conservation and management*. Emu 102: 71-97.

Cochran, W.G. (1977) *Sampling Techniques, 3rd ed*, John Wiley & Sons.

Department of Environment and Heritage (2006) T*hreat Abatement Plan 2006 for the incidental catch (or bycatch) of seabirds during oceanic longline fishing operations*. Department of Environment and Heritage, Canberra, Australia.

Lawrence, E., Wise, B., Bromhead, D., Hindmarsh, S., Barry, S., Bensley, N. and Findlay, J. (2006) Analyses of AFMA seabird mitigation trials – 2001 to 2004. Bureau of Rural Sciences. Canberra.

Royall, R.M. (1970) *On Finite Population Sampling Theory under Certain Linear Regression Models*. Biometrika 57: 377-387