

Seabird bycatch loss rate variability in pelagic longline fisheries

Can Zhou*[1], Nigel Brothers[2], Joan Browder[3], Yan Jiao[1]

[1] Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Virginia, 24060, USA

[2] Marine Ecology and Technology Consultant, Wonga Beach, Queensland, 4873, Australia

[3] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, Florida, 33176, USA

* Corresponding author

Present address: Visiting researcher at Texas A&M University, College Station, TX, 77840, USA

Phone: +1 979 473 9124

Email: eidotog@gmail.com

1 Abstract:

2 The incidental mortality of seabirds from fisheries ranks as the greatest threat impacting
3 seabirds globally. However, its impact on seabird populations may have been
4 substantially underestimated due to lost, undetected bycatch. To estimate the full extent
5 of the bycatch problem, knowledge about the magnitude and variability of lost bycatch is
6 necessary. Based on a long-term dataset, this study aims to facilitate the loss-corrected
7 bycatch estimates for pelagic longline fisheries that do not have a concurrent bycatch loss
8 observation component. We analyze information from all types of fishery interactions of
9 seabirds to improve the estimate of bycatch loss rate and also reveal its variability.
10 Specifically, we analyze how environmental and ecological factors affect seabird bycatch
11 loss rate using Bayesian state-space models. Results show strong species effects in the
12 bycatch loss rate. Inclement weather and strong competition among seabird species also
13 affect bycatch loss rate. Estimates of the species-specific bycatch loss rate indicate that,
14 for some species, the loss can well exceed the average loss rate, suggesting that seabird
15 bycatch loss cannot be further ignored in assessing the fishery impact on seabird
16 populations. To gauge the full scale of seabird bycatch, it is critical to account for this
17 lost bycatch in bycatch assessments, at minimum, using an average loss rate with the
18 ultimate goal of species-specific loss-corrected assessments.

19 Keywords: Bayesian statistics; state-space models; bycatch assessment; cryptic bycatch

20

21 1 Introduction

22 The seabird bycatch problem in pelagic longline fisheries has been exposed for
23 only about three decades (Brothers 1991), and yet bycatch in fisheries ranks as the top
24 threat by impact to populations of albatrosses, large petrels/shearwaters and penguins
25 (Anderson et al. 2011; Croxall et al. 2012; Dias et al. 2019). The incidental mortality
26 from fisheries is currently recognized as a serious global concern (ACAP 2019a). It
27 threatens 17 of the 22 albatross species with extinction and puts an additional 7 petrel
28 species under elevated risk (ACAP 2019b; Anderson et al. 2011; IUCN 2019; Robertson
29 and Gales 1998).

30 Seabirds foraging near a longline fishing vessel are vulnerable to being
31 incidentally caught primarily during two windows of opportunity/risk, when the baited
32 hook is accessible to seabirds either in the line-setting stage or in the line-hauling stage
33 (Brothers et al. 2010). Many seabirds are surface-scavengers that take baits from hooks,
34 and this behavior makes them vulnerable to longline fishing operations (Camphuysen et
35 al. 1995). Those hooked or entangled at the setting stage are subject to loss during set,
36 soak and haul (Brothers et al. 2010). Almost all fishery observer protocols to date only
37 record bycatch at the haul, and consequently those caught at the setting stage that drop off
38 the gear before they can be observed, i.e., cryptic bycatch (Gilman et al. 2013), are not
39 included in the records. Due to this, the actual seabird bycatch in pelagic longline
40 fisheries could well exceed what is reported (Anderson et al. 2011; Brothers et al. 2010).
41 Cryptic seabird bycatch has also been documented in trawl fisheries, such as mortalities
42 from warp strikes (Maree et al. 2014; Sullivan et al. 2006; Watkins et al. 2008).

43 In order to recover the cryptic seabird bycatch in pelagic longline fisheries, it is
44 necessary to consider a much broader class of seabird-fishery interactions, which
45 themselves are observable and cover both the apparent and cryptic bycatch events (Figure
46 1). Seabird-fishery interactions can be classified into different types based on whether the
47 sequence of interactions leads to a bycatch event and the associated observation
48 uncertainty (Figure 2A) (Brothers et al. 2010). Based on the seabird interactions with the
49 highest certainty of getting caught or entangled by the fishing gear (observed caught type;
50 also type O in Figure 2A), more than 50% of the observed caught seabirds were not
51 retrieved at the haul (Brothers et al. 2010). Similar estimates of loss rate were also
52 reported in Brothers (1991); Gilman et al. (2007) and Gilman et al. (2003). For this type
53 of interaction (observed caught type), observation uncertainty, i.e., mistakenly classifying
54 an interaction of an uncaught seabird into a caught category, is relatively low and can be
55 ignored to a first approximation. However, only a small fraction of all recorded
56 interactions qualifies as this type, e.g., less than 2.9% of all interactions were classified as
57 observed caught (Brothers et al. 2010), with the majority of interactions unutilized in the
58 estimation of loss rate, thus substantially limiting the inferential power of the analysis.

59 Pooling information from all recorded interactions has the potential to improve
60 the estimate of bycatch loss rate and also reveal its variability. A recent study based on
61 the same set of observation records as in Brothers et al. (2010) but making use of all
62 interaction types estimates the average bycatch loss rate at 29.8% with a 95% credible
63 interval of [0.24%, 51.88%] (Zhou et al. 2019a). The estimate is consistent with two
64 regional bycatch loss rate estimates: 27% for the Japanese longline tuna vessels operating
65 in the region of Tasmania, Australia (Brothers 1991) and 28% for the Hawaii longline

66 tuna and swordfish fisheries (Gilman et al. 2003; Gilman et al. 2007). Regional
67 differences in the percentages of observed seabirds caught during setting and
68 subsequently retrieved at the haul were noted in Brothers et al. (2010); however, it is
69 unclear whether regional differences contribute significantly to the variability of loss rate.

70 Since revelation of the bycatch loss problem at the global scale (Brothers et al.
71 2010), little has been done to try to estimate the lost portion of seabird bycatch in bycatch
72 assessments, with a few notable exceptions. In the assessment of seabird bycatch risk
73 from New Zealand commercial fisheries, a multiplier of 2.08 was used for all the
74 observed bycatches on pelagic longlines (Richard et al. 2017), taking into account the
75 sampling effect but still ignoring observation uncertainty. Such an approach is useful in
76 gauging the approximate scale of the total bycatch. The multiplier approach has also been
77 developed for trawl and demersal longline fisheries (Richard et al. 2017; Watkins et al.
78 2008). To avoid the problem of over-estimation, an integrated bycatch assessment model
79 built for the US Western North Atlantic pelagic longline fishery incorporates both
80 observation uncertainty in the bycatch loss process and bycatch origin (Zhou et al. 2019a).
81 By comparison with results from this integrated model, the corresponding loss-free
82 assessment model substantially under-estimated both total bycatch and the associated
83 uncertainty in that fishery. A loss-free assessment model is thus harmful both in
84 discounting the actual impact of bycatch and in making that false statement
85 overconfidently.

86 The aim of this study is to facilitate loss-corrected bycatch estimation based on
87 existing data for pelagic longline fisheries that do not have a concurrent bycatch loss
88 observation component (most qualify as such). The strategy is to extend models to test

89 variability of the bycatch loss rate among alternative factors and conditions to improve
90 our understanding of loss rate and the seabird bycatch process in longline fisheries. Using
91 Bayesian state-space models we analyze how environmental factors at the time of the
92 bait-taking interaction and ecological traits of seabirds affect bycatch loss rate.

93 2 Material and methods

94 2.1 Bait-taking attempts and outcome confirmation

95 The seabird bait-taking attempt and confirmation observations data in pelagic
96 longline fisheries was collected by XX from 11 fishing vessels. over a 15-year period,
97 from 1988 to 2003, in four geographical regions: Indian Ocean, Coral Sea, Southern
98 Ocean and Central Pacific. This data set contains a total of 5,969 observed seabird
99 interactions on a total of 726,626 baited hooks. The same data were previously presented
100 in Brothers et al. (2010).

101 The focal point of Brothers et al. (2010) was interacting seabirds, whereas, in this
102 study, the focus is instead on the baited hooks. A baited hook may be pursued by a single
103 individual or multiple individuals. When multiple individuals compete over the same
104 baited hook, the bait-taking attempt of each individual registers as a separate count of
105 interaction. While multiple bycatch incidences on the same hook are theoretically
106 possible, they have not been observed in the field, and in this study, we assume that a
107 baited hook may catch at most one individual. Due to this change of focus, the count of
108 different types of bait-taking attempts (Table 1) differs from that of Brothers et al. (2010).

109 The seabird interaction methodology was developed in 1988 by Brothers (1991).
110 Here, we present the methodology on a conceptual level and refer the reader to Gilman et

111 al. (2003) for a detailed description. The seabird interaction methodology involves two
112 linked observation components (Figure 2), one at the line setting stage and one at the
113 hauling stage. Time and other positional aids, such as the interaction location relative to
114 line surface floats distances, which provide time intervals, are used to link an observed
115 seabird interaction at the line setting stage to a retrieved carcass during the haul. In
116 contrast, a traditional observer protocol only involves observations at the hauling stage.

117 Multiple hooks are observed simultaneously and independently of each other; for
118 simplicity, the following description only pertains to the observations of a single baited
119 hook. At the line setting stage, a bait-taking attempt is classified into one of five types
120 based on whether the sequence of interactions that lead to a bycatch event and also the
121 classification uncertainty (Figure 2A). Indeterminate (I) will be assigned if an individual
122 is seen to successfully take the bait but circumstances do not allow further confirmations;
123 a possibly caught (P) individual is seen to successfully take the bait, display one of the
124 typical capture responses momentarily but circumstances do not allow the final
125 confirmation of the capture; an observed caught (O) individual displays clear evidence of
126 struggle and its inability to escape the line. I, P and O bait-taking attempts, in decreasing
127 uncertainty, eventually lead to a bycatch event. On the other hand, the attempt is
128 successful (S) if an individual was seen to successfully remove the bait from the hook
129 and not be caught in the process; it is unsuccessful (U) if the individual made no contact
130 with the fishing gear during the attempt. Multiple individuals may attempt to interact with
131 the same hook, and all attempts were recorded, but in this study, we are only concerned
132 with the last observed attempt. At the line hauling stage, a carcass is either retrieved from

133 the observed hook or not, and this result is recorded as the final confirmation of the
134 interaction (Figure 2B).

135 Note that all observations are based on behavioral responds of seabirds towards
136 baited hooks above the surface of the water, and underwater attacks cannot be observed
137 *directly*. However, each underwater attack attempt, i.e., the underwater dive pursuit, and
138 its outcome, e.g., successful or unsuccessful bait take when the bird that dived returns to
139 the surface, can be observed and accounted for in the model.

140 2.2 Probability model of the seabird bycatch and observation processes

141 To remove observation uncertainty from the estimation of bycatch loss rate and
142 also to pool information from different stages of bait-taking attempts (I, P and O) leading
143 to a bycatch event, a state-space probability model was developed. In this model, other
144 attempts and bycatch events are two hidden states, upon which two sets of observations
145 are made (Figure 2). The probability of classifying a bait-taking attempt (A) that does not
146 lead to a bycatch event as one of five types is

$$147 \text{Prob}(A=i) = \beta_i,$$

148 where $i \in \{O, P, I, S \text{ and } U\}$ with the constraint $\sum_i \beta_i = 1$, and similarly for an attempt

149 leading to a bycatch event, the classification probability is

$$150 \text{Prob}(A=i) = \gamma_i,$$

151 with the constraint $\sum_i \gamma_i = 1$. For a no-bycatch event, no carcass will be retrieved, and for

152 a bycatch event, a carcass will be retrieved with a probability of $1 - p_{loss}$. Non-

153 informative Dirichlet priors, i.e., Dirichlet (1,1,1,1,1), were used for both the vectors of
154 β_i s and γ_i s for $i \in \{O, P, I, S \text{ and } U\}$. It is assumed that the observations for different
155 hooks are independent and identically distributed.

156 2.3 Predictors of the loss rate

157 Two sets of predictors were tested for their performance to predict bycatch loss
158 rate in this study: 1) environmental factors and 2) ecological traits. Environmental factors
159 include physical conditions and also biological competition, and these factors were
160 recorded concurrently with the bait-taking observations; ecological traits of seabirds were
161 extracted from published literature.

162 For the environmental factors, three variables were analyzed, i.e., *reg*: the four
163 fishing regions where the interaction is taking place, *phy*: the physical oceanic condition
164 at the time of the bait-taking attempt and *cmp*: the risk score at the nearest bird abundance
165 count interval. Variable *phy* is the sum of the wind score and sea score at the time of the
166 bait-taking attempt. It measures the roughness of the oceanic condition. The wind score is
167 a combination of wind speed and wind direction with respect to the vessel to determine
168 the score with a range from 1 (calm) to 8 (rough), and the sea score is based on the
169 Douglas sea scale with a score of 2 denoting slight waves and 8 denoting very rough
170 conditions. Three levels of *phy* representing calm, intermediate and rough conditions
171 were used, i.e., $phy \leq 4$, $4 < phy \leq 8$, and $8 < phy$. Most of the observed interactions
172 occurred when the condition was calm, and the least interactions occurred when the
173 condition was rough. Variable *cmp* is the sum of the counts of seabirds by species around
174 the vessel weighted by their respective bycatch risk score. Spot counts of seabird

175 abundance around the vessel were recorded mostly at either 15- or 30-min intervals
176 throughout the duration of line sets. The weight for each observed seabird species ranges
177 from 0 to 10 based on their tendency to engage in bait-taking interactions, with 0
178 denoting species that do not interact with fishing operations and 10 denoting species most
179 adept at bait locating and recovery. Four levels of competition severity were used, i.e.,
180 $cmp \leq 200$, $200 < cmp \leq 400$, $400 < cmp \leq 600$, and $600 < cmp$. See supplementary
181 material for a detailed description of the bycatch risk score for each species.

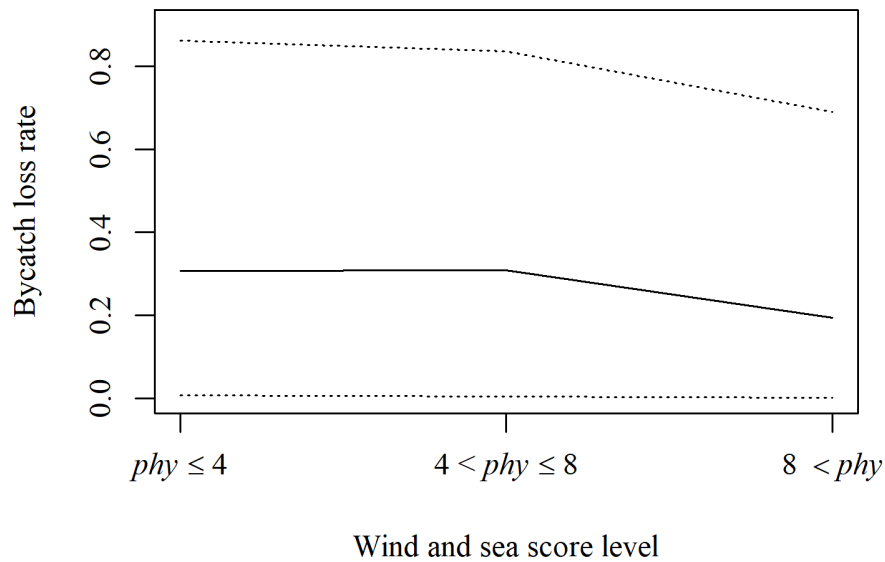
182 For the ecological traits, three variables were analyzed, i.e., *spp*: the species
183 identity of the seabird making the final bait-taking attempt, *diver* and *scavenger*: the
184 primary feeding strategies of the species. While all seabirds are capable of taking baits
185 close to the surface, some species regularly dive to snatch items at some distance below
186 the surface and some species are regular scavengers. These different feeding strategies
187 may have incurred different forms of hooking and/or entanglement, which consequently
188 led to different loss rates.

189 2.4 Hypotheses

190 Eight hypotheses on the variability of the bycatch loss rate were tested (Table 2).
191 The null hypothesis (H0) assumes a constant loss rate ($p_{loss} = p_0$). Here, the domain of p_0
192 is on the interval $[0, 1]$, and we used the probit link function to transform the domain
193 from $[0, 1]$ into the entire real line, i.e., $probit(p_{loss}) = c$. The use of probit link simplifies
194 the choice of the non-informative prior for c , which is the standard normal because of the
195 probability integral transformation between variables c and p_{loss} . All the following
196 hypotheses were constructed by adding covariates (predictors) to $probit(p_{loss})$.

594 [Production instructions: 1.5 or 2 columns; no color needed in print]

595



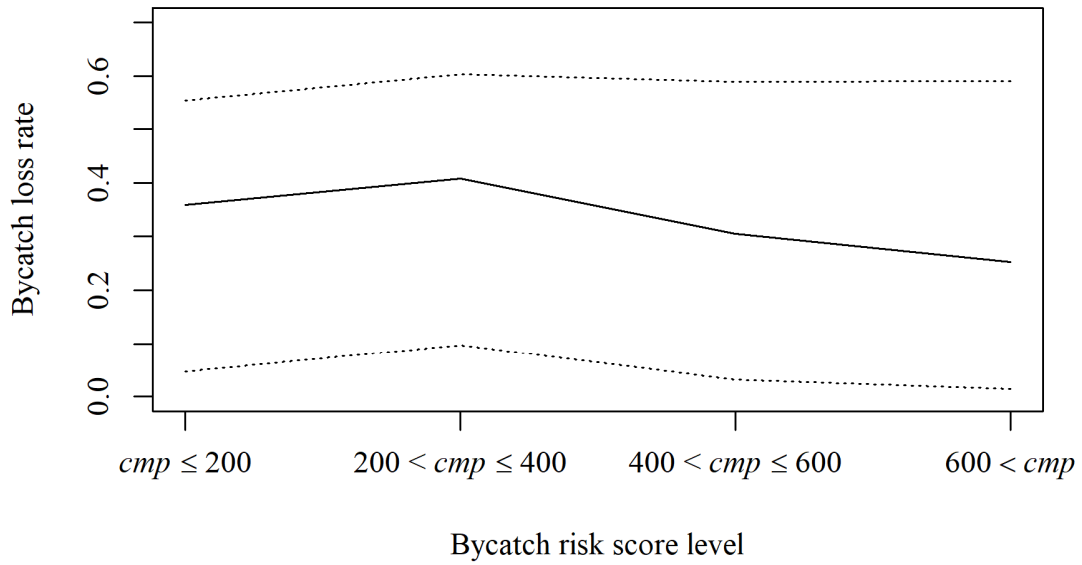
596

597 *Figure 5 Median (solid line) and 95% credible interval (dotted lines) of the posterior*
 598 *estimate of the bycatch loss rate at calm ($phy \leq 4$), intermediate ($4 < phy \leq 8$) and*
 599 *rough ($8 < phy$) physical conditions based on model H2.*

600

601 [Production instructions: 1 column; no color needed in print]

602



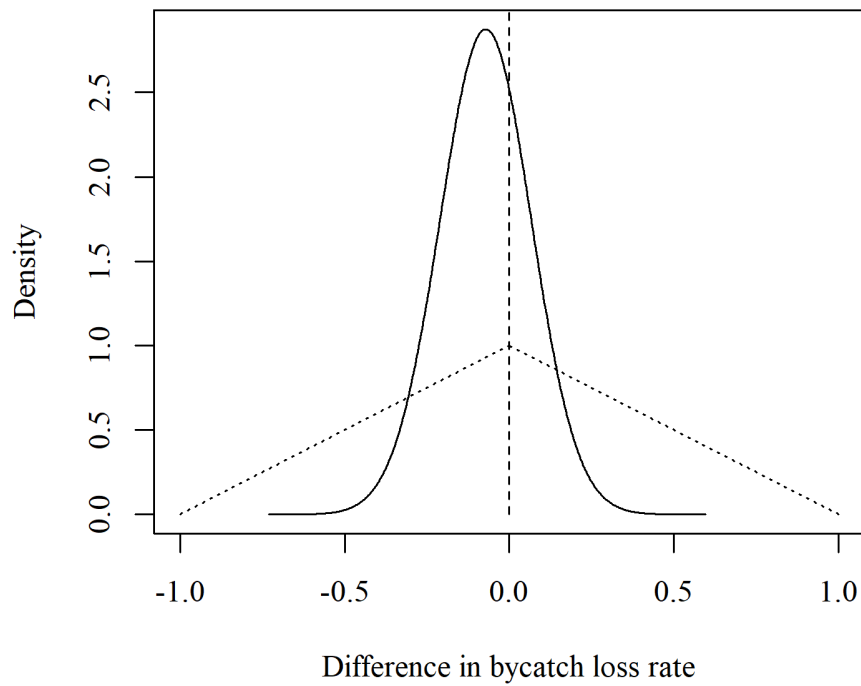
603

604 *Figure 6 Median (solid line) and 95% credible interval (dotted lines) of the posterior*
 605 *estimate of the bycatch loss rate at different levels of bycatch risk score based on model*
 606 *H3.*

607

608 [Production instructions: 1 column; no color needed in print]

609



610

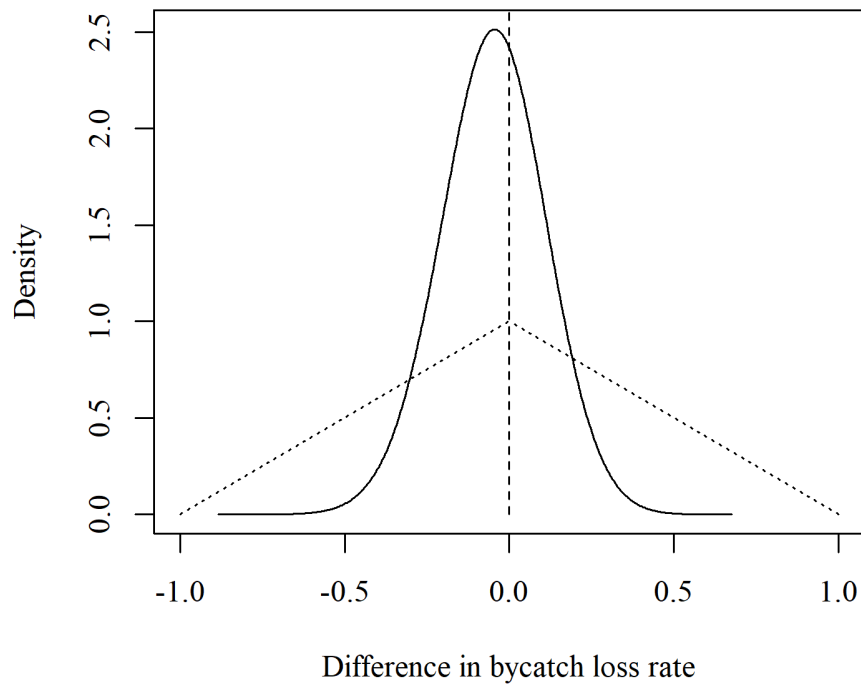
Difference in bycatch loss rate

611 *Figure 7 Prior (two dotted line segments) and posterior (solid curve) of the difference in*
612 *bycatch loss rate between divers and non-divers based on model H4e1. A negative value*
613 *indicates a lower loss rate for divers, and the vertical dashed line separates negative*
614 *values and positive ones.*

615

616 [Production instructions: 1 column; no color needed in print]

617



618

Difference in bycatch loss rate

619 *Figure 8 Prior (two dotted line segments) and posterior (solid curve) of the difference in*
620 *bycatch loss rate between scavengers and non-scavengers based on model H4e2. A*
621 *negative value indicates a lower loss rate for scavengers, and the vertical dashed line*
622 *separates negative values from positive ones.*

623

624 [Production instructions: 1 column; no color needed in print]