**Supplemental Material**

**Effect of pelagic longline bait type on species selectivity: A global synthesis of evidence**

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**S1. Systematic Literature Search**

Fig. S1 summarizes the process and results of a systematic literature search. A systematic literature search was conducted using Google Scholar and Web of Science, designed to find records that must contain the words longline, squid, bait and pelagic anywhere in the record; must contain either bait type or bait species anywhere in the record; that may contain one or more of the following additional search terms, also anywhere in the record: pelagic, bycatch, by-catch, seabird, turtle, shark, tuna, swordfish, billfish, mackerel, sardine, saury, sanma, herring, palangrera, palangreros; and that does not contain the words demersal or cod anywhere in the record. The browsing history was disabled prior to conducting the Google Scholar and Web of Science searches. The Western and Central Pacific Fisheries Commission's Bycatch Management Information System online database of references https://www.bmis-bycatch.org/references was also searched, filtered for fishing gear of longline, and database of mitigation technique of "fish not squid bait". The Consortium for Wildlife Bycatch Reduction's online database of references, https://www.bycatch.org/, was searched, filtered for hook-and-line fishing gear and mitigation technique of "alternative bait", for both field and non-field studies. Published and grey literature were included in the search. The search did not restrict the time period or language of publication.

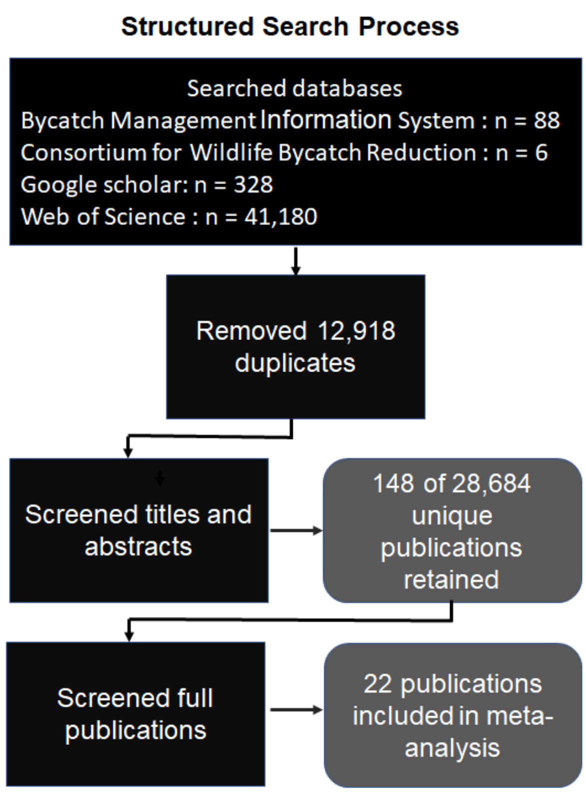


Fig. S1. Process and results of a structured literature search conducted to compile publications for an assessment of pelagic longline bait type effects on catch selectivity.

**S2. Records from Compiled Publications**

Table S1 summarizes the database of records assembled for the meta-analysis of the effect of pelagic longline bait type on species- and group-specific catch risk. Publications that contained data for the same fishery or experiment and for the same time periods were integrated into a single ‘study’ to avoid duplication, hence some of the studies in Table S1 have multiple citations. If data reported in a study could be split into subsets so that only a single hook shape, hook size and/or leader material was employed in each subset, then these subsets of data were included as separate records in the meta-analysis database, identified in the second column of Table S1. Each row in Table S1 is referred to as a ‘study’, where some studies are made up of multiple publications. Each of the 112 records from the 33 studies were uniquely labelled to be able to support any form of random effects structures (Table S1).

Table S1. Metadata on records from compiled publications used for meta-analytic regression modelling to estimate overall expected species- and group-specific relative risk of capture on forage fish species compared with squid species used as bait. Each of the 112 records from the 33 studies were uniquely labelled to be able to support any form of random effects structures.

| citation | sample of study dataset | labels for records within each study | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | sharks | blue shark | rays | seabirds | turtles | marine mammals | tunas | billfishes | swordfish | other teleosts |
| Amorim et al. 2014 | NA | 3 | 4 | 2 | | | | | | | 1 |
| Ariz et al. 2006 | NA | 4 | | 2 | 3 | 5 | 6 | | | | 1 |
| Bach et al. 2000; ECOTAP, 1998; Abbes et al. 1996 | NA | 3 | 4 | 2 | | | | 1 | 5 | 6 | 7 |
| Bach et al. 2008 | excludes data from bonito bait | 4 | | 3 | | | | 5 | 1 | 6 | 2 |
| Baez et al. 2013 | includes data from the "LLJAP" and "LLALB" fisheries | | | | | 1 | | | | | |
| Coelho et al. 2015 | NA | | | | | 1 | | | | | |
| Fernandez-Carvalho e al. 2015 | NA | 3 | | 2 | | | | | | | 1 |
| Foster et al. 2012 | circle hooks | 2 | 5 | | | 4 | | 3 | 1 | 6 | |
| Galeana-Villasenor et al. 2009 | NA | 2 | 3 | | | | | | | | 1 |
| García-Cortés et al. 2009 | NA | | | | | 1 | | | | | |
| Gilman et al. 2007, 2014 | NA | 2 | 8 | 1 | 7 | 4 | 10 | 3 | 5 | 9 | 6 |
| Gilman et al. 2012 | NA | 7 | 8 | 1 | 6 | 3 | 10 | 2 | 4 | 9 | 5 |
| Gilman et al. 2016 | NA | 6 | 7 | 1 | | 3 | | 2 | 4 | 8 | 5 |
| Gonzalez et al. 2012 | NA | | | | 1 | | | | | | |
| Januma et al. 1999 | squid and saury bait | 3 | | | | | | 4 | 1 | 5 | 2 |
| Javitech 2003 | NA | | | | | 1 | | | | | |
| Kim et al. 2007, 2008 | NA | 3 | | | | 5 | | 4 | 1 | | 2 |
| Li et al. 2012 | NA | | | | 1 | | | | | | |
| Mejuto et al. 2008 | excludes data from blue shark bait | 2 | 4 | | | 3 | | | 1 | 5 | |
| MRAG 2008 | NA | | | | | 1 | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Petersen et al. 2008 | J hooks | 1 | 3 | | | | | | | | |
| Petersen et al. 2008 | circle hooks | 2 | 4 | | | | | | | | |
| Rueda et al. 2006 | NA | | | | | 1 | | | | | |
| Santos et al. 2012 | NA | | | | | 1 | | | | | |
| Santos et al. 2013 | NA | | | | | 1 | | | | | |
| Shomura 1955 | sardine and squid bait experiment | | | | | | | 1 | | | |
| Stokes et al. 2011 | single-baited hooks | | | | | 1 | | | | | |
| Trebilco et al. 2010; Personal communication, R. Trebilco, 16 Feb 2020, CSIRO Oceans and Atmosphere | hooks with live and dead forage fish bait and dead squid bait | | | | 1 | | | | | | |
| Watson et al. 2005 | circle hooks | 1 | 5 | | | 3 | | | | | |
| Watson et al. 2005 | J hooks | 2 | 6 | | | 4 | | | | | |
| Yokota et al. 2006 | circle hooks | | | | | 2 | | | | | |
| Yokota et al. 2006 | tuna hooks | | | | | 1 | | | | | |
| Yokota et al. 2009 | NA | 7 | 8 | 5 | 6 | 3 | | 2 | 4 | 9 | 1 |
| | **total records:** | 18 | 13 | 9 | 7 | 21 | 3 | 10 | 10 | 9 | 12 |

**S3. Contour-enhanced Funnel Plots to Explore Potential Publication Bias**
Fig. S2 is an example of a contour-enhanced funnel plot (Peters et al. 2008) for sharks. See Sterne et al. (2011) for a detailed explanation of interpreting funnel plot asymmetry and how contour-enhance funnel plots are effective at supporting that interpretation.

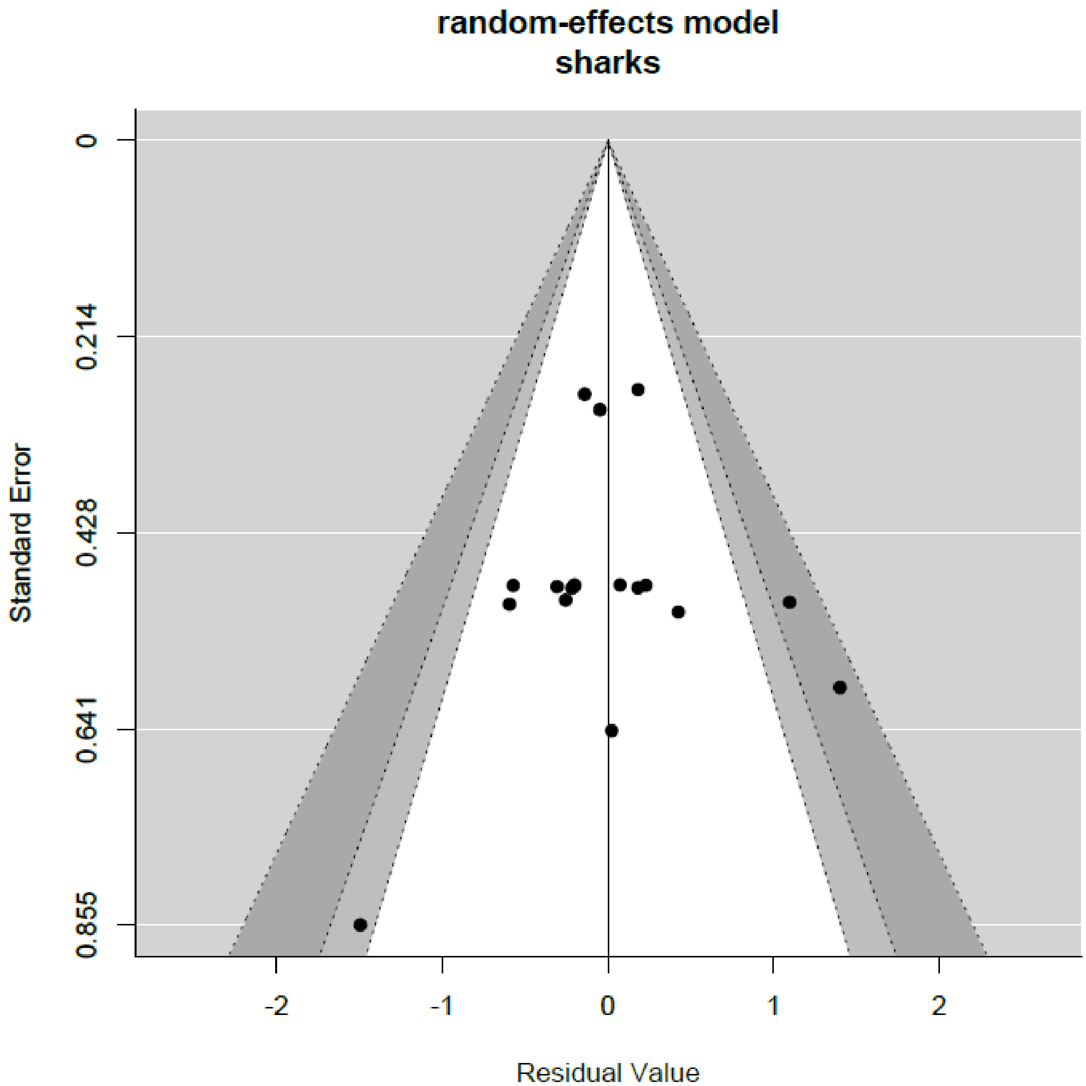


Fig. S2. A contour-enhanced funnel plot of the predicted study-specific log risk ratios derived from the normal-normal hierarchical meta-analytic model fit to the 18 pelagic shark effect sizes sourced from 16 studies.

**S4. Forest Plots for Taxa with Non-Significant Overall Random Effects Estimates**
Figs. S3-S9 are forest plots summarizing the model-predicted log risk ratios and the estimated overall or pooled random effect for taxa with non-significant overall random effects estimates. Some citations listed in the forest plots were pooled with data from additional publications, shown in Table S1. All 112 records from the 33 studies were uniquely labelled to be able to support any form of random effects structures, identified in Table S1, and the labels are referenced in Figs. S3-S9 for records from studies with more than 1 record.

In the case of the swordfish model, several of the estimated study-specific posterior densities were heavily left skewed and so a posterior mean might not provide the best point estimate summary. The same applies to the estimated left skewed random effect estimate summarizing all of those studies. So, for swordfish, the posterior mode might provide a better summary metric than the posterior mean. For completeness, we provide both summary estimates: The posterior mean overall log relative risk estimate was -0.07 (95% credible interval: -0.37 to 0.10) (Fig. S4). When back-transformed, the overall swordfish random effects estimate was 0.94 (95% HDI: 0.71 to 1.13) and there was a posterior mean -6% (95% HDI: -29% to 13%) lower catch risk on fish bait than on squid bait. The posterior mode back-transformed overall random effects estimate was 1.01 (95% HDI: 0.71 to 1.13), and the posterior mode indicated a 4% (95% HDI: -28% to 14%) higher catch risk on fish bait than on squid bait. Including both the posterior mean and mode summary estimates demonstrates how Bayesian meta-analytic approaches are informative by using the whole posterior distribution in the forest plot to reveal issues for various point summary estimates such as the mean, median or mode. For swordfish, the posterior mean and median are very similar but the posterior mode suggests a different conclusion about the percent risk reduction.

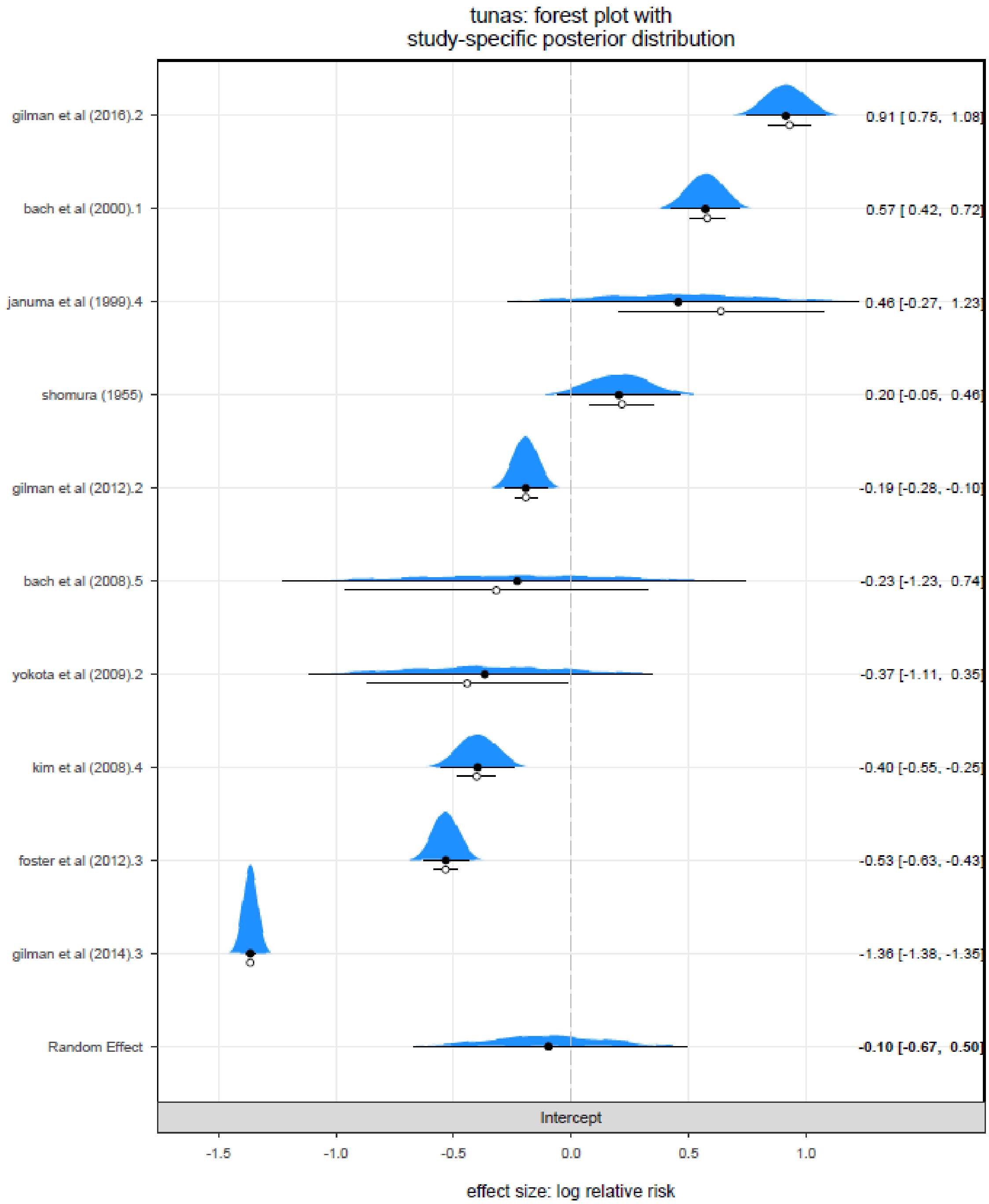


Fig. S3. Model-predicted log risk ratios for bait-specific catch rates derived from 10 study-specific effect sizes for tunas. The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws, horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 10 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower tuna catch rate on pelagic forage fish bait than on squid bait, open dot = observed effect size with the horizontal line = effect size 95% confidence interval. Bigeye tuna was the predominant tuna species caught in 6 of the 10 records.

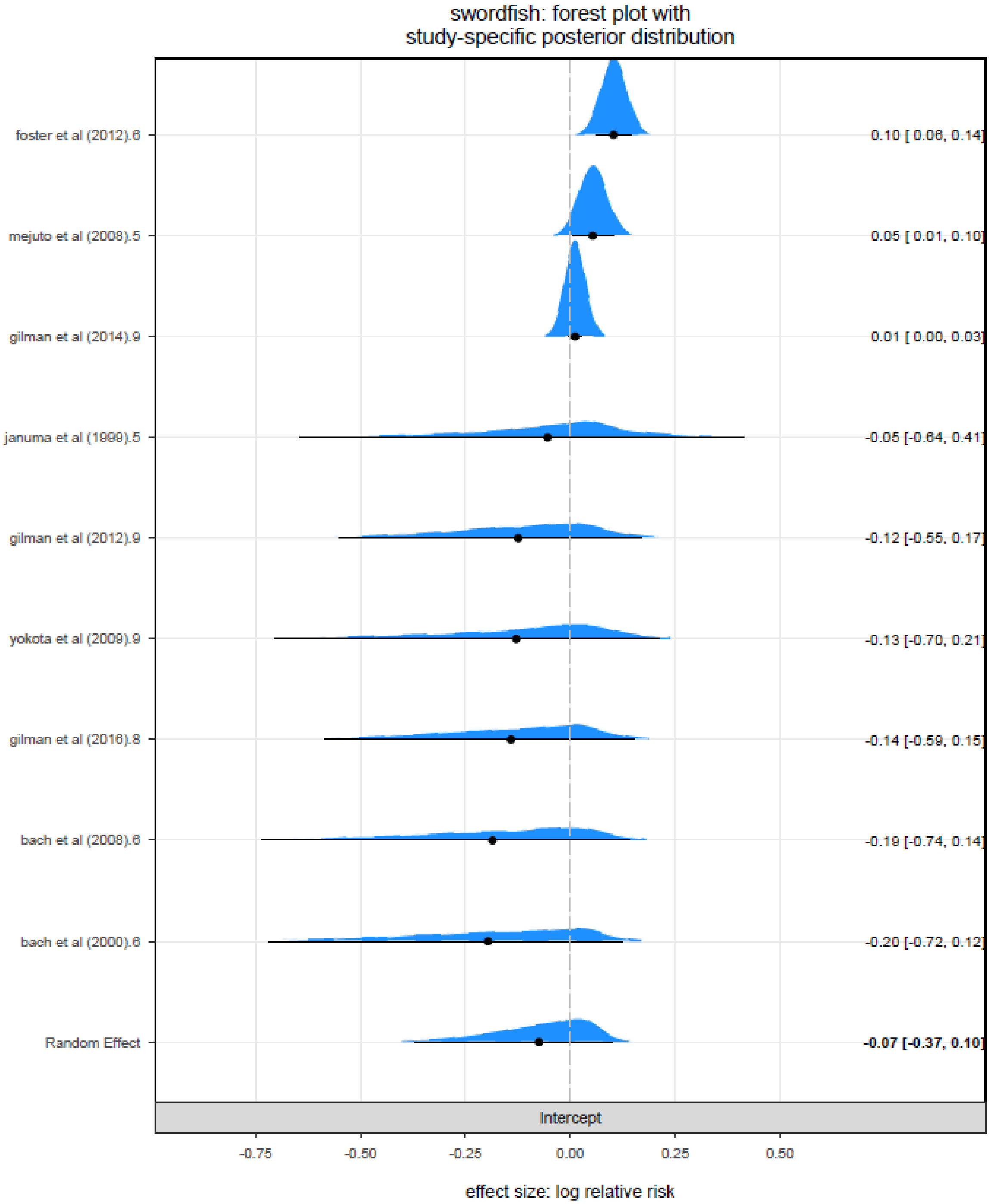


Fig. S4. Model-predicted log risk ratios for bait-specific catch rates derived from 9 study-specific effect sizes for swordfish. The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws (the effective sample size = 10k), horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 9 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower catch rate on pelagic forage fish bait than on squid bait.

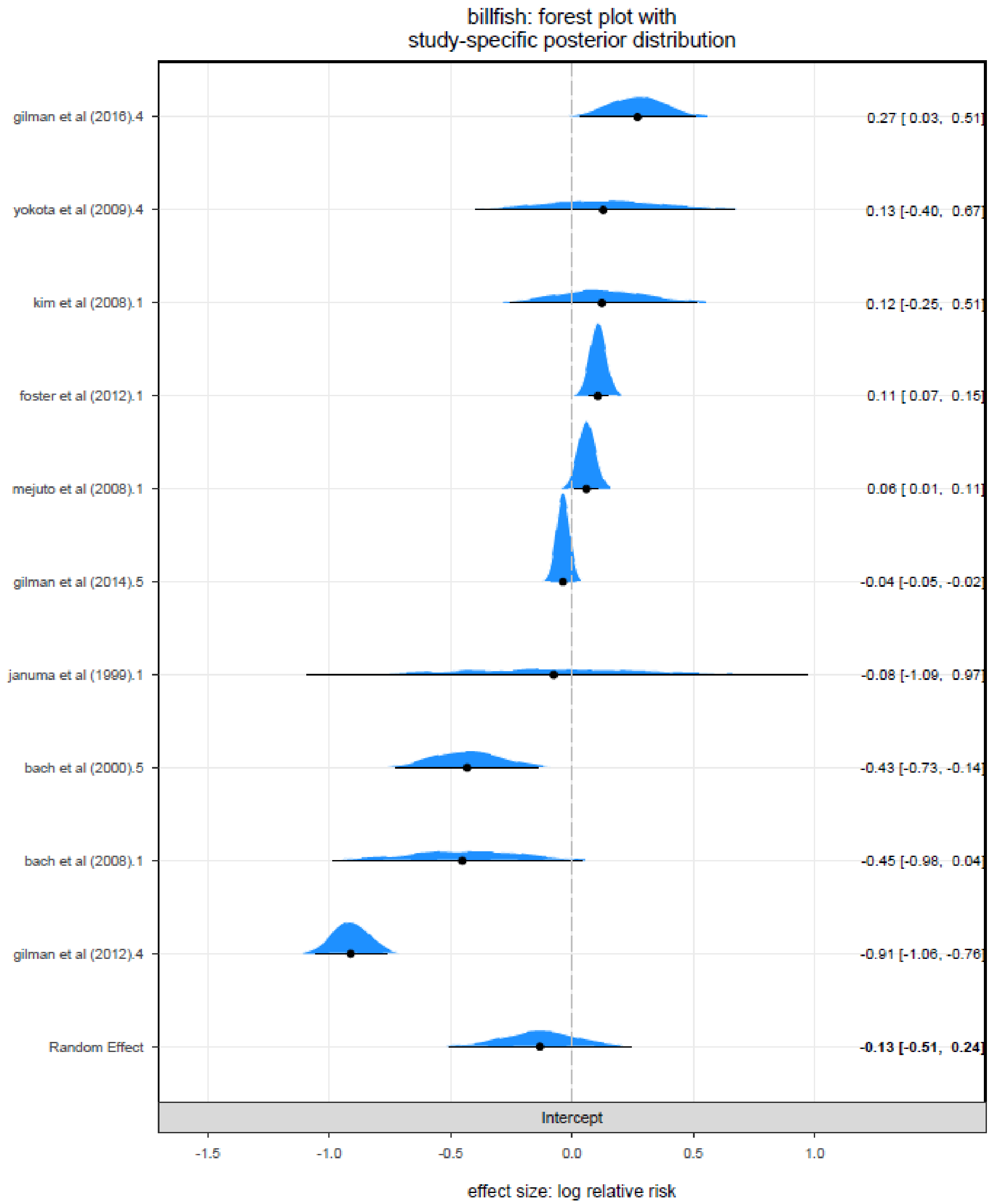


Fig. S5. Model-predicted log risk ratios for bait-specific catch rates derived from 10 study-specific effect sizes for billfishes. The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws (the effective sample size = 10k), horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 10 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower catch rate on pelagic forage fish bait than on squid bait. Swordfish was the predominant billfish species caught in 8 of the 10 records.

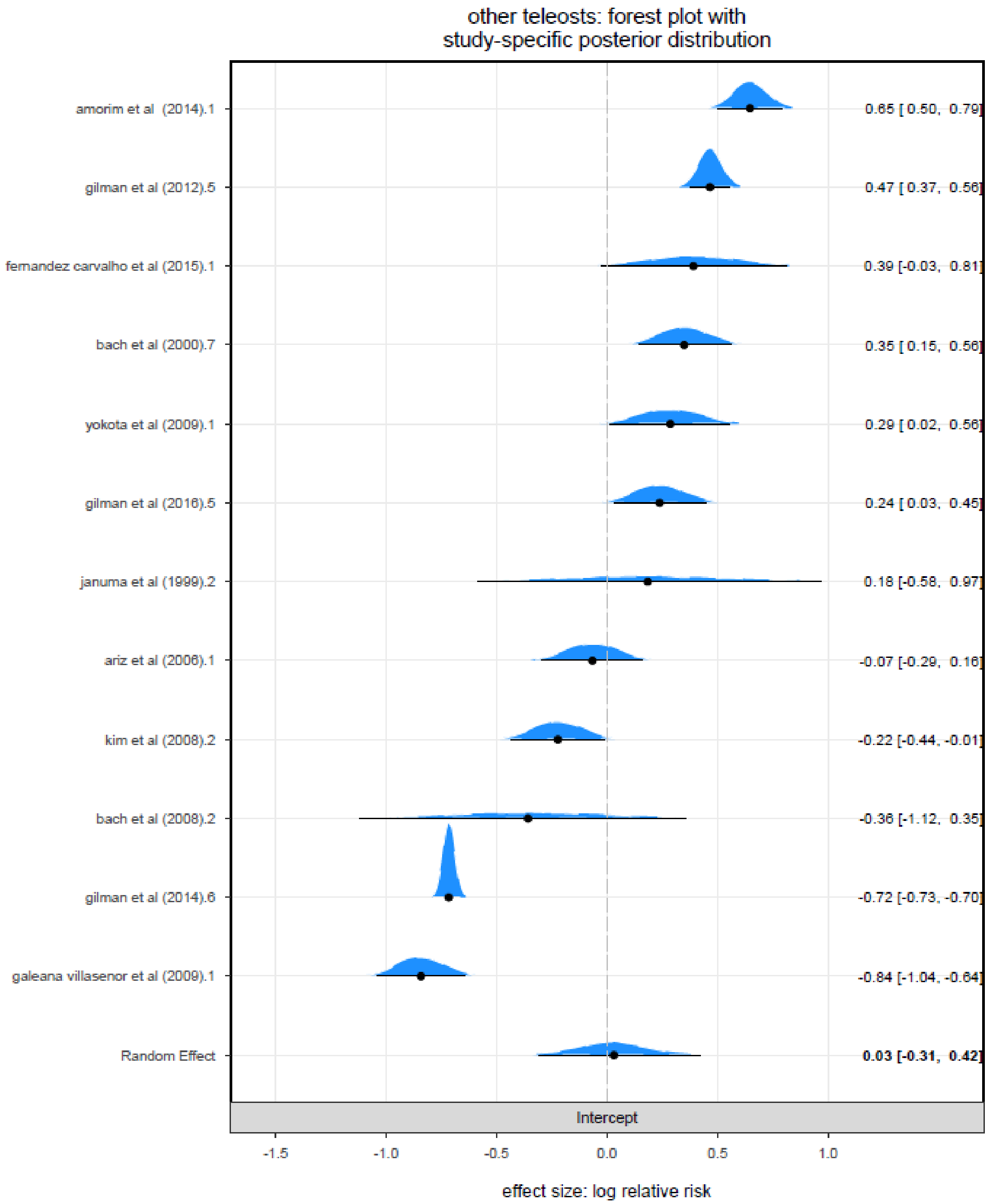


Fig. S6. Model-predicted log risk ratios for bait-specific catch rates derived from 12 study-specific effect sizes for ‘other’ teleosts (other than tunas and billfishes). The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws (the effective sample size = 10k), horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 12 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower catch rate on pelagic forage fish bait than on squid bait. Longnose lancetfish (*Alepisaurus ferox*) and dolphinfish (*Coryphaena hippurus*) were the predominant ‘other’ teleost species caught for 5 records each of the 12 records.

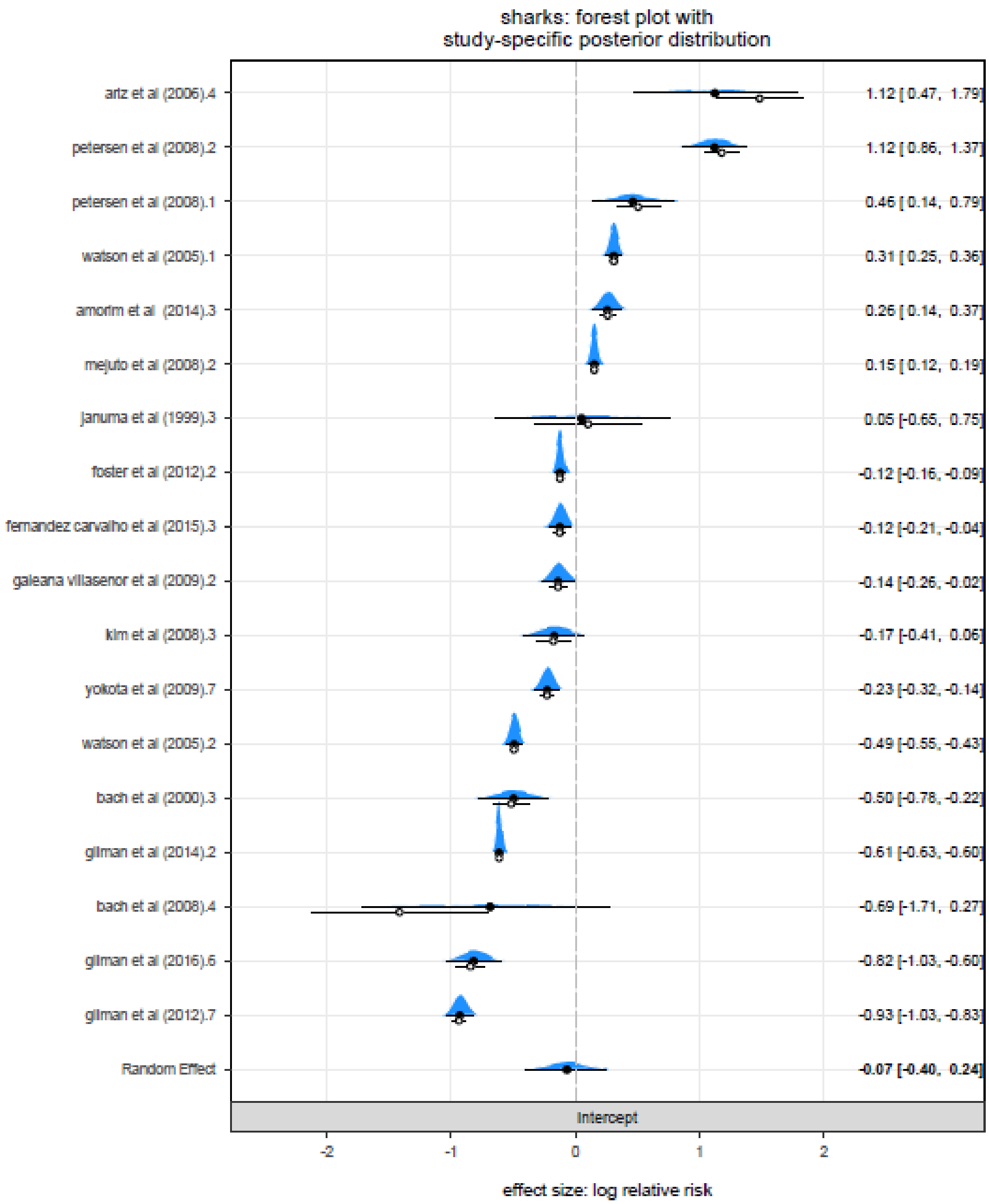


Fig. S7. Model-predicted log risk ratios for bait-specific catch rates derived from 18 study-specific effect sizes for pelagic sharks. The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws, horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 18 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower shark catch rate on pelagic forage fish bait than on squid bait, open dot = observed effect size with the horizontal line = effect size 95% confidence interval. Blue shark was the predominant shark species caught in 11 of the 19 records.

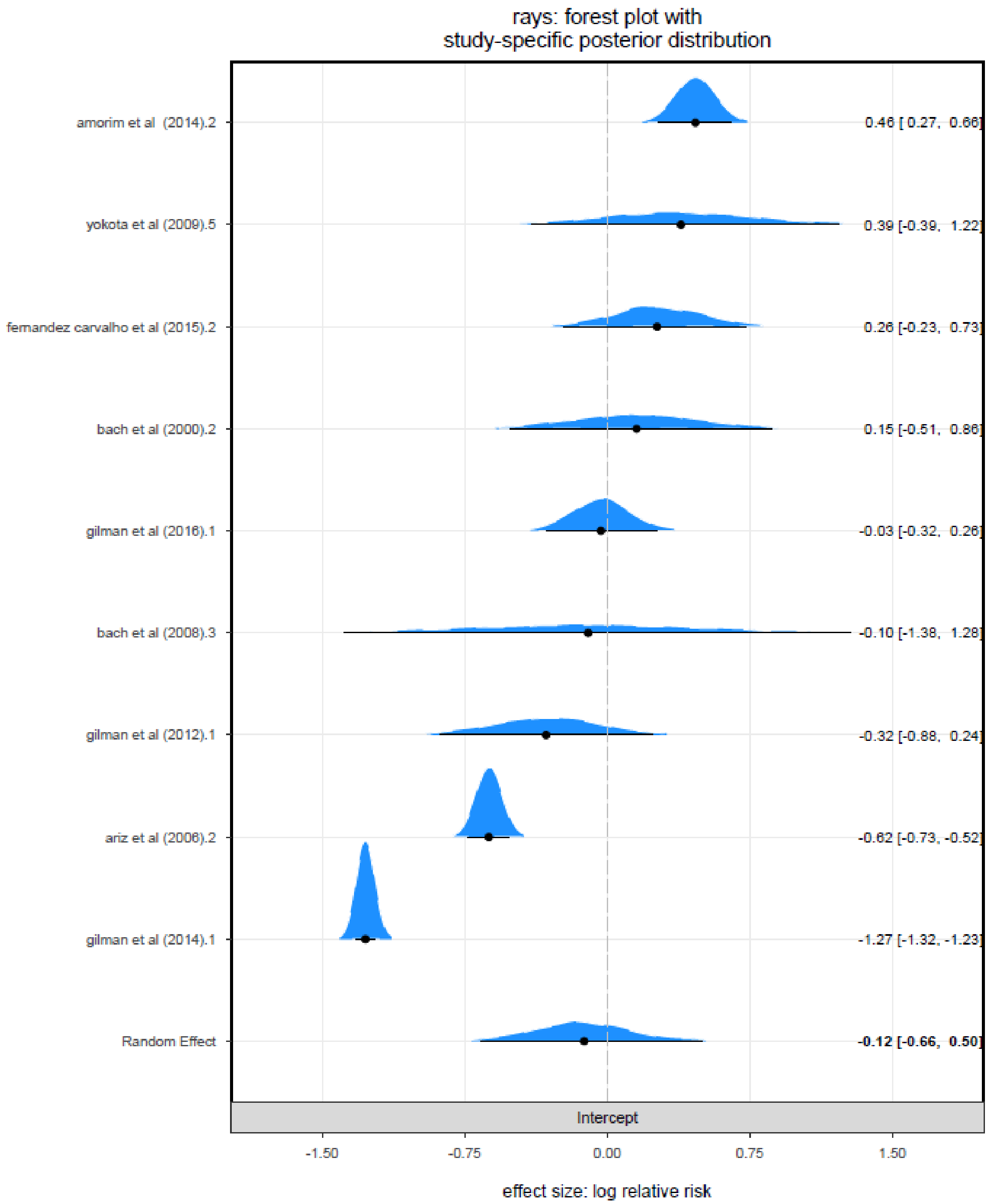


Fig. S8. Model-predicted log risk ratios for bait-specific catch rates derived from 9 study-specific effect sizes for rays. The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws (the effective sample size = 10k), horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 9 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower catch rate on pelagic forage fish bait than on squid bait. Pelagic stingray (*Pteroplatytrygon violacea*) was the predominant ray species caught in 6 of the 9 records.

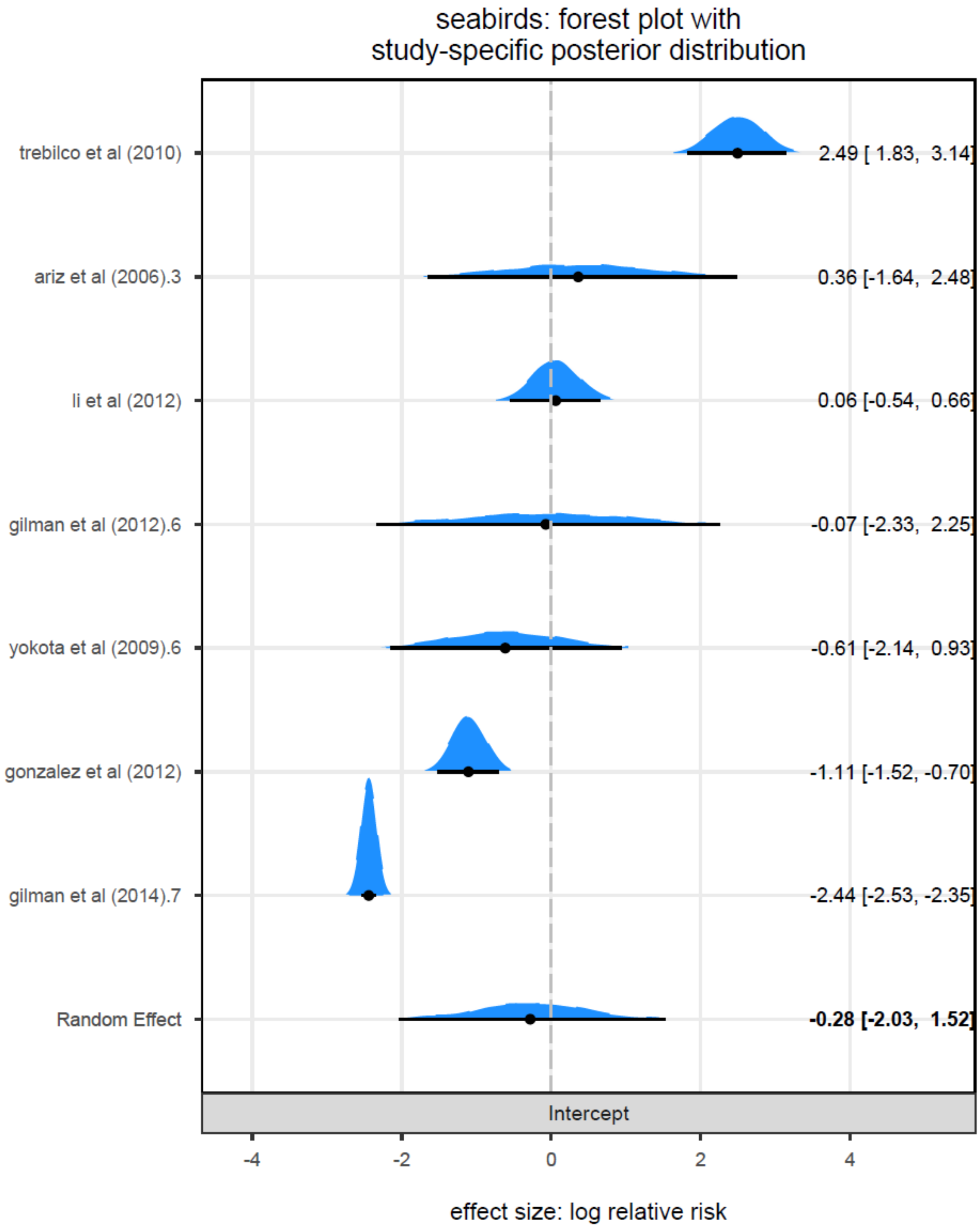


Fig. S9. Model-predicted log risk ratios for bait-specific catch rates derived from 7 study-specific effect sizes for seabirds. The shrinkage estimates were derived using a Bayesian random-effects meta-analytic model with Gaussian likelihood. Polygon = density of the posterior draws (the effective sample size = 10k), horizontal line = 95% credible interval of the posterior draws, solid dot = mean of the posterior draws shrunk towards the Random Effect estimate that is the pooled or overall log risk ratio for all 7 records, dashed vertical line indicates no bait-specific effect with shrinkage estimates to the left of this line reflecting a lower catch rate on pelagic forage fish bait than on squid bait. The black-footed albatross (*Phoebastria nigripes*) was the predominant seabird species caught in 3 of the 7 records.

**S5. Bait Type Underlying Mechanisms for Effect on Survival**

Bait type has been observed to affect haulback condition of some pelagic teleosts, likely due to the prevalent hooking position (Broadhurst and Hazin 2001; Epperly et al. 2012). Bait type may explain anatomical hooking position due to differences in shielding the hook and to feeding behavior (Gilman and Hall 2015; Gilman et al. 2016). For instance, as a result of squid being firm and difficult to remove from the hook, hard shelled sea turtles tend to ingest squid bait whole or in a few large bites, along with the hook. In addition to increasing their catch risk, this feeding behavior may also result in a larger proportion of hard-shelled turtles caught on squid bait to become deeply hooked relative to those caught while tearing small pieces of relatively soft fish bait from the hook (Watson et al. 2005; Stokes et al. 2011; Parga et al. 2015; Gilman and Huang 2017).

Relative to deeply-hooked organisms (in combination with trailing fishing line for sea turtles), organisms externally hooked in the mouth or body are expected to have a lower degree of injury and concomitant lower at-vessel, pre-catch and post-release mortality rate (Chaloupka et al. 2004). The removal of deeply ingested hooks by crew is also more likely to be lethal than removal from externally- and mouth-hooked organisms (Santos et al. 2012; Parga et al. 2015).

The effect of bait type on survival may also be due to the size selectivity of bait type, which has been observed for some pelagic teleost and elasmobranch species (Amorim et al. 2014). Differences in survival probability has been observed by size (and sex for species that exhibit sexual size dimorphism) within species (Campana et al. 2009; Musyl et al. 2011; Coelho et al. 2012; Gallagher et al. 2014).

**S6. Artificial Bait and Using Pieces of the Longline Catch for Bait**

No studies were identified that found an artificial bait to be economically viable for use in pelagic longline fisheries. A polyurethane mold stuffed with fish pulp reduced unwanted catch of pelagic stingrays and dolphinfish but also reduced target species catch rates (Bach et al. 2012). Mejuto et al. (2005) found that artificial bait made of a plastic mold shaped like mackerel and squid, filled either with a sponge soaked with sardine oil or filled with a piece of mackerel, produced lower swordfish catch rates than mackerel bait. Januma et al. (1999, 2003) estimated pelagic longline catch rates on an artificial bait made of squid liver and strengthened with gauze and other fillers vs. conventional squid and saury bait, finding lower tuna, shark and total fish catch rates on the artificial bait. Artificial bait made of a latex sponge shaped like squid (Koyama, 1956) and vinyl chloride shaped like flying fish (Turudome 1970) have also been developed for use in pelagic longline fisheries.

Pieces of large marine species, including of tunas, sharks, rays, marine mammals and other species, are used for bait in some pelagic longline fisheries targeting sharks (e.g., Echwikhi et al. 2010; Mangel et al. 2010; Mintzer et al. 2018; Saidi et al. 2019) and tunas (Afonso et al. 2011). This bait type is also used on ‘shark lines’ (branchlines attached to floats or floatlines) used to catch sharks by pelagic longline vessels primarily targeting tuna and tuna-like species and billfishes (Bromhead et al. 2012, 2013; Gilman and Hall 2015). A few studies have compared catch rates on pieces of large marine organisms to catch rates using small forage fish species or squid for bait. Mejuto et al. (2008) observed lower catch rates of blue shark, shortfin mako and swordfish, and higher catch rates of loggerhead and olive Ridley sea turtles on pieces of blue shark for bait than with squid or mackerel for bait. Echwikhi et al. (2010) observed significantly lower loggerhead turtle and higher sandbar shark (*Carcharhinus plumbeus*) catch rates with pieces of stingray used for bait than on mackerel bait. Saidi et al. (2019) also found significantly higher sandbar shark catch rates on pieces of stingray than on mackerel bait. There is a large body of evidence of the effect of fishing depth on species-specific catch risk, where shallower hooks, including on shark lines, have higher catch rates of epipelagic species, than deeper hooks (Bromhead et al. 2013; Gilman et al. 2019).

## S7. References


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