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PROGRESS ON A META-ANALYSIS FOR COMPARING HOOK, BAIT AND LEADER EFFECTS ON TARGET, BYCATCH AND VULNERABLE FAUNA INTERACTIONS

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SUMMARY

This paper describes the progress of an EU Project "Evaluation of the effects of hooks' shape & size on the catchability, yields and mortality of target and by-catch species, in the Atlantic Ocean and adjacent seas surface longline fisheries". At this stage, a meta-analysis of 36 publications totaling 55 experiments was conducted to assess effects of hook, bait, and leader type on retention and at-haulback mortality rates of swordfish, blue shark, and loggerhead sea-turtle. Using circle hooks significantly lowers retention rates of loggerhead sea-turtles and swordfish. Fish bait significantly reduces the retention of loggerhead sea-turtles but does not significantly affect the retention of swordfish or blue shark. The effects of using wire leaders could not be assessed for the loggerhead turtle and significantly increased retention of blue sharks. As for at-haulback mortality, it was significantly reduced for swordfish when using circle hooks. Fish bait increased at-haulback mortality of blue shark and was not significant for the other taxa. The effects of using wire leaders on at-haulback mortality were only possible to calculate for blue shark and were not significant.

RÉSUMÉ

Le présent document décrit les progrès réalisés dans le cadre du projet de l'UE « Évaluation des effets de la forme et de la taille des hameçons sur la capturabilité, la production et la mortalité des espèces cibles et des prises accessoires, dans les pêcheries palangrières de surface de l'océan Atlantique et des mers adjacentes ». À ce stade, une méta-analyse de 36 publications totalisant 55 expériences a été menée pour évaluer les effets de l'hameçon, de l'appât et du type d'avançons sur les taux de rétention et de mortalité à la remontée de l'engin de l'espadon, du requin peau bleue et de la tortue caouanne. L'utilisation d'hameçons circulaires réduit considérablement les taux de rétention des tortues caouannes et des espadons. L'appât de poissons réduit considérablement la rétention des tortues caouannes, mais n'affecte pas de manière significative la rétention de l'espadon ou du requin peau bleue. Les effets de l'utilisation d'avançons métalliques n'ont pas pu être évalués pour la tortue caouanne et la rétention considérablement accrue des requins peau bleue. Quant à la mortalité à la remontée de l'engin, elle a été significativement réduite pour l'espadon avec l'utilisation des hameçons circulaires. Les appâts de poissons ont augmenté la mortalité à la remontée de l'engin du requin peau bleue, alors que cela n'était pas significatif pour les autres taxons. Les effets de l'utilisation d'avançons métalliques n'ont pas pu être évalués pour la tortue caouanne et ont considérablement accru la rétention des requins peau bleue.

RESUMEN

Este documento describe el progreso de un proyecto de la UE «Evaluación de los efectos del tamaño y forma de los anzuelos en la capturabilidad, el rendimiento y la mortalidad de las especies objetivo y de captura fortuita en las pesquerías de palangre de superficie del océano Atlántico y mares adyacentes». En este momento, se realizó un meta-análisis de 36 publicaciones, con un total de 55 experimentos para evaluar los efectos del anzuelo, carnada y tipo de cable en las tasas de retención y de mortalidad en la virada del pez espada, la tintorera y la tortuga boba. Utilizar anzuelos circulares disminuye notablemente las tasas de retención de las tortugas bobas y el pez espada. La carnada de peces reduce notablemente la retención de las tortugas bobas, pero no afecta de manera importante a la retención del pez espada o de la tintorera. Los efectos

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de utilizar cable de acero no pudieron ser evaluados para las tortugas bobas y aumentaban significativamente la retención de la tintorera. Respecto a la mortalidad en la virada, se reducía significativamente para el pez espada al utilizar anzuelos circulares. La carnada de peces aumentaba la mortalidad en la virada de la tintorera y no era importante para los otros taxones. Los efectos de utilizar cable de acero, en la mortalidad en la virada eran solo posibles de calcular para la tintorera y no eran significativas.

KEYWORDS

Meta-analysis, J-hooks, circle hooks, squid, fish, target, bycatch

1. Introduction

Marine fisheries have a major anthropogenic influence on marine systems worldwide, affecting both marine populations and ecosystems, and warranting urgent and comprehensive management. Among the different key issues in marine fisheries, bycatch - the unintended capture of non-target organisms during fishing operations, is a major problem. Amongst these species are sea turtles, sharks and rays, seabirds and marine mammals. While some bycaught species are also commercial species, and therefore retained, others are discarded having no economical value. There is an evident need for measures that minimize catches of the bycatch species and/or measures that decrease mortality rates, that together with good handling practices, could decrease the at-haulback and post-release mortality.

Awareness of the impacts of incidental catches on species of concern is increasing, as well as the research on measures that minimize catch of non-target species. Gear modifications type of measures are seen as of easy implementation and low economical impact. The use of circle hooks instead of J-hooks is one of the measures seen as beneficial in reducing bycatch while maintaining the target species catch, however different results between studies and species have prevented a wider implementation of this measure. Besides hook type, bait species type has also been reported to have an effect on the catches of bycatch species. A species-specific meta-analysis of the changes in retention and at-haulback mortality rates between hook, bait and leader type is presented in this study.

This study is part of an ongoing EU project "*Evaluation of the effects of hooks' shape & size on the catchability, yields and mortality of target and by-catch species, in the Atlantic Ocean and adjacent seas surface longline fisheries*", within the Framework Contract (FWC) EASME/EMFF/2016/008 for the "*Provision of scientific advice for fisheries beyond EU waters*". The results presented here are part of the interim project results, with the final results expected in July 2020.

2. Methods

2.1 Data collection

Information from studies and experiments that examined hook type (circle, tuna or J-hook) effects, bait type (squid or fish) effects and leader type (nylon or steel) effects on retention and at-haulback mortality in pelagic longline fisheries was compiled. Published literature, technical reports and unpublished data relevant to our search were identified based on electronic database searches, using relevant keywords (e.g. "circle hook", "bait type", "leader type", "pelagic longline"). Initial references were collected from a recent meta-analysis by Reinhardt *et al*. (2017). Further references in the available literature were also analyzed if there was a match with the searching criteria. Following Reinhardt *et al*. (2017), the term "reference" is used to refer to a document; "experiment" to refer to a unique data set considered in our analysis. An experiment was considered unique if they differed with respect to attributes such as the year of study or season, location, gear, vessel size or fleet. Each unique experiment was assigned an identification number, and a unique reference could have more than one experiment. References used were collected by January 2019.

Data collected from each reference included date and location, set type, species name, hook type, size, offset and manufacturer, bait type, leader type, number of hooks, total catch, and at-haulback mortality. The set type was classified as "Deep-set" or "Shallow-set" depending on the longline depth during the fishing operation. If this information was not available, the target species and number of hooks between floats were used to differentiate between set type. Hook type was classified as "circle", "J" or "Tuna" hook. When available, information on hook size, offset and manufacturer were also recorded. Bait type was classified as "fish" or "squid" depending on the bait species used. Leader type was classified as "nylon" or "wire"; when available information on leader length was also recorded. Some values that were required, but not directly reported, were derived where possible. For example, the number of fish caught was often derived from retention rates and effort reported in the reference.

Data from the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center Pelagic Observer Program (POP), Epperly *et al*. (2012) and Foster *et al*. (2012) were obtained from Reinhardt *et al*. (2017). Data from Coelho *et al*. (2012), Amorim *et al*. (2015), Fernandez-Carvalho *et al*. (2015), Santos & Coelho (2016) and Santos *et al*. (2017) was used directly from the raw data provided by the authors.

2.2. Meta-analysis

Differences in retention and at-haulback mortality rates for bony fishes (tuna and billfish species), both target and bycatch, elasmobranchs and sea turtles retained on different hook, bait and leader type for shallow setting pelagic longlines were analysed through a meta-analysis. Tuna hooks were not considered in the analysis. Our analysis follows the method used by Reinhardt *et al*. (2017) but is specific to the shallow pelagic longline fishery and expands the analysis to include bait type and the leader type. The difference between the calculated RR and a value of 1.0 represents the mean percent change associated with the experimental treatment, such that an RR < 1.0 indicates lower values for treatment compared with the control (e.g circle vs J-hooks).

The RR is equal to:

RR=ai/n1ici/n2i

where for the ith experiment, a_i is the number of animals retained on experimental hook (circle hook), $n1_i$ is the number of experimental hooks fished, c_i is the number of animals retained on control hooks (J-hooks), and $n2_i$ is the number of control hooks fished for the analysis of retention rate.

For the comparison between bait type, for the ith experiment, a_i is the number of animals retained on experimental bait (squid), $n1_i$ is the number of experimental hooks fished, c_i is the number of animals retained on control hooks (fish), and $n2_i$ is the number of control hooks fished for the analysis of retention rate.

For the comparison between leader type, for the ith experiment, a_i is the number of animals retained on experimental leader (nylon), $n1_i$ is the number of experimental hooks fished, c_i is the number of animals retained on control hooks (steel wire), and $n2_i$ is the number of control hooks fished for the analysis of retention rate.

The same methods apply to at-haulback mortality, where the a_i and c_i is the number of animals dead at-haulback for the experiment and control, respectively, and $n1_i$ and $n2_i$ is the number of animals retained for the experiment and control, respectively.

Retention and at-haulback mortality rates were estimated using the "metafor" package (Viechtbauer, 2010) in R 3.5.1 (R Core Team, 2018) for each species. The RR value is log-transformed to normalize the distribution of effect sizes around zero and to meet the assumption of normality for the analysis. A summary effect size was computed for all taxa that had at least two experiment IDs. For this preliminary analysis, experiments with low sample size and large confidence intervals on the RR were excluded. A two-sided Wald-type Z test was used to test for differences between effects mean and zero. Effect sizes were estimated using a random effects model. The random effects model computes a global mean effect size based on a weighted mean of the studies' effect sizes. Weights were computed as the inverse of the sample variance and the between-study variance (τ2). Sample variance, v_i, for ln(RR) of the ith experiment was calculated as:

Vi=1ai-1n1i+1ci-1n2i

For the validation procedure, we used a multiple step approach. The first step was to calculate and test the heterogeneity (I^2) value, which represents the extent to which effect sizes vary within the meta-analysis. Values of I^2 vary from 0% to 100%, with higher values indicating greater heterogeneity between experiments. High values of I^2 can be problematic from a statistic point of view as they might mean that there are two or more subgroups of studies present in the data, which would have a different true effect; in such cases, it might be problematic to calculate and report pooled effects (Borenstein *et al*. 2011).

The second step was to search and detect possible outliers. The method used was to define any study as an outlier if such study confidence intervals do not overlap with the confidence intervals of the pooled effect calculated from the meta-analysis. Finally, the third and final step was to use influence analysis. For this, several values were estimated and are presented, with each representing different influence measures. This type of influence analysis has been described by Viechtbauer and Cheung (2010), and the outcomes should be analyzed in a comparative way. As a general rule, influential cases are studies that present consistently very extreme values in all or several of those measurements, that represent the following:

- Dffits: Represents in standard deviations how much the predicted pooled effect changes after excluding each individual study;
- Cook's distance: Calculated as the distance between the value once the study is included compared to when it is excluded;
- Covariance ratio (cov.r): It is the determinant of the variance-covariance matrix of the parameter estimates when the study is removed, divided by the determinant of the variance-covariance matrix of the parameter estimates when the full dataset is considered. Values of cov.r < 1 indicate that removing the study will lead to a more precise effect size estimation (i.e., less heterogeneity).

For the influence analysis we also used the Baujat Plot analysis (Baujat *et al*. 2002), which is a diagnostic to detect studies that are overly contributing to the heterogeneity of a meta-analysis versus their influence in the final estimations. The plots show specifically the contribution of each study to the overall heterogeneity measured by Cochran's Q on the horizontal-axis, and its influence on the pooled effect size on the vertical-axis (Baujat *et al*. 2002). Studies represented in the on the right side are the main contributors to the heterogeneity observed, and it is even more significant if at the same time such studies are small contributors to the overall pooled effect, as in those cases they most likely have very low sample sizes. Finally, we used a Leave-One-Out-method, in which the meta-analysis is re-calculated K-1 times, each time leaving out one study (with k=number of studies available). This is then analyzed in terms of the overall gains in homogeneity, as well as changes in the final model estimations.

3. Results

For data compilation, in total 36 unique references were identified, totaling 55 experiments (**Table 1**). For this analysis, 25 references were available, totaling 31 experiments, as studies comparing "tuna hooks" have not been used. At this point, retention and at-haulback mortality rates analyses between hook, bait and leader type were performed for swordfish, blue shark and loggerhead sea turtle.

3.1. Shallow setting - Retention rates

3.1.1. Hook type

Swordfish had lower retention rates on circle hooks when compared to J-hooks. When all data is used, the RR is calculated at 0.82 (95% CIs: 0.73-0.94), which means that the retention of swordfish decreases by 18% when using circle hooks, with 95% confidence intervals varying between reductions of 6% and 27% (**Figure 1**). In this specific analysis using all available experiments we also see that the overall heterogeneity is very high, failing the statistical assumption of homogeneity (p-value<0.05). Results of the validation with search for possible outliers and influence analysis indicated that some experiments are identified in several of the diagnostics, as for example studies 24, 26 and 32, but their influence was not identified at a sufficient level to exclude them (**Figure 2**). It is also shown that experiment 15 is a large contributor to the heterogeneity, while at the same time not contributing too much for the pooled results; however, when excluding that specific experiment the heterogeneity would only decrease from 100% to 98%, which means that there is not a strong reason to exclude that experiment. This is confirmed by the leave-one-out-analysis, that shows that the overall heterogeneity and estimation would not change that much if that experiment is excluded.

For blue shark, when all experiments are considered, the RR is calculated at 1.08 (95% CIs: 0.89-1.33) (**Figure 3**). This means that the retention rate of blue shark when using circle hooks is 8% higher than when using J hooks, but with 95% confidence intervals varying between a reduction of 11% and an increase of 33%. In this specific analysis, considering all experiments, the overall heterogeneity is very high and fails the statistical assumption of homogeneity (p-value<0.05). The validation procedure demonstrated that some experiments are consistently identified in several of the diagnostics, for example experiments 24, 26 and 47 (**Figure 4**). Within those, experiments 26 and 47 specifically have very low sample sizes and therefore very large confidence intervals, but also due to their low sample size have a very low weight and contribution to the final estimation. With regards to experiment 24, it is a large contributor to the overall heterogeneity but is also an experiment with a very large sample size, and as such it has a relatively large influence in the final estimation. Even though some of those experiments can represent outliers for the analysis, overall, their influence does not seem to be sufficient to exclude them from the final analysis and estimation. This seems to be confirmed by the leave-one-out-analysis, that shows that the overall heterogeneity and estimation would not change that much if those experiments were excluded.

Loggerhead sea turtles demonstrated lower retention rates on circle hooks when compared to J-hooks. When all data is used, the RR is calculated at 0.47 (95% CIs: 0-34-0.63). This means that the retention rate of loggerhead sea turtles when using circle hooks is 53% lower than when using J-hooks, with 95% confidence intervals varying between a reduction of 37% and 66% (**Figure 5**). The validation analysis identified one particular outlier experiment that can be considered for exclusion, namely experriment15 (**Figure 6**). The analysis was therefore re-run excluding that experiment. The final analysis showed a retention reduction of 47% (RR=0.53; 95% CIs:0.42-0.67) when using circle hooks (**Figure 7**). The heterogeneity between studies was reduced from 86% to 75% by excluding experiment 15. The new validation is shown in **Figure 8**.

3.1.2 Bait type

In the specific case of swordfish, when all data is used, the RR is calculated at 1.00 (95% CIs: 0.80-1.25), which means that changing from squid bait to fish bait does not change the retention of SWO, with 95% confidence intervals varying between reductions of 20% and increases of 25% in retention (**Figure 9**). In this specific analysis the overall heterogeneity is very high and fails the statistical assumption of homogeneity (p-value<0.05). The results of the validation process are represented in **Figure 10**. Some experiments are identified in several of the diagnostics, as for example experiment 15, 42, 43 and 50, but their influence was not identified at a sufficient level to exclude them. Experiments 50 and 42 are large contributors to the heterogeneity while at the same not contributing too much for the pooled results; however, when excluding each one of those specific studies the heterogeneity would only decrease from 98% to 96%, which means that there is not a strong reason to exclude those experiments. This is confirmed by the leave-one-out-analysis, that shows that the overall heterogeneity and estimation would not change that much if those experiments were excluded.

For blue shark, considering all experiments, the RR is calculated at 1.07 (95% CIs: 0.70-1.63), meaning that the retention of blue shark when using fish bait is 7% higher than when using squid bait, but with 95% confidence intervals varying between a reduction of 30% and an increase of 63% in retention (**Figure 11**). The overall heterogeneity is very high and fails the statistical assumption of homogeneity (p-value<0.05). The validation process showed that some experiments are consistently identified in several of the diagnostics, for example experiments30 and 50 (**Figure 12**). Those studies are large contributors to the overall heterogeneity but are also studies with large sample size, and as such they have a relatively large influence in the final estimation. Even though those studies can represent outliers for the analysis, overall, their influence does not seem to be sufficient to exclude them from the final analysis and estimation. This seems to be confirmed by the leave-one-out-analysis, that shows that the overall heterogeneity and estimation would not change that much if those studies were excluded.

For the loggerhead sea turtle, **Figure 13** shows the model when all experiments compiled are used. In this case the RR is calculated at 0.23 (95% CIs: 0.15.0.38). This means that the retention of loggerhead sea turtles when using fish bait is 77% lower than when using squid bait, with 95% confidence intervals varying between a reduction of 62% and 85%. The overall heterogeneity is high (70%) and fails the statistical assumption of homogeneity (p-value<0.05). Some experiments are identified in several of the diagnostics, for example experiments 15, 42 and 50 (**Figure 14**). Removing experiment 15 would reduce the overall heterogeneity from 70% to 28% (p>0.05) and the RR estimation would slightly change from 0.23 (95% CIs: 0.18-0.42) to 0.27 (CIs: 0.18- 0.42), as can be seen by the leave-one-out-analysis.

3.1.3 Leader type

For swordfish, when all experiments are used when comparing nylon and wire leaders, the RR is calculated at 0.87 (95% CIs: 0.67-1.13) (**Figure 15**). This means that changing from nylon leader to wire leader would lead to a decrease in retention of swordfish, although not significant, with 95% confidence intervals varying between reductions of 33% and increases of 13% in retention. In this specific analysis the overall heterogeneity is fairly low (48%) and does not fail the statistical assumption of homogeneity (p-value>0.05). The results of the validation process are represented in **Figure 16**. Experiments 51 and 52 are identified in several of the diagnostics as possible outliers, however in this case as only three studies are available, removing the possible outliers would hinder the meta-analysis as only two studies would remain.

Regarding blue shark, changing from nylon to wire leaders would lead to an increase in retention of 46%, with 95% confidence intervals varying between increases of 11% and 93% (RR=1.46; 95% CIs: 1.11-1.93) (**Figure 17**). The results of the validation with search for possible outliers and influence analysis is represented in **Figure 18**. Like in the case of swordfish, possible outliers were identified (experiments 51 and 52) however were not excluded from the analysis.

It was not possible to conduct a meta-analysis for retention rates of loggerhead sea turtle regarding changes in leader type, as there is only one experiment available that reported this data. In this experiment (experiment 52), 8 loggerhead sea turtles were caught with nylon leaders (out of 47600 nylon leaders) and 2 with wire leaders (out of 47600 wire leaders).

3.2. Shallow setting - At-haulback mortality rates

3.2.1. Hook type

For swordfish, results with all experiments included pointed to a decrease of 6% in at-haulback mortality rates when using circle hooks, with 95% confidence intervals varying between reductions of 1% and 11% (RR=0.94; 95% CIs:0.89-0.99) (**Figure 19**). In this case, the influence analysis that followed (**Figure 20**) identified 2 experiments (24 and 42) that are outliers with significant leverage and as such could be considered to be deleted from the pooled analysis. The analysis was therefore re-run excluding those 2 experiments, with the results of the new pooled analysis indicated in **Figure 21** and validation indicated in **Figure 22**. With the exclusion of those 2 outliers, the heterogeneity was largely reduced, specifically from 97% when including all studies to 73% with those 2 exclusions. On the other hand, the pooled analysis results did not change by much as results indicated a reduction of also 6% with slightly different CIs (RR=0.94; 95% CIs: 0.89-0.98).

For blue shark, when all experiments are considered, the RR is calculated at 0.80 (95% CIs: 0.63-1.01), meaning that at-haulback mortality of blue shark when using circle hooks is 20% lower than when using J-hooks, with 95% confidence intervals varying between a reduction of 37% and an increase of 1% (**Figure 23**). Again, the heterogeneity between studies is high, with p-value <0.05. In terms of the influential analysis (**Figure 24**), experiment 24 was identified in several diagnostics as a large contributor to the overall heterogeneity but also important and with some weight in the final estimation. In this specific case, if experiment 24 was removed the overall heterogeneity would be reduced from 94% to 55%, which is an important decrease. The final RR estimation would then change from 0.80 (CIs: 0.63-1.01) to 0.75 (CIs: 0.59-0.95).

With regards to the loggerhead sea-turtle, when changing hook type from J to circle, there is a 12% increase in at-haulback mortality rate (RR=1.12; 95% CIs: 0.61-2.08), but this increase is not statistically significant (**Figure 25**). In this specific analysis there is no overall heterogeneity (I^2=0%). In the influence analysis, represented in **Figure 26**, some experiments are identified in several of the diagnostics. For example, experiment 50 has low contribution to the overall heterogeneity but is also a study with a very large sample size, and as such it has a large influence in the final estimation. Overall, the influence of any particular experiment does not seem to be sufficient to exclude them from the final analysis and estimation. This seems to be confirmed by the leave-one-out-analysis, that shows that the overall heterogeneity and estimation would not change that much if any experiment were excluded.

3.2.2. Bait type

In the specific case of swordfish, when all experiments are used, the RR is calculated at 1.02 (95% CIs: 0.99-1.05). This means that the al-haulback mortality rate increases by 2% when changing from squid bait to fish bait, with 95% confidence intervals varying between reductions of 1% and increases of 5% in retention (**Figure 27**). The influence analysis that followed (**Figure 28**) identified one experiment (experiment 42) that is an outlier with significant leverage and as such could be considered to be deleted from the pooled analysis. The analysis was therefore re-run excluding that study, with the results of the new pooled analysis indicated in **Figure 29** and validation indicated in **Figure 30**. With the exclusion of that outlier, the heterogeneity was largely reduced, specifically from 38% when including all studies to 0%. On the other hand, the pooled analysis results did not change by much (RR=1.03; 95% CIs: 1.02-1.05).

With regards to the at-haulback mortality of blue shark, the model considering all experiments is shown in **Figure 31**. In this case, the influence analysis that followed (**Figure 32**) identified one experiment (experiment 50) that is an outlier with a high overall contribution to the heterogeneity and influence on the pooled results. The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in **Figure 33** and validation indicated in **Figure 34**. With the exclusion of that outlier, the heterogeneity was largely reduced, specifically from 70% when including all studies to 50%, however the pooled analysis results also changed. The final RR estimation would then change from 1.71 (95%CIs: 1.39-2.11) to 1.80 (95% CIs: 1.35-2.45). This indicates that changing from squid bait to fish bait has a significant increase in the at-haulback mortality of blue shark.

In the specific case of loggerhead sea turtle, RR is calculated at 1.25 (95% CIs: 0.24-6.62), suggesting that there is no significant effect of changing bait type in the at-haulback mortality of the loggerhead sea turtle (**Figure 35**). In this specific analysis there is no overall heterogeneity (I^2=0%). The results of the validation with search for possible outliers and influence analysis is represented in **Figure 36**. Overall, the influence of any particular experiment does not seem to be sufficient to exclude them from the final analysis and estimation. This seems to be confirmed by the leave-one-out-analysis, that shows that the overall heterogeneity and estimation would not change that much if any experiment were excluded.

3.2.3. Leader type

With regards to the effect of leader type on the at-haulback mortality of swordfish, only two experiments were available (experiment 51 and 52), so the meta-analysis was not conducted. Experiment51 shows a decrease in the at-haulback mortality of swordfish when using wire leaders (RR=0.87; 95% CIs: 0.80-0.93), while experiment 52 indicated there are no differences in the at-haulback mortality (RR=0.99; 95% CIs:0.95-1.04).

With regards to the effect of leader type on the at-haulback mortality of blue shark, when changing from nylon to wire leaders the RR is calculated at 0.88 (95% CIs: 0.66-1.17), meaning that changing from nylon to wire leaders would decrease the at-haulback mortality by 22%, but with 95% confidence intervals varying between reductions of 34% and increases of 17% in at-haulback mortality (**Figure 37**). In this specific analysis there is no overall heterogeneity (I^2=0%). The influence analysis is represented in **Figure 38**. For this case no particular experiment seems to be an outlier and removing any of them would not lead to a change in the overall heterogeneity nor in the RR estimations, as can be seen by the leave-one-out-analysis.

It was not possible to conduct a meta-analysis for at-haulback mortality rates for loggerhead sea turtle regarding changes in leader type, as there is only one study available that reported this data. In this experiment (experiment 52), 8 loggerhead sea turtles were caught with nylon leaders (out of 47600 nylon leaders) and 2 with wire leaders (out of 47600 wire leaders) and none suffered at-haulback mortality.

3.3. Deep setting

Only three studies compared circle and J-hooks when using deep-set pelagic longline and reported retention. The only species for which it was possible to conduct a meta-analysis was yellowfin tuna, that was reported by the three studies. Regarding retention rate of yellowfin tuna, when changing from J-hooks to circle hooks the RR is calculated at 0.69 (95% CI: 0.08-5.93) (**Figure 39**), suggesting that there is no significant effect of changing hook type in the retention of yellowfin tuna. In this specific analysis, the overall heterogeneity is relatively low and does not fail the statistical assumption of homogeneity (p-value>0.05). The results of the validation with search for possible outliers and influence analysis is represented in **Figure 40**. Experiment 6 is identified in several of the diagnostics as a possible outlier, however in this case as only three studies are available, removing this study would hinder the meta-analysis as only two studies would remain. Additionally, experiment 50 has a low weight on the pooled result, while it is the study that contributed more to the overall heterogeneity. Removing this study would lead to a decrease in the overall heterogeneity and a slight change in the RR point estimate.

For at-haulback mortality no meta-analysis was conducted given that only one study is available.

4. Discussion

4.1. Retention rates

The main results of our study are that loggerhead sea turtles interactions seem to be reduced when J-hooks are changed to circle hooks. For swordfish, the main target species of shallow pelagic longlines, there were also reductions in retention rates when using circle instead of J-hooks.

Bait type did not seem to have a major influence on the retention rates of swordfish and blue shark. For the loggerhead sea turtle, interactions were lower when the bait used was fish.

Regarding leader type, changing from nylon to wire leaders leads to a decrease in retention of swordfish. For blue sharks there is a significant increase in retention rate when using wire leaders. It was not possible to compare the retention rates of the loggerhead sea turtle by leader type as not enough information was available.

There were only three studies using deep setting longlines that compared circle and J-hooks and reported retention. As such, the only species for which it was possible to conduct a meta-analysis was yellowfin tuna. The meta-analysis suggested that there is no significant effect of changing hook type in the retention of yellowfin tuna.

4.2. At-haulback mortality rates

Changing from J-hooks to circle hooks significantly decreased at-haulback mortality rates of blue shark. Regarding swordfish, there was a tendency for lower at-haulback mortality rates when circle hooks were used.

Bait type had no significant effect on at-haulback mortality rates, except for blue shark, in which case changing from squid bait to fish bait has a significant increase in at-haulback mortality.

Few studies are available comparing at-haulback mortality by leader type, therefore it was only possible to conduct this analysis for blue shark, with at-haulback mortality rate not significantly influenced when changing leader type.

For deep setting studies no meta-analysis was conducted given that only one study is available.

4.3. Final remarks

This study is looking at retention rates, as it is not possible to know the true catch of the gear. It is known that bite-offs occur, especially in monofilament leaders, however it is very difficult to ascertain which species has bitten off the leader and escaped. Also, only at-haulback mortality is being analysed so there is the need to estimate what are the effects of changing hook type on post-release mortality. On one hand, J-hooks tend to deep hook the specimens more than circle hooks, which could imply that post-release mortality due to internal injuries would be higher. On the other hand, sharks or other species caught on J-hooks that are able to bite-off and escape, spend much less time hooked (lower retention times), which in this case would likely imply a higher survival rate. As such, it is very difficult to estimate what could be the implications on the post-release mortality of using one hook type versus the other, especially on specimens that can bite-off the line and escape when using J-hooks.

It is important to note that the results presented here are part of an ongoing study. Here we focus only on some of the main species with regards to shallow pelagic longline, however other important species and types of gear are also being analysed in the future. We highlight that for some species only few studies are available, therefore the data used does not allow for strong conclusions, especially when analysing bait and leader type effects. More experimental studies are needed, especially for the rarer species with low sample sizes. Further work will, if possible, expand on the fishery characteristics considered (e.g. include tuna hooks).

5. Acknowledgments

This study is part of the EU project "*Evaluation of the effects of hooks' shape & size on the catchability, yields and mortality of target and by-catch species, in the Atlantic Ocean and adjacent seas surface longline fisheries*", within the Framework Contract (FWC) EASME/EMFF/2016/008 for the "*Provision of scientific advice for fisheries beyond EU waters*". The information reported in this paper are those of the authors and do not necessarily reflect the official opinion of EASME or the EU Commission. Neither EASME nor the EU Commission can guarantee the accuracy of the data included in this study. Neither EASME nor the EU Commission or any person acting on their behalf may be held responsible for the use which may be made of the information contained therein. C. C. Santos and D. Rosa are supported by FCT Doctoral grants (Ref: SFRH/BD/139187/2018 and SFRH/BD/136074/2018).

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Table 1. List of references that is being used for the meta-analysis. Each specific reference (Ref.) can have several experiments (Exp.) described.

Ref.	Exp.	Bibliographic reference
1	1 – 5	Bolten, A.B. & Bjorndal, K.A. (2005). Experiment to Evaluate Gear Modification on Rates of Sea Turtle Bycatch in the Swordfish Longline Fishery in the Azores-Phase 4. Final project report NOAA Award Number NA03NFM4540204. 21p.
2	6	Largacha, E., Parrales, M., Rendon, L., Velasquez, V., Orozco, M. & Hall, M (2005). Working with the Ecuadorian fishing community to reduce the mortality of sea turtles in longlines: The First Year, March 2004-March 2005. Project Report. 66p.
3	7	Kim, S.-S., Moon, D.-Y., Boggs, C.H., Koh, J.-R. & Hae An, D. (2006). Comparison of circle hook and J-hook catch rate for target and bycatch species taken in the Korean tuna longline fishery. *Journal of Korean Society and Fisheries Technology*, 42:210-216.
4	8 - 9	Yokota, K., Kiyota, M. & Minami, H. (2006). Shark catch in a pelagic longline fishery: Comparison of circle and tuna hooks. *Fisheries Research*, 81:337-341.
5	10 - 14	Boggs, C. H. & Swimmer, Y. (2007). Developments (2006-2007) in scientific research on the use of modified fishing gear to reduce longline bycatch of sea turtles. WCPFC document WCPFC-SC3-EB-SWG_WP-7. 9p.
6	15	Gilman, E., Kobayashi, D., Swenarton, T., Brothers, N, Dalzell, P. & Kinan-Kelly, I. (2007). Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. *Biological Conservation*, 139:19-28.
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12	21	Afonso, A.S., Hazin, F.H.V., Carvalho, F., Pacheco, J.C., Hazin, H., Kerstetter, D.W., Murie, D. & Burgess, G.H. (2011). Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research*, 108:336-343.
13	22 - 23	Curran, D. & Bigelow, K. (2011). Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. *Fisheries Research*, 109:265-275.
14	24	NMFS (2011). Southeast Fisheries Science Center Pelagic Observer Program Data. Miami, FL: Southeast Fisheries Science Center. Unpublished raw data.
15	25	Pacheco, J. C., Kerstetter, D. W., Hazin, F. H., Hazin, H., Segundo, R. S., Graves, J. E. & Travassos, P. E. (2011). A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. *Fisheries Research*, 107:39-45.
16	26	Cambiè, G., Muiño, R., Freire, J. & Mingozzi, T. (2012). Effects of small (13/0) circle hooks on loggerhead sea turtle bycatch in a small-scale, Italian pelagic longline fishery. *Bulletin of Marine Science*, 88:719-730.
17	27 - 28	Domingo, A., Pons, M., Jiménez, S., Miller, P., Barceló, C. & Swimmer, Y. (2012). Circle hook performance in the Uruguayan pelagic longline fishery. *Bulletin of Marine Science*, 88:499–511.

18	29	Epperly, S. P., Watson, J. W., Foster, D. G. & Shah, A. K. (2012). Anatomical hooking location and condition of animals captured with pelagic longlines: The Grand Banks experiments 2002–2003. *Bulletin of Marine Science*, 88:513–527.
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21	34 - 40	Andraka, S., Mug, M., Hall, M., Pons, M., Pacheco, L., Parrales, M. & Vogel, N. (2013). Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the Eastern Pacific Ocean. *Biological Conservation*, 160:214–224.
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25	44	Vega, R. & Licandeo, R. (2009). The effect of American and Spanish longline systems on target and non-target species in the eastern South Pacific swordfish fishery. *Fisheries Research*, 98:22–32.
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27	47	Piovano, S., Swimmer, Y. & Giacoma, C. (2009). Are circle hooks effective in reducing incidental captures of loggerhead sea turtles in a Mediterranean longline fishery? *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19:779–785.
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30	49	Fernandez-Carvalho, J., Coelho, R., Santos, M. N. & Amorim, S. (2015). Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: Part II—Target, bycatch and discard fishes. *Fisheries Research*, 164:312-321.
31	50	Amorim, S., Santos, M. N., Coelho, R. & Fernandez-Carvalho, J. (2015). Effects of 17/0 circle hooks and bait on fish catches in a Southern Atlantic swordfish longline fishery. *Aquatic Conservation: Marine* and Freshwater ecosystems, 52:518–533.
32	50	Santos, M. N., Coelho, R., Fernandez-Carvalho, J. & Amorim, S. (2013). Effects of 17/0 circle hooks and bait on sea turtles bycatch in a Southern Atlantic swordfish longline fishery. *Aquatic Conservation: Marine and Freshwater ecosystems*, 23:732–744.
33	51	Santos, M. N., Lino, P.G. & Coelho, R. (2017). Effects of leader material on catches of shallow pelagic longline fisheries in the southwest Indian Ocean. *Fishery Bulletin*, 115:219–232.
34	52	Santos, M.N. & Coelho, R. (2016). LL-SHARKS - Mitigação das capturas de tubarões na pescaria de palangre de superfície. Final project report FCT reference 31-03-05-FEP-44.. 74p.
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36	53-55	Anon. (2008). Field study to assess some mitigation measures to reduce bycatch of marine turtles in surface longline fisheries.

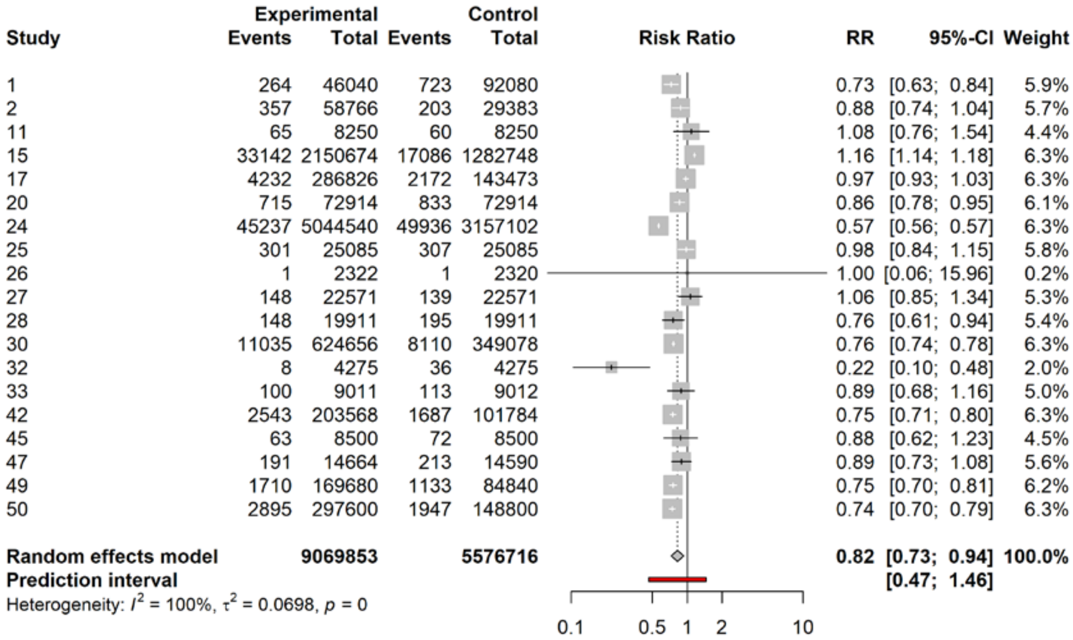

Figure 1. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish with circle vs J-hooks. (Note: control = J-hook; experimental = circle hook).

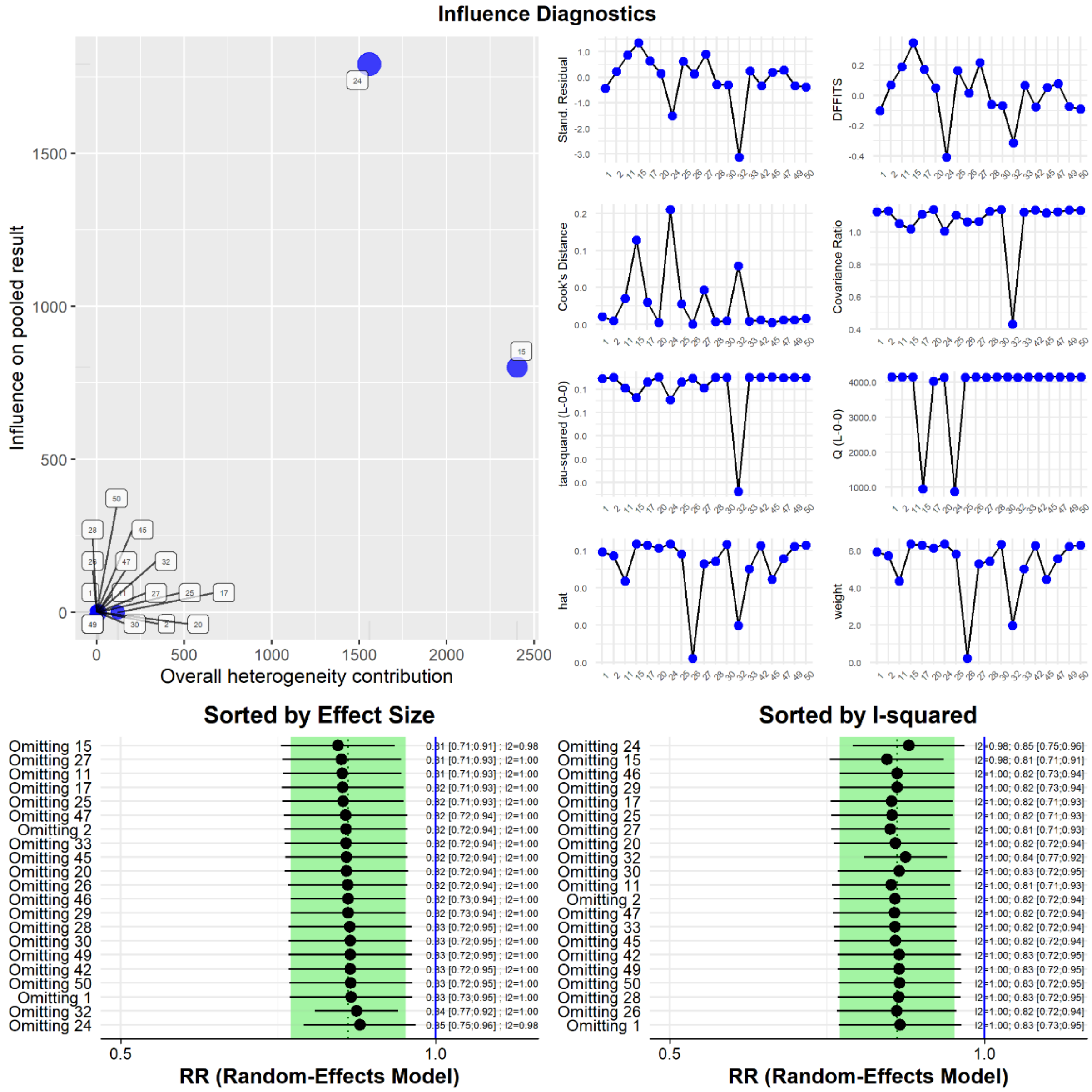

Figure 2. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish with circle vs J-hooks.

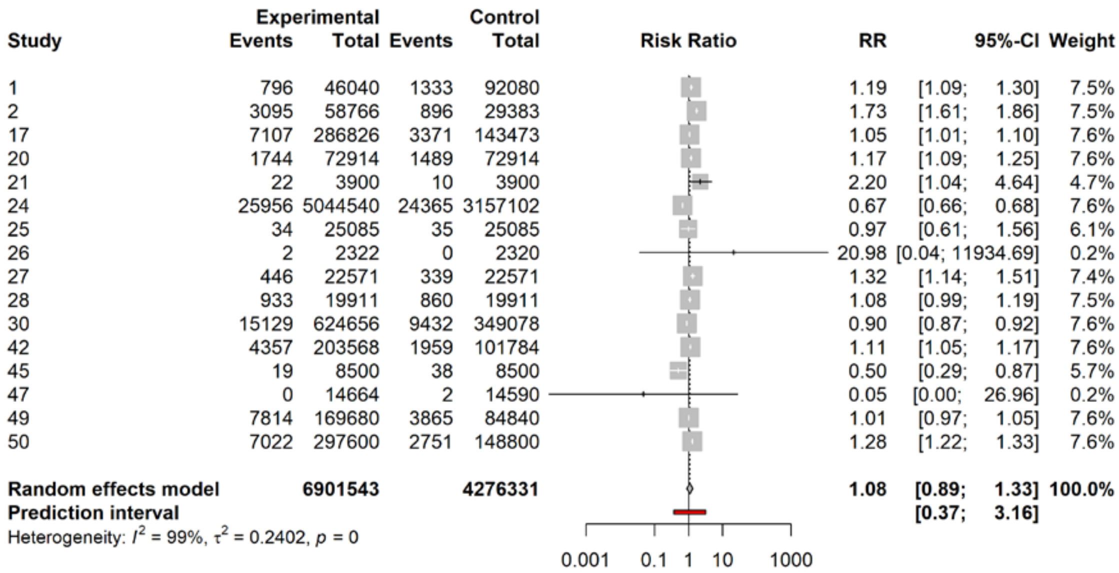

Figure 3. Forest plot of the random effects meta-analysis performed for the retention rates of blue shark with circle vs J-hook. (Note: control = J-hook; experimental = circle hook).

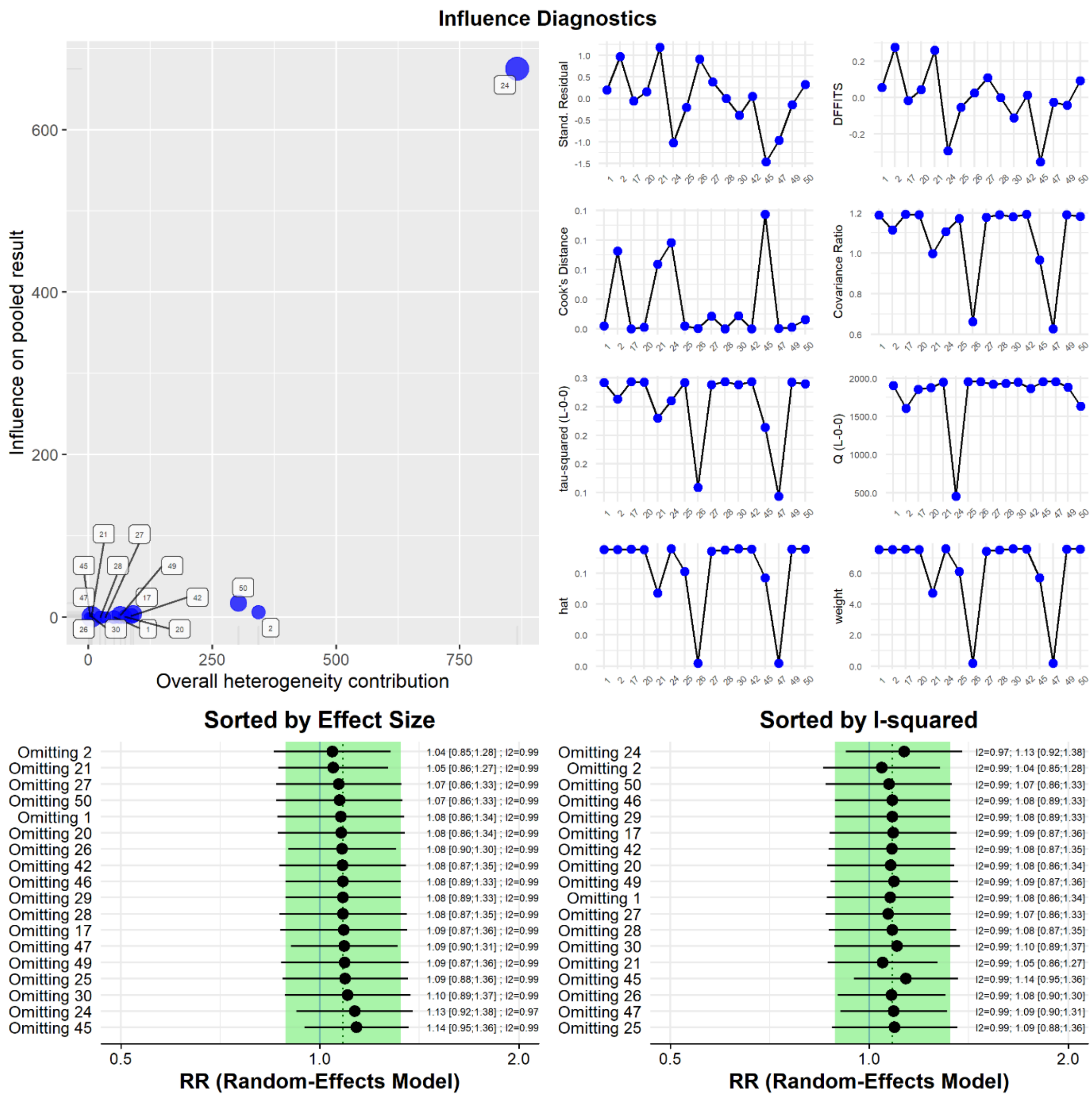

Figure 4. Influence analysis for validating the meta-analysis performed for the retention rates of blue shark with circle vs J-hooks.

Study	Experimental Events	Experimental Total	Control Events	Control Total	RR	95%-CI	Weight
1	85	46040	147	92080	1.16	[0.89; 1.51]	7.5%
2	30	58766	14	29383	1.07	[0.57; 2.02]	6.0%
10	3	10000	14	10000	0.21	[0.06; 0.75]	3.5%
12	11	37968	18	37968	0.61	[0.29; 1.29]	5.4%
15	27	2150674	182	1282748	0.09	[0.06; 0.13]	7.0%
17	86	286826	87	143473	0.49	[0.37; 0.67]	7.4%
20	53	72914	117	72914	0.45	[0.33; 0.63]	7.3%
24	329	5044540	504	3157102	0.41	[0.36; 0.47]	7.8%
26	9	2320	14	2322	0.64	[0.28; 1.48]	5.1%
27	11	22571	20	22571	0.55	[0.26; 1.15]	5.5%
28	36	19911	48	19911	0.75	[0.49; 1.15]	6.9%
30	41	325845	126	349078	0.35	[0.25; 0.50]	7.2%
31	2	13286	9	13287	0.22	[0.05; 1.03]	2.7%
36	0	11174	1	11195	0.09	[0.00; 59.00]	0.2%
42	3	203568	7	101784	0.21	[0.06; 0.83]	3.2%
47	6	14664	20	14590	0.30	[0.12; 0.74]	4.7%
49	10	169680	12	84840	0.42	[0.18; 0.96]	5.0%
50	122	297600	138	148800	0.44	[0.35; 0.56]	7.6%
Random effects model		**8788347**		**5594046**	**0.44**	**[0.32; 0.61]**	**100.0%**
Prediction interval						**[0.13; 1.52]**	

Heterogeneity: $I^2 = 87\%$, $\tau^2 = 0.3194$, $p < 0.01$

Figure 5. Forest plot of the random effects meta-analysis performed for the retention rates of loggerhead sea-turtles with circle vs J-hooks. (Note: control = J-hook; experimental = circle hooks).

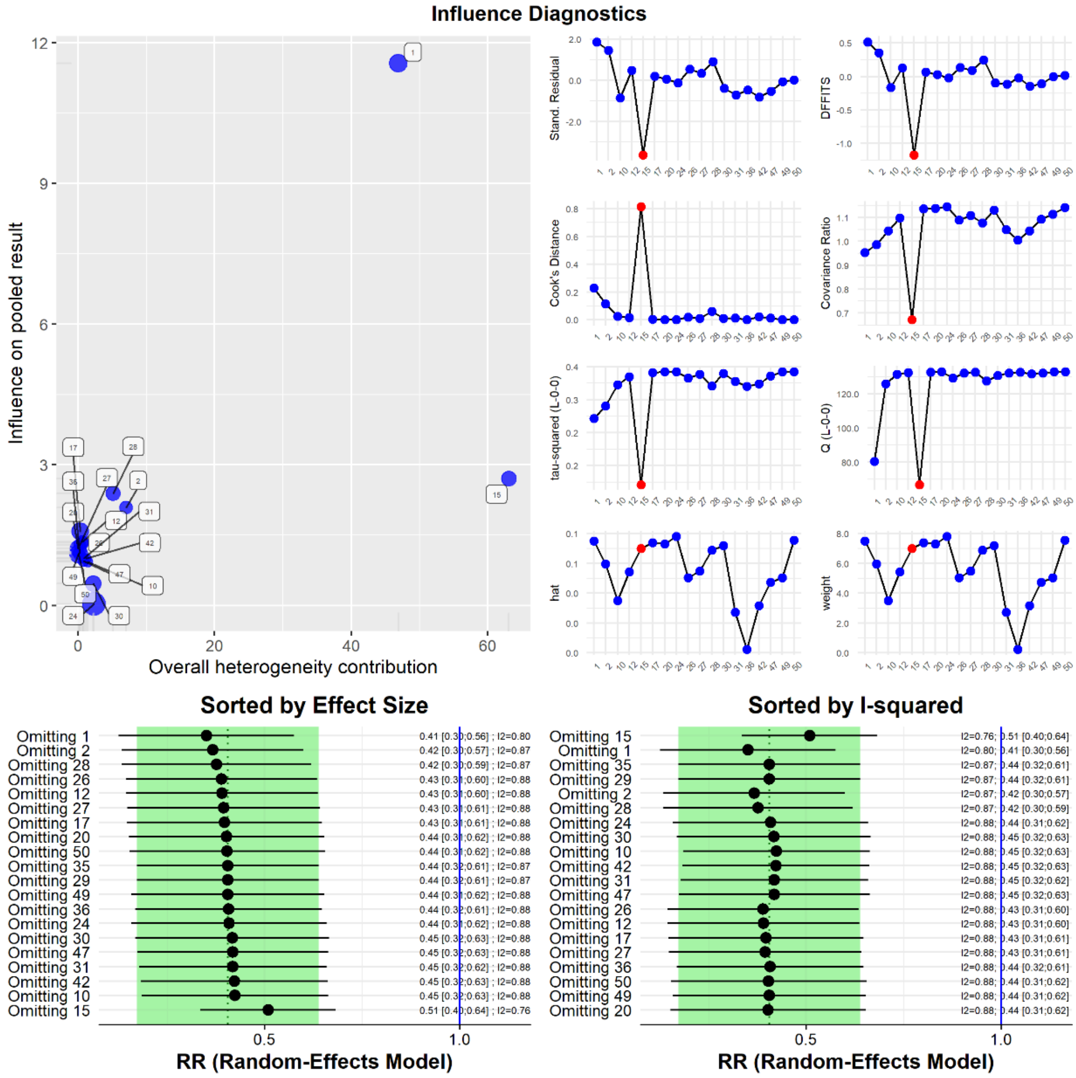

Figure 6. Influence analysis for validating the meta-analysis performed for the retention rates of loggerhead sea-turtles with circle vs J-hooks.

Study	Experimental Events	Experimental Total	Control Events	Control Total	RR	95%-CI	Weight
1	85	46040	147	92080	1.16	[0.89; 1.51]	9.0%
2	30	58766	14	29383	1.07	[0.57; 2.02]	6.2%
10	3	10000	14	10000	0.21	[0.06; 0.75]	3.0%
12	11	37968	18	37968	0.61	[0.29; 1.29]	5.4%
15	27	2150674	182	1282748	0.09	[0.06; 0.13]	0.0%
17	86	286826	87	143473	0.49	[0.37; 0.67]	8.8%
20	53	72914	117	72914	0.45	[0.33; 0.63]	8.6%
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29	40	.	126	.			0.0%
30	41	325845	126	349078	0.35	[0.25; 0.50]	8.4%
31	2	13286	9	13287	0.22	[0.05; 1.03]	2.2%
35	0	11930	0	12197			0.0%
36	0	11174	1	11195	0.09	[0.00; 59.00]	0.2%
42	3	203568	7	101784	0.21	[0.06; 0.83]	2.6%
47	6	14664	20	14590	0.30	[0.12; 0.74]	4.4%
49	10	169680	12	84840	0.42	[0.18; 0.96]	4.8%
50	122	297600	138	148800	0.44	[0.35; 0.56]	9.1%
Random effects model		**8800277**		**5606243**	**0.51**	**[0.40; 0.64]**	**100.0%**
Prediction interval						**[0.20; 1.26]**	

Heterogeneity: $I^2 = 76\%$, $\tau^2 = 0.1712$, $p < 0.01$

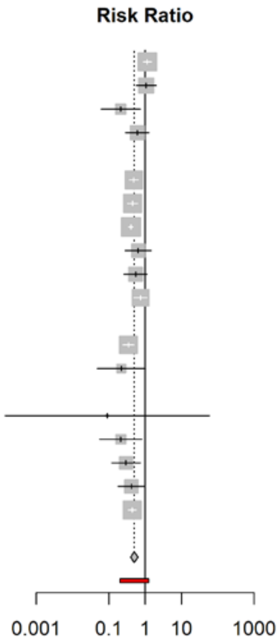

Figure 7. Forest plot of the random effects meta-analysis after excluding one outlier, performed for the retention rates of loggerhead sea-turtle with circle vs J- hooks. (Note: control = J-hook; experimental = circle hook). The study excluded is study 15, that is still shown in the plots but excluded from the analysis.

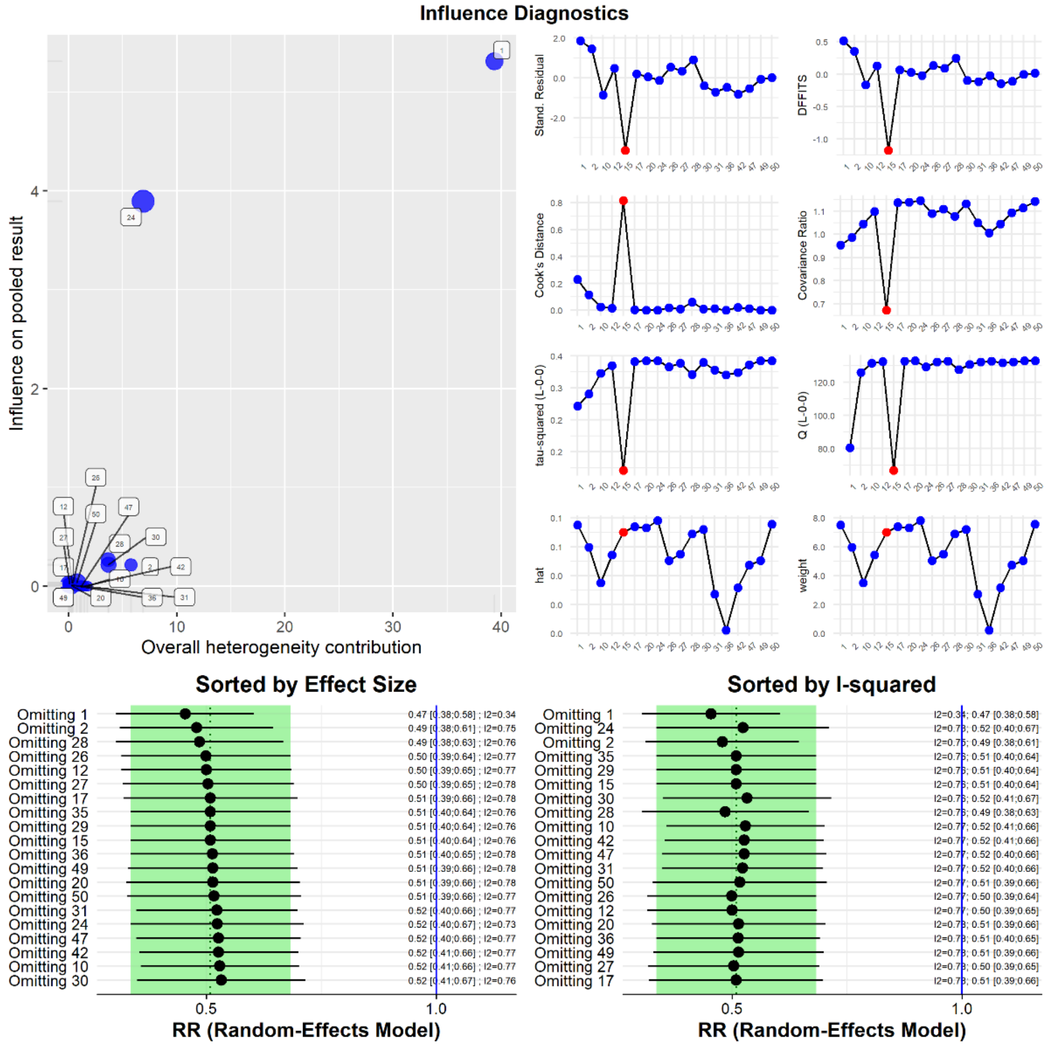

Figure 8. Influence analysis for validating the meta-analysis performed for the retention rates of loggerhead sea-turtle with circle vs J-hooks, after excluding one outlier study (study 15). The study excluded is still shown in the plots but is not included in the final meta-analysis.

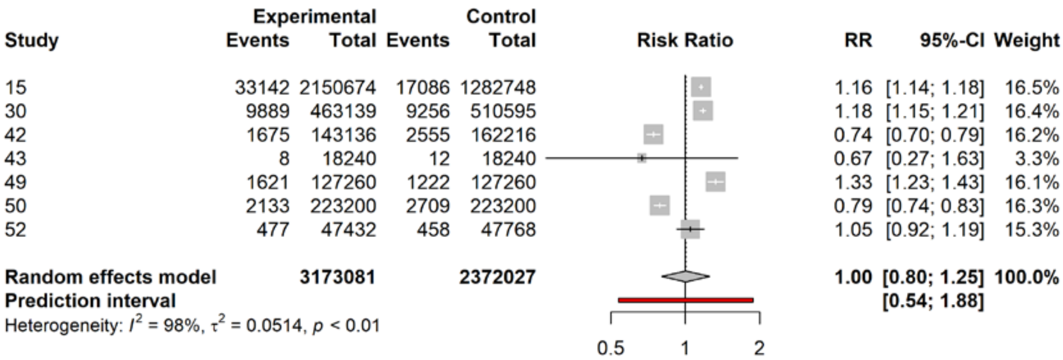

Figure 9. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish with fish vs squid bait. (Note: control = squid bait; experimental = fish bait).

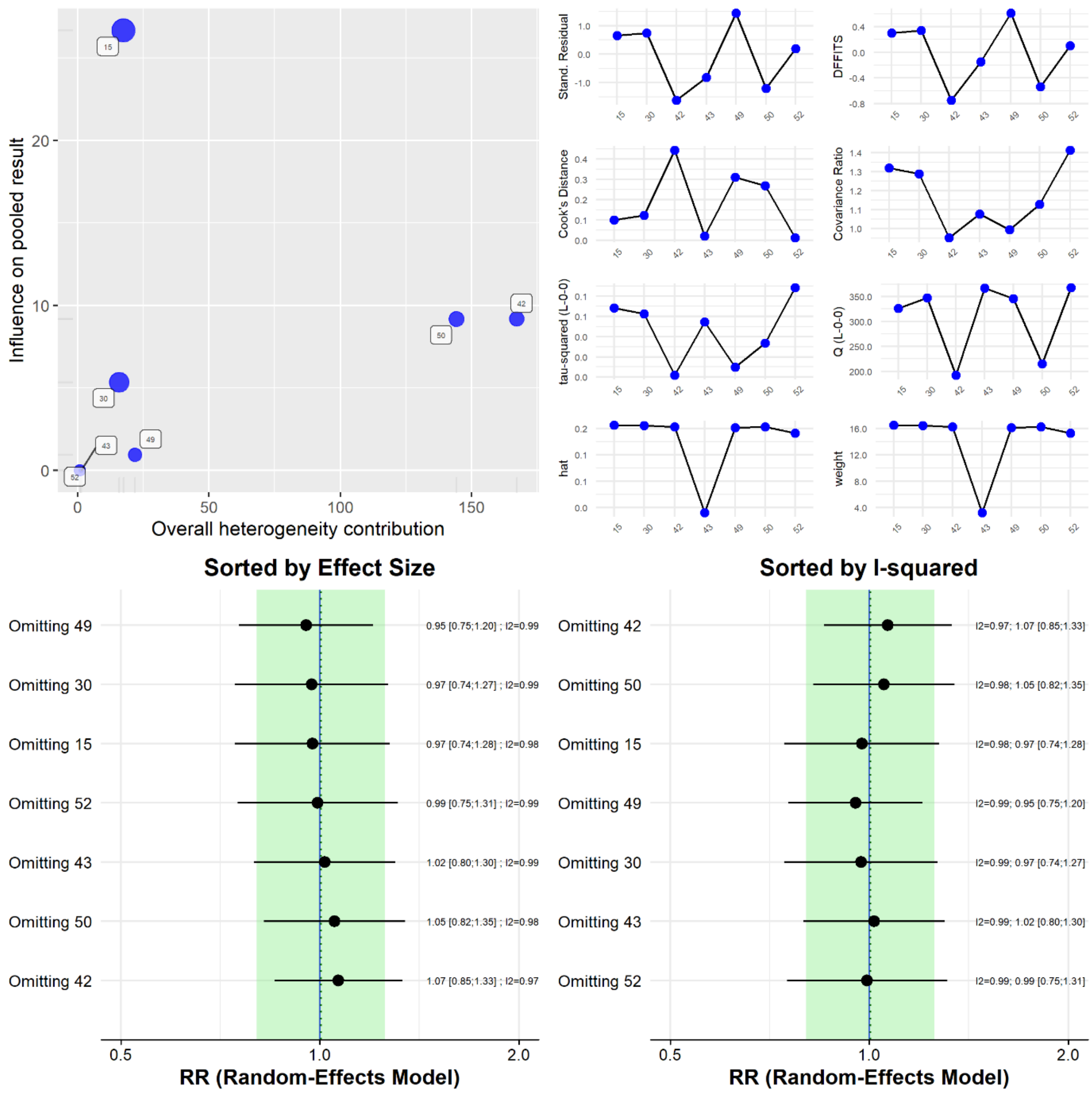

Figure 10. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish with fish vs squid bait. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

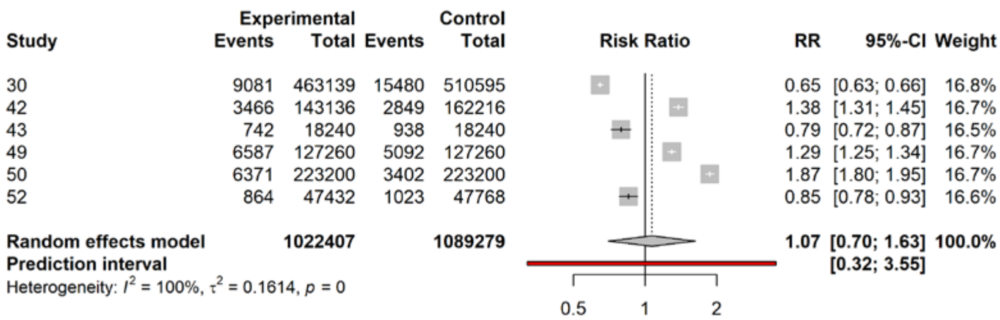

Figure 11. Forest plot of the random effects meta-analysis performed for the retention rates of blue shark with fish vs squid bait. (Note: control = fish bait; experimental = squid bait).

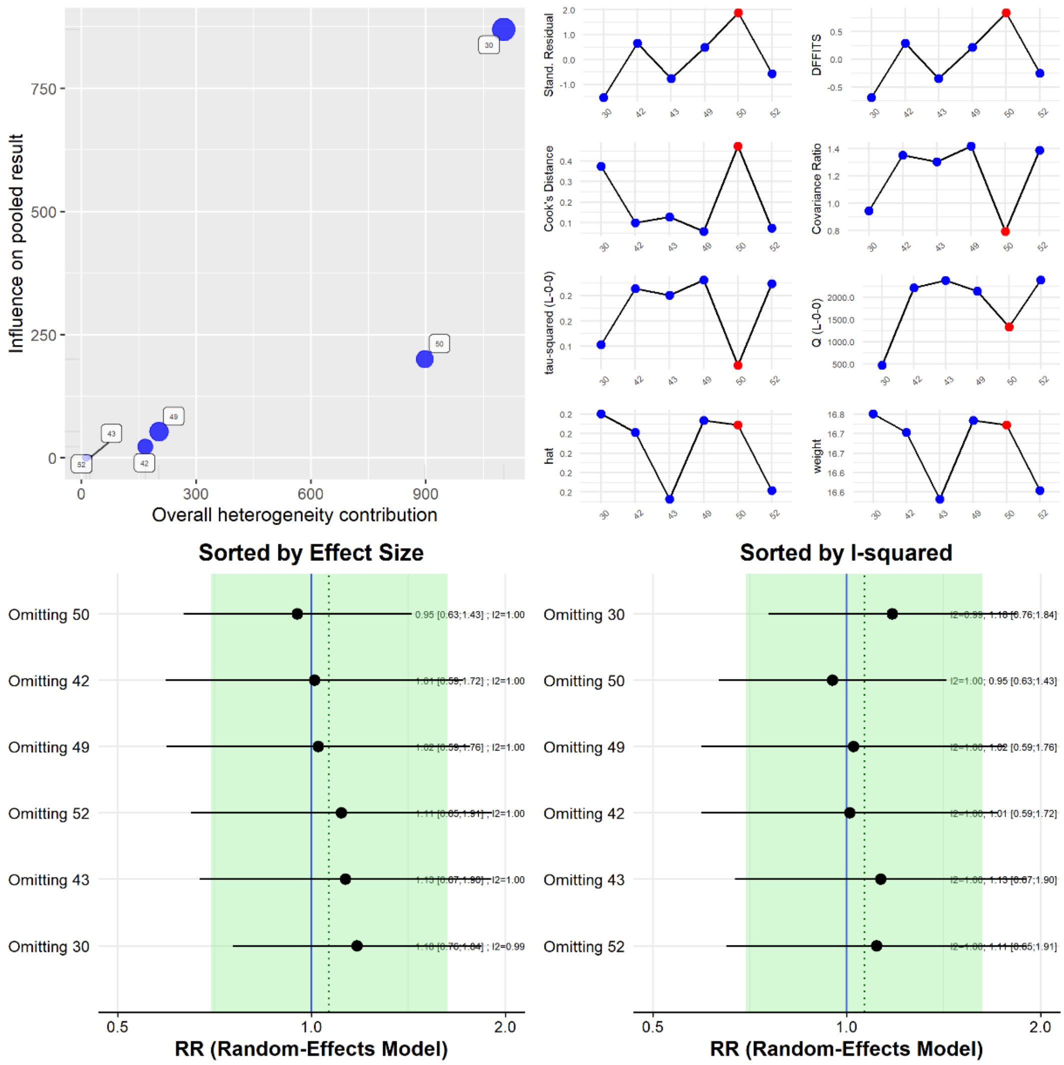

Figure 12. Influence analysis for validating the meta-analysis performed for the retention rates of blue shark with fish vs squid bait. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I2 (right).

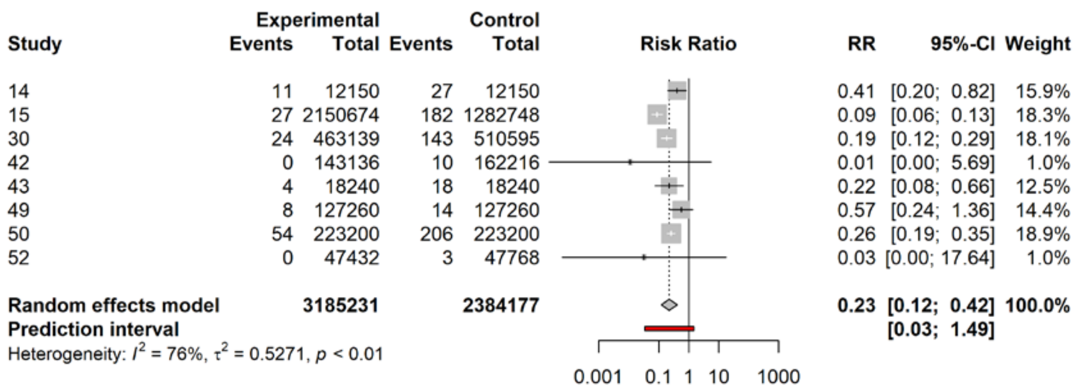

Figure 13. Forest plot of the random effects meta-analysis performed for the retention rates of loggerhead sea-turtles with fish vs squid bait. (Note: control = squid bait; experimental = fish bait).

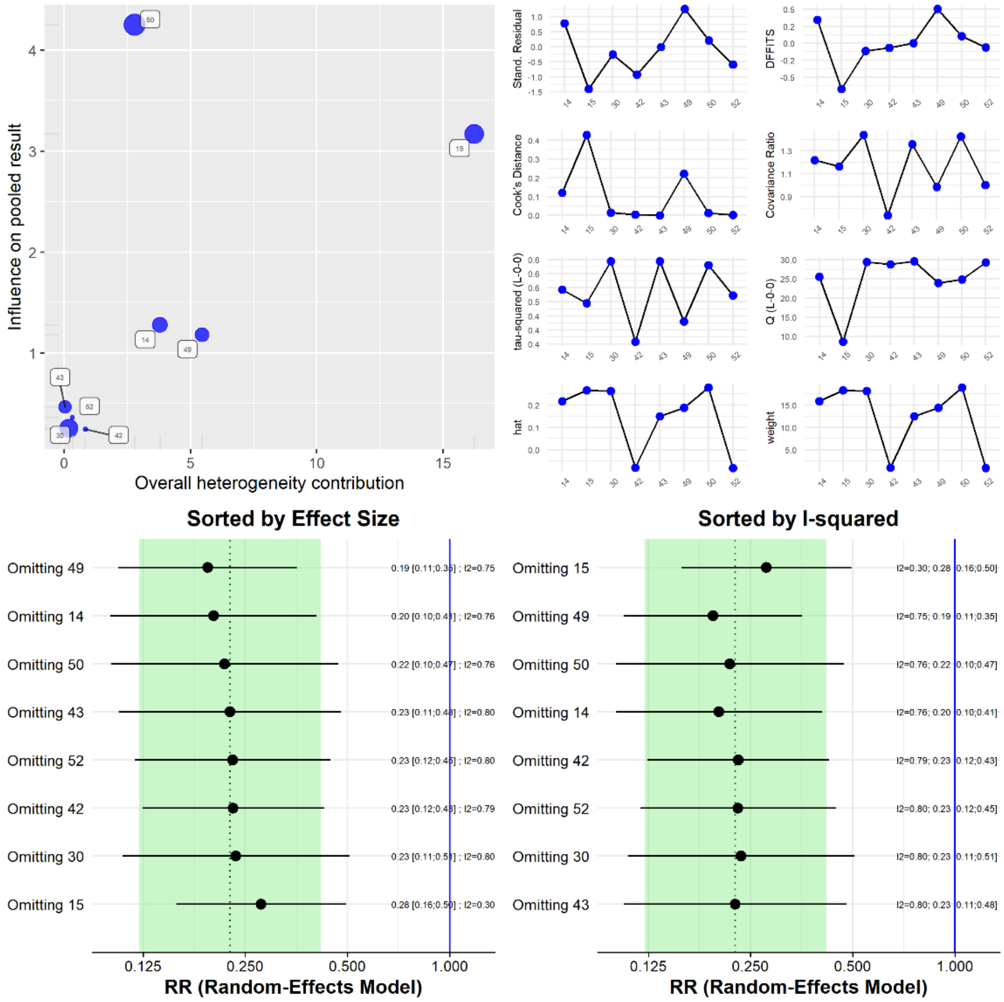

Figure 14. Influence analysis for validating the meta-analysis performed for the retention rates of loggerhead sea-turtles with fish vs squid bait. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

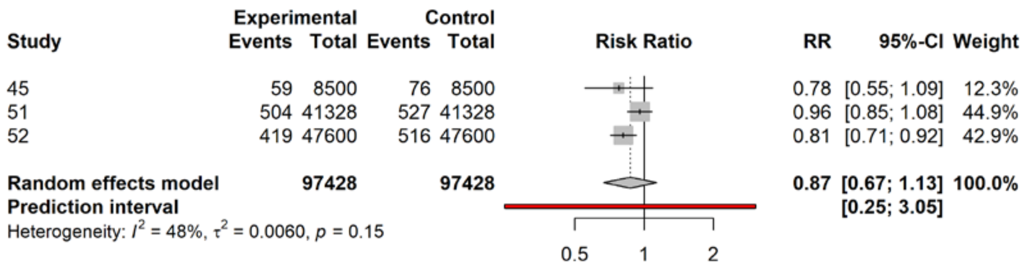

Figure 15. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish with wire vs nylon leader. (Note: control = nylon leader; experimental = wire leader).

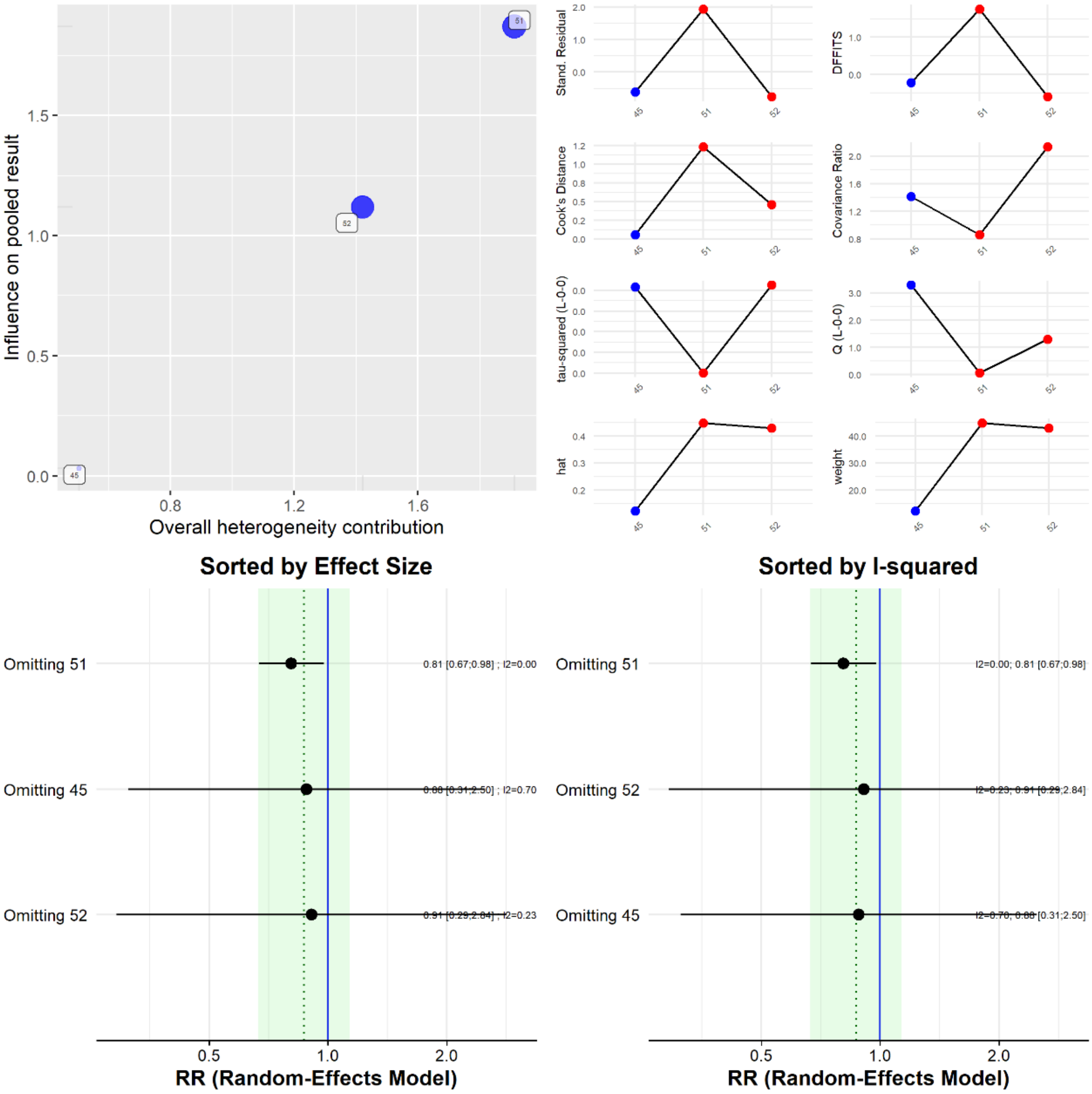

Figure 16. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish with wire vs nylon leader. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

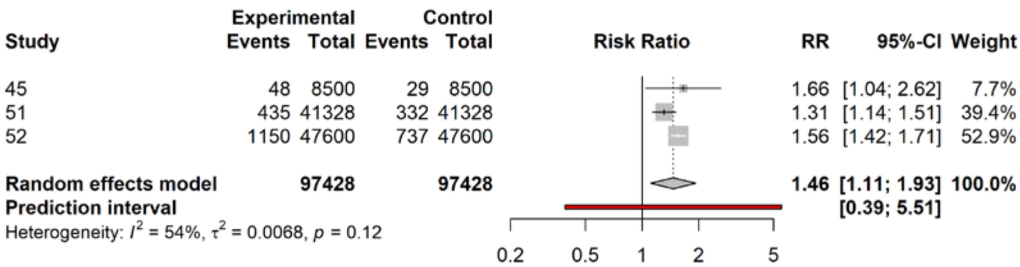

Figure 17. Forest plot of the random effects meta-analysis performed for the retention rates of blue shark with wire vs nylon leader. (Note: control = nylon leader; experimental = wire leader).

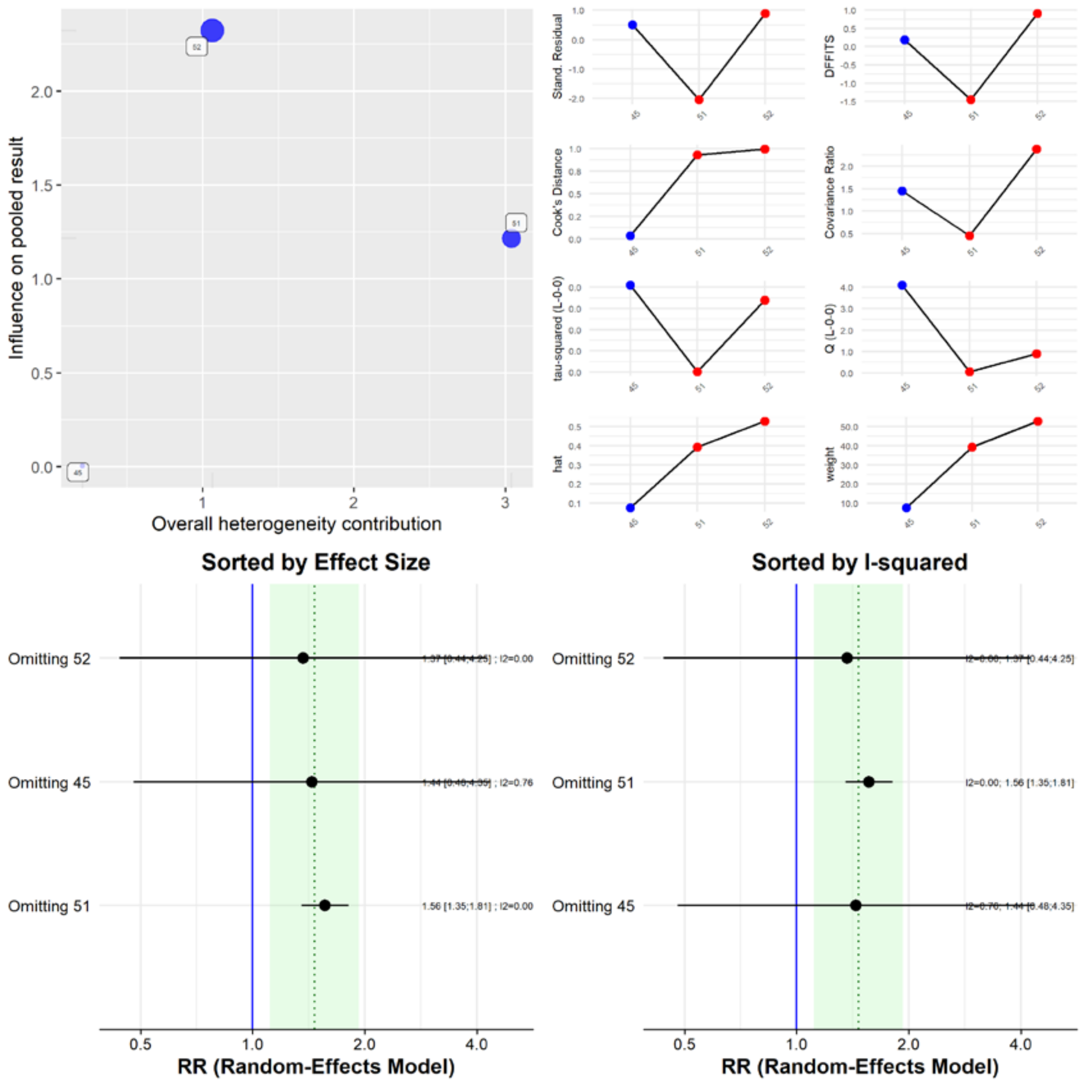

Figure 18. Influence analysis for validating the meta-analysis performed for the retention rates of blue shark with wire vs nylon leader. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

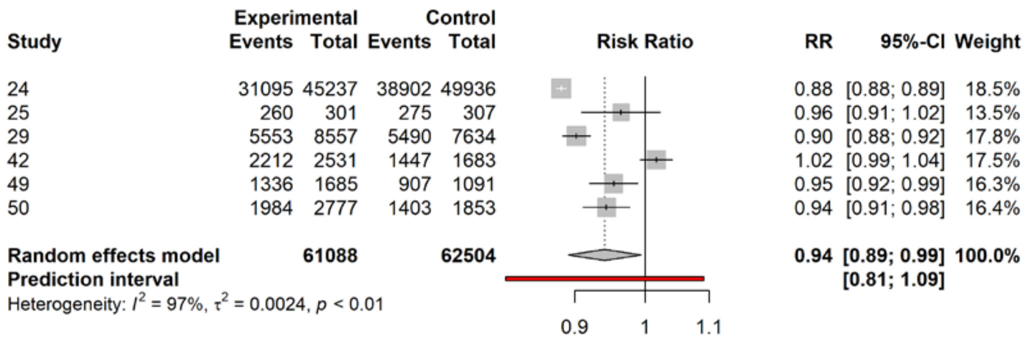

Figure 19. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of swordfish with circle vs J-hooks. (Note: control = J-hook; experimental = circle hook).

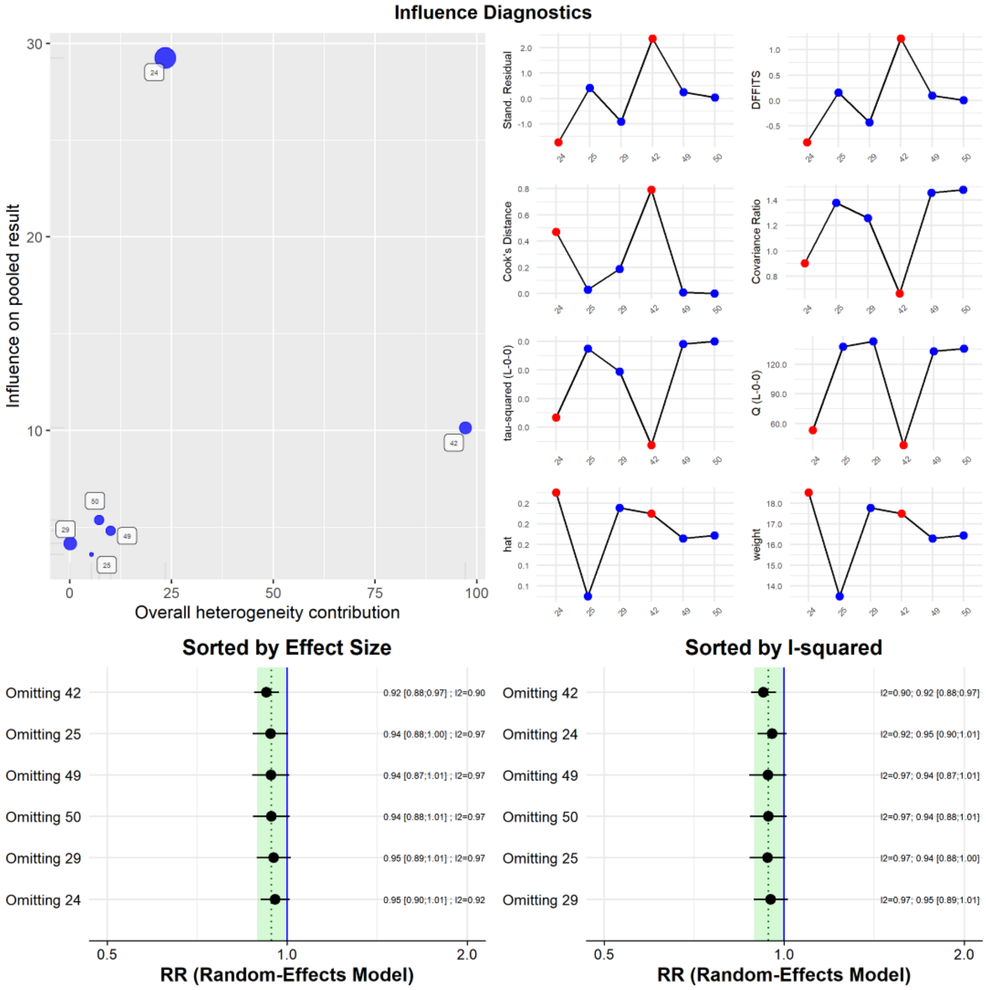

Figure 20. Influence analysis for the meta-analysis performed for the at-haulback mortality of swordfish with circle vs J-hooks.

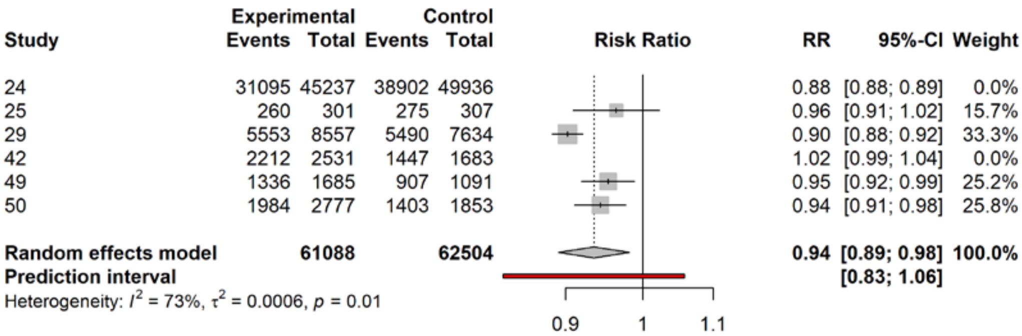

Figure 21. Forest plot of the random effects meta-analysis excluding 2 outliers in the at-haulback mortality of swordfish with circle vs J-hook. (Note: control = J-hook; experimental = circle hook). Studies excluded were numbers 24 and 42 (that are still represented in the plots but not considered in the analysis, as they now have a weight of 0% for the final pooled analysis).

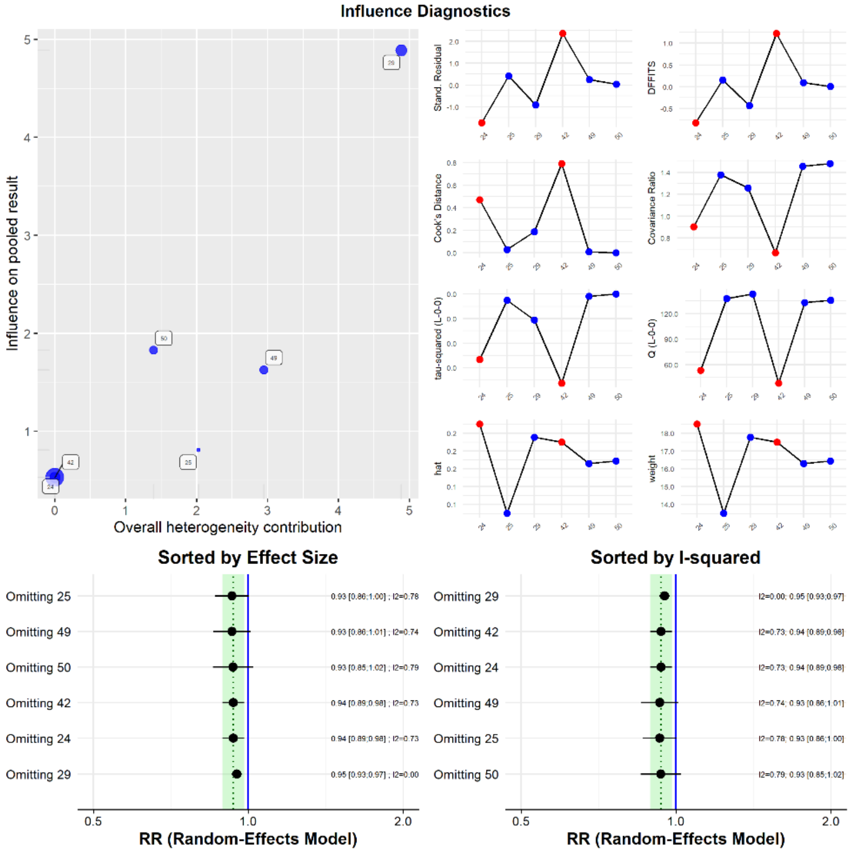

Figure 22. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the at-haulback mortality of swordfish with circle vs J-hooks. Studies excluded were numbers 24 and 42 (that are still represented in the plots but not considered in the analysis).

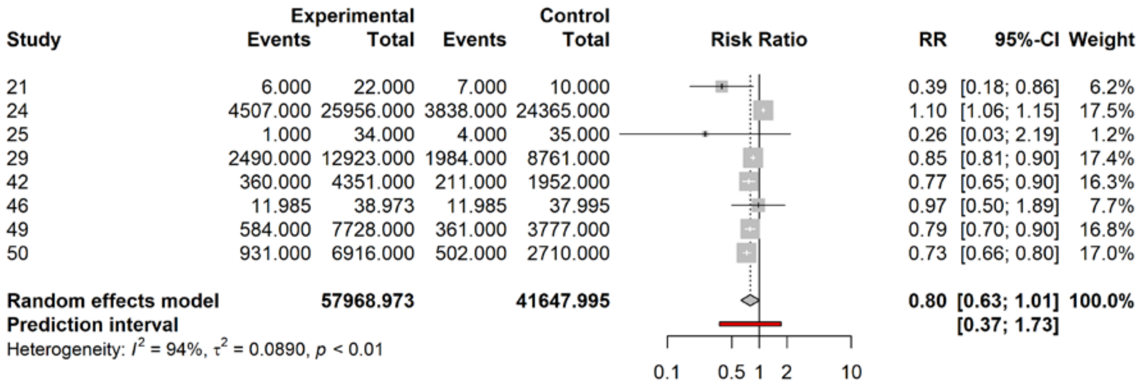

Figure 23. Forest plot of the random effects meta-analysis performed for the at-haulback mortality rates of blue shark with circle vs J-hooks. (Note: control = J-hook; experimental = circle hook).

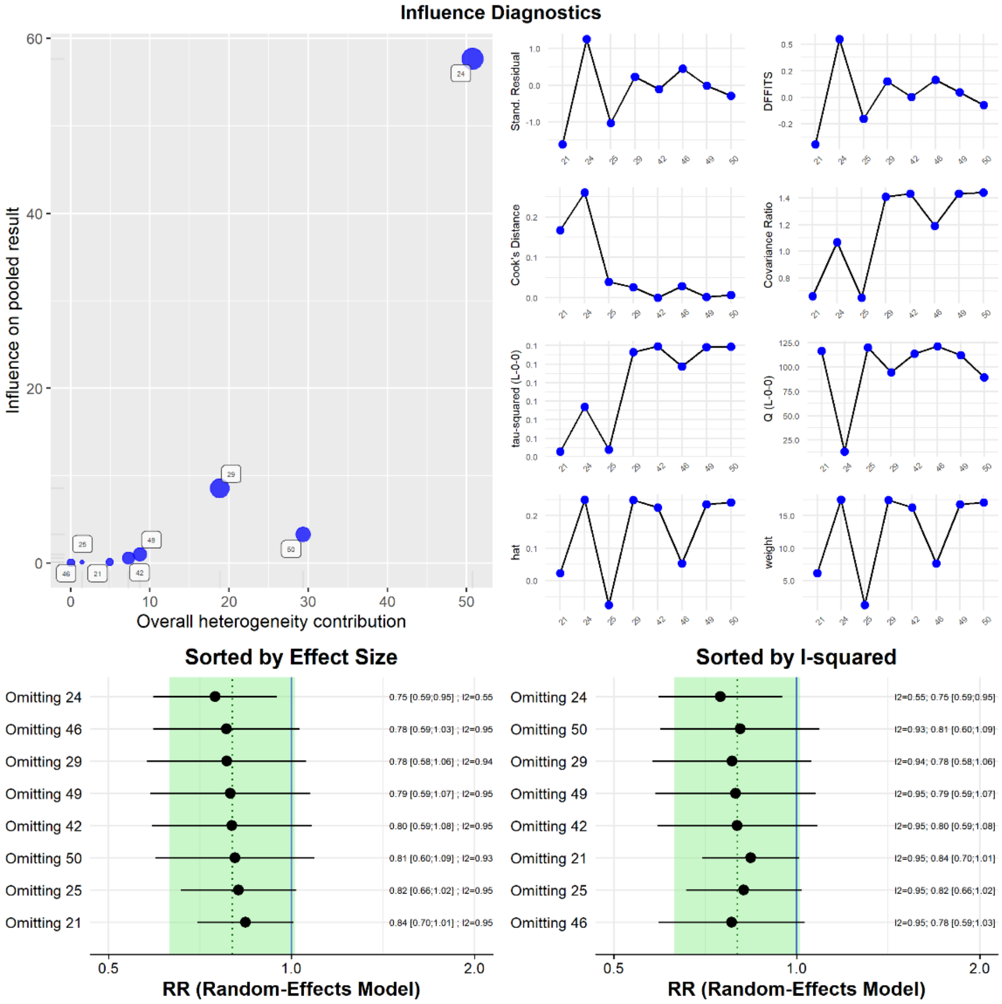

Figure 24. Influence analysis for validating the meta-analysis performed for the mortality rates of blue shark with circle vs J-hooks.

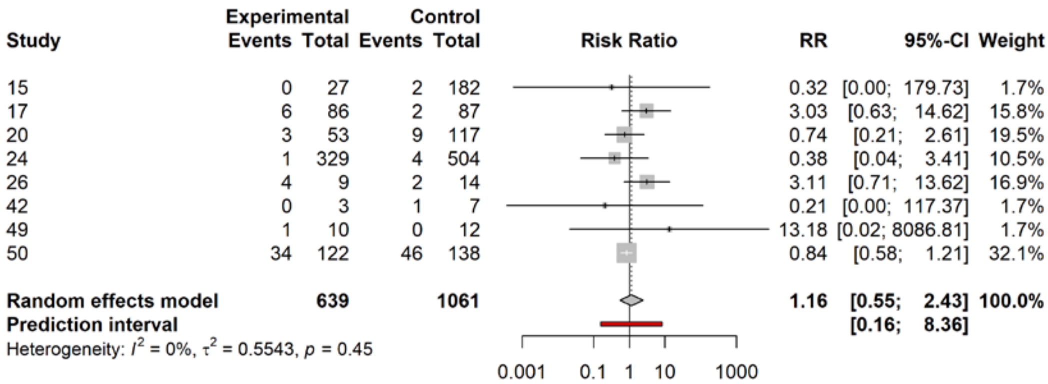

Figure 25. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of loggerhead sea-turtle with circle vs J-hooks. (Note: control = J-hook; experimental = circle hook).

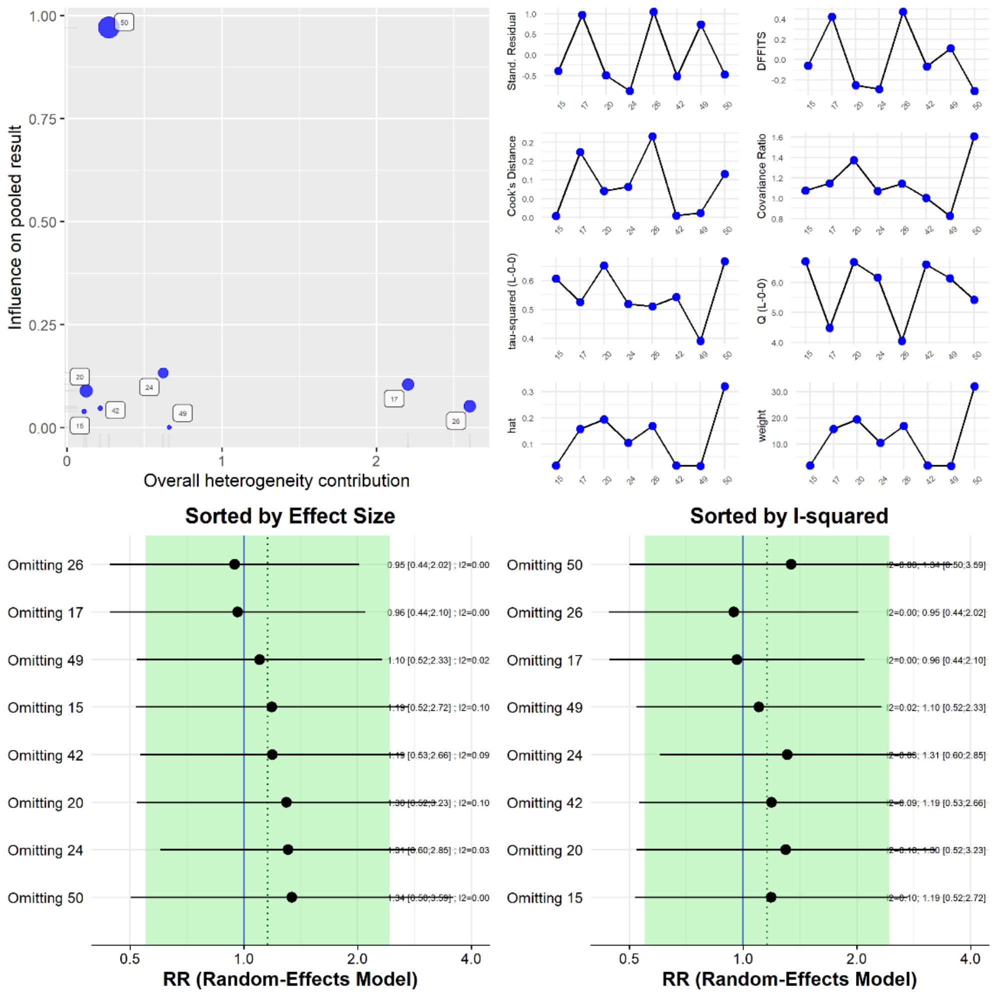

Figure 26. Influence analysis for validating the meta-analysis performed for the at-haulback mortality of loggerhead sea-turtle with circle vs J-hooks, after excluding one outlier study (study 15). The study excluded is still shown in the plots but is not included in the final meta-analysis.

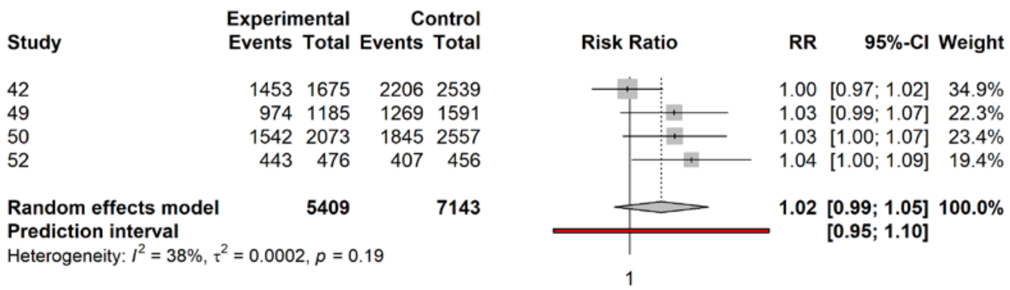

Figure 27. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of swordfish with fish vs squid bait. (Note: control = squid bait; experimental = fish bait).

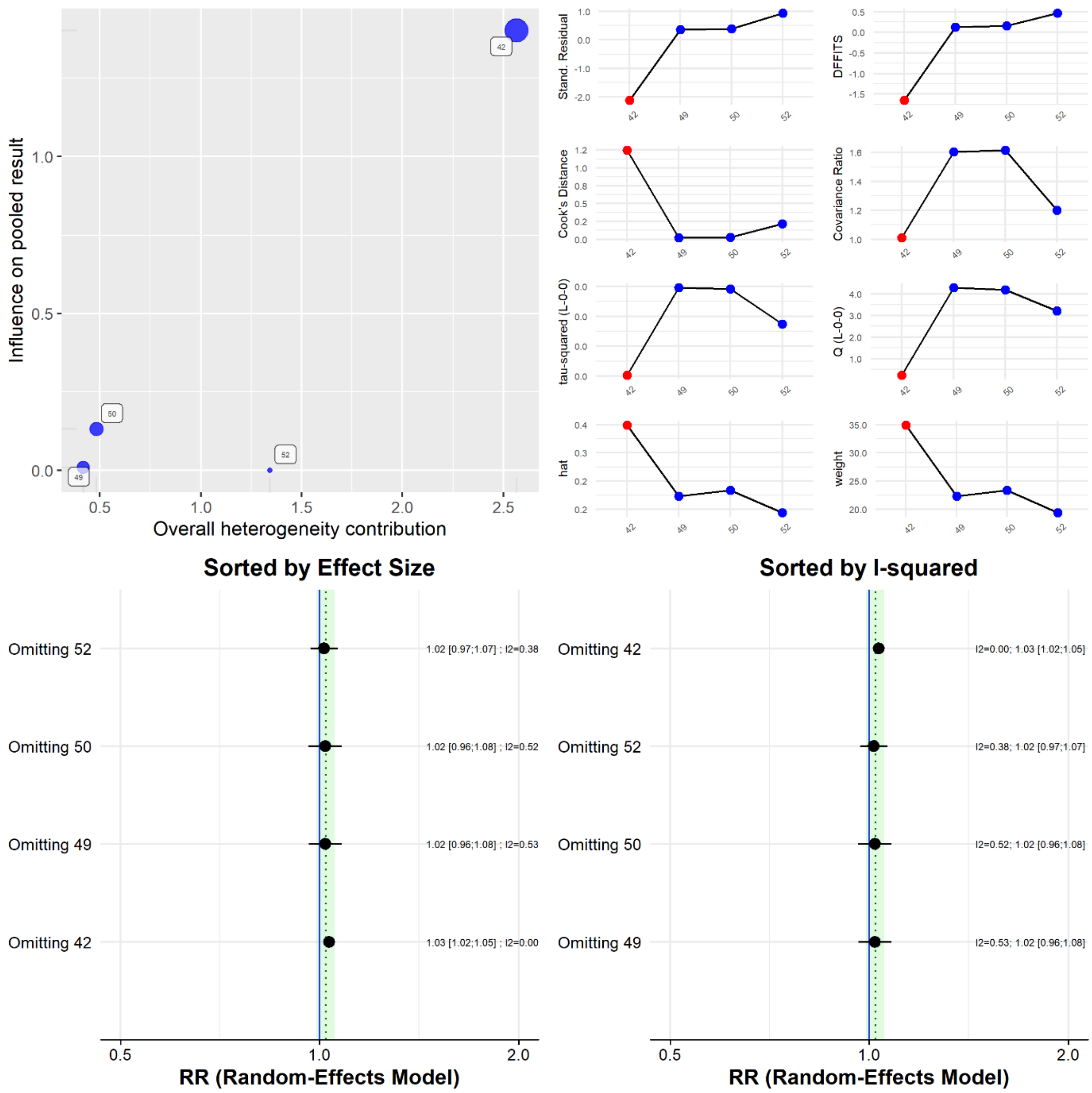

Figure 28. Influence analysis for the meta-analysis performed for the at-haulback mortality of swordfish with fish vs squid bait. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

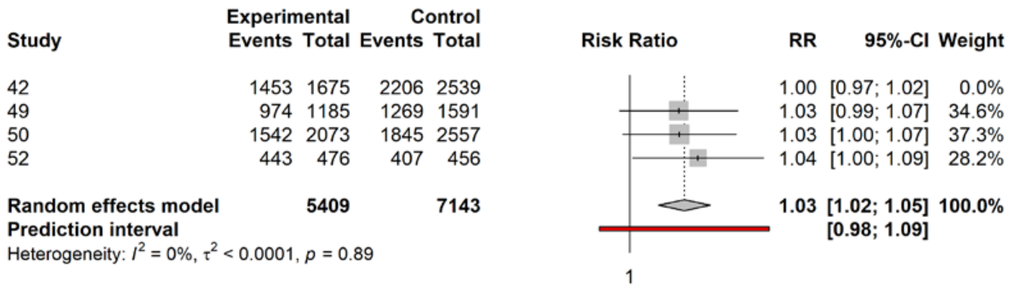

Figure 29. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of swordfish with fish vs squid bait. (Note: control = squid bait; experimental = fish bait). The excluded study is number 42 (that is still represented in the plots but not considered in the analysis).

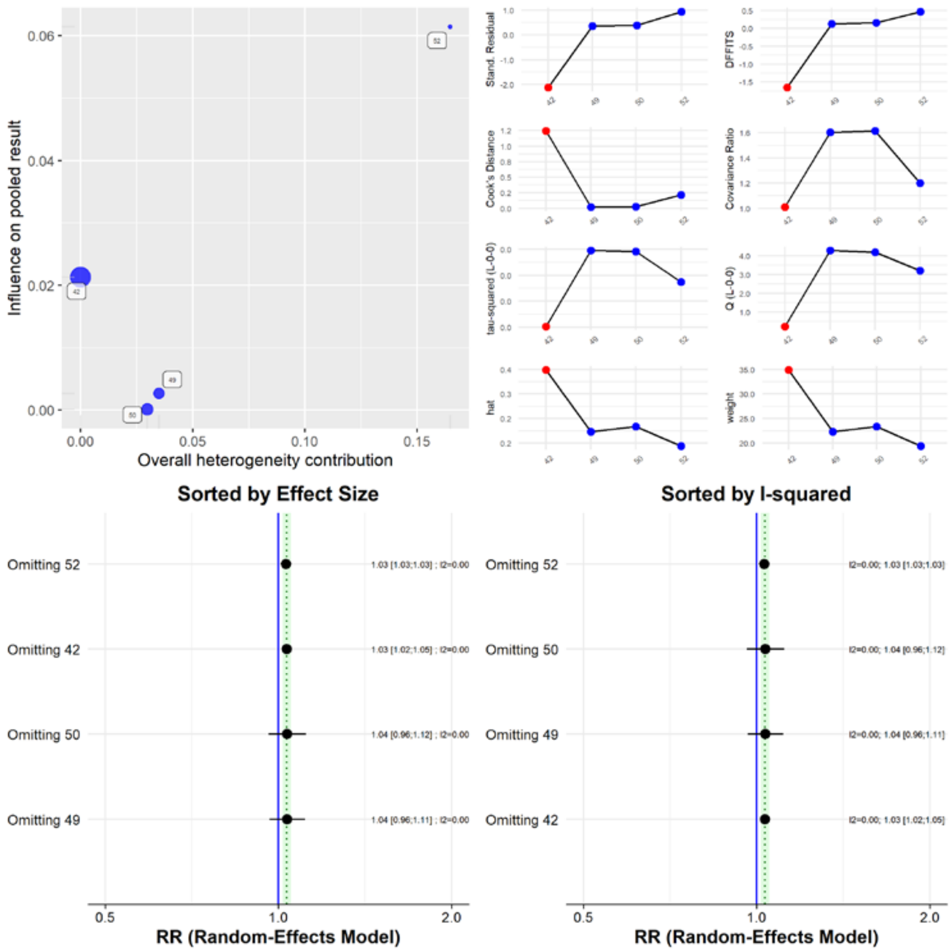

Figure 30. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of swordfish with fish vs squid bait. The excluded study is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

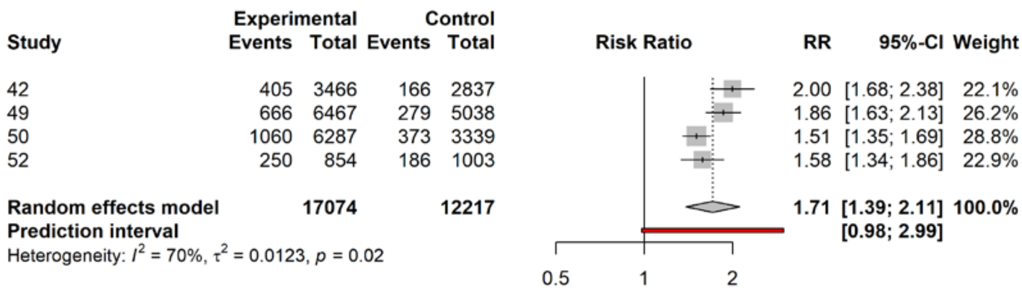

Figure 31. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of blue shark with fish vs squid bait. (Note: control = squid bait; experimental = fish bait).

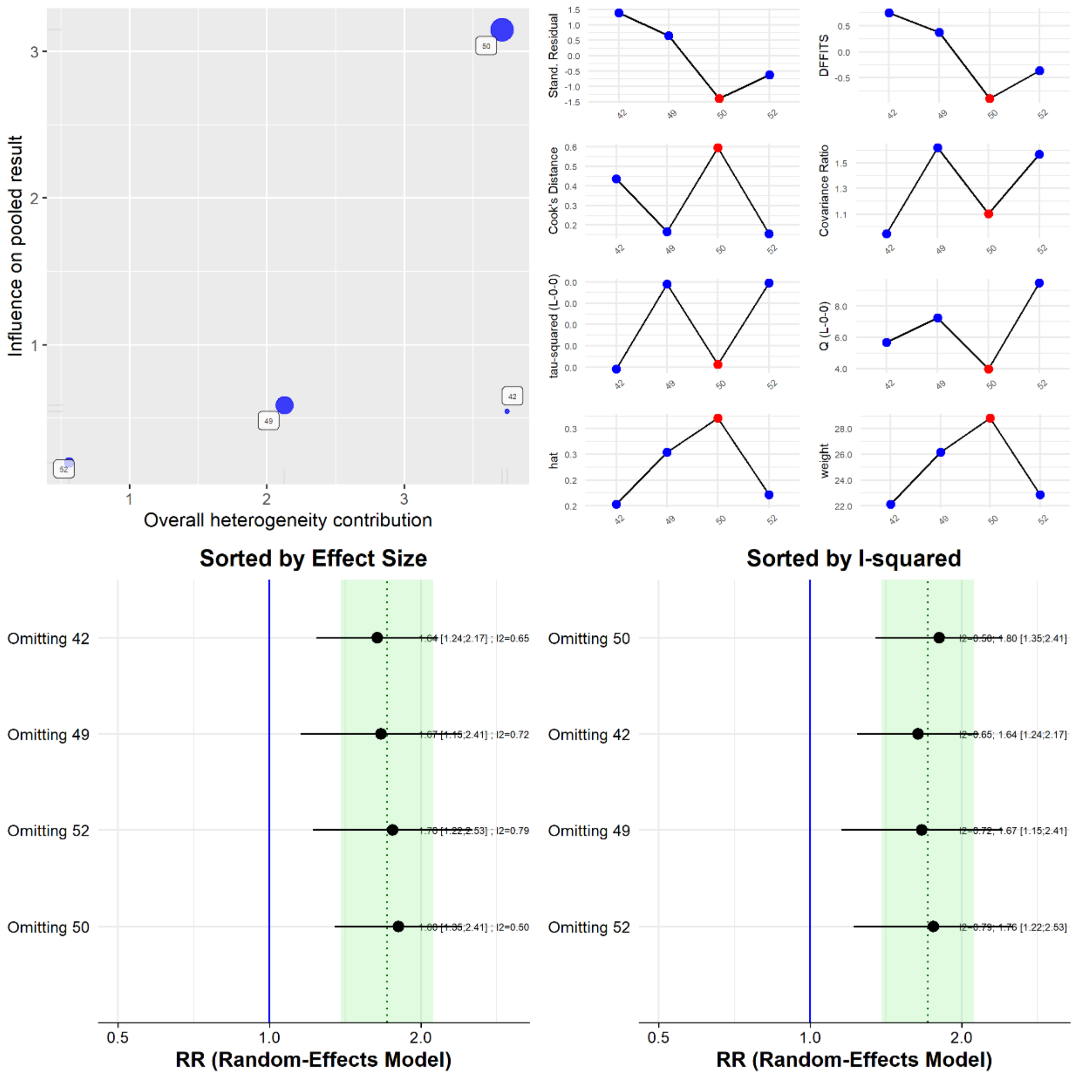

Figure 32. Influence analysis for validating the meta-analysis performed for the mortality of blue shark with fish vs squid bait. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

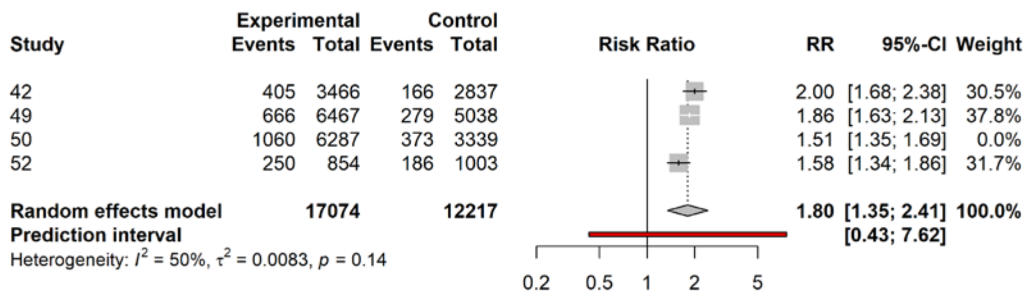

Figure 33. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of blue shark with fish vs squid bait. (Note: control = squid bait; experimental = fish bait). The excluded study is number 42 (that is still represented in the plots but not considered in the analysis).

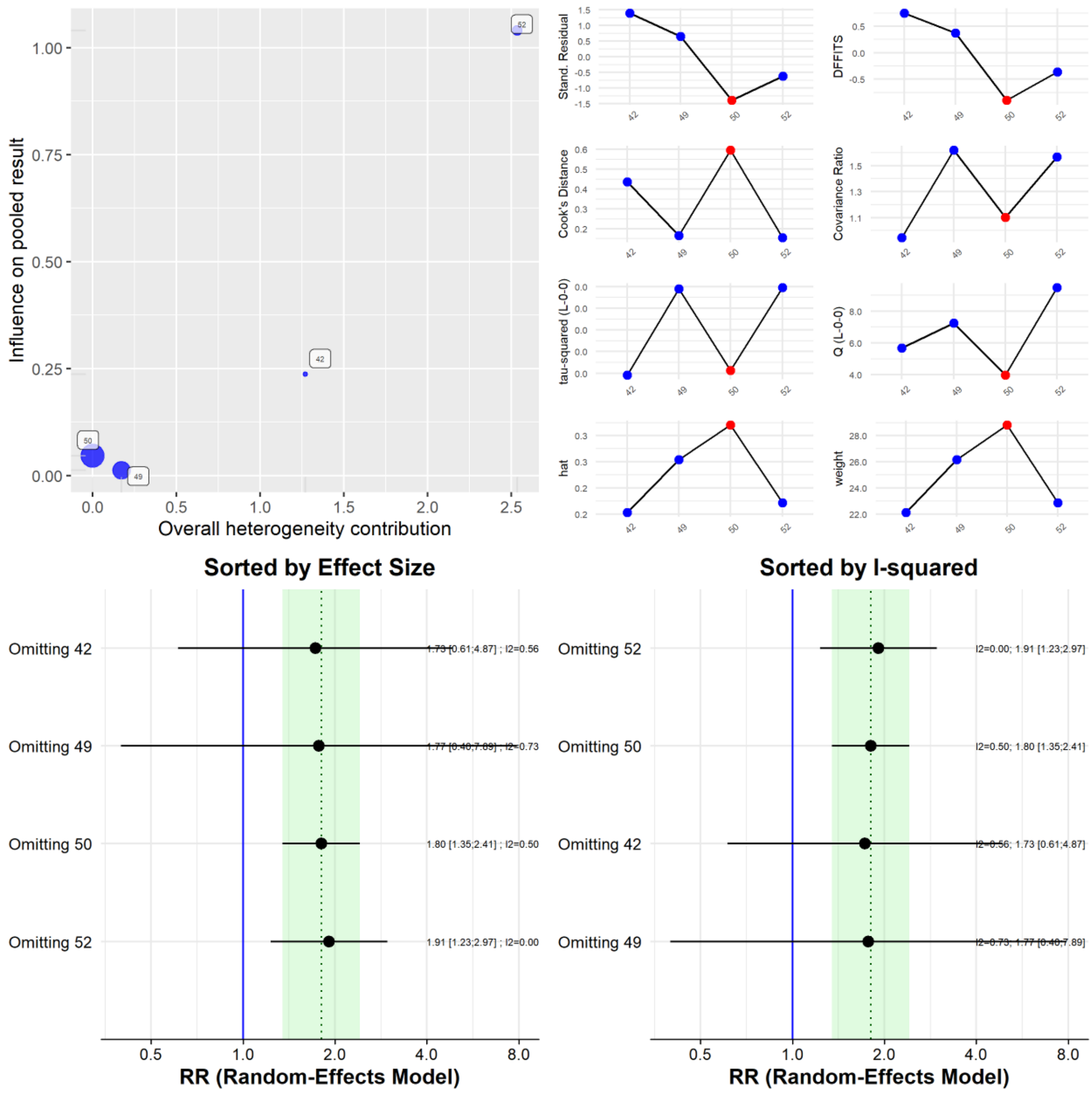

Figure 34. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of blue shark with fish vs squid bait. The excluded study is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

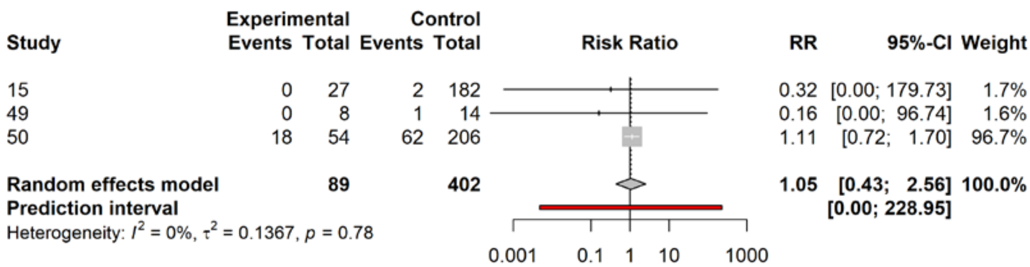

Figure 35. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of loggerhead sea-turtles with fish vs squid bait. (Note: control = squid bait; experimental = fish bait).

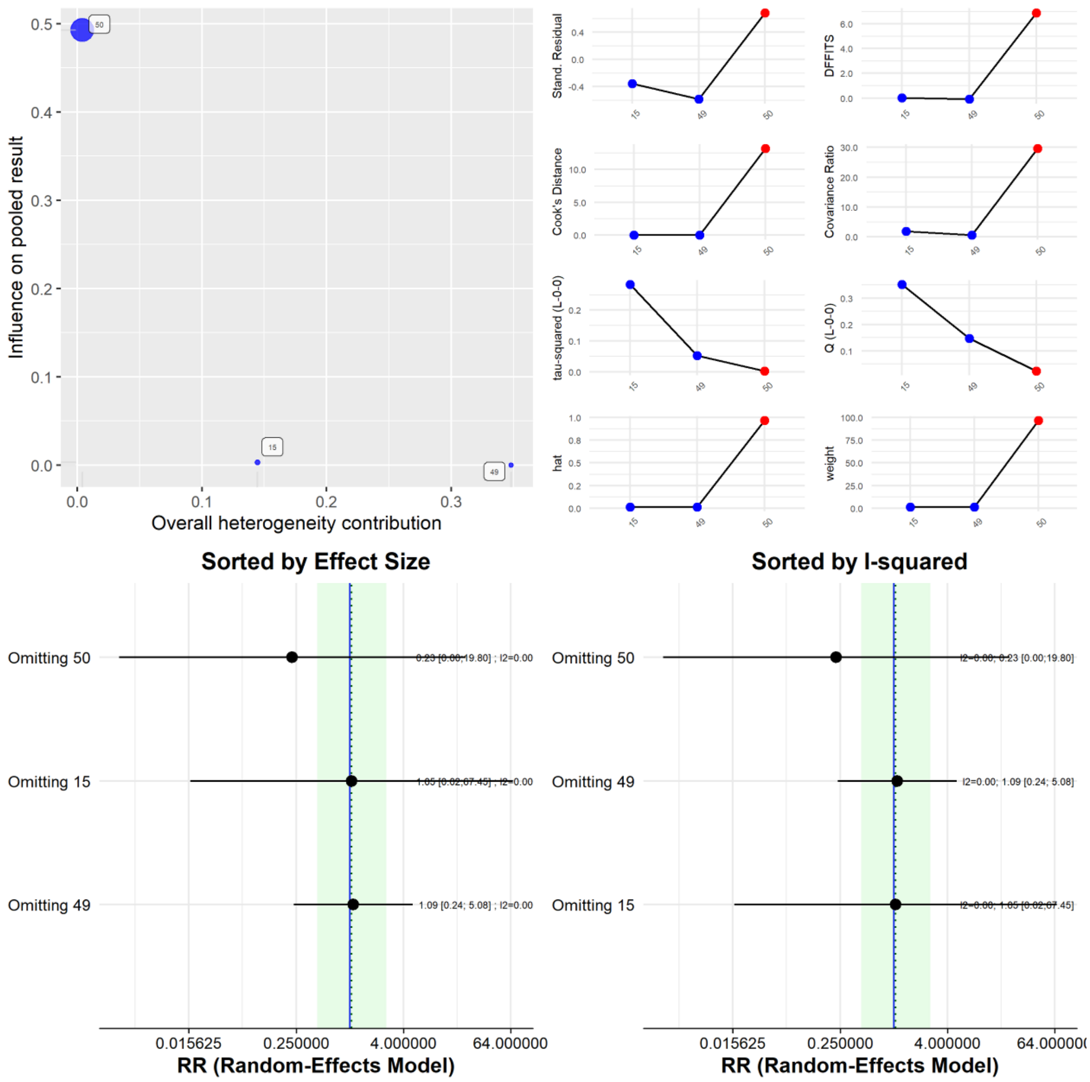

Figure 36. Influence analysis for validating the meta-analysis performed for the at-haulback mortality rates of loggerhead sea-turtles with fish vs squid bait. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

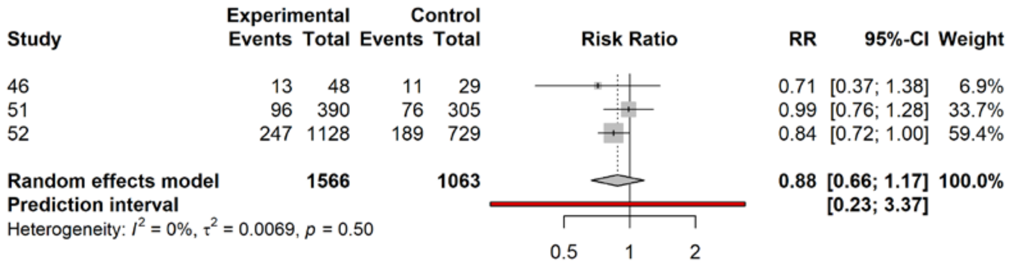

Figure 37. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of blue shark with wire vs nylon leader. (Note: control = nylon leader; experimental = wire leader).

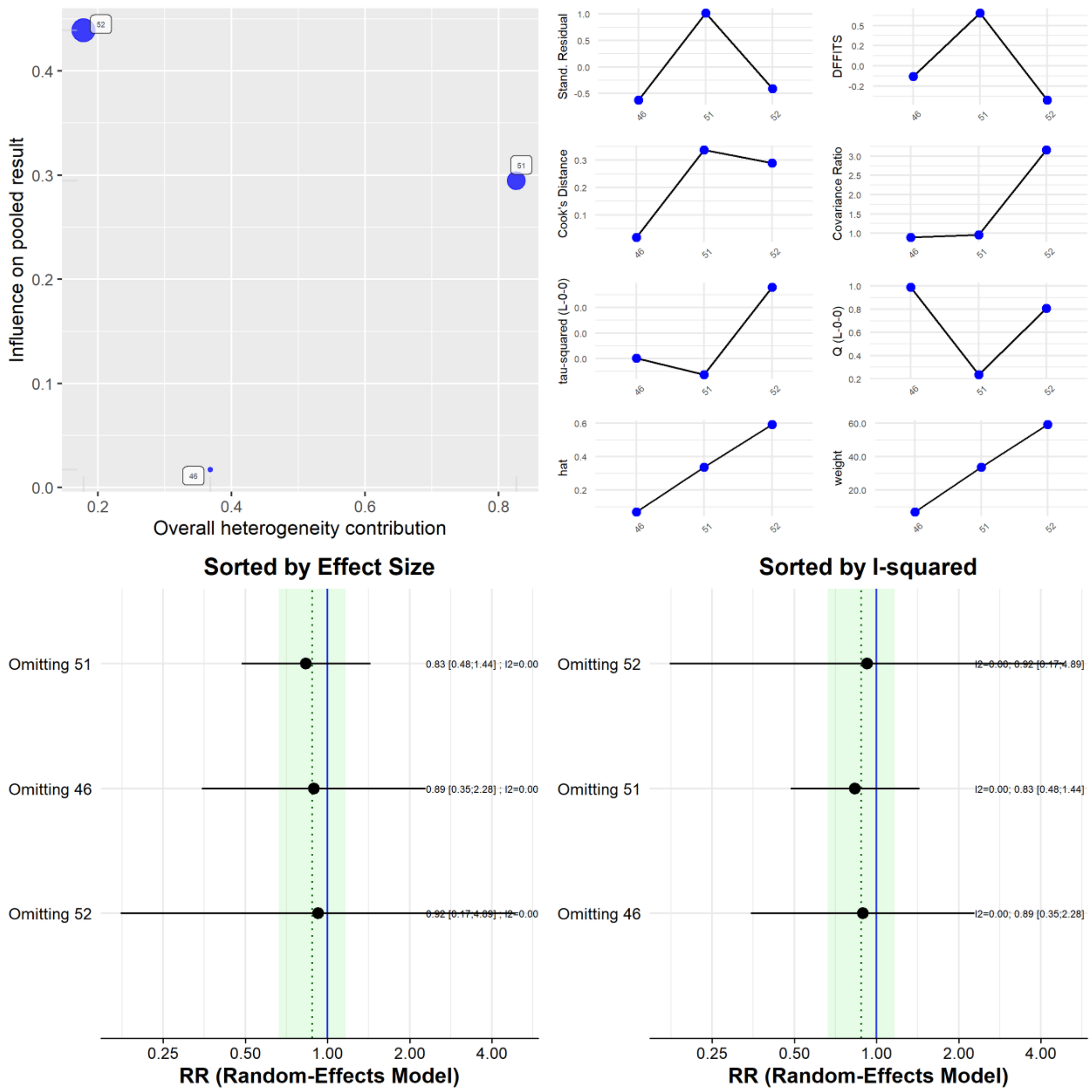

Figure 38. Influence analysis for validating the meta-analysis performed for the at-haulback mortality of blue shark with wire vs nylon leader. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).

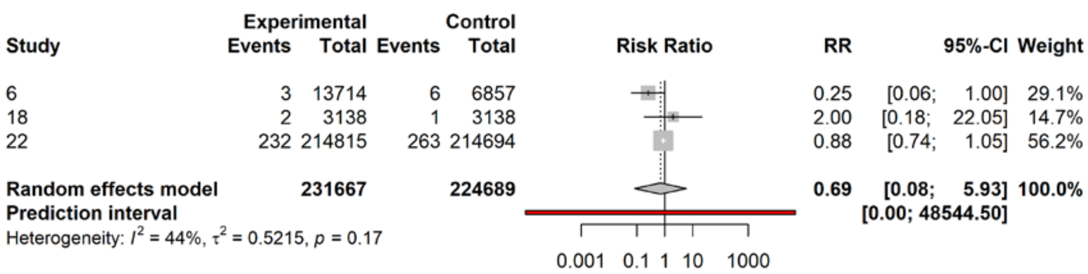

Figure 39. Forest plot of the random effects meta-analysis performed for the retention rates of yellowfin tuna deep setting pelagic longline with circle vs J-hooks. (Note: control = J-hook; experimental = circle hook).

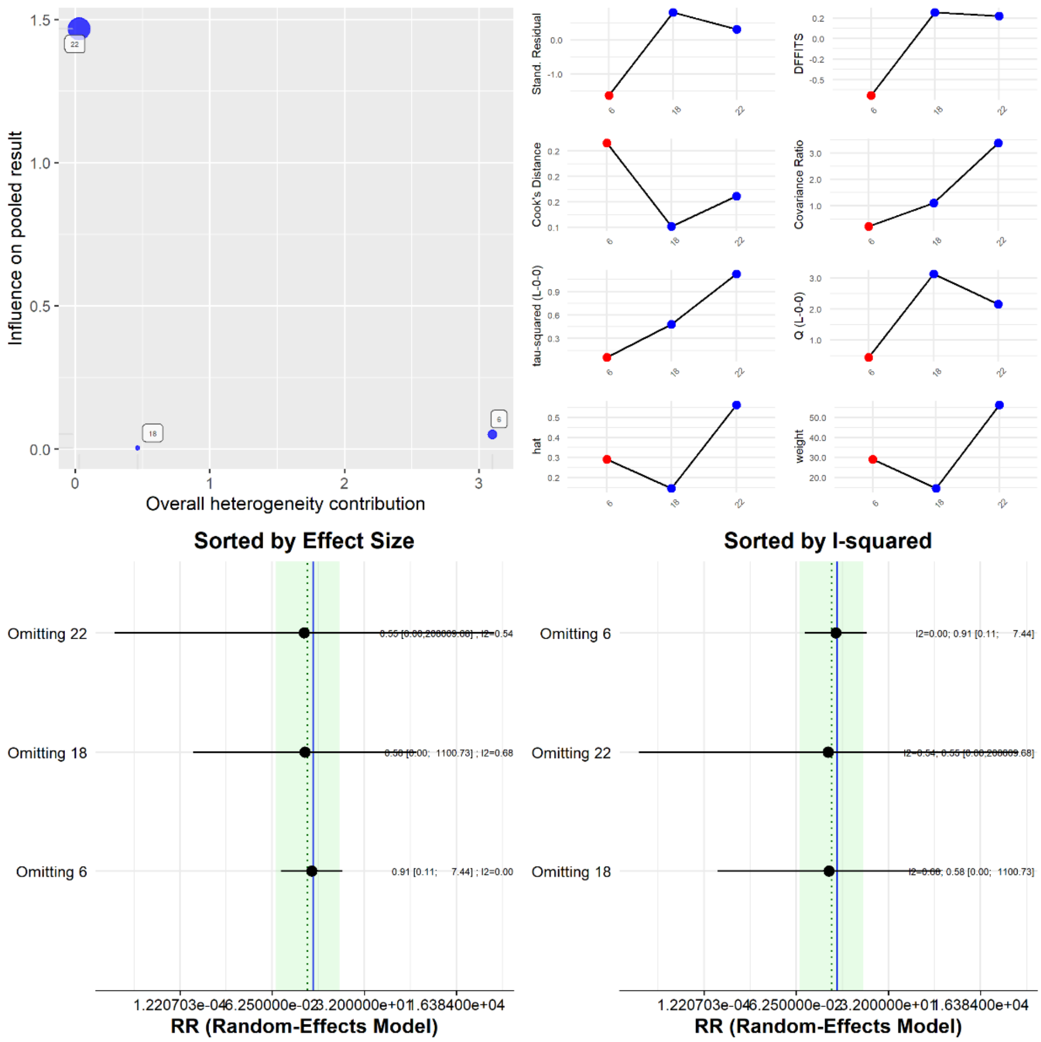

Figure 40. Influence analysis for validating the meta-analysis performed for the retention rates of yellowfin tuna deep setting pelagic longline with circle vs J-hooks. Top left panel - Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I2 (right).