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FRAMEWORK CONTRACT

EASME/EMFF/2016/008

Evaluation of the effects of hooks' shape & size on the catchability, yields and mortality of target and bycatch species, in the Atlantic Ocean and adjacent seas surface longline fisheries

Final Report

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2. EXECUTIVE SUMMARIES

Executive Summary

The main purpose of this study is to provide advice to the Directorate-General for Maritime Affairs and Fisheries (DG MARE) on whether the use of circle hooks per se is effective in reducing mortalities of unwanted species (i.e. species protected and/or subject to release-alive policy), without significantly affecting the catch rates and yields of the targeted species and/or the economic viability of longline fisheries. Other gear configuration modifications, namely bait type and leader material, are also considered.

This study concerns the pelagic longline fisheries targeting, in the Atlantic Ocean and adjacent seas (Mediterranean Sea), swordfish, tropical and/or temperate tunas, as well as desirable bycatches of certain species of shark (e.g. blue sharks and shortfin mako) and marlins/sailfishes contributing to the economic viability of the fisheries.

The following tasks were developed under the project:

Task 1 – Advise on the use of circle hooks

This task's main objective is to provide advice on the impact of introducing circle hooks to pelagic longline fisheries, especially in terms of retention rates, at-haulback and post-release mortality. This task was subdivided into target, desirable and unwanted bycatch species. For this task we also focused on economic issues related with changes in retention rates, and on the hook shape and size at maturity with reference to the minimum conservation reference sizes.

Swordfish was the only main target species with significant effects in retention rates, showing significant decreases when circle hooks were used instead of J hooks. Specifically, when using circle hooks the retention of swordfish decreased on average 18%, varying between reductions of 6% and 27%. Both swordfish and yellow-fin tuna showed lower at-haulback mortality with the use of circle hooks. For the desirable bycatch, blue marlin and white marlin had lower retention rates when circle hooks were used, while the shortfin mako had higher retention with the use of circle hooks. In terms of at-haulback mortality, both blue marlin and blue shark had lower at-haulback mortality with circle hooks. For the unwanted bycatch species, both the loggerhead and leatherback sea-turtles had reductions on the retention rates when circle hooks were used, while for the at-haulback mortality the effects were only significant for the leatherback and indicated higher at-haulback mortality with the use of circle hooks.

Figures 2.1 and 2.2 provide the synthesis of these results in terms of retention rates and at-haulback mortality for the various species when changing hook types.

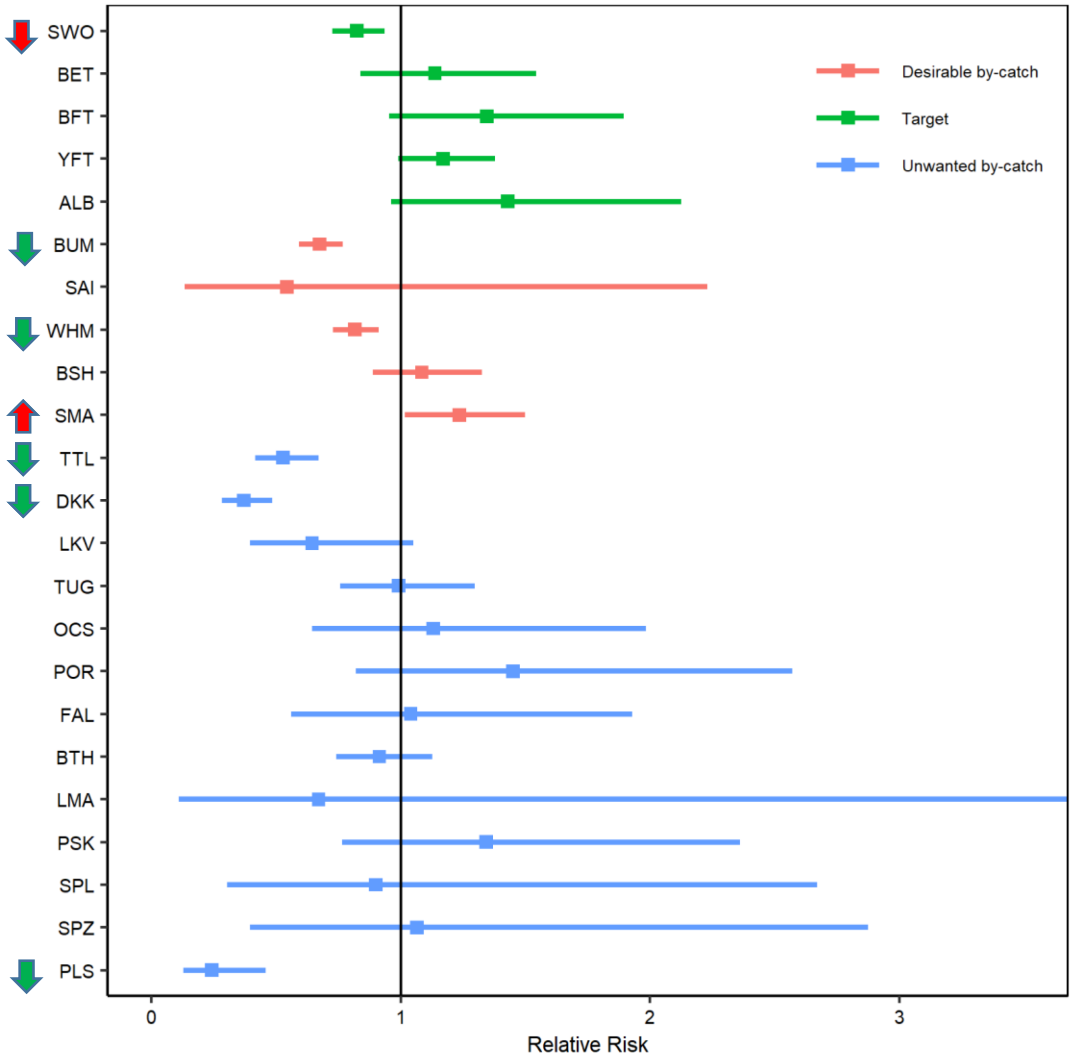


Figure 2.1. Synthesis of results of the meta-analysis of the retention rates of the three species components: target species, desirable bycatch and unwanted bycatch. The error bars represent the 95% confidence intervals. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the retention rates. The colour of the arrows assumes the following: 1) for target species higher retention assumes a positive (green) outcome while a decrease in retention is a negative (red) outcome; 2) the contrary is assumed for bycatch species, both wanted and unwanted, i.e., a reduction in retention is assumed a positive outcome (green) while an increase in retention is assumed a negative (red) outcome. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

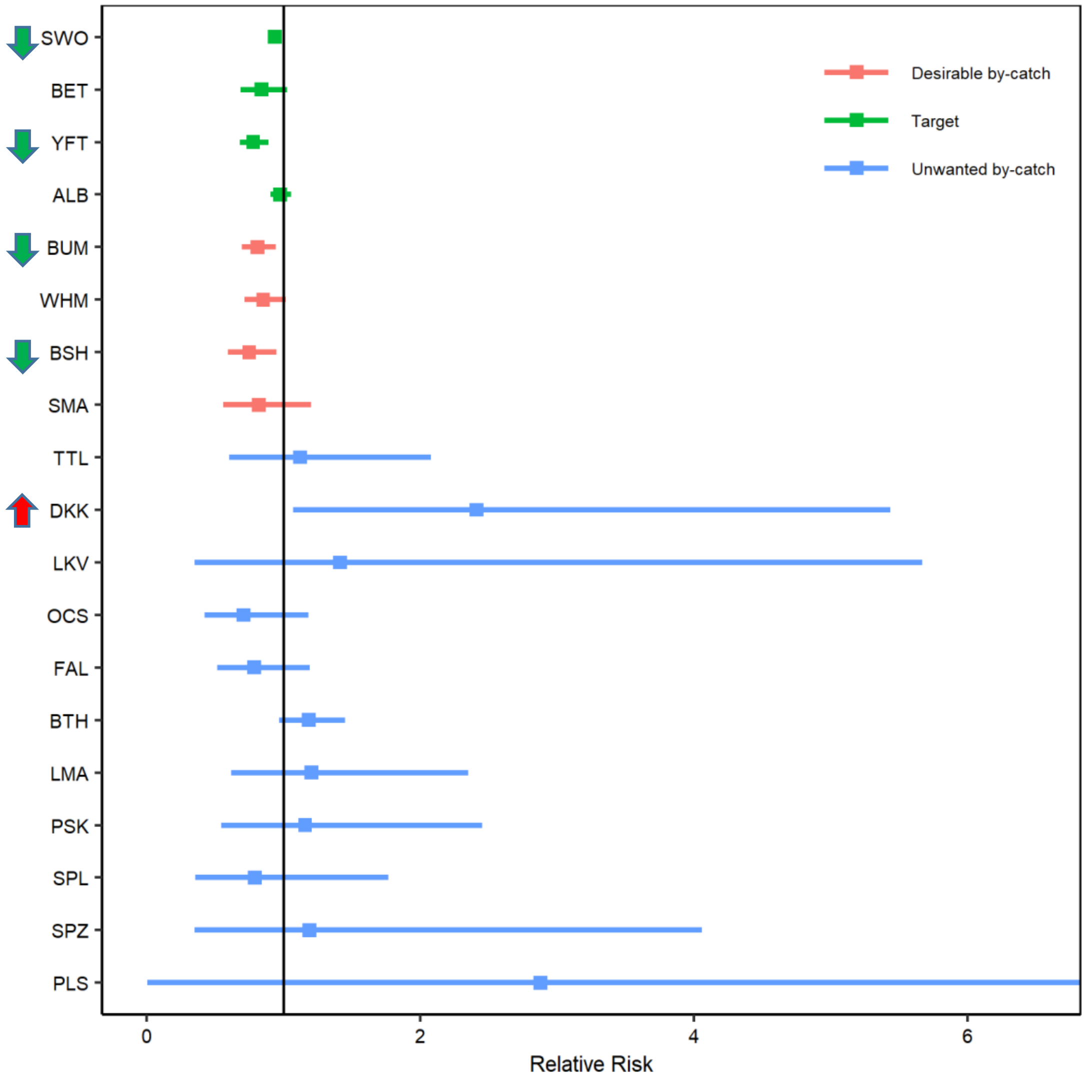


Figure 2.2. Synthesis of results of the meta-analysis of at-haulback mortality of the three species components: target species, desirable bycatch and unwanted bycatch. The error bars represent the 95% confidence intervals. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the at-haulback mortality. The colour of the arrows assumes the following: for all species groups (target and bycatch), a lower at-haulback mortality is a positive (green) outcome while higher at-haulback mortality is a negative (red) outcome. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

In terms of economic aspects, if the EU pelagic longline fleet were to change from J to circle hooks there would be expected increases in the catch, mostly because increases in catches of sharks would compensate for the reduction in species like swordfish. However, in terms of economic impact, and taking into account current regulations/quotas for the main shark species, if circle hooks were implemented for the EU pelagic longline fleets, there would be an expected reduction in the value of the retained catch. The main reduction would be for the North Atlantic (loss of 7.0% in value of the retained catch), followed by the Mediterranean (loss of 4.4% in the value of the retained catch) and finally the South Atlantic (loss of 3.7% in the value of the retained catch). Table 2.1 provides a summary of those results.

Given the that circle hooks tend to decrease retention of the main target species (swordfish), increase retention of some vulnerable sharks (namely shortfin mako), which results in an overall lower value of the retained catch, the use of circle hooks is not recommended for surface longline fisheries such as the EU pelagic longline.

In terms of the sizes, it is noted that for swordfish the mean capture sizes with both J and circle hooks are larger than the currently established options for minimum landing sizes. By contrast, for shortfin mako the mean size captured with both hook types is smaller than the current size management option. Additionally, the size at maturity (size at which 50% of the population has reached maturity) for shortfin mako varies between 180 and 220 cm FL for males and 270 and 300 cm FL for females, meaning that the currently established minimum conservation size is relatively approximate for males (180 cm FL), but not adequate for females (210 cm FL).

Table 2.1. Summary table of the stock-specific main species catch analysis for the changes (in catch and corresponding value) from J hooks to circle hooks, assuming restriction in the catches of blue shark (quota of 32758 t) and shortfin mako (0 t). The data to start the analysis correspond to the stock-specific catches for all the EU pelagic LL fleets using the ICCAT Task 1 database (average of the last five years of available data, 2014-2018). The four species considered are swordfish, albacore, blue shark and shortfin mako, that together represent 95% of the EU pelagic LL retentions (in weight). At the end of the table, the differences between using J and circle hooks (in catch and value) are indicated. The arrows on the bottom assume that an increase in catch and/or value is a positive (green) outcome, while a decrease in catch and/or value is a negative (red) outcome.

Sp	Value (€/kg)	RR	J hooks (T1 catch, t)			Circle hooks (simulated catch, t)			J hooks value (€)			Circle hooks value (€)		
			N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med
SWO*	7.1	0.82	5304.0	4960.0	6377.0	4349.3	4067.2	5229.1	37499280	35067200	45085390	30749410	28755104	36970020
ALB*	4.8	1.43	216.9	279.7	2674.8	310.2	399.9	3825.0	1041199	1342446	12839128	1488915	1919698	18359953
BSH**	1.6	1.08	32578.0	16203.7	96.1	32578.0	17500.0	103.7	52124800	25925969	153692	52124800	28000046	165988
SMA**	4.0	1.23	0.0	1278.7	0.2	0.0	1572.8	0.3	0	5114831	932	0	6291242	1146
Total			**38098.9**	**22722.1**	**9148.1**	**37237.5**	**23540.0**	**9158.2**	**90665279**	**67450446**	**58079142**	**84363124**	**64966091**	**55497107**
Differences (using circle instead of J hooks)						**-861.4**	**817.9**	**10.1**				**-6302154.8**	**-2484355.4**	**-2582035.4**
Differences (%)						**-2.3**	**3.6**	**0.1**				**-7.0**	**-3.7**	**-4.4**

* ALB and SWO quotas were not considered as the simulated catch is lower than those limits.
** BSH and SMA catch limits and quotas were considered as the simulated catch is higher than those limits

Task 2 – Technical and biological aspects related to hooks

The main objective of this task was to provide advice on the technical and biological reasons for the supposed practical effects of the circle hooks compared to other shapes of hooks (J-hook, Japanese-hook, teracima hook, etc.) by taking into account the circle hook morphology (e.g., offset/non-offset, width, length, gape, bite, incurved point angle, barb type, etc.).

A catalogue of the main hook shapes and sizes deployed in pelagic longline fisheries worldwide was produced with their respective measurements, establishing relationships between the length of the different elements of the hooks. It is noted that the term "circle hooks" does not have a clear definition, particularly regarding first the value of the point angle and second whether it is an object in two or three dimensions (i.e., offset vs. non-offset). Likewise, the heterogeneity of size and shape of a given hook type between manufacturers is raised as a major issue that might explain the high variability of hooking responses estimated for several species.

A questionnaire was developed and distributed to international scientists identified globally as responsible for scientific observer programmes for pelagic longline fisheries in the global ocean. Seven responses (10%) were received, and these included answers from national (government) institutions, research institutions and NGOs. Six respondents have already implemented or are implementing pelagic longline observer programmes or experimental longline trials. Fisheries data is usually collected, such as fishing gear used and the size of gear elements, for example branchline, floatline, etc. Regarding the catches, in general data on the species are collected for both target species and bycatch species. Specimen sizes are collected by the majority of the observer programmes, plus some collect additional data on biology (e.g. sex, sexual maturity, etc.). Almost all respondents mentioned that their programmes also collect data on at-haulback mortality, including for sharks and rays. For studies implemented the results of many of them were published and considered in our meta-analysis.

Finally, because of the specific shape of the circle hook - point turned towards the shank with a theoretical maximum angle of 90° with the tangent of the front part of the hook relative to the base – the circle hook slips out from the fish gut (when the tension of the fishing line increases) without hooking fish soft tissues. It engages on contact with hard parts of the fish mouth: mostly maxillary bones. However, the respect of this behaviour when there is an offset is not really established.

Task 3 – Advise on other variables and effects.

The main objective of this task was to provide advice on whether issues other than hook shape, such as bait and leader types, could also be influential in the retention and at-haulback mortality rates. As in Task 1, the effects of those variables were tested and analysed with species-specific meta-analyses, for the target, desirable and unwanted bycatch species.

When fish bait was used instead of squid, there were significant decreases in the retention of yellowfin tuna, sailfish and the loggerhead sea-turtle. By contrast, the silky shark had a significantly higher retention with fish bait. For the at-haulback mortality, swordfish, blue shark and the oceanic whitetip had a significantly higher at-haulback mortality when fish was used, while the silky shark had a lower at-haulback mortality. In terms of leader materials, far fewer studies are available, hence the analyses were much more limited. The effects on the retention rates were only significant for two species when changing from nylon to wire leaders, with a decrease in retention of blue marlin and an increase for blue shark.

Task 4 – Effects with longline depth.

The main objective of this task was to provide advice on whether the implementation of circle hooks could have the same effects on the catchability, mortality and survivability regardless of the fishing depth and soaking time, comparing and commenting, as adequate, the results by taking into account the fishing effort repartition between shallow and deep fishing operations.. In this task, both changes from J to circle hooks and from tuna to circle hooks were considered.

It was noted that in general there are far fewer references for deep setting longlines, particularly comparison between J and circle hooks. The only species for which it was possible to conduct a meta-analysis was the yellowfin tuna, which showed no significant differences in the retention rates. For the comparison between tuna and circle hooks it was possible to conduct the meta-analysis for several more species, but the effects were not significant for any of the studied species.

For this task, in the future, it will also be important to separate and consider the longline fishing effort repartition between the shallow and deep setting in the Atlantic. Such data depend on the International Commission for the Conservation of Atlantic Tunas (ICCAT) Effort Distribution (EFFDIS) database, which is currently not yet available. When available, the effort repartition between those two longline components can then be taken into consideration, and what is presented as ratios in this report could be converted to total biomass changes.

Task 5 – Justifications for exclusion of certain studies.

The main objective of this task was to provide explanations for which certain scientific papers were not retained for the meta-analysis and conclusions.

The most common reason for not including papers is that sample sizes were too small, especially for the rarer and/or more occasionally captured species. This study also excludes papers relating to studies that were not carried out on pelagic longlines, studies comparing different fleets that caused confounding effects, studies that did not report the data necessary for the meta-analysis, studies on satellite tagging that did not separate post-release mortality from premature release of tags, and studies using satellite tags whose main objective was to address movements.

Data gaps

After the multiple tasks carrying out meta-analysis, specifically tasks 1, 3 and 4, we provide a summary of the current data gaps that can be highlighted for prioritisation for future planning of experimental at-sea studies. In summary, there are more studies available for surface longlines, especially for factors such as hook type and bait, and far fewer for the leader materials. For deep setting longlines the data gaps are much more considerable, especially for changes in J-style hooks, while a few more studies are available for tuna hooks (Table 2.2).

Additionally, most of the current studies only focus in changing one variable at a time, for example changing hooks or bait types, but in an independent and separate way. This can cause confounding effect in those variables that are being studied. It would be important in the future to plan for more full factorial design studies that change several variables in one study, for example by changing baits within the various hook types. Due to the multilevel of the various variables, such studies would require a considerable effort in terms of at-sea experimental trials, but would be more powerful in detecting changes in the various factors. Finally, such studies should be conducted in conjunction with scientists working with other pelagic longline nations/fleets, to assure that all fleet characteristics and areas in the Atlantic and Mediterranean Sea are considered.

Table 2.2. Summary of the data gaps on studies for conducting the meta-analysis on the various species and factors. "Hook_J" refers to studies on changes from J hooks to circle hooks, whole "Hook_T" refers to studies on changes from tuna hooks to circle hooks. A colour gradient from green to red is used on the number of studies available in each cell of the table (note on the colour gradient: upper limit (N=21) = green; lower limit (N=0) = red; middle color (N=5) = yellow).

Sp	Surface setting longlines						Deep setting longlines			
	Retention rates			At-haulback mortality			Retention rates		At-haulback mortality	
	Hook_J	Bait	Leader	Hook_J	Bait	Leader	Hook_J	Hook_T	Hook_J	Hook_T
SWO	19	7	3	6	4	2	2	4	0	2
BET	11	6	4	6	4	2	2	4	2	2
BFT	4	2	0	2	0	0	0	0	0	0
YFT	9	4	3	5	4	2	3	4	0	2
ALB	11	6	3	6	3	2	1	4	0	0
BUM	6	4	3	5	4	2	1	0	0	0
SAI	4	4	2	3	4	1	0	0	0	0
WHM	5	4	1	5	4	1	0	0	0	0
BSH	16	6	3	8	4	3	2	4	0	2
SMA	12	6	2	7	4	2	0	1	0	0
TTL	21	11	2	10	5	2	0	1	0	1
DKK	12	7	1	9	4	1	0	1	0	1
LKV	7	3	1	4	3	1	1	4	0	2
LKY	2	2	0	2	2	0	0	0	0	0
TUG	5	0	0	2	0	0	1	0	0	0
OCS	5	4	2	5	4	2	0	2	0	0
POR	5	2	1	2	1	0	0	0	0	0
FAL	8	4	3	5	4	2	1	0	0	0
BTH	4	5	2	4	4	2	2	3	0	1
LMA	3	3	1	3	3	1	0	0	0	0
PSK	5	4	3	5	4	2	0	2	0	0
SPL	5	2	0	3	1	0	0	2	0	0
SPZ	3	4	2	3	4	2	0	2	0	0
PLS	9	5	3	3	1	1	1	3	0	1

Resumen Ejecutivo

El objetivo principal de este estudio es ofrecer consejo sobre el uso de anzuelos circulares y su efectividad para la reducción de especies no deseadas (p.e. especies protegidas y/o sujetas a políticas de liberación en vida) sin reducir el rendimiento y las capturas de las especies objetivo ni/o la viabilidad económica de las pesquerías de palangre a la Dirección General de Asuntos Marítimos y Pesca (DG MARE). También se han considerado modificaciones a la configuración del arte de pesca, en concreto al tipo de cebo y tipo de hilo.

Este estudio se centra en pesquerías de palangre pelágico del Atlántico y mares adyacentes (Mediterráneo) dirigidas al pez espada, atunes templados y/o tropicales y también a pesquerías accesorias deseables como algunas especies de tiburones (p.e. tiburón azul y marrajo) y marlines/pez vela, que contribuyen a la viabilidad económica de las pesquerías.

Durante el Proyecto se desarrollaron las siguientes tareas:

Tarea 1 – Consejo sobre el uso de anzuelos circulares

El objetivo principal de esta tarea es ofrecer consejo sobre el impacto del uso de anzuelos circulares en pesquerías pelágicas, especialmente en términos de tasas de retención, durante la recogida y la mortalidad después de liberación. Esta tarea ha sido divida en especies objetivo, deseables y especies accesorias no deseadas. Para esta tarea nos hemos centrado en aspectos económicos relacionados con cambios en las tasas de retención, y en la forma del anzuelo y la tasa de madurez, en relación con unos mínimos de conservación de referencia.

El pez espada fue la única especie principal sobre la cual se observaron efectos significativos en las tasas de retención, mostrando descensos significativos cuando se utilizaron anzuelos circulares en lugar de anzuelas J. En particular, la retención de pez espada se redujo una media del 18%, variando entre reducciones del 6% y el 27%. Tanto el pez espada como el rabil mostraron menor mortalidad en la recogida con el uso de anzuelos circulares. En cuanto a la pesca accesoria deseable, los marlines azul y blanco tuvieron menores tasas de retención con anzuelos circulares, mientras que el marrajo tuvo tasas mayores de retención. En cuanto a las tasas de mortalidad durante la recogida, tanto el marlin azul como el tiburón azul sufrieron mortalidades menores con anzuelos circulares. En cuanto a las especies no deseadas, tanto para las tortugas boba como laúd, se redujo la tasa de retención cuando se utilizaron anzuelos circulares, mientras que la mortalidad en la recogida se aumentó para la tortuga laúd con el uso de anzuelos circulares. Las figuras 2.1 y 2.2 muestran los resultados obtenidos en términos de tasas de retención y mortalidad en la recogida para las especies de estudio al cambiar el tipo de anzuelo.

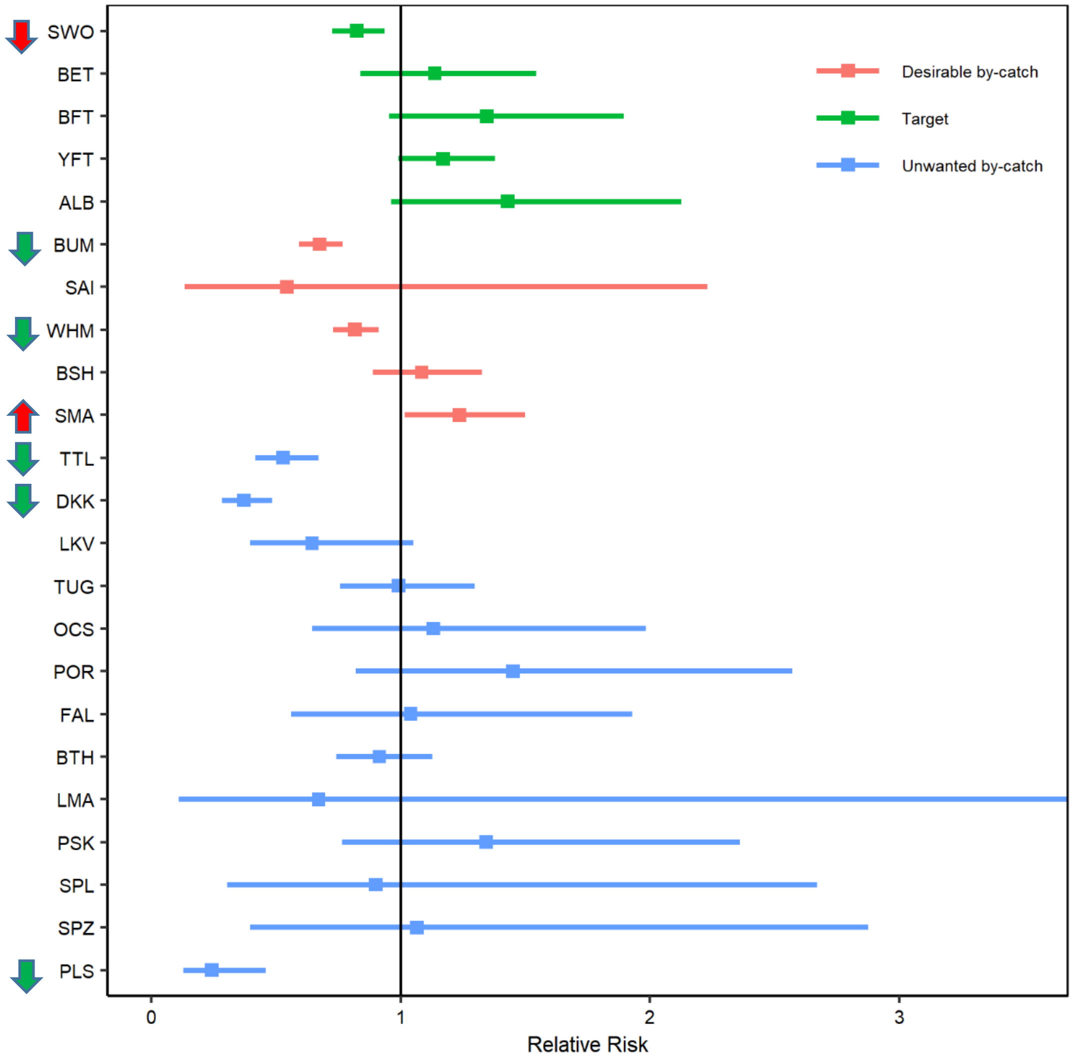


Figura 2.1. Sintesis de resultados del meta-análisis de las tasas de retención de tres grupos de especies: especies objetivo, especies accesorias deseables y accesorias no deseadas. Las barras de error representan el 95% de intervalo de confianza. Las flechas en la parte izquierda se muestran solo para especies con efectos significativos, siendo la dirección de las flechas hacia arriba (incremento) y hacia abajo (reducción) de las tasas de retención. El color de las flechas asume que: 1) para las especies objetivos un aumento de la tasa de retención es positiva (verde), mientras que una reducción es negativa (rojo); 2) para las especies accidentales se considera lo contrario, tanto para las deseadas como las no deseadas, i.e. una reducción de la retención es considerada positiva (verde) y un aumento de la reducción se considera negativa (rojo). (Nota: Los anzuelos en forma de J se consideran el control y los anzuelos circulares son los experimentales; un riesgo relativo (RR) > 1 indica que la retención es mayor con los anzuelos circulares.

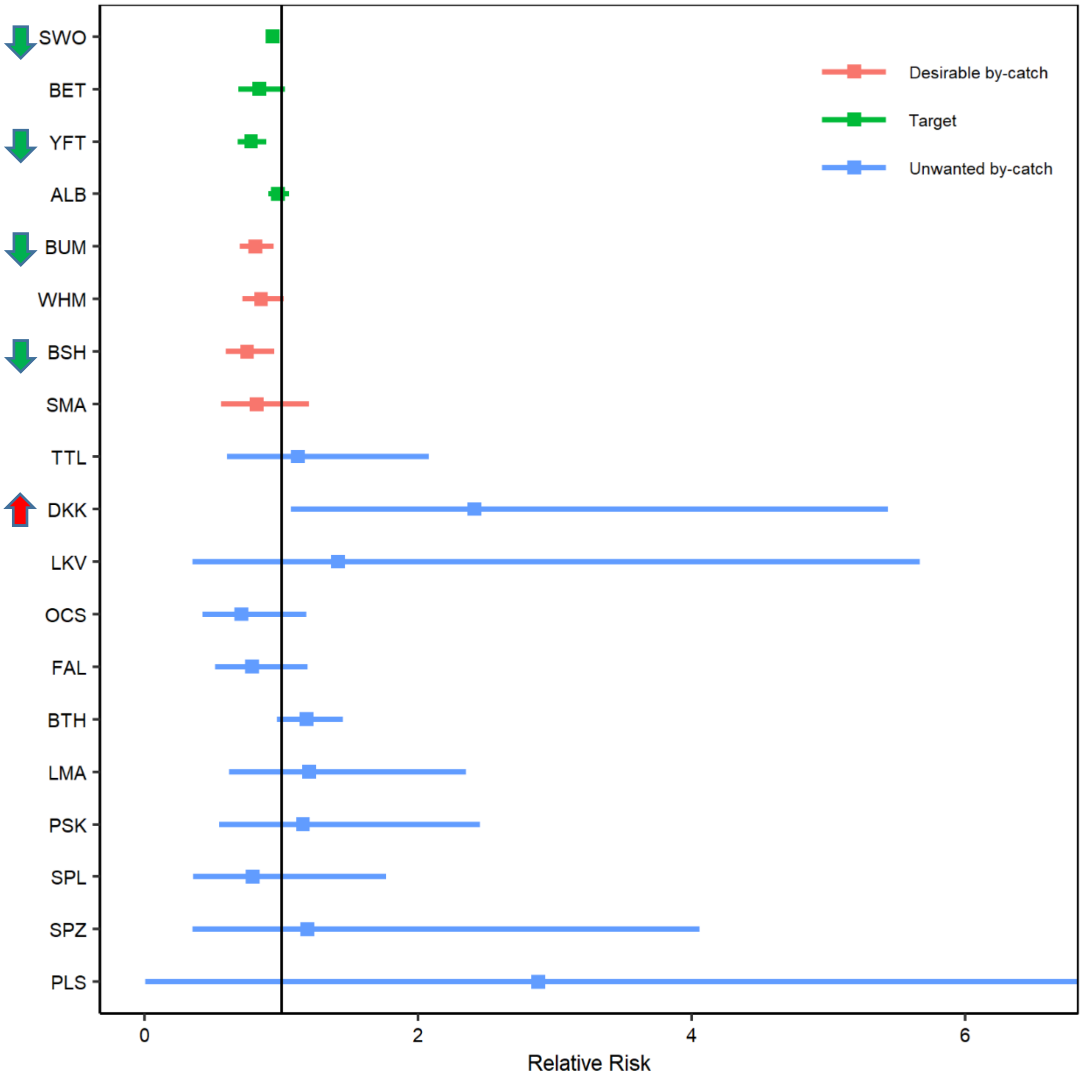


Figura 2.2. Síntesis de resultados del meta-análisis de la mortalidad en la recogida para los tres grupos de especies: especies objetivo, accesorias deseables y no deseadas. Las barras de error representan el 95% de intervalo de confianza. Las flechas en la parte izquierda se muestran solo para especies con efectos significativos, siendo la dirección de las flechas hacia arriba (incremento) y hacia abajo (reducción) de la mortalidad en la recogida. El color de las flechas asume que para todas las especies (objetivos y accesorias) una menor mortalidad en la recogida es positiva (verde), mientras que un aumento es negativo (rojo). (Nota: Los anzuelos en forma de J se consideran el control y los anzuelos circulares son los experimentales; un riesgo relativo (RR) > 1 indica que la mortalidad en la recogida es mayor con los anzuelos circulares).

En cuanto a los aspectos ecnómicos, si la flota de palangre europea cambiase los anzuelos tipo J por anzuelos circulares se esperaría un aumento en las capturas, sobre todo debido al aumento de tiburones, que compensaría la reducción de otras especies como el pez espada. Sin embargo, en términos de impacto económico, y teniendo en cuenta el marco regulatorio actual y los límites de capturas para las especies principales de tiburones, en caso de que se implementasen los anzuelos circulares en la flota de palangre europea, se esperaría una reducción del valor de las capturas. La reducción de valor ocurriría principalmente en el Atlántico Norte (pérdida de 7.0% del valor de la captura retenida), seguida por el Mediterraneo (pérdida del 4.4% sobre el valor de la captura retenida) y el Atlántico Sur (pérdida del 3.7%). La Table 2.1 ofrece un resumen de estos resultados. A este respecto, teniendo en cuanta que el uso de anzuelos circulares aumentaría las capturas pero reduciría su valor, no se recomienda el uso de anzuelos circulares para la flota de palangre de superficie que tiene el pez espada como objetivo.

En cuanto a las tallas, destacamos que la talla media de las capturas de pez espada, tanto para los anzuelos en forma de J como para los circulares, son mayores que las tallas mínimas de desembarco establecidas actualmente. Por el contrario, la talla media de marrajo capturada con ambos tipos de anzuelo es menor que la establecida actualmente. Además, la talla de madurez (talla a la que el 50% de la población ha alcanzado la madurez) para el marrajo varía entre 180 y 220 cm FL para machos y 270 y 300 cm FL para las hembras, lo que significa que los mínimos establecidos actualmente son adecuados para los machos (180 cm FL), pero inadecuados para las hembras (210 cm FL).

Tabla 2.1. Tabla resumen del análisis de las capturas de las especies principales con cambios (en capturas y valor de captura) desde anzuelos en forma de J a circulares, asumiendo las restricciones actuales sobre el tiburón azul (cuota de 32758 t) y marrajo (0 t). Los datos iniciales del análisis corresponden a capturas para toda la flota de palangre pelágico europea utilizando la base de datos de Tarea 1 de ICCAT (promedio de los últimos 5 años disponibles, 2014-2018). Las cuatro especies consideradas son pez espada, atún blanco, tiburón azul y marrajo, que conjuntamente representan el 95% de la captura retenida por la flota de palangre europea (en peso). Al final de la tabla se indican las diferencias entre el uso de anzuelos J y circulares (en capturas y su valor). Las flechas en la parte inferior asumen que un aumento de captura/valor es positivo (verde) y un descenso es negativo (rojo).

Especie	Valor (€/kg)	RR	Anzuelos J (T1 captura, t)			Anzuelo circular (captura simulada, t)			Valor con anzuelos J (€)			Valor con anzuelos circulares (€)		
			N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med
SWO*	7.1	0.82	5304.0	4960.0	6377.0	4349.3	4067.2	5229.1	37499280	35067200	45085390	30749410	28755104	36970020
ALB*	4.8	1.43	216.9	279.7	2674.8	310.2	399.9	3825.0	1041199	1342446	12839128	1488915	1919698	18359953
BSH**	1.6	1.08	32578.0	16203.7	96.1	32578.0	17500.0	103.7	52124800	25925969	153692	52124800	28000046	165988
SMA**	4.0	1.23	0.0	1278.7	0.2	0.0	1572.8	0.3	0	5114831	932	0	6291242	1146
Total			**38098.9**	**22722.1**	**9148.1**	**37237.5**	**23540.0**	**9158.2**	**90665279**	**67450446**	**58079142**	**84363124**	**64966091**	**55497107**
Diferencias (usando circular en lugar de J)						**-861.4**	**817.9**	**10.1**				**-6302154.8**	**-2484355.4**	**-2582035.4**
Diferencias (%)						**-2.3**	**3.6**	**0.1**				**-7.0**	**-3.7**	**-4.4**

* Las cuotas de ALB y SWO no se consideran porque la captura simulada es menor.
** Los límites de captura para BSH y SMA se utilizaron porque la captura simulada era mayor.

Tarea 2 – Aspectos técnicos y biológicos relacionados con los anzuelos

El objetivo principal de esta tarea es ofrecer consejo sobre los motivos técnicos y biológicos y los efectos prácticos de los anzuelos circulares en comparación con otras formas de anzuelo (p.e. anzuelo J, anzuelo japonés, anzuelo teracima, etc.), teniendo en cuenta la morfología del anzuelo circular (p.e, desplazamiento (o no), profundidad, longitud, mordedura, ángulo de curvatura, tipo de lengüeta, etc.).

Durante esta tarea se realizó un catálogo de las principales formas de anzuelos utilizadas a nivel global en pesquerías de palangre con sus respectivas medidas, estableciendo relaciones entre la longitud de los diferentes elementos de los anzuelos. Destacamos que el término "anzuelos circulares" no tiene una definición clara, en particular en relación a su punto angular y a si es un objeto definido en dos o tres dimensiones (p.e. con desplazamiento frente a sin desplazamiento). Asimismo, enfatizamos la heterogeneidad de tallas y formas de cada tipo de anzuelo observadas entre tipos de fabricantes como un problema mayor que podría explicar la variabilidad entre las respuestas estimadas a cada forma de anzuelo en relación a la captura de diferentes especies.

Se preparó y distribuyó un cuestionario a científicos internacionales identificados como responsables de programas de observación científica de pesquerías de palangre pelágico a nivel global. Se recibieron siete respuestas (10%), incluidas las de instituciones nacionales (gobiernos), institutos de investigación y ONGs. Seis organismos han implementado o están implementando programas de observadores en flotas de palangre or experimentos con diferentes tipos de palangres experimentales.

Los datos pesqueros que se recopilan, como el tipo y tamaño del arte, por ejemplo el ramal y el tipo de flotador etc. En cuanto a las capturas, en general se obtienen datos de las especies objetivo como accesorias. Las tallas de los especímenes se recopilan en la mayoría de programas de observadores, y además algunos programas recopilan información biológica adicional (p.e. sexo, madurez sexual, etc.). Casi todas las respuestas obtenidas mencionaron que los programas de observadores también recopilan datos de mortalidad en la recogida, incluyendo tiburones y rayas. Los resultados de la mayoría de estudios implementados están considerados en nuestro meta-analisis.

Finalmente, debido a la forma del anzuelo circular – punta girada hacia la caña con un ángulo teórico máximo de 90º con la tangente de la parte frontal del anzuelo relativa a la base – el anzuelo circular se desliza fuera del estómago del pez (al incrementar la tensión del sedal) sin engancharse con tejidos blandos. Se engancha con al contactar con las partes duras: sobre todo huesos maxilares.

Sin embargo, este comportamiento no se observa cuando existe desplazamiento en el anzuelo circular.

Tarea 3 – Consejo sobre otras variables y sus efectos

El objetivo principal de esta tarea es ofrecer consejo sobre si variables diferentes a la forma del anzuelo, como el cebo y tipo de sedal, podrían influenciar la retención y mortalidad en la recogida. Como en la Tarea 1, los efectos de estas variables se evaluaron y analizaron a través de meta-análisis específicos para cada especie objetivo y accesoria.

El uso de peces como cebo en lugar de calamar produjo una reducción significativa en la retención de rabil, pez vela y tortuga boba. Por el contrario, se observe una mayor retención de tiburón sedoso con el uso de peces en el cebo. En cuanto a la mortalidad en la recogida, el pez espada, el tiburón azul y de punta blanca sufrieron un incremento en la mortalidad en la recogida cuando se usó pescado en el cebo, mientras que para el tiburón sedoso ésta fue menor. En relación al material del sedal se encontraron pocos estudios y por este motivo los análisis son limitados. Los efectos en la retención fueron significativos solo para dos especies cuando se pasó del nylon al alambre, con una reducción en la retención para el marlín azul y un incremento para el tiburón azul.

Task 4 – Efecto de la profundidad de las líneas de palangre

El objetivo principal de esta tarea es ofrecer consejo sobre si la implementación de anzuelos circulares podría tener el mismo efecto sobre la capturabilidad, mortalidad y supervivencia independientemente de la profundidad y tiempo bajo el agua comparando y comentando, según fuese necesario, los resultados teniendo en consideración el reparto de esfuerzo pesquero entre zonas superficiales y profundas. En esta tarea, se consideraron estos cambios en los anzuelos en forma de J y en los circulares.

Destacamos que en general existen pocas referencias de calados profundos en palangres, en particular en relación con comparativas entre anzuelos de forma de J y circulares. La única especie para la que se pudo aplicar un metaanálisis fue el rabil, que no mostró diferencias significativas en las tasas de retención. Para la comparativa entre anzuelos de atunes y circulares fue posible para otras especies pero los efectos fueron insignificantes para todas ellas.

Para poder desarrollar esta tarea en el futuro será importante separar y considerar el esfuerzo pesquero del palangre entre zonas someras y profundas del Atlántico. Estos datos se encuentran en la base de datos (EFFDIS) de ICCAT, que actualmente no se encuentra disponible. Cuando esté disponible, el reparto de esfuerzo entre los dos componentes del palangre podrá ser tenido en consideración y lo que se presenta como ratios en el presente estudio podría convertirse en cambios de biomasa total.

Tarea 5 – Justificación para la exclusión de algunos estudios.

El objetivo principal de esta tarea fue ofrecer explicaciones para no utilizar algunos estudios científicos en los meta-análisis y conclusiones de este estudio.

El motivo más común es que los tamaños muestrales eran demasiado pequeños en algunos estudios, especialmente para las especies más raras y capturadas de manera ocasional. Este estudio excluye también artículos sobre artes de pesca diferentes al palangre pelágico, estudios que comparan flotas, estudios que no reportaron los datos necesarios para el metaanálisis, estudios con marcado satelital, que no separaban mortalidad post-marcado de las marcas con liberación prematura y estudios usando marcado por satélite cuyo objetivo principal fue evaluar movimientos.

Brechas de datos

Tras las tareas realizadas en el metaanálisis, especialmente las Tarreas 1, 3 y 4, se ofrece un sumario de las brechas de datos que pueden enfatizarse para priorizar futuros experimentos en el mar. En resumen, existen más estudios para palangres de superficie, especialmente interesados en factores como el tipo de anzuelo y cebo, y muchos menos sobre el material del sedal. Para palangres de profundidad las brechas de datos son más relevantes, especialmente para cambios en los anzuelos tipo J, con algunos más estudios con anzuelos atuneros (Tabla 2.2.).

Adicionalmente, la mayoría de estudios actuales se centran en cambiar una variable cada vez, por ejemplo cambiando anzuelos o tipo de cebo, pero de manera independiente y separada. Esto puede causar efectos secundarios en las variables d estudio. Sería importante que en un futuro se desarrollaran diseños factoriales que permitieran modificar más de una variable en un estudio, por ejemplo, cambiando cebos con diferentes tipos de anzuelo. Debido a los múltiples niveles de cada variable, estos estudios requerirían un esfuerzo considerable en términos de experimentos, pero serían adecuados para identificar cambios en diferentes factores. Finalmente, estos estudios deberían ser dirigidos de manera coordinada con científicos que trabajen con palangres pelágicos de otras regiones/flotas, para asegurar que todas las características de las flotas y las áreas del Atlántico y Mediterráneo fuesen consideradas.

Tabla 2.2. Sumario de brechas de datos en estudios para llevar a cabo metaanálisis sobre varias especies y factores. "Hook J" se refiere a estudios donde se cambiaron anzuelos en forma de J por circulares. "Hook T" se refiere a estudios con cambios de anzuelos atuneros por circulares. El gradiente de color de verde a rojo se utiliza para ilustrar el numero de estudios disponibles en cada celda de la table (limite superior (N=21) = verde; limite inferior (N=0) = rojo; color medio (N=5) = amarillo).

Sp	Palangres de superficie						Palangres de profundidad			
	Tasa de retención			Mortalidad en recogida			Tasa de retención		Mortalidad en recogida	
	Hook_J	Cebo	Sedal	Hook_J	Cebo	Sedal	Hook_J	Hook_T	Hook_J	Hook_T
SWO	19	7	3	6	4	2	2	4	0	2
BET	11	6	4	6	4	2	2	4	2	2
BFT	4	2	0	2	0	0	0	0	0	0
YFT	9	4	3	5	4	2	3	4	0	2
ALB	11	6	3	6	3	2	1	4	0	0
BUM	6	4	3	5	4	2	1	0	0	0
SAI	4	4	2	3	4	1	0	0	0	0
WHM	5	4	1	5	4	1	0	0	0	0
BSH	16	6	3	8	4	3	2	4	0	2
SMA	12	6	2	7	4	2	0	1	0	0
TTL	21	11	2	10	5	2	0	1	0	1
DKK	12	7	1	9	4	1	0	1	0	1
LKV	7	3	1	4	3	1	1	4	0	2
LKY	2	2	0	2	2	0	0	0	0	0
TUG	5	0	0	2	0	0	1	0	0	0
OCS	5	4	2	5	4	2	0	2	0	0
POR	5	2	1	2	1	0	0	0	0	0
FAL	8	4	3	5	4	2	1	0	0	0
BTH	4	5	2	4	4	2	2	3	0	1
LMA	3	3	1	3	3	1	0	0	0	0
PSK	5	4	3	5	4	2	0	2	0	0
SPL	5	2	0	3	1	0	0	2	0	0
SPZ	3	4	2	3	4	2	0	2	0	0
PLS	9	5	3	3	1	1	1	3	0	1

Résumé de Synthèse

Le principal objectif de cette étude réside dans la production d'une expertise à l'intention de la Direction Générale des Affaires Matines et des Pêches de l'Union Européenne quant à l'efficacité de l'utilisation des hameçons circulaires proprement dit pour réduire la mortalité des espèces non souhaitées (i.e espèces protégées et/ou sujettes à des obligations de rejets vivantes) tout à maintenant les rendements des espèces cibles et/ou la viabilité économique des pêcheries palangrières pélagiques. D'autres facteurs liés au processus de capture comme le type d'appât ou le matériel pour le bas de ligne sont aussi considérés.

Cette étude concerne les pêcheries palangrières pélagiques dans l'océan Atlantique et les mers adjacentes (Mer Méditerranée) ciblant l'espadon, les thons tropicaux et tempérés ainsi que des prises accessoires commerciales d'espèces de requins (e.g. peau-bleu et mako) et de marlins/voiliers contribuant à la viabilité économique de ces pêcheries.

Les tâches suivantes ont été développées dans le cadre du projet:

Tâche 1 – Conseils sur l'utilisation des hameçons circulaires

Le principal objectif de cette tâche est de produire des avis sur l'impact de l'introduction des hameçons circulaires dans les pêcheries palangrières, en particulier en termes de taux de rétention et de mortalités au virage et au rejet. Cette tâche a considéré séparément les espèces cibles, prises accessoires à valeur commerciales et espèces non conservées à bord. Pour cette tâche, nous nous sommes concentrés sur les aspects économiques liés à l'évolution des taux de rétention, ainsi que sur la forme de l'hameçon et le taux de maturité, par rapport à des valeurs de tailles limites en référence à la conservation des stocks.

L'espadon a été la seule espèce cible avec des effets significatifs sur le taux de rétention montrant une diminution significative lorsque les hameçons circulaires sont utilisés à la pace des hameçons droits (hameçon J). Plus précisément, quand les hameçons circulaires sont utilisés le taux de rétention de l'espadon diminue en moyenne de 18% avec des variations de 6% à 27%. L'espadon et le thon jaune ont montré une mortalité au virage plus faible avec l'utilisation des hameçons circulaires. Pour les prises accessoires à valeur commerciale, le marlin bleu et le marlin blanc ont des taux de rétention plus faible avec les hameçons circulaires et une réponse inverse pour le requin mako. Pour la mortalité au virage, le marlin bleu et le requin peau-bleu montre des valeurs plus faibles pour les hameçons circulaires. Pour les espèces non conservées, la tortue caouanne et la tortue luth montrent des taux de rétention plus faibles pour les hameçons circulaires, alors que pour la mortalité au virage seule une augmentation

significative a été testée pour la tortue luth avec des hameçons circulaires. Les Figures 2.1 et 2.2 ci-dessous présentent une synthèse de ces résultats en termes de taux de rétention et de mortalité au virage pour les différentes espèces avec un changement du type d'hameçon.

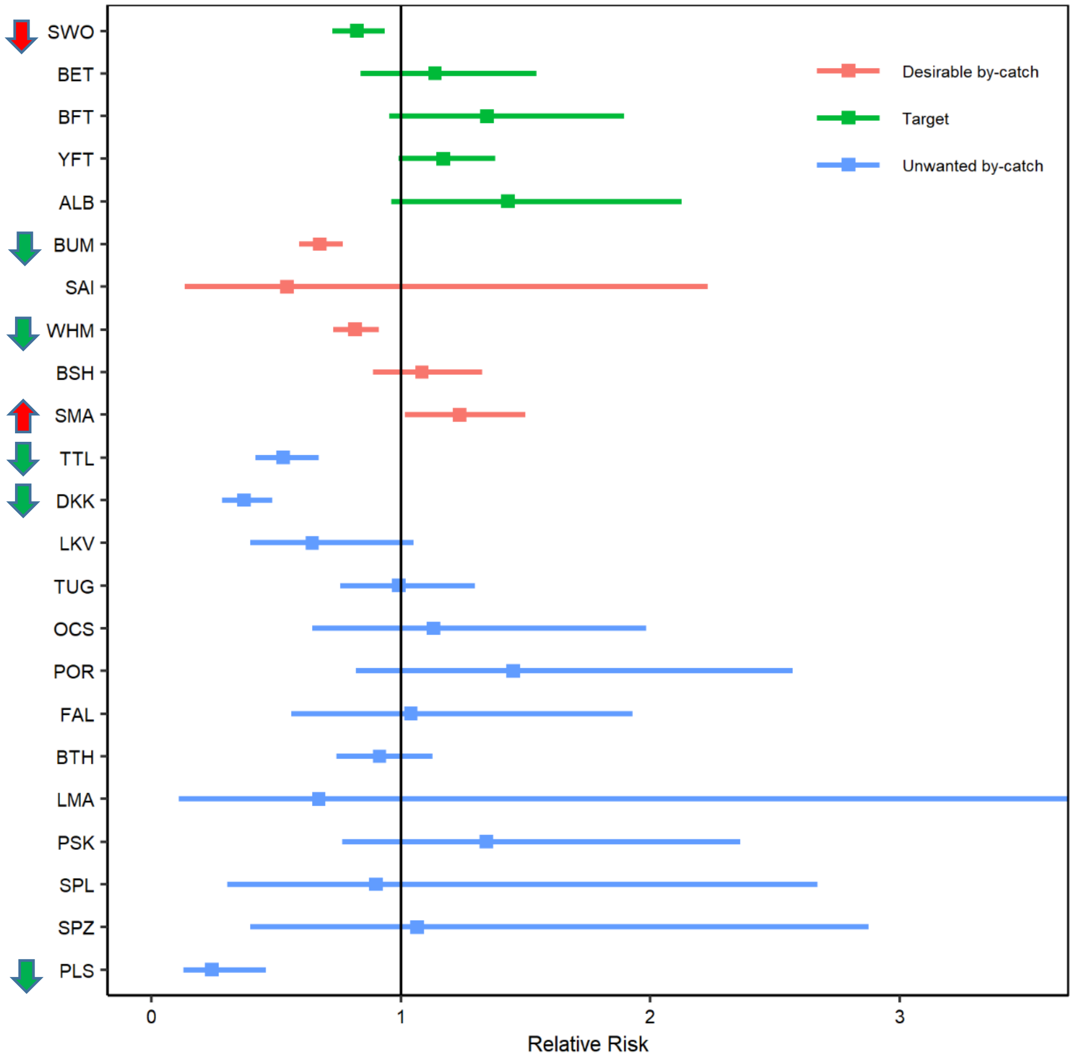


Figure 2.1. Synthèse des résultats de la méta-analyse sur le taux de rétention des 3 groupes d'espèces : cibles, prises accessoires à valeur commerciale et espèces non conservées à bord. Les barres d'erreurs correspondent à un intervalle de confiance de 95%. Les flèches à gauche ne sont présentées que pour les espèces avec un effet significatif testé, avec une direction de la flèche vers le haut pour une augmentation et vers le bas pour une baisse. La couleur de la flèche suppose que pour les espèces cibles une augmentation de la rétention constitue un effet positif (vert) et une réduction au contraire est un effet négatif (rouge), l'inverse étant supposé pour les prises accessoires à valeur commerciale et les espèces non conservées à bord, ainsi une diminution de la rétention est considérée comme bénéfique (vert) et son augmentation comme néfaste (rouge). (Note: Les hameçons droits sont considérés comme "contrôle" et les hameçons circulaires expérimentaux, ainsi un risque relatif (RR) >1 signifie une rétention supérieure pour les hameçons circulaires).

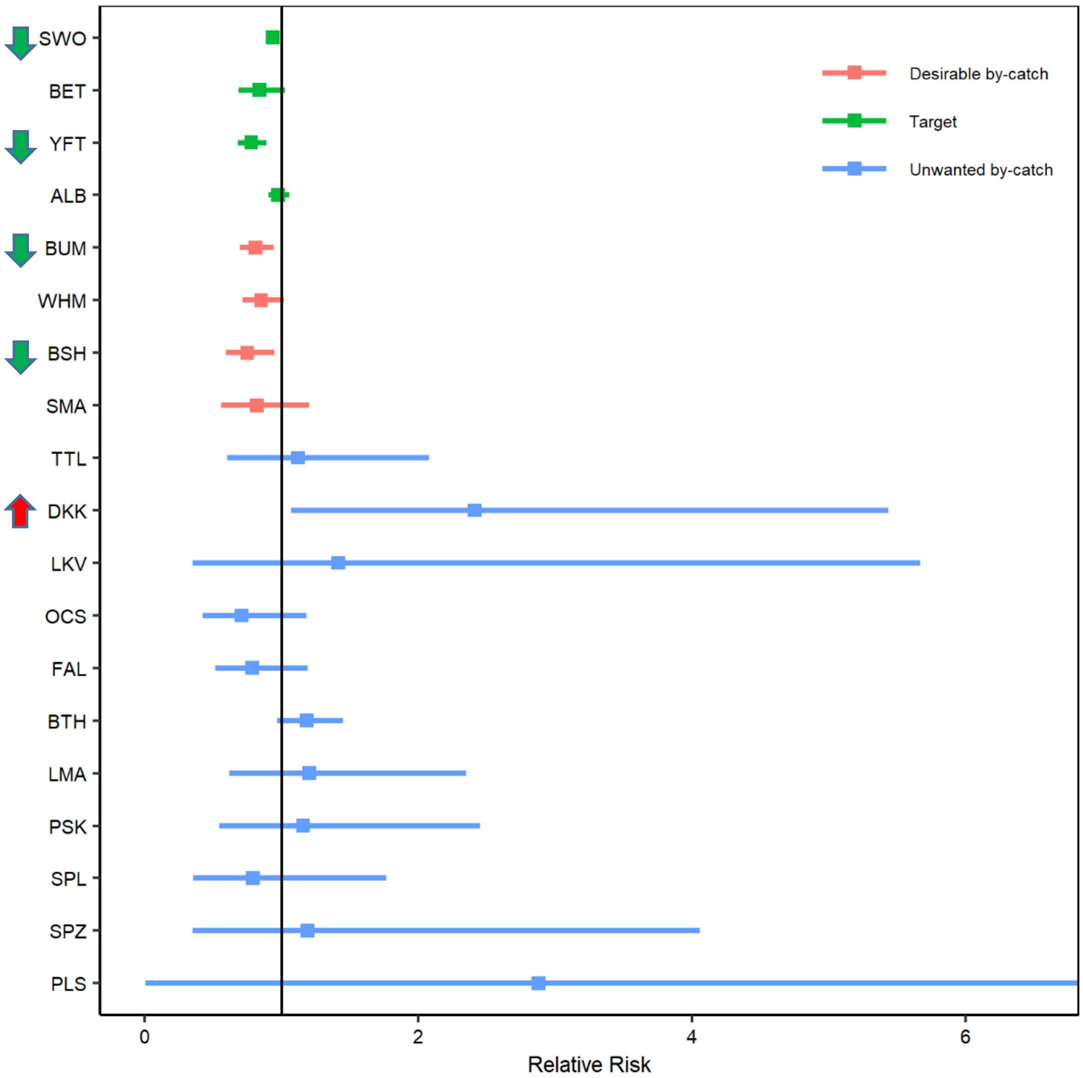


Figure 2.2. Synthèse des résultats de la méta-analyse sur la mortalité au virage pour les 3 groupes d'espèces : cibles, prises accessoires à valeur commerciale et espèces non conservées à bord. Les barres d'erreurs correspondent à un intervalle de confiance de 95%. Les flèches à gauche ne sont présentées que pour les espèces avec un effet significatif testé, avec une direction de la flèche vers le haut pour une augmentation et vers le bas pour une baisse de la mortalité au virage. La couleur de la flèche suppose que pour les trois groupes d'espèces espèces cibles une faible mortalité au virage est bénéfique alors qu'une forte mortalité est néfaste (rouge). (Note: Les hameçons droits sont considérés comme "contrôle" et les hameçons circulaires expérimentaux, ainsi un risque relatif (RR) >1 signifie une rétention supérieure pour les hameçons circulaires).

En termes de retombées économiques, si la flottille palangrière pélagique de l'Union Européenne devait remplacer les hameçons droits par les hameçons circulaires, une augmentation des captures serait attendue, principalement car l'augmentation de la rétention des requins compenserait la diminution de la rétention d'espèces comme l'espadon. En revanche, en ce qui concerne la valeur des prises, et en prenant en compte les régulations/quotas en vigueur pour les principales espèces de requins, une implémentation de l'utilisation des hameçons circulaires par la pêcherie européenne conduirait à une réduction de la valeur des débarquements. La principale diminution affecterait l'Atlantique Nord (diminution de 7% de la valeur des prises), puis la Méditerranée (diminution de 4.4% de la valeur des prises) et l'Atlantique Sud (diminution de 3.7% de la valeur des prises). Le tableau 2.1 présente un résumé de ces résultats.

Ainsi, considérant que l'utilisation des hameçons circulaires conduirait à une augmentation des débarquements mais une diminution de leur valeur, ce type d'hameçon ne peut être recommandée pour la pêcherie palangrière de surface ciblant l'espadon.

En ce qui concerne la taille des captures, il est noté que les tailles moyennes des captures de l'espadon quelque soit le type d'hameçon, J ou circulaire, sont plus grandes que les options en cours concernant les tailles minimales de débarquements. Contrairement à cela, la taille moyenne de capture du requin mako quelque soit le type d'hameçon est inférieure à la taille actuellement préconisée dans les options d'aménagement du stock. De plus, la taille à maturité (taille à laquelle 50% de la population a atteint la maturité sexuelle) du requin mako varie entre 180 et 220 cm (longueur à la fourche, LF) pour les mâles et 270 à 300 cm (LF) pour les femelles signifiant que la taille minimale retenue pour les mesures de conservation est relativement adéquate pour les mâles (180 cm LF) mais pas pour les femelles (210 cm LF).

Tableau 2.1. Synthèse de l’analyse par stocks des changements sur les captures et leurs valeurs respectives induits par un remplacement des hameçons droits par les hameçons circulaires, en appliquant les restrictions sur les captures du requin peau-bleu (quota de 32748 t) et du requin mako (débarquements nuls). Pour le lancement de l’analyse, les données correspondant aux captures par stock pour l’ensemble de flotte palangrière européenne sont extraites de la base des données de la tâche 1 de la CICTA (moyenne des données de capture disponibles des 5 dernières années 2014- 2018). Les quatre espèces considérées sont l’espadon, le germon, le requin peau-bleu et le requin mako, qui ensemble représentent 95% des débarquements en volume de la flottille palangrière pélagique européenne. Au bas du tableau, les différences entre les captures et les valeurs pour les hameçons doits et circulaires sont mentionnées. Les flèches au bas du tableau supposent qu’une hausse dans les captures et/ou leur valeur correspond à une retombée positive (vert) du changement alors qu’une diminution est une retombée négative (rouge).

Sp	Valeur (€/kg)	RR	Hameçon droit (T1 capture, t)			Hameçon circulaire (capture simulée, t)			Valeur des prises pour hameçon droit (€)			Valeur des prises pour hameçon circulaire (€)		
			N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med
SWO*	7.1	0.82	5304.0	4960.0	6377.0	4349.3	4067.2	5229.1	37499280	35067200	45085390	30749410	28755104	36970020
ALB*	4.8	1.43	216.9	279.7	2674.8	310.2	399.9	3825.0	1041199	1342446	12839128	1488915	1919698	18359953
BSH**	1.6	1.08	32578.0	16203.7	96.1	32578.0	17500.0	103.7	52124800	25925969	153692	52124800	28000046	165988
SMA**	4.0	1.23	0.0	1278.7	0.2	0.0	1572.8	0.3	0	5114831	932	0	6291242	1146
Total			**38098.9**	**22722.1**	**9148.1**	**37237.5**	**23540.0**	**9158.2**	**90665279**	**67450446**	**58079142**	**84363124**	**64966091**	**55497107**
Differences (using circle instead of J hooks)						**-861.4**	**817.9**	**10.1**				**-6302154.8**	**-2484355.4**	**-2582035.4**
Differences (%)						**-2.3**	**3.6**	**0.1**				**-7.0**	**-3.7**	**-4.4**
						↓	↑	↑				↓	↓	↓

* ALB et SWO : les quotas ne sont pas considérés puisque les captures simulées sont inférieures à ces limites
** BSH et SMA : les limites de captures et quotas ont été considérés les captures simulées étant supérieures à ces limites

Tâche 2 – Aspects techniques et biologiques liés aux hameçons

Le principal objectif de cette tâche était de fournir un avis sur les raisons techniques et biologiques concernant les supposés effets pratiques des hameçons circulaires comparés à d'autres formes (droit, japonais ou à thon et teracima) en prenant en compte la morphologie de l'hameçon circulaire (désaxage de la pointe, mordant, longueur de la hampe, ouverture, angle de la pointe, type de barbe, etc).

Un catalogue des principale formes et tailles des hameçons déployées dans les pêcheries palangrières pélagiques mondiales a été produit avec les mesures respectives d'éléments de l'hameçon et établissant des relations entre la longueur de l'hameçon et d'autres variables. Il est noté que le terme ‛hameçon circulaire » ne dispose pas d'une définition bien établie en ce qui concerne l'inclinaison de la pointe et s'il s'agit d'un objet en 2 ou 3 dimensions (présence ou non d'un désaxage de la pointe). De même, l'hétérogénéité de la taille et de la forme d'un type d'hameçon donné entre les fabricants est soulevée comme un problème majeur qui pourrait expliquer la variabilité importante des réponses sur la rétention à l'hameçon estimées pour plusieurs espèces.

Un questionnaire a été développé et diffusé auprès de scientifiques internationaux identifié comme responsables de programmes observateurs scientifiques embarqués pour les pêcheries palangrières pélagiques de l'océan mondial. Sept réponses (10%) ont été obtenues, elles proviennent d'institutions gouvernementales nationales, d'organismes de recherche, d'organisations non gouvernementales. Six interlocuteurs avaient déjà mis en place ou étaient en train de mettre en place des programmes observateurs pour les pêcheries palangrières ou des essais de pêche expérimentales. Des données de pêche sont communément collectées par les observateurs comme l'engin de pêche utilisé, la taille des éléments de l'engin, par exemple, avançon, orin de bouée, etc. Pour les captures, les données sur les espèces sont collectées pour les espèces cibles et accessoires. La taille des captures est collectée dans la plupart de ces programmes ainsi que des informations additionnelles sur la biologie (e.g. sexe, maturité sexuelle, etc). Presque tous les interlocuteurs ont mentionné le fait que des données sur la mortalité au virage des spécimens étaient collectées, en incluant requins et raies. Pour les programmes implémentés, les résultats de la plupart d'entre eux ont été publiés et les données considérées dans notre méta-analyse.

Finalement, en raison de la forme particulière de l'hameçon circulaire avec la pointe de la barbe retournée vers la hampe avec un angle maximum théorique de 90° avec la tangente de la barbe en référence à une base horizontale – l'hameçon circulaire glisse hors de l'estomac du poisson (quand la tension de la ligne augmente) sans accrocher les tissus mous du poisson. Il s'engage au contact des parties dures, principalement les mâchoires. Pour autant, le respect de ce fonctionnement quand la pointe de l'hameçon est désaxée n'est pas vraiment établi.

Tâche 3 – Avis sur d'autres variables et effets

Le principal objectif de cette tâche était de fournir un avis concernant l'influence sur la rétention et la mortalité au virage de facteurs autres que la forme de l'hameçon comme l'appât et le type de bas de ligne. Comme pour la tâche 1, l'effet de ces variables a été testé et analysé à partir de méta-analyses spécifiques, for les espèces cibles, les prises accessoires à valeur commerciales et les espèces non conservées.

Quand le poissons est utilisé comme appât à la place du calmar, des diminutions significatives de la rétention du thon jaune, du marlin voilier et de la tortue caouanne ont été testés. A l'inverse, une augmentation significative de la rétention du requin soyeux avec le poisson comme appât a été testée. Pour la mortalité au virage, L'espadon, le requin peau-bleu et le requin longimane ont une mortalité au virage significativement plus forte avec le poisson comme appât, alors que l'inverse est testé pour le requin soyeux. Pour ce qui concerne le matériau du bas de ligne, peu d'études sont disponibles et en conséquence les analyses ont été beaucoup plus limitées. Les effets sur le taux de rétention ont été significatifs pour deux espèces avec un remplacement du nylon par du câble métallique, avec une diminution de la rétention du marlin et une augmentation pour le requin peau-bleu.

Tâche 4 – Effets de la profondeur de la palangre

L'objectif de cette tâche était de fournir un avis sur les différences de l'effet d'une implémentation des hameçons circulaires sur la capturabilité, la mortalité et la survie en référence à la profondeur de pêche et à la durée du mouillage en comparant et commentant, le cas échéant, les résultats en prenant en compte la répartition de l'effort de pêche entre des opérations de pêches en surface et profondes. Dans cette tâche, les changements des hameçons droits par des hameçons circulaires et des hameçons « à thons » par des hameçons circulaires ont été considérés.

Il fut noté qu'en général peu de références concernent des pêches profondes en particulier en ce qui concerne la comparaison entre hameçons droits et hameçons circulaires. L'unique espèce pour laquelle il fut possible de mener une méta-analyse a été le thon jaune, pour lequel aucune différence significative a pu être montré pour le taux de rétention. Pour la comparaison entre hameçon « à thon » et hameçon circulaire, il fut possible de conduite une méta-analyse pour plusieurs espèces, mais aucun effet significatif put être mis en évidence et ce quelles que soient les espèces.

Pour cette tâche, dans le futur il sera important de séparer et considérer la répartition de l'effort de pêche dans des stratégies de pêche de surface et profondes dans l'océan

Atlantique. Ces données dépendent de la base de données sur la distribution de l'effort de pêche (EFFDIS) de la CICTA qui n'est pas encore disponible. Lors de sa mise à disposition, la répartition de l'effort entre ces deux stratégies de pêche pourra être prise en considération, et ce qui fut présenté comme ratio dans cette étude pourrait être converti en changement de biomasse totale.

Tâche 5 – Justification de l'exclusion de certains travaux

L'objectif principal de cette tâche consistait à fournir des explications justifiant l'exclusion de certains travaux dans nos méta-analyses et les conclusions.

La principale raison commune d'exclusion des travaux concernait un effectif trop réduit de l'échantillon, en particulier pour les espèces les plus rares capturées ou rencontrées plus occasionnellement. Ce travail a aussi exclu des publications faisant référence à des travaux non dédiées aux palangres pélagiques, des études comportant différentes flottilles introduisant des facteurs de confusion, des études n'ayant pas reportées les données utiles aux méta-analyses, des données sur des marquages électroniques ne distinguant pas la mortalité après rejet d'un détachement prématuré du la marque et des études à partir de marquages électroniques dont l'objectif principal concernait l'analyse des mouvements.

Manque de données

Après les méta-analyses réalisées, spécifiquement pour les tâches 1, 3 et 4, nous avons produit un résumé de l'actuel manque de données qui mérite d'être signalé afin de prioriser une future planification de campagnes d'expérimentations en mer. En résumé, il y a plus d'études disponibles pour les pêches de surface, en particulier pour des facteurs comme le type d'hameçon et l'appât et beaucoup moins pour le matériau du bas de ligne. Pour la stratégie de pêche profonde, le manque de données est bien plus considérable, en particulier pour les changements en hameçons circulaires, bien que quelques études soient disponibles pour les hameçons « à thon » (Tableau 2.2).

En outre, la plupart des études actuelles se focalisent sur le changement d'une seule variable à la fois, par exemple changer les hameçons ou les types d'appâts mais d'une manière indépendante et distincte. Cela peut générer des effets de confusion pour ces variables lorsqu'elles sont étudiées.

Il serait ainsi important dans le futur de planifier des études avec des plans factoriel complet avec un changement de plusieurs variables au sein d'une même étude, par exemple et changeant les appâts entre divers types d'hameçons. En raison du niveau multiple des diverses variables, ces études nécessiteraient un effort considérable en termes d'expérimentations en mer mais elles seraient bien plus performantes pour l'identification de changements associées aux divers facteurs. Enfin, ces études devraient être conduites en liaison avec des scientifiques travaillant avec d'autres pêcheries nationales/flottilles palangrières, afin de s'assurer que toutes les caractéristiques des flottilles et toutes les zones de pêche de l'océan Atlantique et de la Mer Méditerranée seront couvertes.

Tableau 2.2. Résumé des manques de données dans les études susceptibles d'être considérées dans les méta-analyses sur les diverses espèces et facteurs. Hameçon (Ham.) J se réfère à des travaux sur le changement d'hameçons droits par des hameçons circulaires, alors que "Ham. T" se réfère à des études sur le changement d'hameçons "à thon" par des hameçons circulaires. Un gradient de couleur de vert à rouge est utilisé sur le nombre d'études disponibles pour chaque cellule du tableau. (Note sur le gradient de couleur : limite supérieure (N=21) en vert, limite inférieure (N=0) en rouge et limite intermédiaire (N=5) en jaune).

SP	Palangre dérivante de surface						Palangre dérivante profonde			
	Taux de rétention			Mortalité au virage			Taux de rétention		Mortalité au virage	
	Ham. J	Appât	Bas de ligne	Ham. J	Appât	Bas de ligne	Ham._J	Ham._T	Ham. J	Ham. T
SWO	19	7	3	6	4	2	2	4	0	2
BET	11	6	4	6	4	2	2	4	2	2
BFT	4	2	0	2	0	0	0	0	0	0
YFT	9	4	3	5	4	2	3	4	0	2
ALB	11	6	3	6	3	2	1	4	0	0
BUM	6	4	3	5	4	2	1	0	0	0
SAI	4	4	2	3	4	1	0	0	0	0
WHM	5	4	1	5	4	1	0	0	0	0
BSH	16	6	3	8	4	3	2	4	0	2
SMA	12	6	2	7	4	2	0	1	0	0
TTL	21	11	2	10	5	2	0	1	0	1
DKK	12	7	1	9	4	1	0	1	0	1
LKV	7	3	1	4	3	1	1	4	0	2
LKY	2	2	0	2	2	0	0	0	0	0
TUG	5	0	0	2	0	0	1	0	0	0
OCS	5	4	2	5	4	2	0	2	0	0
POR	5	2	1	2	1	0	0	0	0	0
FAL	8	4	3	5	4	2	1	0	0	0
BTH	4	5	2	4	4	2	2	3	0	1
LMA	3	3	1	3	3	1	0	0	0	0
PSK	5	4	3	5	4	2	0	2	0	0
SPL	5	2	0	3	1	0	0	2	0	0
SPZ	3	4	2	3	4	2	0	2	0	0
PLS	9	5	3	3	1	1	1	3	0	1

3. GENERAL INTRODUCTION

General introduction to this specific contract and study

EASME has commissioned the AZTI-led Consortium (AZTI, AGROCAMPUS, CEFAS, IEO, IPMA, Wageningen Marine Research, IRD, MRAG) for the Framework Contract (FWC) EASME/EMFF/2016/008 for the "Provision of scientific advice for fisheries beyond EU waters". Within this FWC, the present study and interim report refers to the Specific Contract (SC) Nº 16, namely for the "Evaluation of the effects of hooks' shape & size on the catchability, yields and mortality of target and bycatch species, in the Atlantic Ocean and adjacent seas surface longline fisheries".

The main purpose of this study is to provide advice to the Directorate-General for Maritime Affairs and Fisheries (DG MARE) on whether the use of circle hooks *per se* is effective in reducing mortalities of unwanted species (i.e. species protected and/or subject to release-alive policy), without significantly affecting the catch rates and yields of the targeted species and/or the economic viability of longline fisheries. Other gear configuration modifications, namely bait type and leader material, are also being considered.

This study concerns the pelagic longline fisheries targeting, in the Atlantic Ocean and adjacent seas (Mediterranean Sea), swordfish, tropical and/or temperate tunas, as well as desirable bycatches of certain species of shark (e.g. blue sharks and shortfin mako) and marlins/sailfishes contributing to the economic viability of the fisheries.

Tasks being performed

Within this study the following tasks were carried out:

- **Task 1:** Advise on the impact of introducing the compulsory use of circle hooks by the pelagic longline fisheries, as a priority in the Atlantic but possibly also in adjacent seas.
- **Task 2:** Provide technical and biological reasons to explain the supposed practical effects of circle hooks with respect to other shapes of hook (e.g., J hook, Japanese hook, teracima hook) by taking into account the circle hook morphology (e.g., offset/non-offset, width, length, gape, bite, incurved point angle, barb type).
- **Task 3:** Advise on whether issues other than hook shape, such as hook size, bait type, depth of fishing, soak time, leader type, etc., could explain the reported differences. Comparison and comments on the results will be provided.
- **Task 4:** Advise on whether the implementation of circle hooks could have the same effects on catch rates, retention rates, mortality and survivability, where

possible to estimate, regardless of the fishing depth and/or soaking time, with comparison of and comments on the results. This should consider the fishing effort repartition between shallow and deep fishing operations.

- **Task 5:** Provide justifications for which scientific papers may be considered not scientifically sound and have not been retained for the main analysis and conclusions.

Objective and structure of the report

This document is the Final (Draft) Report of the project. Each task is one chapter of the report and starts with a summary of the key findings, followed by the objectives, methods, results and discussion. In each task reported, the main summaries from the results and discussion are presented in the main report body, while all detailed and additional information is provided in the Appendices.

The report contains several Appendices, organised as follows: Appendix I provides the list of deliverables, meetings and milestones; Appendix II provides the list of abbreviations and acronyms used in the report; Appendix III provides the references used in the meta-analysis; Appendix IV provides the detailed species-specific analysis for sub-task 1.1; Appendix V provides the detailed species-specific analysis for sub-task 1.2; Appendix VI provides the detailed species-specific analysis for sub-task 1.3, Appendix VII provides the detailed species-specific analysis for task 3; Appendix VIII provides the detailed species-specific analysis for task 4; Appendix IX provides the catalogue of hooks; Appendix X provides the measurements of hooks; and Appendix XI provides the online questionnaire used to gather data on the hook types and hooking mortality.

4. TASK 1 – ADVICE ON THE USE OF CIRCLE HOOKS

Key findings

- Meta-analyses were carried out for retention rates and at-haulback mortality for target species, desirable bycatch and unwanted bycatch. When circle hooks are used, there are significant decreases in the retention rates of swordfish, blue and white marlins, loggerhead and leatherback sea-turtles, and the pelagic stingray. By contrast, the shortfin mako has a significantly higher retention with circle hooks.
- In terms of at-haulback mortality, there is a decrease for swordfish, yellowfin tuna, blue marlin and blue shark when circle hooks are used. By contrast, at-haulback mortality increases significantly for the leatherback sea turtle with the use of circle hooks.
- If the EU pelagic longline fleet changed from J to circle hooks, there would be increases in the catch (in biomass), mostly due to increase in retention of sharks, which would be greater than the reduction in species like swordfish.
- However, in terms of economic impact, and taking into account current regulations/quotas for the main shark species, if circle hooks were implemented for the EU pelagic longline fleets, there would be a reduction in the value of the retained catch of 7.0% for the North Atlantic, 3.7% for the South Atlantic and 4.4% in the Mediterranean. The main driver for this would be loss in species like swordfish, that could not be compensated for by the higher retention of sharks because of regulations that would require the discard of the increased shark catch when using circle hooks.
- For swordfish, the mean capture sizes regardless of using J or circle hooks are higher than the currently established options for minimum landing sizes (119 or 125 cm lower jaw fork length (LJFL) in the Atlantic). By contrast, for shortfin mako the mean sizes captured with both hooks is smaller than one of the current management options establishing minimum retention sizes for that species in the North Atlantic.
- In terms of size selectivity, J hooks and circle hooks with offset tend to capture smaller swordfish compared to circle hooks without offset, while the opposite is observed with blue shark, i.e., smaller species are captured with circle hooks without offset compared with larger specimens with J hooks and circle hook with offset. For the shortfin mako the size selectivity is very similar between J hooks and circle hooks without offset.

- With regard to the size at first maturity, the only pelagic shark with a minimum size limit (as one of the conservation options) is shortfin mako (180 cm FL for males and 210 cm FL for females); however, the size at maturity varies between 180 and 220 cm FL for males and between 270 and 300 cm FL for females.

Objectives

The main objective of this task is to provide advice on the impact of introducing the compulsory use of circle hooks in pelagic longline fisheries, as a priority in the Atlantic but also possibly in adjacent seas such as the Mediterranean.

To accomplish this, task 1 is divided in the following 6 sub-tasks:

- Sub-task 1.1: Retention rates and discarded/post-release mortality of targeted species.
- Sub-task 1.2: Retention rates and discarded/post-release mortality of desirable bycatch species.
- Sub-task 1.3: Retention rates and discarded/post-release survivability of unwanted bycatch species.
- Sub-task 1.4: Short-term (3-5 years) and long term (>10 years) economic profitability of the fishing activities concerned by taking into account the retention rates of targeted species and desirable bycatch species.
- Sub-task 1.5: The optimum hook size and shape to ensure compliance with the minimum conservation reference size.
- Sub-task 1.6: The appropriateness of the existing or potential new minimum conservation reference size.

Methodology

A database of published references (scientific papers, technical papers and scientific reports) was compiled and is provided in Appendix III. Following Reinhardt et al. (2018), the term "reference" is used to refer to a document, while "experiment" is used to refer to a unique data set considered in the analysis. An experiment is considered unique if it differs with respect to attributes such as the year of study or season, location, gear or fleet. Therefore, each reference can have more than one experiment. Each experiment was assigned a unique number in the database.

The data collected from each reference was dependent on the availability of the specific information, or the possibility of using proxies to derive specific information. In general, and when available, the compiled data includes date, general location, species, set type, hook type, size, offset and manufacturer, bait type, leader type, number of hooks, total catch, and at-haulback mortality. The set types have been classified as deep or shallow setting, depending mostly on the target species of the fishery. Typically, swordfish and shark targeting sets that tend to operate down to a maximum of around 100 m depth have been classified as shallow sets; while tropical tuna targeting sets tend to operate mainly between 100 and 300 m depth and have been classified as deep sets. Hook types were classified as "circle", "J" or "tuna" hook and, when available, information on hook size, offset and manufacturer was also recorded. Bait types were generally classified as "fish" or "squid", but other more specific baits can also be used and all those were noted in the database. Leader types are usually "nylon" or "wire" and that was also recorded when the information was available.

The specific details on each sub-task from this particular task are described below.

Sub-task 1.1: Retention rates and discarded/post-release mortality of targeted species

This sub-task focused on the retention rates, at-haulback mortality and discarded/post-release mortality of targeted species, namely swordfish, bigeye tuna, yellowfin tuna, bluefin tuna and albacore. The sub-task 1.1 described here, together with sub-tasks 1.2 (desirable bycatch) and 1.3 (unwanted bycatch) described below, enable contrasts, comparisons and options in terms of trade-offs from the results that might be achieved for each specific group (i.e., target species vs. desirable bycatch vs. unwanted bycatch).

The meta-analysis carried out was based on the method used by Reinhardt et al. (2018), where the differences were calculated and shown as Relative Risk (RR). Specifically, we carried out a random effects meta-analysis from the compiled database described above. In this specific sub-task, the effect that was studied was the hook effect, combining the effects of all other variables.

For each species, we first calculated the combined effects (i.e., relative risk) from all studies available from the compiled database. This was followed by a validation procedure, to identify and eventually exclude possible outliers with significant leverage in the models.

The reference value for the RRs is 1.0, which represents no differences between treatment and controls. An RR > 1.0 indicates higher values for treatment compared with the control (e.g., higher retention or at-haulback mortality with circle compared to J-hooks), while an RR < 1.0 indicates lower values for treatment compared with the control (e.g., lower retention or at-haulback mortality with circle compared to J-hooks).

The RR is calculated as follows:

$$RR = \frac{ai/n1i}{ci/n2i}$$

where for the i^{th} experiment, ai is the number of animals caught on the experimental treatment (e.g., circle hooks), $n1i$ is the number of experimental hooks fished, ci is the number of animals caught on the control treatment (e.g., J-hooks), and $n2i$ is the number of control hooks used.

For the comparison between bait types, the experimental treatment considered was fish bait, while the control was squid. For the leader material analysis, the treatment considered was wire leaders while the control was nylon (monofilament) leaders.

The estimations were carried out using the "metafor" package (Viechtbauer, 2010) in R 3.5.1 (R Core Team, 2018). The RR value was log-transformed to normalise the distribution of effect sizes around zero and to meet the assumption of normality for the analysis. 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, vi, for ln(RR) of the i^{th} experiment was calculated as:

$$Vi = \frac{1}{ai} - \frac{1}{n1i} + \frac{1}{ci} - \frac{1}{n2i}$$

For the validation procedure, we used a multiple step approach. The first step was to calculate and test the heterogeneity value (I^2), which represents the extent to which effect sizes vary within the meta-analysis (as a percentage, with low values representing low heterogeneity and high values representing high heterogeneity). High values of I^2 can be problematic from a statistical 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 mean 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 defined any study as an outlier if study confidence intervals did not overlap with the confidence interval of the pooled effect calculated from the meta-analysis. This is a simple way of determining statistical significance, in this case by determining whether the confidence intervals of individual studies and the pooled effects overlap or not (when they do not overlap, individual studies are considered outliers).

The third and final step was influence analysis. For this, several values were estimated and presented, each representing different influence measures. This type of influence analysis has been described by Viechtbauer and Cheung (2010), and the outcomes should be analysed 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:

- Difference in fits (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 the value when it is excluded, represented as scaled distances in relation to the mean of the observation;
- Covariance ratio (cov.r): 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 test on the horizontal-axis, and its influence on the pooled effect size on the vertical-axis (Baujat et al*.,* 2002). Studies represented on the right side of the Baujat plot 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 was re-calculated k-1 times, each time leaving out one study (with k = number of studies available). This was then finally analysed in terms of the overall gains in homogeneity, as well as changes in the final model estimations.

Concerning the post-release mortality, the option to conduct specific meta-analysis was explored. However, at this point, there are no studies with an experimental design to compare circle and J-hooks that have reported on post-release mortality estimates. Therefore, for this report, we provided summary tables with the post-release mortality studies that are available for those species described in sub-tasks 1.1 (target), 1.2 (desirable bycatch) and 1.3 (unwanted bycatch). Those detailed summary tables are provided at the end of each species meta-analysis in Appendix IV.

Sub-task 1.2 – Retention rates and discarded/post-release mortality of desirable bycatch species

This sub-task is similar to sub-task 1.1 but focuses on the retention rates, at-haulback mortality and discarded/post-release mortality of desirable bycatch species, namely blue shark, shortfin mako, and marlins/sailfishes. The methods used are the same as described above for sub-task 1.1.

Sub-task 1.3 – Retention rates and discarded/post-release survivability of unwanted bycatch species

This sub-task is similar to sub-tasks 1.1 and 1.2 described above but focuses on the retention rates, at-haulback mortality and discarded/post-release survivability of unwanted bycatch species, namely sea turtles and protected (i.e., no-retention) elasmobranchs. The methods used are the same as described above for sub-task 1.1.

Sub-task 1.4 – Short-term (3-5 years) and long term (>10 years) economic profitability of the fishing activities concerned by taking into account the retention rates of targeted species and desirable bycatch species

This sub-task focuses on the economic profitability of the fishing activities concerned, taking mostly into account changes in the retention rates of targeted species and desirable bycatch species. This task also takes into consideration ICCAT management measures in place in the Atlantic, and that can have an impact in future catches/retention, and therefore on the fisheries profitability (e.g., species quotas). The original objective of this sub-task was to look into the economic profitability of the fishing activities. However, for this projet, only a simplified analysis was done, on what would be the changes in value that would correspond to the estimated changes in retention rates when comparing hook types, and taking into consideration the catch composition of the EU surface pelagic longline fishery targeting mainly swordfish.

For this specific work, the retention rates on the various hook types, for both target and desirable bycatch (coming from sub-tasks 1.1 and 1.2) were converted into value (€/Kg) using species-specific average first sale/market prices. Specifically, we used as a reference the values from the Peniche fishing harbour in Portugal, the largest fishing harbour in Portugal mainland for trade of highly migratory species. We used data published by the Portuguese Fisheries Authorities, when available at a species-specific level (DGRM, 2019), that was then verified and complemented with personal communications from the Instituto Português do Mar e da Atmosfera (IPMA) fishery observers who sample the local market and onboard the fishing vessels and are therefore familiar with the current average prices (IPMA, *pers. comm.*). We then used ICCAT Task 1 data published in the ICCAT Standing Committee on Research and Statistics (SCRS) report from 2019 to extract the catch statistics for those species in the EU longline fleet (SCRS, 2019). For the catch composition calculation, an average of the last five years of data available (i.e., 2014-2018) was used.

Sub-task 1.5 – The optimum hook size and shape to ensure compliance with the minimum conservation reference size

This sub-task focuses on the optimum hook size and shape in relation to the minimum conservation reference sizes. For the completion of this task, we provide tables with species-specific mean sizes that have been reported from experimental studies comparing various hook types, and compare those with minimum conservation reference sizes that are established (see also sub-task 1.6, done in conjunction with sub-task 1.5).

Additionally, raw data information from experimental studies were compiled and size selectivity curves calculated. The data used come from experimental fishing trials conducted by IPMA, Portugal, comparing three different stainless steel hook types manufactured by WON YANG (Korea), namely a J-style hook (model EC-9/0-R), a non-offset circle hook (model H17/0-M-S) and a 10° offset circle hook (model H17/0-M-R). A photograph of the hooks and full details of the specific measurement are provided in Santos et al. (*2012*), while the details of the experimental at-sea trial are described in Amorim et al. (2015), Coelho et al. (2012) and Fernandez-Carvalho et al. (2015). The data was described with boxplots, representing the median, inter-quartile ranges and outliers. Selection curves were fitted to the hook and species-specific size data using the approach described in Szuwalski and Punt (2016), here adapted to establish the relationship between the size classes of the fish and probability of retention in each hook type. Selectivity was assumed to be a logistic function of size, with the selectivity pattern given by:

$$S_l = (1 + exp[-S_{slope}(L_l - SL_{50})])^{-1}$$

where L_l is the midpoint of length-class l, S_{slope} is the slope of the selectivity curve, and SL_{50} is the length at which 50% of individuals encountered are selected.

The selectivity curves were only calculated for species with sufficient captures in number with each of the hook types, and were the main species of the EU surface longline fishery, namely swordfish, blue shark and shortfin mako. Specifically, for both swordfish and blue shark, the calculations could be carried out for the three different hooks types (J hook, circle hooks with and without offset), while for the shortfin mako calculations were only carried out for J hooks and circle hooks without offset. This was because the sample size was much smaller for shortfin mako compared with that for both swordfish and blue shark.

Sub-task 1.6 – The appropriateness of the existing or potential new minimum conservation reference size

This sub-task is related to sub-task 1.5 described above, in this case focusing on the appropriateness of the existing or potential new minimum conservation reference sizes for the relevant targeted or bycatch species.

The sizes reported and compiled in the tables currently provided under sub-task 1.5 are here compared with any minimum conservation reference sizes that have been established in ICCAT.

Results and discussion

Sub-task 1.1 – Retention rates, at-haulback mortality and discarded/post-release mortality of targeted species

For this sub-task, we carried out species-specific meta-analysis for the following species: albacore (ALB), bigeye tuna (BET), bluefin tuna (BFT), yellow fin tuna (YFT) and swordfish (SWO). These represent the main bony fishes targeted by oceanic pelagic longline fisheries. It is of note that some of those species can be either targeted or bycatch (retained) depending on the specific fishery; however, for the purposes of this meta-analysis, all these main species of bony fishes were considered the main targets of the fisheries. Other species like marlins or retained sharks were considered mainly as desirable bycatch species (see sub-task 1.2). In the main report we provide the main summaries and conclusions of the multiple species-specific meta-analysis, in a comparison between those species, specifically with regard to retention rates and at-haulback mortality. All the individual and detailed species-specific analyses conducted for this task are provided in Appendix IV. Detailed post-release mortality tables for these target species are also provided in Appendix IV.

For the main target species, the results of the species-specific meta-analysis of the retention rates are shown in Figure 4.4.1. Swordfish is the only species with significant effect, specifically with a decrease of 18% in retention when circle hooks are used, varying between reductions of 6% and 27%. For the various tunas, the point estimates showed general increases in retention rates for all species when circle hooks were used, but those values were not significant (Figure 4.4.1).

With regard to at-haulback mortality, the results for the target species are shown in Figure 4.4.2. The effects of changing from J to circle hooks are significant for swordfish and yellowfin tuna, specifically with a reduction on at-haulback mortality of 6% in swordfish (varying between reductions of 2% and 11%) and 22% in yellowfin tuna (varying between reductions of 11% and 32%) when circle hooks are used instead of J hooks. For the remaining target species (bigeye and albacore tunas), the point estimate also pointed to a reduction in at-haulback mortality when circle hooks are used, but the effects were not significant (Figure 4.4.2)

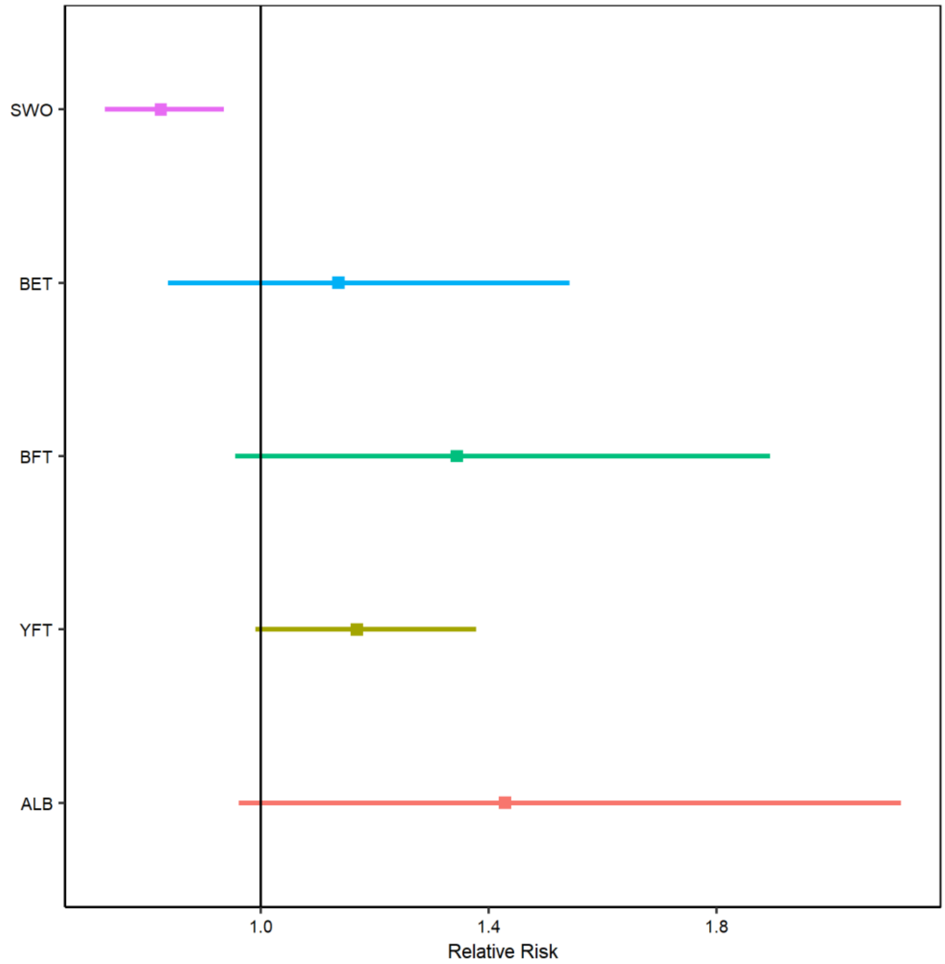


Figure 4.4.1. Results of the meta-analysis of the retention rates of target species. The error bars represent the 95% confidence intervals. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

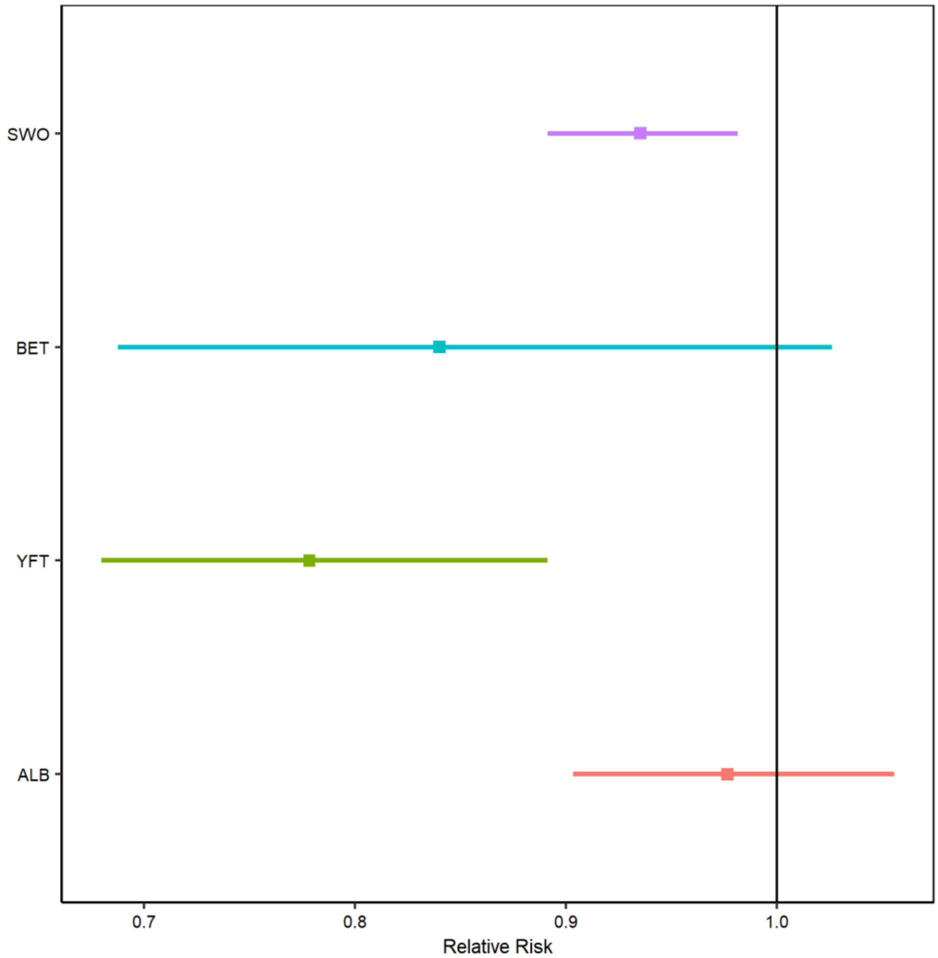


Figure 4.4.2. Results of the meta-analysis of the at-haulback mortality of target species. The error bars represent the 95% confidence intervals. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

Sub-task 1.2 – Retention rates, at-haulback mortality and discarded/post-release mortality of desirable bycatch species

For this sub-task, we carried out species-specific meta-analysis for the following species of bony fishes and sharks: blue marlin (BUM), white marlin (WHM), Atlantic sailfish (SAI), blue shark (BSH) and shortfin mako (SMA). These represent the marlins/sailfish and the major sharks that are usually retained if captured, if their respective quota is still available. As for the previous sub-task, the main report we provide the final summary results and comparison between species. All the detailed individual species-specific analysis and validation procedures are provided in Appendix V. Detailed post-release mortality summary of studies available for the desirable bycatch species are also provided in Appendix V.

For these desirable bycatch species, the results of the meta-analysis on the retention rates are shown in Figure 4.4.3. It is possible to see that the retention of marlins, namely blue marlin and white marlin is lower when circle hooks are used, specifically 33% less for blue marlin (varying between reductions of 23% and 41%) and 18% for white marlin (varying between reductions of 9% and 27%). By contrast, the retention of shortfin mako when circle hooks are used is higher, specifically 23% more retention (varying between increases in retention of 2% and 50%). Finally, for the Atlantic sailfish and blue shark there are no significant effects when the hooks are changed from J to circle hooks, even though it is noted that the point estimates indicate a reduction of retention in the Atlantic sailfish and an increase in retention of blue shark when circle hooks are used instead of J-hooks.

With regard to at-haulback mortality, the effects of changing from J to circle hooks are significant for blue marlin and blue shark, specifically with reductions on at-haulback mortality of 19% for blue marlin (varying between reductions of 6% and 30%) and 25% for blue shark (varying between reductions of 5% and 41%). For the other desirable bycatch species, like white marlin and shortfin mako, the effects of changing between hook type are not significant, even though the point estimates point also to reduction in at-haulback mortality (Figure 4.4.4).

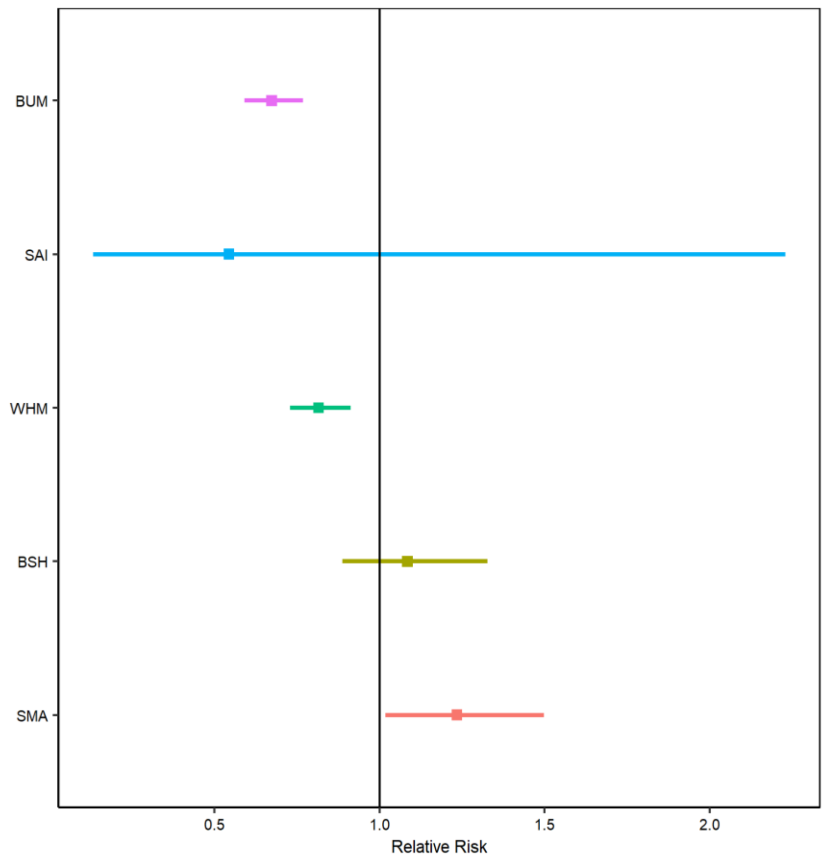


Figure 4.4.3. Results of the meta-analysis of the retention rates of desirable bycatch species. The error bars represent the 95% confidence intervals. (Note: J-hooks are

considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

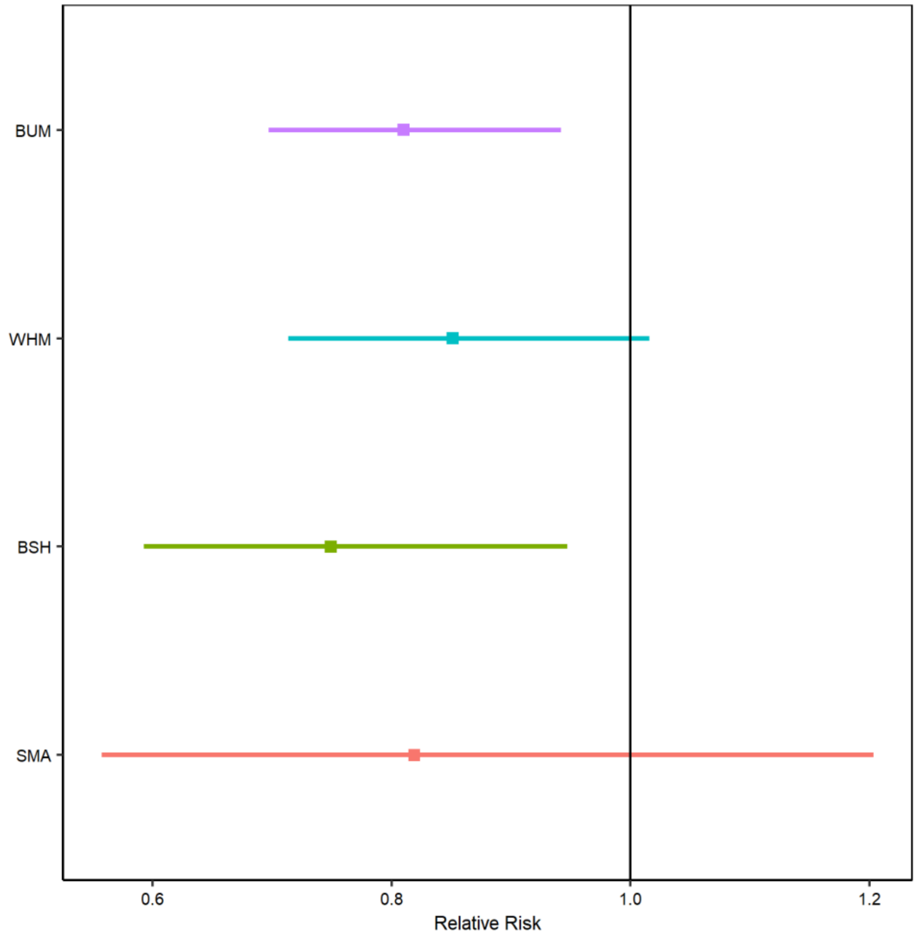


Figure 4.4.4. Results of the meta-analysis of the at-haulback mortality of desirable bycatch species. The error bars represent the 95% confidence intervals. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

Sub-task 1.3 – Retention rates, at-haulback mortality and discarded/post-release mortality of unwanted bycatch species

For this sub-task, we carried out species-specific meta-analysis for unwanted bycatch species, including sea turtles and some elasmobranchs that are no-retention species, either because of regulations or lack of commercial value. For the sea-turtles the species focused on were loggerhead (TTL), leatherback (DKK), olive ridley (LKV), Kemp's ridley (LKY) and green turtle (TUG). For the sharks, the species focused were oceanic whitetip shark (OCS), porbeagle (POR), silky shark (FAL), bigeye thresher (BTH), longfin mako

(LMA), crocodile shark (PSK), scalloped hammerhead (SPL), smooth hammerhead (SPZ) and the pelagic stingray (PLS).

As for the previous sub-task, the main report we provide the final results and comparisons between species, while all the detailed species-specific analyses are provided in Appendix VI. Detailed post-release mortality summary of studies available for the unwanted bycatch species are also provided in Appendix VI.

For the unwanted bycatch species, the result of the meta-analysis of the retention rates is shown in Figure 4.4.5. Two sea turtle species show significant effects in reduction of retention when changing from J to circle hooks, namely the loggerhead with a reduction of 47% (varying between reductions of 33% and 58%) and the leatherback with a reduction of 63% (varying between reductions of 52% and 72%). Within the elasmobranchs, only the pelagic stingray showed significant effects, with a reduction in retention of 76% when using circle hooks, varying between reductions of 54% and 87%. For the other sea turtle and elasmobranch species, the effects of changing hook type on the retention rates are not significant. However, it is noted that for some of the other elasmobranchs there is a tendency for the point estimates to point to an increase in retention when circle hooks are used, and that is particularly evident for the oceanic whitetip, porbeagle and crocodile shark (Figure 4.4.5). By contrast, for the olive ridley sea turtle there is a tendency for lower retention with circle hooks, even though the effects are not significant (Figure 4.4.5).

With regard to at-haulback mortality, the effects of changing from J to circle hooks are significant only for the leatherback sea turtle, with an increase of 2.41 times on at-haulback mortality when circle hooks are used instead of J hooks, varying between increases of 7% and 5.44 times (Figure 4.4.6). For the other species considered, both sea turtles and elasmobranchs, the effects of changing hook type are not significant on the at-haulback mortality (Figure 4.4.6).

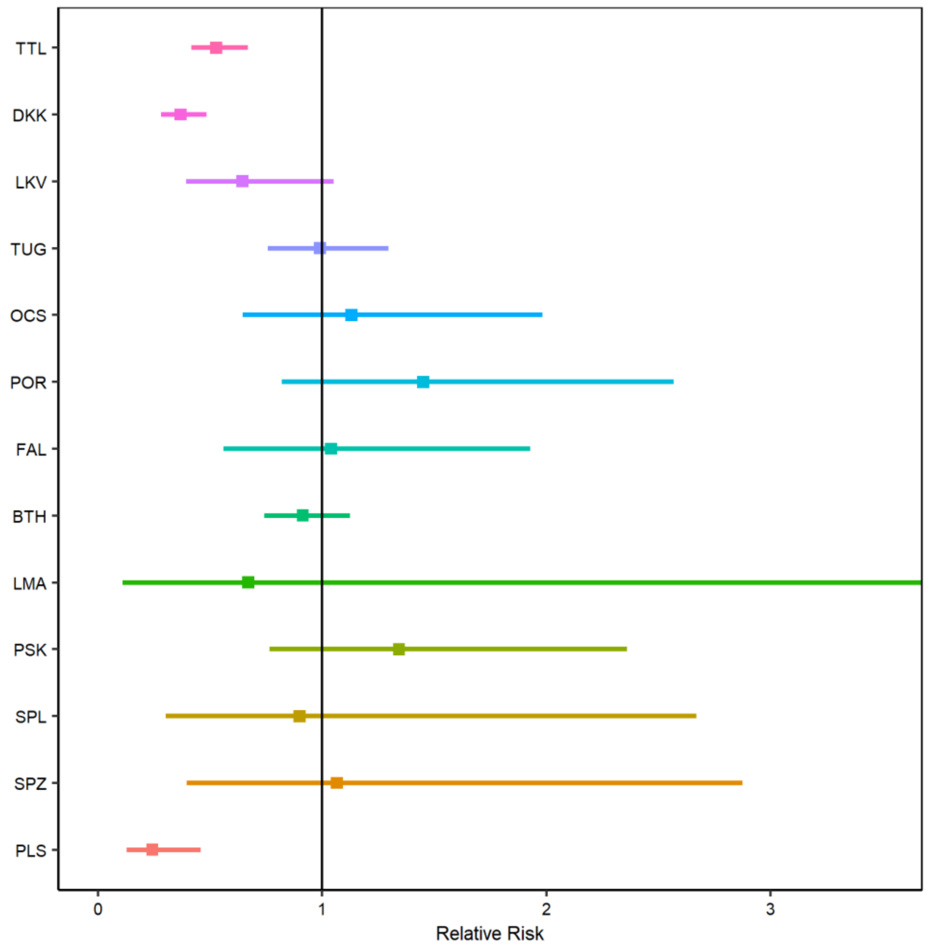


Figure 4.4.5. Results of the meta-analysis of the retention rates of unwanted bycatch species. The error bars represent the 95% confidence intervals. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

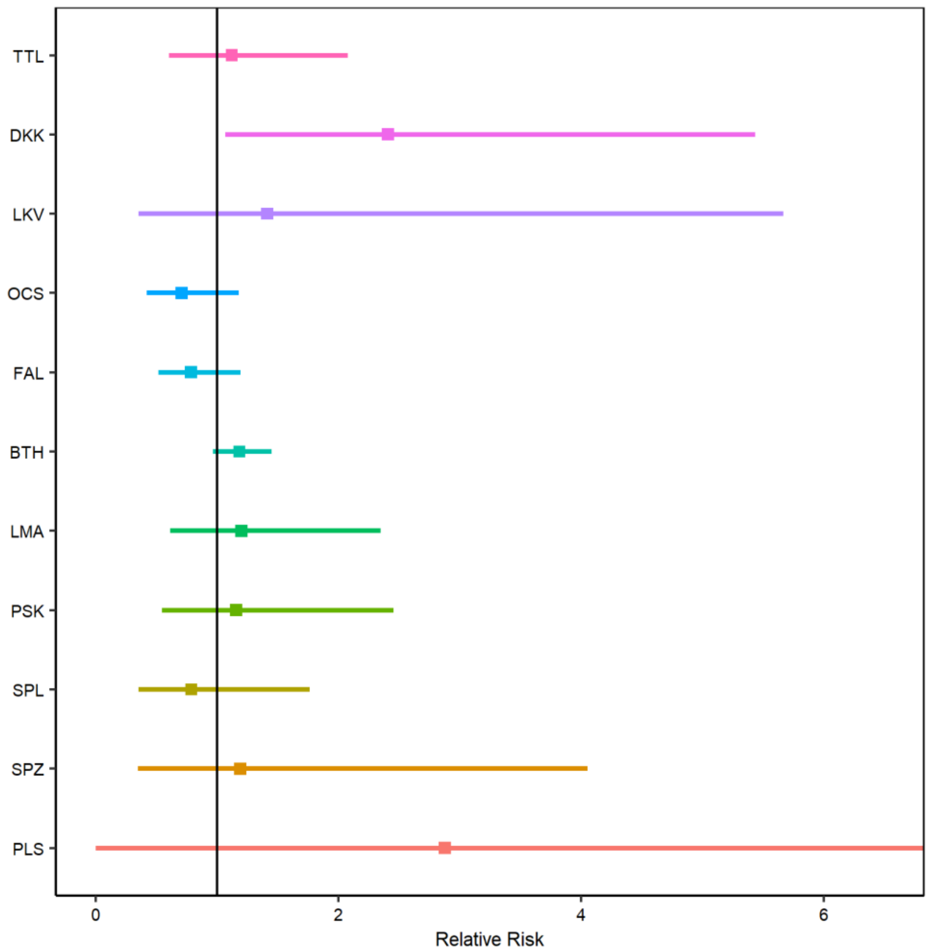


Figure 4.4.6. Results of the meta-analysis of the at-haulback mortality of unwanted bycatch species. The error bars represent the 95% confidence intervals. (Note: J-hooks are considered the control and circle hooks the experimental hook; a Relative Risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

Synopsis of sub-tasks 1.1, 1.2 and 1.3

In this sub-section, we provide a comparative joint overview of the previous three sub-tasks. While in each of the previous sub-tasks the objective was to focus on one individual species group at a time, here we combine all data for a clearer view of the trade-offs that are achieved, comparing each of the groups. The information provided here is the same as that presented in the previous sections, but is provided in a joint format for comparative purposes.

Specifically, Figure 4.4.7 presents the overall comparative view in retention rates for the three taxa components, while Figure 4.4.8 presents the overall comparative view in at-haulback mortality. All the specific species summary details are provided, respectively, in tables 4.4.1 and 4.4.2. It is noteworthy the high heterogeneity values detected for some species, which has consequences mainly in producing larger confidence intervals.

Full details and explorations on possible outliers and their consequences in heterogeneity and the final results are presented in the Appendices IV, V and VI.

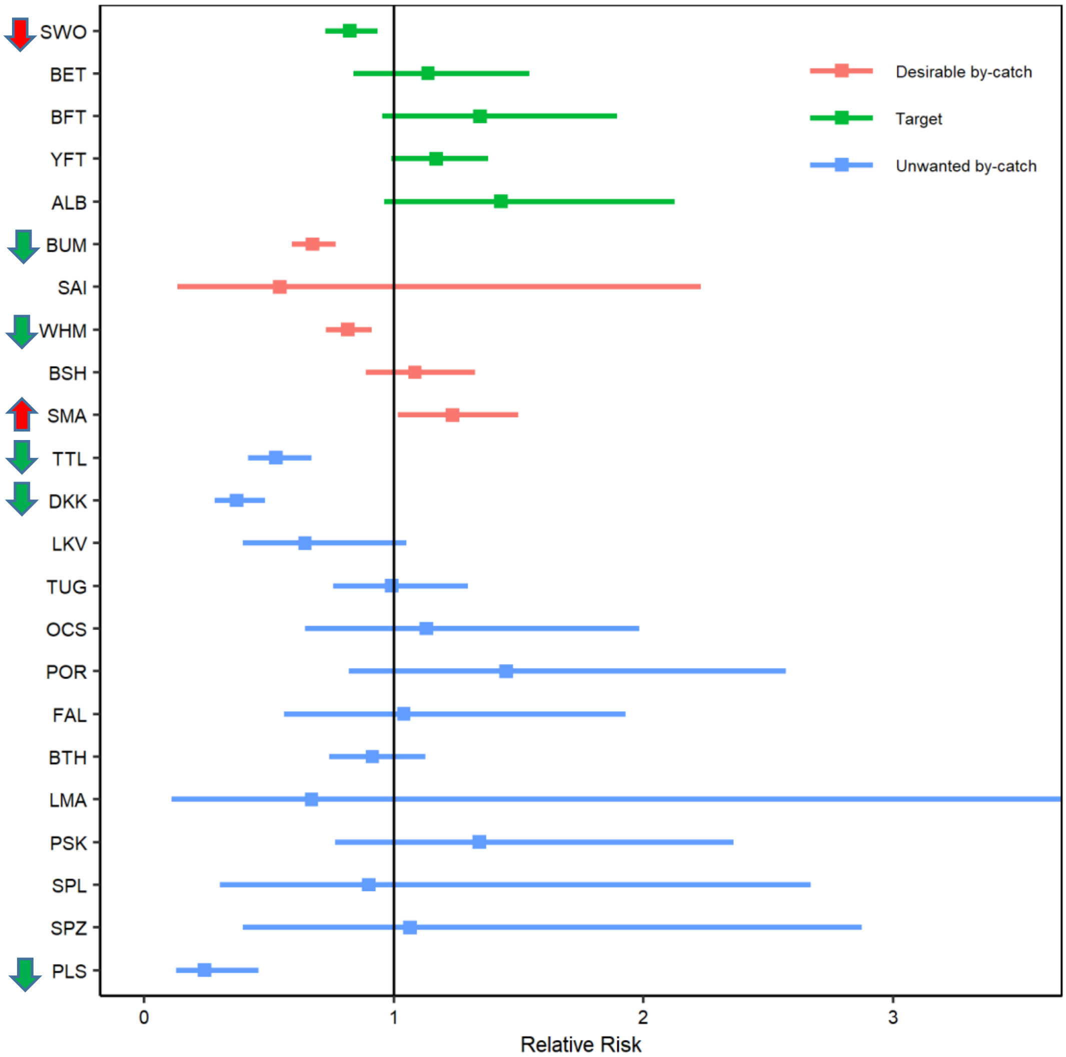


Figure 4.4.7. Results of the meta-analysis of the retention rates of the three species components: target species, desirable bycatch and unwanted bycatch. The error bars represent the 95% confidence intervals. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the retention rates. The colour or the arrows assumes the following: 1) for target species higher retention assumes a positive (green) outcome while a decrease in retention is a negative (red) outcome; 2) the contrary is assumed for bycatch species, both wanted and unwanted, i.e., a reduction in retention is assumed a positive outcome (green) while an increase in retention is assumed a negative (red) outcome. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

Table 4.4.1. Summary of the results of the species-specific meta-analysis of retention rates when changing hook type, for the three species components: target species, desirable bycatch and unwanted bycatch. Note: J is considered the control and circle the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks. "Exp" refers to the number of experiments available for each analysis and the bracketed number is the number used after the validation procedure (see Appendices IV, V and VI). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative risk			Heterogeneity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
SWO	19	0.82	0.73-0.94	**<0.01**	100	<0.01	1, 2, 11, 15, 17, 20, 24, 25, 26, 27, 28, 30, 32, 33, 42, 44, 46, 50, 49
BET	11	1.14	0.84-1.54	0.37	98	<0.01	20, 24, 25, 27, 28, 30, 42, 44, 45, 48, 49
BFT	4	1.34	0.95-1.89	0.07	36	0.20	24, 26, 30, 46
YFT	9(8)	1.17	0.99-1.38	0.06	23	0.25	20, 25, 27, 28, 42, 44, 48, 49 (24)
ALB	11	1.43	0.96-2.12	0.07	97	<0.01	20, 24, 25, 27, 28, 30, 42, 44, 46, 48, 49
BUM	6(5)	0.67	0.59-0.77	**<0.01**	13	0.33	24, 42, 44, 48, 49 (25)
SAI	4	0.54	0.13-2.23	0.26	43	0.16	42, 44, 48, 49
WHM	5(3)	0.82	0.73-0.91	**0.02**	0	0.92	25, 48, 49 (24, 42)
BSH	16	1.08	0.89-1.33	0.40	99	<0.01	1, 2, 17, 20, 21, 24, 25, 26, 27, 28, 30, 42, 44, 46, 48, 49
SMA	12	1.23	1.02-1.50	**0.04**	84	<0.01	17, 20, 21, 24, 25, 27, 28, 29, 30, 42, 48, 49
TTL	21(20)	0.53	0.42-0.67	**<0.01**	75	<0.01	1, 2, 10, 12, 17, 20, 24, 26, 27, 28, 30, 31, 36, 42, 46, 48, 49, 52, 53, 54 (15)
DKK	12(11)	0.37	0.28-0.48	**<0.01**	25	0.21	15, 20, 24, 25, 27, 28, 30, 42, 48, 49, 52 (17)
LKV	7	0.64	0.39-1.05	0.07	55	0.04	17, 25, 35, 36, 40, 42, 48
TUG	5(4)	0.99	0.76-1.3	0.92	0	0.91	20, 25, 35, 40 (36)
OCS	5	1.13	0.65-1.98	0.58	32	0.21	21, 25, 42, 48, 49
POR	5	1.45	0.82-2.57	0.14	29	0.23	24, 27, 28, 30, 49
FAL	8	1.04	0.56-1.93	0.89	91	<0.01	21, 24, 25, 40, 42, 44, 48, 49
BTH	4(3)	0.91	0.74-1.13	0.20	0	0.57	42, 48, 49 (24)
LMA	3	0.67	0.11-4.06	0.44	85	<0.01	42, 48, 49
PSK	5(3)	1.34	0.76-2.36	0.15	0	0.48	25, 44, 48 (42, 49)
SPL	5	0.90	0.30-2.67	0.80	46	0.11	21, 24, 25, 42, 48
SPZ	3	1.07	0.40-2.87	0.81	69	0.04	42, 48, 49
PLS	9	0.24	0.13 - 0.46	**<0.01**	70	<0.01	25, 26, 27, 28, 42, 45, 46, 48, 49

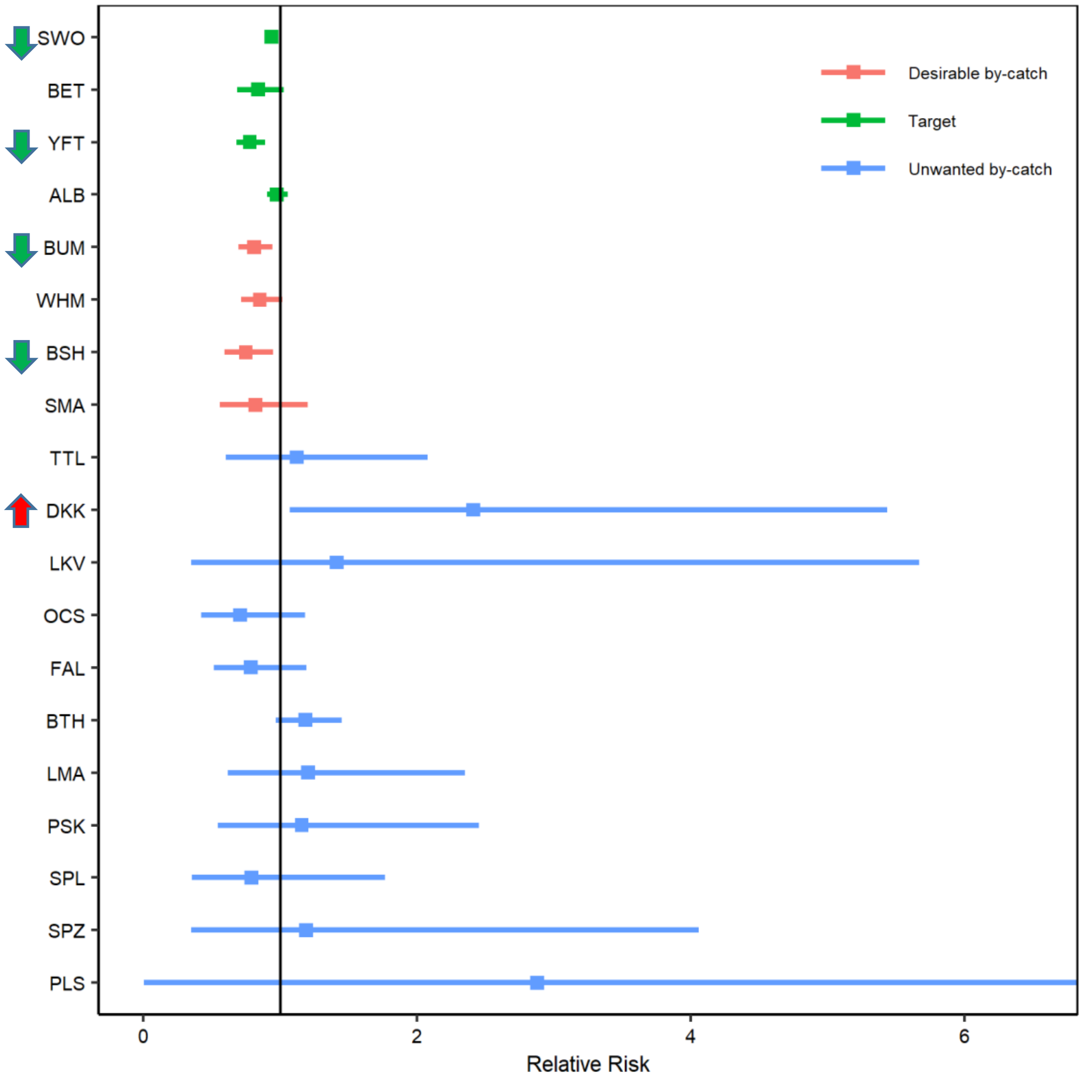


Figure 4.4.8. Results of the meta-analysis of at-haulback mortality of the three species components: target species, desirable bycatch and unwanted bycatch. The error bars represent the 95% confidence intervals. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the at-haulback mortality. The colour or the arrows assumes the following: for all species groups (target and bycatch) a lower at-haulback mortality is a positive (green) outcome, while higher at-haulback mortality is a negative (red) outcome. (Note: J-hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

Table 4.4.2. Summary of the results of the species-specific meta-analysis of at-haulback mortality when changing hook type, for the three species components: target species, desirable bycatch and unwanted bycatch. Note: J is considered the control and circle the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks. "Exp" refers to the number of experiments available for each analysis and the bracketed number is the number used after the validation procedure (see Appendices IV, V and VI). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative risk			Heterogeneity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
SWO	6(4)	0.94	0.89-0.98	0.02	73	0.01	25, 29, 48, 49 (24, 42)
BET	6(5)	0.84	0.69-1.03	0.07	34	0.20	24, 29, 42, 48, 49 (25)
YFT	5	0.78	0.68-0.89	0.01	38	0.17	24, 25, 42, 48, 49
ALB	6(4)	0.98	0.9-1.06	0.40	0	0.59	25, 29, 42, 48 (24, 49)
BUM	5	0.81	0.7-0.94	0.02	0	0.51	24, 25, 42, 48, 49
WHM	5	0.85	0.71-1.02	0.06	0	0.65	24, 25, 42, 48, 49
BSH	8(7)	0.75	0.59-0.95	0.02	55	0.04	21, 25, 29, 42, 45, 48, 49 (24)
SMA	7	0.82	0.56-1.2	0.25	0	0.45	21, 24, 25, 29, 42, 48, 49
TTL	10	1.12	0.61-2.08	0.68	0	0.60	15, 17, 20, 24, 26, 42, 48, 49, 52, 54
DKK	9	2.41	1.07-5.44	0.04	0	0.71	15, 17, 24, 25, 29, 42, 48, 49, 52
LKV	4	1.41	0.35-5.67	0.40	0	0.51	17, 25, 42, 48
OCS	5	0.71	0.42-1.18	0.14	0	0.47	21, 25, 42, 48, 49
FAL	5	0.79	0.52-1.19	0.18	23	0.27	21, 24, 42, 45, 48
BTH	4	1.19	0.97-1.45	0.07	13	0.33	24, 42, 48, 49
LMA	3	1.2	0.62-2.35	0.36	0	0.73	42, 48, 49
PSK	5(4)	1.16	0.55-2.45	0.58	10	0.34	25, 45, 48, 49 (42)
SPL	3	0.79	0.35-1.77	0.33	0	0.54	21, 24, 42
SPZ	3	1.19	0.35-4.06	0.60	11	0.33	42, 48, 49
PLS	3	2.88	0 - 2108.09	0.56	4	0.35	25, 42, 45

Sub-task 1.4 – Short-term (3-5 years) and long term (>10 years) economic profitability of the fishing activities concerned, taking into account changes in retention rates of targeted species and desirable bycatch species

Here we have carried out simulations using the results from this report on the meta-analysis for the retention rates that were carried out previously (see details in sub-tasks 1.1 and 1.2, specifically for target and desirable bycatch species).

The ratios of increase or decrease in retention that would result for each of the species by changing from J to circle hooks are indicated in Table 4.4.3. By applying these ratios to the respective catch reported by the EU longline (LL) fleets in the Atlantic (from the ICCAT Task 1 database), we estimated that were the EU fleets to change from J-hooks to circle hooks, the retention of species like swordfish would be reduced by 18% (or a corresponding increased fishing effort would have to be conducted, with additional operation costs), while retention of species like blue shark would be increased by 8%. Given the different ratios of the various species in the overall catch, we simulated the changes in both catch and value per 1,000 kg of catch (using data for J hooks as the baseline), and calculated the corresponding changes for using circle hooks. With such changes, the actual catch with circle hooks (in kg) would increase, mostly because increase in retention of sharks (both blue shark and shortfin mako) would more than compensate for the reduction in swordfish (Table 4.4.3). However, in terms of value, changing from J to circle hooks would lead to a decrease. Specifically, for each 1,000 kg of catch with J hooks, a change to circle hooks would result in an increase of 43.3 kg by weight (varying between a decrease of 143.2 kg and an increase of 301.5 kg) but the overall catch value would decrease by EUR 16.9 (varying between a decrease of EUR 581.4 and an increase of EUR 774.7) (Table 4.4.3). This value can then be extrapolated into the overall EU pelagic LL catch (75,586 kg, representing 96% of the total EU LL yearly mean catch in 2014-2018). For that overall value, if the entire fleet were to change from J to circle hooks, the catch would increase from 75,586.1 tonnes (t) to 78,856.4 t, and the corresponding overall value would decrease from EUR 245,811,771 to EUR 244,534,588 (Table 4.4.3).

Table 4.4.3. Summary table of the species-specific total catch analysis of the changes (catch and corresponding value) from J to circle hooks. The data presented in this table correspond to the total for the Atlantic + Mediterranean from catches for all the EU pelagic LL fleets using ICCAT Task 1 database (average of the last five years of data available, 2014-2018).

Sp	RR (J to circle)			Catch Atl + Med (T1)	Comp. (%)	Value (€/Kg)	J hooks (1000 Kg)		Circle hooks catch (kg)			Circle hooks value (€)		
	Estimate	Low	Upp				catch (kg)	value (€)	Estimate	Low	Upp	Estimate	Low	Upp
SWO	0.82	0.73	0.94	16450	21.8	7.1	217.6	1538.6	178.5	158.9	204.6	1261.7	1123.2	1446.3
BET	1.14	0.84	1.54	998	1.3	4.8	13.2	62.9	15.1	11.1	20.3	71.6	52.8	96.8
BFT	1.34	0.95	1.89	1184	1.6	10.0	15.7	156.7	21.0	14.9	29.6	209.9	148.8	296.1
YFT	1.17	0.99	1.38	827	1.1	4.8	10.9	52.1	12.8	10.8	15.1	60.9	51.6	71.9
ALB	1.43	0.96	2.12	3171	4.2	4.8	42.0	199.7	60.0	40.3	89.0	285.6	191.7	423.4
BUM	0.67	0.59	0.77	341	0.5	3.0	4.5	13.5	3.0	2.7	3.5	9.1	8.0	10.4
SAI	0.54	0.13	2.23	627	0.8	3.0	8.3	24.9	4.5	1.1	18.5	13.4	3.2	55.5
WHM	0.82	0.73	0.91	88	0.1	3.0	1.2	3.5	1.0	0.9	1.1	2.9	2.6	3.2
BSH	1.08	0.89	1.33	48903	64.7	1.6	647.0	1041.7	698.7	575.8	860.5	1125.0	927.1	1385.4
SMA	1.23	1.02	1.5	2996	4.0	4.0	39.6	158.6	48.8	40.4	59.5	195.0	161.7	237.8
Total catch*				**75586**			**1000.0**	**3252.1**	**1043.3**	**856.8**	**1301.5**	**3235.2**	**2670.7**	**4026.8**

* The total catch of the listed species represents 96% of the total catch from the EU pelagic LL fleets. The remining 4% are other species not listed in this work, but are also captured/reported occasionally by the EU pelagic LL fleets.

The first simulation above was carried out for the entire catch from the Atlantic and Mediterranean combined, but it is interesting and potentially important to split those by stock, because of differences in the catch composition in each region that can be related to species availability and distribution, and because of specificities in the fishing gear in each region. As the various species have different stock definitions, this simulation was carried out using the four main species in the catch composition of the pelagic LL fishery (i.e., swordfish, albacore, blue shark and shortfin mako), that all have three separate stocks, namely in the North Atlantic, South Atlantic and Mediterranean. The summary results are presented in Table 4.4.4, and show that when changing from J to circle hooks there would be increases in the retention on all stocks, but that these increases would be greater for the North Atlantic (2,141.8 t more with circle hooks, representing an increase of 5.4% in catch), followed by the South Atlantic with an increase of 3.6% in catch with circle hooks (817.9 t more) and finally the Mediterranean with 0.1% increase in catch with circle hooks (10.1 t more) (Table 4.4.4). The main reason for these differences is that the use of circle hooks in the Atlantic (North and South) leads to large increases, especially in the retention of sharks (both blue shark and shortfin mako), while in the Mediterranean the main species are swordfish and albacore for which the change to circle hooks would result in contrary and compensating effects but sharks are captured in much lower quantities. In terms of value, this would mean that the largest differences for changing from J to circle hooks would be found in the Mediterranean with a loss of 4.4% in value of the retained catch, followed by the South Atlantic with a loss of 3.7% and finally the North Atlantic with a loss of 0.6%.

One final simulation option that is highlighted and can be taken into account is to note that the previous analyses are assuming future catches are the average of the species composition in the last five years (2014-2018); however, species like the shortfin mako are likely to have restrictions in their retention in the near future, and as such that would change the future retentions for the simulation. Additionally, between 2014 and 2018 there were no specific quotas established for blue shark. However, quotas for blue shark were established in 2019 for implementation in 2020 for the North Atlantic (ICCAT Rec 19-07), setting the EU blue shark quota (i.e., future catches) at 32,578 t in the North Atlantic. Table 4.4.5 also provides stock-specific simulations for the four main surface longline species, but now simulating with limits in the catches by stock, taking into consideration those regulations, especially by including the quota limits in the blue shark in the North Atlantic and assuming a possible future zero retention of shortfin mako also in the North Atlantic. In such a scenario, there would be limits in the trade-offs that circle hooks are showing in the previous simulations in terms of value due to higher retention of sharks, as many of those additional catches would have to be discarded because of the regulations. In this new scenario, represented in Table 4.4.5, the losses in value would be higher for the North Atlantic (reduction of 7% in the value of the retained catch when using circle hooks), while for the other stocks the losses would remain the same, specifically 3.7% loss in the South Atlantic and 4.4 loss in the Mediterranean. Those economic values results need to be interpreted with caution due to the simplified nature of the analysis performed. Additional factors would need to be considered, as for example the different prices for the meat/fins of the various shark species, as well as future fluctuations in prices if there were disruptions in the supply of the markets.

Given the that circle hooks tend to decrease retention of the main target species (swordfish), increase retention of some vulnerable sharks (namely shortfin mako), which results in an overall lower value of the retained catch, the use of circle hooks is not recommended for surface longline fisheries such as the EU pelagic longline.

Table 4.4.4. Summary table of the stock-specific main species catch analysis for the changes (in catch and corresponding value) from J to circle hooks. The data to start the analysis correspond to the stock-specific catches for all the EU pelagic LL fleets using the ICCAT Task 1 database (average of the last five years of available data, 2014-2018). The four species considered are swordfish, albacore, blue shark and shortfin mako, that together represent 95% of the EU pelagic LL retentions (in weight). At the end of the table, the differences between using J and circle hooks (in catch and value) are indicated. The arrows on the bottom assume that an increase in catch and/or value is a positive (green) outcome, while a decrease in catch and/or value is a negative (red) outcome.

Sp	Value (€/kg)	RR	J hooks (T1 catch, t)			Circle hooks (simulated catch, t)			J hooks value (€)			Circle hooks value (€)		
			N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med
SWO	7.1	0.82	5304.0	4960.0	6377.0	4349.3	4067.2	5229.1	37499280	35067200	45085390	30749410	28755104	36970020
ALB	4.8	1.43	216.9	279.7	2674.8	310.2	399.9	3825.0	1041199	1342446	12839128	1488915	1919698	18359953
BSH	1.6	1.08	32603.7	16203.7	96.1	35212.0	17500.0	103.7	52165924	25925969	153692	56339198	28000046	165988
SMA	4.0	1.23	1717.1	1278.7	0.2	2112.0	1572.8	0.3	6868444	5114831	932	8448186	6291242	1146
Total			**39841.7**	**22722.1**	**9148.1**	**41983.5**	**23540.0**	**9158.2**	**97574847**	**67450446**	**58079142**	**97025708**	**64966091**	**55497107**
Differences (using circle instead of J hooks)						**2141.8**	**817.9**	**10.1**				**-549138.8**	**-2484355.4**	**-2582035.4**
Differences (%)						**5.4**	**3.6**	**0.1**				**-0.6**	**-3.7**	**-4.4**

Table 4.4.5. Summary table of the stock-specific main species catch analysis for the changes (in catch and corresponding value) from J hooks to circle hooks, assuming restriction in the catches of blue shark (quota of 32758 t) and shortfin mako (0 t catch). The data to start the analysis correspond to the stock-specific catches for all the EU pelagic LL fleets using the ICCAT Task 1 database (average of the last five years of available data, 2014-2018). The four species considered are swordfish, albacore, blue shark and shortfin mako, that together represent 95% of the EU pelagic LL retentions (in weight). At the end of the table, the differences between using J and circle hooks (in catch and value) are indicated. The arrows on the bottom assume that an increase in catch and/or value is a positive (green) outcome, while a decrease in catch and/or value is a negative (red) outcome.

Sp	Value (€/kg)	RR	J hooks (T1 catch, t)			Circle hooks (simulated catch, t)			J hooks value (€)			Circle hooks value (€)		
			N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med	N-Atl	S-Atl	Med
SWO*	7.1	0.82	5304.0	4960.0	6377.0	4349.3	4067.2	5229.1	37499280	35067200	45085390	30749410	28755104	36970020
ALB*	4.8	1.43	216.9	279.7	2674.8	310.2	399.9	3825.0	1041199	1342446	12839128	1488915	1919698	18359953
BSH**	1.6	1.08	32578.0	16203.7	96.1	32578.0	17500.0	103.7	52124800	25925969	153692	52124800	28000046	165988
SMA**	4.0	1.23	0.0	1278.7	0.2	0.0	1572.8	0.3	0	5114831	932	0	6291242	1146
Total			**38098.9**	**22722.1**	**9148.1**	**37237.5**	**23540.0**	**9158.2**	**90665279**	**67450446**	**58079142**	**84363124**	**64966091**	**55497107**
Differences (using circle instead of J hooks)						**-861.4**	**817.9**	**10.1**				**-6302154.8**	**-2484355.4**	**-2582035.4**
Differences (%)						**-2.3**	**3.6**	**0.1**				**-7.0**	**-3.7**	**-4.4**

* ALB and SWO quotas were not considered as the simulated catch is lower than those limits.
** BSH and SMA catch limits and quotas were considered as the simulated catch is higher than those limits

Sub-task 1.5 – The optimum hook size and shape to ensure compliance with the minimum conservation reference size

The various species-specific mean sizes that have been reported on experimental studies comparing various hook styles are shown in Table 4.4.6 for bony fishes, Table 4.4.7. for elasmobranchs and Table 4.4.8. for sea turtles.

Those can be compared with currently established minimum conservation sizes established by ICCAT, as listed in Table 4.4.9. For example, for swordfish the mean captured sizes in the Atlantic, regardless of using J or circle hooks, vary between 126 and 165 cm LJFL, which are higher than the currently established options for minimum conservation reference sizes (119 or 125 cm LJFL in the Atlantic). By contrast, for shortfin mako, the mean sizes captured with both hooks vary between 131 and 179 cm FL, while one of the current management options establishes minimum retention sizes of 180 cm FL for males and 210 cm FL for females.

Table 4.4.6. Mean sizes (with standard deviation – SD) for the main bony fish species (tunas and billfishes) that have been reported in experimental studies comparing various hook types: J hooks vs. circle hooks. The size type refers to the specific measurement taken in each case: FL – fork length, LJFL – lower jaw fork length. The complete references (referring to each specific experiment) are provided in Appendix I.

Species	Hook type				Size type	Reference	Experiment
	J hook		Circle hook				
	Mean (cm)	SD	Mean (cm)	SD			
SWO – Swordfish	126.2	27.6	127.6	27.9	LJFL	Fernandez-Carvalho et al. (2015)	49
	165	36.6	164.3	34.8	LJFL	Amorim et al. (2015)	50
	143	30.2	142.7	28.8	LJFL	Coelho et al. (2012)	42
	140	NA	138.5	NA	LJFL	Mejuto et al. (2008)	17
ALB – Albacore	92.5	15.1	102.5	6.7	FL	Fernandez-Carvalho et al. (2015)	49
	106.6	9.5	108.7	9.2	FL	Amorim et al. (2015)	50
	98.2	1.5	94.6	20.8	FL	Coelho et al. (2012)	42
BET – Bigeye tuna	129.9	28.6	115.4	28.4	FL	Fernandez-Carvalho et al. (2015)	49
	144.5	26.3	119.6	31.5	FL	Amorim et al. (2015)	50
	139.4	27.0	135.8	28.6	FL	Coelho et al. (2012)	42
YFT – Yellowfin tuna	146.1	26.1	134.8	30.2	FL	Fernandez-Carvalho et al. (2015)	49
	154.4	9.1	156.8	11.2	FL	Amorim et al. (2015)	50
	151.1	17.5	152.9	16.1	FL	Coelho et al. (2012)	42
BUM – Atlantic blue marlin	204.8	26.4	211	32.2	LJFL	Fernandez-Carvalho et al. (2015)	49
	222.8	29.2	228.4	35.2	LJFL	Amorim et al. (2015)	50
	214.4	42.5	207.2	36.1	LJFL	Coelho et al. (2012)	42
SAI – Atlantic sailfish	166.9	8.4	161.3	9.0	LJFL	Fernandez-Carvalho et al. (2015)	49
	197	0	NA	NA	LJFL	Amorim et al. (2015)	50
	170.2	15.0	169.1	13.5	LJFL	Coelho et al. (2012)	42
WHM – White marlin	163.5	11.5	153.8	14.5	LJFL	Fernandez-Carvalho et al. (2015)	49
	171.2	15.0	170	16.9	LJFL	Amorim et al. (2015)	50
	158.5	13.3	164.2	28.6	LJFL	Coelho et al. (2012)	42

Table 4.4.7. Mean sizes (with standard deviation – SD) of elasmobranch species that have been reported in experimental studies comparing various hook types: J hooks vs. circle hooks. The size type refers to the specific measurement taken in each case: FL – fork length, TL – total length. The complete references (referring to each specific experiment) are provided in Appendix I.

Species	Hook type				Size type	Reference	Experiment
	J hook		Circle hook				
	Mean (cm)	SD	Mean (cm)	SD			
BSH – Blue shark	163	NA	161.3	NA	FL	Mejuto et al. (2008)	17
	211	26.0	210.8	24.1	FL	Fernandez-Carvalho et al. (2015)	49
	195.1	29.8	196.2	29.0	FL	Amorim et al. (2015)	50
	207.1	20.1	206.9	20.2	FL	Coelho et al. (2012)	42
BTH – Bigeye thresher	161.2	27.8	163.7	26.3	FL	Fernandez-Carvalho et al. (2015)	49
	193.4	28.1	192.6	28.3	FL	Amorim et al. (2015)	50
	168.7	26.1	170.1	27.3	FL	Coelho et al. (2012)	42
FAL – Silky shark	139.5	38.9	119.9	20.9	FL	Fernandez-Carvalho et al. (2015)	49
	NA	NA	176.5	30.3	FL	Amorim et al. (2015)	50
	115.8	37.5	126.2	44.1	FL	Coelho et al. (2012)	42
LMA – Longfin mako	155.3	28.9	156.9	22.7	FL	Fernandez-Carvalho et al. (2015)	49
	95.4	33.4	118.8	56.4	FL	Amorim et al. (2015)	50
	160.6	18.3	160.2	23.8	FL	Coelho et al. (2012)	42
OCS – Oceanic whitetip	145.7	42.8	139	34.9	FL	Fernandez-Carvalho et al. (2015)	49
	101.6	33.2	97.3	40.8	FL	Amorim et al. (2015)	50
	113.6	23.2	114.4	25.9	FL	Coelho et al. (2012)	42
POR – Porbeagle	175	0	NA	NA	FL	Amorim et al. (2015)	50
PSK – Crocodile shark	83.3	8.2	83.7	7.5	FL	Fernandez-Carvalho et al. (2015)	49
	86.1	5.1	85	7.8	FL	Amorim et al. (2015)	50
	80.3	12.8	80.5	10.2	FL	Coelho et al. (2012)	42
SMA – Shortfin mako	131	NA	168.2	NA	FL	Mejuto et al. (2008)	17
	162	22.6	162.2	22.5	FL	Fernandez-Carvalho et al. (2015)	49
	175.2	33.5	169.9	26.0	FL	Amorim et al. (2015)	50
	175.3	22.6	178.8	30.6	FL	Coelho et al. (2012)	42
SPL – Scalloped hammerhead	217.7	19.6	186.7	4.6	FL	Fernandez-Carvalho et al. (2015)	49
	204	1.0	185	7.4	FL	Coelho et al. (2012)	42
SPZ – Smooth hammerhead	211.6	24.9	202.2	25.2	FL	Fernandez-Carvalho et al. (2015)	49
	202	0	215.2	11.1	FL	Amorim et al. (2015)	50
	186.5	18.3	184.2	17.7	FL	Coelho et al. (2012)	42
TIG – Tiger shark	196.3	27.8	216	22.3	FL	Fernandez-Carvalho et al. (2015)	49
	NA	NA	175	14.1	FL	Coelho et al. (2012)	42
PLS – Pelagic stingray	115	12.1	110	6.0	TL	Amorim et al. (2015)	50
	46	3.3	52	5.6	TL	Coelho et al. (2012)	42

Table 4.4.8. Mean sizes (with standard deviation – SD) of sea turtle species that have been reported in experimental studies comparing various hook types: J hooks vs. circle hooks. The size type refers to the specific measurement taken in each case: TCL – total carapace length, CCL – curved carapace length. The complete references (referring to each specific experiment) are provided in Appendix I.

Species	Hook type				Size type	Reference	Experiment
	J-hook		Circle hook				
	Mean (cm)	SD	Mean (cm)	SD			
TTL – Loggerhead	59	NA	59.3	NA	TCL	Mejuto et al. (2008)	17
	57.9	7.9	60.5	6.7	CCL	Sales at al. (2010)	20
	47.6	3.01	34.4	2.98	CCL	Cambie et al. (2012)	26
	50	NA	53	NA	CCL	Piovano (2012)	31
	75	1.2	74	0.8	CCL	Santos et al. (2012)	42
	49.8	4.9	49.7	8.5	CCL	Piovano et al. (2009)	47
	62.5	10.2	61	10.6	CCL	Coelho et al. (2015)	49
	60.4	6.0	62.6	5.9	CCL	Santos et al. (2013)	50
DKK – Leatherback	131	NA	131.4	NA	TCL	Mejuto et al. (2008)	17
	91.4	39.7	113.7	33.2	CCL	Santos et al. (2012)	42
	119.8	32.3	117.3	35.6	CCL	Coelho et al. (2015)	49
	80.9	29.2	125	10.8	CCL	Santos et al. (2013)	50
LKV – Olive ridley	76	NA	82	NA	TCL	Mejuto et al. (2008)	17
	60.1	6.0	60.7	5.5	CCL	Santos et al. (2012)	42
	62.4	10.9	63.3	11.1	CCL	Coelho et al. (2015)	49

Table 4.4.9. Minimum conservation sizes established in ICCAT. Note that in some cases there are equivalents provided in weight, but for the purposes of this report we only refer to sizes. The size type refers to the specific measurement taken in each case: LJFL – lower jaw fork length, FL – fork length.

Species	Region	Min size (cm)	Size unit	Regulation	Notes
SWO	Atlantic	A:125; B:119	LJFL	Rec 17-02	Option A: 15% tolerance; B: 0% tolerance
	Mediterranean	100	LJFL	Rec 16-05	5% tolerance
BUM	All regions	251	LJFL	Rec 19-05	Applies only to recreational fisheries
WHM/RSP	All regions	168	LJFL	Rec 19-05	Applies only to recreational fisheries
BFT	West Atlantic	115	FL	Rec 17-06	
	East Atlantic	115	FL	Rec 18-02	Various exception for gears/farming in the Mediterranean
SMA	All regions	180 males; 210 females	FL	Rec 19-06	One of the various management options

For this sub-task we also calculated selectivity curves for species and various hook types, as described above in the methodology. This analysis used raw data from large-scale experimental at-sea trials carried out by IPMA, Portugal, described in Amorim et al. (2015), Coelho et al. (2012) and Fernandez-Carvalho et al. (2015). These studies covered wide areas of the Atlantic Ocean (including the NE tropical, equatorial region and South Atlantic, see Figure 4.4.9) where the EU longline fleets mainly operate.

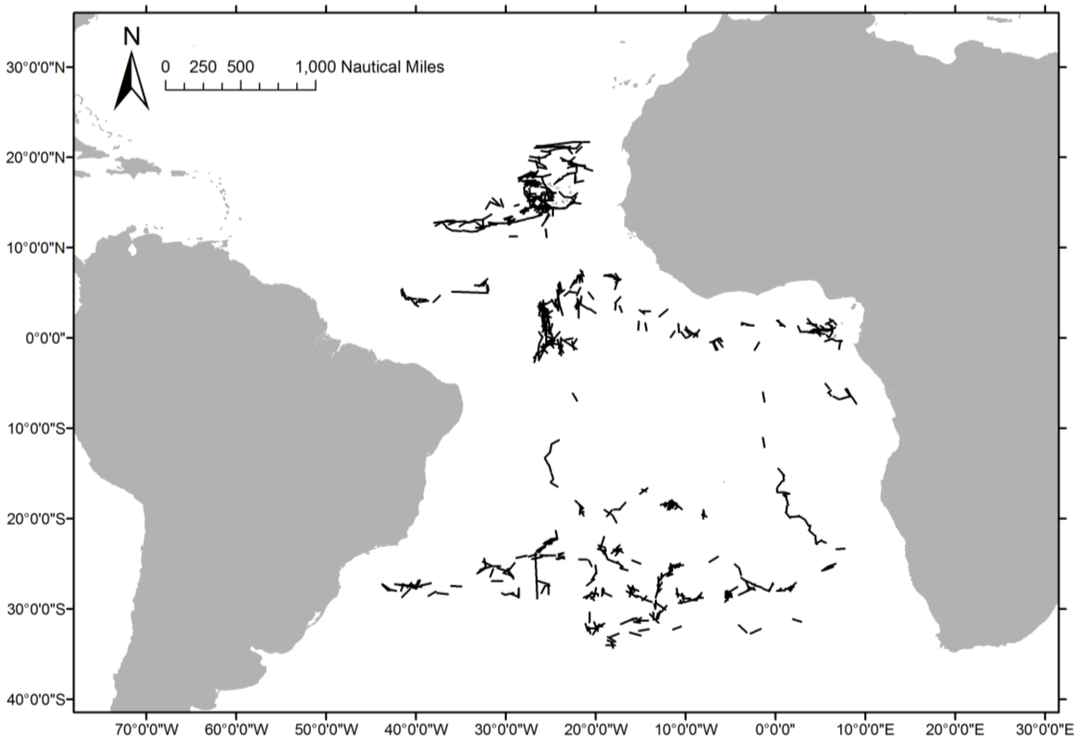


Figure 4.4.9. Geographical distribution of the experimental fishing sets comparing hook types (J hook with circle hooks with and without offset), described in Amorim et al. (2015), Coelho et al. (2012) and Fernandez-Carvalho et al. (2015).

The descriptive statistics used for the size selectivity data is represented in Figure 4.4.10, where it is noteworthy that there are no major differences in the sizes captured with the various hook types for any of the species considered. Specifically, for all three species analysed, the median values, inter-quartiles ranges and size ranges were very similar regardless of hook type used (Figure 4.4.10).

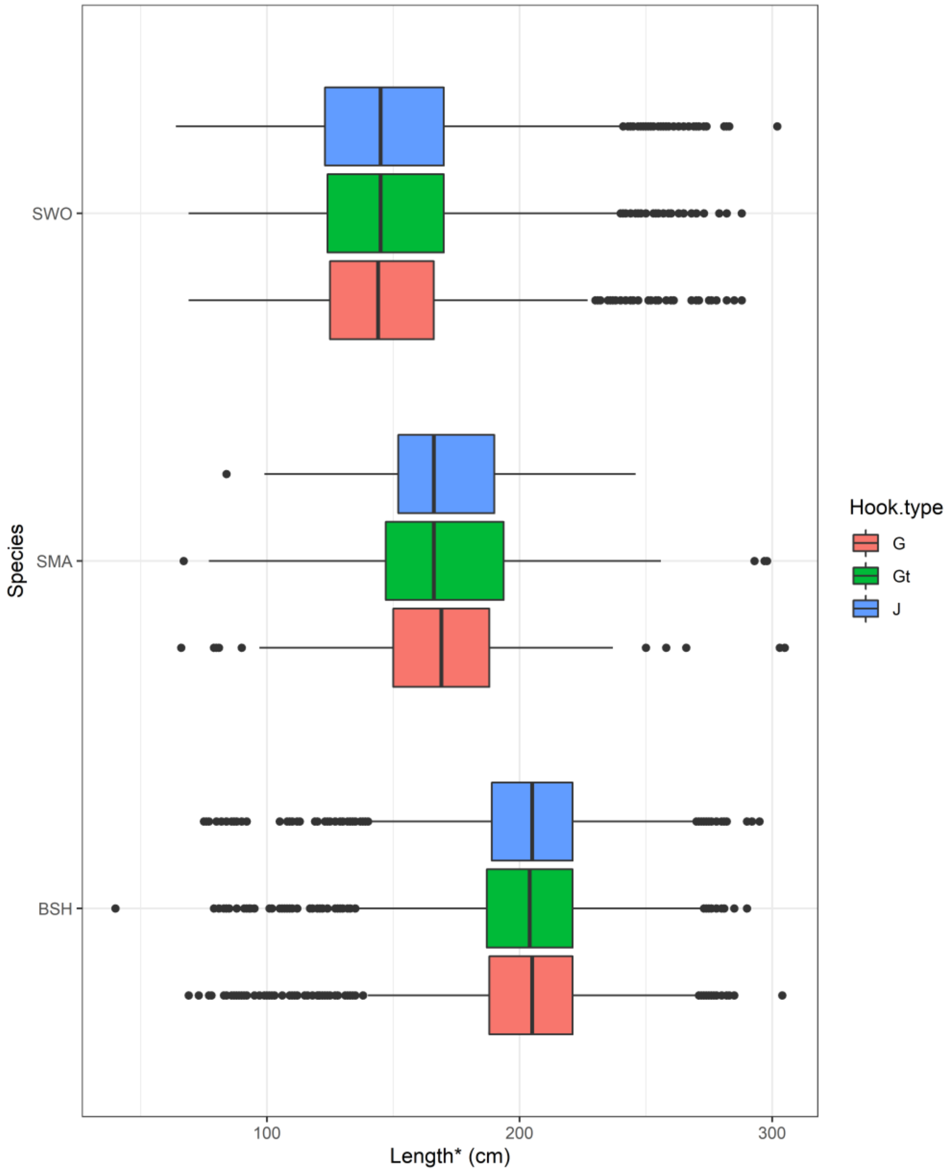


Figure 4.4.10. Boxplots describing the data used for the selectivity analysis. Within the hook types J = J hook, G = circle hook without offset and Gt = circle hook with 10º offset. * Lengths of BSH and SMA refer to FL (cm) and SWO refer to LJFL (cm).

The figures below represent the size selectivity curves with estimates of the size at which 50% of the individuals encountered are selected. In the case of swordfish it is noted that the selectivity of both J hook and circle hooks with offset is smaller than circle hooks without offset, namely 111.6 cm LJFL for J hooks, 109.5 cm LJFL for circle hooks with offset and 118.9 cm LJFK for circle hooks without offset (Figure 4.4.11). By contrast, for the blue shark, the size selectivity was larger with both J hooks (189.9 cm FL) and circle hooks with offset (189.1 cm FL), and smaller with circle hooks without offset (185.9 cm FL) (Figure 4.4.12). Finally, for the shortfin mako the results were very similar with both J hooks and circle without offset, namely 147.6 cm FL with J hooks and 148.5 cm FL with circle hooks without offset (Figure 4.4.13).

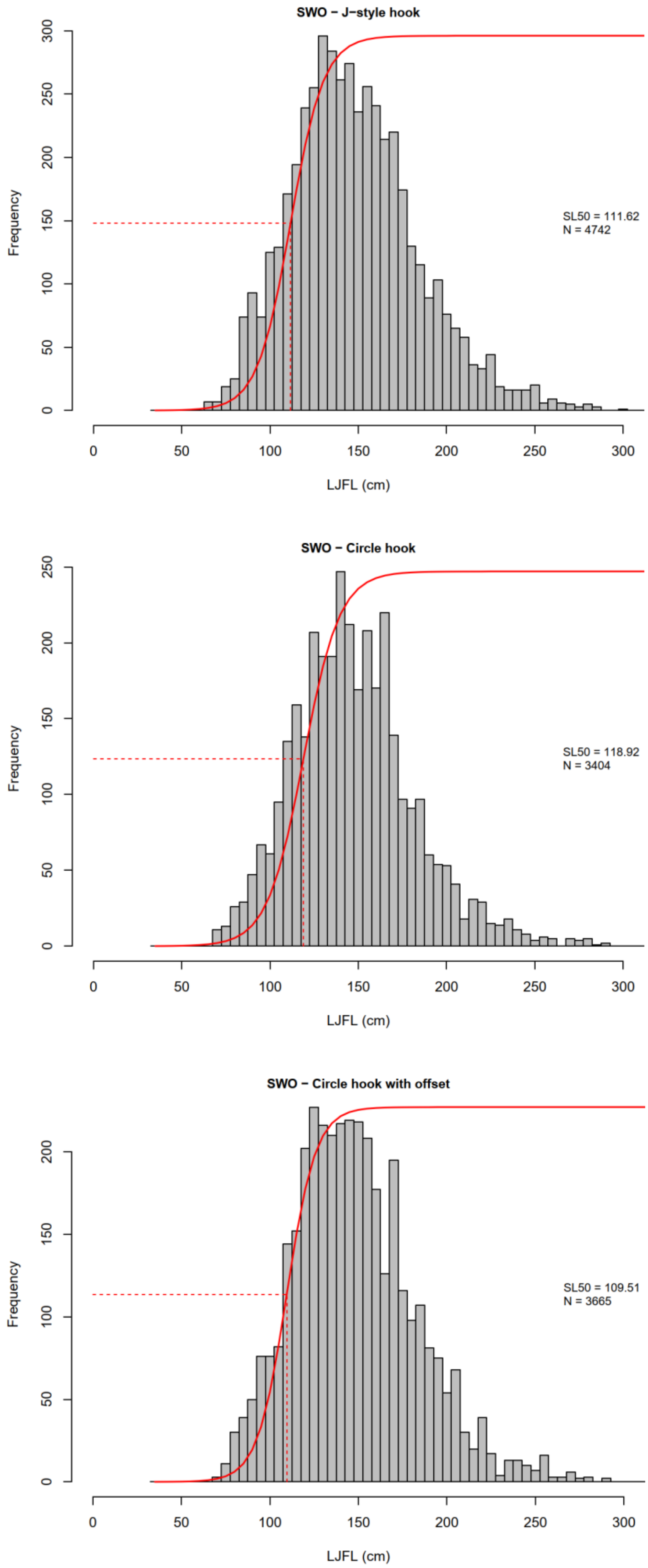


Figure 4.4.11. Size selectivity for swordfish using J hooks (top), circle hooks without offset (middle), and circle hooks with 10° offset (bottom).

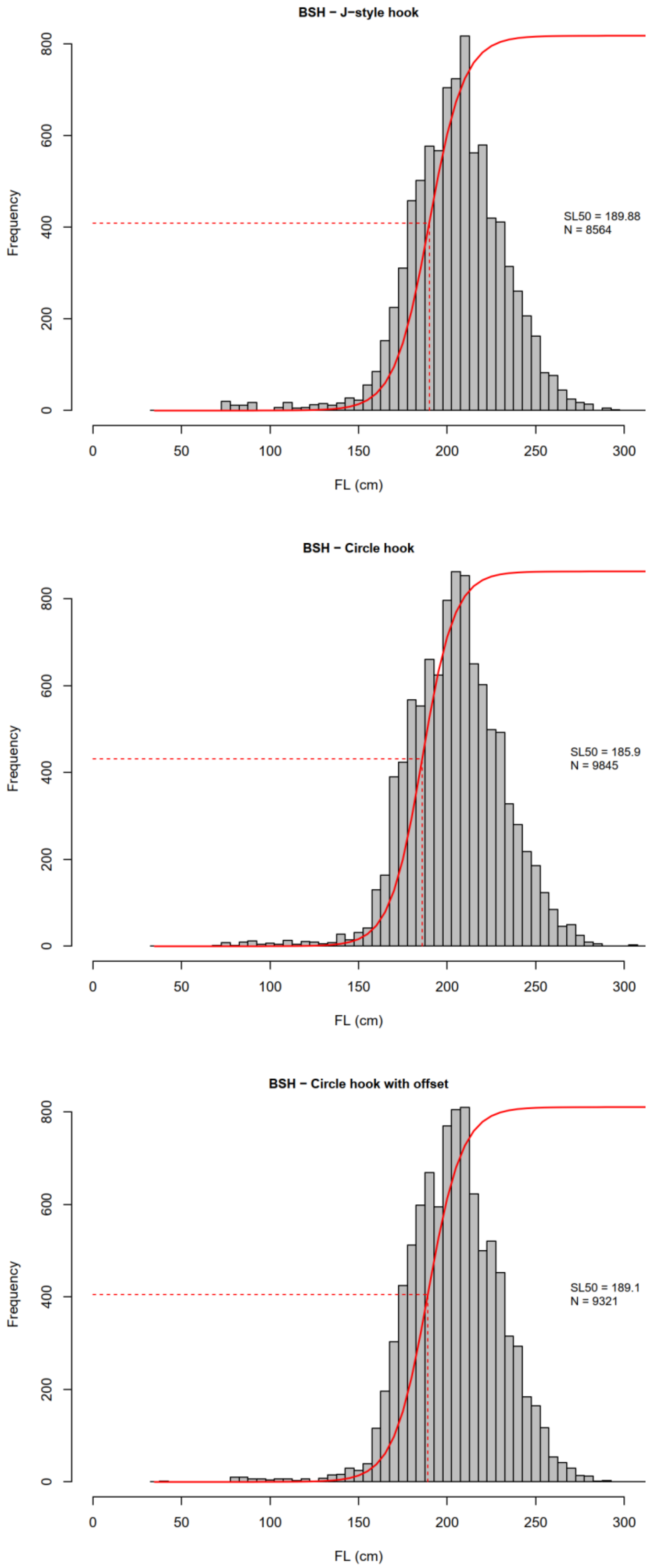
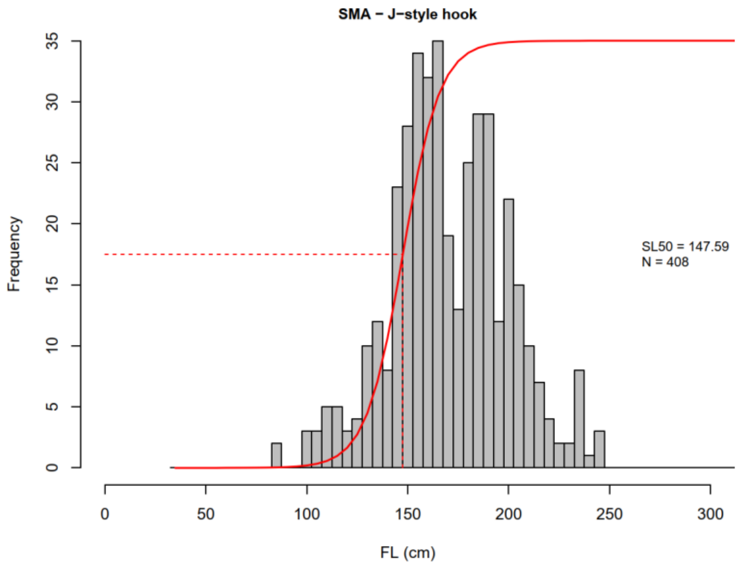


Figure 4.4.12. Size selectivity for blue shark using J hooks (top), circle hooks without offset (middle), and circle hooks with 10° offset (bottom).



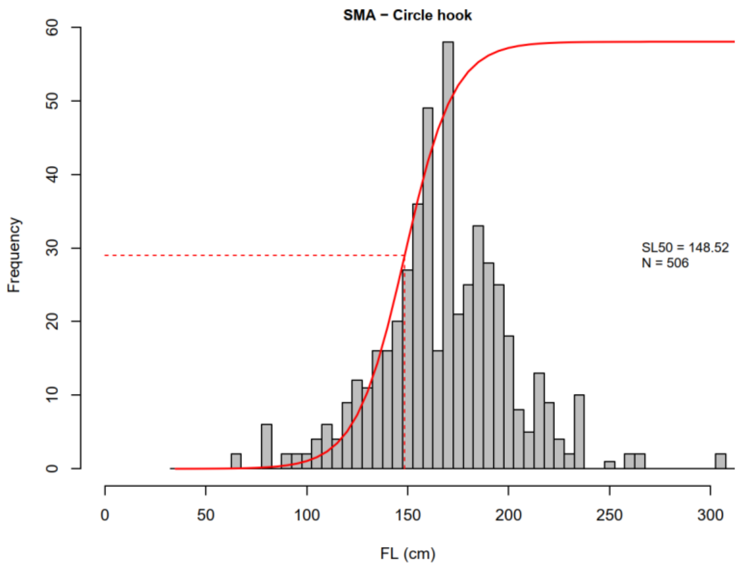


Figure 4.4.13. Size selectivity for the shortfin mako using J hooks (top) and circle hooks without offset (bottom).

Sub-task 1.6 – The appropriateness of the existing or potential new minimum conservation reference size

For this task we compiled information on size at first maturity (L_{50}) that can be compared with both the currently established minimum conservation sizes (provided in sub-task 1.5) and also used for the establishment of potential new ones. This has been carried out for all the species that are focused on this report, including 1) target species, 2) desirable bycatch and 3) unwanted bycatch. The information available for elasmobranchs is provided in Table 4.4.10. These values can now be used to compare with those in previous and existing conservation size regulations, as well in considering establishing future measures. Likewise, the information available for bony fishes is provided in Table 4.4.11, and that for sea turtles is provided in Table 4.4.12.

With regard to elasmobranchs, in the Atlantic Ocean the only pelagic elasmobranch that has a minimum size limit (as one of the conservation options) is the shortfin mako, namely 180 cm FL for males and 210 cm FL for females (Table 3.1.7). However, the size at maturity (size at which 50% of the population has reached maturity) varies between 180 and 220 cm FL for males and 270 and 300 cm FL for females. This means that the currently established minimum conservation size is relatively approximate for males, but not adequate for females.

Table 4.4.10. Size at first maturity for male and female elasmobranchs. The size type refers to the specific measurement taken in each study: FL – fork length; TL – total length.

Species	Female size at maturity (cm)	Reference	Male size at maturity (cm)	Reference
BSH – Blue shark	221 TL	Compagno (1984)	182-281 TL	Compagno (1984)
	>185 FL	Pratt (1979)		Carpenter & Niem (1998)
	228 TL	Hazin et al. (1994)		Fishbase (2017)
		IOTC (2011)	193-210 FL	COSEWIC (2006)
		Campana et al. (2005)		Campana et al. (2004)
		ICCAT (2006-2016)	183 FL	Pratt (1979)
	180 FL	Castro & Mejuto (1995)	225 FL	Hazin et al. (1994)
	194.4 TL	Jolly et al. (2013)		IOTC (2011)
	171.1 FL	Montealegre-Quijano et al. (2014)		Campana et al. (2005)
				ICCAT (2006-2016)
			L95=205 FL	Hazin et al. (1994)
			201.4 TL	Jolly et al. (2013)
			185-241 FL	Calich & Campana (2015)
			180.2 FL	Montealegre-Quijano et al. (2014)
BTH – Bigeye thresher	294-355 TL	Compagno (2001)	279-300 TL	Compagno (2001)
	350 TL	Stillwell & Casey (1976)	290-300 TL	Stillwell & Casey (1976)
	208.2 FL	Carvalho et al. (2011)	159.2 FL	Carvalho et al. (2011)
	282 TL	Verghese et al. (2017)	276 TL	Moreno & Morón (1992)
			263.50 TL	Verghese et al. (2017)
FAL – Silky shark	>225 TL	Branstetter (1987)	210-220 TL	Branstetter (1987)
	135-140 PCL	Oshitani et al. (2003)	135-140 PCL	Oshitani et al. (2003)
	232-245 TL	Bonfil et al. (1993)	225 TL	Bonfil et al. (1993)
LMA – Longfin mako	245 TL	Compagno (2001)	245 TL	Compagno (2001)
			229 TL	Reardon et al. (2006)
	189-198 TL	Bonfil et al. (2008)	180-190 TL	Lessa et al. (1999)

OCS – Oceanic whitetip	180-190 TL	Lessa et al. (1999)	175-198 TL	Compagno (1984)
	180-200 TL	Compagno (1984)	160-196 TL	Coelho & Burgess (2009)
	181-203 TL	Coelho & Burgess (2009)	170-190 TL	Tambourgi et al. (2013)
	170 TL	Tambourgi et al. (2013)		
POR – Porbeagle	237 TL	Compagno (2001)	196 TL	Compagno (2001)
	212 FL	Campana et al. (1999)	150-200 TL	Compagno (2001)
	210-230 FL	Jensen et al. (2002)	175 FL	Campana et al. (1999)
	217.5 FL (50%)	Campana et al. (2012)	162-185 FL	Jensen et al. (2002)
	215.3 - 248.0 FL	Natanson et al. (2019)	173.7 FL (50%)	Campana et al. (2012)
SMA – Shortfin mako	275-293 TL	Compagno (2001)	203-215 TL	Compagno (2001)
	298 TL	Mollet et al. (2000)	185 FL	Natanson et al. (2006)
	273 TL	Mollet et al. (2000)	180 FL	Maia et al. (2007)
	275 FL	Natanson et al. (2006)	200-220 FL	Campana et al. (2005)
	270-300 FL	Campana et al. (2005)	173-187 FL	Natanson et al. (2020)
	263 -291 FL	Natanson et al. (2020)		
SPL – Scalloped hammerhead	212 TL	Compagno (1984)	140-165 TL	Compagno (1984)
	250 TL	Branstetter (1987)	180 TL	Branstetter (1987)
	210-250 TL	Baum et al. (2007)	140-198 TL	Baum et al. (2007)
	240 TL	Hazin et al. (2001)	180-200 TL	Hazin et al. (2001)
SPZ – Smooth hammerhead	304 TL	Compagno (1984)	256 TL	Compagno (1984)

Table 4.4.11. Size at first maturity for bony fishes. The size type refers to the specific measurement taken in each study: FL – fork length, LJFL – lower jaw fork length; EFL – eye fork length; CFL – curved fork length.

Species	Female size-at-maturity (cm)	Ref	Male size-at-maturity (cm)	Ref
SWO – Swordfish	178.7 LJFL	Arocha (2007)	120-130 LJFL	Hazin et al. (2002)
	156 LJFL	Arocha (2007)	95 LJFL	Abid et al. (2019)
	142.2 LJFL	Arocha (2007)		
	156 LJFL	Hazin et al. (2002)		
	140 LJFL	Macías et al. (2005)		
	170 LJFL	Abid et al. (2019)		
	146.5 LJFL	Mejuto & Cortés (2014)		
WHM – White marlin	160.46 LJFL	Arocha & Bárrios (2009)		
	130 EFL	Amorim et al. (1998)	130 EFL	Amorim et al. (1998)
	130 EFL	Amorim & Arfelli (2003)	130 EFL	Amorim & Arfelli (2003)
BUM – Blue marlin	183.5 LFL	Torres-Silva et al. (2008)	150.1 FL	Torres-Silva et al. (2008)
	179.76 EFL	Sun et al. (2009)	130 EFL	Sun et al. (2009)
	183 LJFL	Shimose et al. (2009)	160 LJFL	Shimose et al. (2009)
SAI – Atlantic sailfish	166 LJFL	Chiang et al. (2006)		
	175 EFL	Hernandez-H & Ramirez-R (1998)		
	154.93 LJFL	Mourato et al. (2009)		
	150.2 EFL	Cerdenares-Ladrón De Guevara et al. (2013)		
	147-160 LJFL	Jolley (1977)		
	180.2 LJFL	Arocha & Marcano (2006)		
	146.12 LJFL	Mourato et al. (2018)		
BFT – Bluefin tuna	110 FL	Susca & Bridges (2003)		
	103.6 FL	Corriero et al. (2005)		
	>134 CFL	Heinisch et al. (2014)		
	97.5 FL	Rodríguez-Roda (1967)		
	>115 FL	Tawil et al. (2002)		
	116 FL	Medina et al. (2002)		

Table 4.4.12. Size at first maturity for male and female sea turtles. The size type refers to the specific measurement taken in each study: CCL – curved carapace length; SCL – straight carapace length.

Species	Female size at maturity (cm)	Ref	Male size at maturity (cm)	Ref
TTL – Loggerhead sea turtle	80 CCL	Casale et al. (2011)	75-80 CCL	Casale et al. (2005)
	74.9-80 SCL	Bjorndal et al. (2013)	74.9-80 SCL	Bjorndal et al. (2013)
	74-92.2 SCL	Frazer et al. (1985)	95.8 SCL	Avens et al. (2015)
	90.5 SCL	Avens et al. (2015)		
	66.5-84.7 CCL	Casale et al. (2009)		
	91.2 SCL	Ehrhart et al. (2014)		
DKK – Leatherback sea turtle	145 CCL	NMFS–SEFSC (2001)		
	138.5 CCL	Stewart et al. (2007)		
	125, 145, 155 CCL	Avens et al. (2009)		
	144.5 CCL	Zug & Parham (1996)		
	121, 117, 116 SCL	Jones et al. (2011)		
LKV – Olive ridley sea turtle	*c.* 60 SCL	Zug et al. (2006)	*c.* 60 SCL	Zug et al. (2006)
	66 CCL	Petitet et al. (2015)	66 CCL	Petitet et al. (2015)
LKY – Kemp's ridley sea turtle	60 SCL	Craven et al. (2019)	60 SCL	Craven et al. (2019)
	53.3-68.3 SCL	Avens et al. (2017)	53.3-68.3 SCL	Avens et al. (2017)
	47.0-61.0 CCL	Bjorndal et al. (2014)		
	65 SCL	Zug et al. (1997)		
	64.2 SCL	Schmid & Witzell (1997)		
	60.0 SCL	Snover et al. (2007)	60.0 SCL	Snover et al. (2007)
TUG – Green sea turtle	95-100 CCL	Limpus & Chaloupka (1997)	<= 95 CCL	Limpus & Chaloupka (1997)
	81.3-111.8 CCL	Wood & Wood (1980)		
	90-100 CCL	Chaloupka et al. (2004)	90-100 CCL	Chaloupka et al. (2004)
	86.7 CCL	Zárate et al. (2003)		

5. TASK 2 – TECHNICAL AND BIOLOGICAL ASPECTS

Key findings

- A catalogue of the main hook shapes and sizes deployed in pelagic longline fisheries worldwide has been produced with the respective measurements of several parts aiming to describe the size, the shape of the hook and to estimate indicators related to the selectivity (species and fish size).
- The relationship between the length of the different elements of the hook whatever the hook type is always linear.
- The value of the intercept of the relationship between the straight total length and the length of other hook elements (front length, width, …) could be an indicator of the shape of the hook but not of its size.
- The circle hook does not have a clear definition, in particular whether it is an object in two or three dimensions (offset versus non offset) and this situation might impede the adoption of regulations related to the hook size and shape.
- The heterogeneity of size and shape of hook type between manufacturers is a major issue in the setting up of regulations.
- The point angle of the circle hook is not perpendicular to the shank and it exhibits a rather large interval of values. Moreover, it is always more or less deviated out of the loop drawn by the shape of the bend.
- The selectivity indicator (ratio between the gap and the width of the hook) appears as an efficient discriminant indicator to be used when (1) analysing the interaction between hooks and the marine megafauna in fishing trials that test the hooking responses of the marine megafauna in relation to the hook shape and (2) to validate gear technology advice to managers.
- The major part of research analysing the potential benefits of circle hooks in mitigating the negative impact of the pelagic longline fisheries on the ecosystem was carried out between the years 2000 and 2010.
- A large offset angle would negate the effect of circle hooks in terms of both deep hooking and reducing interactions with sea turtles (Cooke and Suski, 2004; Swimmer *et al.*, 2010). A comparative analysis offset versus non offset circle hooks taking into account the severity of the offset on the hooking injuries of capture would be a productive research topic to provide clear insights to managers.

Objectives

The main objective of this task is to provide advice on the technical and biological factors that explain the supposed practical effects of circle hooks with respect to other shapes of hook (J hook, Japanese-hook, teracima hook, etc.) by taking into account the circle hook morphology (e.g., offset/non-offset, width, length, gape, bite, incurved point angle, barb type, etc.).

A hook is a very simple but important item that has been created by hominids to catch fish in order to ensure food security. The earliest fish hooks were probably designed with sea snail shells around 30,000 years ago by Cro-Magnon man as revealed by archaeological digs on Okinawa Island (Fujita et al., 2016), (Price, 2016). The hook was circular, and similar hook types have been found in other parts of the world; for example, similar hooks were used by pre-Columbian native peoples in Latin America and by Polynesian people. Moreover, it has been established that the fish hook had a major impact on human civilization. In 2005, editors, readers and experts of *Forbes* magazine ranked the fish hook as the 19th-most-important tool of all time (Ewalt, 2005).

In the 20th century the hook became less important because commercial fisheries rely more upon nets (gillnet, net traps, trawl, purse seine), however both recreational and professional fisheries still depend on the hook. Broadly, we can identify three type of hooks: baited hook, fly hook and lure hook. The baited hook is the hook type used in many hook and line fisheries (demersal longline, pelagic longline, vertical line). For demersal and pelagic longline fisheries, the most classical shapes are: J hook, circle hook (also called G hook), teracima hook and tuna hook. For each shape, there are several sizes. However, unfortunately, there is no unique size unit for hook measurements. Mustad, one of the most important manufacturers of hooks in the world, particularly in Europe and the United States, uses a size range from 32 (the smallest) to 20/0 (the largest). For the largest hooks, ranging from 1/0 (smallest) to 20/0 (biggest) the measurement unit is an "aught". Generally, this measurement system is a ranking system that is not informative when it comes to the actual dimensions of the hook. For Japanese manufacturers, the unit used to measure a tuna hook is called a "sun" and has a unit value of about 3.3 cm (Beverly, 2006). Hence, a 4-sun hook measures 4 x 3.3 cm (= 13.2 cm) long. This length corresponds to the length of the material used to manufacture the hook from the eye or the ring to the tip of the point. In the case of circle hooks, manufacturers in Europe use the same principle to measure the size of the hook: a 20/0 circle hook corresponds to a hook with a length of wire from the eye to the point of 20 cm, approximately the same size as a hook with a size of 6 sun.

Besides formulating a simplistic generic description of hooks based on the characteristics of main parts of the hook as shown in Figure 5.2.1, it must be noted that there is large variation in actual hook designs among and within different manufacturers' product lines. This is particularly true for circle hooks, which, for the last three decades have become increasing known for their apparent conservation benefits compared with other hook types in general and J-style hooks particularly (Cooke and Suski, 2004).

Our demonstration was based on i) the analysis of measurements, shape and morphological attributes of different type of hook used in both artisanal and industrial pelagic longline fisheries worldwide, ii) the analysis of hooking location in relation to the hook type (data collected in the literature and via responses to a questionnaire developed for this purpose) and iii) a literature analysis of arguments justifying why the circle hook displays potential practical effects that act as mitigation measures in pelagic longlining.

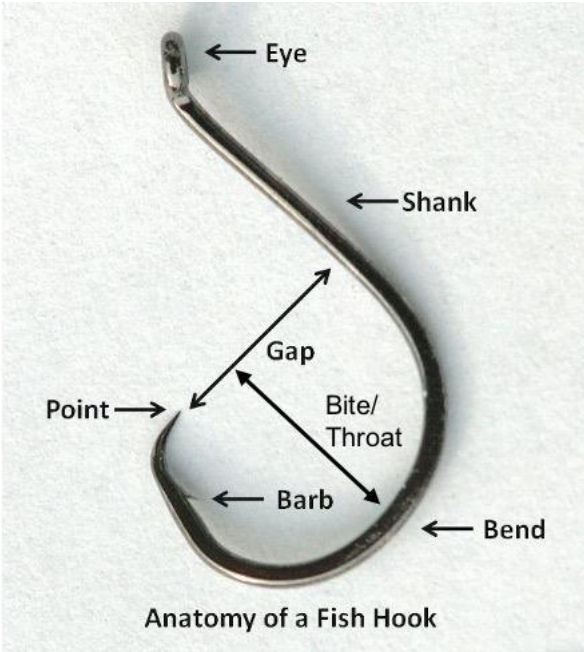


Figure 5.2.1. Anatomy of the fish hook.
(modified from https://en.wikipedia.org/wiki/Fish_hook)

Methodology

Sub-task 2.1 – Shape and morphological attributes of hook styles used in pelagic longlining

The aim of this sub-task is to deliver a presentation of the different hook styles (e.g., J hook, tuna hook, teracima hook, circle hook) used in both artisanal and industrial pelagic longline fisheries. An example of each hook type is presented in Figure 5.3.1.

Measurement points of circle hooks appropriated for morphological comparison and evaluation of the effects of hook design have been proposed in order to describe shape, size and various characteristics of hook types (Yokota et al., 2006). These measurements can be made based on hook pictures, as suggested by Yokota et al. (2006). Beverly and Park (2009) have published a guide for longline terminal gear identification with drawings of several hook types. Mituhasi and Hall (2011) have produced a hook catalogue for scientific observers aiming to identify hooks used in artisanal longline fisheries in the Eastern Pacific region.

Hook measurements presented in this study were carried out for hook pictures and drawings published in the two catalogues (Beverly and Park, 2009; Mituhasi and Hall, 2011). Also, additional unpublished pictures of several hooks were provided by E. Romanov (unpublished data). All the hooks considered in this study are presented in Appendix IX (catalogue of hooks).

Hook measurements made aimed to characterise their respective size and shape. The respective morphological attributes (e.g., offset/non-offset, width, length, shank thickness, incurved point angle, etc.) of those hooks are certainly important drivers of gear selectivity (individual size, species), hooking location and fishing mortality (at-vessel and/or post release).

In order to collect data from pictures, the hook pictures selected in the two catalogues and provided by E. Romanov were extracted using the open source software Gimp version 2.10.14. When necessary, the picture was rotated in order to have the shank as a vertical axis. Hook measurements were done with the open source software ImageJ version 1.52a. The original measurement of the computer screen is in pixels and the pixel values for all variables were converted into millimetres All measurements considered the hook on a plan (2 dimensions); the information relating to the offset angle (the third dimension) when available for some models was not collected.

Eight size variables and three angles of the hook were measured (Figure 5.3.2): the front length, the straight total length, the minimum inner width, the straight total width, the maximum inner width, the total length, the minimum total width and the maximum total width, the bending (angle) of the front of the hook and the bending (angle) of the back of the hook. The full dataset of measurements made is listed in Appendix X.

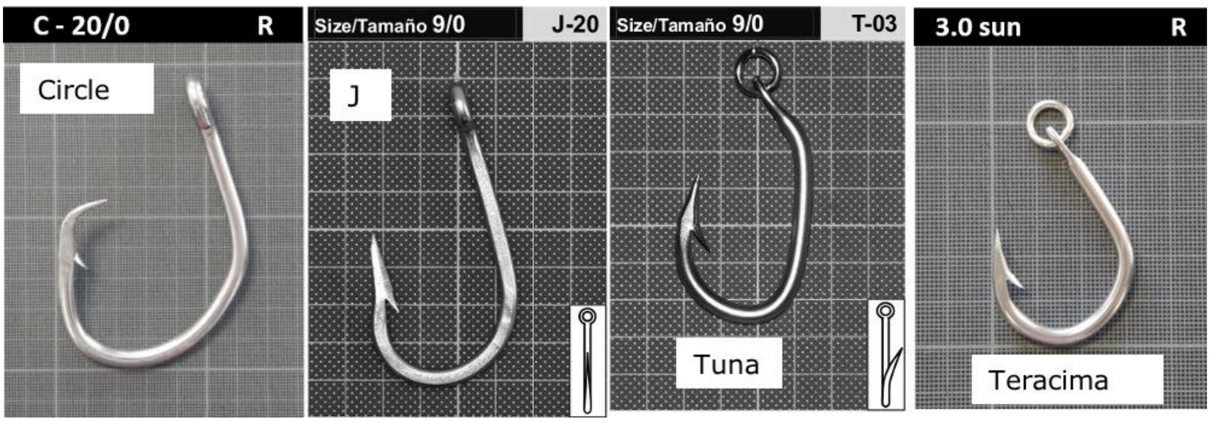


Figure 5.3.1. Example of hook types (circle, J, tuna, teracima) analysed in this study. The full catalogue of hooks is provided in Appendix IX.

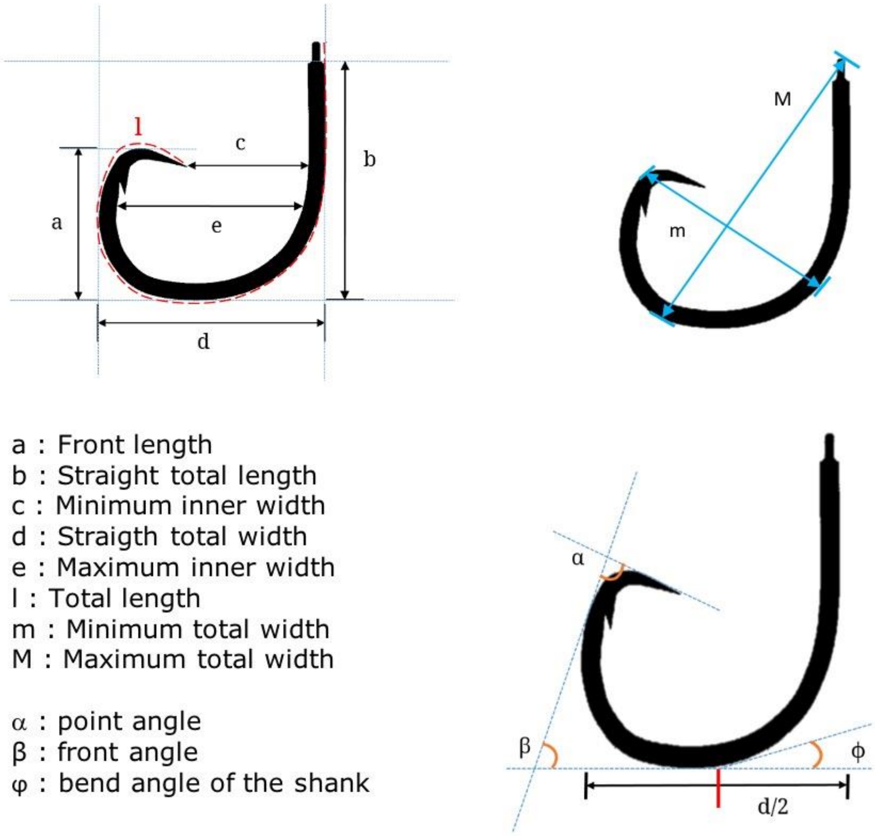


Figure 5.3.2. List of variables measured to describe the hook shape.

Among these variables, some have already been considered in relation to selectivity and hooking issues:

- <u>The hook width</u> (called straight total width in Figure 5.3.2) is a morphological attribute of the hook related to the deep-hooking of individuals. Logically, it is more difficult for a fish with a small mouth to swallow a wider hook. For fish of a given size, likely deep-hooking is inversely related to the hook width. A positive effect of hook width on sea turtle catch has been documented in past studies: the wider the hook, the lower the catch rate (Gilman et al., 2006).
- <u>The straight total length</u> of the shank and the front length are important factors in hook design for reasons similar to those mentioned in relation to hook width. However, if the sizes of different elements are proportional, it is important to consider the effect of the individual elements in light of the total hook design (Yokota et al., 2012).

- <u>The incurved point</u> is the singular attribute of circle hooks. It was admitted that increasing incurved points increased hooking in the jaw or mouth instead of deep-hooking.

The actual size and shape characteristics of hooks differ between product types and manufactures (Mituhasi and Hall, 2011). First, we illustrate these differences for the four hook types considered in the study. Second, we analyse the relationship between the size of the different parts of "average" hooks. The length or angle of parts of an "average" hook correspond to the respective "mean" values of each part for a given manufacturer size, for example 16/0 or 3.8 sun. Third, we provide estimates of some shape indicators for each average hook based on a combination of elements or measurements.

<u>*Sub-task 2.2 – Meta-analysis of hooking locations in relation to the hook design (mainly hook shape and offset) in pelagic longlining*</u>

This sub-task comprises a meta-analysis of hooking locations (Fig. 5.3.3) for pelagic longline target and bycatch species in relation to the hook design (mainly hook shape and offset) as the hooking location is considered one of the main drivers of the fate of the hooked individuals in terms of injures, stress and mortality. However, the hooking location on capture of both target species and bycatch is not the type of data that are routinely collected in the framework of observer programmes and such information is rarely collected in pelagic longline surveys. For the first step of this sub-task carried out a broad survey to verify whether fishery biologists involved in pelagic longline research and/or observer programmes and also biologists involved in sea turtle rescue centres are collecting such information on hooking location, and eventually the fate of the catch, and whether this data has been published in peer reviewed journals (where the data easy to recover) or in the grey literature. All the information needed was requested in a questionnaire distributed to longline observer programme coordinators worldwide.

For the available data, we performed meta-analysis, aiming to analyse a likely relationship between the hook type and the hooking location and in particular the level of internal hooking (gills, throat and gut) and to link the hooking location with the fate and the mortality (at-vessel mortality or post-release mortality) of the fish.

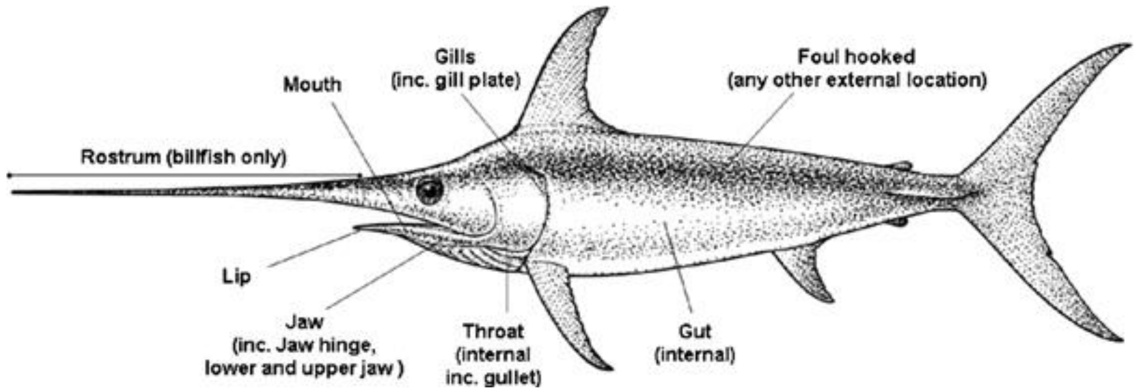


Fig 5.3.3. Representation of the eight parts of the fish body used in analysing hooking locations (from Ward et al., 2009).

Sub-task 2.3 – Why do circle hooks display potential practical effects as mitigation measures in pelagic longlining?

The aim of this sub-task is to present the reasons both technical and biological that could explain the preference for the circle hook compared to other hook shapes, based on reasons intrinsically related to the hook design itself.

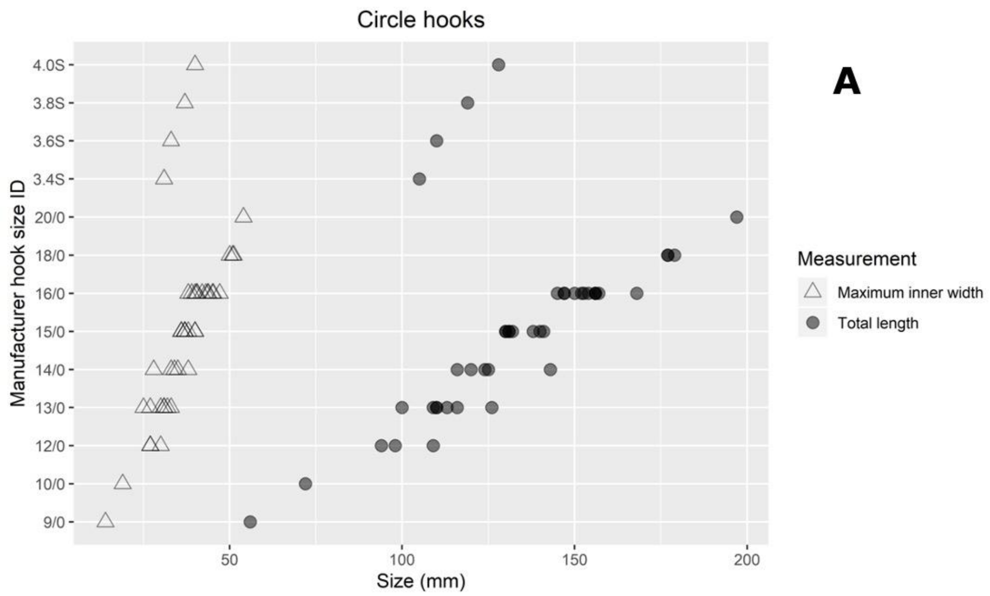
At the beginning of the 1990s, there was an increasing interest within catch-and-release recreational fisheries to promote or develop a terminal gear aiming to reduce fish injuries and post-release mortality (Ward et al., 2009; Serafy et al., 2012). This sub-task explores the reasons why the circle hook might be or is an effective mitigation measure, in reducing either bycatch for some groups of species or injuries and immediate or delayed fishing mortality. We explore whether such positive effects are related to the mechanics of the hooking mechanism, which in turn is related to shape of the hooks. For example, the final hooking location in the fish (e.g., gut or mouth) can be linked to the way the hook behaves while ingested by the captured fish.

Results and discussion

Sub-task 2.1 – Shape and morphological attributes of hook styles used in pelagic longlining

Several scientific reports and publications have pointed out the differences in size of a given size ID of hook types. The dimension/size of a hook is usually determined by the gap of the hook (Sivertzen, 2012 in Anonymous, 2012) but it can also be determined by the total length of the wire (Beverly, 2006). Based on gap size, the overall dimension is very simple to determine for a J hook; however, such size determination is not straightforward for curved hooks. For example, sizing of circle hooks is challenging and standards can differ between manufacturers. Figure 5.4.1 illustrates sizing variations for a given size ID, whatever the hook type, but particularly for the circle hook –the hook type that varies the most in the catalogues and pictures provided. In the case of circle hooks (Figure 5.4.1) the difference between the smallest and greatest total length can be as large as 2.5 to 3 cm for a given size ID and about 1 cm for the maximum inner width (circle hooks 13/0, 14/0, 15/0 and 16/0). Moreover, we observe a large overlap of length values (total length and maximum inner width) between several ID sizes (from 13/0 to 16/0 for circle hooks, 7 and 6 or 7/0 and 8/0 for J hooks, 7/0 and 8/0 or 9/0 and 10/0 for tuna hooks). In addition, some size IDs are incorrect (J hooks 1/0 and 2/0). Finally, the lengths of hook elements for an ID size based on the "sun" unit appears more consistent than those based on the "aught" unit (Figure 5.4.1).

The ID sizes given by manufacturers were used in order to estimate the average length of hook elements as shown in Figure 5.3.2. A correlation matrix was established to identify the relationship pattern between the length of elements for the different hook types (Figure 5.4.6). This correlation analysis clearly shows that the relationship between length of the different hook elements is always linear. A constant proportionality is observed between several of the variables. However, one variable, the straight total length, has a different relationship (similar slope but different intercept) with the other variables. The straight total length corresponds to the length of the shank; the intercept of its relationship with other variables (element size) depends on the width of the hook as well as the front length and the total length. Hence, the value of the intercept of the relationship between the straight total length and the length of other elements could be an indicator of the shape of the hook but is not an indicator of the size.



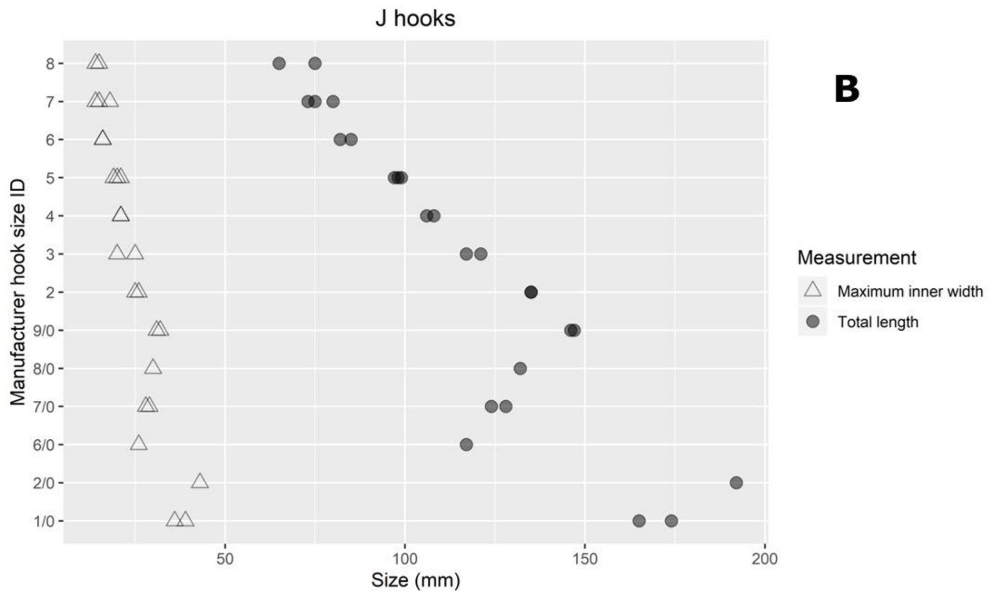


Figure 5.4.1. Plot of the total length and the maximum inner width in relation to the hook size ID for the various hook types.

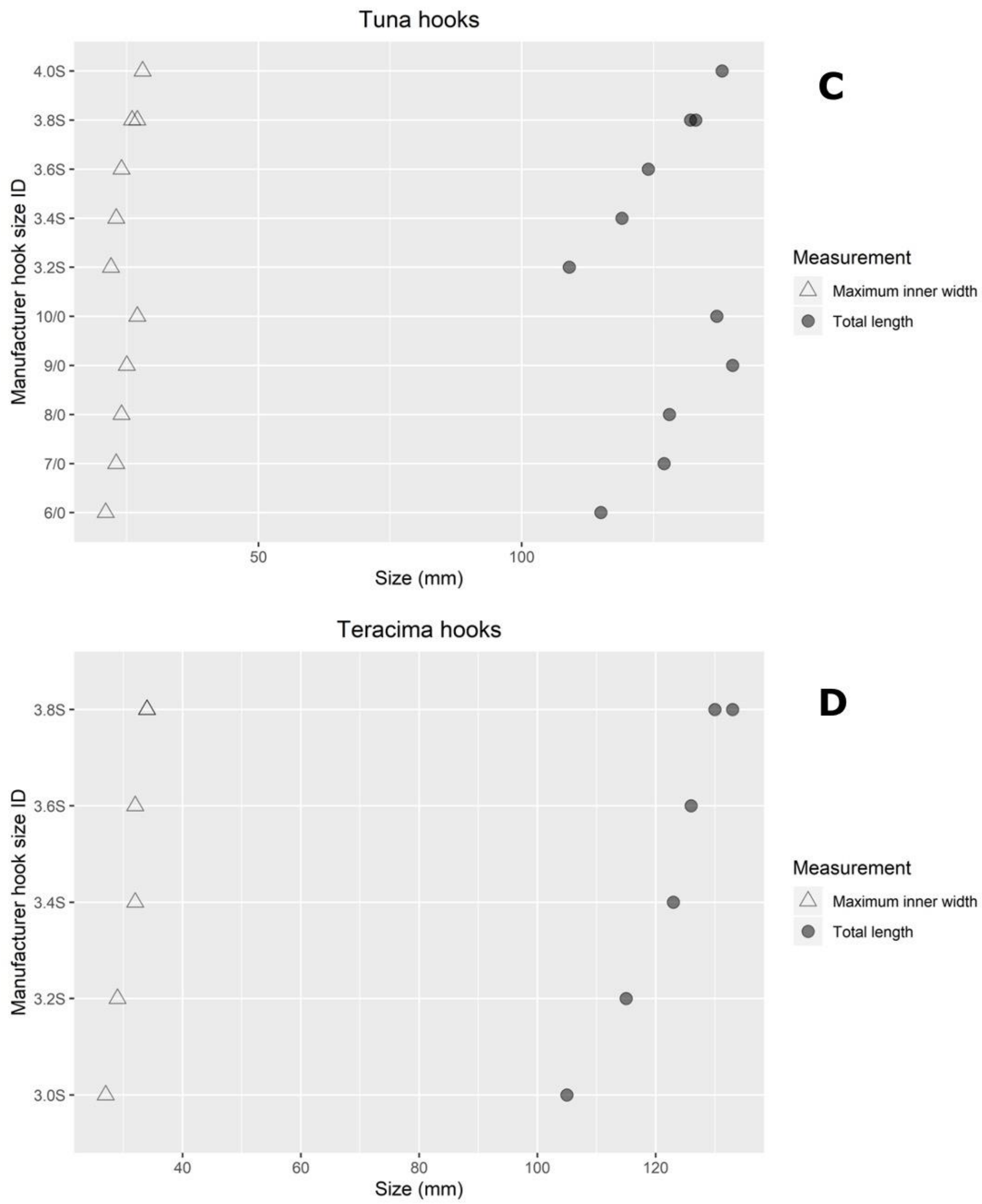


Figure 5.4.1. (continued).

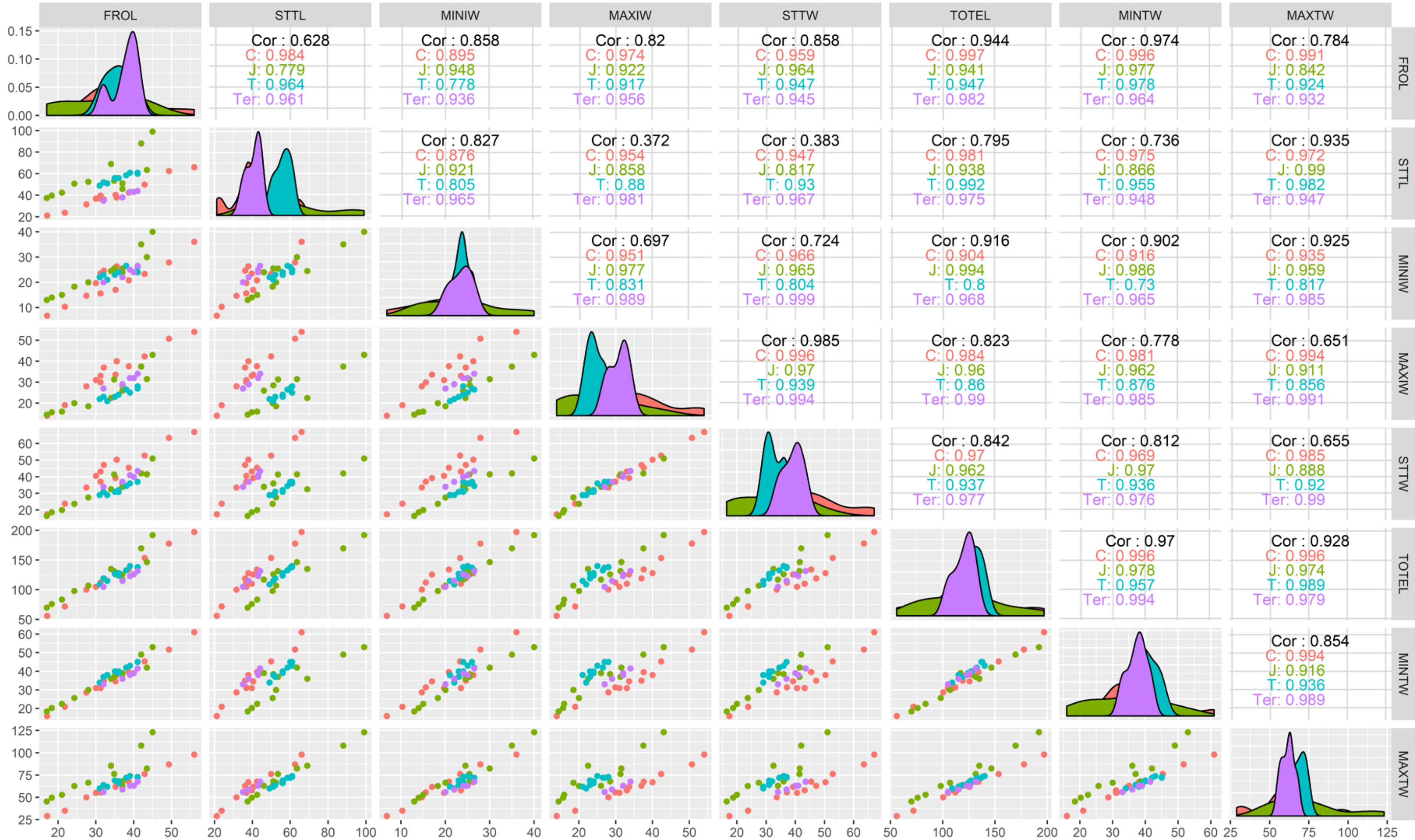


Figure 5.4.2. Correlation matrix between mean size of hook elements for the four hook types considered in the study (C = circle hook, J = J hook, T = tuna hook, Ter = teracima hook). (List of variables: FROL = front length, STTL = straight total length, MINIW = minimum inner width, MAXIW = maximum inner width, STTW= straight total width, TOTEL = total length, MINTW = minimum total width, MAXTW = maximum total width).

The incurved point or the point angle is a particular attribute of circle hooks (Yokota et al., 2012) as is the deviation of the front length. Boxplots of the value of these two angles are displayed in Figure 5.4.3. In the case of the point angle, it is logical that for hooks other than circle hooks the angle value is close to 180°, corresponding to a direction parallel to the shank. However, for circle hooks, it is surprising to note that the frequency distribution of values is rather extended (from 115° to 155°) with an average value of 130°. It would have been logical to obtain a narrower distribution with an average value of 90° meaning a tilt of the point angle perpendicular to the shank.

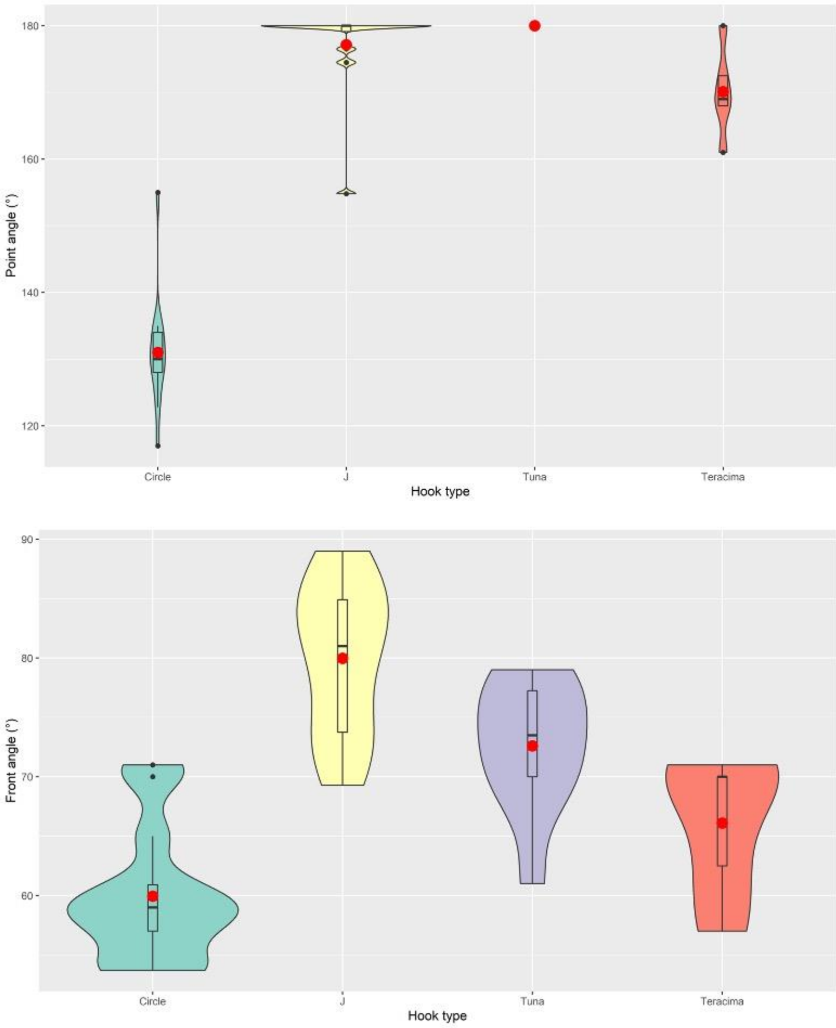


Figure 5.4.3. Boxplots of the point angle (top) and front angle (below) values (°) for different hook sizes from manufacturers for the four hook types considered in this study (circle, J, tuna and teracima).

Also, values recorded for the point angle characterise an “open” angle rather than a “closed” angle, which is expected if the benefit of the circle hook is to reduce deep-hooking at least when the point is in line with the shank. When there is an offset on the circle hook contradictory evidences are published regarding the deep-hookingo.

Regarding the front angle, the frequency distribution observed for the circle hook clearly shows tilt of the front in the direction of the shank, thereby reducing the gap of the hook.

Boxplots of some indicators (combinations of hook elements) aiming to characterise both the shape and the size of hook types are shown in Figure 2.8. The loop indicator, which represents the part of the hook occupied by the bait is fairly similar whatever the hook type. It shows an average surface of about 15 cm with the highest value calculated for the circle hook and the teracima hook (Figure 5.4.4). The second indicator – the Space indicator – represents the ratio between the width and the height of the hook (Figure 5.4.4). According to the space indicator, the J hook is clearly discriminated, this hook type being the tallest hook type of the four hook types in the study. For the two other indicators, the shape indicator and the selectivity indicator, the singularity of the circle hook is again clearly highlighted. For these two indicators lowest values are calculated for the circle hook and particularly for the selectivity indicator the frequency distribution of values of the circle hook showing to not ovelap with those of other hook types. Therefore, the selectivity indicator appears the most discriminant and could be used as a factor when analysing the interaction between hooks and the marine megafauna in fishing trials testing the hooking responses of the marine megafauna relative to the hook shape. However, this indicator does not consider the presence of an offset or not. The offset and more its severity (weak for an angle less than 10° and severe for higher angle values) should be consider as an additional indicator.

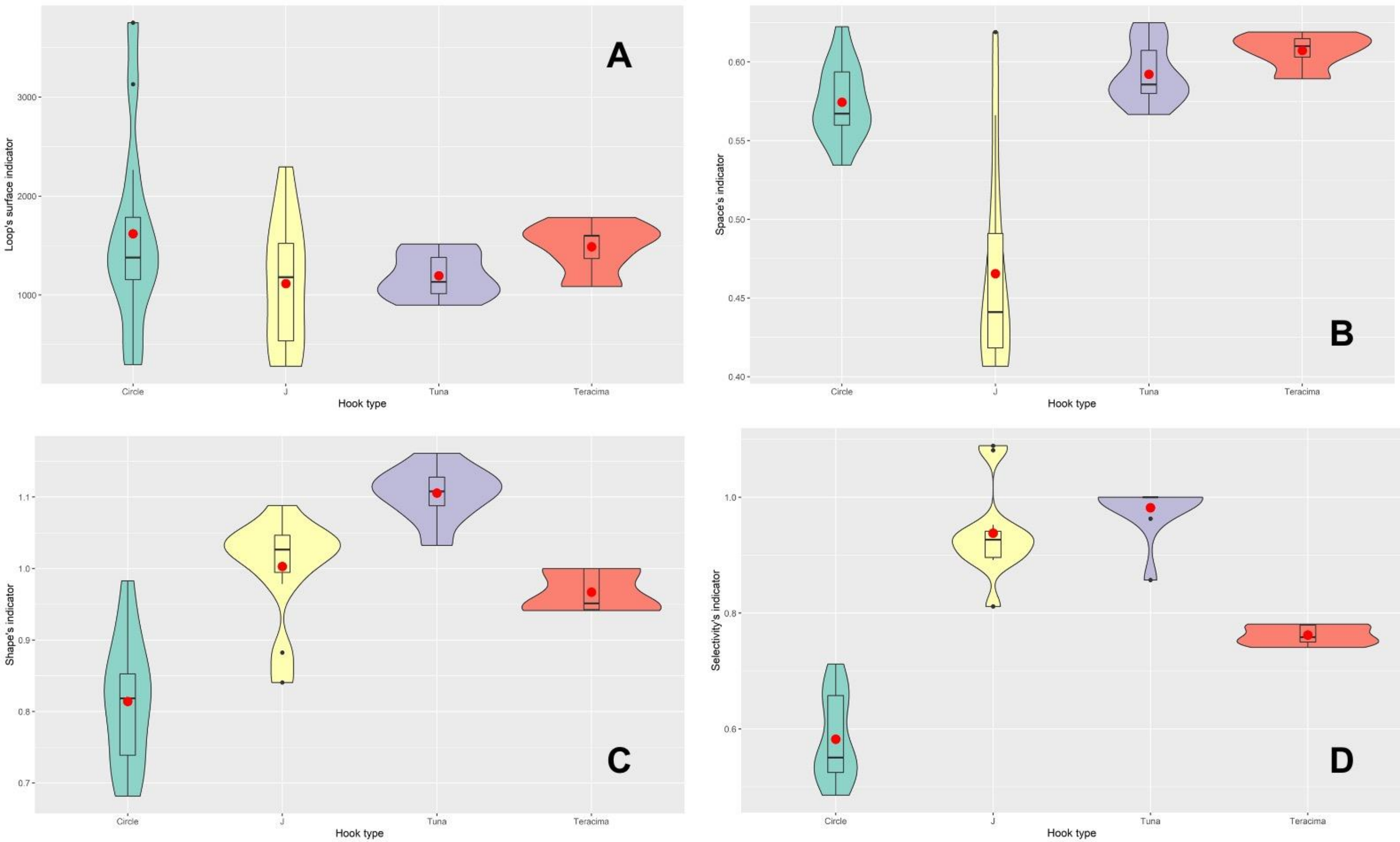


Figure 5.4.4. Boxplots of several indicators based on the combination of individual elements of the four different hook types: circle hook, J hook, tuna hook and teracima hook. A = loop indicator = front length * straight total length, B = space indicator = minimum total width / maximum total width, C = shape indicator = front length / straight total length, D = selectivity indicator = gap / width.

Sub-task 2.2 – Meta-analysis of hooking locations in relation to the hook design (mainly hook shape and offset) in pelagic longlining.

In order to produce a meta-analysis of hooking locations in relation to the hook design (hook shape, size and offset) in pelagic longlining a questionnaire (Appendix XI) was developed using Google forms. The questionnaire was sent to those responsible for pelagic longline human observer programmes worldwide ([1]). After completing the Google form, a web link was displayed giving access to an Excel file in order to collect the additional information required to enable the meta-analysis ([2]).

In May 2020, we contacted a total of 71 scientists identified as responsible for scientific observer programmes for pelagic longline fisheries in the global ocean (East Pacific, Central West Pacific, Atlantic Ocean and Indian Ocean) We received seven responses (10%) – from Brazil, Micronesia, Cook Island, Taiwan, Reunion Island (France), Spain and Pakistan. The responses came from a range of organisations: national (government) institutions, research bodies and NGOs.

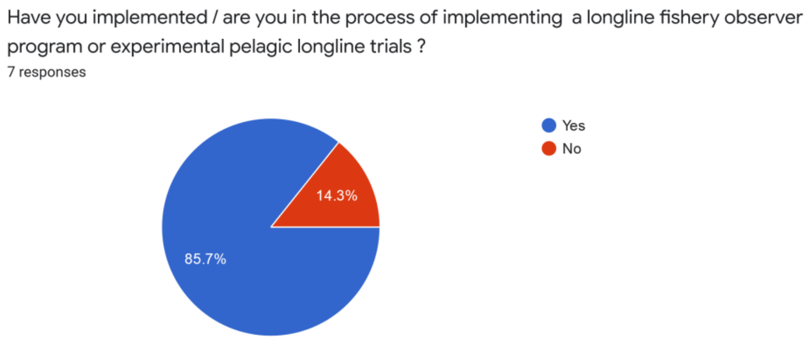
The responses to the questionnaire are presented in Figure 5.4.5). A total of 85.7% of participants have implemented or are implementing pelagic longline observer programmes or experimental longline trials. When experiments are carried out, 100% of projects collected data describing longline characteristics (fishing gear used, and size of gear elements like branchline, floatline, etc.).

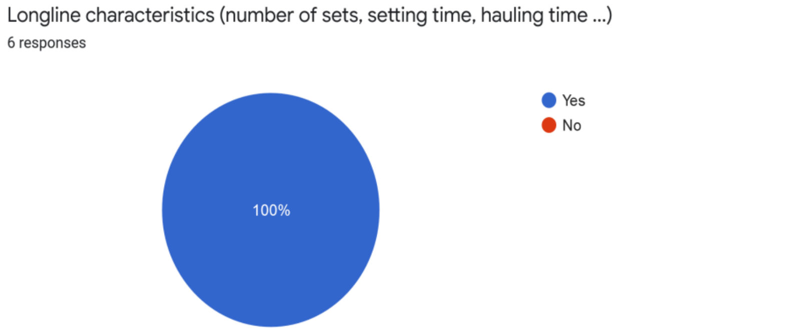
Generally, species information is collected for target species and bycatch. The length of individuals is collected in the majority of observer programmes and a few programmes (between one and three depending on the information collected) collect data on the biology of fishes (sex, sexual maturity, etc.).

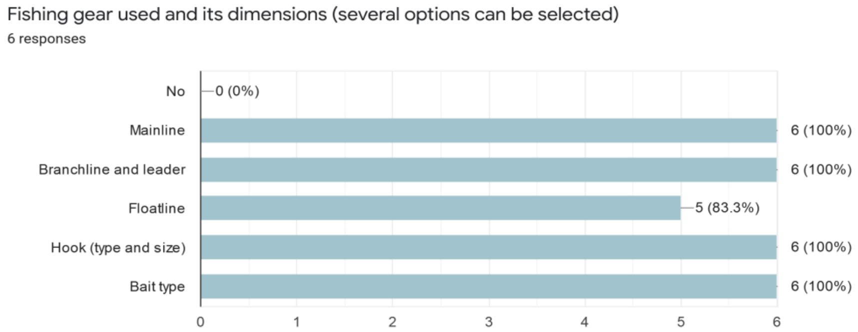
Regarding information on at-haulback mortality of both target and bycatch species, five (out of six) observer programmes collect data for many species, and all those collect data for sharks and rays. The hooking location was always reported. In 50% of cases only information relating to external versus internal hooking was collected, the remaining 50% collected detailed information about the hooking location. However, apparently there is no transfer of marine turtles hooked and injured to recovery centres and institutions. However, in the case of the Reunion-based pelagic longline fishery, the transfer of injured sea turtles depends on the distance of the boat from the mainland. Fishing vessels in the Reunion fleet that are smaller than 10 m length overall and operating on one- or two-day trips can transfer injured turtles to Kelonia, a marine rescue centre with veterinary services and recovery tanks for injured marine turtles ([3]).

([1]) https://docs.google.com/forms/d/e/1FAIpQLSdgTT8Jtb9BD-TSWJbZIa-twosVg8brsEHBJDkTlkEDAoBhwA/viewform
([2]) https://drive.google.com/open?id=173JrdicztdN3VcGqlH4yPjpiFE9iOjIE
([3]) https://en.reunion.fr/organize/to-see-and-do/tourist-sites/kelonia-558342

Regarding the data collected from responses to the questionnaire, it should be noted that many programmes provided data collected before 2010. This dataset has already been published in working papers for t-RFMOs meetings and has been presented at the International Symposium on Circle Hooks (Anonymous, 2012).







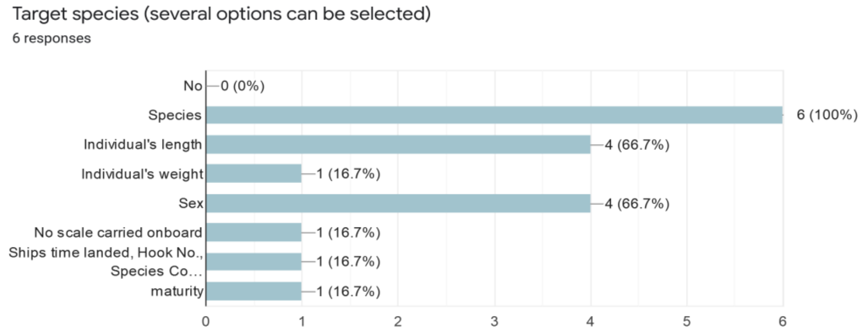
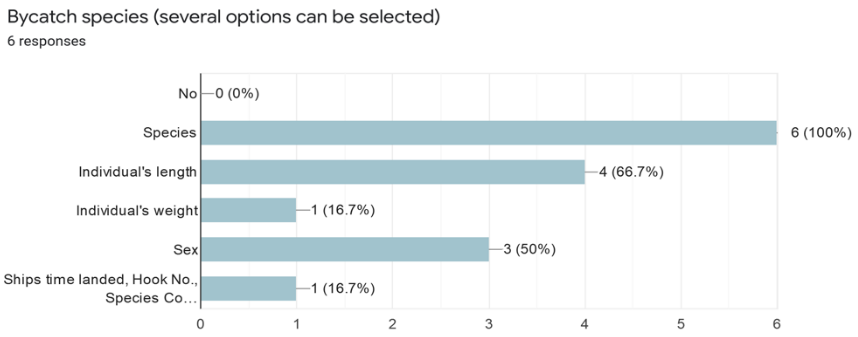
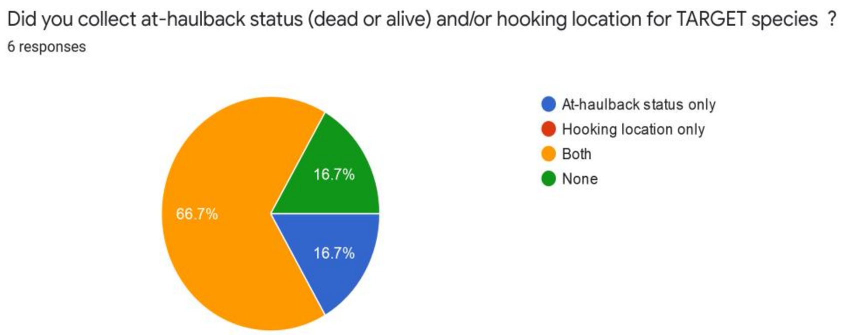
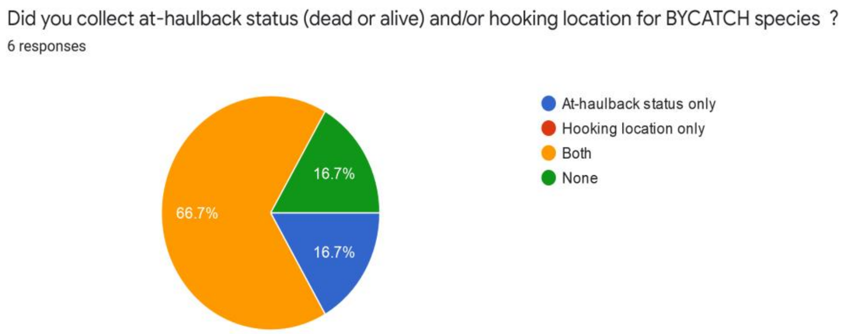


Figure 5.4.5. Summary of responses to the questionnaire aiming to assess the number of both observer and experimental longline fishing programmes collecting detailed information on the hooking location of catches.







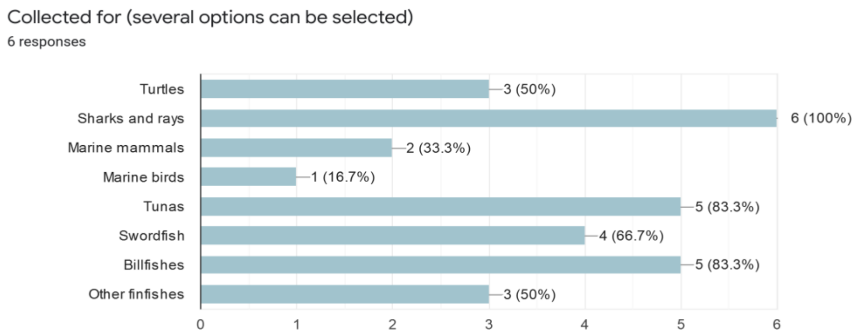
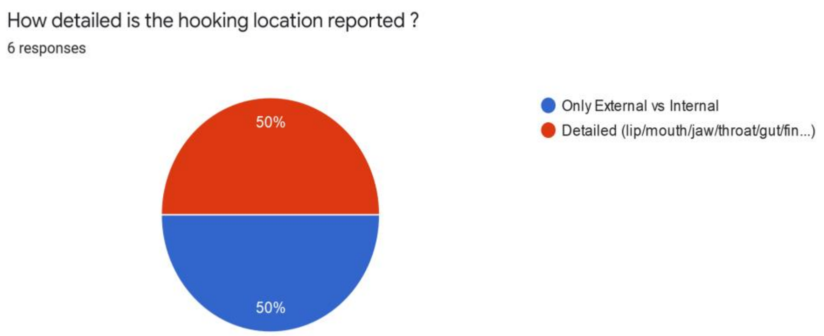
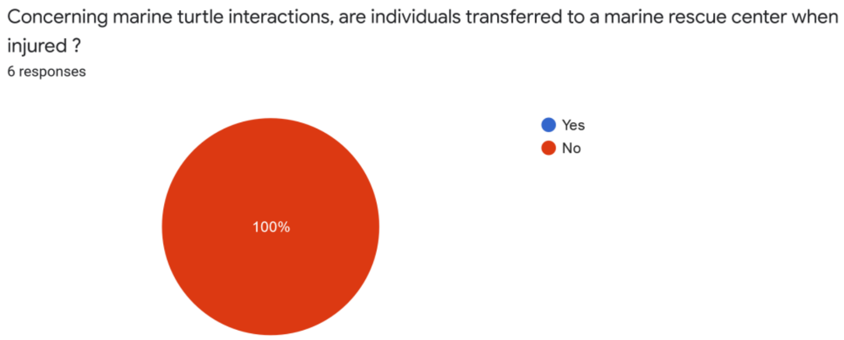


Figure 5.4.5 (continued)





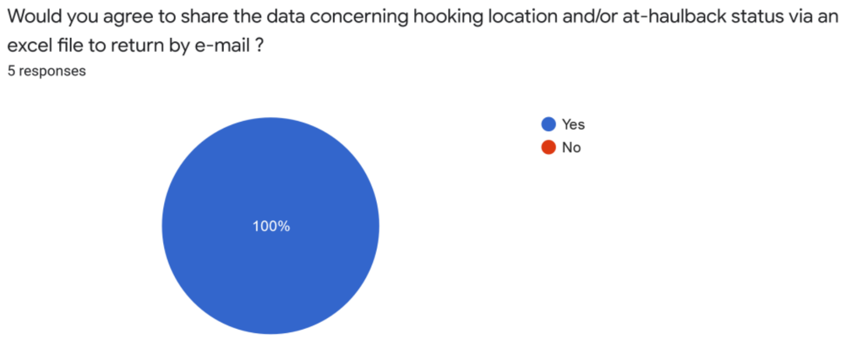


Figure 5.4.5 (continued)

Sub-task 2.3 – Why do circle hooks display potential practical effects as mitigation measures in pelagic longlining?

Before the great success of the circle hook in recreational fisheries, this hook type was used extensively in commercial marine longline settings because of the higher retention of fish while hooking and the reduced bycatch mortality (Bjordal and Løkkeborg, 1996). At the beginning of 1990s, the development of a tackle gear aiming to reduce injuries and mortality of fish at release gained increasing interest. At the end of 1990s, the circle hook type was promoted for its apparent conservation benefits compared to conventional J-style hooks and other hook types. But what is a circle hook? The main difference between a circle hook and other hook types is that the end point of the hook is in general oriented perpendicular to the shank, while in other hook types, particularly the J hook, the point is generally parallel to the shank. Moreover, a large part of the bend is round and the shank is short giving the circle hook an open-ring aspect. However, besides this generic description of the circle hook, differences in the design between and within different manufacturers as described previously should be considered.

How does a circle hook work? Some authors argue that the design of the circle hook promotes hooking when the fish removes the bait it cannot swallow. However, Johannes (1981, in Cooke and Suski, 2004) proposed a mechanical explanation for the circle hook's function (Figure 5.4.6): "As fish attempt to consume a baited circle hook, the fish moves away, or a gentle pressure from the angler pulls the hook to the side of the mouth. The point of the hook then catches on flesh at the jaw and pivots outwards as the amount of applied pressure steadily increases. Once tension exceeds a threshold, the hook pulls over the jaw and rotates as the fish moves or angler sets the hook. The design of the hook prevents the hook from backing out on its own and should hold a fish even under slack line conditions". Some scientists believe that because of the specific shape of a circle hook - point turned towards the shank – the circle hook slips out from the fish guts (when tension of fishing line increases) without hooking fish soft tissues. It engages on contact with hard parts of the fish mouth: mostly maxillary bones. So even deeply swallowed baited circle hooks result in fewer deep hooked fish (E. Romanov, pers. comm.).

Many pelagic longline trials have been carried out to assess the potential benefits for marine resource conservation of using circle hooks. For many species it was noted that: when circle hooks are deployed 1) fish are frequently hooked in the jaw, facilitating hook removal and 2) gut hooking is reduced, resulting in reduced mortality.

However, these general positive trends are counterbalanced by controversial results that indicate decreasing catch rates observed for some target species like swordfish and some acceptability issues raised by some fishermen.

Since the Circle Symposium organised in 2011 (Anonymous, 2012) thus far the biggest event relating to the application of the gear technology for resource conservation in pelagic longline fisheries, some tuna regional fishery management organisations have been promoting the circle hook as a mitigation measure (Table 5.4.1). Some national legislation, e.g. in the USA (Wilson and Diaz, 2012), makes the use of circle hooks mandatory for several types of line fishery. However, one of the conclusions of the symposium was that additional research was required in relation to the effectiveness of the circle hook in conservation.

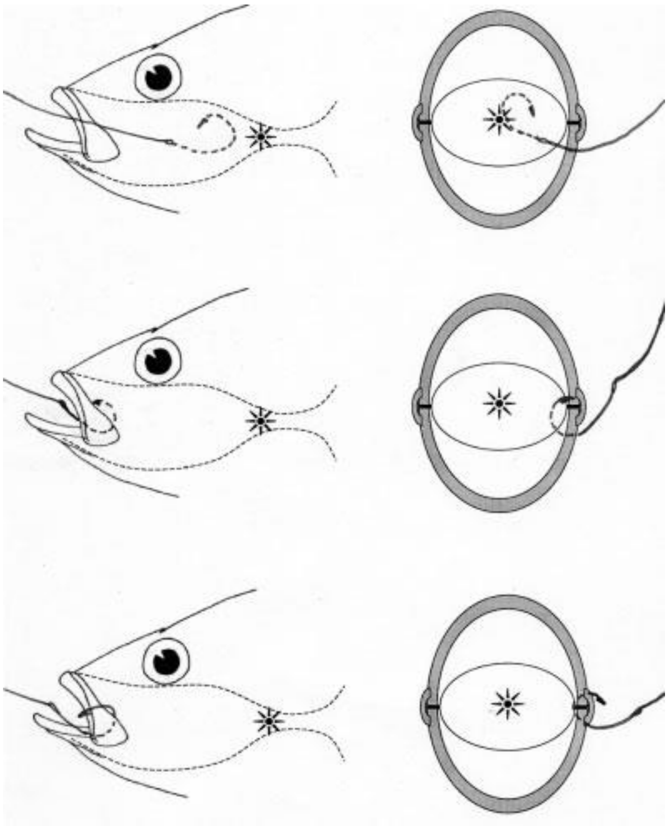


Figure 5.4.6. Circle hook function when pressure is applied to the line (from Cooke and Suski, 2004).

Some concerns regarding the use of circle hooks were raised in relation to the question of the offset of the point. While it was agreed that the criterion that defines a circle hook is that it is two dimensional, meaning that the point is in the same plane as the shank (2D CH), some so-called circle hooks have an offset point, thereby introducing a third dimension (3D CH) with a deviation in the plane of the hook point relative to that of the shank. With regard to practical aspects for fishermen, an offset angle is expected to influence the baiting process primarily, particularly in the case of circle hooks as the deviation between the point and the shank facilitates the baiting process. However, studies analysing the ease of baiting at different degrees of the offset must be carried out. Moreover, based on some evidence, it was stated that a large offset angle would negate the effect of circle hooks in terms of deep hooking and in reducing interactions with sea turtles (Cooke and Suski, 2004; Swimmer *et al.*, 2010). Obviously, 3D CH would perform differently to 2D CH. The analysis of the impact of the offset for circle hooks would be a productive research topic to provide clear insights to managers.

Table 5.4.1. List of resolutions or recommendations adopted by t-RFMOs regarding the use of circle hooks in pelagic longline fisheries (from Bycatch Management Information System ([4]))

tRFMOs	Year	Resolution n°
ICCAT	2005	Resolution 05-08 (Resolution by ICCAT on Circle Hooks)
WCPFC	2018	CMM 2018-04 (Conservation and Management of Sea Turtles)
ICCAT	2017	Recommendation 17-08 (Conservation of North Atlantic Stock of Shortfin Mako)
CCSBT	2019	Recommendation ERS (Impact mitigation on Ecologically Related Species of Fishing for Southern Bluefin Tuna)
IOTC	2012	Resolution 12/04 (Conservation of Marine Turtles)
IATTC	2004	Resolution C-04-07 (Mitigate the Impact of Tuna Fishing on Sea Turtles)
IATTC	2007	Resolution C-07-03 (Mitigate the Impact of Tuna Fishing Vessels on Sea Turtles)
IATTC	2016	Resolution C-16-06 (Conservation Measures for Shark Species for years 2017, 2018)
IATTC	2019	Resolution C-19-05 (Conservation Measures for Shark Species for years 2020, 2021)
CCSBT	2018	Resolution ERS tRFMOs (Resolution to Align CCSBT's Ecologically Related Species measures with those of other tuna RFMOs)

([4]) https://www.bmis-bycatch.org

6. TASK 3 – OTHER VARIABLES AND EFFECTS

Key findings

- In this task, the effects of other variables such as bait and leader materials were analysed and tested with meta-analyses.
- When fish bait was used instead of squid, there were significant decreases in the retention of yellowfin tuna, sailfish and the loggerhead sea-turtle. By contrast, the silky shark had a significantly higher retention with fish bait.
- For the at-haulback mortality, swordfish, blue shark and the oceanic whitetip had a significantly higher at-haulback mortality when fish was used, while the silky shark had a lower at-haulback mortality.
- In terms of leader materials, when changing from nylon the wire leaders, the retention of blue marlin decreased while blue shark increased.

Objectives

The main objective of this task is to provide advice on whether issues other than hook shape, such as hook size, bait type, fishing depth, soak time, leader type, etc., could explain the reported differences.

Methodology

This task was carried out mostly to complement the results from Task 1. While Task 1 focused on effects related to use of circle hooks, Task 3 focuses on other variables or effects that might also explain differences in the results obtained in terms of retention rates and at-haulback mortality.

Several additional variables can be considered for this analysis, such as hook size, bait type, depth of fishing operation, soak time, leader type, etc. However, for most of those variables there is almost no information available as no studies have been conducted with experimental designs, making it impossible to conduct meta-analyses. As such, we have focused on the bait type and leader materials, as those are two variables that have been more widely studied. As for Task 1 (sub-tasks 1.1, 1.2 and 1.3), we also provide species-specific analysis for 1) target species, 2) desirable bycatch and 3) unwanted bycatch species.

As such, this task follows an approach similar to that used for Task 1, where a meta-analysis is used for the comparisons (see methods described in section 4.3 of this report). For this task, for bait type, fish was considered the treatment and squid the control; while for leader type, wire was considered the treatment and nylon the control. We have identified data gaps where experimental sea trials with certain combinations of variables have not yet taken place and it is not possible to draw conclusions (presented in section 7.4 of this report, at the end of Task 4).

Results and discussion

For this task, we carried out species-specific meta-analysis for the species identified in Task 1, specifically for 1) target species, 2) desirable bycatch and 3) unwanted bycatch species. The meta-analysis is for both retention rates and at-haulback mortality, comparing bait and leader types. Here we provide the main summaries and conclusions for each species group, followed by a synopsis comparing the various groups. All the detailed species-specific analyses conducted for this task are then provided in Appendix VII.

Effects of changing bait type

For the main target species, the results of the meta-analysis of retention when changing bait type are shown in Figure 6.4.1. This shows that the only species exhibiting significant effects is yellowfin tuna, with a reduction of 60% in retention when the bait is changed from squid to fish. With regard to the at-haulback mortality, the only species with significant effects is swordfish, in this case showing an increase in at-haulback mortality of 3% when bait is changed from squid to fish (Figure 6.4.2).

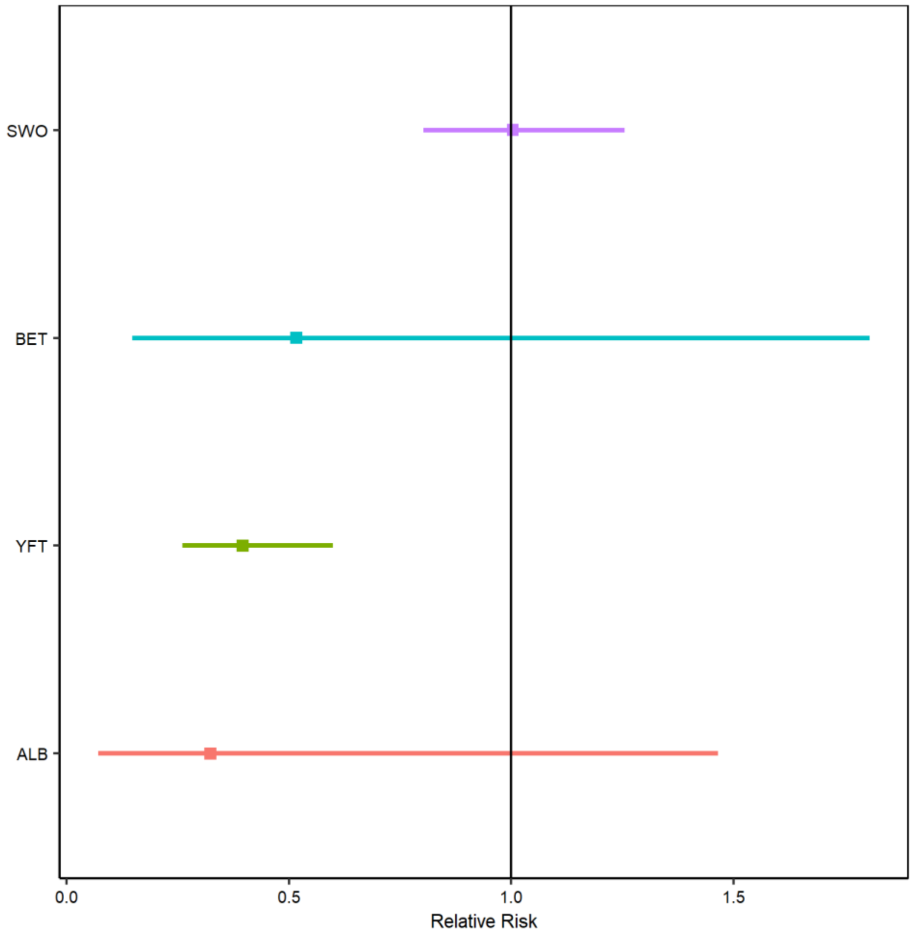


Figure 6.4.1. Results of the meta-analysis of the retention rates of target species when changing bait type. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

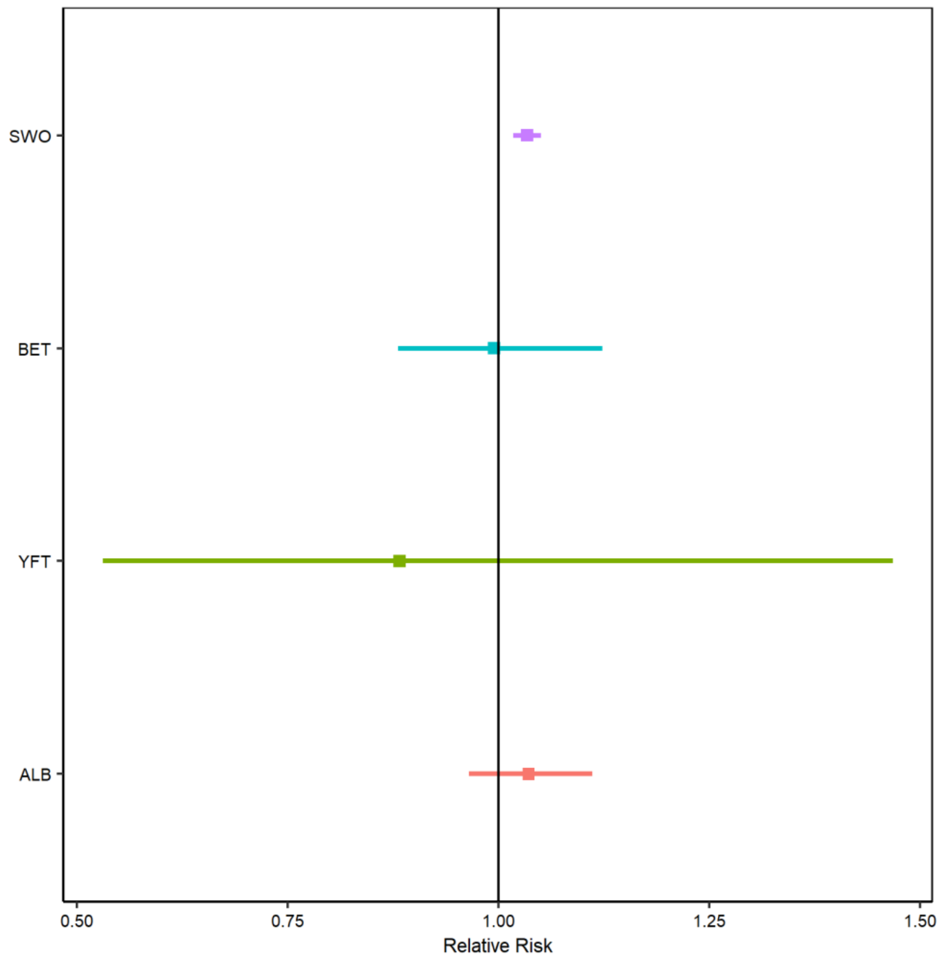


Figure 6.4.2. Results of the meta-analysis of the at-haulback mortality of target species when changing bait type. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

For the desirable bycatch species, the results of the meta-analysis of retention rates when changing bait type are shown in Figure 6.4.3. In this case, there are only significant effects for Atlantic sailfish, specifically with a reduction of 65% in retention when fish bait is used instead of squid. With regard to at-haulback mortality, the only species exhibiting significant effects is the blue shark, in this case with an increase in at-haulback mortality of 80% when bait is changed from squid to fish (Figure 6.4.4).

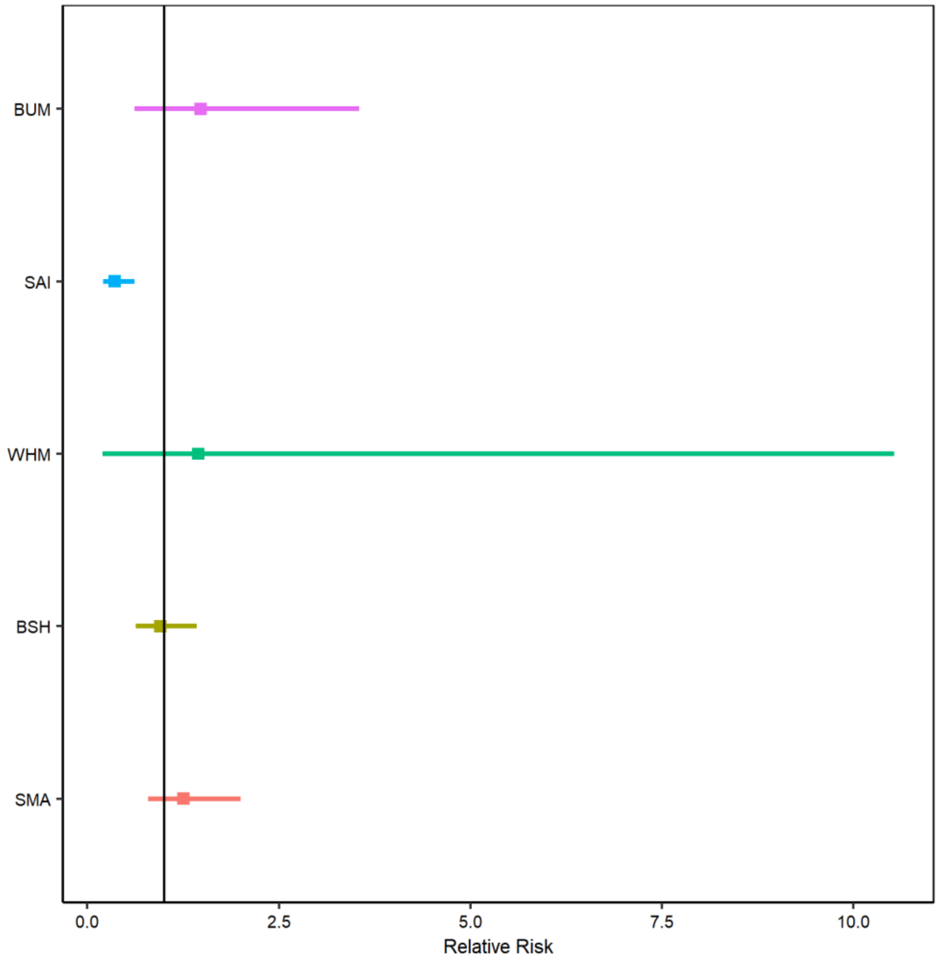


Figure 6.4.3. Results of the meta-analysis of the retention rates of desirable bycatch species when changing bait type. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

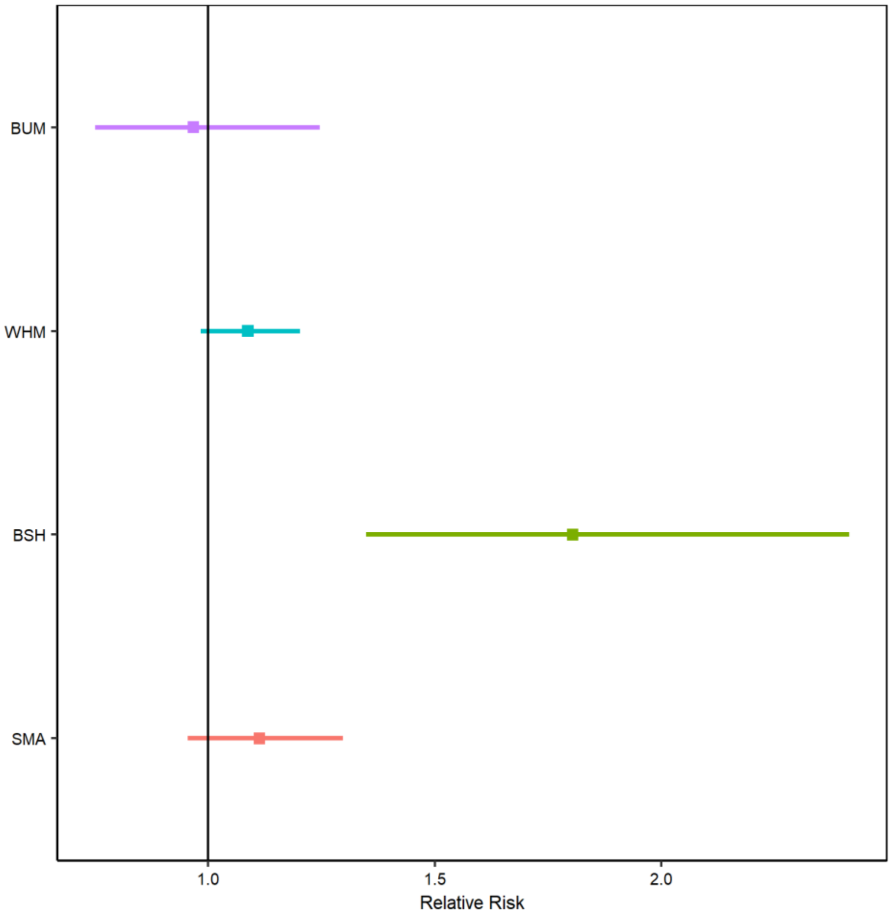


Figure 6.4.4. Results of the meta-analysis of the at-haulback mortality of desirable bycatch species when changing bait type. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

Finally, for the unwanted bycatch species, the result of the meta-analysis of the retention rates when changing bait type is indicated in Figure 6.4.5. This shows significant effects for the loggerhead sea turtle (77% reduction in retention when fish bait is used instead of squid) and for silky shark but with opposite effects (97% increase in retention when fish bait is used instead of squid). With regard to the at-haulback mortality, the effects were only significant for two of the sharks, namely oceanic whitetip and silky shark (Figure 6.4.6). In the specific case of the oceanic whitetip, there was an increase of 24% in at-haulback mortality when fish bait was used instead of squid, while for the silky shark there were opposite effects, with a reduction of 31% when fish bait was used.

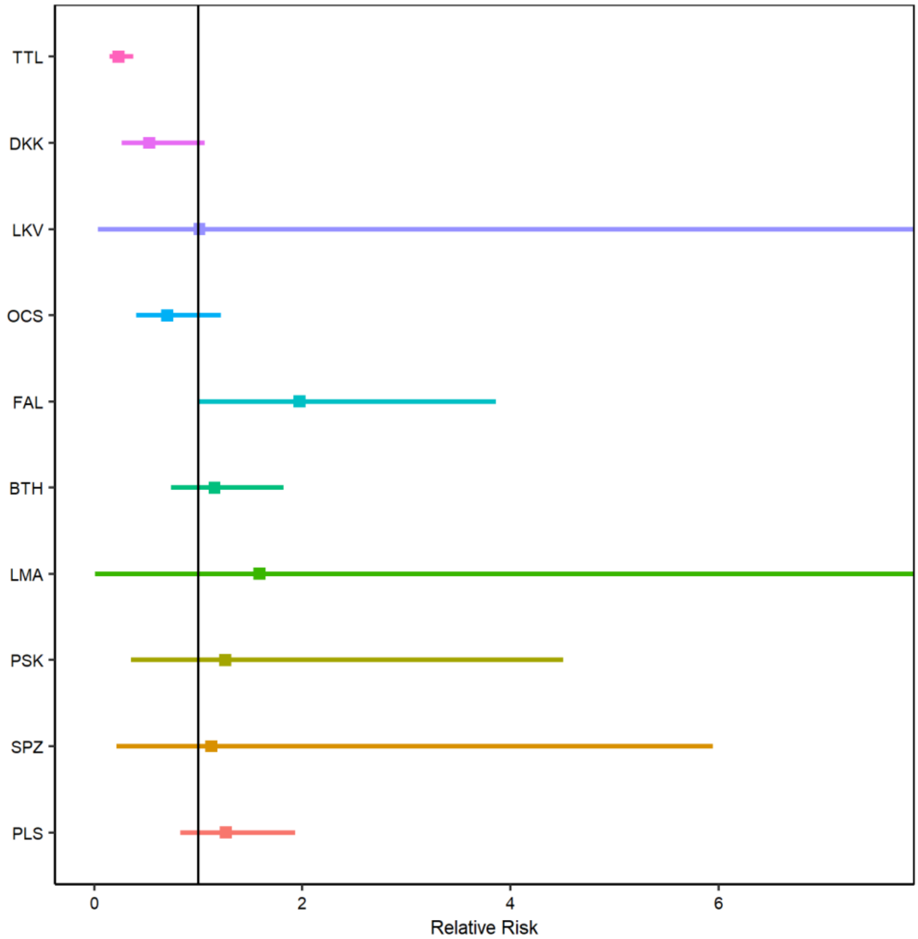


Figure 6.4.5. Results of the meta-analysis of the retention rates of unwanted bycatch species when changing bait type. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

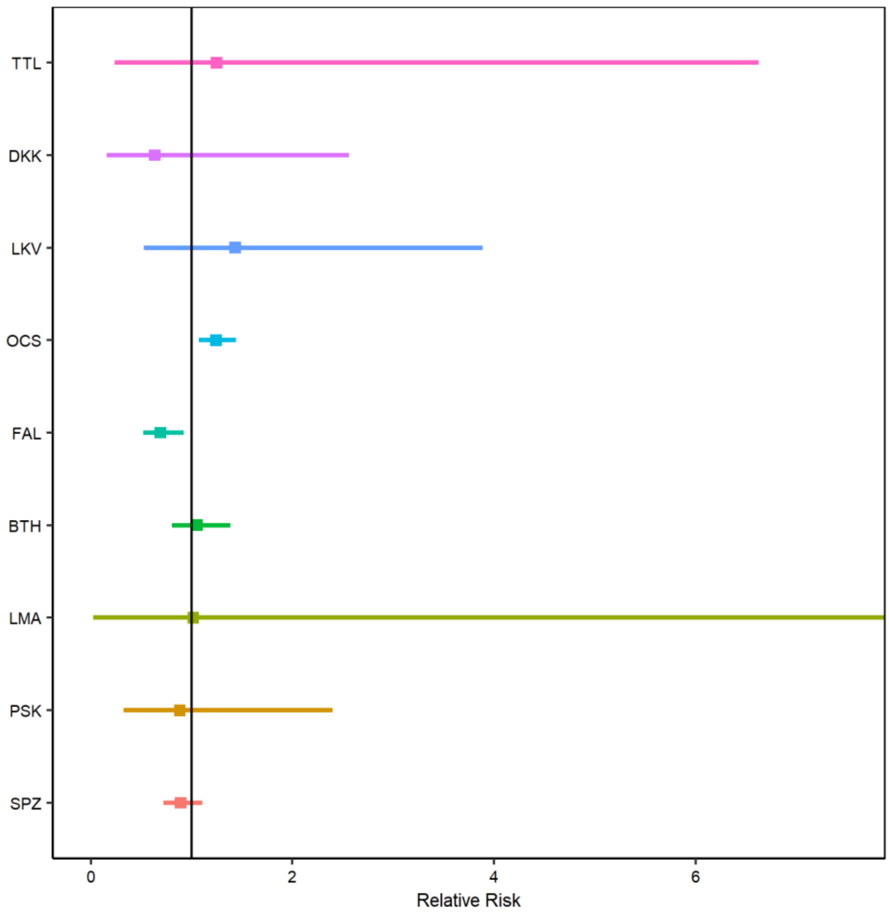


Figure 6.4.6. Results of the meta-analysis of the at-haulback mortality of desirable bycatch species when changing bait type. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

Effects of changing leader type

This section provides an analysis of the effects of changing leader type, namely from nylon monofilament to wire leaders.

For the main target species, the results of the meta-analysis on the retention rates are shown in Figure 6.4.1, and while capture rates tended to lower with wire leaders, the effects were not significant for any of the species. With regard to the at-haulback mortality, it was not possible to conduct meta-analysis for any of the target species as there are no adequate studies available.

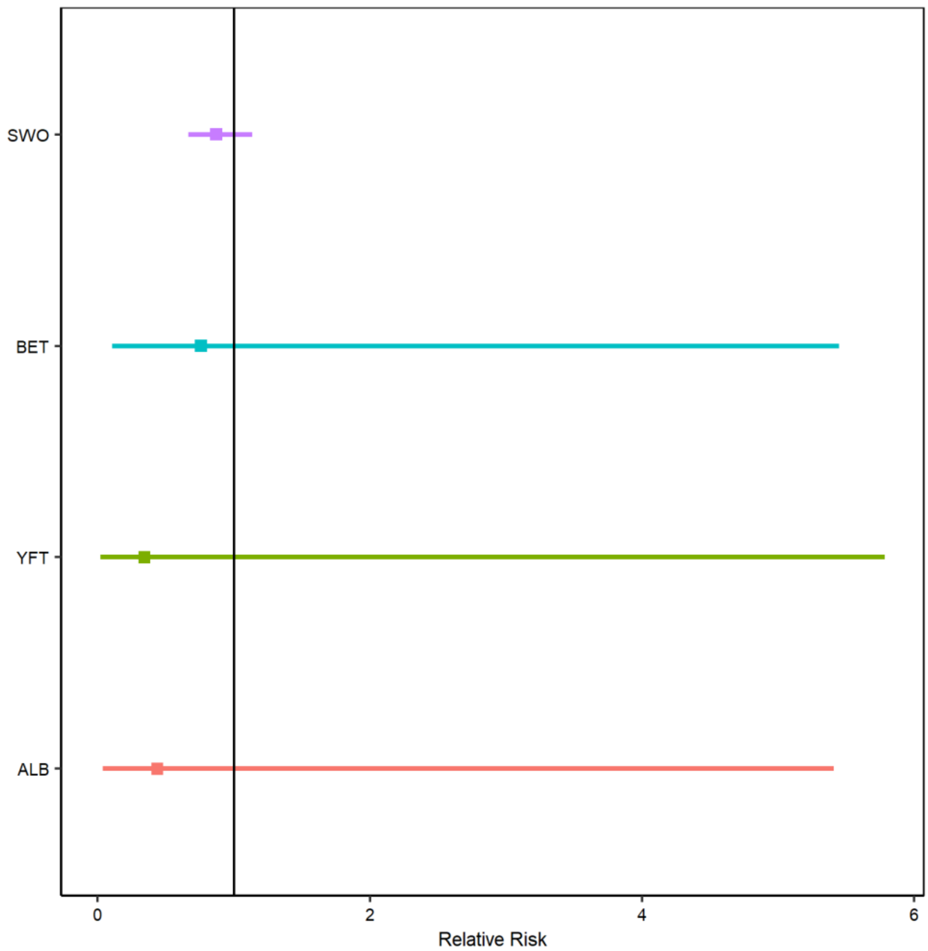


Figure 6.4.7. Results of the meta-analysis of the retention rates of target species when changing leader material. The error bars represent the 95% confidence intervals. (Note: nylon is considered the control and wire the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

For the desirable bycatch species, the results of the meta-analysis of the retention rates when changing leader material are indicated in Figure 6.4.8. It was only possible to conduct this analysis for two of the species, namely blue marlin and blue shark, and both showed opposite effects. Specifically, changing from nylon to wire leaders reduced the retention of blue marlin by 37% and increased the retention of blue shark by 46%. With regard to at-haulback mortality, the analysis was only possible for blue shark, but the effect of changing leader materials on the at-haulback mortality were not significant.

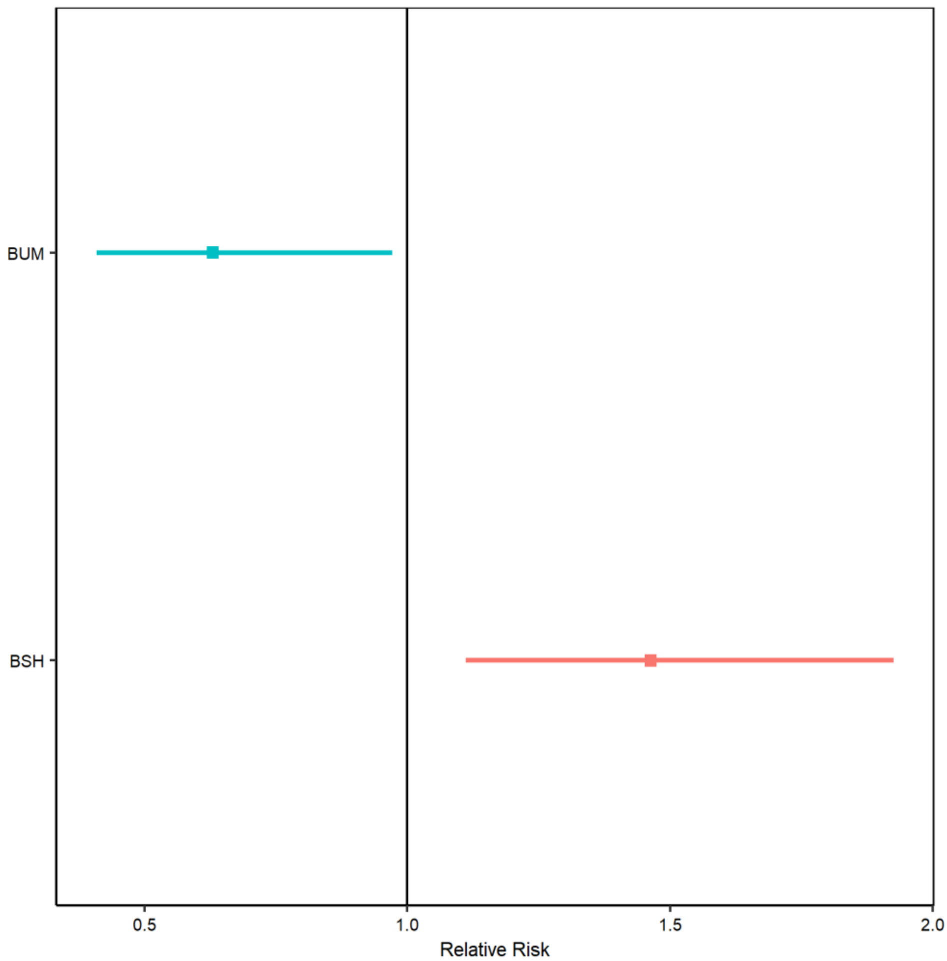


Figure 6.4.8. Results of the meta-analysis of the retention rates of desirable bycatch species when changing leader material. The error bars represent the 95% confidence intervals. (Note: nylon is considered the control and wire the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

For the unwanted bycatch species, the results of the meta-analysis of the retention rates when changing leader material are indicated in Figure 6.4.9. It was only possible to conduct that analysis on three of the elasmobranch species, and the effects were not significant in any of the cases. With regard to the at-haulback mortality, it was not possible to conduct meta-analysis for any of the unwanted bycatch species as there are no adequate studies available.

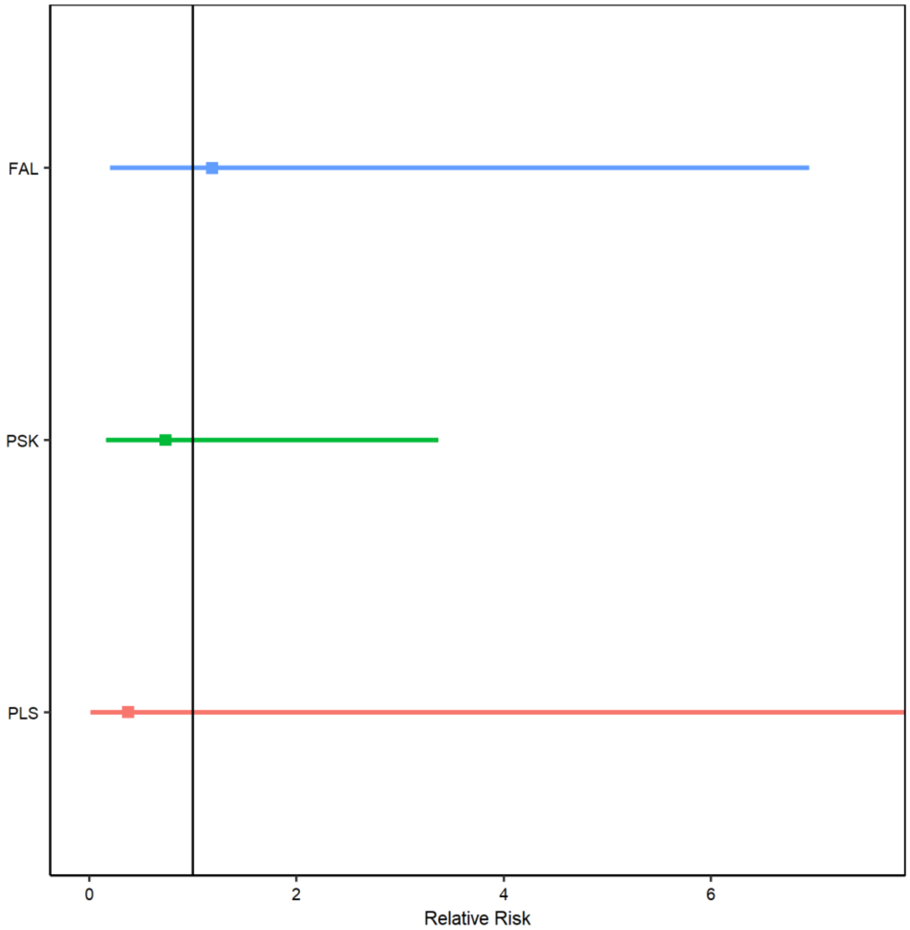


Figure 6.4.9. Results of the meta-analysis of the retention rates of unwanted bycatch species when changing leader material. The error bars represent the 95% confidence intervals. (Note: nylon is considered the control and wire the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

Synopsis of task 3

In this short summary sub-section, we provide a comparative final view of the previous task, for an easier comparison between the various species groups.

The overall comparative view in retention rates for the three taxa components when changing bait type is shown in Figure 6.4.10 and the details provided in Table 6.4.1. For the leader material, the comparative species plot with regard to the retention rates is shown in Figure 6.4.11 and the summaries of the species-specific analysis is shown in Table 6.4.2.

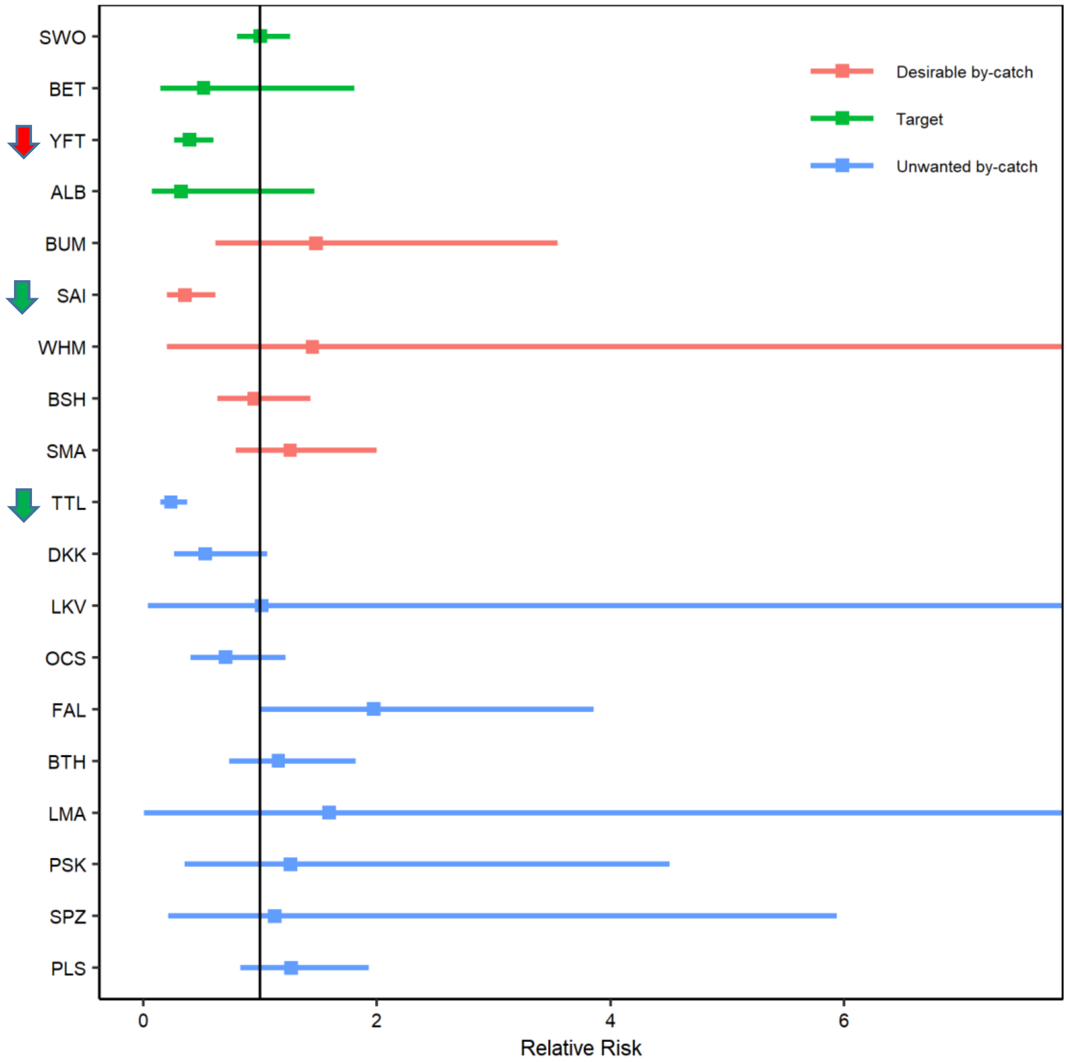


Figure 6.4.10. Results of the meta-analysis for the retention rates of the three species components, namely target species, desirable bycatch and unwanted bycatch when changing bait type. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the retention rates. The colour or the arrows assumes the following: 1) for target species higher retention assumes a positive (green) outcome while a decrease in retention is a negative (red) outcome; 2) the contrary is assumed for bycatch species, both wanted and unwanted, i.e., a reduction in retention is assumed a positive outcome (green) while an increase in retention is assumed a negative (red) outcome. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

Table 6.4.1. Summary of the results of the species-specific meta-analysis of the retention rates when changing bait type, for the three species components: target species, desirable bycatch and unwanted bycatch. Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait. "Exp" refers to the number of experiments available for each analysis; the bracketed number is the number used after the validation procedure (see Appendix VII). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative risk			Heterogeneity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
SWO	7	1.00	0.8-1.25	0.97	98	<0.01	15, 30, 42, 43, 48, 49, 51
BET	6(4)	0.52	0.15-1.81	0.19	98	<0.01	42, 43, 48, 49 (30, 51)
YFT	4(3)	0.4	0.26-0.60	**0.01**	27	0.26	42, 48, 49 (51)
ALB	6(4)	0.32	0.07-1.46	0.10	0	0.54	42, 43, 48, 51 (30, 49)
BUM	4	1.48	0.62-3.55	0.25	87	<0.01	42, 48, 49, 51
SAI	4(3)	0.35	0.20-0.62	**0.02**	0	0.81	42, 48, 49 (51)
WHM	4(3)	1.45	0.20-10.53	0.51	91	<0.01	48, 49, 51 (42)
BSH	6(5)	0.95	0.63-1.43	0.75	100	<0.01	30, 42, 43, 48, 51 (49)
SMA	6(5)	1.26	0.79-2.00	0.24	87	<0.01	42, 43, 48, 49, 51 (30)
TTL	11	0.23	0.15-0.38	**<0.01**	70	<0.01	14, 15, 30, 42, 43, 48, 49, 51, 52, 53, 54
DKK	7	0.53	0.26-1.06	0.07	84	<0.01	15, 30, 42, 48, 49, 51, 52
LKV	3	1.01	0.04-27.42	0.99	95	<0.01	42, 48, 51
OCS	4(3)	0.70	0.41-1.22	0.11	0	0.60	48, 49, 51 (42)
FAL	4(3)	1.97	1.01-3.86	**0.05**	0	0.58	42, 49, 51 (48)
BTH	5	1.16	0.74-1.82	0.42	46	0.11	42, 43, 48, 49, 51
LMA	3	1.59	0.01-380.27	0.75	98	<0.01	42, 48, 49
PSK	4(3)	1.26	0.35-4.51	0.52	81	0.01	48, 49, 51 (42)
SPZ	4(3)	1.12	0.21-5.94	0.79	93	<0.01	42, 48, 51 (49)
PLS	5(3)	1.26	0.83-1.93	0.14	0	0.72	43, 48, 49 (42, 51)

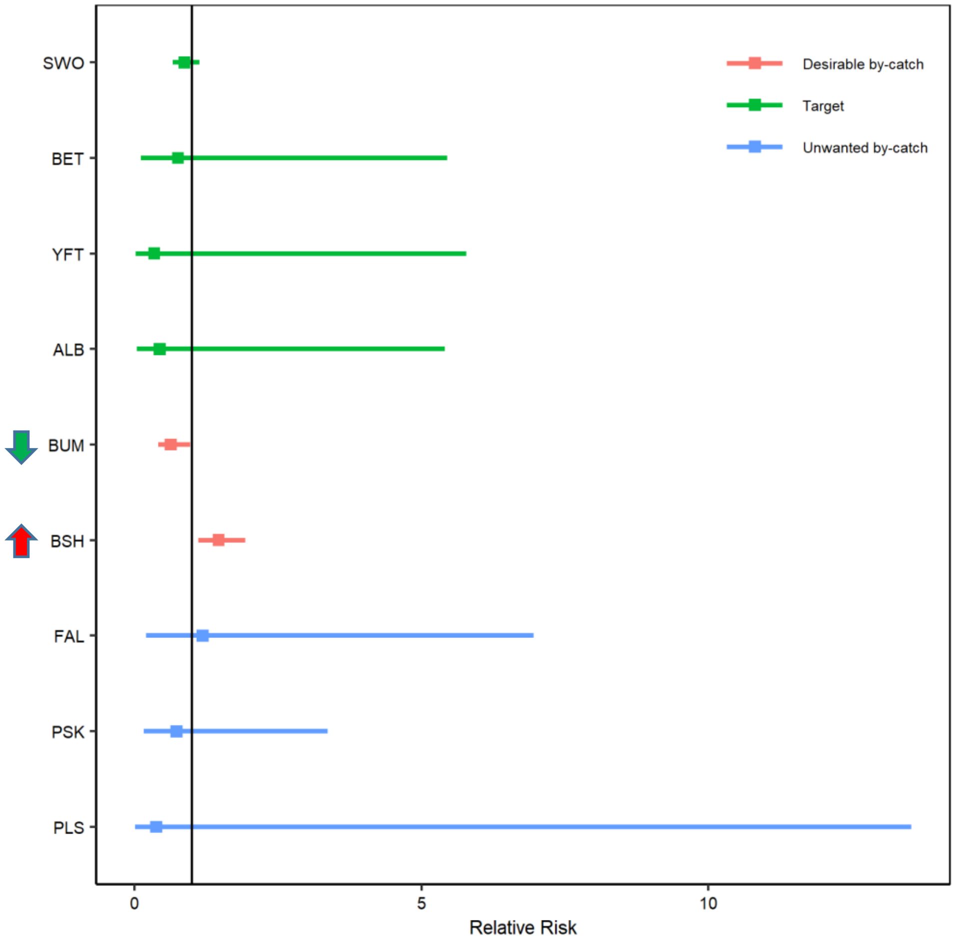


Figure 6.4.11. Results of the meta-analysis of the retention rates of the three species components, namely target species, desirable bycatch and unwanted bycatch when changing leader material. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the retention rates. The colour or the arrows assumes the following: 1) for target species higher retention assumes a positive (green) outcome while a decrease in retention is a negative (red) outcome; 2) the contrary is assumed for bycatch species, both wanted and unwanted, i.e., a reduction in retention is assumed a positive outcome (green) while an increase in retention is assumed a negative (red) outcome. The error bars represent the 95% confidence intervals. (Note: nylon is considered the control and wire the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leader).

Table 6.4.2. Summary table of the results of species-specific meta-analysis of the retention rates when changing leader material, for the three species components: target species, desirable bycatch and unwanted bycatch. Note: nylon is considered the control and wire the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders. "Exp" refers to the number of experiments available for each analysis; the bracketed number is the number used after the validation procedure (see Appendix VII). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative Risk			Heterogeinity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
SWO	3	0.87	0.67-1.13	0.15	48	0.15	44, 50, 51
BET	4	0.76	0.11-5.45	0.61	81	<0.01	44, 45, 50, 51
YFT	3	0.34	0.02-5.78	0.24	86	<0.01	44, 50, 51
ALB	3	0.44	0.04-5.41	0.29	0	0.55	44, 50, 51
BUM	3	0.63	0.41-0.97	**0.04**	0	0.83	44, 50, 51
BSH	3	1.46	1.11-1.93	**0.03**	54	0.12	44, 50, 51
FAL	3	1.18	0.2-6.95	0.72	50	0.13	44, 48, 52
PSK	3	0.73	0.16-3.37	0.48	0	0.60	45, 50, 51
PLS	3	0.38	0.01-13.53	0.36	92	<0.01	44, 50, 51

With regard to changes in at-haulback mortality, the overall comparative view when changing bait type is presented in Figure 6.4.12 and the details are provided in Table 6.4.3. As for leader materials, and as mentioned above in the detailed species groups analysis, this was only carried out for one species, namely blue shark, and the effects were not significant.

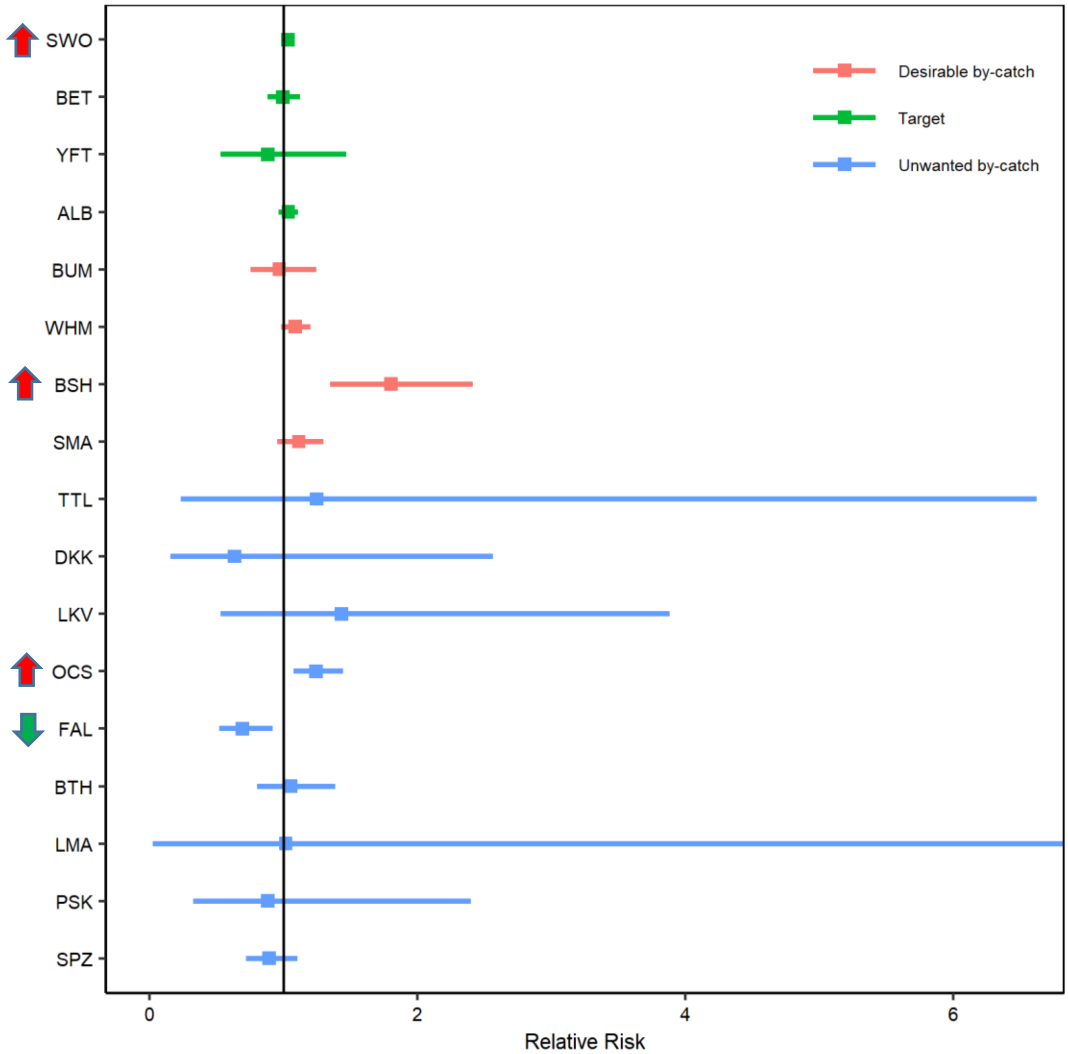


Figure 6.4.11. Results of the meta-analysis of the at-haulback mortality of the three species components, namely target species, desirable bycatch and unwanted bycatch when changing bait types. The arrows in the left side are shown only for species with significant effects, with the direction of the arrow pointing towards an increase (up) or decrease (down) on the at-haulback mortality. The colour or the arrows assumes the following: for all species groups (target and bycatch) a lower at-haulback mortality is a positive (green) outcome, while higher at-haulback mortality is a negative (red) outcome. The error bars represent the 95% confidence intervals. (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

Table 6.4.3. Summary of the results of species-specific meta-analysis of at-haulback mortality when changing bait types, for the three species components: target species, desirable bycatch and unwanted bycatch. Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait. "Exp" refers to the number of experiments available for each analysis and the bracketed number is the number used after the validation procedure (see Appendix VII). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative risk			Heterogeneity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
SWO	4(3)	1.03	1.02-1.05	**0.01**	0	0.89	48, 49, 51 (42)
BET	4	0.99	0.88-1.12	0.90	0	0.66	42, 48, 49, 51
YFT	4(3)	0.88	0.53-1.47	0.40	13	0.32	48, 49, 51 (42)
ALB	3	1.04	0.97-1.11	0.17	0	0.73	42, 48, 49
BUM	4	0.97	0.75-1.25	0.71	12	0.33	42, 48, 49, 51
WHM	4(3)	1.09	0.98-1.2	0.07	0	0.85	48, 49, 51 (42)
BSH	4(3)	1.8	1.35-2.41	**0.01**	50	0.14	42, 48, 51 (49)
SMA	4	1.11	0.96-1.3	0.11	0	0.82	42, 48, 49, 51
TTL	5	1.25	0.24-6.62	0.73	0	0.72	15, 48, 49, 52, 54
DKK	6	0.63	0.16-2.56	0.37	0	0.68	15, 42, 48, 49, 51, 52
LKV	3	1.43	0.53-3.88	0.26	0	0.78	42, 48, 51
OCS	4	1.24	1.07-1.44	**0.02**	0	0.96	42, 48, 49, 51
FAL	4(3)	0.69	0.52-0.92	**0.03**	0	0.57	42, 49, 51 (48)
BTH	4	1.06	0.8-1.39	0.58	28	0.24	42, 48, 49, 51
LMA	3	1.02	0.02-45.25	0.99	35	0.21	42, 48, 49
PSK	4(3)	0.88	0.32-2.4	0.65	13	0.32	48, 49, 51 (42)
SPZ	4	0.89	0.72-1.11	0.19	14	0.32	42, 48, 49, 51

7. TASK 4 – EFFECTS WITH LONGLINE DEPTH

Key findings

- In this task, the effects of changing hooks on deep setting longlines was studied. Changes from J to circle hooks, and from tuna to circle hooks were considered. This task also provides a summary of the data gaps related to Tasks 1, 2 and 4 of this report.
- In general, there are far fewer available references for deep setting longlines. There is some literature that compares tuna hooks to circle hooks, but there are very few references comparing J hooks to circle hooks.
- The only species for which it was possible to conduct a meta-analysis for the deep-set comparison between J hooks and circle hooks was the yellowfin tuna, and there are no significant differences in the retention rates
- For the comparison between tuna hooks and circle hooks it was possible to conduct the meta-analysis in several more species, and the effects were not significant for any of the species.
- In terms of data gaps, there are more studies available for surface longlines, especially for factors such as hook type and bait, and fewer for the leader materials. For deep setting longlines the data gaps are more considerable, especially for changes in J-style hooks.

Objectives

The main objective of this task is to provide on whether the implementation of circle hooks could have the same effects on the catchability, mortality and survivability regardless of the fishing depth and soaking time, comparing and commenting, as adequate, the results by taking into account the fishing effort repartition between shallow and deep fishing operations. This task should also take into account the fishing effort repartition between shallow and deep fishing operations.

Methodology

As for Task 3 described above, Task 4 was carried out in close collaboration and to complement the results provided in Task 1. The meta-analysis focuses separately, and as much as possible depending on data availability, on shallow vs. deep setting longline fisheries. Here we define shallow setting longlines mainly as swordfish/shark-targeting longlines that operate mainly down to 100 m depth, and deep setting longlines as the ones that target mainly tunas and set the hooks deeper, mainly between 100 and 300 m depth.

In general, there are far fewer available references for deep setting longlines comparing hook types, with works focusing both on changes from J to circle hooks and from tuna to circle hooks. This task considers both scenarios. We have identified data gaps where experimental sea trials have not yet taken place or the limited number of studies hinder conducting a meta-analysis, these are presented at the end of the results of this task.

Originally, this task included the objective of considering the effort repartition from the two longline components (shallow and deep setting) in the Atlantic. Currently, the ICCAT Secretariat statistics department is in the process of adding depth of setting to the Effort Distribution (EFFDIS) database, but that work has not been completed. The use of factors such as nation/fleet was explored for use as a proxy for longline setting, but that is very complex, especially as many fleets switch their operation types over time, areas and seasons. As such, at this point and until the ICCAT EFFDIS database is completed and includes depth of operation, it is not yet possible to estimate the slip between shallow and deep setting longlines in the Atlantic.

Results and discussion

Effects of changing J to circle hooks in deep setting longlines

In the compiled database, only three experiments compared retention of circle hooks and J hooks when using deep-set pelagic longline and from these, only one reported on at-haulback mortality. The only species for which it was possible to conduct a meta-analysis for the deep-set comparison was yellowfin tuna. This was reported by the three experiments, the remaining species were reported either by two or only one experiments (see Appendix VIII). For at-haulback mortality, no meta-analysis was conducted given that only one experiment is available. Reported retention and at-haulback data for these experiments are presented in Table 7.4.1. For some species (e.g. SWO; BSH) retention either increased or decreased when using circle hooks depending on the study. For BTH, both studies reported a decrease in retention; however, with great variability (14% or 78% decrease, depending on the study)

Table 7.4.1 Effect of changing hook type in the deep-set pelagic longline for the available experiments. The relative risks are shown for the effect of changing from J hooks to circle hooks.

Experiment/ Species	Hook type						Relative risk	
	Circle hook			J hook				
	No. hooks	Retention (N)	At-haulback mortality	No. hooks	Retention (N)	At-haulback mortality	Retention	At-haulback mortality
6								
BET	13714	9		6857	5		0.90	
YFT	13714	3		6857	6		0.25	
BSH	13714	33		6857	9		1.83	
TUG	13714	2		6857	2		0.50	
LKV	13714	4		6857	8		0.25	
18								
YFT	3138	2		3138	1		2.00	
SWO	3138	12		3138	9		1.33	
BTH	3138	2		3138	9		0.22	
FAL	3138	5		3138	5		1.00	
PLS	3138	2		3138	4		0.50	
PTH	3138	0		3138	1		0.00	
TIG	3138	0		3138	1		0.00	
22								
ALB	215517	25	15	214815	29	28	0.86	0.62
BET	214781	930	194	214777	843	153	1.10	1.15
YFT	214815	232	96	214694	263	112	0.88	0.97
BUM	215054	20	11	214660	41	27	0.49	0.84
SWO	215909	19	8	214286	27	9	0.70	1.26
BSH	214724	630	16	214787	796	21	0.79	0.96
BTH	214612	47	6	214844	55	3	0.86	2.34

Yellowfin tuna was the only species for which it was possible to conduct a meta-analysis on the retention rates, and for this species the RR of the pooled effects was calculated at 0.69 (95% CIs: 0.08; 5.93) suggesting that there is no significant effect of changing hook type (from J to circle) in the retention rates in deep setting longlines (Figure 7.4.1). The summary the analysis is provided in Table 7.4.2. All the specific details, including model validation, are provided in Appendix VIII.

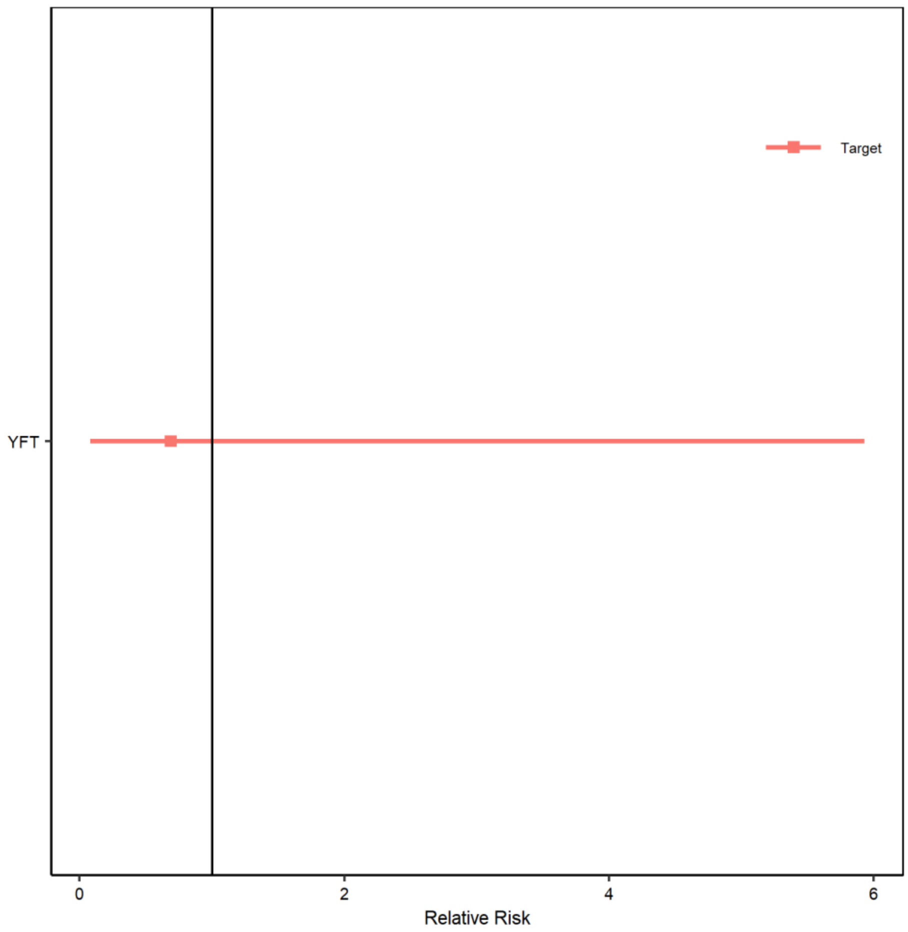


Figure 7.4.1. Results of the meta-analysis of the retention rates of changing hook type (from J to circle) in deep setting longlines. The error bars represent the 95% confidence intervals. (Note: J hook is considered the control and circle the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

Table 7.4.2. Summary of the species-specific meta-analysis of the retention rates when changing hook type (from J to circle) in deep setting longlines. The only species shown is the one for which it was possible to conduct a meta-analysis, namely yellowfin tuna. Note: J hook is considered the control and circle the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks. "Exp" refers to the number of experiments available for each analysis and the bracketed number is the one used after the validation procedure (see Appendix VIII). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative risk			Heterogeneity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
YFT	3	0.69	0.08-5.93	0.53	44	0.17	6, 18, 22

Effects of changing tuna hooks to circle hooks in deep setting longlines

Although studies comparing J hooks to circle hooks on deep setting longlines are very scarce, the comparison between tuna hooks and circle hooks has been more widely studied in relation to retention rates. The summary for this analysis shows that, overall, there are no significant effects for any of the species that have been studied (target, desirable bycatch and unwanted bycatch) when changing from tuna hooks to circle hooks in deep setting longlines (Figure 7.4.2 and Table 7.4.3). Figure 7.4.2 and Table 7.4.3 provide the summary results of the meta-analysis, while all the species-specific and detailed analysis, as well as model validation, are provided in Appendix VIII. With regard to at-haulback mortality, there are no adequate studies to enable a meta-analysis for any of the species. In some cases, there are one or two studies available, and all details are provided in Appendix VIII.

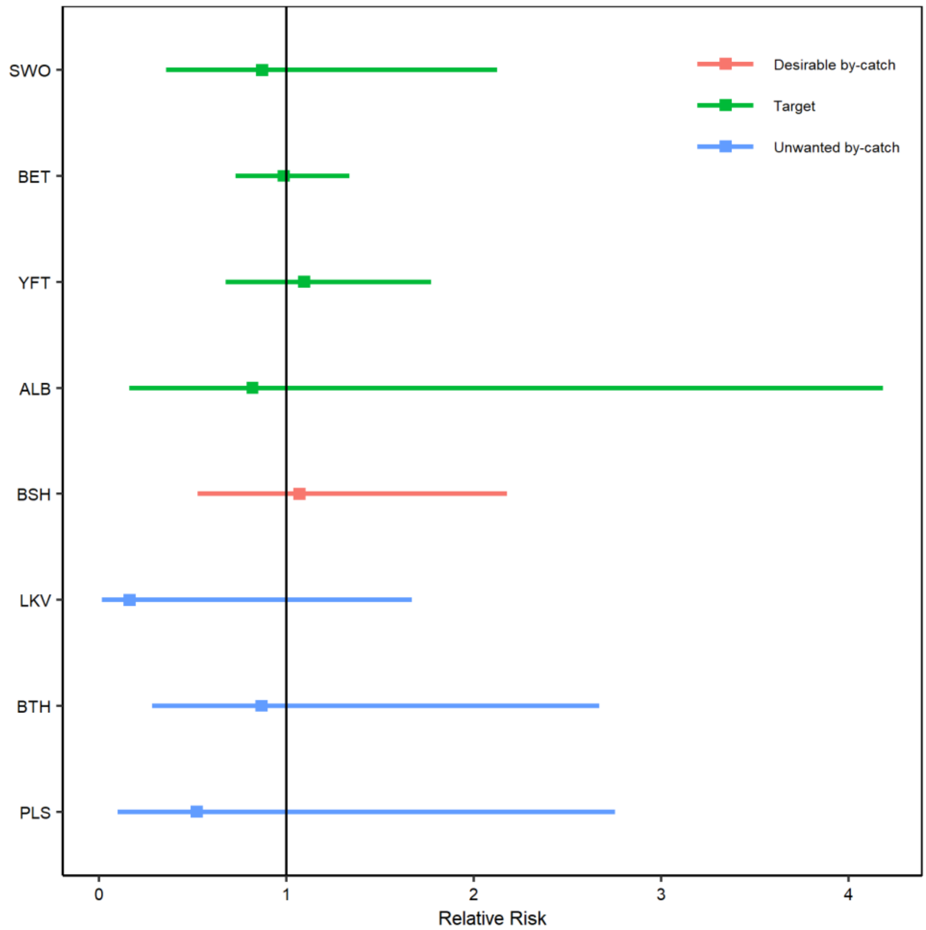


Figure 7.4.2. Results of the meta-analysis of the retention rates of changing hook type (from tuna to circle) in deep setting longlines, for the various species groups: target species, desirable bycatch and unwanted bycatch. The error bars represent the 95% confidence intervals. (Note: Tuna hook is considered the control and circle the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

Table 7.4.3. Summary of the species-specific meta-analysis of the retention rates when changing hook type (from J to circle) in deep setting longlines. The only species shown is the one where it was possible to conduct a meta-analysis, namely yellowfin tuna. Note: J hook is considered the control and circle the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks. "Exp" refers to the number of experiments available for each analysis and the bracketed number is the number used after the validation procedure (see Appendix VIII). The references used are listed in "Refs" (see Appendix III).

Species	Exp	Relative Risk			Heterogeinity		Refs
		RR	CIs (95%)	p-val	I^2	p-val	
LKV	4(3)	0.16	0.02-1.67	0.08	0	0.72	7, 13, 16 (41)
SWO	4	0.87	0.36-2.13	0.66	95	<0.01	7, 16, 23, 41
BET	4(3)	0.99	0.73-1.34	0.86	39	0.19	7, 16, 23 (41)
YFT	4	1.09	0.68-1.77	0.59	72	0.01	7, 16, 23, 41
ALB	4(3)	0.82	0.16-4.18	0.65	18	0.29	7, 23, 41 (16)
BSH	4(3)	1.07	0.53-2.18	0.72	0	0.45	7, 16, 41 (23)
BTH	3	0.87	0.28-2.67	0.64	66	0.05	7, 16, 23
PLS	3	0.52	0.1-2.75	0.23	66	0.05	7, 16, 23

Summary of the data gaps

In this sub-section, we provide a summary of the data gaps that still exist in a number of studies that make it impossible to carry out meta-analysis on the various species and for each component focused in this study. For the surface longlines, and especially for studying effects of changing hooks and baits, there are a number of studies on most species, while for the leader materials there are still many data gaps (Table 7.4.4.). For deep setting longlines the data gaps are more considerable, especially for changes in J-style hooks; considerably more studies have been performed for changes between tuna hooks and circle hooks (Table 7.4.4.). This could be because tuna hooks tend to be more widely used in deep setting longlines (targeting mostly tunas), while J hooks tend to be more used in surface longlines (targeting mainly swordfish and shark).

Table 7.4.4. Summary of the data gaps on studies for conducting the meta-analysis on the various species and factors. "Hook_J" refers to studies on changes from J hooks to circle hooks, whole "Hook_T" refers to studies on changes from tuna hooks to circle hooks. A colour gradient from green to red is used on the number of studies available in each cell of the table (note on the colour gradient: upper limit (N=21) = green; lower limit (N=0) = red; middle color (N=5) = yellow).

Sp	Surface setting longlines						Deep setting longlines			
	Retention rates			At-haulback mortality			Retention rates		At-haulback mortality	
	Hook_J	Bait	Leader	Hook_J	Bait	Leader	Hook_J	Hook_T	Hook_J	Hook_T
SWO	19	7	3	6	4	2	2	4	0	2
BET	11	6	4	6	4	2	2	4	2	2
BFT	4	2	0	2	0	0	0	0	0	0
YFT	9	4	3	5	4	2	3	4	0	2
ALB	11	6	3	6	3	2	1	4	0	0
BUM	6	4	3	5	4	2	1	0	0	0
SAI	4	4	2	3	4	1	0	0	0	0
WHM	5	4	1	5	4	1	0	0	0	0
BSH	16	6	3	8	4	3	2	4	0	2
SMA	12	6	2	7	4	2	0	1	0	0
TTL	21	11	2	10	5	2	0	1	0	1
DKK	12	7	1	9	4	1	0	1	0	1
LKV	7	3	1	4	3	1	1	4	0	2
LKY	2	2	0	2	2	0	0	0	0	0
TUG	5	0	0	2	0	0	1	0	0	0
OCS	5	4	2	5	4	2	0	2	0	0
POR	5	2	1	2	1	0	0	0	0	0
FAL	8	4	3	5	4	2	1	0	0	0
BTH	4	5	2	4	4	2	2	3	0	1
LMA	3	3	1	3	3	1	0	0	0	0
PSK	5	4	3	5	4	2	0	2	0	0
SPL	5	2	0	3	1	0	0	2	0	0
SPZ	3	4	2	3	4	2	0	2	0	0
PLS	9	5	3	3	1	1	1	3	0	1

8. TASK 5 – SCIENTIFIC SOUNDNESS OF PAPERS

Key findings

- In this task we provide reasons for exclusion of certain papers from the meta-analysis. There are several reasons why certain studies are not included in the meta-analysis, and they are described in detail in this task
- We also provide some specific examples of studies that fall under each of these categories, with the specific reasons for exclusion.

Objectives

The main objective of this task is to provide explanations for which certain scientific papers may be considered as not scientifically sound and not be retained for the analysis and conclusions.

Methodology

In this task we document and provide justifications on why some specific papers may not be retained for the analysis and conclusions, especially with regard to the meta-analyses described in Tasks 1 and 3.

The most common reasons for not including papers are related to small sample sizes, especially for the rarer and/or more occasionally captured species. For some species only few studies are available, sometimes none, which hinders the estimation of the relative risks in the meta-analysis or provides highly uncertain estimates. This is further complicated when combinations of the various variables are being tested, for example the combination and possibly confounded effects of hook, bait and leader types (as described and addressed in Task 3).

As such, within this task, we will comment particularly on two points: i) possible non-inclusion of some references and ii) references for which estimates are more uncertain due to limited information available, usually because of low samples sizes.

Upon completion of this task, we will try, as far as possible, to identify data gaps in terms of species and combinations of experimental effects and recommend these as future experimental research needs and sea trials.

For this report the focus was on detailing the reasons for non-inclusion of some references in the database that was used for the meta-analysis in Tasks 1, 3 and 4.

Results and discussion

During the compilation of studies for the database for the meta-analysis several studies were identified that were not included in the database. Below, the exclusion factors are detailed.

- *Studies that were not on pelagic longlines*

These included studies that looked at retention and/or mortalities of specimens caught in gears other than pelagic longline (e.g. recreational fisheries).

One study (Branstetter and Musick, 1993) that did use longlines was also not included because in the more coastal settings the hooks were on or near the bottom and therefore targeting more semi-demersal species, and not pelagic species as is the scope of the present study.

- *Studies comparing different fleets*

Studies in which two fleets were compared but no experimental design (e.g. using different hook types) was considered within the fleets were not included. For example, Vega and Lincandeo (2009) report on differences between the American and Spanish fishing systems. These differences would lead to confounding effects when trying to analyse the effects of changing hook/bait/leader type.

- *Studies comparing only different characteristics within hook/bait/leader type*

Studies for which only differences within hooks/leader/bait were compared were also not included. For example, Rice et al. (2012) compared circle hooks with and without offset; Echwikhi et al. (2010) compared different types of fish bait (mackerel and stingray); Stone and Dixon (2001) tested the effect of using mono or multifilament wire. These studies could be considered for inclusion if a more specific analysis was to be conducted, considering for example different shapes of the same type of hook, or bait to a higher species level. It should be noted that not all studies report on these characteristics to such a detailed level, therefore it might not be possible to conduct such a detailed analysis.

- *Studies that did not report the data necessary for the meta-analysis*

For some studies it was also not possible to obtain the necessary data (e.g. species-specific catch and/or number of hooks). For example, Carruthers et al. (2009) reports only on discarded/released alive and García-Cortés et al. (2009) reports on standardized catch per unit effort (CPUE) but not the species-specific catch.

- *Studies using satellite tags that did not separate post-release mortality from premature release of tags*

These included studies that looked mostly into movement of sharks using satellite tags. As is usual for such studies, the main objectives are the movement patterns; sharks that are tracked for very short periods (only a few days) are usually excluded from the analysis. In these cases, sharks with very short tracking times can be a mix of premature release of tags and post-release mortality, but unless that is reported, it is not possible to determine the percentages within each scenario. Such studies are useful for studying the movement (horizontal and vertical) patterns of the sharks but cannot be used for determining post-release mortality because of confounding effects.

One example of such a study that was not included is that of Vaudo et al., 2017. In such cases, we recommend that for the excluded tags (tags that remain in the sharks for very short periods and are excluded from the study on movements), the papers start to report whether the exclusions were due to tag premature release or post-release mortality.

Another issue with such studies, is that for studying the movement patterns sharks that are tagged are often selected (only the ones in better condition) to assure that the tagged sharks survive and the tags produce results. As such, the choice of sharks tagged in such studies is not random, but biased towards those that are in better condition, and therefore not representative of the condition of the sharks that are captured and released.

- *Studies using satellite tags where the main objective was to address movements*

It might be possible to use such studies for post-release mortality, depending on the study design and information provided in the papers. However, in general the use of such studies for determining post-release mortality is very limited.

The main reason for this is that there is usually a tendency for such studies to tag only specimens in good condition. If that happens, then the sample used is not randomly chosen to represent the various conditions of the catch, and as such using such results to determine post-release mortality can result in biased results.

- *Studies on satellite tagging of sea turtles deployed on the nesting beaches*

Several studies focusing on habitat use and migration of sea turtles tag those animals from the nesting beaches. In such cases, the results can only be used for the habitat use and migration studies, but not for post-release mortality as the sea turtles do not undergo any type of fishing operation and stress, but are captured and handled on land.

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APPENDIX I: LIST OF DELIVERABLES, MEETINGS AND MILESTONES

List of deliverables

The following table provides a summary and the timing of the deliverables/reports submitted to EASME/DG-MARE during the course of this project:

Nr.	Deliverable name	Nature[5]	Dissemination level	Del. date	Status
D 0.1	Inception Report	R	EASME/DG MARE	30 Oct 2019	Delivered in time
D 0.2	Interim Report	R	EASME/DG MARE	16 March 2020	Delivered in time
D 0.3	Draft Final Report	R	EASME/DG MARE	14 July 2020	Delivered in time
D 0.4	Final Report and Executive Summary ([6])	R	EASME/DG MARE	16 August 2020	Delivered in time

([5]) Nature of the deliverable/milestone: M = meeting; R = Report, O = Other (specify).

([6]) As with previous SCs coming from this FWC, the final report can be published in the EU library / repository in case EASME/DG-MARE wishes to do so. The authors are highly in favour of publication in an open and accessible repository.

List of meetings

The following table provides a summary and the timing of the meetings to be carried out within the course of this project, with objectives, tentative location and participation:

Nº	Name	Objectives and description	Location	Participation	Date (7)
M0.1	Kick-off meeting	The methodology as detailed in the inception report will be discussed with EASME/DG-MARE. A detailed work plan will be agreed, with adjustments to the original proposal if needed. All agreed points will be provided in the minutes of the meeting.	Brussels	EASME/DG MARE + SC coord. (IPMA) + FWC coord. (AZTI)	7 Nov 2019
M0.2	Interim meeting	The status of the development of each task, as reflected in the interim report, will be presented and discussed with EASME/DG-MARE. Any deviations from the original plan will be discussed. All details and agreements from the meeting will be provided in the meeting minutes.	Online[8]	EASME/DG MARE + 4 scientists from the consortium developing this SC	2 April 2020
M0.3	Final meeting	The draft final report will be discussed with EASME/DG-MARE. The Consortium team will integrate any comments to prepare and submit the final project report	Online[8]	EASME/DG MARE + at least 2 scientists from the consortium developing this SC	17 July 2020

(7) Meeting dates that have been discussed and agreed at the kick-off meeting.
(8) Meetings that were originally scheduled to be in-person but changed to online format due to Covid-19.

List of milestones

The following table provides a list of the milestones of each specific task of the project, including the means of verification during the project

No.	Milestone description	Task no.	Nature (9)	Date	Means of verification
MS 1.1	Preliminary meta-analysis with analysis and advice on the use of circle hooks. Includes retention rates and discarded/post-release mortality of targeted, desirable bycatch and unwanted bycatch species. Also includes comments on short (3-5 yrs) and long-term (>10 yrs) economic aspects.	1	R	16 March 2020	Interim Report
MS 1.2	Final meta-analysis with analysis and advice on the use of circle hooks. Includes retention rates and discarded/post-release mortality of targeted, desirable bycatch and unwanted bycatch species. Also includes comments on short (3-5 yrs) and long-term (>10 yrs) economic aspects.	1	R	14 Jul and 16 Aug 2020	Final Draft and Final Report
MS 2.1	Preliminary comments on the technical/biological reasons explaining the supposed practical effects of circle hooks with respect to other shapes. It will take into account circle hook morphology (i.e. offset/non-offset, etc.).	2	R	16 March 2020	Interim Report
MS 2.2	Final comments on the technical/biological reasons explaining the supposed practical effects of circle hooks with respect to other shapes. It will take into account circle hook morphology (i.e. offset/non-offset, etc.).	2	R	14 Jul and 16 Aug 2020	Final Draft and Final Report
MS 3.1	Preliminary advice on issues other than hook shape (e.g., hook size, bait type, depth fishing, soak time, leader type, etc.), could actually explain the reported differences.	3	R	16 March 2020	Interim Report
MS 3.2	Final advice on issues other than hook shape (e.g., hook size, bait type, depth fishing, soak time, leader type, etc.), could actually explain the reported differences.	3	R	14 Jul and 16 Aug 2020	Final Draft and Final Report
MS 4.1	Preliminary advice on whether the implementation of circle hooks is dependent on fishing depth and/or soaking time, taking into account the fishing effort repartition between shallow and deep fishing operations.	4	R	16 March 2020	Interim Report
MS 4.2	Final advice on whether the implementation of circle hooks effects is dependent on fishing depth and/or soaking time, taking into account the fishing effort repartition between shallow and deep fishing operations.	4	R	14 Jul and 16 Aug 2020	Final Draft and Final Report
MS 5.1	Justifications provided for scientific papers that may be considered as not scientifically sound and have not been retained for the conclusions.	5	R	14 Jul and 16 Aug 2020	Final Draft and Final Report

(9) Nature of the deliverable/milestone: M = meeting; R = report, O = other (specify).

APPENDIX II: LIST OF ABBREVIATIONS AND ACRONYMS

The following table provides a list of abbreviations and acronyms used in this report.

Acronym	Name
ALB	Albacore tuna, *Thunnus alalunga*
AZTI	AZTI-Tecnalia
BET	Bigeye tuna, *Thunnus obesus*
BFT	Bluefin tuna, *Thunnus thynnus*
BSH	Blue shark, *Prionace glauca*
BTH	Bigeye thresher, *Alopias superciliosus*
BUM	Blue marlin, *Makaira nigricans*
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CI(s)	Confidence interval(s)
cov.r	Covariance ratio (meta-analysis)
CPUE	Catch per unit effort
Dffits	Difference in fits (meta-analysis)
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DGRM	Direcção Geral de Recursos Marinhos, Portugal
DKK	Leatherback turtle, *Dermochelys coriacea*
EASME	Executive Agency for Small and Medium-sized Enterprises
EU	European Union
FAL	Silky shark, *Carcharhinus falciformis*
FWC	Framework contract
I^2	Heterogeneity value (meta-analysis)
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IEO	Instituto Español de Oceanografía
IOTC	Indian Ocean Tuna Commission
IPMA	Instituto Português do Mar e da Atmosfera
IRD	Institut de Recherche pour le Développement
LKV	Olive ridley turtle, *Lepidochelys olivacea*
LKY	Kemp’s ridley turtle, *Lepidochelys kempii*
LMA	Longfin mako, *Isurus paucus*
MRAG	MRAG, Ltd
OCS	Oceanic whitetip shark, *Carcharhinus longimanus*
PLS	Pelagic stingray, *Pteroplatytrygon violacea*
POR	Porbeagle, *Lamna nasus*

PSK	Crocodile shark, *Pseudocarcharias kamoharai*
RR(s)	Relative risk(s)
SL50	Size at which 50% of the individuals are selected (size selectivity)
SAI	Atlantic sailfish, *Istiophorus albicans*
SCRS	Standing Committee on Research and Statistics
SMA	Shortfin mako, *Isurus oxyrinchus*
SPL	Scalloped hammerhead, *Sphyrna lewini*
SPZ	Smooth hammerhead, *Sphyrna zygaena*
SWO	Swordfish, *Xiphias gladius*
t-RFMO	tuna Regional Fisheries Management Organisation
TTL	Loggerhead turtle, *Caretta caretta*
TUG	Green turtle, *Chelonia mydas*
WCPFC	Western and Central Pacific Fisheries Commission
WHM	Atlantic white marlin, *Tetrapturus albidus*
YFT	Yellowfin tuna, *Thunnus albacares*

APPENDIX III: LIST OF REFERENCES FOR THE META-ANALYSIS

Below we provide the current list of references used for the meta-analysis. Each specific reference (Ref) can have several experiments (Exp) described.

Ref.	Exp.	Biliographic 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.
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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.
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10	19	Ward, P., Epe, S., Kreutz, D., Lawrence, E., Robins, C. & Sands, A. (2009). The effects of circle hooks on bycatch and target catches in Australia's pelagic longline fishery. *Fisheries Research*, 97:253-262.
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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.

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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.
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APPENDIX IV: SPECIES-SPECIFIC ANALYSIS FOR SUB-TASK 1.1 – TARGET SPECIES

In this Appendix we provide the detailed species-specific results for Task 1, namely sub-task 1.1, referring to the meta-analysis for retention rates and at-haulback mortality for the main target species considered in the study: swordfish (SWO), bigeye tuna (BET), bluefin tuna (BFT), yellowfin tuna (YFT) and albacore (ALB). We also provide detailed tables with the post-release mortality information available for those species.

Swordfish (SWO)

Retention rates

Figure IV.1 shows the random effects model when all compiled experiments that reported on swordfish retention are used. In this case, the RR from the meta-analysis is 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%. In this analysis, one problem when using all experiments, is that the overall heterogeneity (I^2) is very high, failing the statistical assumption of homogeneity (p-value<0.05).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
1	264	46040	723	92080	0.73	[0.63; 0.84]	5.9%
2	357	58766	203	29383	0.88	[0.74; 1.04]	5.7%
11	65	8250	60	8250	1.08	[0.76; 1.54]	4.4%
15	33142	2150674	17086	1282748	1.16	[1.14; 1.18]	6.3%
17	4232	286826	2172	143473	0.97	[0.93; 1.03]	6.3%
20	715	72914	833	72914	0.86	[0.78; 0.95]	6.1%
24	45237	5044540	49936	3157102	0.57	[0.56; 0.57]	6.3%
25	301	25085	307	25085	0.98	[0.84; 1.15]	5.8%
26	1	2322	1	2320	1.00	[0.06; 15.96]	0.2%
27	148	22571	139	22571	1.06	[0.85; 1.34]	5.3%
28	148	19911	195	19911	0.76	[0.61; 0.94]	5.4%
30	11035	624656	8110	349078	0.76	[0.74; 0.78]	6.3%
32	8	4275	36	4275	0.22	[0.10; 0.48]	2.0%
33	100	9011	113	9012	0.89	[0.68; 1.16]	5.0%
42	2543	203568	1687	101784	0.75	[0.71; 0.80]	6.3%
44	63	8500	72	8500	0.88	[0.62; 1.23]	4.5%
46	191	14664	213	14590	0.89	[0.73; 1.08]	5.6%
50	1710	169680	1133	84840	0.75	[0.70; 0.81]	6.2%
49	2895	297600	1947	148800	0.74	[0.70; 0.79]	6.3%
Overall effect		**9069853**		**5576716**	**0.82**	**[0.73; 0.94]**	**100.0%**

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 0.0698$, $p = 0$

Figure IV.1. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

The results of the validation with search for possible outliers and influence analysis are represented in Figure IV. 2. Some experiments are identified in several of the diagnostics (Figure IV.2 – top right panel), as for example experiments 24, 26 and 32, but their influence was not identified at a sufficient level to exclude them. Experiment 15 is a large contributor to the heterogeneity, while at the same time not contributing too much for the pooled results (Figure IV.2 – top left panel); however, when excluding that specific experiment, the I^2 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 (Figure IV.2 – bottom panel), that shows that the overall heterogeneity and estimation would not change that much if that experiment were to be excluded.

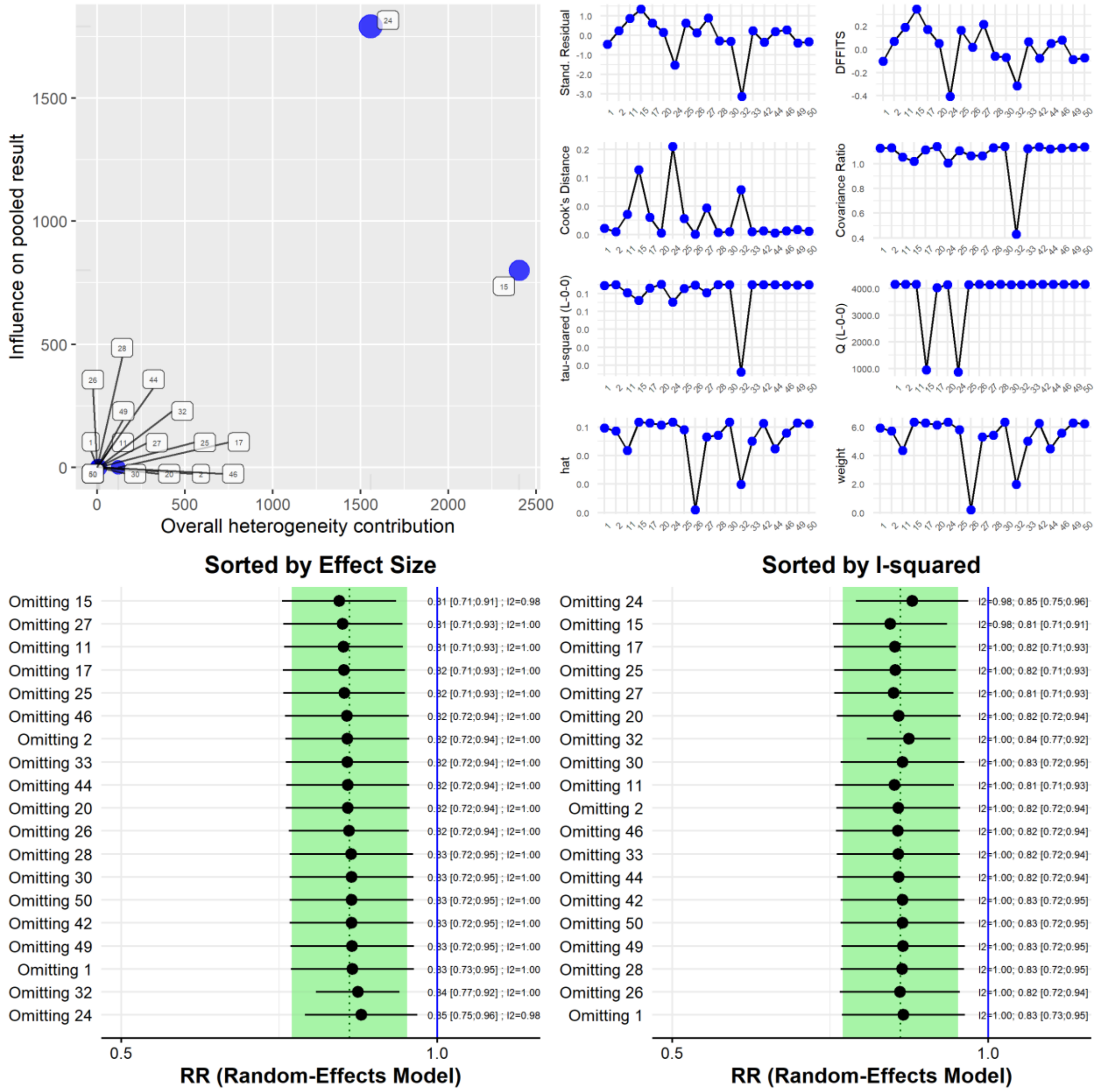


Figure IV.2. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I2 (right).

At haulback-mortality

With regard to at-haulback mortality, the random effects model considering all experiments is shown in Figure IV.3. In this case, experiment 24 and 42 CIs do not overlap with the estimated overall RR. The influence analysis that followed (Figure IV.4) also identified these 2 experiments as outliers with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was re-run excluding those 2 experiments, with the results of the new pooled analysis indicated in Figure IV.5 and validation indicated in Figure IV.6.

With the exclusion of those 2 outliers, the heterogeneity was largely reduced, specifically from 97% when including all experiments to 73% with those 2 exclusions; however, still not passing the homogeneity assumption (p-value < 0.05). On the other hand, the pooled analysis results did not change by much. In the first analysis including all experiments, the results pointed to a decrease of 6% in at-haulback mortality when using circle hooks (95% CIs: 1% to 11% reduction), while after excluding the outliers the results pointed to a reduction also of 6% with slightly different CIs (95% CIs: 2% to 11% reduction).

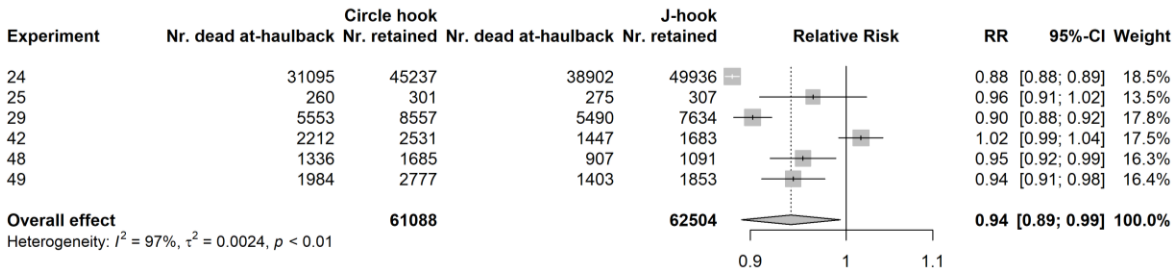


Figure IV.3. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of swordfish with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

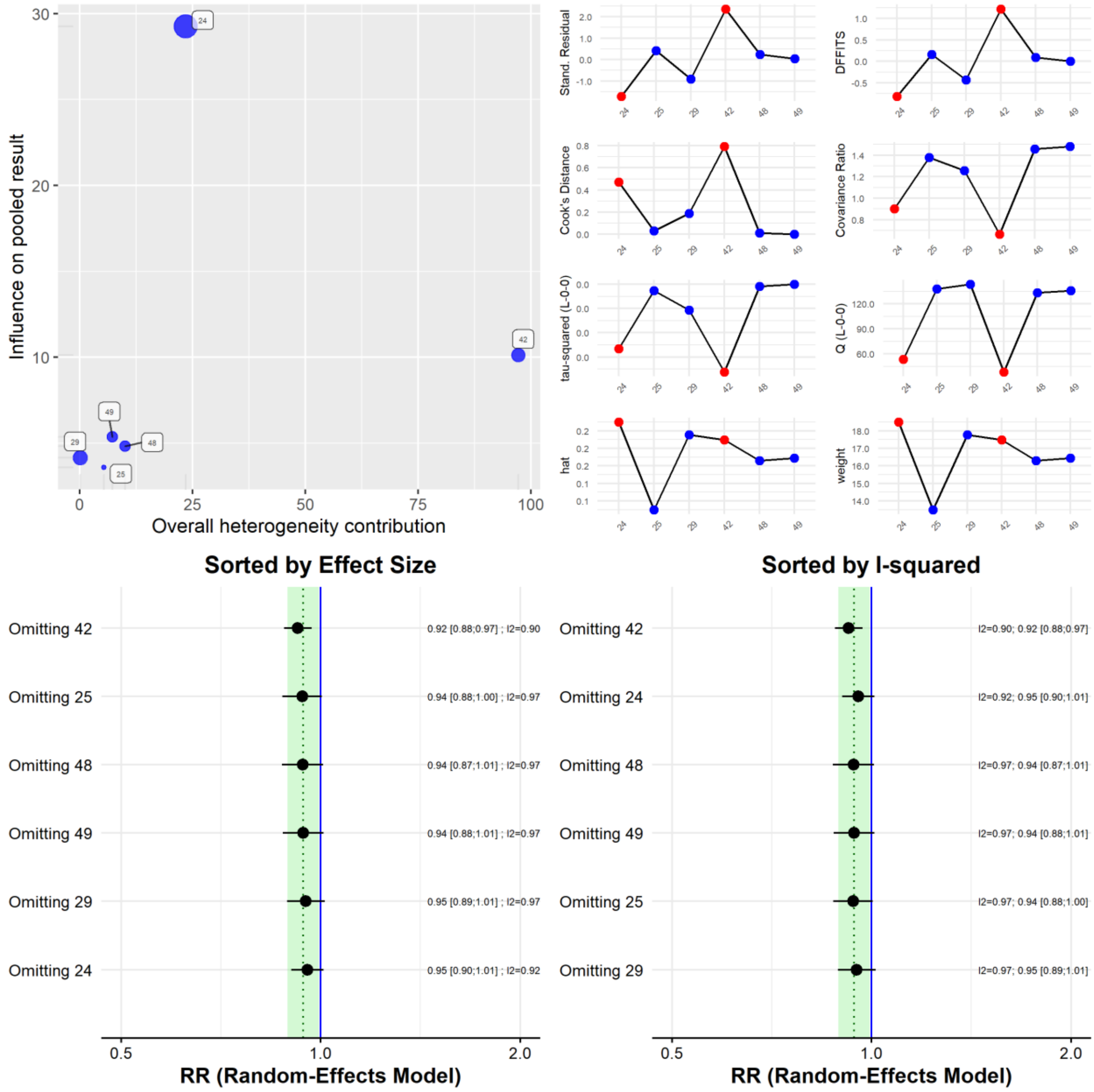


Figure IV.4. Influence analysis for the meta-analysis performed for the at-haulback mortality of swordfish with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. dead at-haulback	Circle hook Nr. retained	J-hook Nr. dead at-haulback	J-hook Nr. retained	RR	95%-CI	Weight
24	31095	45237	38902	49936	0.88	[0.88; 0.89]	0.0%
25	260	301	275	307	0.96	[0.91; 1.02]	15.7%
29	5553	8557	5490	7634	0.90	[0.88; 0.92]	33.3%
42	2212	2531	1447	1683	1.02	[0.99; 1.04]	0.0%
48	1336	1685	907	1091	0.95	[0.92; 0.99]	25.2%
49	1984	2777	1403	1853	0.94	[0.91; 0.98]	25.8%
Overall effect		**61088**		**62504**	**0.94**	**[0.89; 0.98]**	**100.0%**

Heterogeneity: $I^2 = 73\%$, $\tau^2 = 0.0006$, $p = 0.01$

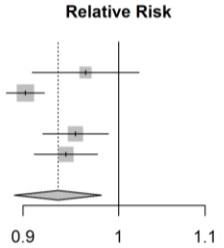


Figure IV.5. Forest plot of the random effects meta-analysis excluding 2 outliers in the at-haulback mortality of swordfish with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiments 24 and 42 were excluded (these are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

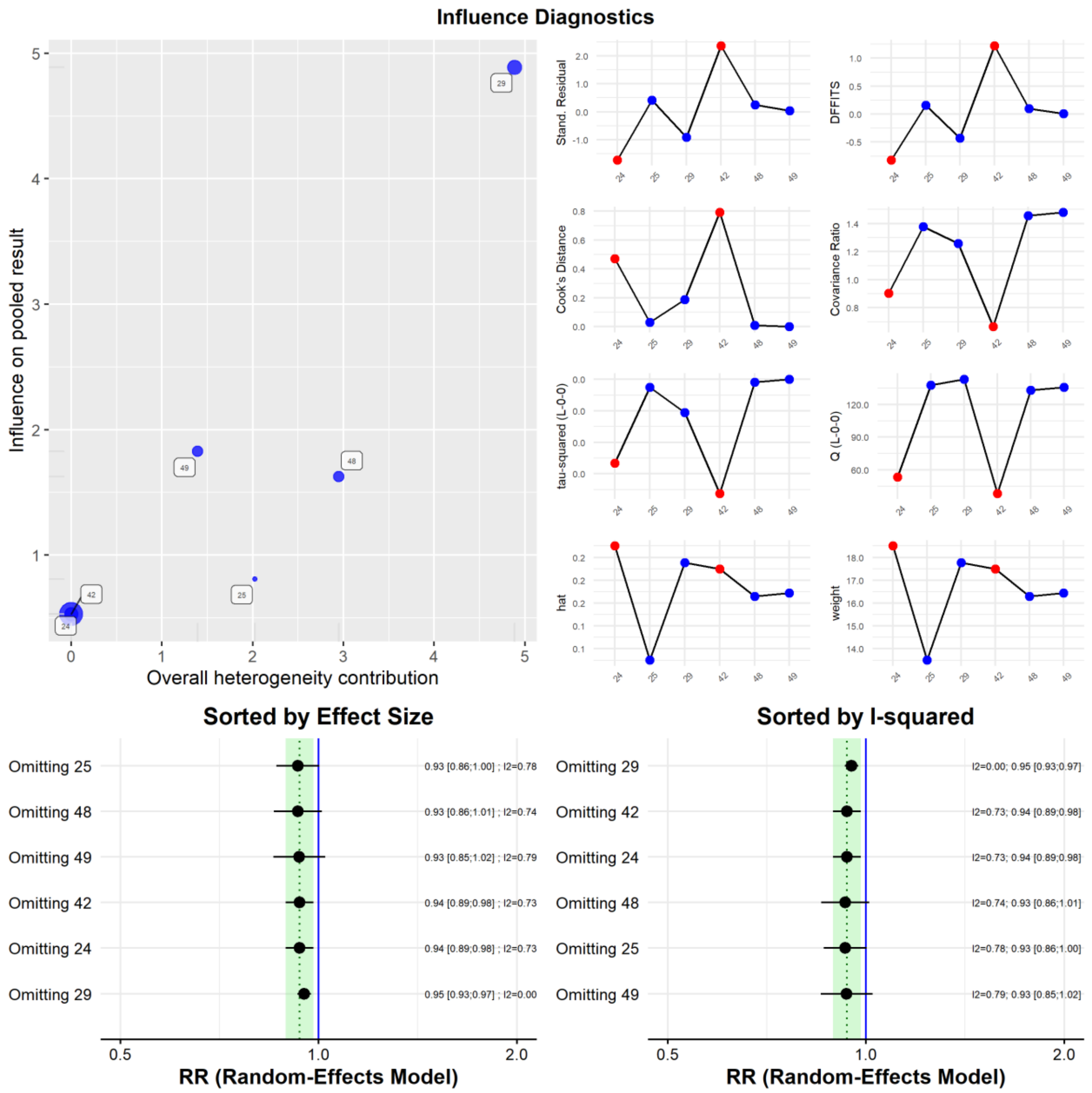


Figure IV.6. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the at-haulback mortality of swordfish with circle vs. J hooks. Experiments 24 and 42 were excluded (these are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table IV.1 provides a summary of the currently available studies specific for swordfish. As stated previously, most of the studies do not provide specific information on the hook type used, so it was not possible to conduct a meta-analysis for the post-release mortality of swordfish.

Table IV.1. Summary of post-release mortality studies for swordfish with indication of gear and region, and whether factors such as hook, bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
SWO – Swordfish	14	35.7	Recreational	NE Atlantic (Florida Straits)	NA	NA	NA	Fenton (2012)
	21	38.1	Longline	SE Pacific	J*	NA	NA	Abascal et al. (2010)
	19	15.4	Longline or harpoon fishery	Mediterranean Sea	J*	NA	NA	Canese et al. (2008)
	19	10.5	Longline	SW Pacific (New Zealand)	NA	NA	NA	Holdsworth et al. (2010)
	9	22.2	Recreational or longline	NW Atlantic – Caribbean	NA	NA	NA	Dewar et al. (2011)
	11	0	Longline	Central Pacific	NA	NA	NA	Dewar et al. (2011)
	13	38.5	Longline or harpoon fishery	Eastern Pacific (California Bights)	NA	NA	NA	Dewar et al. (2011)
	30	6.7	Longline or harpoon fishery	North Pacific (California; Hawaii)	NA	NA	NA	Abecassis et al. (2012)

* refers to information that is not available/provided but assumed given the specific fisheries and years of the study.

Bigeye tuna (BET)

Retention rates

Figure IV.7 shows the random effects model when all compiled experiments that reported on bigeye tuna retention are used. The RR is 1.14 (95% CIs: 0.84; 1.54), which means that the point estimate indicates a 12% increase in retention when using circle hooks; however, with 95% confidence intervals varying between reductions of 26% and increases of 54%. In this analysis, one problem detected when using all experiments, is that the overall heterogeneity (I^2) is very high, failing the statistical assumption of homogeneity (p-value<0.05).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
20	46	72914	23	72914	2.00	[1.21; 3.30]	8.3%
24	7663	5044540	9625	3157102	0.50	[0.48; 0.51]	11.1%
25	526	25085	390	25085	1.35	[1.18; 1.54]	10.8%
27	5	22571	1	22571	5.00	[0.58; 42.79]	1.5%
28	36	19911	27	19911	1.33	[0.81; 2.20]	8.3%
30	946	624656	667	349078	0.79	[0.72; 0.88]	10.9%
42	876	203568	307	101784	1.43	[1.25; 1.62]	10.8%
44	50	8500	54	8500	0.93	[0.63; 1.36]	9.2%
45	50	8500	54	8500	0.93	[0.63; 1.36]	9.2%
48	213	169680	94	84840	1.13	[0.89; 1.44]	10.3%
49	154	297600	43	148800	1.79	[1.28; 2.51]	9.6%
Overall effect		**6497525**		**3999085**	**1.14**	**[0.84; 1.54]**	**100.0%**

Heterogeneity: $I^2 = 98\%$, $\tau^2 = 0.1899$, $p < 0.01$

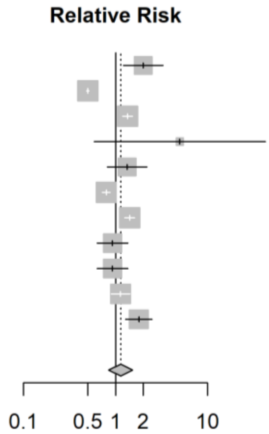


Figure IV.7. Forest plot of the random effects meta-analysis performed for the retention rates of bigeye tuna with circle vs J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

The results of the validation with search for possible outliers and influence analysis are represented in Figure IV.8. Some experiments are identified as possible outliers in several of the diagnostics (Figure IV.8 – top right panel), as for example experiments 20, 24, 25 and 27, but their influence was not identified at a sufficient level to exclude them. Experiment 24 is a relatively large contributor to the heterogeneity, while at the same time contributing to changes in the pooled results (Figure IV.8 – bottom panel). If excluding that experiment (Figure IV.8 – bottom panel), the I^2 would only decrease from 98% to 89%, while the RR would change to 1.24 (95% CIs: 0.97; 1.59). Given this analysis, all experiments were considered for calculating the RR.

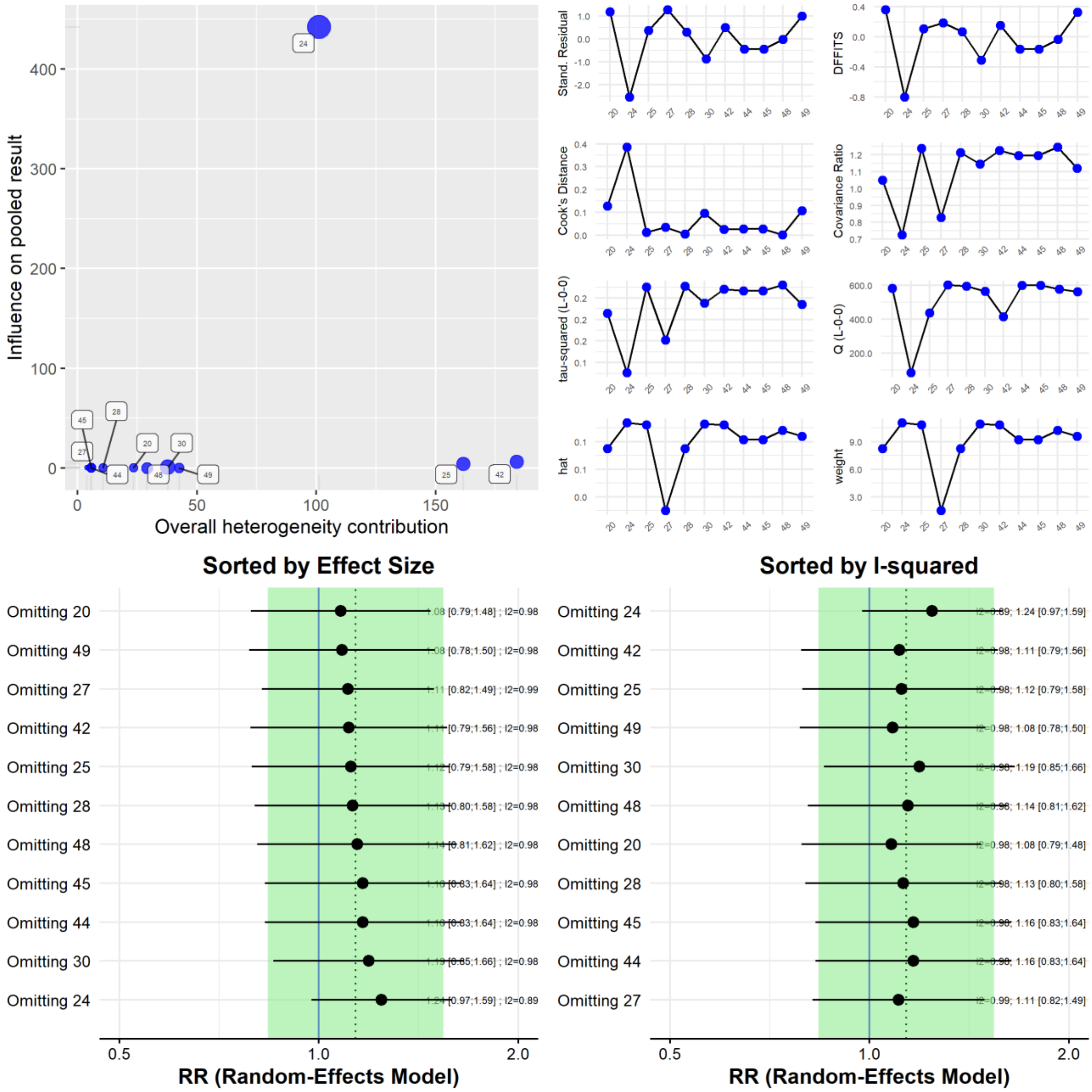
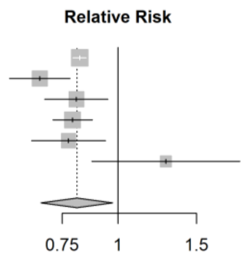


Figure IV.8. Influence analysis for validating the meta-analysis performed for the retention rates of bigeye tuna with circle vs. J-hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At haulback-mortality

With regard to at-haulback mortality, the random effects model considering all experiments for bigeye tuna is shown in Figure IV.9. When all experiments are used, the RR is calculated at 0.81 (95% CIs: 0.67; 0.97), which means that the at-haulback mortality of bigeye tuna decreases by 19% when using circle hooks, with 95% CIs varying between reductions of 3% and 33%. The overall heterogeneity (I^2) is relatively low (59%), but fails the statistical assumption of homogeneity (p-value=0.03).

Experiments 24, 25 and 50 are identified in some of the diagnostic plots (Figure IV.10). With the exclusion of experiment 25 (Figure IV.11), that has a high influence on the heterogeneity while having a relatively low impact on the estimation of the RR, the heterogeneity was reduced to 34% and did not fail the assumption of homogeneity (p>0.05). In the first analysis including all experiments, the results pointed to a decrease of 19% in at-haulback mortality when using circle hooks, while after excluding the outlier the results pointed to a reduction of 16% – however, not significant any more (95% CIs: 31% reduction to 3% increase). The influence analysis excluding experiment 25 is presented in Figure IV.12.



Experiment	Circle hook Nr. dead at-haulback	Circle hook Nr. retained	J-hook Nr. dead at-haulback	J-hook Nr. retained	RR	95%-CI	Weight
24	2978	7663	4555	9625	0.82	[0.79; 0.85]	21.1%
25	175	526	194	390	0.67	[0.57; 0.78]	17.4%
29	247	1069	186	650	0.81	[0.69; 0.95]	17.1%
42	458	872	201	303	0.79	[0.71; 0.88]	19.4%
48	113	211	58	84	0.78	[0.64; 0.94]	16.0%
49	82	153	18	43	1.28	[0.87; 1.88]	9.1%
Overall effect		**10494**		**11095**	**0.81**	**[0.67; 0.97]**	**100.0%**

Heterogeneity: $I^2 = 59\%$, $\tau^2 = 0.0283$, $p = 0.03$

Figure IV.9. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of bigeye tuna with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

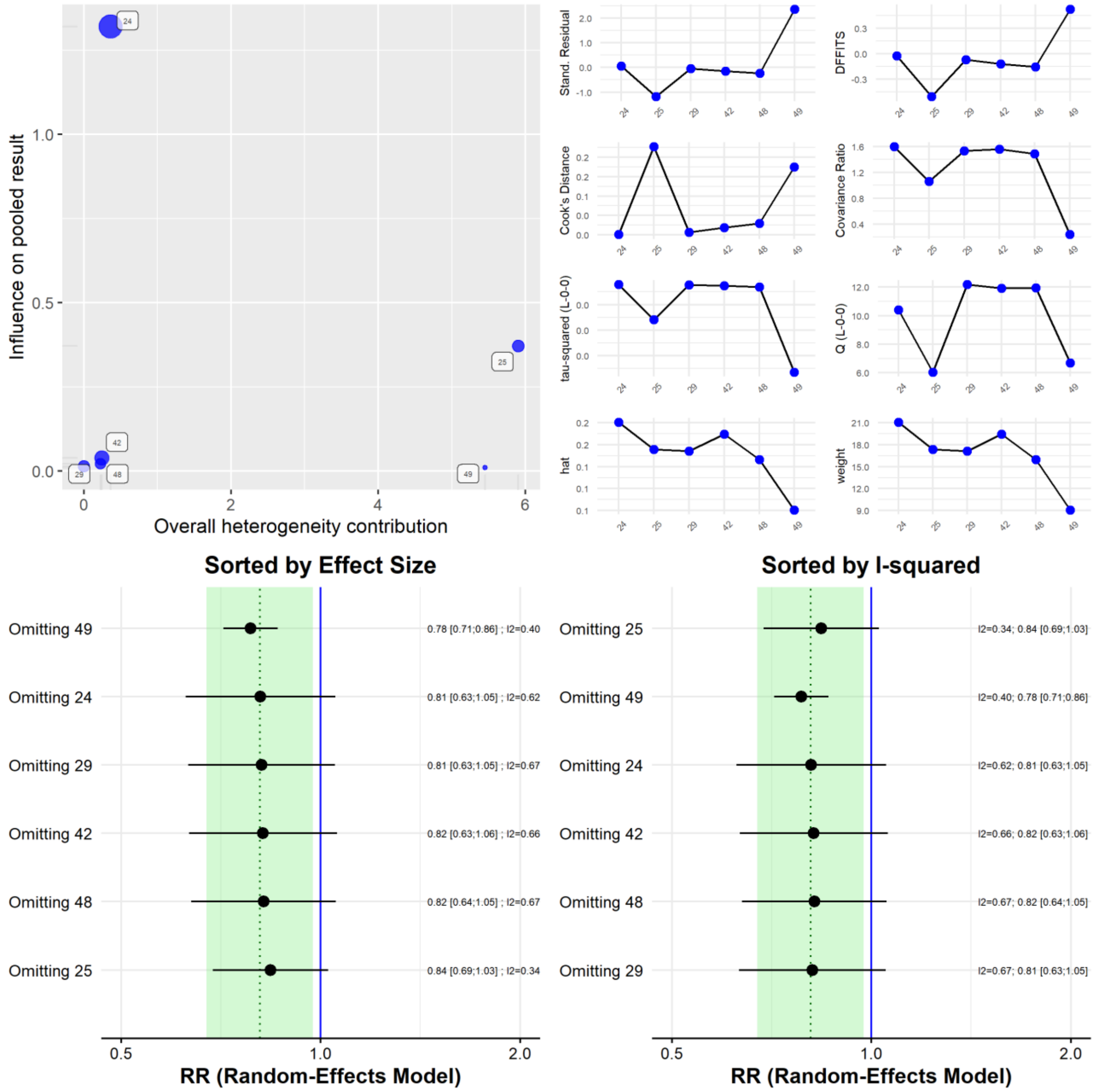


Figure IV.10. Influence analysis for the meta-analysis performed for the at-haulback mortality of bigeye tuna with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

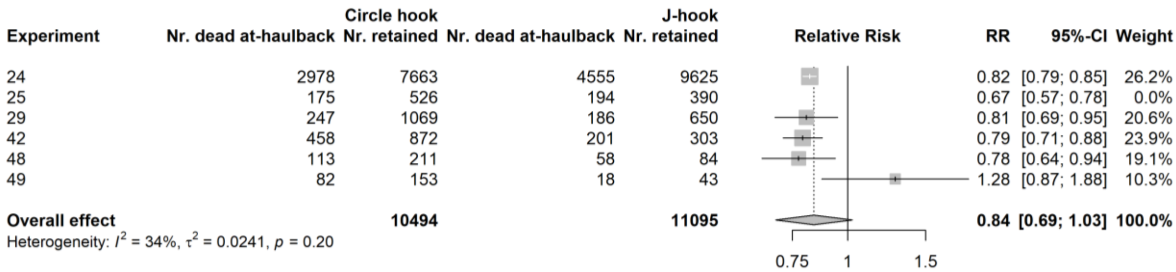


Figure IV.11. Forest plot of the random effects meta-analysis excluding 1 outliers in the at-haulback mortality of bigeye tuna with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiment 25 was excluded (this is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

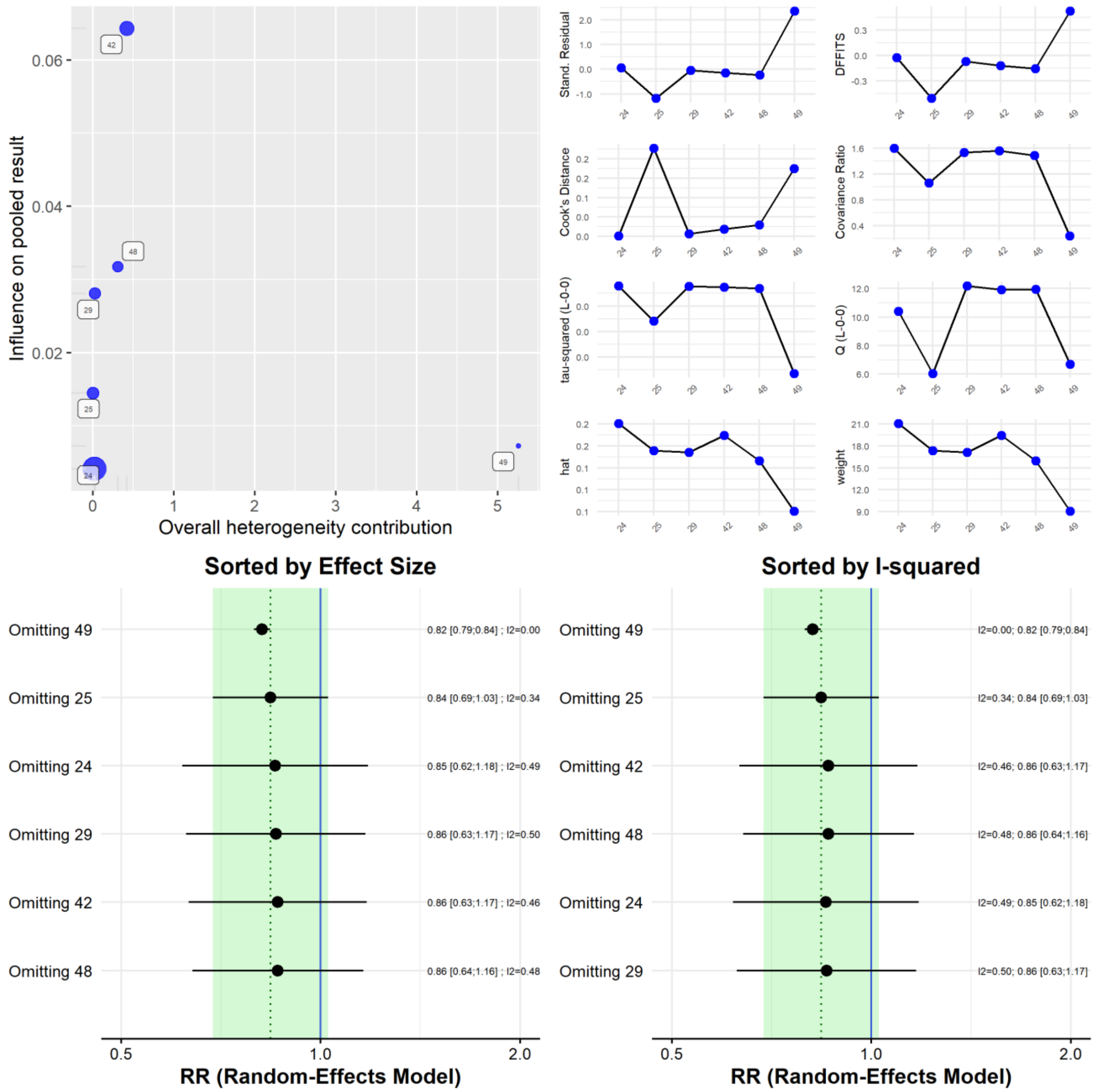


Figure IV.12. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the at-haulback mortality of bigeye tuna with circle vs. J hooks. Experiment 25 was excluded (this is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table IV.2 provides a summary of the currently available studies specific for bigeye tuna.

Table IV.2. Summary of post-release mortality studies for bigeye tuna with indication of gear and region, and whether factors such as hook, bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
BET – bigeye tuna	4	0%	Longline	Equatorial Atlantic	NA	NA	NA	Matsumoto et al. (2005)
	8	0%*	Longline	NW Atlantic	NA	NA	NA	Lam et al. (2014)
	7	0%**	Longline	SW Indian Ocean	Circle	Mostly squid	NA	Sabarros et al. (2017)

*: Fish were at liberty for at least 14 days without indication of post-release mortality.
**: Fish were at liberty for at least 15 days without indication of post-release mortality.

Bluefin tuna (BFT)

Retention rates

When all compiled experiments on retention of bluefin tuna are used, the RR is 1.34 (95% CIs: 0.95; 1.98). This means that the point estimate indicates an increase in the retention of bluefin tuna when using circle hooks (34% more), but this is not significant as the CIs range between an increase of 89% and a decrease of 5% in retention (Figure IV.13). In this analysis, the overall heterogeneity (I^2) does not fail the statistical assumption of homogeneity (p-value>0.05).

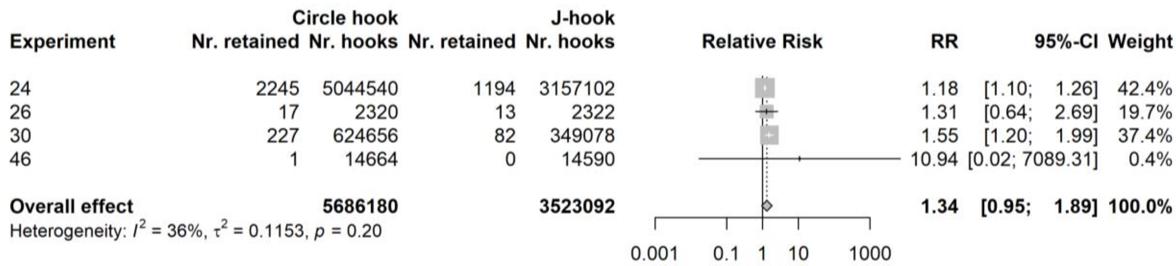


Figure IV.13. Forest plot of the random effects meta-analysis performed for the retention rates of bluefin tuna with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

The results of the validation with search for possible outliers and influence analysis are represented in Figure IV.14. Some experiments are identified in several of the diagnostics, but their influence on the pooled result or on the heterogeneity was not identified at a sufficient level to exclude them. As such, the analysis provided in Figure IV.13 is considered final.

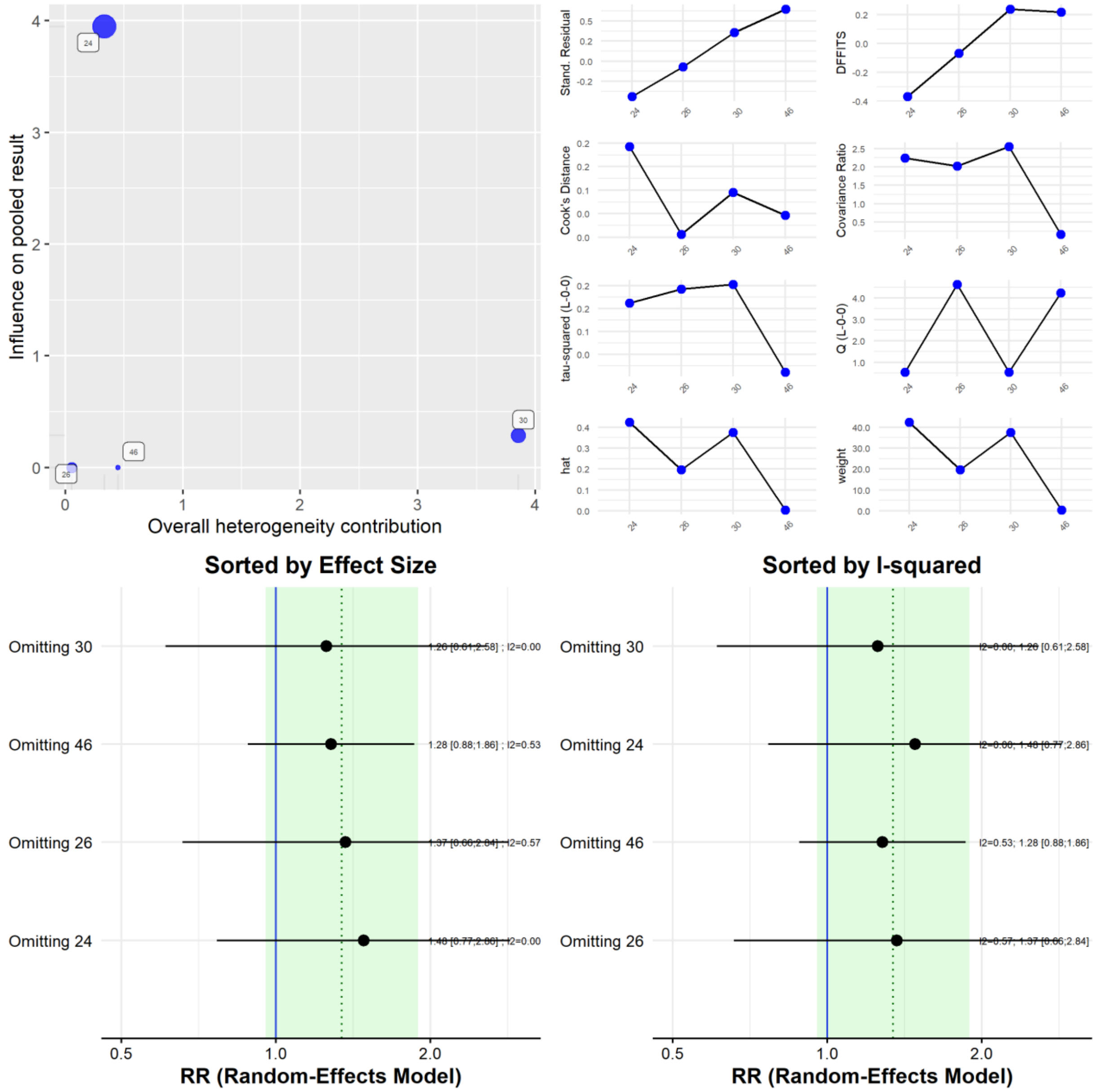


Figure IV.14. Influence analysis for validating the meta-analysis performed for the retention rates of blue fin tuna with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I2 (right).

At haulback-mortality

With regard to the effect of hook type on the at-haulback mortality of bluefin tuna, only two experiments are available (experiments 24 and 29), therefore the meta-analysis was not conducted. Experiment 24 shows a decrease in the at-haulback mortality of bluefin tuna when using circle hooks (RR=0.86; 95% CIs: 0.81; 0.91), while experiment 29 indicated there is an increase in at-haulback mortality (RR=1.50; 95% CIs:1.17; 1.92).

Post-release mortality

With regard to the post-release mortality, Table IV.3 provides a summary of the currently available studies specific for bluefin tuna.

Table IV.3. Summary of post-release mortality studies for bluefin tuna with indication of gear and region, and whether factors such as hook, bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
BFT – Bluefin Tuna	3*	0.0	Rod and reel	NE Atlantic	NA	NA	NA	Stokesbury et al. (2007)
	32**	0.0	Rod and reel and longline	NW Atlantic	C	NA	NA	Galuardi et al. (2010)
	27	0.0	Rod and reel	NW Atlantic	NA	NA	NA	Galuardi & Lutcavage (2012)
	30	3.3	Rod and reel, purse seine	NW Atlantic	C	NA	NA	Stokesbury et al. (2004)
	59	3.4	Rod and reel	NW Atlantic	C	Fish	NA	Stokesbury et al. (2011)
	19	0.0	Rod and reel	NW Atlantic	J	NA	NA	Marcek & Graves (2014)
	15	0.0	Rod and reel	NW Atlantic	J	Fish	NA	Goldsmith et al. (2017)
	33	12-28	Longline	Gulf of Mexico	C	NA	NA	Orbesen et al. (2019)
	60	1.7	Rod and reel, purse seine	NW Atlantic	NA	NA	NA	Wilson et al. (2005)

*: 6 tags were deployed but 3 failed, so the results are only from the 3 that transmitted.

**: 36 tags were deployed, but 3 released in the first week (without any explanation provided on why) and 1 failed to transmit. Therefore, the results are based on the remaining 32 tags.

Yellowfin tuna (YFT)

Retention rates

With regard to retention rates, the random effects model considering all experiments is shown in Figure IV.15. The influence analysis that followed (Figure IV.1.16) identified experiment 24 as an outlier with significant leverage. The analysis was re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure IV.17 and validation indicated in Figure IV.18.

With the exclusion of this outlier, the heterogeneity was largely reduced, specifically from 92% when including all experiments to 23%. The pooled analysis results changed from an RR of 1.08 (95% CIs: 0.88-1.31) to 1.17 (95% CIs: 0.99-1.38). The final results pointed to an increase in retention of 17% when using circle hooks, even though this was not significant, with the confidence intervals varying between an increase of 38% to a decrease of 1%.

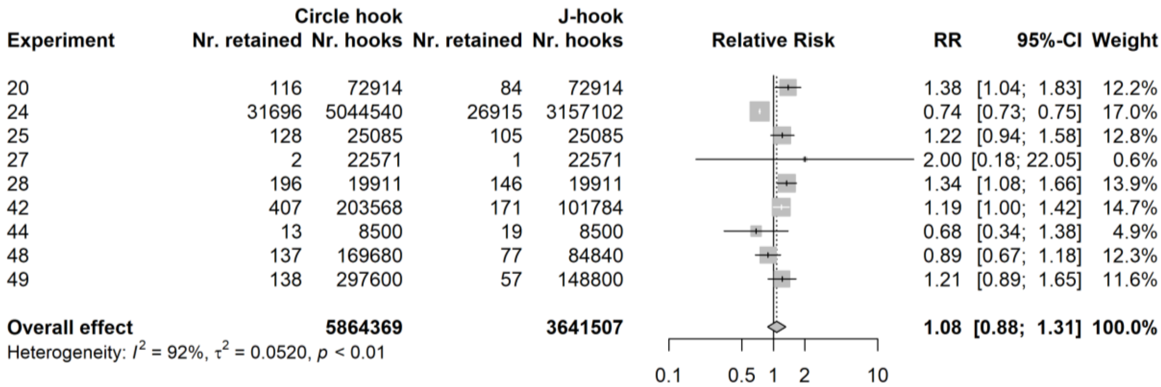


Figure IV.15. Forest plot of the random effects meta-analysis performed for the retention rates of yellowfin tuna with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

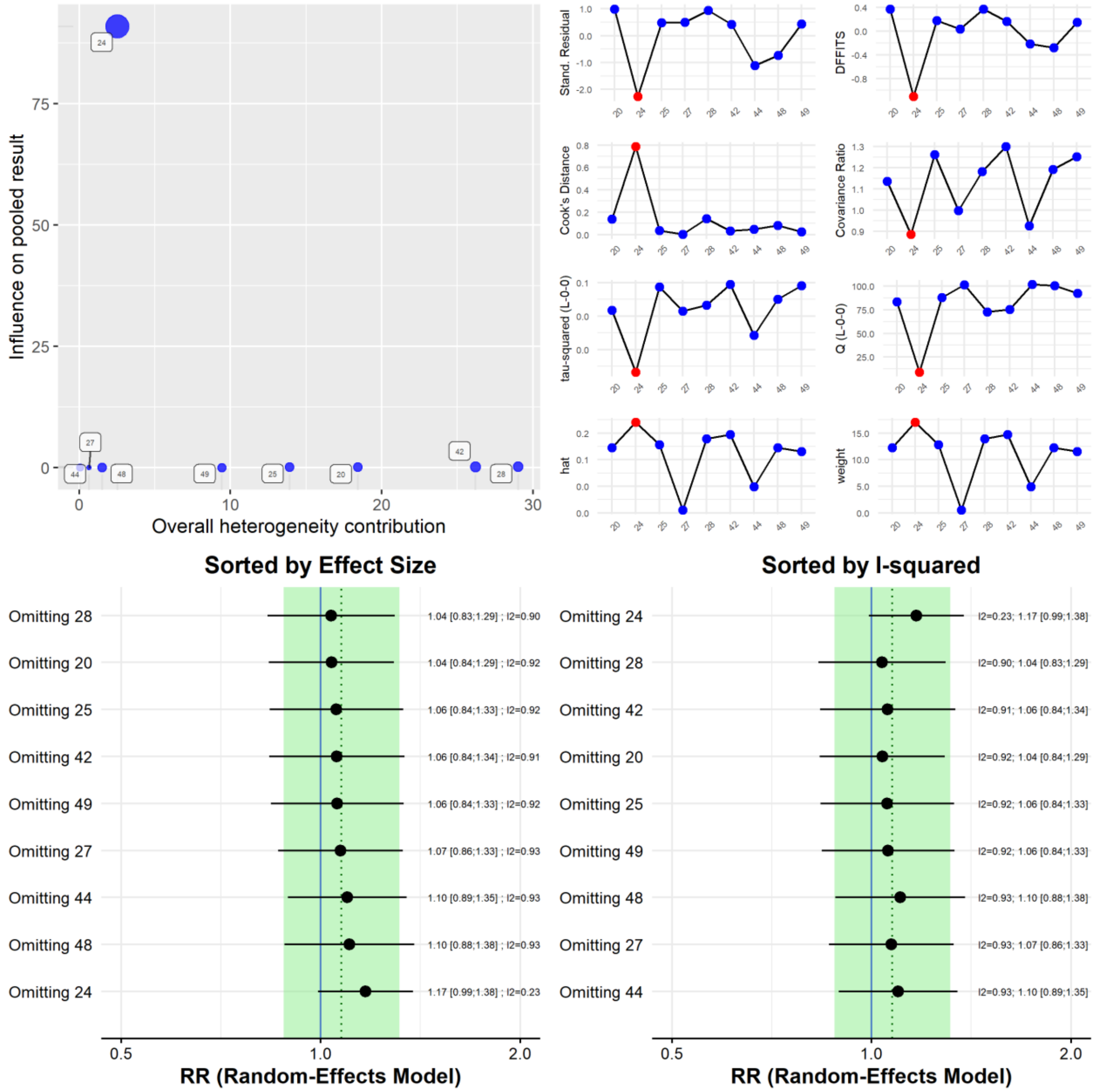


Figure IV.16. Influence analysis for validating the meta-analysis performed for the retention rates of yellowfin tuna with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
20	116	72914	84	72914	1.38	[1.04; 1.83]	14.6%
24	31696	5044540	26915	3157102	0.74	[0.73; 0.75]	0.0%
25	128	25085	105	25085	1.22	[0.94; 1.58]	15.5%
27	2	22571	1	22571	2.00	[0.18; 22.05]	0.5%
28	196	19911	146	19911	1.34	[1.08; 1.66]	17.4%
42	407	203568	171	101784	1.19	[1.00; 1.42]	18.9%
44	13	8500	19	8500	0.68	[0.34; 1.38]	4.8%
48	137	169680	77	84840	0.89	[0.67; 1.18]	14.7%
49	138	297600	57	148800	1.21	[0.89; 1.65]	13.5%
Overall effect		**5864369**		**3641507**	**1.17**	**[0.99; 1.38]**	**100.0%**

Heterogeneity: $I^2 = 23\%$, $\tau^2 = 0.0333$, $p = 0.25$

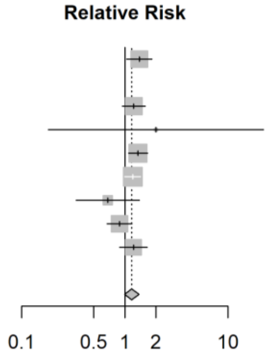


Figure IV.17. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of yellowfin tuna with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiments 24 was excluded (this is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

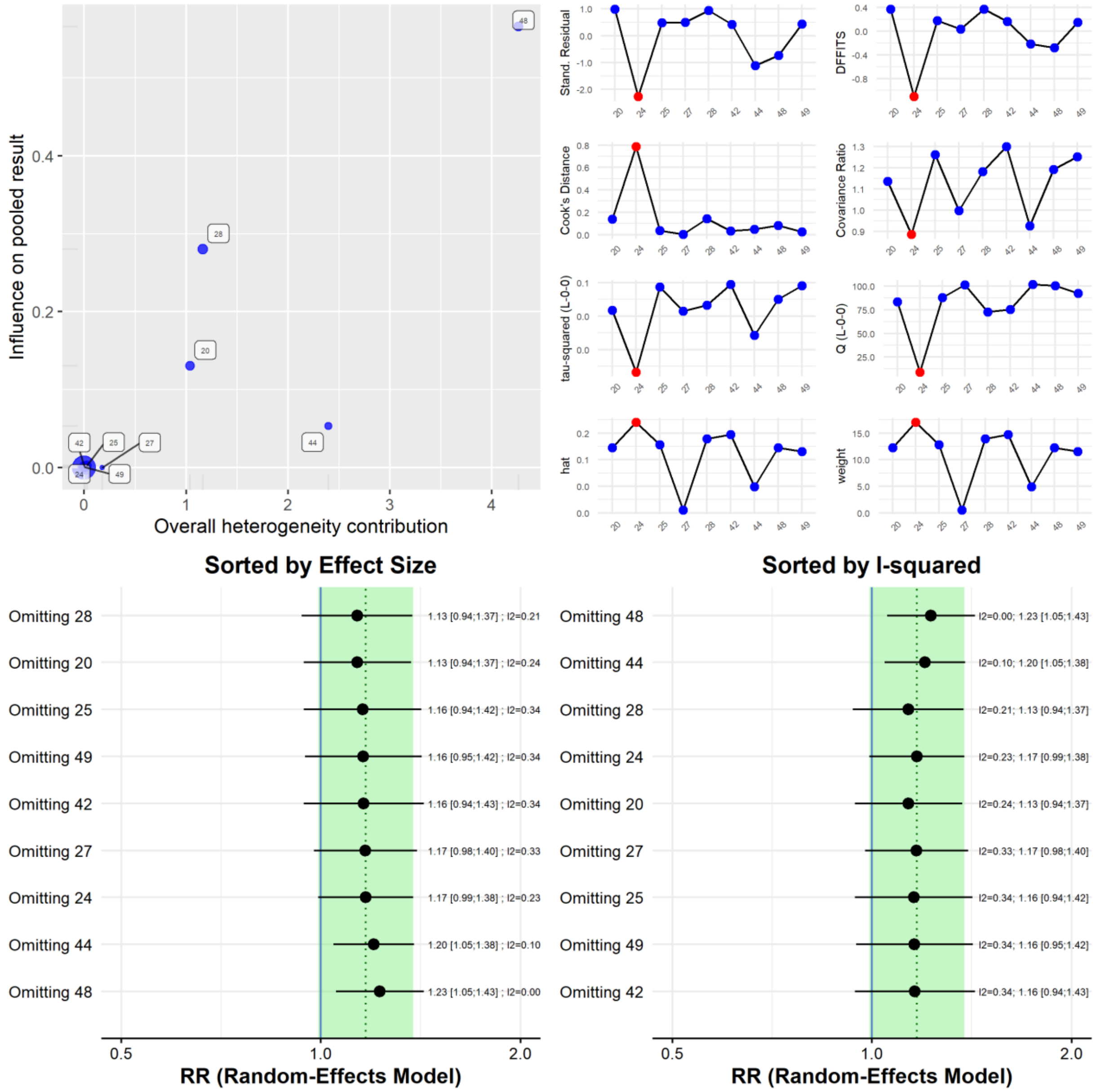


Figure IV.18. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rate of yellowfin tuna with circle vs. J hooks. Experiment 24 was excluded (this is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At haulback-mortality

Figure IV.19 shows the random effects model when all compiled experiments that reported on yellowfin tuna at-haulback mortality are used. When all experiments are used, the RR is calculated at 0.78 (95% CIs: 0.68; 0.89), showing a significant decrease in at-haulback mortality of yellowfin tuna, with this value decreasing by 22%, with the 95% CIs showing reductions between 11% and 32%. 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 are represented in Figure IV.20. Some experiments are identified in several of the diagnostics (Figure IV.20 – top right panel), as for example experiments 24 and 42, but their influence was not identified at a sufficient level to exclude them. This is confirmed by the leave-one-out-analysis (Figure IV.20 – bottom panel), that shows that the overall heterogeneity and estimation would not change that much if those experiments were excluded.

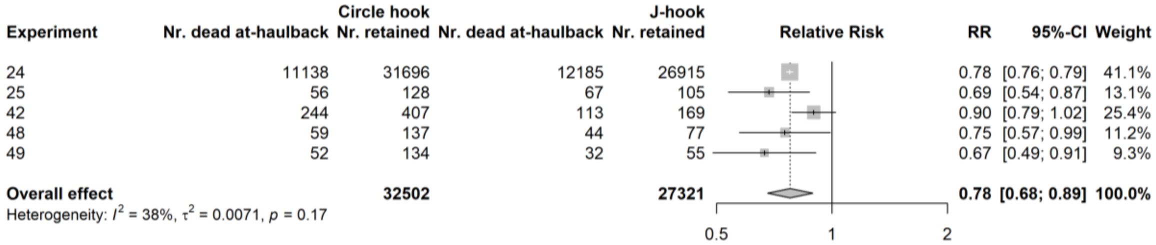


Figure IV.19. Forest plot of the random effects meta-analysis performed for the at-haulback mortality for yellowfin tuna with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

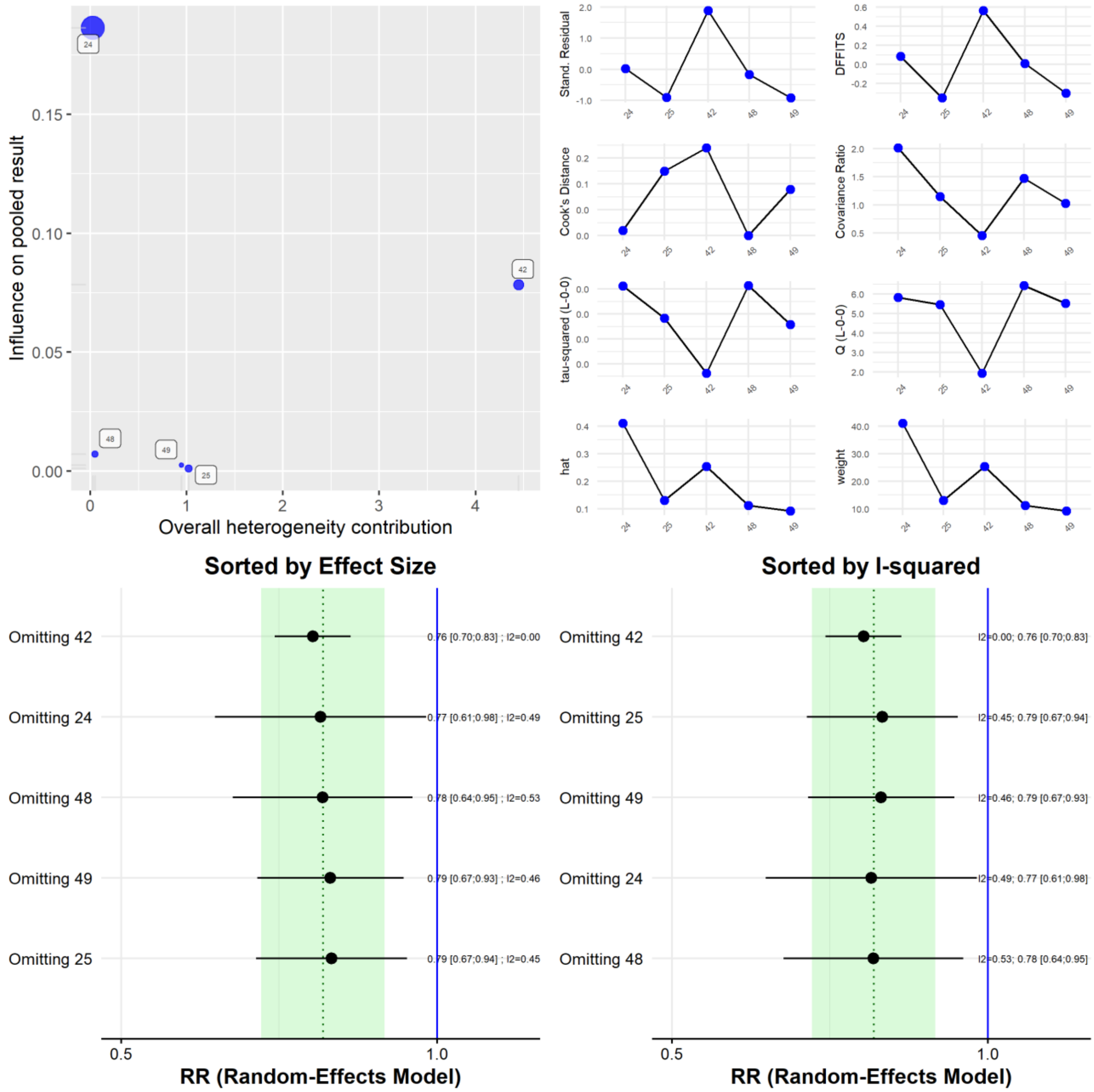


Figure IV.20. Influence analysis for validating the meta-analysis performed for the at-haulback mortality of yellowfin tuna with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table IV.4 provides a summary of the currently available studies specific for yellow fin tuna.

Table IV.4. Summary of post-release mortality studies for yellowfin tuna with indication of gear and region, and whether factors such as hook, bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
YFT – yellowfin tuna	14	14%*	Longline	SW Pacific	NA	NA	NA	Evans et al. (2008)
	10	0%**	Longline	Atlantic, Gulf of Mexico	Circle	Fish or squid	NA	Weng et al. (2009)
	9	0%	Longline	SW Indian Ocean	Circle	Mostly squid	NA	Sabarros et al. (2017)
	6	33%***	Handline	NW Pacific Ocean	NA	NA	NA	Weng et al. (2017)

*: From the tags that transmitted, 4 reached the maximum depth but did not seem to have died; 2 released because the tag pin broke and 2 were confirmed dead. Only those 2 last ones were assumed to have died (confirmed) for the calculation of percentage mortality.

**: Fish were at liberty for at least 15 days without indication of post-release mortality.

***: Fish were at liberty for at least 21 days without indication of post-release mortality or predation.

Albacore tuna (ALB)

Retention rates

Figure IV.21 shows the random effects model when all compiled experiments that reported on albacore retention are used. When all experiments are used, the RR is 1.43 (95% CIs: 0.96; 2.12), which means that the point estimate of retention of albacore points to an increase of 43% when circle hooks are used, but this is not significant as it ranges between an increase of 112% and a decrease of 4%. The overall heterogeneity (I^2) is very high, failing the statistical assumption of homogeneity (p-value<0.05).

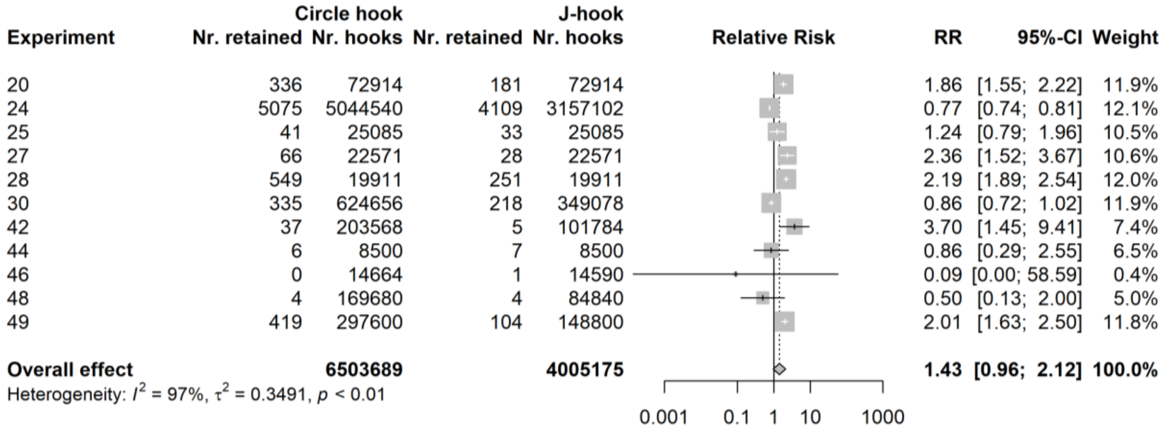


Figure IV.21. Forest plot of the random effects meta-analysis performed for the retention rates of albacore with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

The results of the validation with search for possible outliers and influence analysis are represented in Figure IV.22. Some experiments are identified in several of the diagnostics (Figure IV.22 – top right panel), as for example experiments 24, 28 and 46, but their influence was not identified at a sufficient level to exclude them. Specifically, in this case excluding any particular study would not change the overall heterogeneity or the pooled result by much (Figure IV.22 – bottom panel), so all studies were kept.

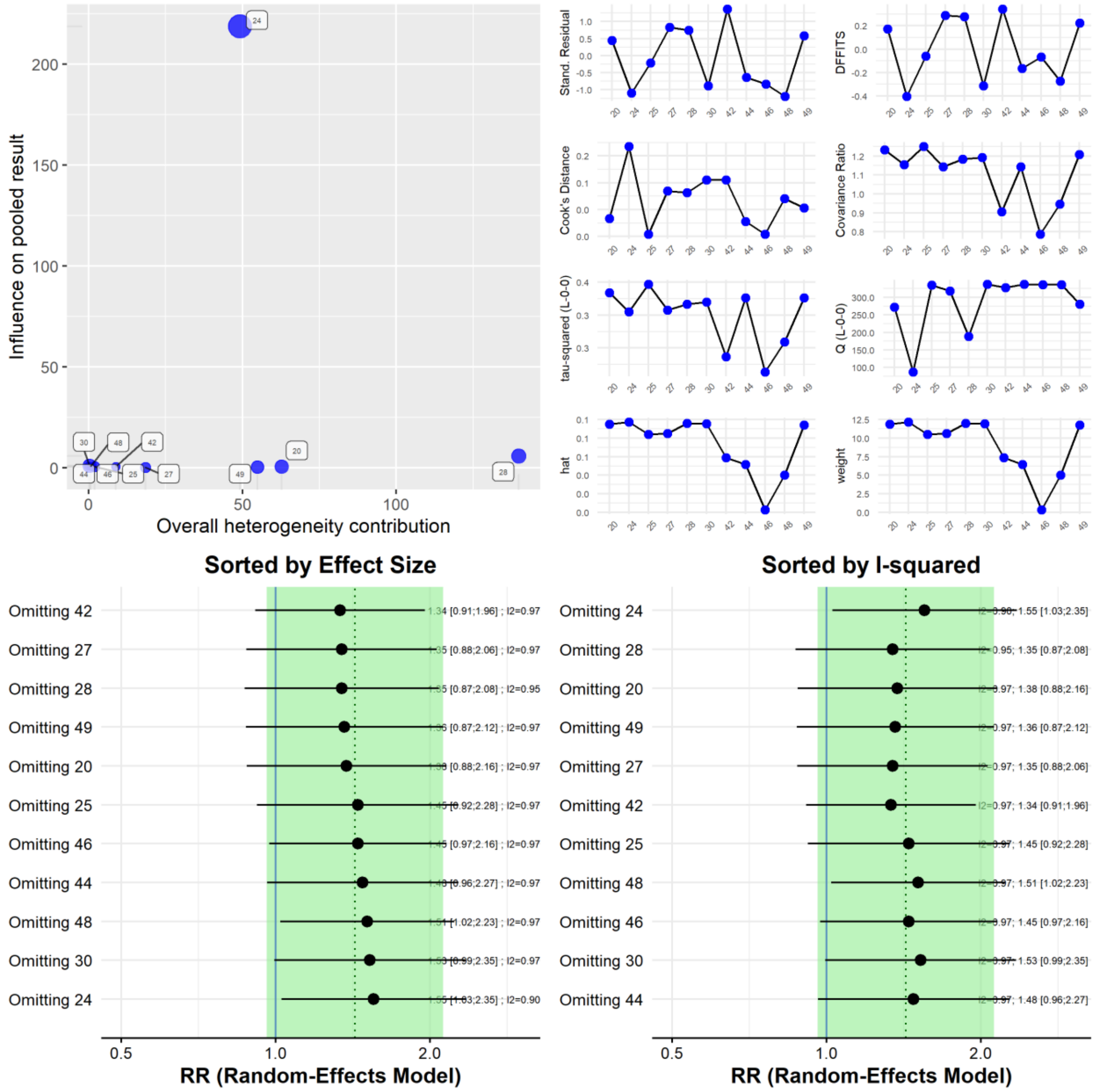


Figure X.22. Influence analysis for validating the meta-analysis performed for the retention rates of albacore with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At haulback-mortality

With regard to at-haulback mortality, the random effects model considering all experiments is shown in Figure IV.23. The influence analysis that followed (Figure IV.24) identified experiments 24 and 49 as outliers with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was re-run excluding those 2 experiments, with the results of the new pooled analysis indicated in Figure IV.25 and validation indicated in Figure IV.26.

With the exclusion of those 2 outliers, the heterogeneity was largely reduced, specifically from 73% when including all experiments to 0% with those 2 exclusions. On the other hand, the pooled analysis results did not change between the two analyses, in both cases with the results pointing to an RR of 0.98 (95% CIs: 0.90-1.06).

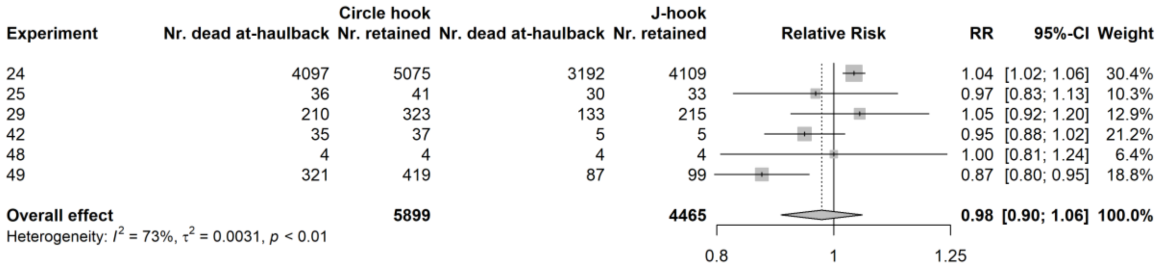


Figure IV.23. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of albacore with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

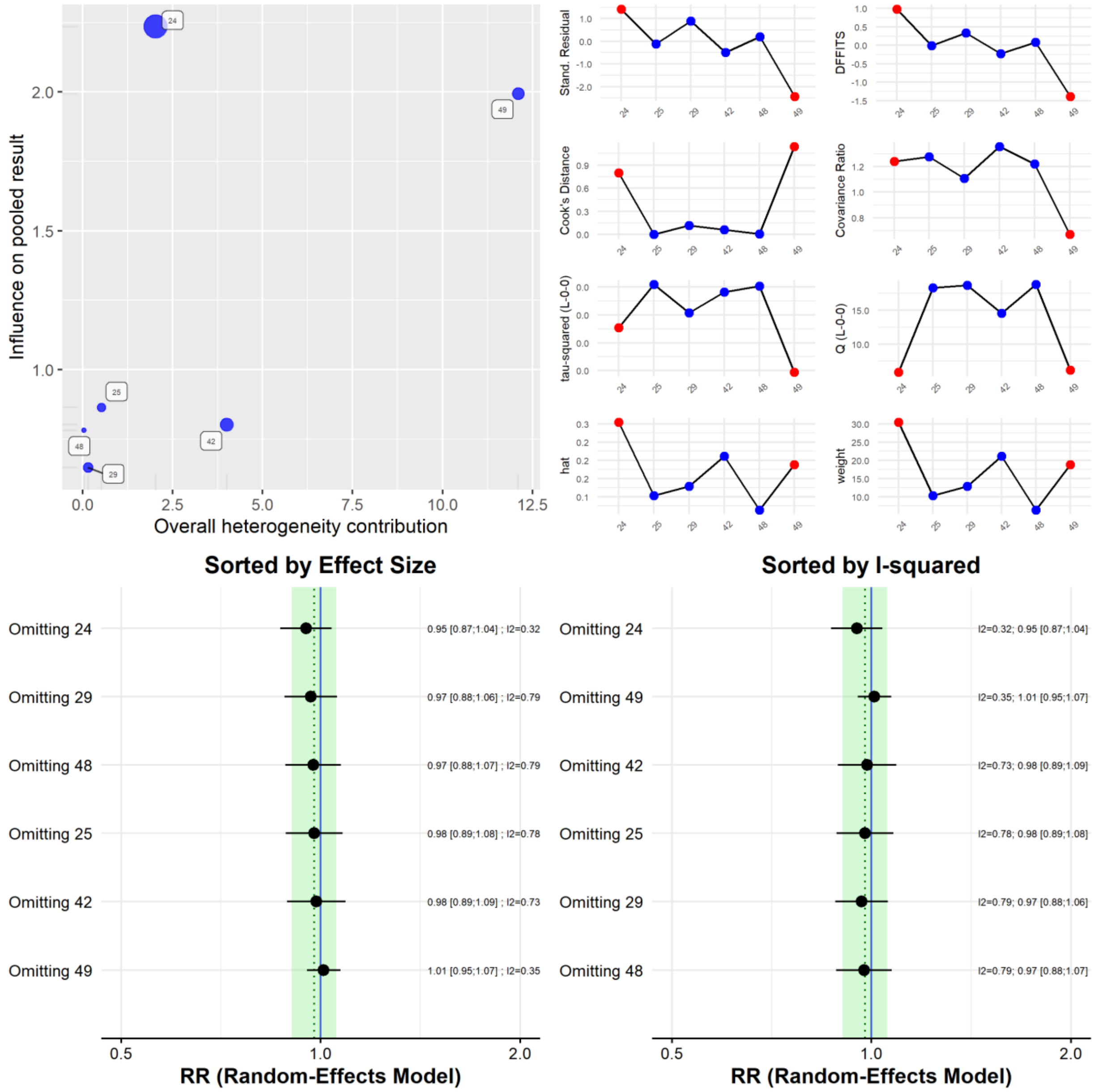


Figure IV.24. Influence analysis for the meta-analysis performed for the at-haulback mortality of albacore with circle vs. J- hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

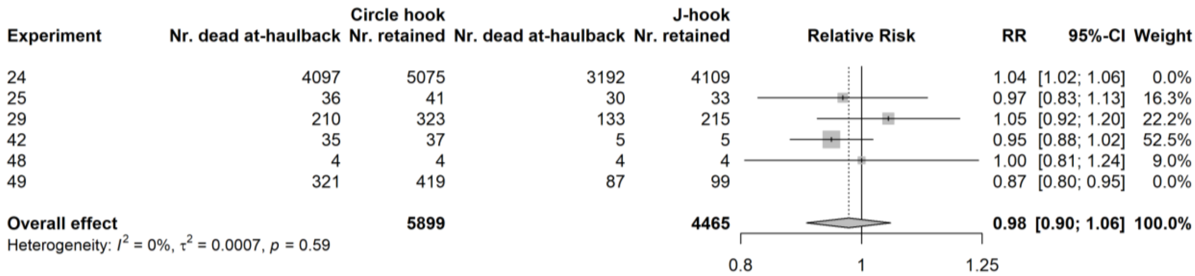


Figure IV.25. Forest plot of the random effects meta-analysis excluding 2 outliers in the at-haulback mortality of albacore with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiments 24 and 42 were excluded (these are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

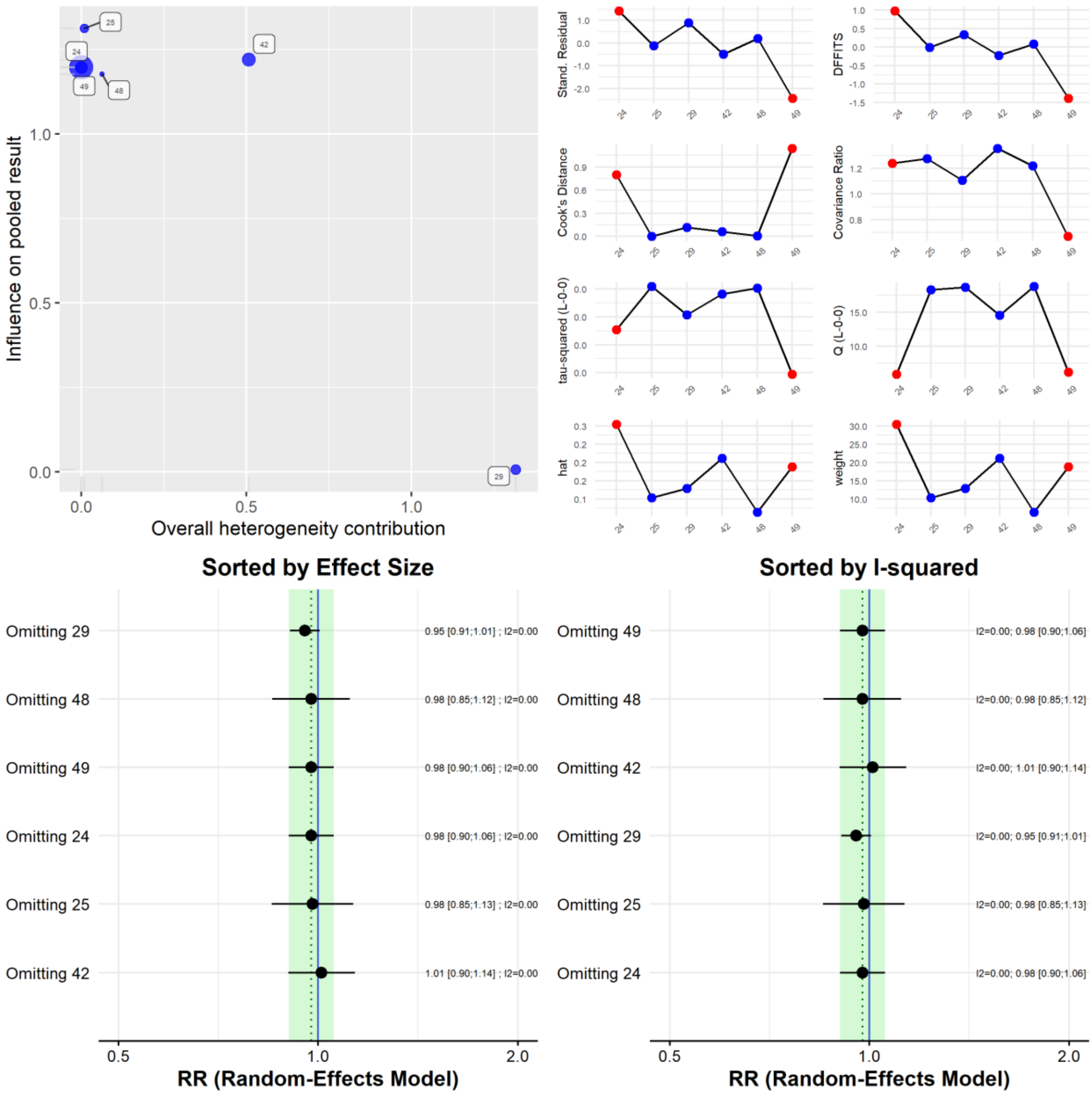


Figure IV.26. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the at-haulback mortality of albacore with circle vs. J hooks. Experiments 24 and 42 were excluded (these are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table IV.5 provides a summary of the currently available studies specific for albacore tuna.

Table IV.5. Summary of post-release mortality studies for albacore tuna with indication of gear and region, and whether factors such as hook, bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
ALB – albacore	6	67%*	Longline	South Pacific, American Samoa	NA	NA	NA	Domokos et al. (2007)
	17	35%*	Longline	SW Pacific	NA	NA	NA	Williams et al. (2015)
	7	29%	Troll and bait	North Atlantic, NW and South Biscay	NA	NA	NA	Cosgrove et al. (2014)

*: Fish that were at liberty for less than 5 days were considered to have suffered from post-release mortality.

APPENDIX V: SPECIES-SPECIFIC ANALYSIS FOR SUB-TASK 1.2 – DESIRABLE BYCATCH

In this Appendix we provide detailed species-specific results for Task 1, namely sub-task 1.2, referring to the meta-analysis for retention rates and at-haulback mortality for the main desirable bycatch species considered in the study: BSH, SMA, BUM, WHM and SAI. We also provide detailed tables with the post-release mortality information available for those species.

Blue shark (BSH)

Retention rates

Figure V.1 shows the random effects model when all data compiled are used for blue shark. When all data are used, we calculate the RR as 1.08 (95% CIs: 0.89; 1.33). This means that on average we expect that the retention 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 analysis we also see that the overall heterogeneity (I^2) is very high and fails the statistical assumption of homogeneity (p-value<0.05).

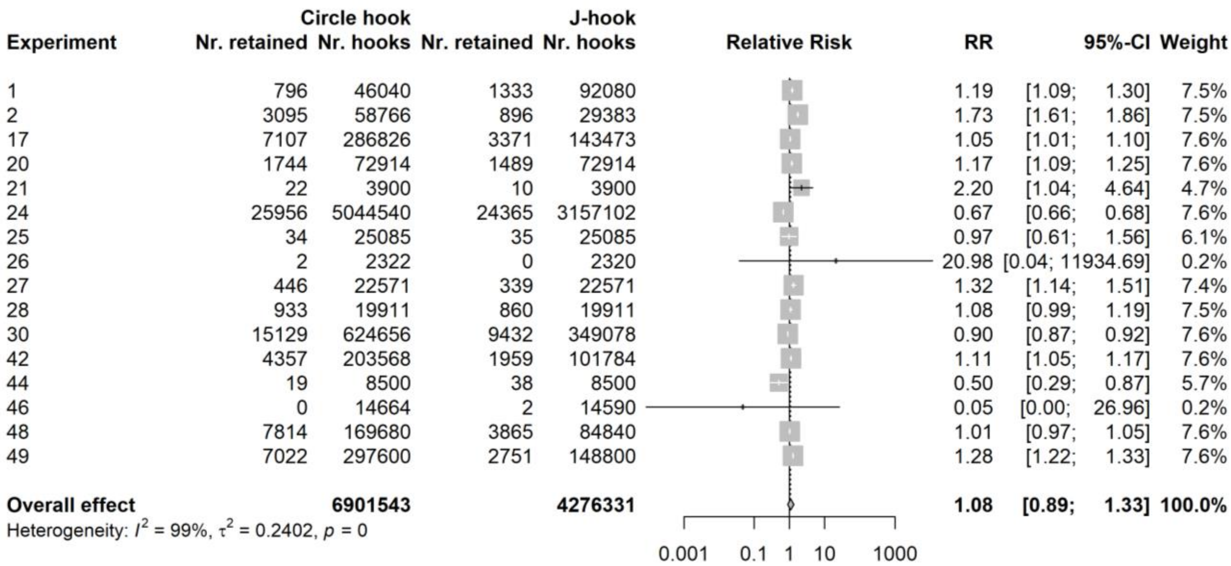


Figure V.1. Forest plot of the random effects meta-analysis in the retention rates of blue shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

We then looked for possible outliers and carried out an influence analysis, which is shown in Figure V.2. As an example of such analysis, we see that some experiments are consistently identified in several of the diagnostics, for example experiments 24, 26 and 46. Within those, experiments 26 and 46 specifically have much lower 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 regard to experiment 24, it is a large contributor to the overall heterogeneity but also a study 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, which shows that the overall heterogeneity and estimation would not change that much if those experiments were to be excluded.

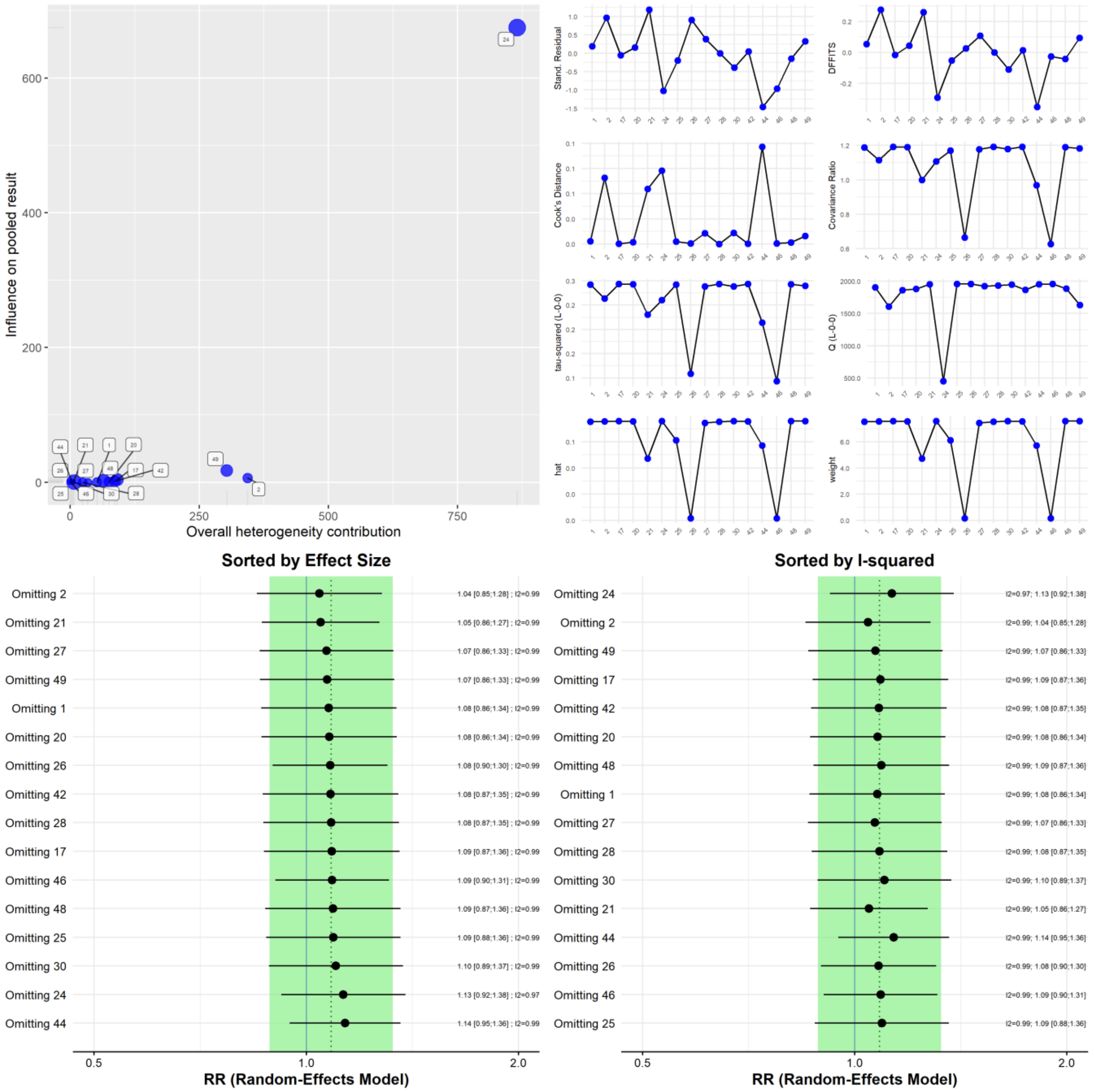


Figure V.2. Influence analysis for the meta-analysis performed for the retention rates of blue shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

With regard to at-haulback hooking mortality, Figure V.3 also provides the random effects model for blue shark. In this case the RR is calculated at 0.80 (95% CIs: 0.63; 1.01). This means that on average we expect that the 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%. Again, and as in the retention rates example provided above, the heterogeneity between studies is also high (94%) with p-value<0.05.

In terms of the influential analysis, in this case the 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 (Figure V.4). In this specific case, if experiment 24 were to be 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). The results of the new pooled analysis are shown in Figure V.5 and results of the validation are shown in Figure V.6.

Experiment	Circle hook Nr. dead at haulback	Circle hook Nr. retained	J-hook Nr. dead at haulback	J-hook Nr. retained	RR	95%-CI	Weight
21	6.000	22.000	7.000	10.000	0.39	[0.18; 0.86]	6.2%
24	4507.000	25956.000	3838.000	24365.000	1.10	[1.06; 1.15]	17.5%
25	1.000	34.000	4.000	35.000	0.26	[0.03; 2.19]	1.2%
29	2490.000	12923.000	1984.000	8761.000	0.85	[0.81; 0.90]	17.4%
42	360.000	4351.000	211.000	1952.000	0.77	[0.65; 0.90]	16.3%
45	11.985	38.973	11.985	37.995	0.97	[0.50; 1.89]	7.7%
48	584.000	7728.000	361.000	3777.000	0.79	[0.70; 0.90]	16.8%
49	931.000	6916.000	502.000	2710.000	0.73	[0.66; 0.80]	17.0%
Overall effect		**57968.973**		**41647.995**	**0.80**	**[0.63; 1.01]**	**100.0%**

Heterogeneity: $I^2 = 94\%$, $\tau^2 = 0.0890$, $p < 0.01$

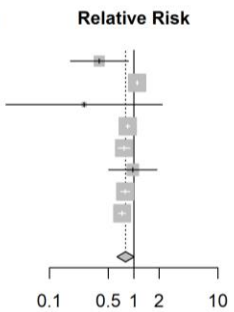


Figure V.3. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of blue shark with circle vs. J hooks (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

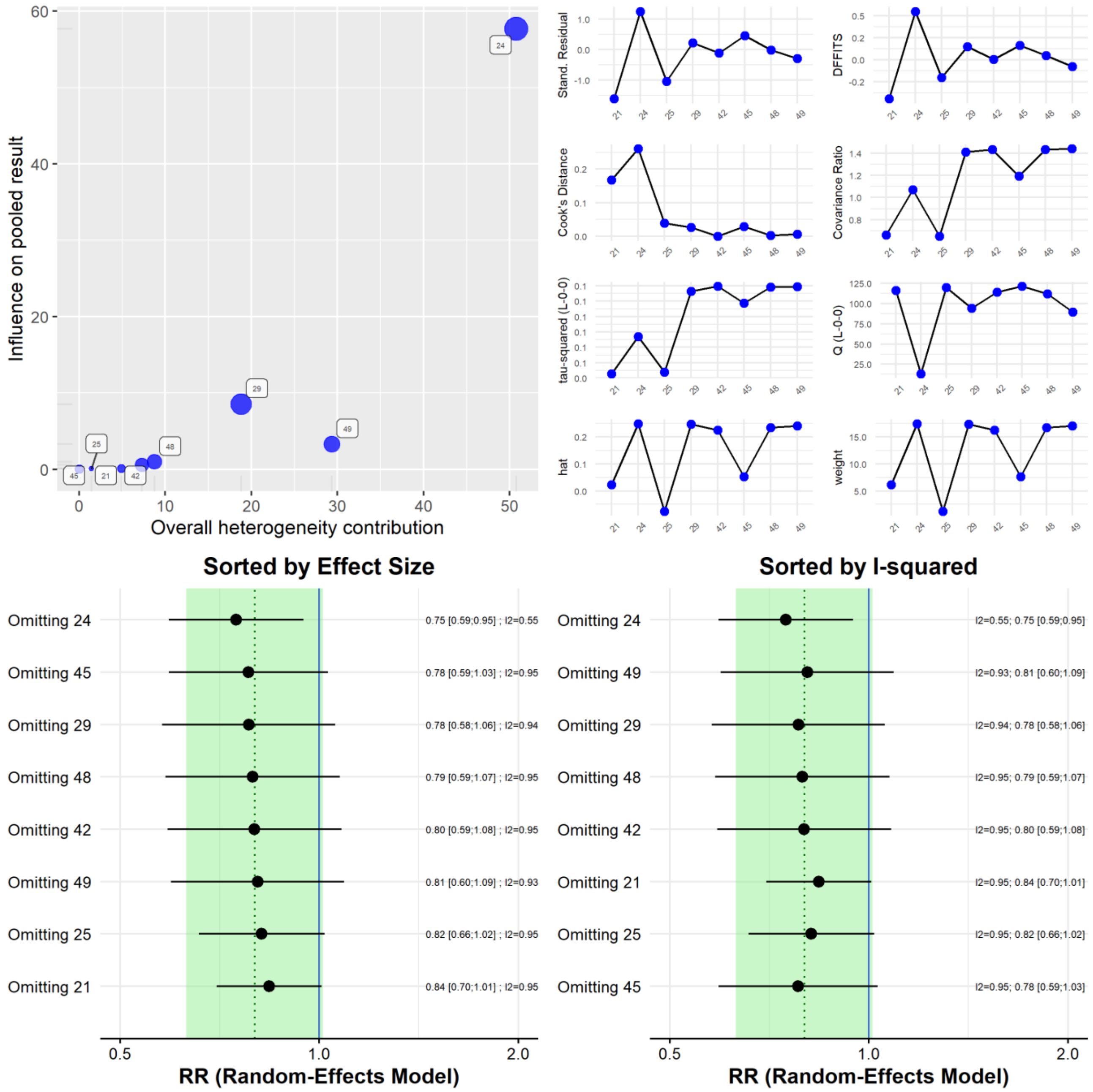


Figure V.4. Influence analysis for the meta-analysis performed for the at-haulback mortality of blue shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. dead at haulback	Circle hook Nr. retained	J-hook Nr. dead at haulback	J-hook Nr. retained	RR	95%-CI	Weight
21	6.000	22.000	7.000	10.000	0.39	[0.18; 0.86]	6.9%
24	4507.000	25956.000	3838.000	24365.000	1.10	[1.06; 1.15]	0.0%
25	1.000	34.000	4.000	35.000	0.26	[0.03; 2.19]	1.3%
29	2490.000	12923.000	1984.000	8761.000	0.85	[0.81; 0.90]	21.5%
42	360.000	4351.000	211.000	1952.000	0.77	[0.65; 0.90]	19.9%
45	11.985	38.973	11.985	37.995	0.97	[0.50; 1.89]	8.7%
48	584.000	7728.000	361.000	3777.000	0.79	[0.70; 0.90]	20.6%
49	931.000	6916.000	502.000	2710.000	0.73	[0.66; 0.80]	21.0%
Overall effect		**57968.973**		**41647.995**	**0.75**	**[0.59; 0.95]**	**100.0%**

Heterogeneity: $I^2 = 55\%$, $\tau^2 = 0.0769$, $p = 0.04$

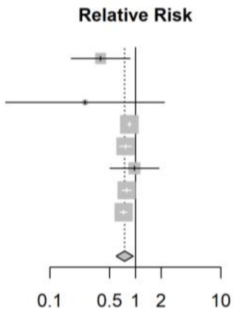


Figure V.5. Forest plot of the random effects meta-analysis excluding 1 outliers in the at-haulback mortality of blue shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiment 24 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

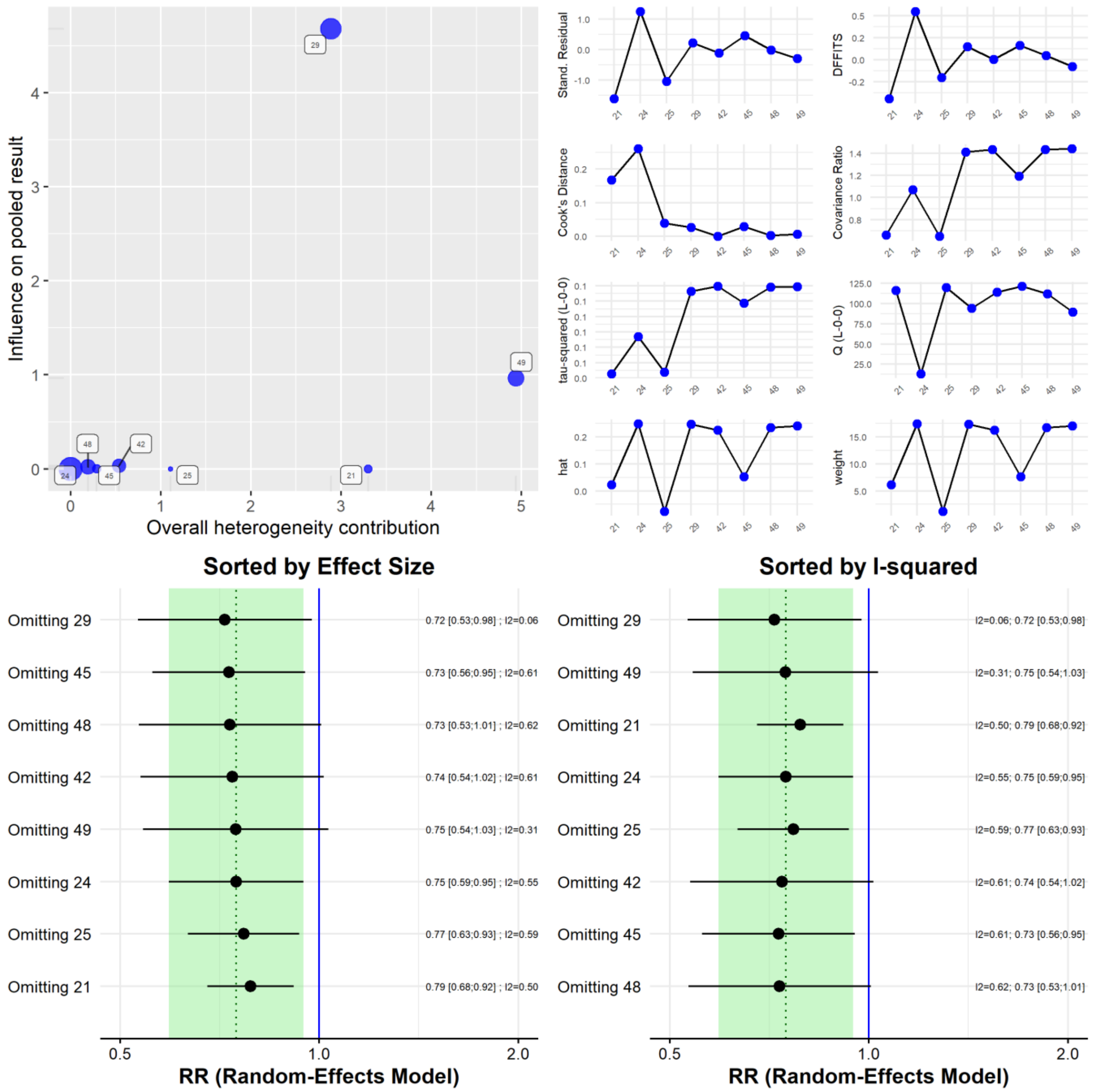


Figure V.6. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of blue shark with circle vs. J hooks. Experiment 24 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table V.1 provides a summary of the currently available studies specific for blue shark.

Table V.1. Summary of post-release mortality studies for blue shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
BSH – Blue shark	19	36.8	Longline	Tropical NE Atlantic (Cabo Verde)	J	NA	NA	Coelho et al. (2020)
	9	0.0	Rod and reel or longline	North Atlantic	J	NA	NA	Queiroz et al. (2010)
	37	24.3	Longline	NE Atlantic	C or J	NA	NA	Campana et al. (2016)
	48	16.7	Longline	Western tropical Pacific	C	Fish	NA	Musyl & Gilman (2018)
	9	11.1	Longline	SW Pacific	NA	NA	NA	Stevens et al. (2010)
	11	0.0	Longline	North Pacific (Hawaii)	C	Squid	NA	Moyes et al. (2006)

Shortfin mako (SMA)

Retention rates

Figure V.7 shows the random effects model when all data compiled are used for shortfin mako. When all data are used, the RR is 1.23 (95% CIs: 1.02; 1.50). This means that on average we expect that the retention of shortfin mako when using circle hooks is 23% higher than when using J hooks, with 95% confidence intervals varying between increases of 2% and 50%. The overall heterogeneity (I^2) is high and fails the statistical assumption of homogeneity (p-value<0.05). However, the influential analysis did not identify outliers with major influence in the results, and for that reason all experiments were kept (Figure V.8).

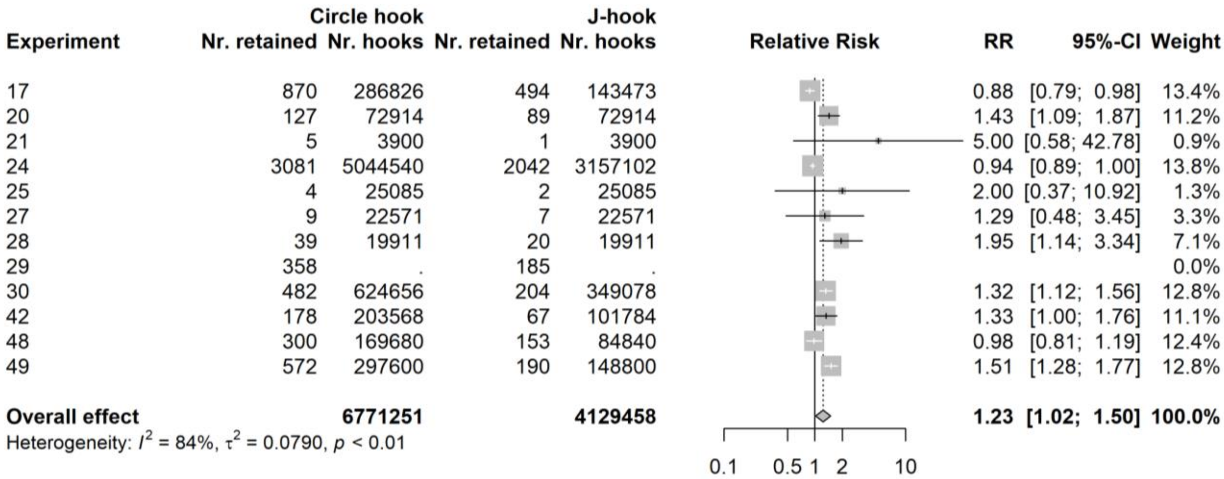


Figure V.7. Forest plot of the random effects meta-analysis in the retention rates of shortfin mako with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

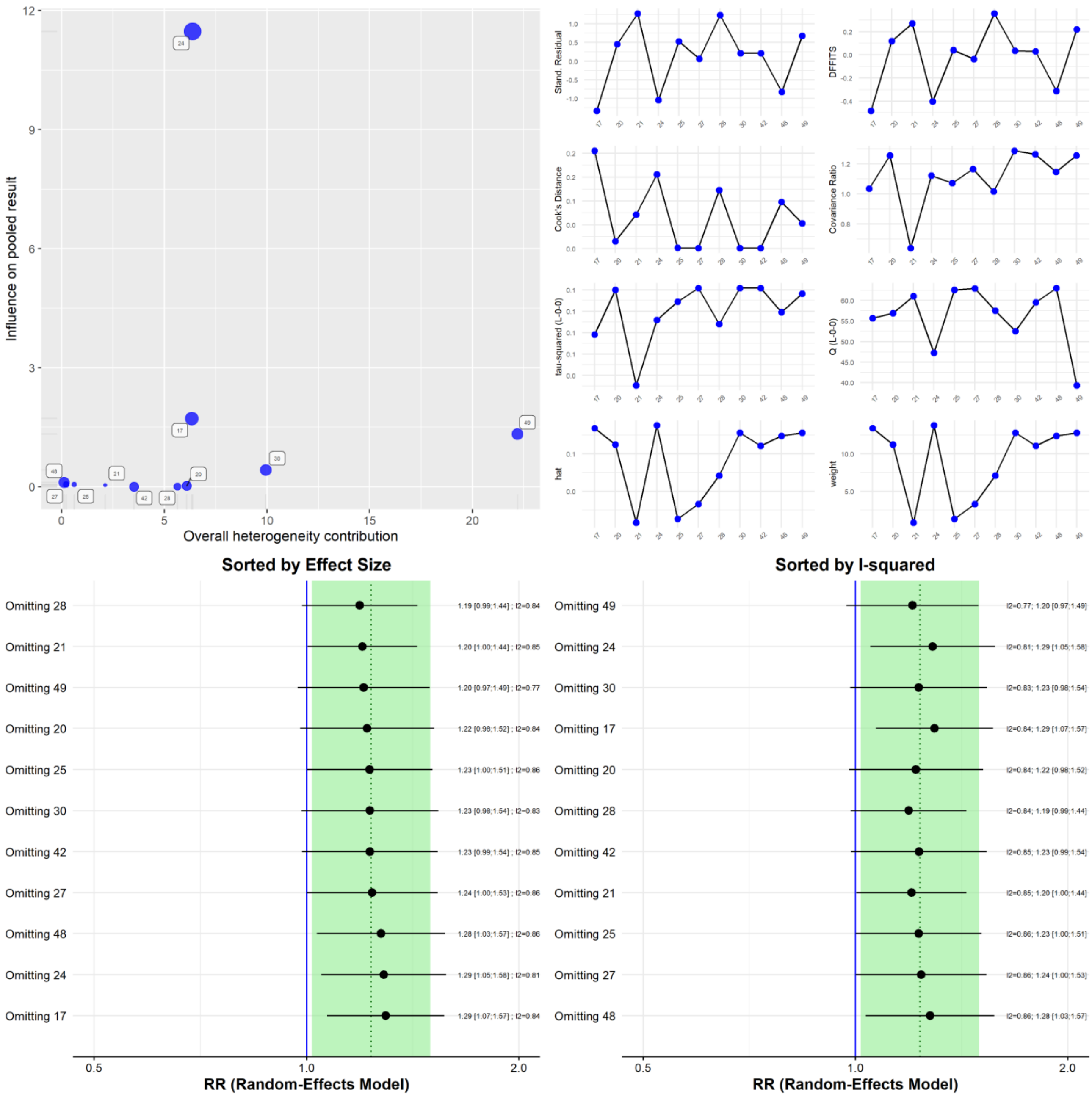


Figure V.8. Influence analysis for the meta-analysis performed for the retention rates of shortfin mako with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure V.9 provides the random effects model for shortfin mako, with regard to at-haulback hooking mortality. In this case the RR is calculated at 0.82 (95% CIs: 0.56; 1.20). This means that on average we expect that the mortality of shortfin mako when using circle hooks is 18% lower than when using J hooks. The 95% confidence intervals varied between a reduction of 44% and an increase of 20%, meaning the reduction in at-haulback mortality is not significant.

In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure V.10. In this case no, major outliers were identified and therefore all experiments were kept.

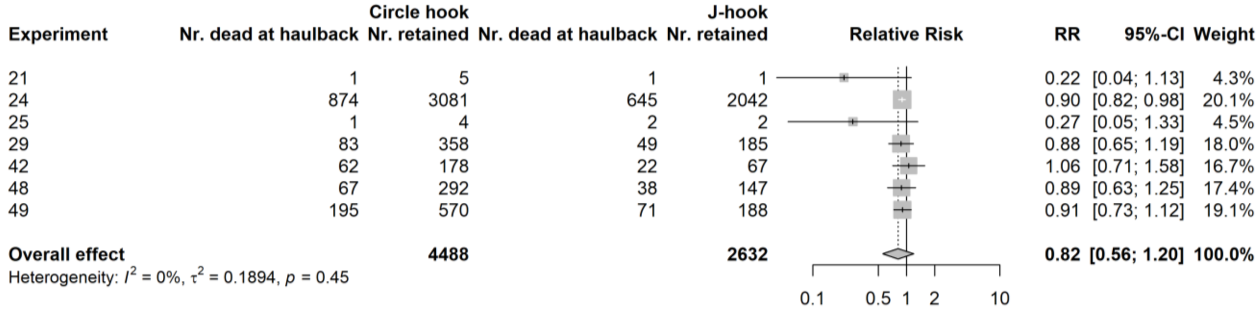


Figure V.9. Forest plot of the random effects meta-analysis in the at-haulback mortality of shortfin mako with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

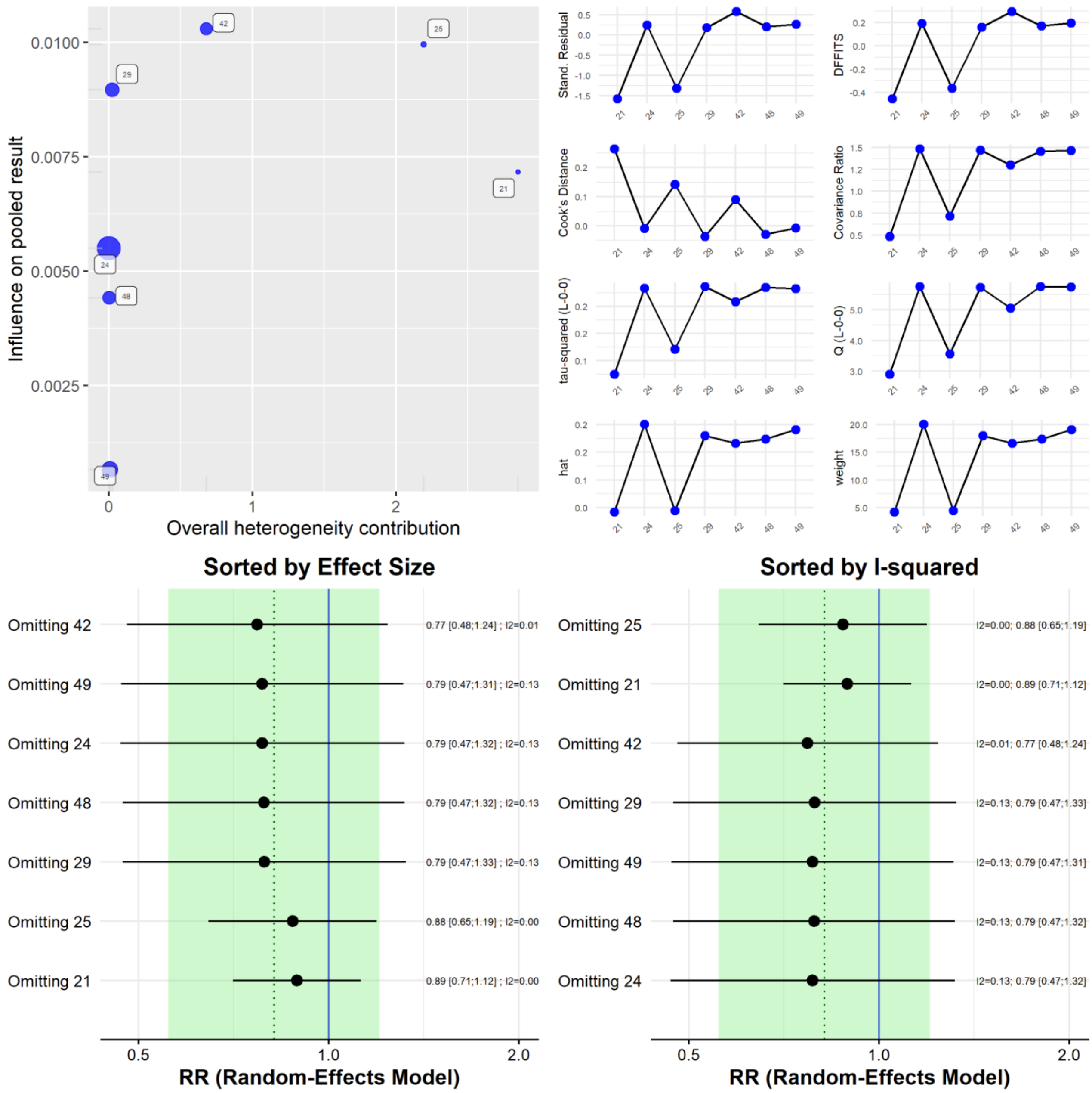


Figure V.10. Influence analysis for the meta-analysis performed for the at-haulback mortality of shortfin mako with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table V.2 provides a summary of the currently available studies specific for shortfin mako shark.

Table V.2. Summary of post-release mortality studies for shortfin mako shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
SMA – Shortfin mako	26	30.8	Longline	NW Atlantic	C or J	NA	NA	Campana et al. (2016)
	35	22.8	Longline	NE, NW, Equatorial, SW Atlantic	C or J	Fish or Squid	Nylon or Wire	Miller et al. (2019)
	9	44.4	Longline	SE Pacific	NA	NA	NA	Abascal et al. (2011)
	30	10.0	Rod and reel	SW Pacific (Tasmania)	C or J	NA	Wire	French et al. (2015)
	2	0.0	Longline	North Pacific (Hawaii)	C	Squid	Nylon	Musyl et al. (2011)

Blue marlin (BUM)

Retention rates

Figure V.11 shows the random effects model when all data compiled are used for blue marlin. When all data are used, the RR is 0.76 (95% CIs: 0.55; 1.05). This means that on average we expect that the retention of blue marlin when using circle hooks is 24% lower than when using J hooks, but with 95% confidence intervals varying between a reduction of 45% and an increase of 5%. In this analysis we see that the overall heterogeneity (I^2) is not very high (44%) and meets the statistical assumption of homogeneity (p-value>0.05).

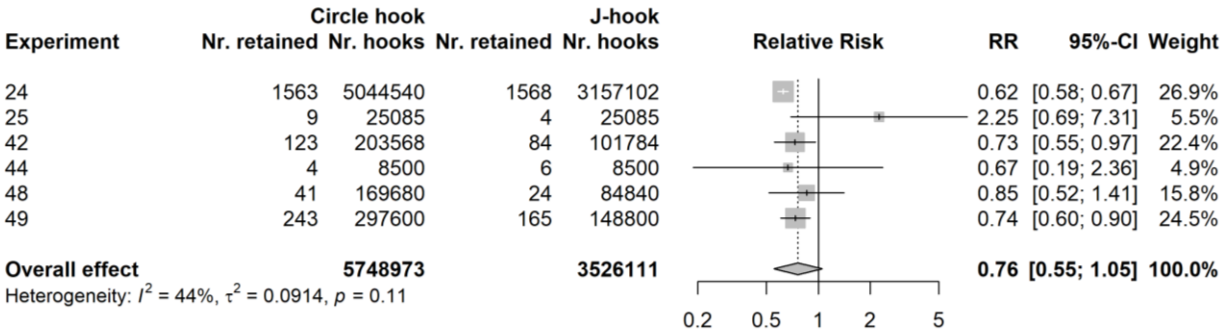


Figure V.11: Forest plot of the random effects meta-analysis, considering all studies, in the retention rates of blue marlin with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

The influence analysis is represented in Figure V.12. Experiment 25 was identified as an outlier with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure V.13 and validation indicated in Figure V.14. When experiment 25 is excluded, the RR is 0.67 (95% CIs: 0.59; 0.77), meaning that the retention of blue marlin when using circle hooks is 33% lower than when using J hooks, with 95% confidence intervals varying between reductions of 23% and 41%. We also see that the overall heterogeneity (I^2) is reduced from 44% to 13%.

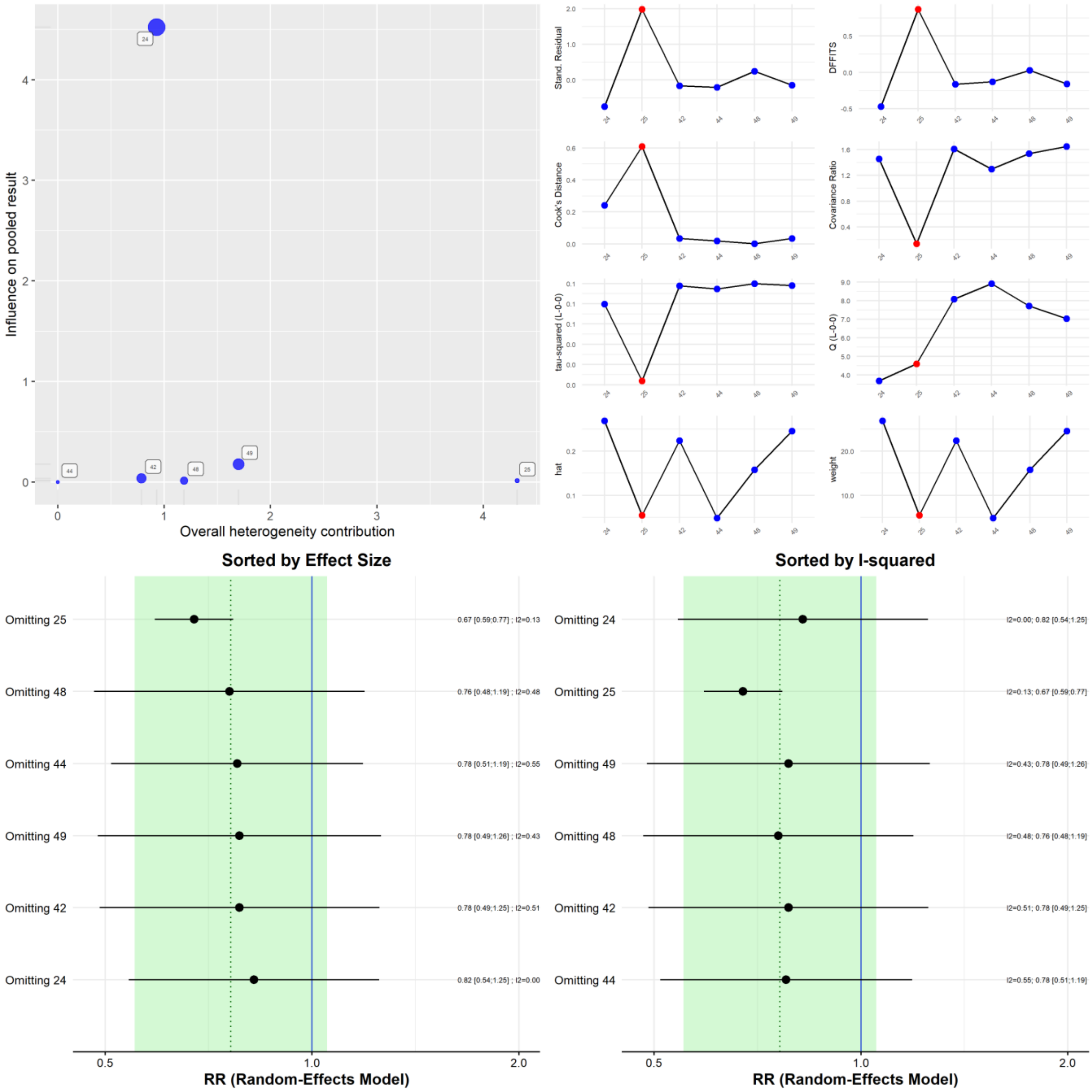


Figure V.12. Influence analysis for the meta-analysis using all data performed for the retention rates of blue marlin with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
24	1563	5044540	1568	3157102	0.62	[0.58; 0.67]	57.0%
25	9	25085	4	25085	2.25	[0.69; 7.31]	0.0%
42	123	203568	84	101784	0.73	[0.55; 0.97]	14.0%
44	4	8500	6	8500	0.67	[0.19; 2.36]	0.8%
48	41	169680	24	84840	0.85	[0.52; 1.41]	4.9%
49	243	297600	165	148800	0.74	[0.60; 0.90]	23.2%
Overall effect		**5748973**		**3526111**	**0.67**	**[0.59; 0.77]**	**100.0%**

Heterogeneity: $I^2 = 13\%$, $\tau^2 = 0.0048$, $p = 0.33$

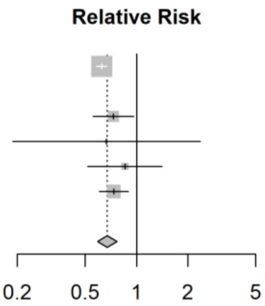


Figure V.13 Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of blue marlin with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiments 25 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

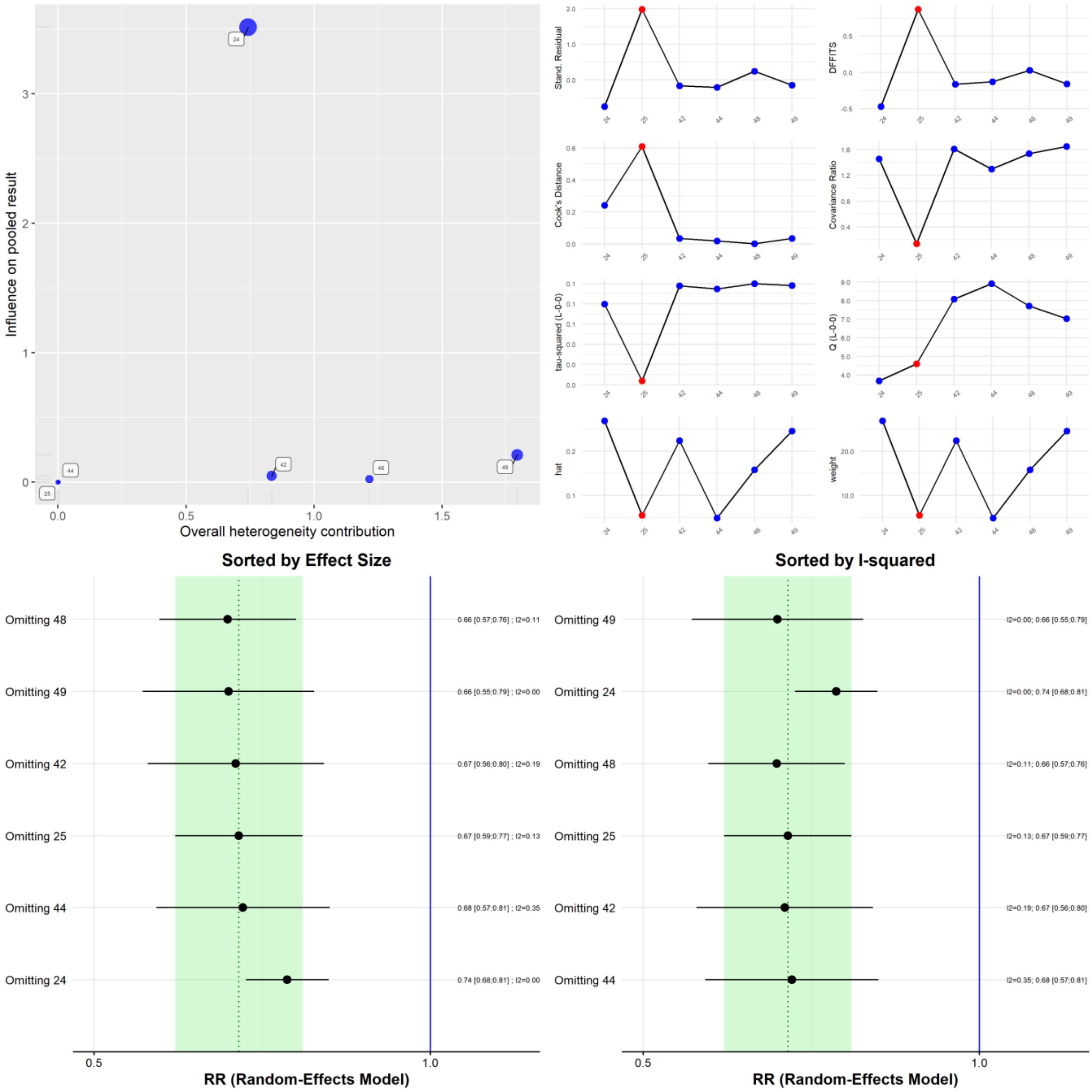


Figure V.14 Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rate of blue marlin with circle vs. J hooks. Experiment 25 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure V.15 provides the random effects model for blue marlin, with regard to at-haulback hooking mortality. In this case the RR is 0.81 (95% CIs: 0.70; 0.94). This means that on average we expect that the mortality of blue marlin when using circle hooks is 19% lower than when using J hooks, with 95% confidence intervals varying between a reduction of 6% and 30%. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure V.16 and in this case no major outliers were identified and therefore all experiments were kept.

	Circle hook		J-hook				
Experiment	**Nr. dead at haulback**	**Nr. retained**	**Nr. dead at haulback**	**Nr. retained**	**RR**	**95%-CI**	**Weight**
24	447	1563	549	1568	0.82	[0.74; 0.91]	36.1%
25	5	9	4	4	0.56	[0.32; 1.00]	5.4%
42	75	123	56	84	0.91	[0.74; 1.12]	23.0%
48	23	41	16	24	0.84	[0.57; 1.24]	10.2%
49	110	239	97	161	0.76	[0.63; 0.92]	25.3%
Overall effect		**1975**		**1841**	**0.81**	**[0.70; 0.94]**	**100.0%**

Heterogeneity: I^2 = 0%, τ^2 = 0.0118, p = 0.51

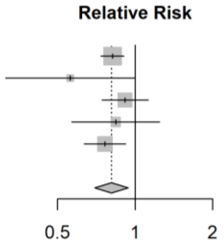


Figure V.15. Forest plot of the random effects meta-analysis, considering all studies, in the at-haulback mortality of blue marlin with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

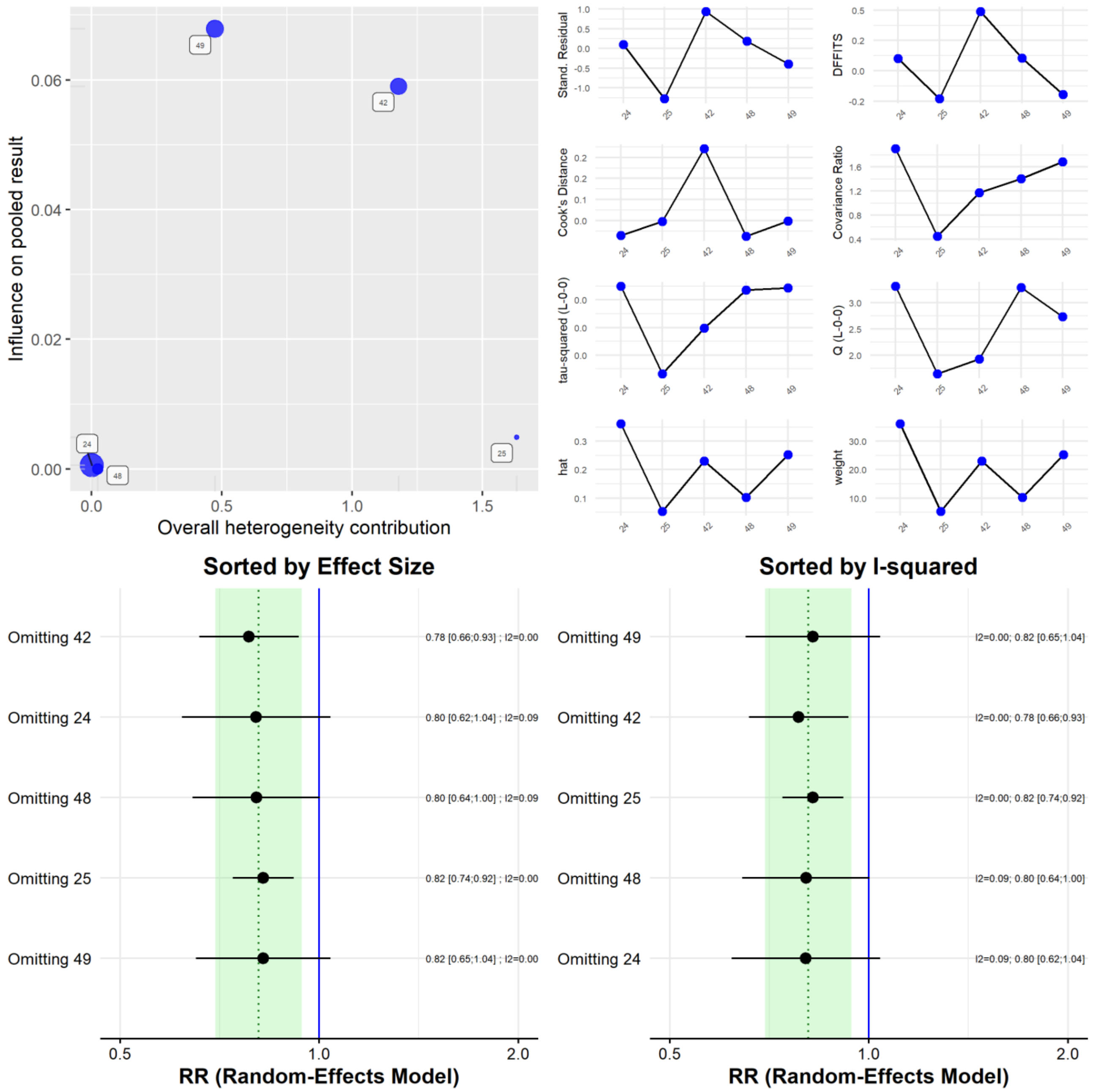


Figure V.16. Influence analysis for the meta-analysis using all data performed for the at-haulback mortality of blue marlin with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table V.3provides a summary of the currently available studies specific for blue marlin.

Table V.3. Summary of post-release mortality studies for blue marlin with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
BUM – Blue marlin	7	0.10	Longline	NW Atlantic, Gulf of Mexico	C or J	Fish or squid	NA	Kerstetter et al. (2003)

White marlin (WHM)

Retention rates

Figure V.17 shows the initial random effects model when all data compiled are used for white marlin. In the case, when all data are used, the RR is 0.73 (95% CIs: 0.35; 1.51). This means that on average we expect that the retention of white marlin when using circle hooks is 27% lower than when using J hooks, with the 95% confidence intervals varying between a reduction of 65% and an increase of 51%. In this analysis we see that the overall heterogeneity (I^2) is very high (96%) and fails the statistical assumption of homogeneity (p-value<0.05).

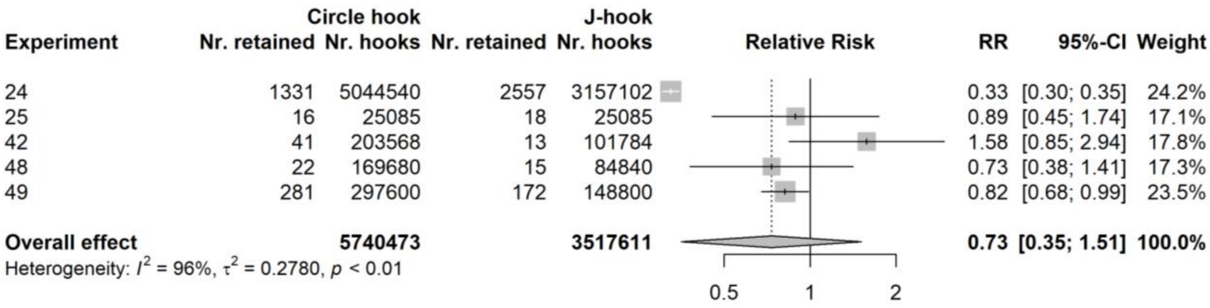


Figure V.17. Forest plot of the random effects meta-analysis, considering all studies, in the retention rates of white marlin with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

The influence analysis of using all data is represented in Figure V.18. Experiments 24 and 42 were identified as outliers with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was therefore re-run excluding those experiments, with the results of the new pooled analysis indicated in Figure V.19 and validation indicated in Figure V.20. When the two experiments are excluded, the RR is 0.82 (95% CIs: 0.73; 0.91), meaning that the retention of white marlin when using circle hooks is 18% lower than when using J hooks, with 95% confidence intervals varying between reductions of 9% and 27%. We also see that there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05).

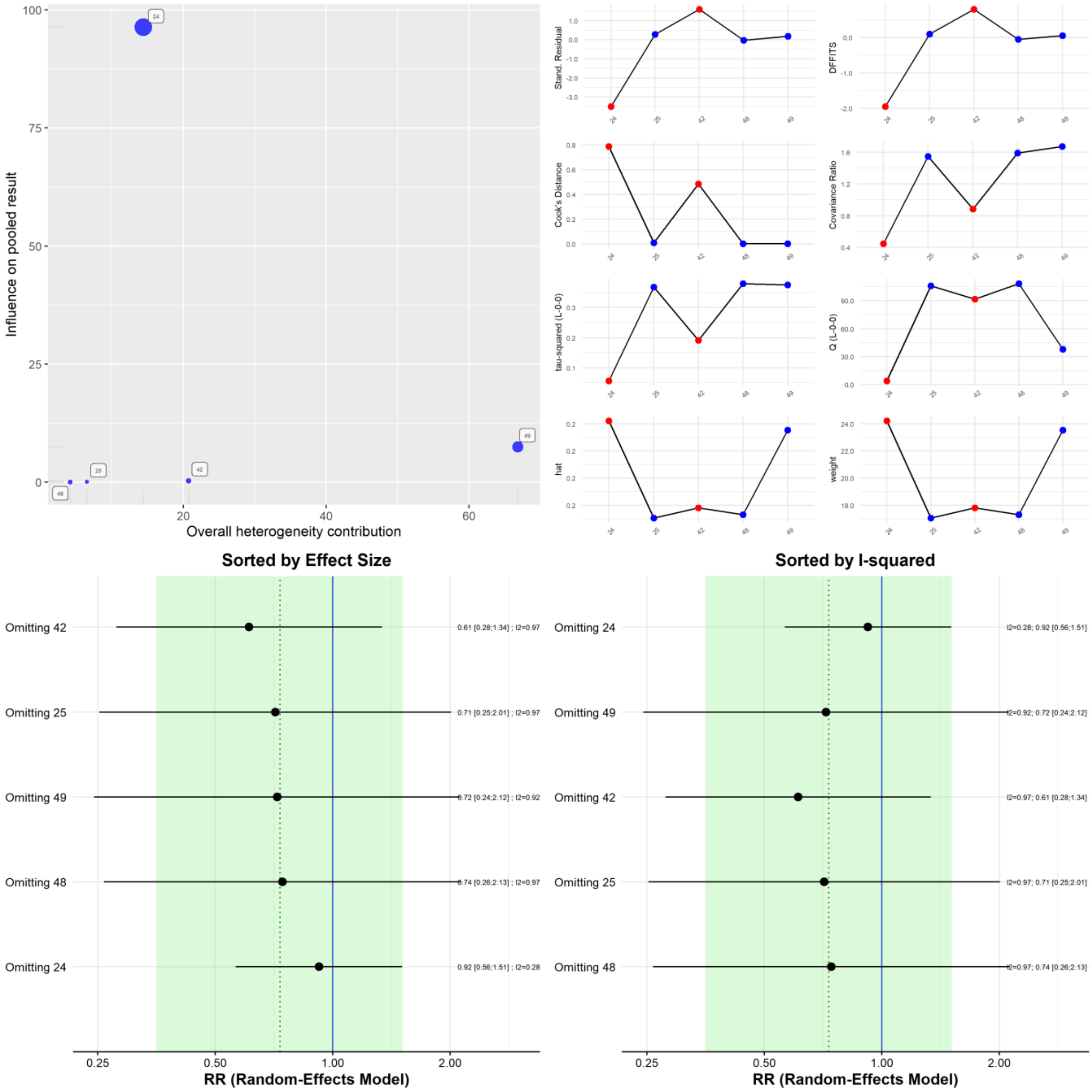


Figure V.18. Influence analysis for the meta-analysis using all data performed for the retention rates of white marlin with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
24	1331	5044540	2557	3157102	0.33	[0.30; 0.35]	0.0%
25	16	25085	18	25085	0.89	[0.45; 1.74]	7.1%
42	41	203568	13	101784	1.58	[0.85; 2.94]	0.0%
48	22	169680	15	84840	0.73	[0.38; 1.41]	7.5%
49	281	297600	172	148800	0.82	[0.68; 0.99]	85.4%
Overall effect		**5740473**		**3517611**	**0.82**	**[0.73; 0.91]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0005$, $p = 0.92$

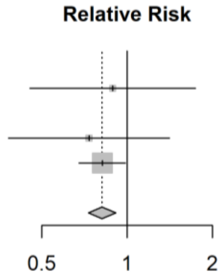


Figure V.19. Forest plot of the random effects meta-analysis excluding 2 outliers in the retention rates of white marlin with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiments 24 and 42 were excluded (they are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

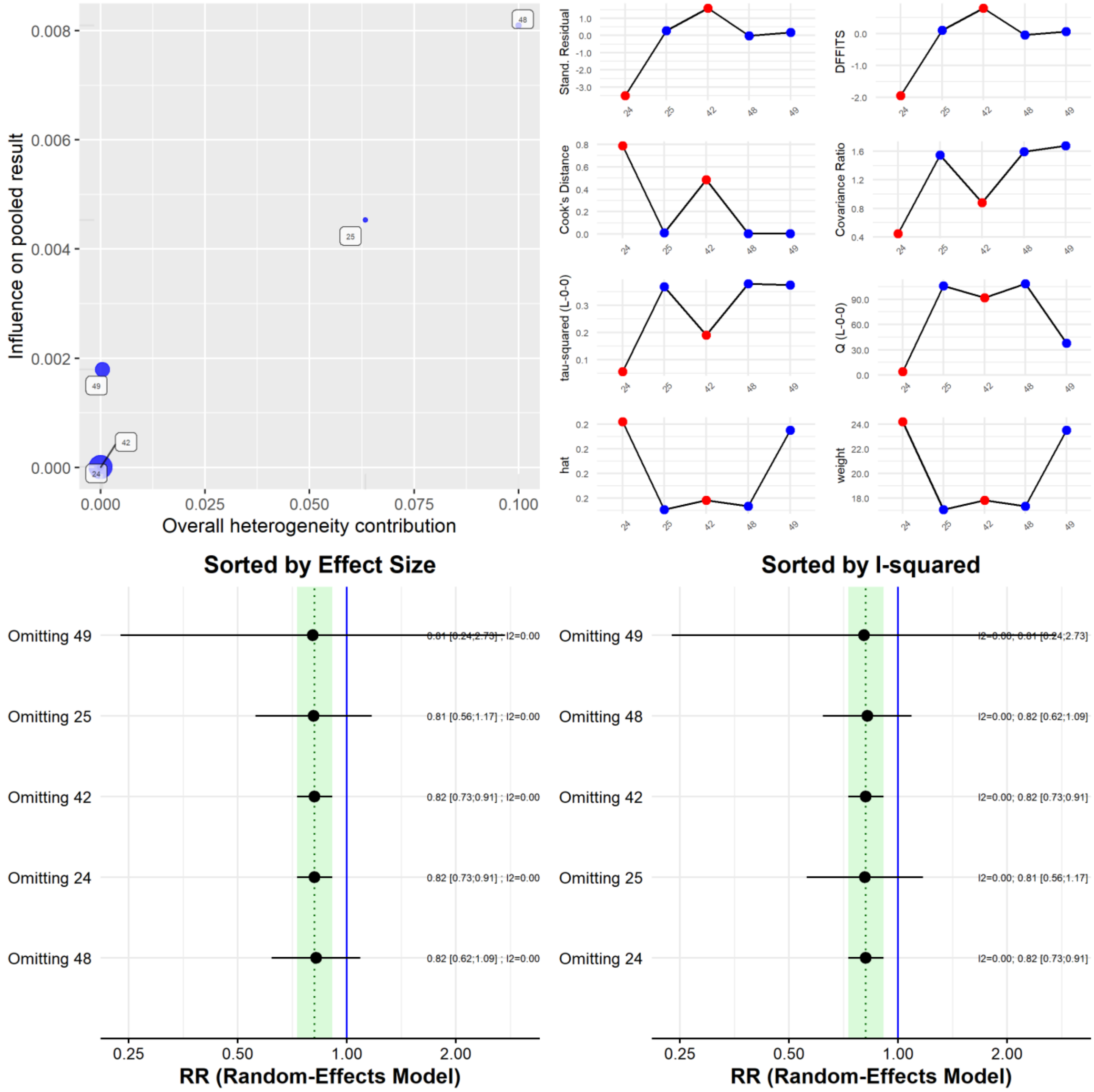


Figure V.20. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the retention rate of white marlin with circle vs. J hooks. Experiments 24 and 42 were excluded (they are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure V.21 provides the random effects model for white marlin, with regard to at-haulback mortality. In this case the RR is 0.85 (95% CIs: 0.71; 1.02), which means that on average we expect that the at-haulback mortality of white marlin when using circle hooks is 15% lower than when using J hooks but this value is not significant, with 95% confidence intervals varying between a reduction of 29% and an increase of 2%. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure V.22 and in this case no major outliers were identified and therefore all experiments were kept.

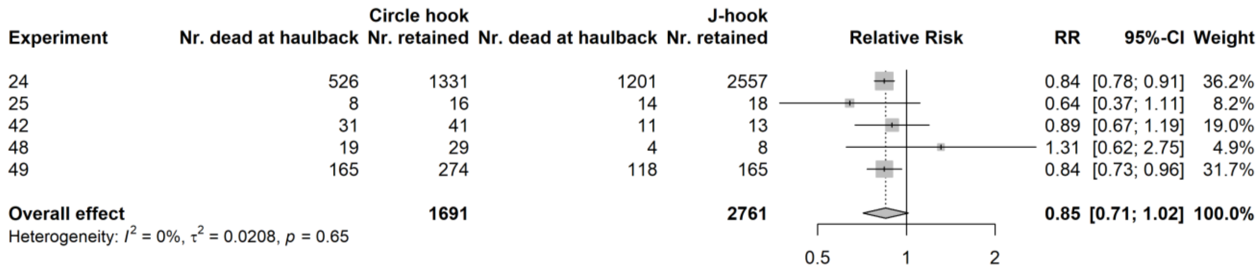


Figure V.21. Forest plot of the random effects meta-analysis, considering all studies, in the at-haulback mortality of white marlin with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

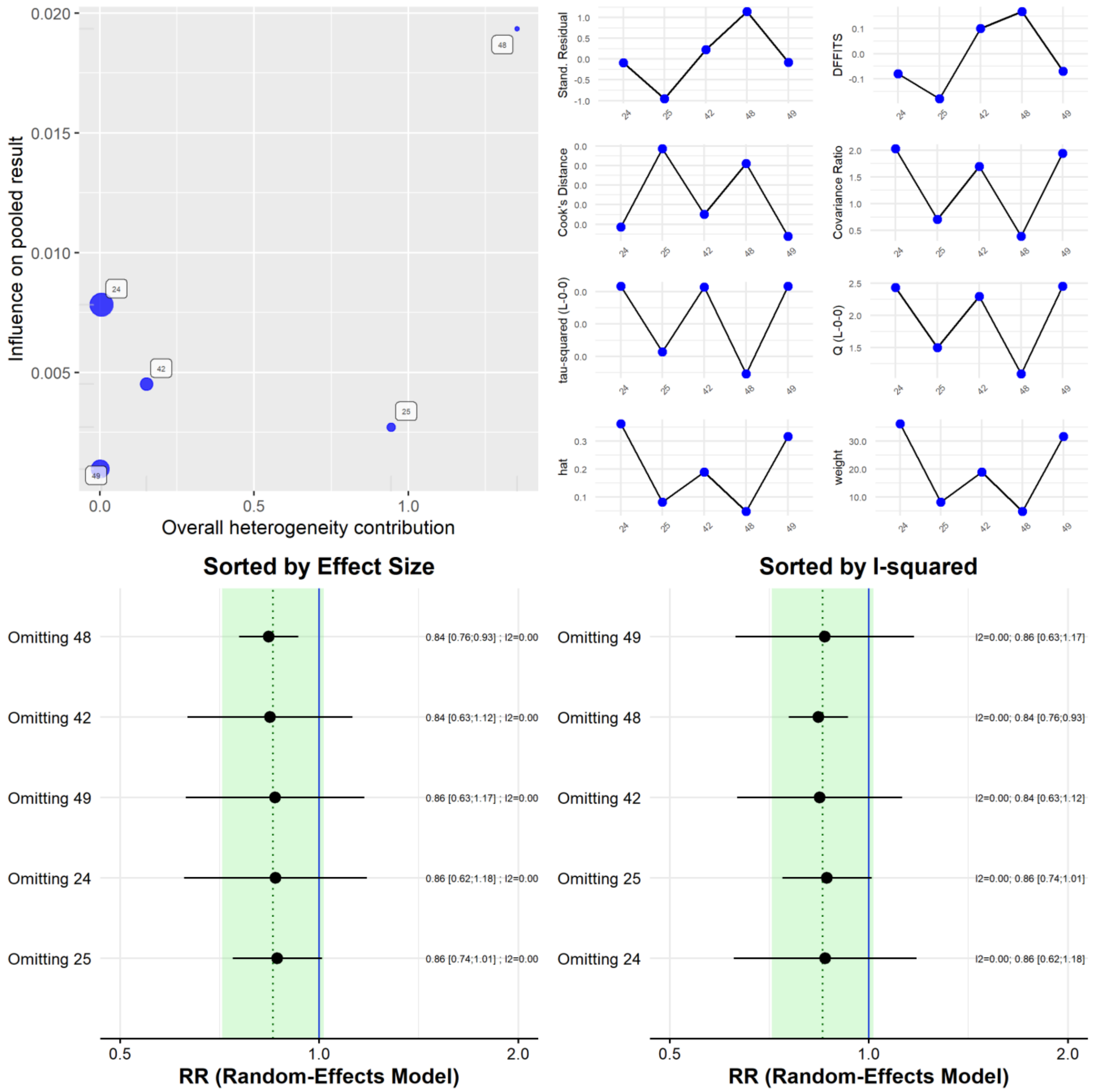


Figure V.22. Influence analysis for the meta-analysis using all studies performed for the at-haulback mortality of white marlin with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

With regard to the post-release mortality, Table V.4 provides a summary of the currently available studies specific for white marlin.

Table V.4. Summary of post-release mortality studies for white marlin with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
WHM – White marlin	8	0.00	Rod and reel	NW Atlantic	J	NA	NA	Graves et al. (2002)
	18	33.3	Rod and reel	NW Atlantic	C	NA	NA	Graves et al. (2016)
	59	1.7	Rod and reel	NW Atlantic	C	Fish	Wire	Graves & Horodysky (2008)
	35	5.7	Rod and reel	NW Atlantic, Caribbean	NA	NA	NA	Hoolihan et al. (2015)
	21	19.0	Rod and reel	NW Atlantic	C	Fish	NA	Schlenker et al. (2016)
	18	5.6	Rod and reel	Gulf of Mexico	C	NA	NA	Vaudo et al. (2018)
	20	0.10	Longline	NW Atlantic, Gulf of Mexico	C or J	Fish or squid	NA	Kerstetter & Graves (2006)

Atlantic sailfish (SAI)

Retention rates

Figure V.23 shows the random effects model when all data compiled are used for the Atlantic sailfish. In this case the RR is 0.54 (95% CIs: 0.13; 2.23). This means that on average we expect that the retention of Atlantic sailfish when using circle hooks is 46% lower than when using J hooks, but this is not significant as the 95% confidence intervals vary between a decrease of 87% and an increase of 2.23 times. In this analysis the overall heterogeneity (I^2) is low (44%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis did not identify outliers with major influence in the results, and for that reason all experiments were kept (Figure V.24).

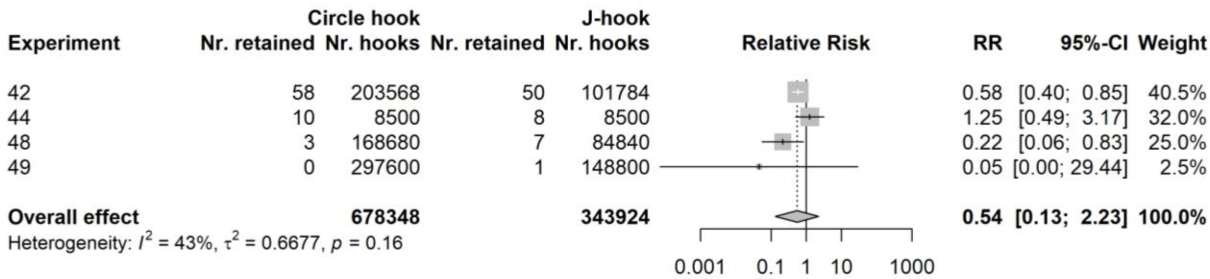


Figure V.23. Forest plot of the random effects meta-analysis, considering all studies, in the retention rates of Atlantic sailfish with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

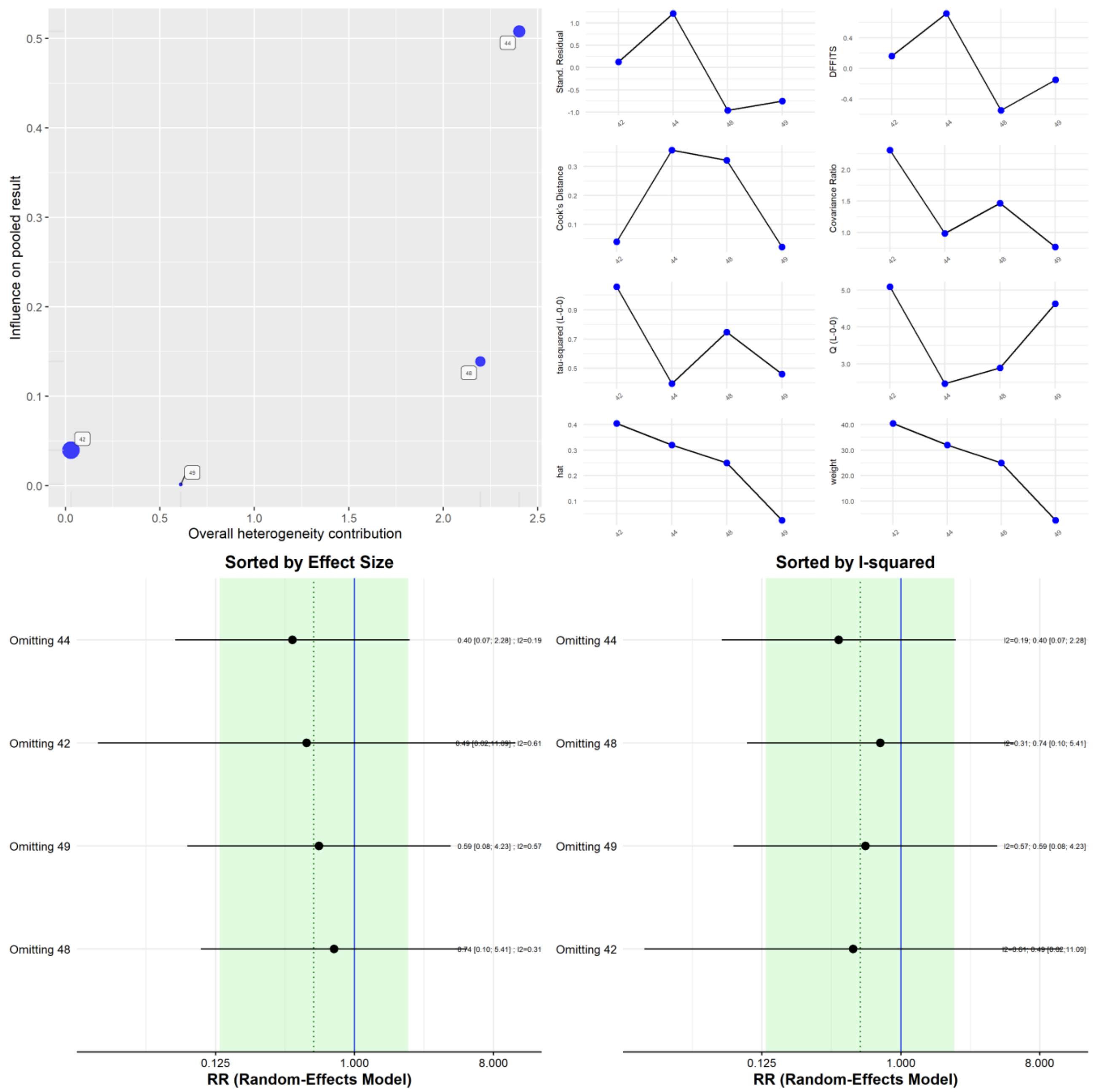


Figure V.24. Influence analysis for the meta-analysis using all studies performed for the retention rates of Atlantic sailfish with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

With regard to the effect of hook type on the at-haulback mortality of Atlantic sailfish, only three experiments were available (experiments 42, 48 and 49), and experiments 48 and 49 had very low sample sizes. In the case of experiment 49 only one individual was retained. Therefore, the meta-analysis was not conducted. For experiment 42 the RR was 0.78 (95% CIs:

0.72; 0.97). For experiment 48 the RR was 0.35 (95% CIs: 0.08; 1.59). Those individual results do not allow any conclusion to be drawn regarding at-haulback mortality of Atlantic sailfish when changing hook type.

Post-release mortality

With regard to the post-release mortality, Table V.5 provides a summary of the currently available studies specific for Atlantic sailfish.

Table V.5. Summary of post-release mortality studies for Atlantic sailfish with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
SAI – Atlantic sailfish	10	0.10	Longline	Gulf of Mexico	C	Fish or squid	NA	Kerstetter & Graves (2007)
	4	0.0	Rod and reel	SW Atlantic	C	NA	NA	Mourato et al. (2014)
	11	9.1	Rod and reel	Indian Ocean (Arabian Gulf)	NA	NA	NA	Hoolihan (2005)
	3	0.0	Set net	NW Pacific (Taiwan)	NA	NA	NA	Chiang et al. (2011)
	32	9.4	Rod and reel	NE Pacific	C	NA	NA	Prince et al. (2006)
	16	18.8	Longline or rod and reel*	NW Atlantic, Gulf of Mexico	C	Fish or squid	NA	Kerstetter et al. (2011)
	23	0.0	Rod and reel	NW Atlantic, Gulf of Mexico	NA	NA	NA	Lam et al. (2016)

*: One specimen was tagged with rod and reel and survived.

APPENDIX VI: SPECIES-SPECIFIC ANALYSIS FOR SUB-TASK 1.3 – UNWANTED BYCATCH

In this Appendix we provide the detailed species-specific results for Task 1, namely sub-task 1.3, referring to the meta-analysis for retention rates and at-haulback mortality for the main unwanted bycatch species considered in the study. For sea turtles the focus species are loggerhead (TTL), leatherback (DKK), Olive ridley (LKV), Kemp ridley (LKY) and green turtle (TUG). For sharks, the focus species are oceanic whitetip shark (OCS), porbeagle (POR), silky shark (FAL), bigeye thresher (BTH), longfin mako (LMA), crocodile shark (PSK), scalloped hammerhead (SPL), smooth hammerhead (SPZ) and the pelagic stingray (PLS).

In this Appendix we also provide detailed tables with the post-release mortality information available for those species.

Loggerhead (TTL)

Retention rates

Figure VI.1 shows the random effects model when all data compiled are used for the loggerhead sea turtle. When all data are used, the RR is 0.47 (95% CIs: 0.34; 0.63). In this analysis the overall heterogeneity is high (I^2=86%) and fails the statistical assumption of homogeneity (p-value<0.05). The influence analysis is represented in Figure VI.1, and experiment 15 was identified as an outlier with significant leverage and as such could be considered for deletion from the pooled analysis.

The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VI.3 and validation indicated in Figure VI.4. When experiment 15 is excluded, the RR is 0.53 (95% CIs: 0.42; 0.67), meaning that the retention of loggerhead sea turtle when using circle hooks is 47% lower than when using J hooks, with 95% CIs varying between decreases of 33% and 58%. We also see that the overall heterogeneity (I^2) decreases from 86% to 75%.

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
1	85	46040	147	92080	1.16	[0.89; 1.51]	6.5%
2	30	58766	14	29383	1.07	[0.57; 2.02]	5.3%
10	3	10000	14	10000	0.21	[0.06; 0.75]	3.3%
12	11	37968	18	37968	0.61	[0.29; 1.29]	4.9%
15	27	2150674	182	1282748	0.09	[0.06; 0.13]	6.1%
17	86	286826	87	143473	0.49	[0.37; 0.67]	6.4%
20	53	72914	117	72914	0.45	[0.33; 0.63]	6.4%
24	329	5044540	504	3157102	0.41	[0.36; 0.47]	6.7%
26	9	2320	14	2322	0.64	[0.28; 1.48]	4.6%
27	11	22571	20	22571	0.55	[0.26; 1.15]	5.0%
28	36	19911	48	19911	0.75	[0.49; 1.15]	6.0%
30	41	325845	126	349078	0.35	[0.25; 0.50]	6.3%
31	2	13286	9	13287	0.22	[0.05; 1.03]	2.6%
36	0	11174	1	11195	0.09	[0.00; 59.00]	0.2%
42	3	203568	7	101784	0.21	[0.06; 0.83]	3.0%
46	6	14664	20	14590	0.30	[0.12; 0.74]	4.3%
48	10	169680	12	84840	0.42	[0.18; 0.96]	4.6%
49	122	297600	138	148800	0.44	[0.35; 0.56]	6.5%
52	25	29845	11	14860	1.13	[0.56; 2.30]	5.1%
53	0	40200	2	19800	0.02	[0.00; 13.34]	0.2%
54	44	47400	33	23700	0.67	[0.42; 1.05]	6.0%
Overall effect		**8905792**		**5652406**	**0.47**	**[0.34; 0.63]**	**100.0%**

Heterogeneity: $I^2 = 86\%$, $\tau^2 = 0.3746$, $p < 0.01$

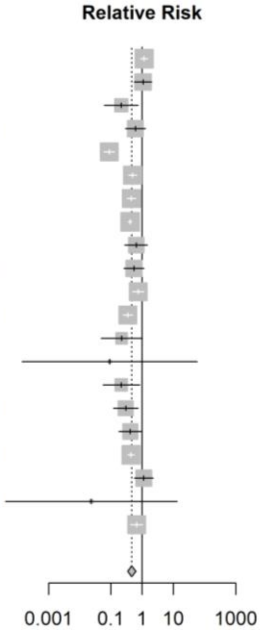


Figure VI.1. Forest plot of the random effects meta-analysis, considering all studies, in the retention rates of the loggerhead sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

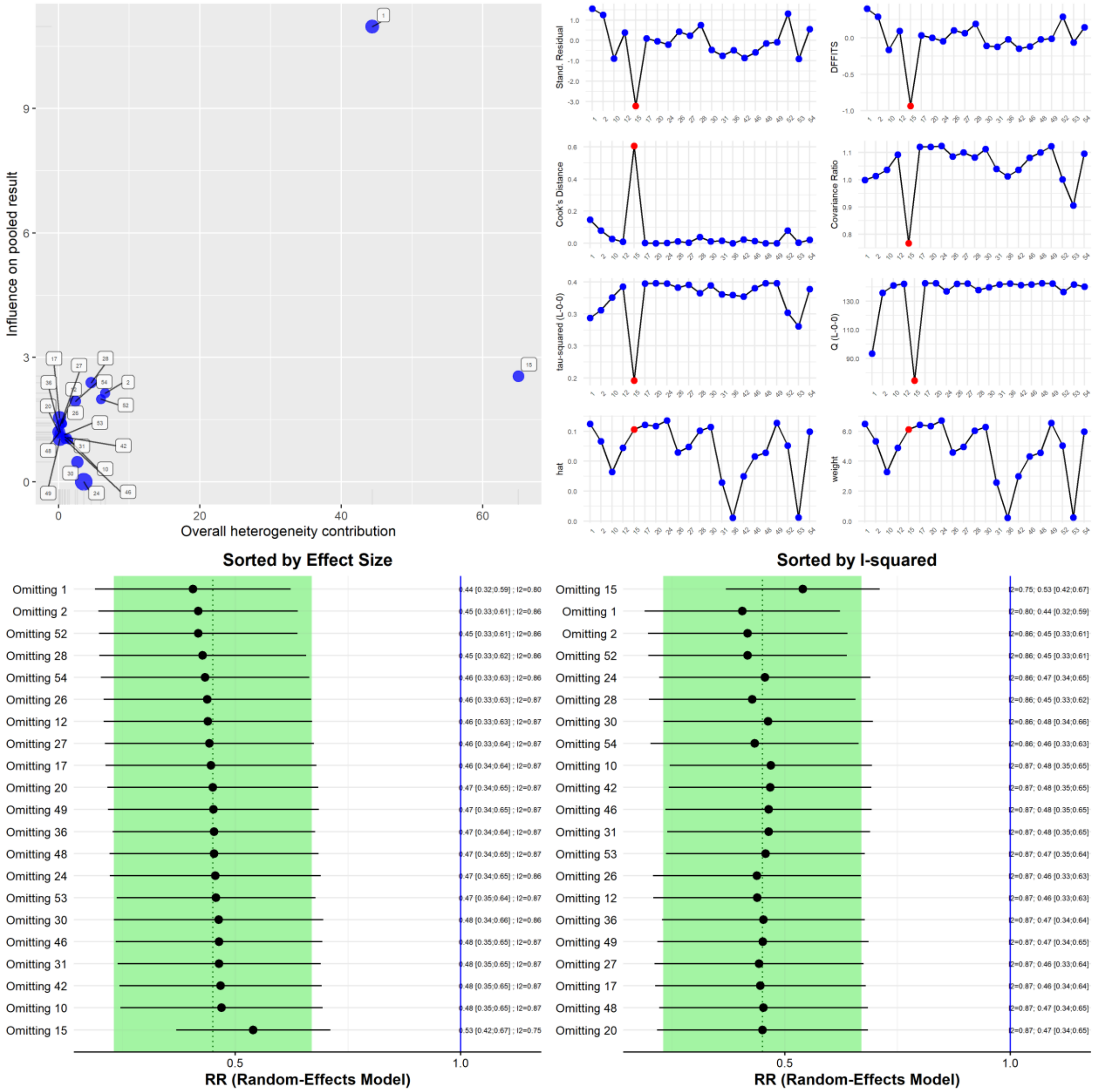


Figure VI.2. Influence analysis for the meta-analysis using all studies performed for the retention rates of the loggerhead sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
1	85	46040	147	92080	1.16	[0.89; 1.51]	7.4%
2	30	58766	14	29383	1.07	[0.57; 2.02]	5.6%
10	3	10000	14	10000	0.21	[0.06; 0.75]	3.0%
12	11	37968	18	37968	0.61	[0.29; 1.29]	5.0%
15	27	2150674	182	1282748	0.09	[0.06; 0.13]	0.0%
17	86	286826	87	143473	0.49	[0.37; 0.67]	7.3%
20	53	72914	117	72914	0.45	[0.33; 0.63]	7.2%
24	329	5044540	504	3157102	0.41	[0.36; 0.47]	7.8%
26	9	2320	14	2322	0.64	[0.28; 1.48]	4.6%
27	11	22571	20	22571	0.55	[0.26; 1.15]	5.1%
28	36	19911	48	19911	0.75	[0.49; 1.15]	6.7%
30	41	325845	126	349078	0.35	[0.25; 0.50]	7.0%
31	2	13286	9	13287	0.22	[0.05; 1.03]	2.3%
36	0	11174	1	11195	0.09	[0.00; 59.00]	0.2%
42	3	203568	7	101784	0.21	[0.06; 0.83]	2.7%
46	6	14664	20	14590	0.30	[0.12; 0.74]	4.2%
48	10	169680	12	84840	0.42	[0.18; 0.96]	4.6%
49	122	297600	138	148800	0.44	[0.35; 0.56]	7.5%
52	25	29845	11	14860	1.13	[0.56; 2.30]	5.2%
53	0	40200	2	19800	0.02	[0.00; 13.34]	0.2%
54	44	47400	33	23700	0.67	[0.42; 1.05]	6.6%
Overall effect		**8905792**		**5652406**	**0.53**	**[0.42; 0.67]**	**100.0%**

Heterogeneity: $I^2 = 75\%$, $\tau^2 = 0.2460$, $p < 0.01$

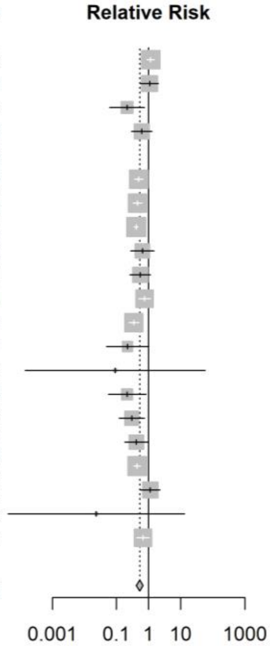


Figure VI.3. Forest plot of the random effects meta-analysis excluding 1 outliers in the retention rates of the loggerhead sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiment 15 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

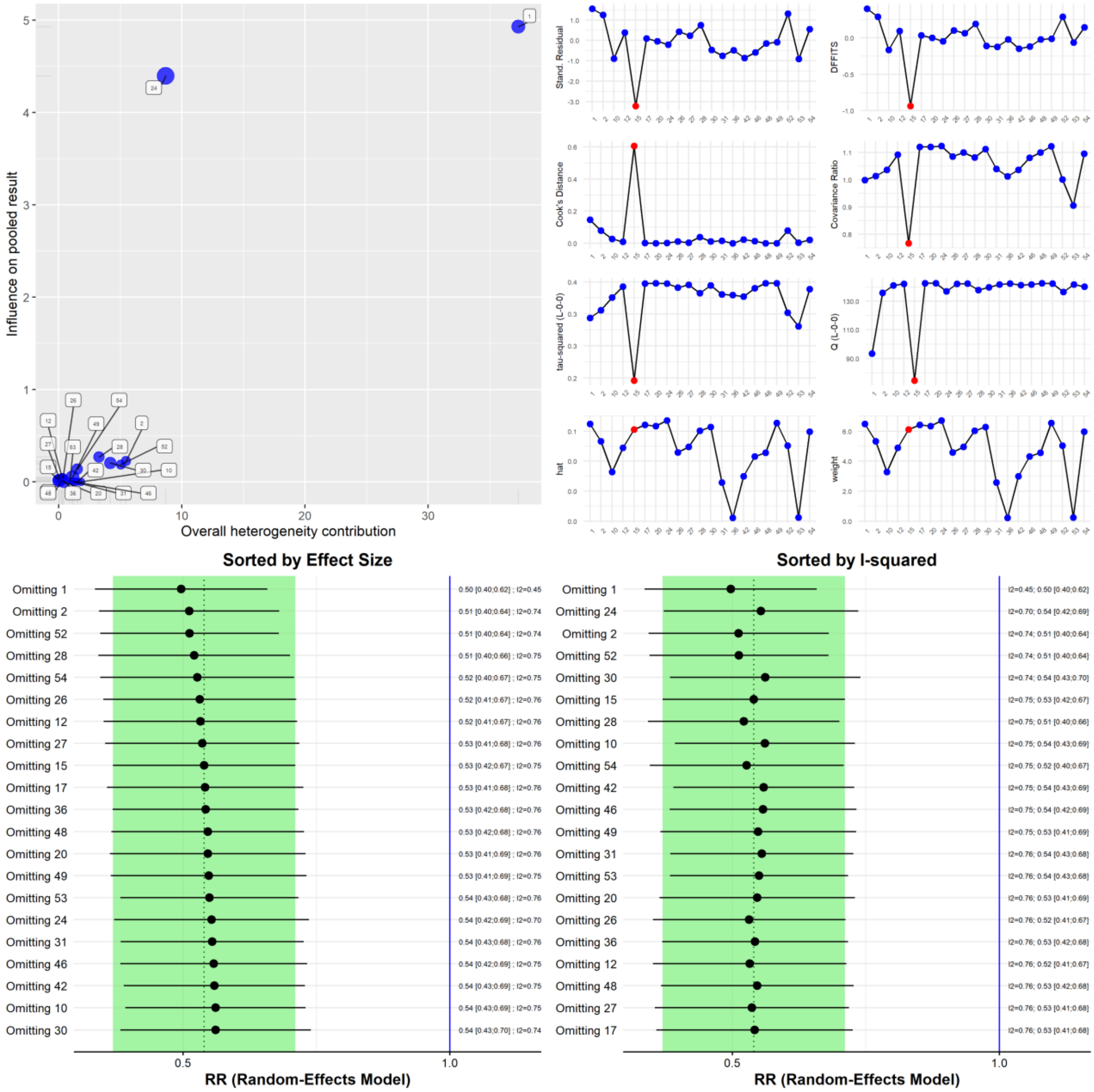


Figure VI.4. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rate of the loggerhead sea turtle with circle vs. J hooks. Experiment 15 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.5 provides the random effects model for the loggerhead sea turtle, with regard to at-haulback hooking mortality. In this case the RR is 1.12 (95% CIs: 0.61; 2.08). This means that on average we expect that the mortality of loggerhead sea turtle when using circle hooks is 12% higher than when using J hooks, but with 95% confidence intervals varying between a reduction of 39% and an increase of 2.08 times. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.6. and in this case no major outliers were identified and therefore all experiments were kept.

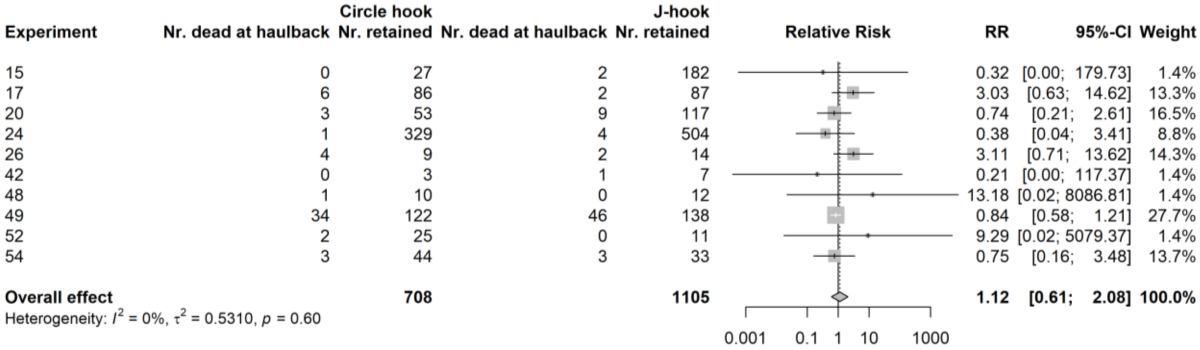


Figure VI.5. Forest plot of the random effects meta-analysis, considering all studies, in the at-haulback mortality of the loggerhead sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

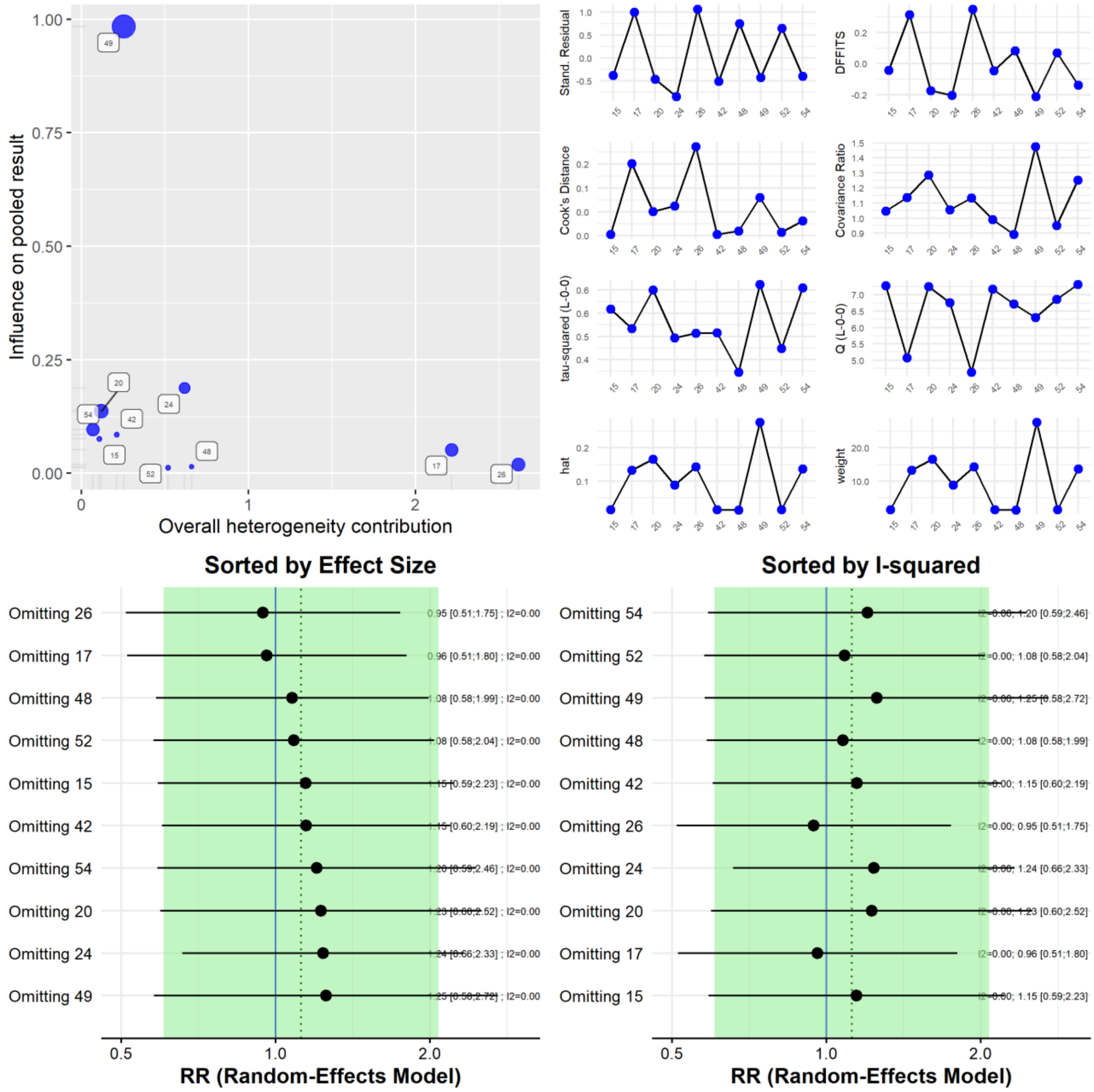


Figure VI.6. Influence analysis for the meta-analysis using all studies, performed for the at-haulback mortality of the loggerhead sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.1 provides a summary of the available studies on post-release mortality for loggerhead sea turtle.

Table VI.1. Summary of post-release mortality studies for loggerhead sea turtle with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
TTL – Loggerhead	11	27.3	Longline	North Pacific (California; Hawaii)	J	NA	NA	Swimmer et al. (2014)
	14	28.6	Longline	North Pacific (California; Hawaii)	C	NA	NA	Swimmer et al. (2014)
	26	30.8	Longline	Mediterranean Sea	J*	NA	NA	de Quevedo et al. (2013)
	14	0.0	Longline	SE Pacific	J	NA	NA	Mangel et al. (2011)
	94	16.0	Longline	Mediterranean Sea	J*	NA	NA	Freggi and Casale (2006)
	9	11.1	NA	Indian	NA	NA	NA	Hays et al. (2003)
	2	50.0	NA	North Pacific	NA	NA	NA	Hays et al. (2003)
	9	0.0	Longline	North Pacific (Hawaii)	J*	NA	NA	Polovina et al. (2000)
	10	20.0	Longline	North-central Atlantic	J*	NA	NA	Sasso et al. (2007)
	7	14.3	Dip nets**	North-central Atlantic	NA	NA	NA	Sasso et al. (2007)
	47	61.7	Longline	Mediterranean Sea	J*	NA	NA	Casale et al. (2008)
	22	20-40	Longline	North Pacific (California; Hawaii)	J*	NA	NA	Parker et al. (2005)

*: Refers to information that is not available/provided but assumed given the specific fisheries and years of the study.
**: Turtles that were dip-netted off the surface to serve as control in the experiment listed.

Leatherback (DKK)

Retention rates

Figure VI.7 shows the random effects model when all data compiled are used for the leatherback sea turtle. When all data are used, the RR is 0.42 (95% CIs: 0.30; 0.60). The overall heterogeneity is high (I^2=78%) and fails the statistical assumption of homogeneity (p-value<0.05). The influence analysis is represented in Figure VI.8. Experiment 17 was identified as an outlier with significant leverage and as such can be considered for deletion from the pooled analysis. The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VI.9 and validation indicated in Figure VI.10.

When experiment 17 is excluded for this final analysis, the RR is 0.37 (95% CIs: 0.28; 0.48), meaning that the retention of leatherback sea turtle when using circle hooks is 63% lower than when using J hooks, with 95% confidence intervals varying between reductions of 52% and 72%. We also see that the overall heterogeneity (I^2) decreases from 78% to 25%, with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05).

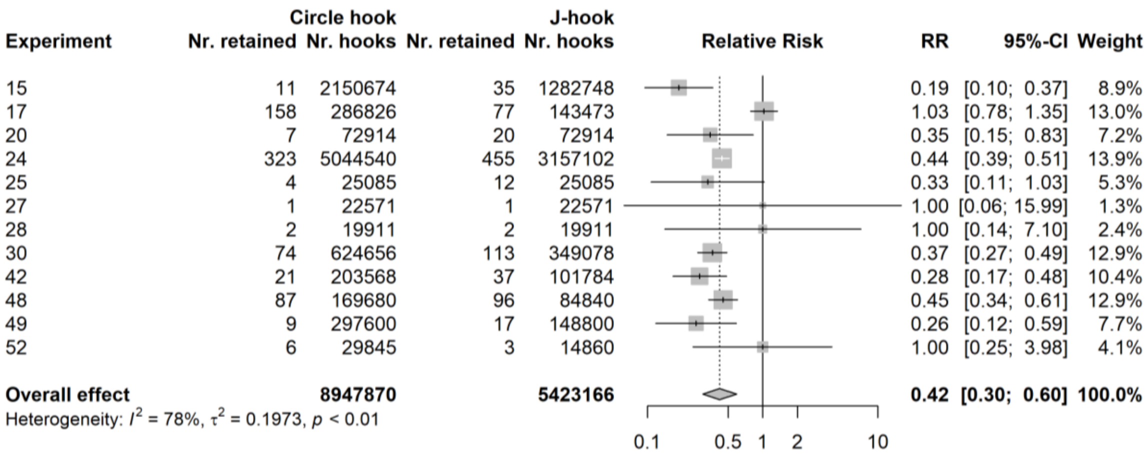


Figure VI.7. Forest plot of the random effects meta-analysis, considering all studies, in the retention rates of leatherback sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

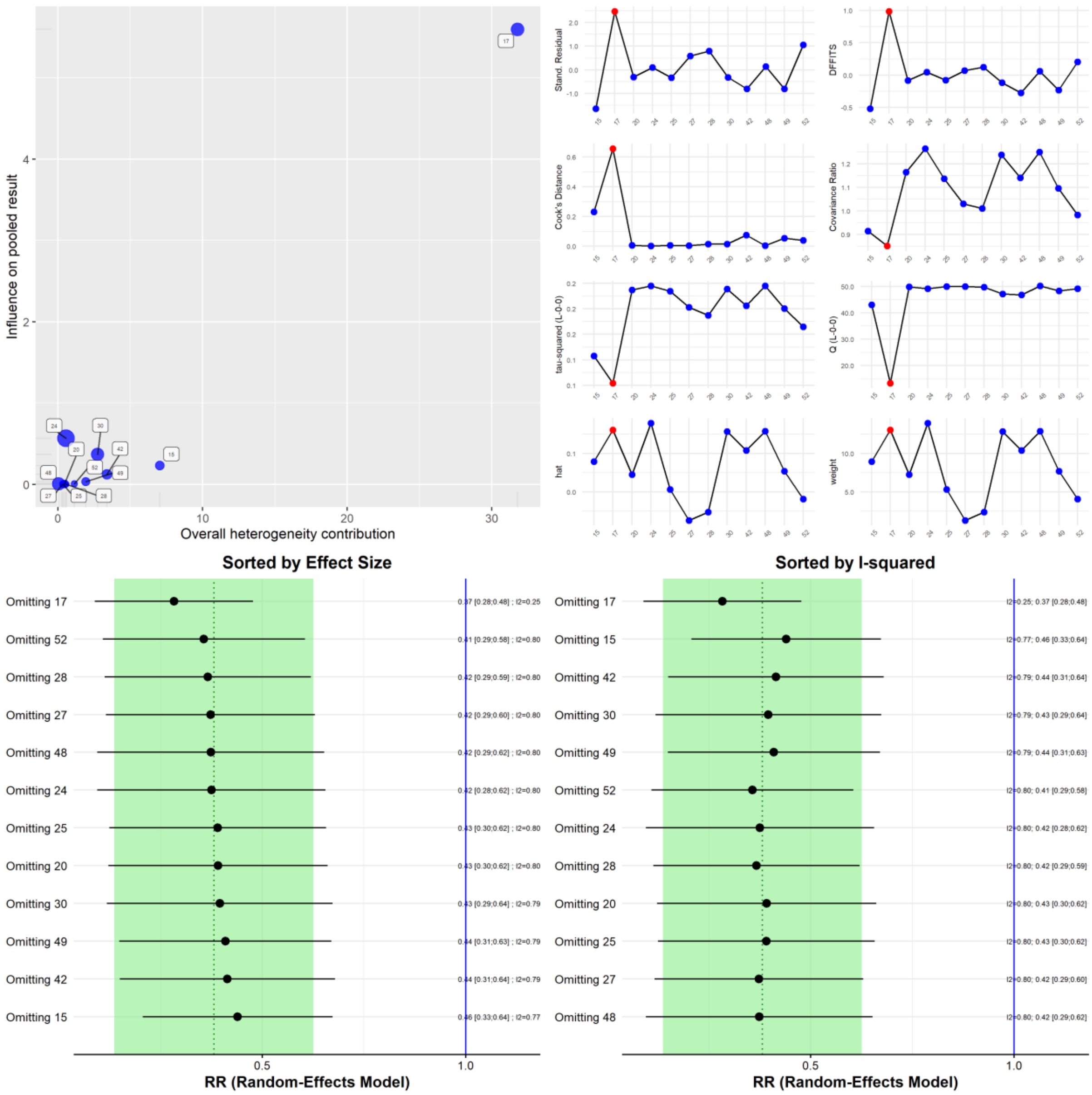


Figure VI.8. Influence analysis for the meta-analysis using all studies performed for the retention rates of leatherback sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

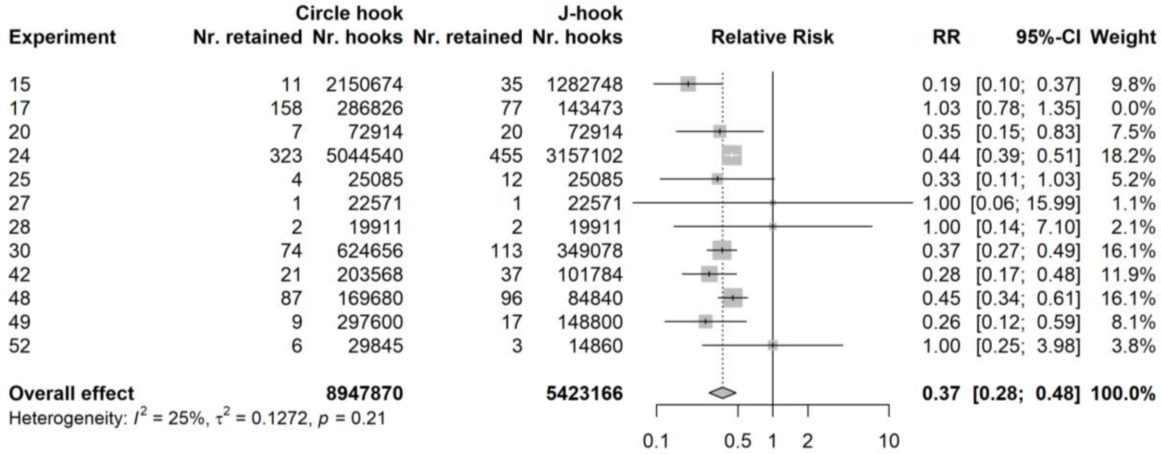


Figure VI.9. Forest plot of the random effects meta-analysis excluding 1 outliers in the retention rates of leatherback sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). Experiment 17 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

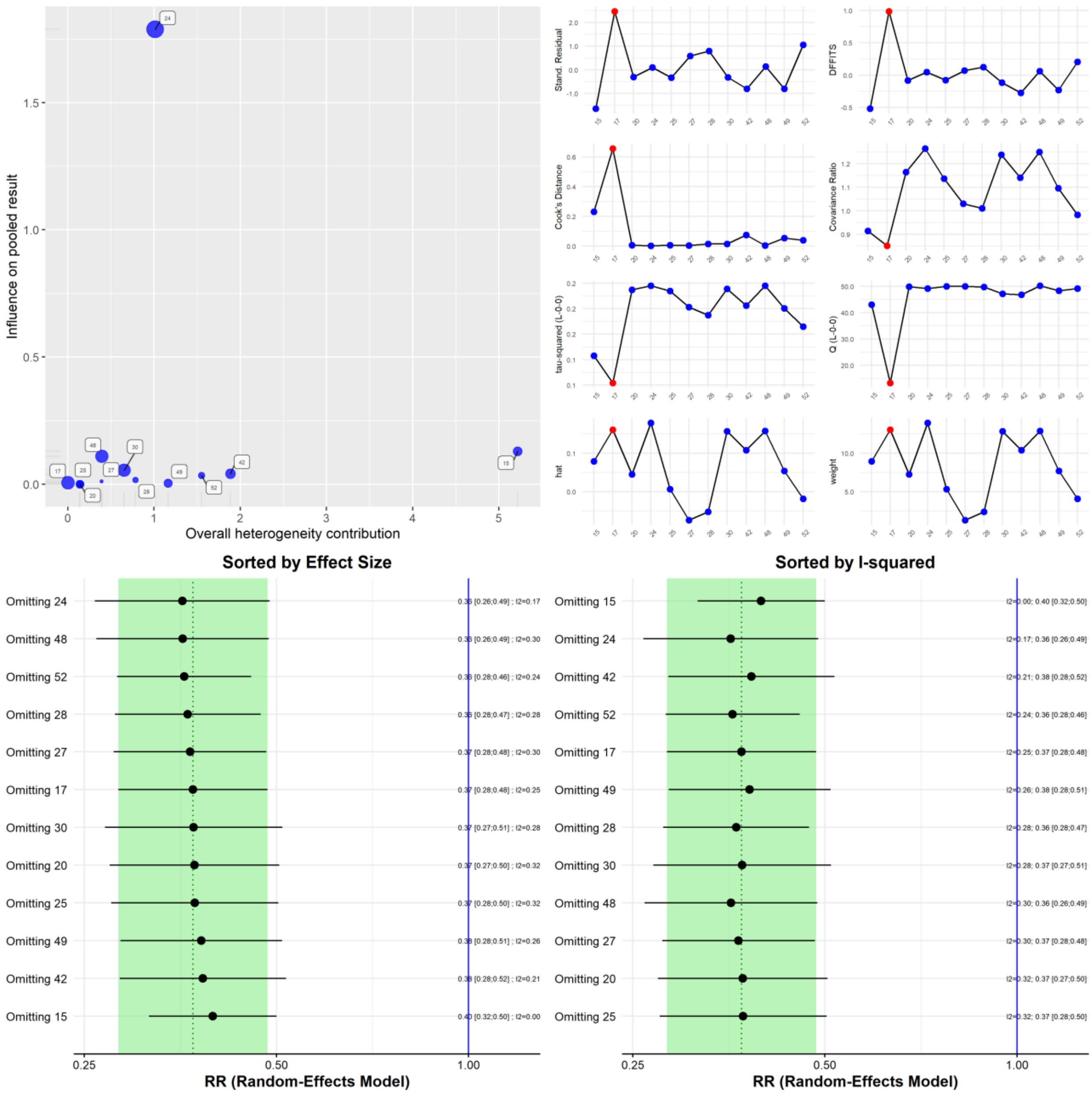


Figure VI.10. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rate of loggerhead sea turtle with circle vs. J hooks. Experiment 17 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.11 shows the random effects model for leatherback sea turtle, with regards to at-haulback hooking mortality. In this case the RR is 2.41 (95% CIs: 1.07; 5.44). This means that on average we expect that the mortality of the leatherback sea turtle when using circle hooks is 2.41 times higher than when using J hooks, and this value is significant with the 95% confidence intervals varying between increases of 7% and 5.44 times.

In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure V.12 and in this case no major outliers were identified and therefore all experiments were kept.

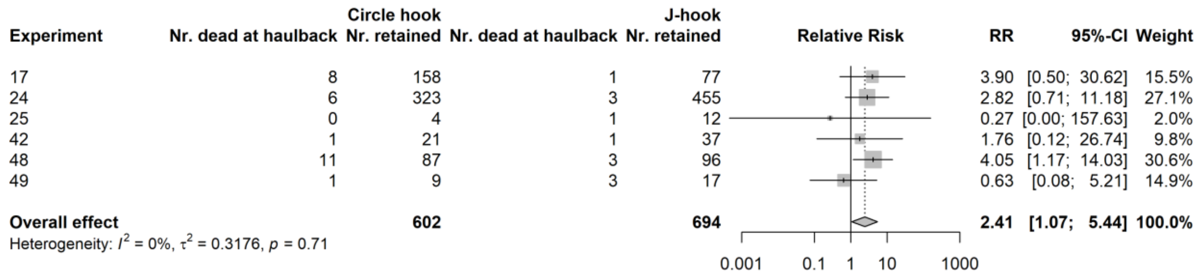


Figure VI.11. Forest plot of the random effects meta-analysis including all studies, in the at-haulback mortality of leatherback sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

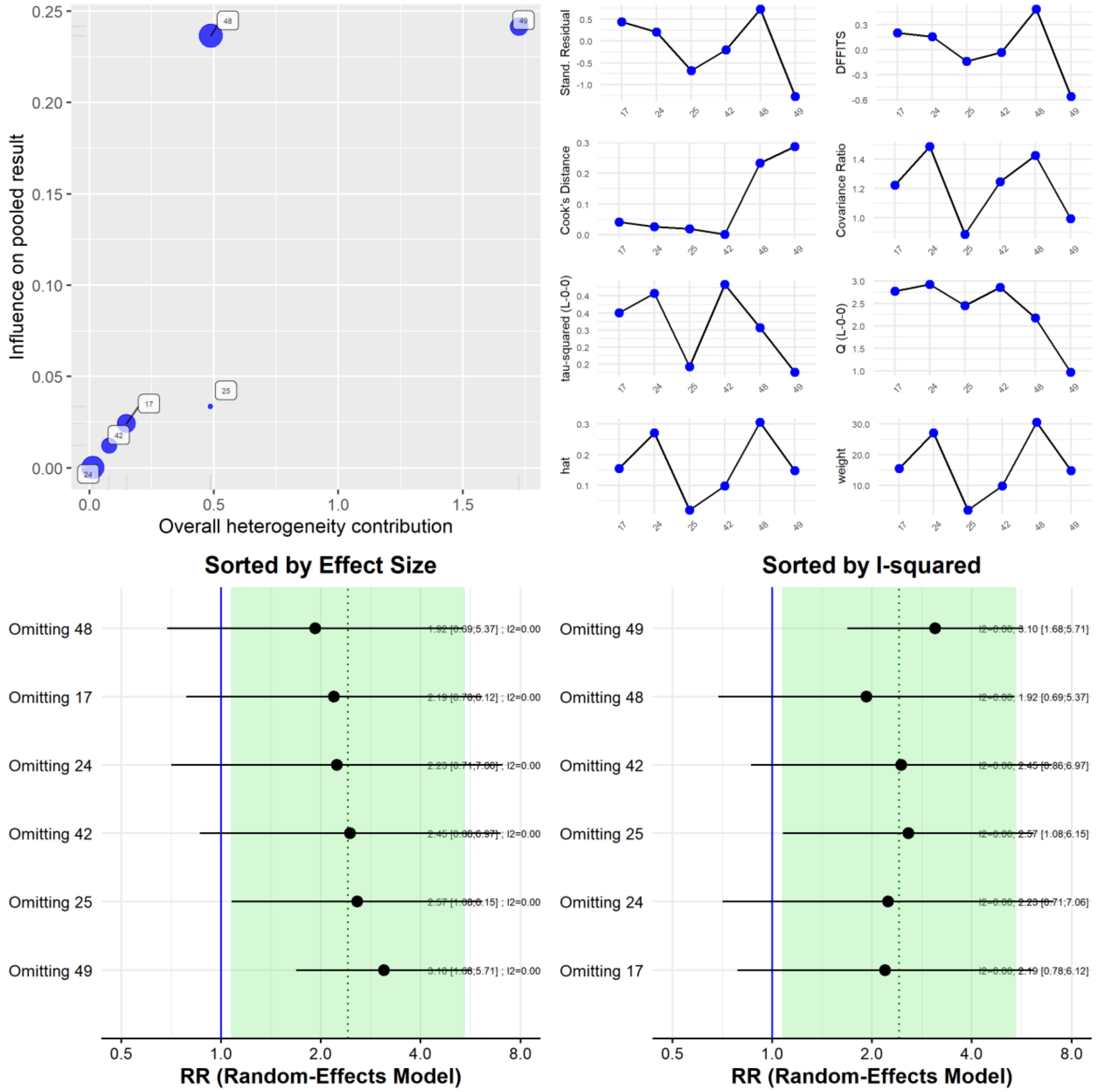


Figure VI.12. Influence analysis for the meta-analysis after including all experiment, performed for the at-haulback mortality of leatherback sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I² (right).

Post release mortality

Table VI.2 provides a summary of the available studies on post-release mortality for leatherback sea turtle.

Table VI.2. Summary of post-release mortality studies for leatherback sea-turtle with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
DKK – Leatherback sea turtle	NA	*	Longline	NA	NA	NA	NA	Ryder et al. (2006)
	38	0.0	Hoop net	NW Atlantic	NA	NA	NA	James et al. (2005a,b)
	25	0.0	Hoop net	NW Atlantic	NA	NA	NA	James et al. (2005a,b)
	2	0.0	Lobster pot rope and drift net	NE Atlantic	NA	NA	NA	Doyle et al. (2008)
	1	0.0	Drift net	SW Atlantic	NA	NA	NA	Almeida et al. (2011)
	4	0.0	Longline and bottom-set gillnet	SW Atlantic	NA	NA	NA	López-Mendilaharsu et al. (2009)
	20	0.0	Hoop net and unknown fishing gear	NW Atlantic	NA	NA	NA	Dodge et al. (2014)

*: Leatherback sea turtles are here hypothesised to have higher rates of post-release mortality relative to hard-shelled turtles because leatherbacks are believed to have more delicate external and internal hard and soft tissue structure relative to hard-shelled turtles, and as a result might be relatively more susceptible to injury from interactions with pelagic longline gear. In this study, the leatherbacks are hypothesised to be relatively less resilient to the stresses incurred during fishery interactions.

Olive ridley (LKV)

Retention rates

Figure VI.13 shows the random effects model when all data compiled are used for olive ridley sea turtle. When all data are used, the RR is 0.64 (95% CIs: 0.39; 1.05). This means that we expect that the retention of olive ridley sea turtle when using circle hooks is 36% lower than when using J hooks, but this value is not significant with the 95% confidence intervals varying between a reduction of 61% and an increase of 5%. In this analysis the overall heterogeneity is I^2=55% and fails the statistical assumption of homogeneity (p-value<0.05). The influence analysis is represented in Figure VI.14. In this case no outliers with significant leverage were identified.

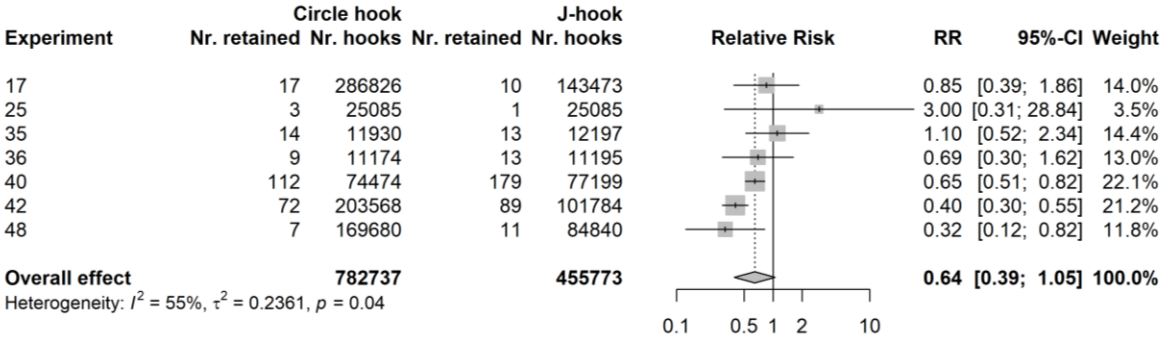


Figure VI.13. Forest plot of the random effects meta-analysis including all studies, for the retention rates of olive ridley sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention rate is higher with circle hooks).

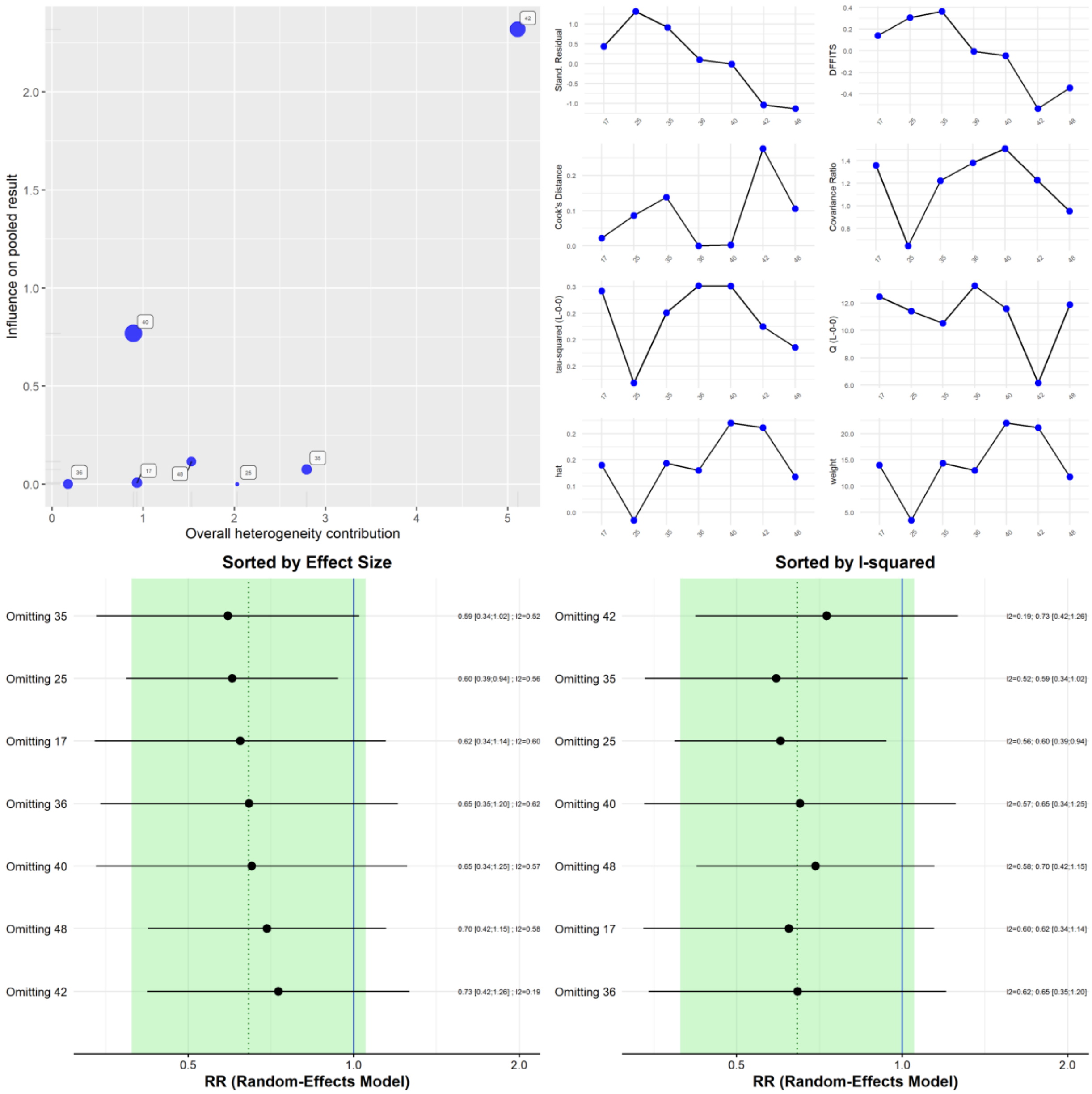


Figure VI.14. Influence analysis for the meta-analysis including all experiments, performed for the retention rates of olive ridley sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.15 shows the random effects model for the olive ridley sea turtle, with regard to at-haulback hooking mortality. In this case the RR is 1.41 (95% CIs: 0.35; 5.67). This means that on average we expect that the mortality of olive ridley sea turtle when using circle hooks is 41% higher than when using J hooks, but this is not significant with the 95% confidence intervals varying between a decrease of 65% and an increase of 5.67 times. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.16. Experiment 42 was identified as an outlier; however, it was included in the analysis because only two other experiments were available.

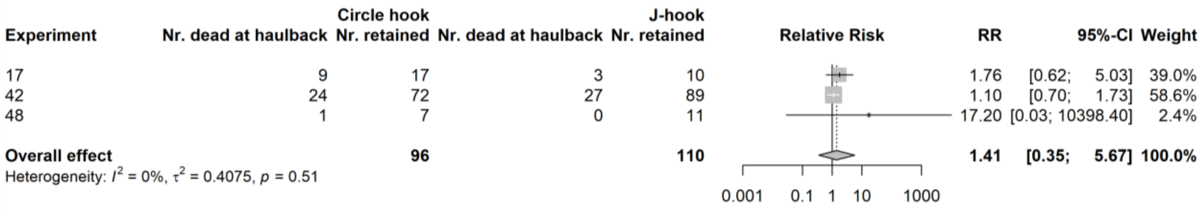


Figure VI.15. Forest plot of the random effects meta-analysis including all studies, for the at-haulback mortality of olive ridley sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

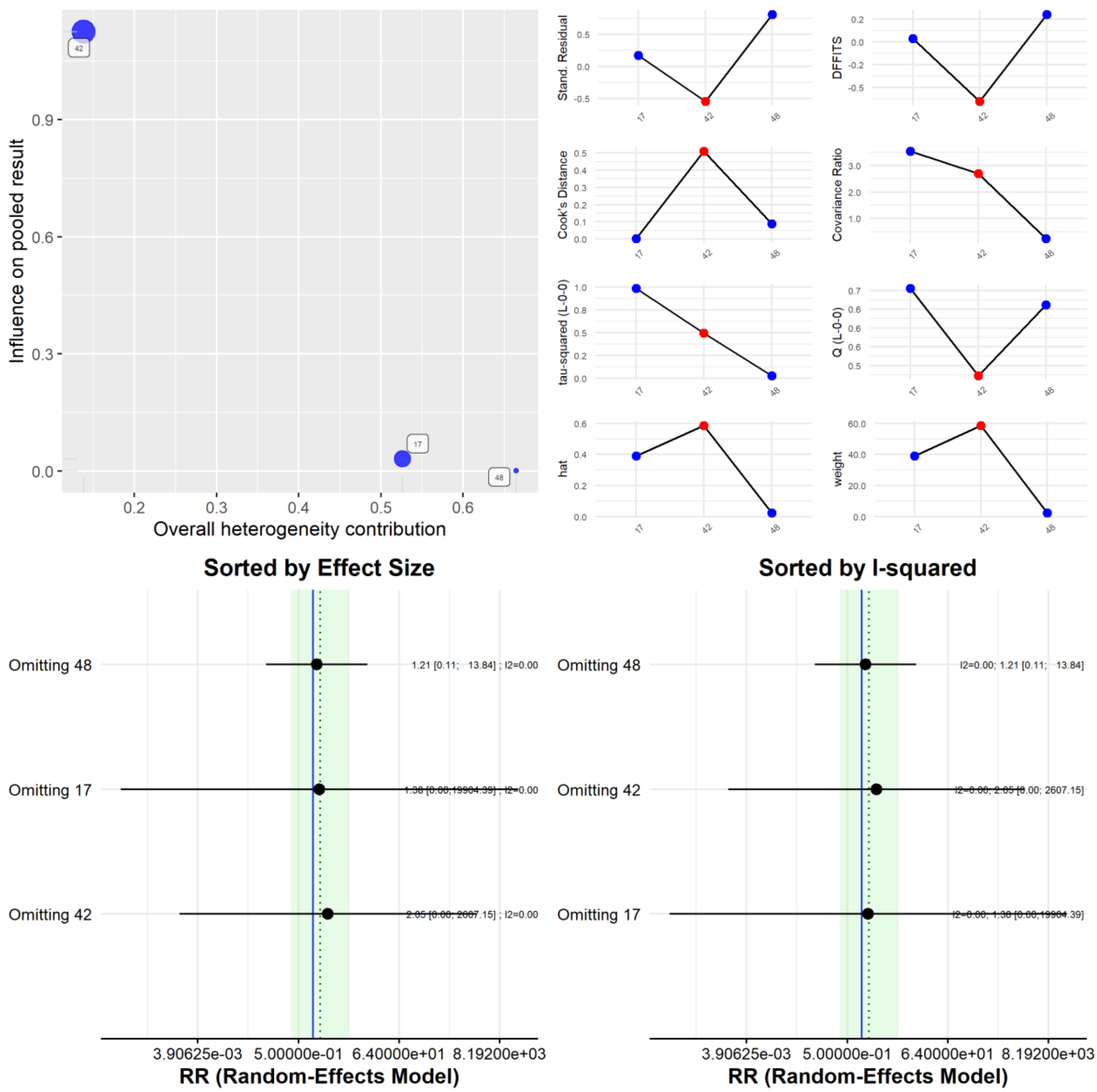


Figure VI.16. Influence analysis for the meta-analysis including all experiments, performed for the at-haulback mortality of olive ridley sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.3 provides a summary of the available studies on post-release mortality for olive ridley sea-turtle.

Table VI.3. Summary of post-release mortality studies for olive ridley sea-turtle with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
LKV – Olive ridley sea turtle	11	9.1	Longline and hand-capture	Equatorial Pacific (Costa Rica)	C	NA	NA	Swimmer et al. (2006)
	10	0.0	Longline	Central North Pacific	NA	NA	NA	Polovina et al. (2004)
	3	0.0/33.3*	Demersal fish trawl	Equatorial Atlantic (coastal Gabon)	NA	NA	NA	Maxwell et al. (2018)
	10	20-40 (depending on hook status)	Longline	North Pacific	NA	NA	NA	Parker et al. (2005)

*: One turtle died. However, the absence of a change in light level but continued diving activity suggested that the turtle was likely predated.

Kemp’s ridley (LKY)

Retention rates

For comparisons between hook type, there were only two experiments that reported on retention of Kemp’s ridley sea turtle for surface longlines and sample sizes were very small. Specifically, one of the experiments (experiment 42) reported 2 specimens retained in 101,784 J hooks and 0 specimens in 203,568 circle hooks (RR=0.02; 95% CIs: 0.00; 13.55). Another experiment (experiment 48) reported 1 specimen retained in 84,840 J hooks and also 1 specimen retained in 169,680 circle hooks (RR=0.50; 95% CIs: 0.03; 7.99). Given that only those 2 studies are available, it was not possible to conduct a meta-analysis.

At-haulback mortality

For comparisons between hook types on at-haulback mortality, again there were only two experiments (42 and 48) that reported on Kemp’s ridley sea turtle at-haulback mortality for surface longlines. In both experiments no turtle suffered any at-haulback mortality. Given that only those two studies are available and on both there were no at-haulback mortality events, it was not possible to conduct a meta-analysis.

Post release mortality

Table VI.4 provides a summary of the available studies on post-release mortality for Kemp’s ridley sea turtle.

Table VI.4. Summary of post-release mortality studies for Kemp's ridley sea-turtle with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
LKY – Kemp's ridley sea turtle	3	33.3/66.7*	Gillnet	NW Atlantic (lower Cape Fear River)	NA	NA	NA	Snoddy & Williard (2010)
	6	0.0	Dip net	Gulf of Mexico	NA	NA	NA	Schmid & Witzell (2006)
	3	0.0	Shrimp trawl	SE Atlantic	NA	NA	NA	Gitschlag (1996)
	6	0.0	Entanglement net	Gulf of Mexico	NA	NA	NA	Renaud & Williams (1997)

* Turtles that displayed satellite transmission patterns indicative of mortality but for which they did not locate a carcass were categorised as suspected mortalities.

Green sea turtle (TUG)

Retention rates

Figure VI.17 shows the random effects model when all data compiled are used for green sea turtle. When all data are used, the RR is 0.80 (95% CIs: 0.34; 1.89). In this analysis there is no overall heterogeneity (I2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05).

The influence analysis is represented in Figure VI.18. Experiment 36 was identified as an outlier with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VI.19 and validation indicated in Figure VI.20. When experiment 36 is excluded, the RR is 0.99 (95% CIs: 0.76; 1.30). This means that the retention of green sea turtle when using circle hooks is on average 1% lower than when using J hooks, but this is not significant as the 95% confidence intervals vary between a reduction of 24% and an increase of 30%. We also see that the overall heterogeneity (I^2) value remains 0%.

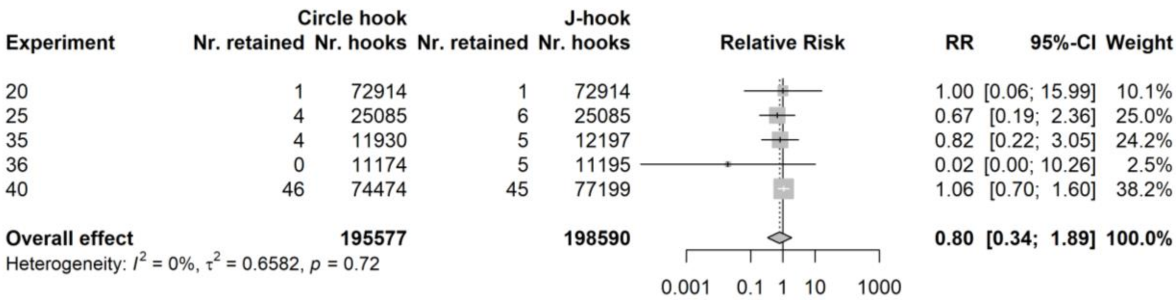


Figure VI.17. Forest plot of the random effects meta-analysis including all studies, for the retention rates of green sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention rate is higher with circle hooks).

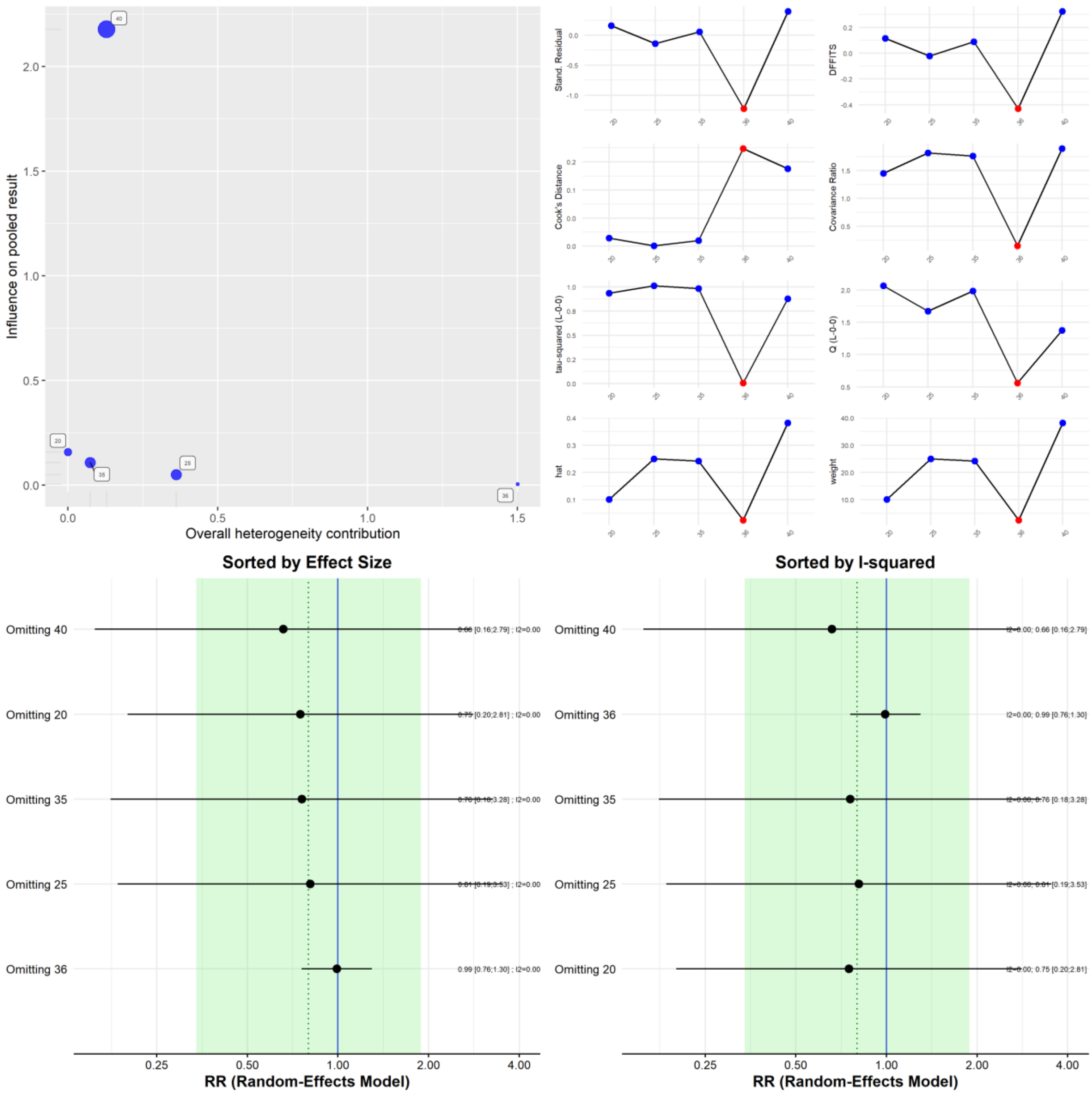


Figure VI.18. Influence analysis for the meta-analysis including all experiments, performed for the retention rates of green sea turtle with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I² (right).

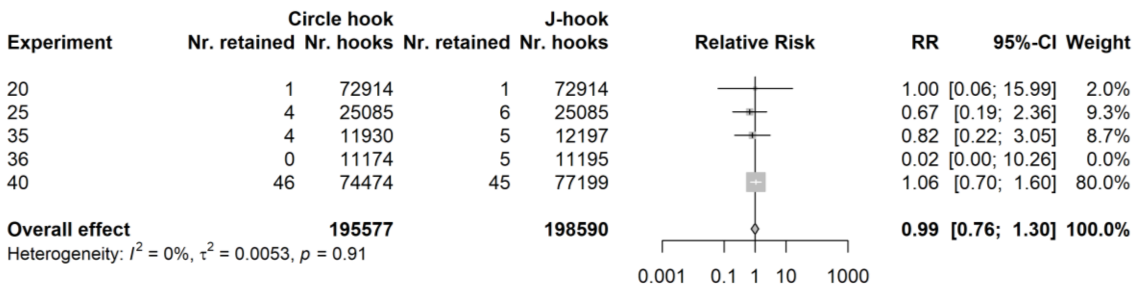


Figure VI.19. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of green sea turtle with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). Experiment 36 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

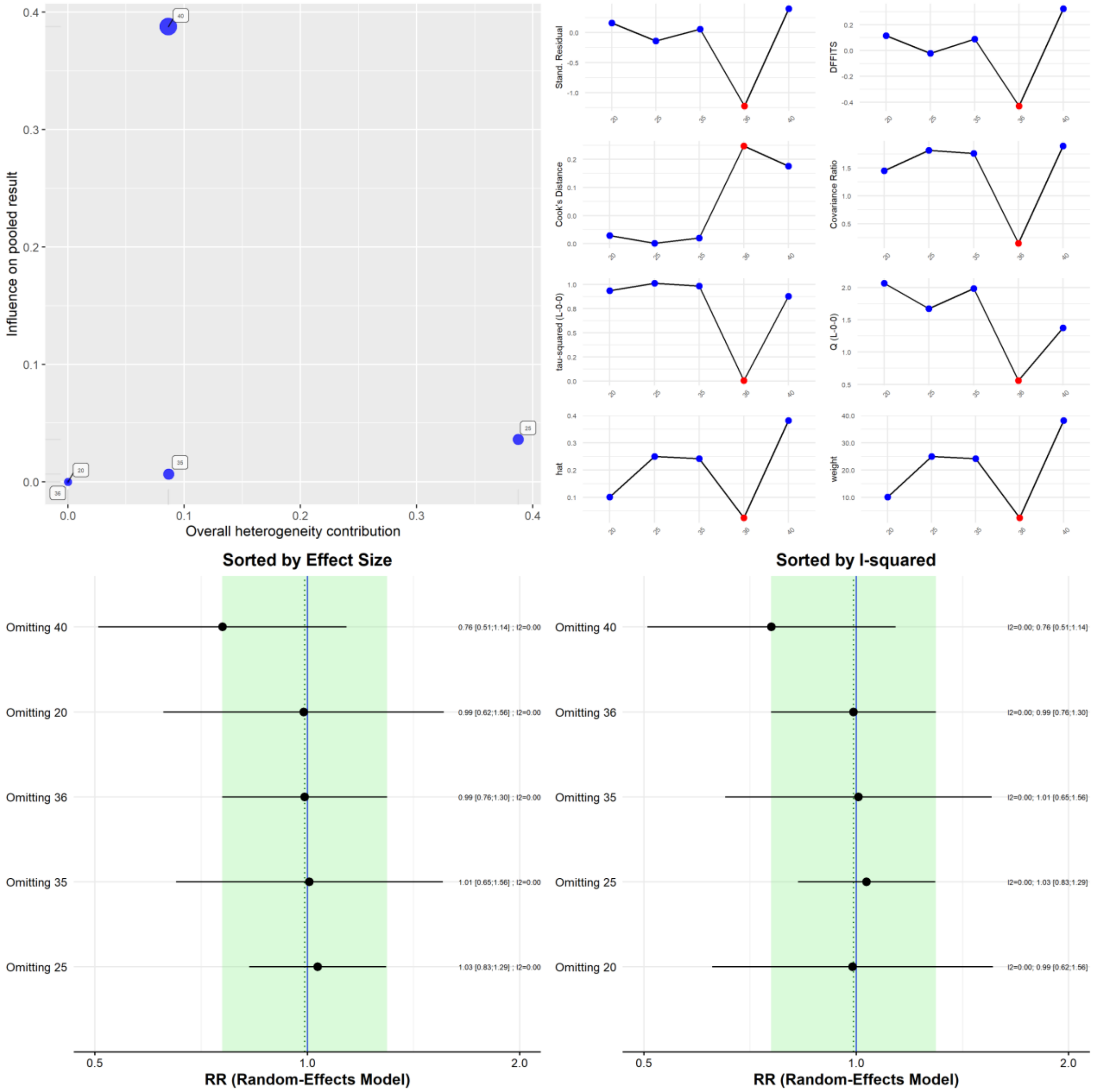


Figure VI.20. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rate of green sea turtle with circle vs. J hooks. Experiment 36 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

There were only two experiments available regarding the at-haulback mortality of green sea turtle in surface longlines. As such, it was not possible to conduct the meta-analysis. In experiment 20, 1 green sea turtle out of 1 died when retained in circle hooks and 1 out of 1 died when retained in J hooks (RR= 1.00; 95% CIs: 0.43; 2.31). In experiment 25, all the specimens survived (6 specimens retained with circle hooks and 4 specimens retained with J hooks). Given that only 2 studies were available, it was not possible to conduct a meta-analysis.

Post release mortality

Table VI.5 provides a summary of the available studies on post-release mortality for green sea turtle.

Table VI.5. Summary of post-release mortality studies for green sea turtle with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
TUG – Green sea turtle	1	0.0	Longline and hand-capture	Equatorial Pacific (Costa Rica)	C	NA	NA	Swimmer et al. (2006)
	9	0.0/22.2*	Gillnet	NW Atlantic (lower Cape Fear River)	NA	NA	NA	Snoddy & Williard (2010)
	3	20-40 (depending on hook status)	Longline	North Pacific	NA	NA	NA	Parker et al. (2005)
	6	0.0	Dip-net and tangle net	Gulf of Mexico (Florida)	NA	NA	NA	Hart & Fujisaki (2010)

* Turtles that displayed satellite transmission patterns indicative of mortality but for which they did not locate a carcass were categorised as suspected mortalities.

Oceanic whitetip (OCS)

Retention rates

Figure V1.21 shows the random effects model when all data compiled are used for oceanic whitetip. When all data are used, the RR is 1.13 (95% CIs: 0.65; 1.98). This means that on average we expect that the retention of oceanic whitetip when using circle hooks is 13% higher than when using J hooks, but this is not significant as the 95% confidence intervals vary between a decrease of 35% and an increase of 98%. In this analysis we also see that the overall heterogeneity (I^2) is relatively low (32%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis represented in Figure VI.22 did not identify outliers with major influence in the results, and for that reason all experiments were kept.

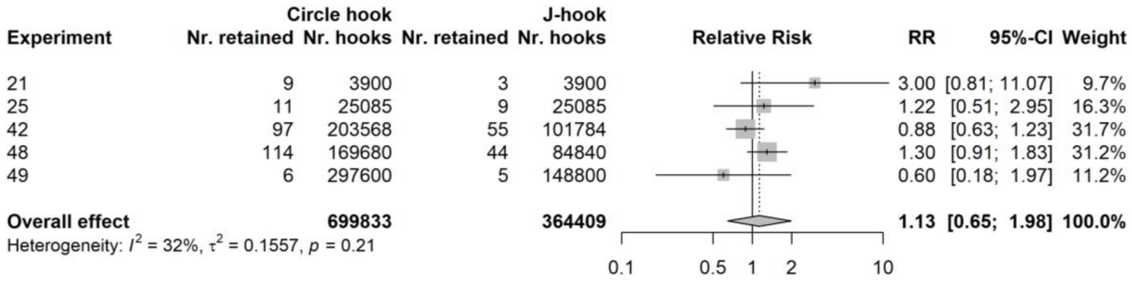


Figure VI.21. Forest plot of the random effects meta-analysis for all data in the retention rates of oceanic whitetip shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

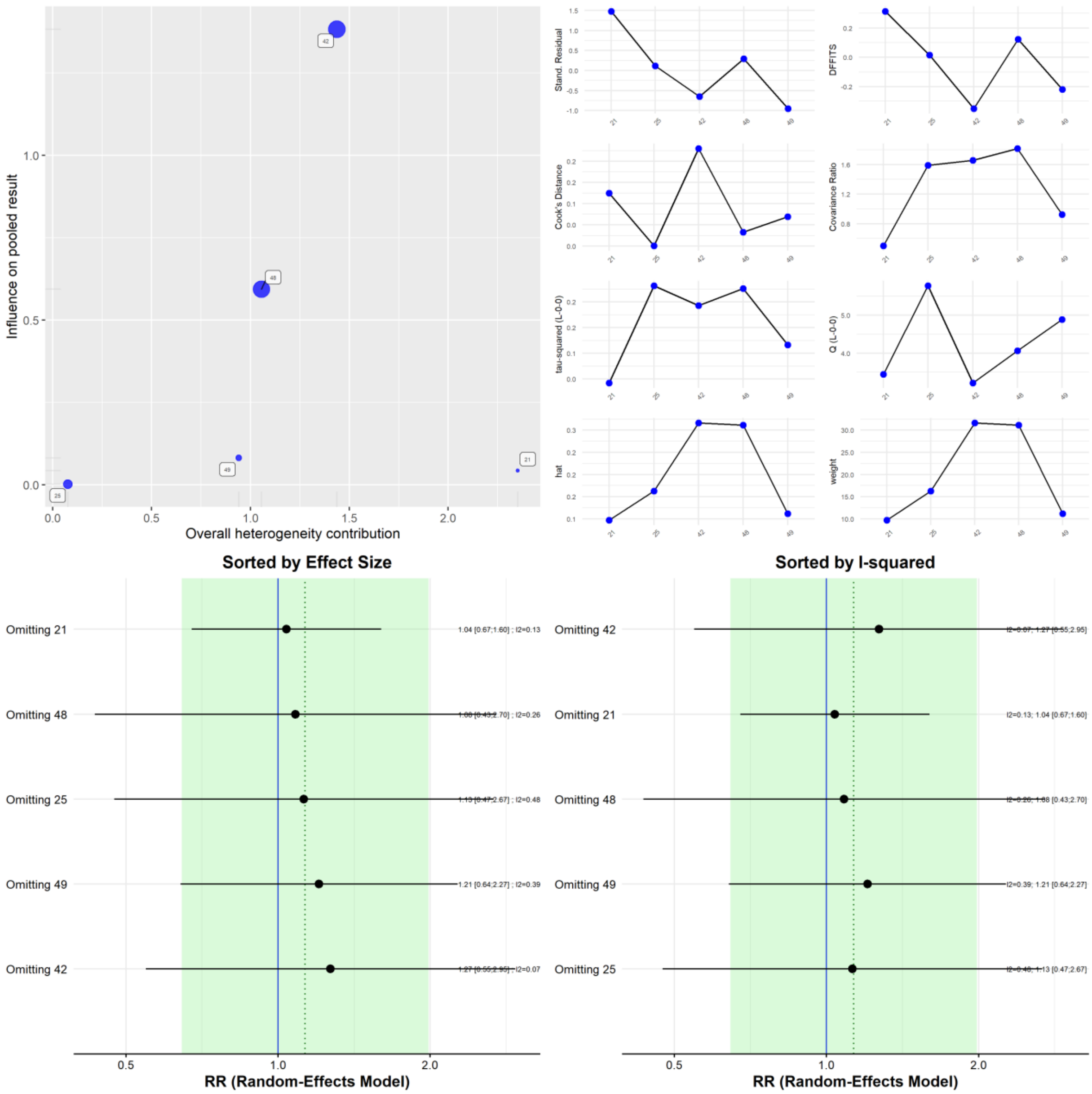


Figure VI.22. Influence analysis for the meta-analysis including all data performed for the retention rate of oceanic whitetip shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.23 provides the random effects model for oceanic whitetip, with regard to at-haulback hooking mortality. In this case the RR is 0.71 (95% CIs: 0.42; 1.18). This means that on average we expect that the mortality of oceanic whitetip when using circle hooks is 29% lower than when using J hooks, but this value is not significant with the 95% confidence intervals varying between a reduction of 58% and an increase of 18%. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI. 24. In this case no major outliers were identified and therefore all experiments were kept.

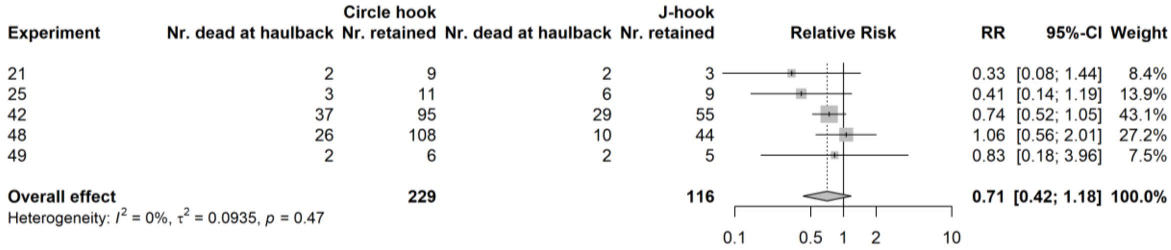


Figure VI.23. Forest plot of the random effects meta-analysis for all data in the at-haulback of oceanic whitetip shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

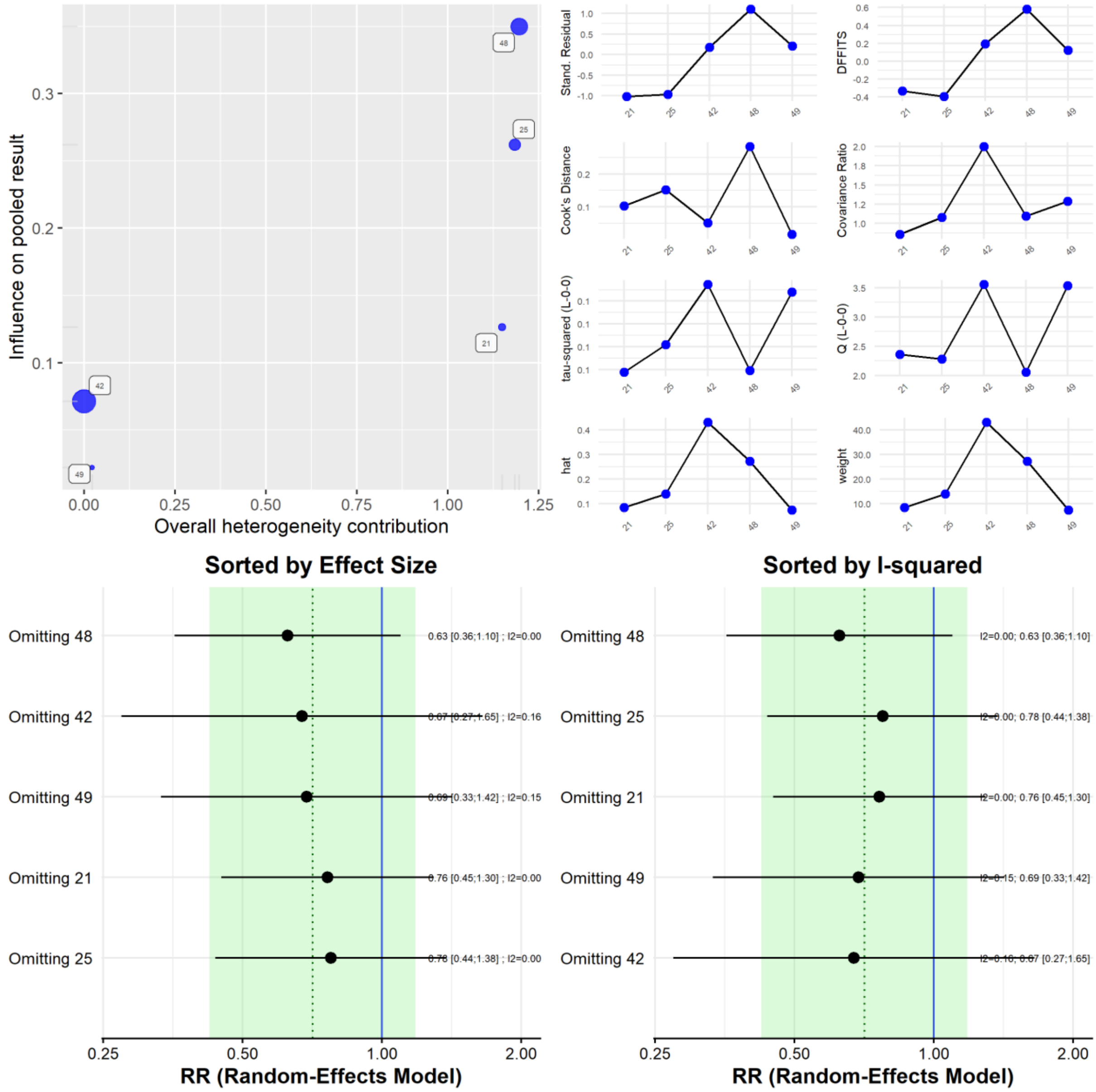


Figure VI.24. Influence analysis for the meta-analysis including all data for the at-haulback mortality of oceanic whitetip shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.6 provides a summary of the available studies on post-release mortality for oceanic whitetip shark.

Table VI.6. Summary of post-release mortality studies for oceanic whitetip shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
OCS – Oceanic whitetip	13	0.0	Longline	Central Pacific	C	Squid	Nylon	Musyl et al. (2011)
	2	50.0	Longline	Central Pacific	C	NA	Wire	Hutchinson (2016)
	16	0.0	Rod and reel	NW Atlantic	C	Fish	Wire	Andrzejaczek et al. (2018)
	11	0.0	Rod and reel	NW Atlantic	C	Fish	Wire	Howey-Jordan et al. (2013)
	8	0.0	Longline	Equatorial Western Atlantic	NA			Tolotti et al. (2015)
	1	0.0	Longline	Gulf of Mexico	NA			Carlson & Gulak (2012)

Porbeagle (POR)

Retention rates

Figure VI.25 shows the random effects model when all data compiled are used for porbeagle shark. When all data are used, the RR is 1.45 (95% CIs: 0.82; 2.57). This means that on average we expect that the retention of porbeagle when using circle hooks is 45% higher than when using J hooks, but this is not significant with the 95% confidence intervals varying between a decrease of 18% and an increase of 2.57 times. In this analysis we also see that the overall heterogeneity (I^2) is relatively low (29%) and passes the statistical assumption of homogeneity (p-value>0.05). The influential analysis represented in Figure VI.26 did not identify outliers with major influence in the results, and for that reason all experiments were kept.

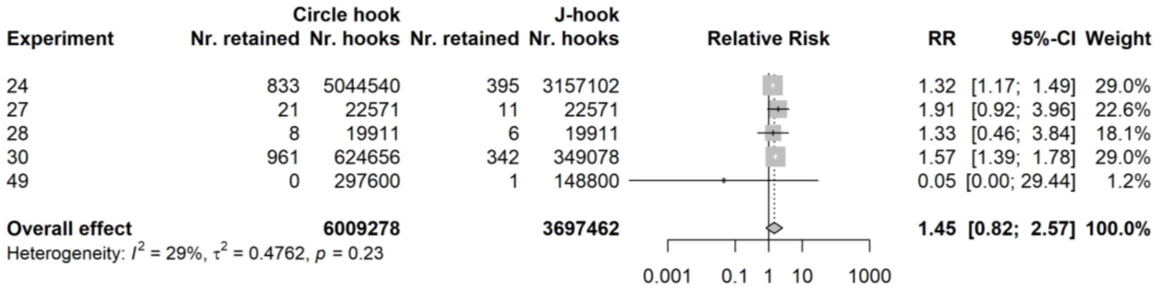


Figure VI.25. Forest plot of the random effects meta-analysis for all data in the retention rates of porbeagle shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

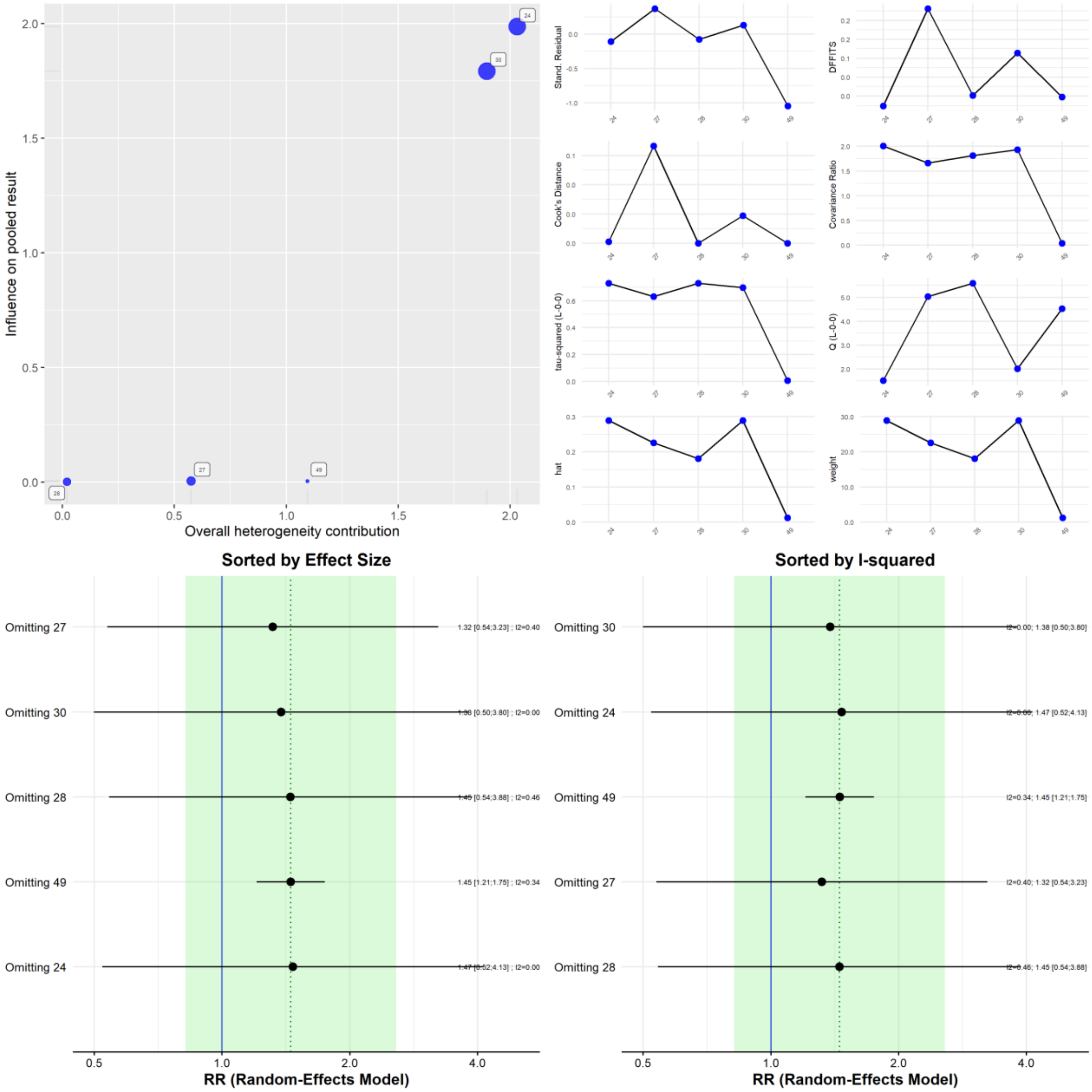


Figure VI.26. Influence analysis for the meta-analysis including all data performed for the retention rate of porbeagle shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

There were six experiments available (24, 27, 28, 29, 30, 49) regarding the at-haulback mortality of porbeagle in surface longlines; however only two experiments (24 and 29) reported at-haulback mortalities for specimens retained in both circle and J hooks. As such, it was not possible to conduct a meta-analysis. Here we therefore provide some details on those specific experiments. In experiment 24, 337 porbeagles died out of 833 retained in circle hooks and 186 porbeagles died out of 395 retained in J-hooks (RR= 0.86; 95% CIs: 0.75; 0.98). In experiment 29, 196 porbeagles died out of 657 retained in circle hooks and 69 porbeagles died out of 229 retained in J-hooks (RR= 0.99; 95% CIs: 0.79; 1.25). In experiments 27, 28 and 30 all specimens retained survived. In experiment 29, only 1 porbeagle was retained (when using J hooks) and this specimen suffered at-haulback mortality.

Post release mortality

Table VI.7 provides a summary of the available studies on post-release mortality for porbeagle shark.

Table VI.7. Summary of post-release mortality studies for porbeagle shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
POR – Porbeagle	33	18.2	Longline	NW Atlantic	C and J	NA	NA	Campana et al. (2016)
	18	14.0	Longline	NW Atlantic	C	NA	NA	Bowlby et al. (2020)
	4	0.0	Rod and reel	NE Atlantic	C	NA	NA	Pade et al. (2009)

Silky shark (FAL)

Retention rates

Figure VI.27 shows the random effects model when all data compiled are used for silky shark. When all data are used, the RR is 1.04 (95% CIs: 0.56; 1.93). This means that on average we expect that the retention of silky shark when using circle hooks is 4% higher than when using J hooks, but this value is not significant with the 95% confidence intervals varying between a decrease of 44% and an increase of 93%. In this analysis we also see that the overall heterogeneity (I^2) is very high (91%) and fails the statistical assumption of homogeneity (p-value<0.05). However, the influential analysis did not identify outliers with major influence in the results (Figure VI.28), and for that reason all experiments were kept.

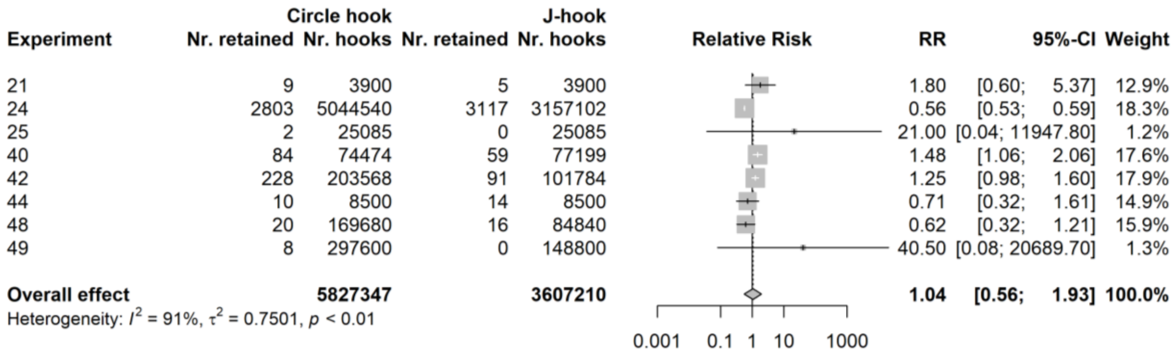


Figure VI.27. Forest plot of the random effects meta-analysis for all data in the retention rates of silky shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

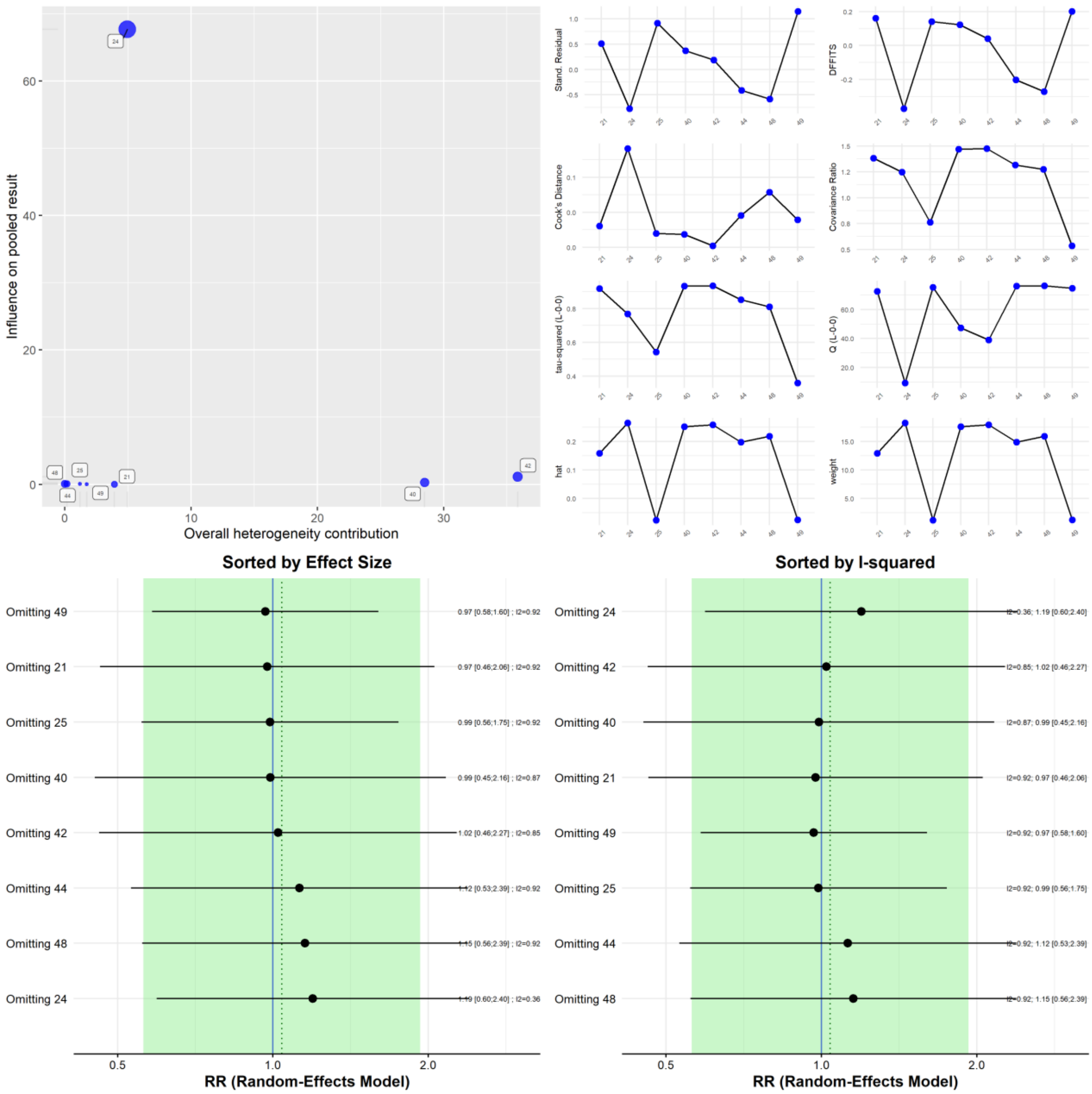


Figure VI.28. Influence analysis for the meta-analysis including all data performed for the retention rate of silky shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.29 provides the random effects model for silky shark, with regard to at-haulback hooking mortality. In this case the RR is 0.79 (95% CIs: 0.52; 1.19). This means that on average we expect that the mortality of silky shark when using circle hooks is 21% lower than when using J hooks, but this is not significant with the 95% confidence intervals varying between a reduction of 48% and an increase of 19% in at-haulback mortality. In this analysis the overall heterogeneity between studies is relatively low (I^2=23%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.30, and as no major outliers were identified all experiments were kept.

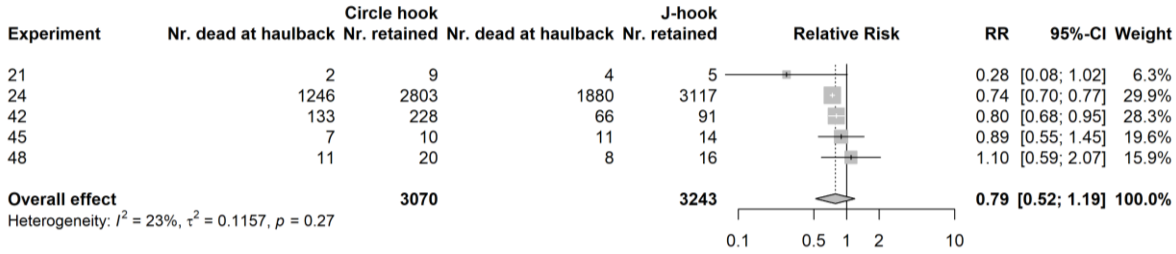


Figure VI.29. Forest plot of the random effects meta-analysis for all data in the at-haulback mortality of silky shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

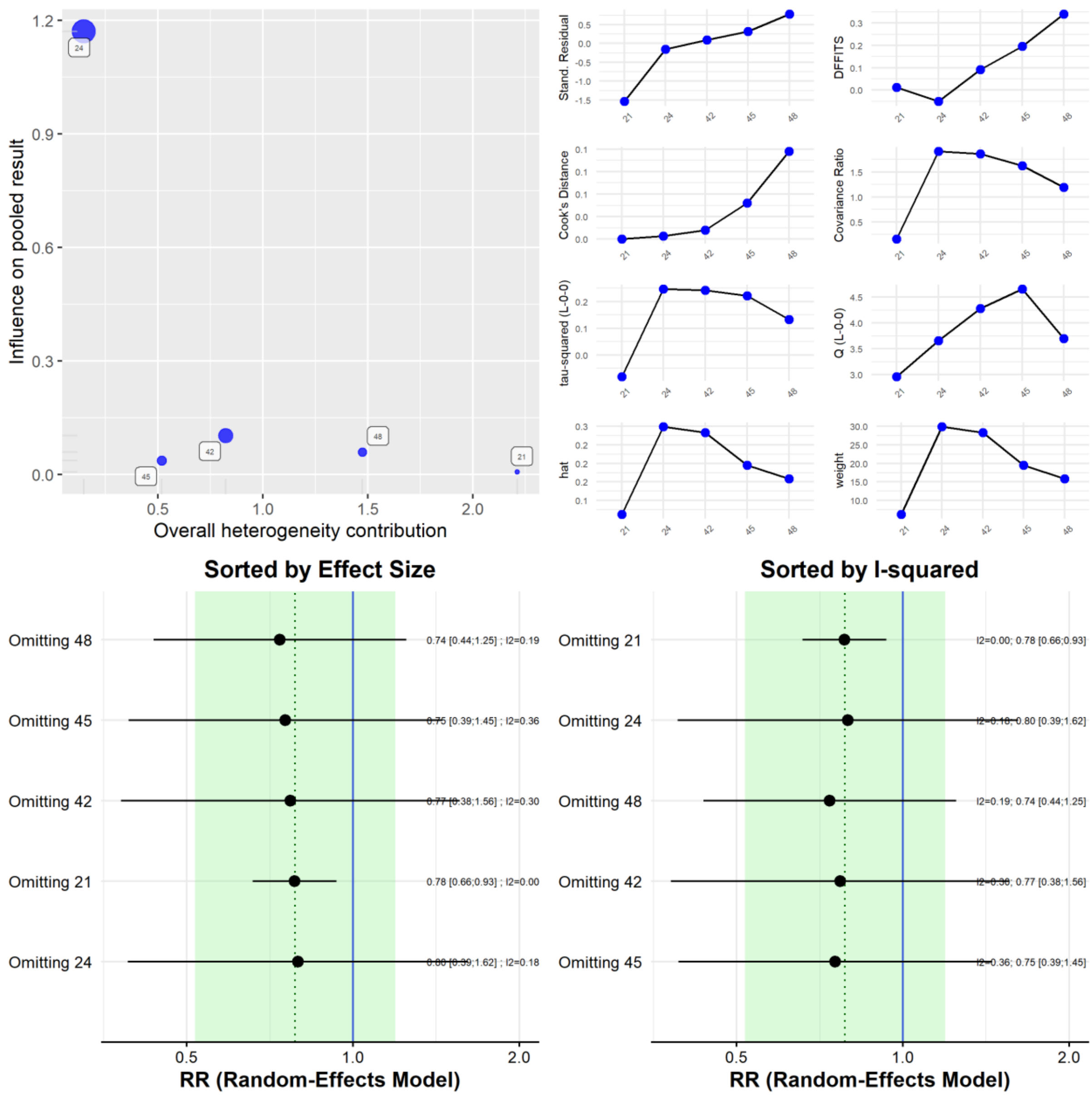


Figure VI.30. Influence analysis for the meta-analysis including all data performed for the at-haulback mortality of silky shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.8 provides a summary of the available studies on post-release mortality for silky shark.

Table VI.8. Summary of post-release mortality studies for silky shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
FAL – Silky shark	20	55.0	Purse-seine	Western Indian Ocean	NA	NA	NA	Poisson et al. (2014)
	23	52.2	Purse-seine	Western and central Pacific	NA	NA	NA	Hutchinson et al. (2015)
	13	61.5	Purse-seine	Equatorial eastern Pacific	NA	NA	NA	Eddy et al. (2016)
	10	0.0	Longline	Central Pacific	C	Squid	Nylon	Musyl et al. (2011)
	35	20.0	Longline	Western Pacific	C	Fish		Musyl & Gilman (2018)
	38	5.3		Equatorial eastern Pacific	C and tuna hooks	Fish	Nylon	Schaefer et al. (2019)
	9	0.0	Longline	Eastern tropical Pacific	C	Squid and fish	NA	Hutchinson et al. (2019)

Bigeye thresher (BTH)

Retention rates

Figure VI.31 shows the random effects model when all data compiled are used for bigeye thresher. When all data are used, the RR is 0.84 (95% CIs: 0.61; 1.16). In this analysis we also see that the overall heterogeneity (I^2) is high (78%) and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis is represented in Figure VI.32, and experiment 24 was identified as an outlier with major influence in the results.

The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VI.33 and validation indicated in Figure VI.34. When experiment 24 is excluded, the RR is 0.91 (95% CIs: 0.74; 1.13), meaning that the retention of bigeye thresher when using circle hooks is 9% lower than when using J hooks, but this is not significant as the 95% confidence intervals vary between a reduction of 26% and an increase of 13%. We also see that the overall heterogeneity (I^2) value changes from 78% to 0%.

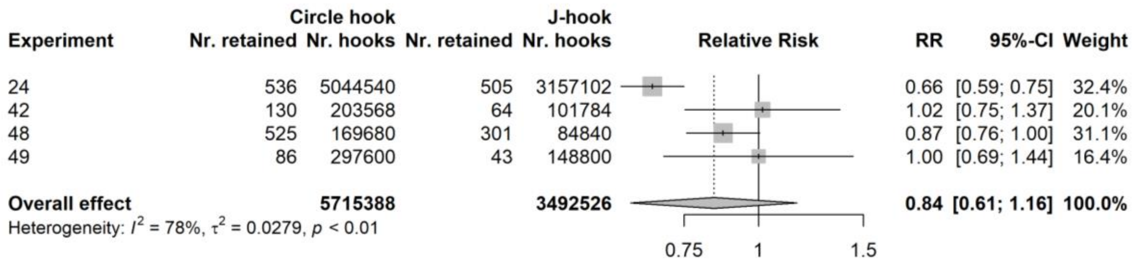


Figure VI.31. Forest plot of the random effects meta-analysis for all data performed for the retention rates of bigeye thresher shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

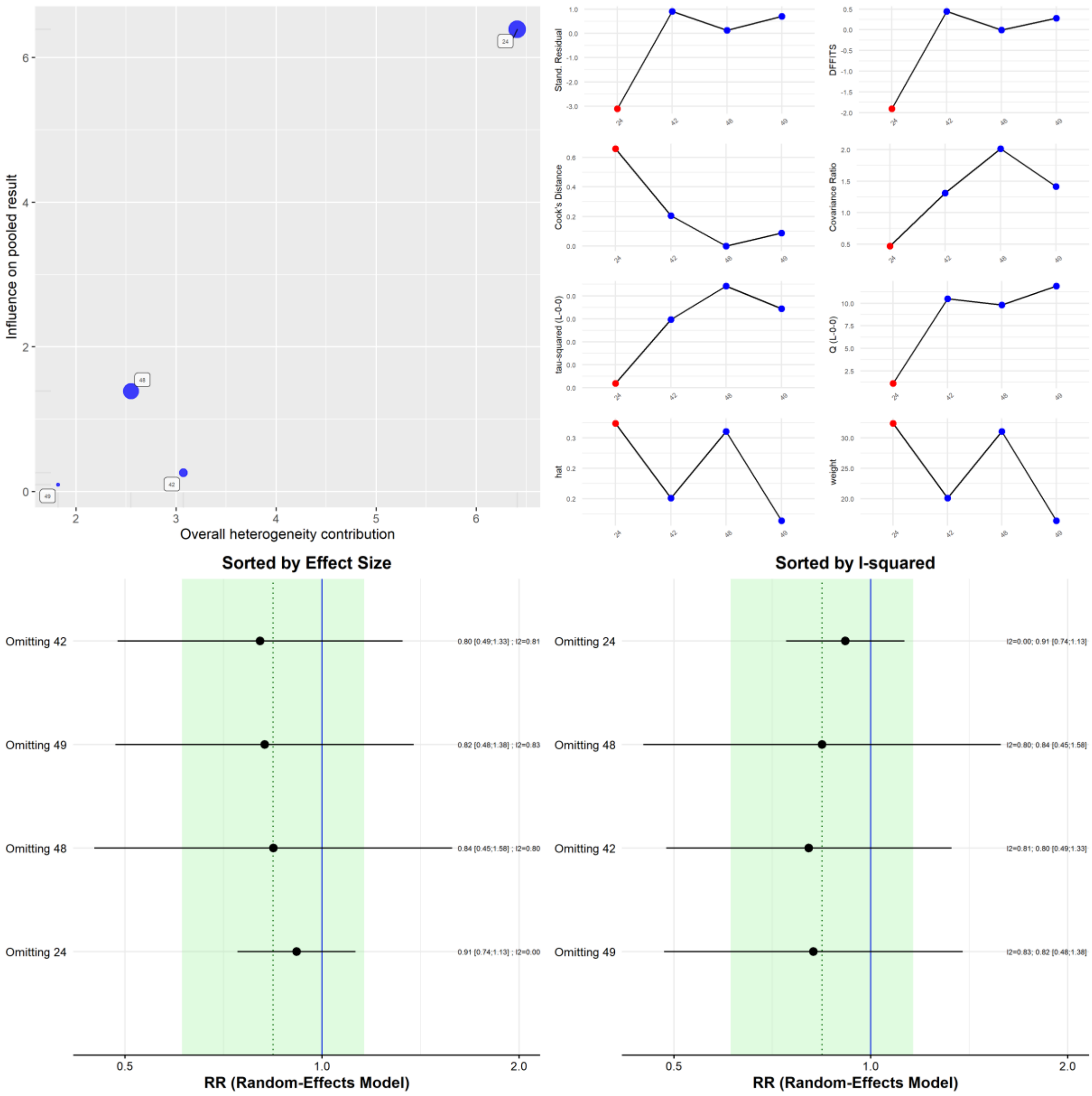


Figure VI.32. Influence analysis for the meta-analysis including all data performed for the retention rates of bigeye thresher shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

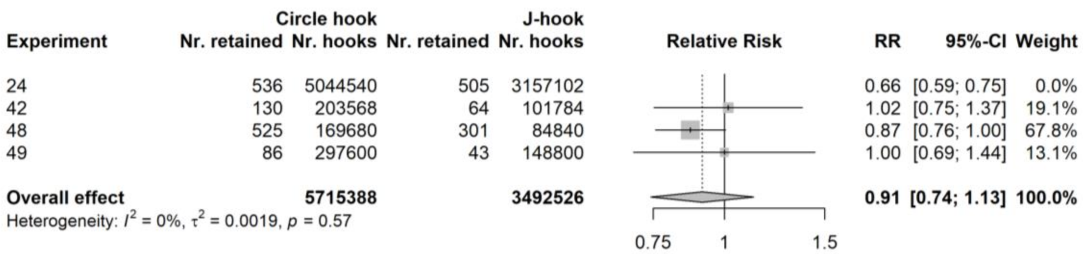


Figure VI.33. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of bigeye thresher shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). Experiment 24 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

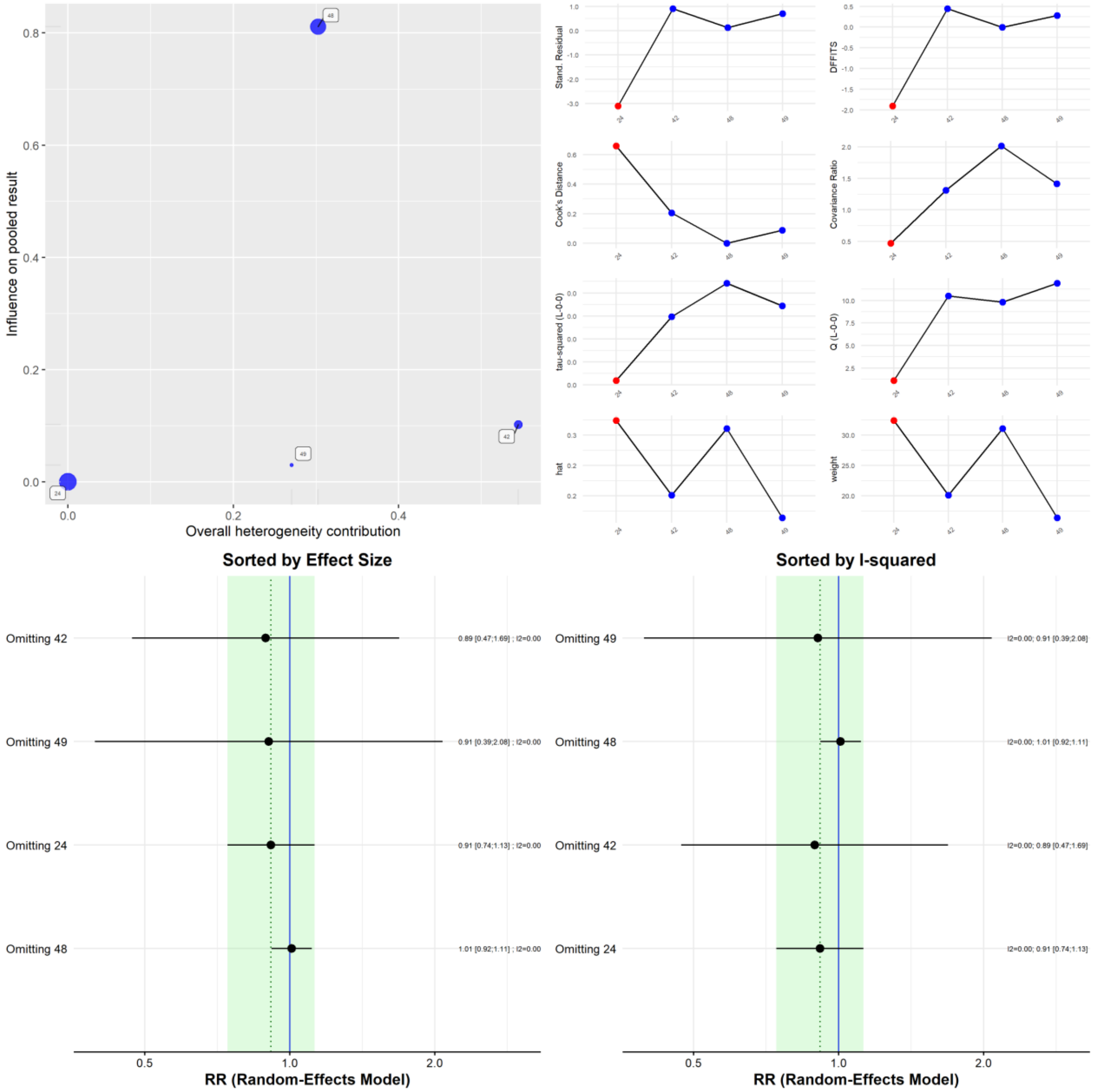


Figure VI.34. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rate of bigeye thresher shark with circle vs. J hooks. Experiment 24 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.35 provides the random effects model for bigeye thresher, with regard to at-haulback hooking mortality. In this case the RR is 1.19 (95% CIs: 0.97; 1.45). This means that on average we expect that the mortality of bigeye thresher when using circle hooks is 19% higher than when using J hooks, but this is not significant as the 95% confidence intervals vary between a reduction of 3% and an increase of 45%. In this specific analysis the overall heterogeneity between studies is low (I^2=13%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.36. In this case no, major outliers were identified and therefore all experiments were kept.

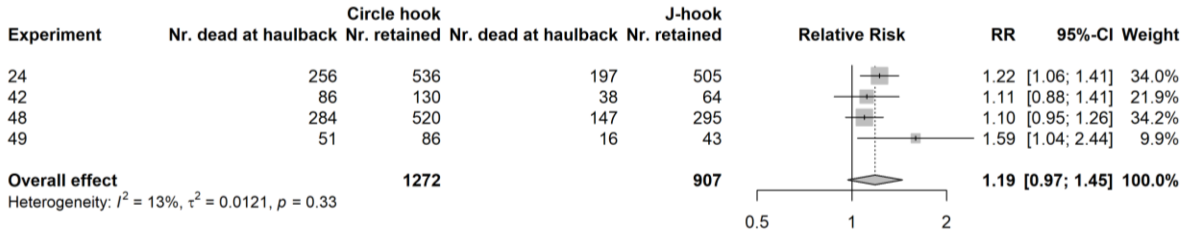


Figure VI.35. Forest plot of the random effects meta-analysis for all data performed for the at-haulback mortality of bigeye thresher shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

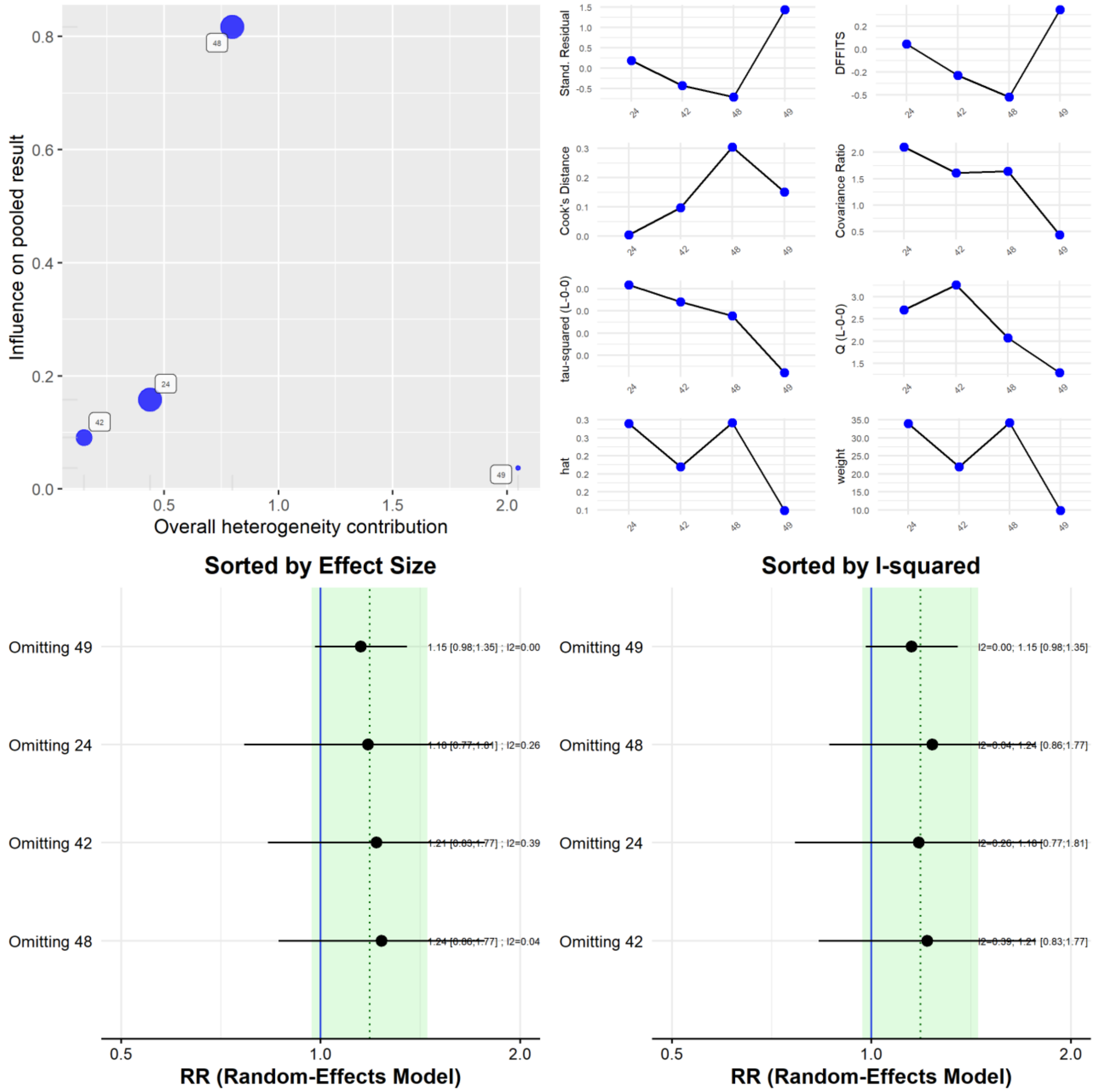


Figure VI.36. Influence analysis for the meta-analysis including all data performed for the at-haulback mortality of bigeye thresher shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.9 provides a summary of the available studies on post-release mortality for bigeye thresher shark.

Table VI.9. Summary of post-release mortality studies for bigeye thresher shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
BTH – Bigeye thresher	3	0.0	Longline	Central Pacific	C	Squid	Nylon	Musyl et al. (2011)
	12	25.0	Longline	Central Pacific	C	NA	Wire	Hutchinson (2016)
	13	7.6	Deep-set buoy gear	NE Pacific	C	Fish and squid	NA	Sepulveda et al. (2019)
	1	0.0	Longline	Gulf of Mexico	NA			Carlson & Gulak (2012)
	28	10.7	Longline	Central Pacific	C	NA	Wire	Hutchinson & Bigelow (2019)
	1	0.0	Longline	SW Pacific	NA	NA	NA	Stevens et al. (2010)
	12	0.0	Longline	NE Atlantic	J	NA	Nylon and wire	Coelho et al. (2015)

Longfin mako (LMA)

Retention rates

Figure VI.37 shows the random effects model when all data compiled are used for longfin mako. When all data are used, the RR is 0.67 (95% CIs: 0.11; 4.06). This means that on average we expect that the retention of longfin mako when using circle hooks is 33% lower than when using J hooks, but this is not significant with the 95% confidence intervals varying between a decrease of 89% and an increase of 4 times. In this analysis we also see that the overall heterogeneity (I^2) is high (85%) and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis represented in Figure VI.38 and identified two outliers (experiments 42 and 49) with major influence in the results. However, these experiments were kept in the analysis otherwise it would not have been possible to conduct the meta-analysis.

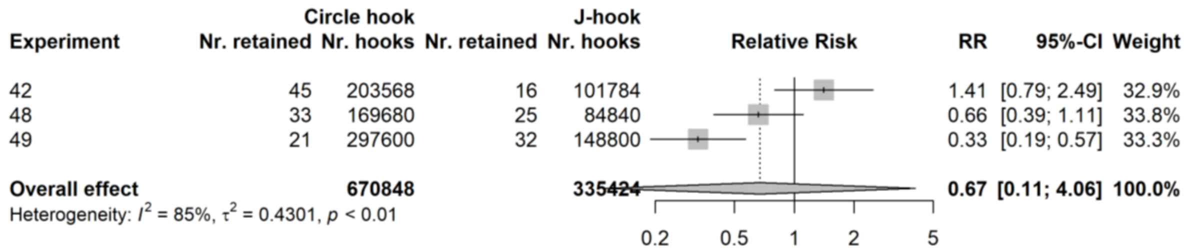


Figure VI.37. Forest plot of the random effects meta-analysis for all data, performed for the retention rates of longfin mako shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

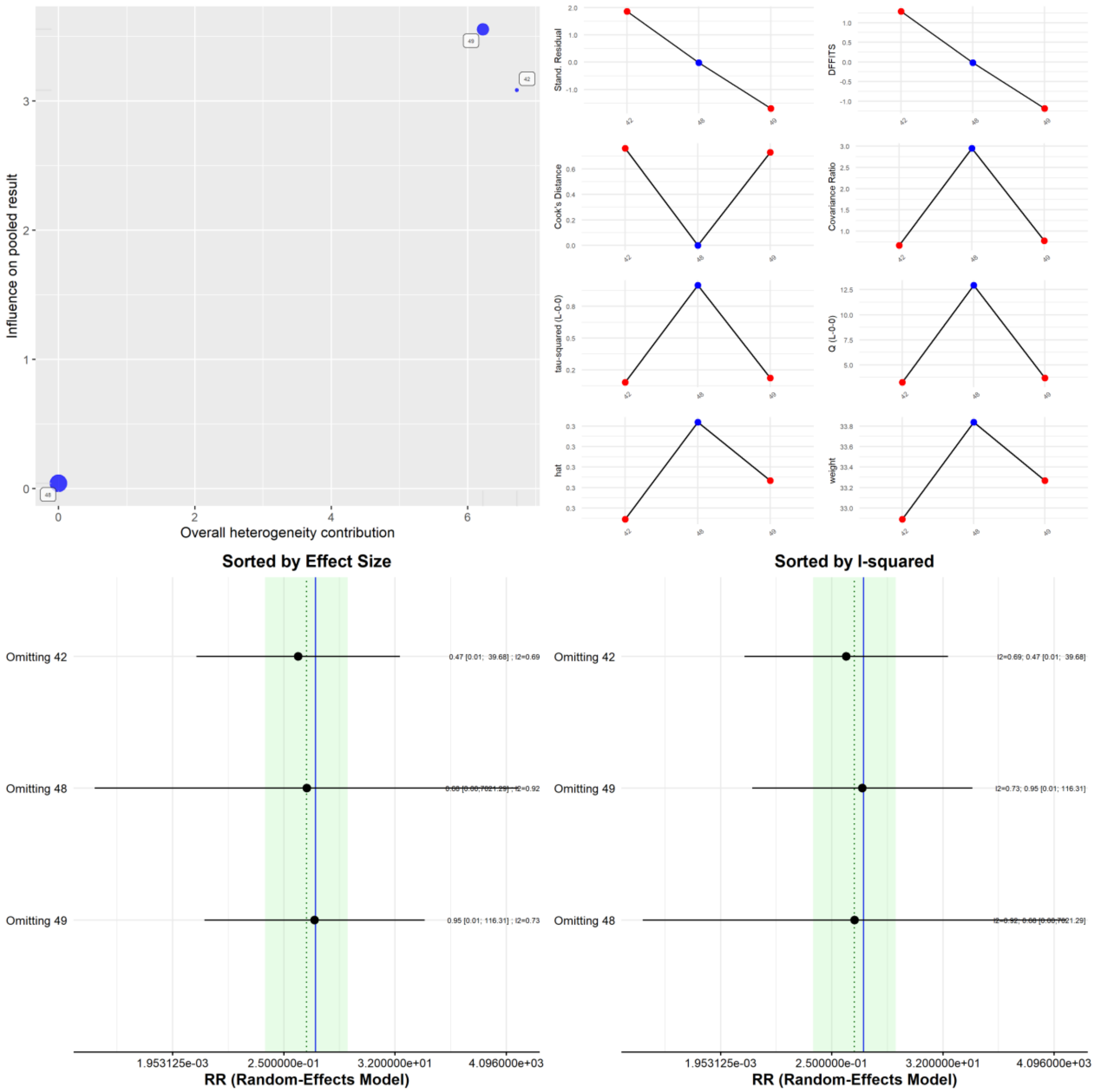


Figure VI.38. Influence analysis for the meta-analysis including all data, performed for the retention rates of longfin mako shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.39 provides the random effects model for longfin mako, with regards to at-haulback hooking mortality. In this case the RR is 1.20 (95% CIs: 0.62; 2.35). This means that on average we expect that the at-haulback mortality of longfin mako when using circle hooks is 20% higher than when using J hooks, but this is not significant with the 95% confidence intervals varying between a reduction of 38% and an increase of 2.35 times. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.40. In this case no major outliers were identified and therefore all experiments were kept.

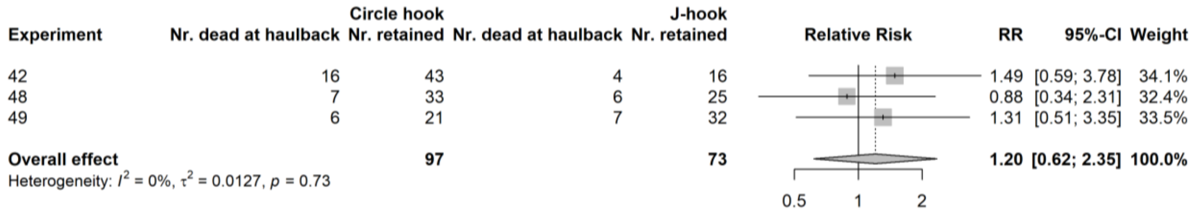


Figure VI.39. Forest plot of the random effects meta-analysis for all data, performed for the at-haulback mortality of longfin mako shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

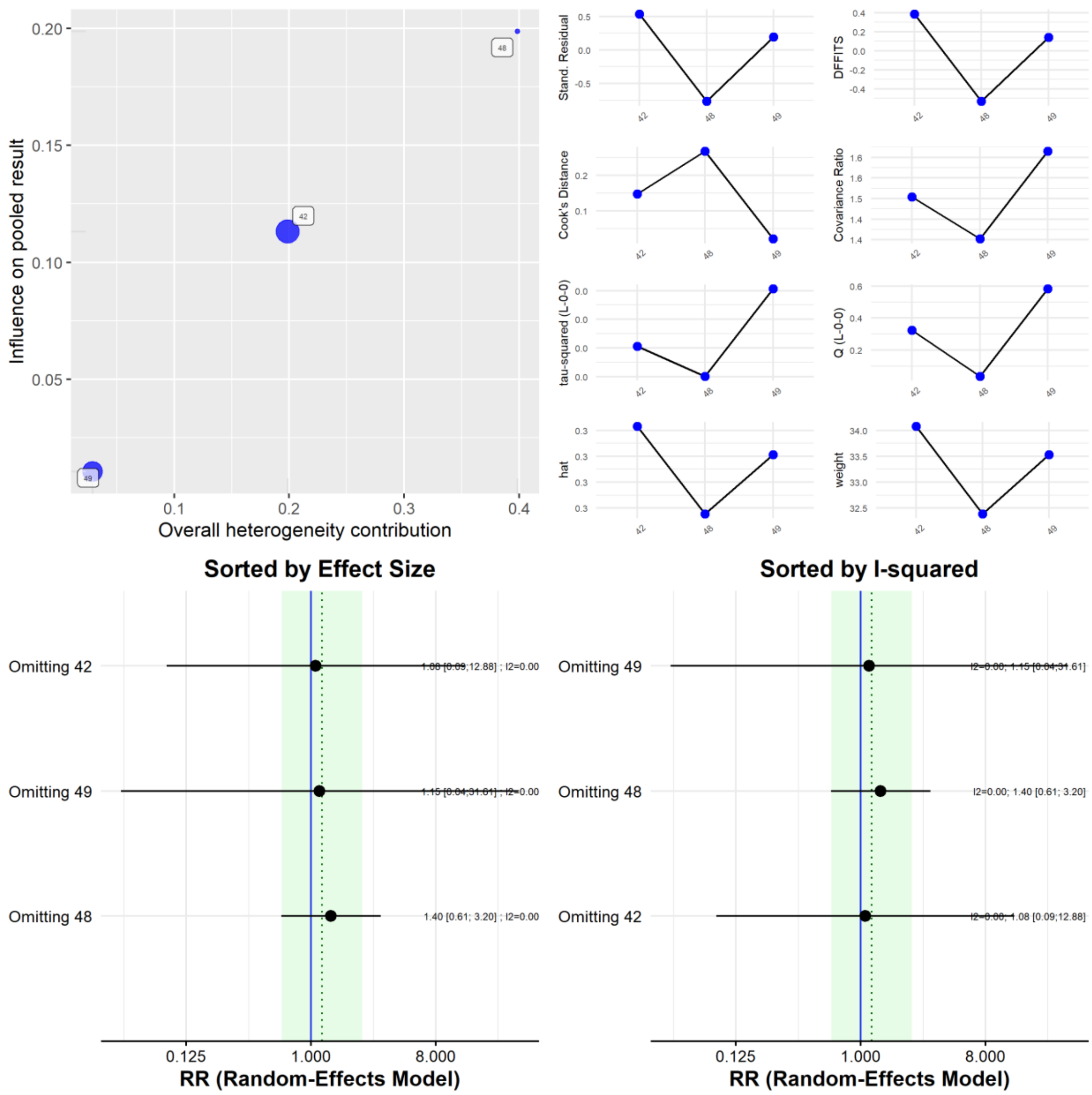


Figure VI.40. Influence analysis for the meta-analysis including all data, performed for the at-haulback mortality of longfin mako shark with circle vs. J hooks. Top left panel

– Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.10 provides a summary of the available studies on post-release mortality for longfin mako.

Table VI.10. Summary of post-release mortality studies for longfin mako with indication of gear and region, and if factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
LMA – Longfin mako	1	100	Longline or Rod and reel	NW Atlantic	C	NA	NA	Adams et al. (2015)

Crocodile shark (PSK)

Retention rates

Figure VI.41 shows the random effects model when all data compiled are used for crocodile shark. When all data are used, the RR is 1.42 (95% CIs: 0.97; 2.08). In this analysis we also see that the overall heterogeneity (I^2) is high (72%) and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis is represented in Figure VI.42, with experiments 42 and 49 identified as outliers with major influence in the results. The analysis was therefore re-run excluding those experiments, with the results of the new pooled analysis indicated in Figure VI.43 and validation indicated in Figure VI.44. When experiments 42 and 49 are excluded, the RR is 1.34 (95% CIs: 0.76; 2.36), meaning that the retention of crocodile shark when using circle hooks is 34% higher than when using J hooks, but this is not significant as the 95% confidence intervals vary between a reduction of 24% and an increase of 2.36 times. We also see that the overall heterogeneity (I^2) value changes from 72% to 0%.

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	RR	95%-CI	Weight
25	17	25085	8	25085	2.12	[0.92; 4.92]	8.6%
42	811	203568	365	101784	1.11	[0.98; 1.26]	32.5%
44	6	8500	5	8500	1.20	[0.37; 3.93]	4.9%
48	473	169680	189	84840	1.25	[1.06; 1.48]	30.8%
49	177	297600	42	148800	2.11	[1.51; 2.95]	23.3%
Overall effect		**704433**		**369009**	**1.42**	**[0.97; 2.08]**	**100.0%**

Heterogeneity: $I^2 = 72\%$, $\tau^2 = 0.0604$, $p < 0.01$

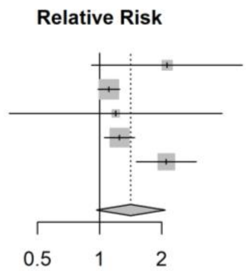


Figure VI.41. Forest plot of the random effects meta-analysis for all data in the retention rates of crocodile shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

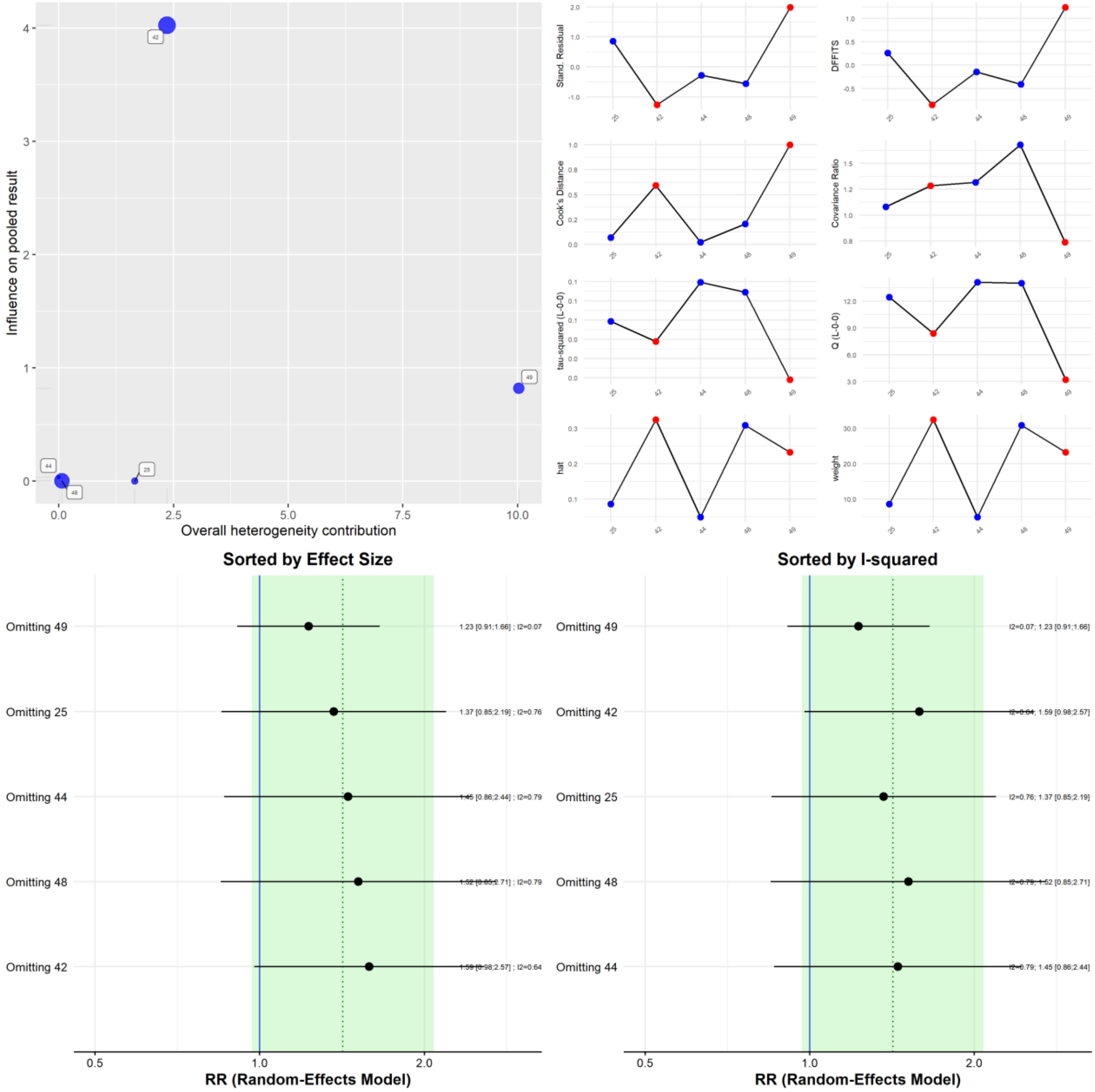


Figure VI.42. Influence analysis for the meta-analysis including all data performed for the retention rate of crocodile shark with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	J-hook Nr. retained	J-hook Nr. hooks	Relative Risk	RR	95%-CI	Weight
25	17	25085	8	25085		2.12	[0.92; 4.92]	14.0%
42	811	203568	365	101784		1.11	[0.98; 1.26]	0.0%
44	6	8500	5	8500		1.20	[0.37; 3.93]	7.6%
48	473	169680	189	84840		1.25	[1.06; 1.48]	78.4%
49	177	297600	42	148800		2.11	[1.51; 2.95]	0.0%
Overall effect		**704433**		**369009**		**1.34**	**[0.76; 2.36]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0309$, $p = 0.48$

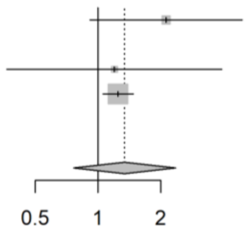


Figure VI.43. Forest plot of the random effects meta-analysis excluding 2 outliers in the retention rates of crocodile shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). Experiments 42 and 49 were excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

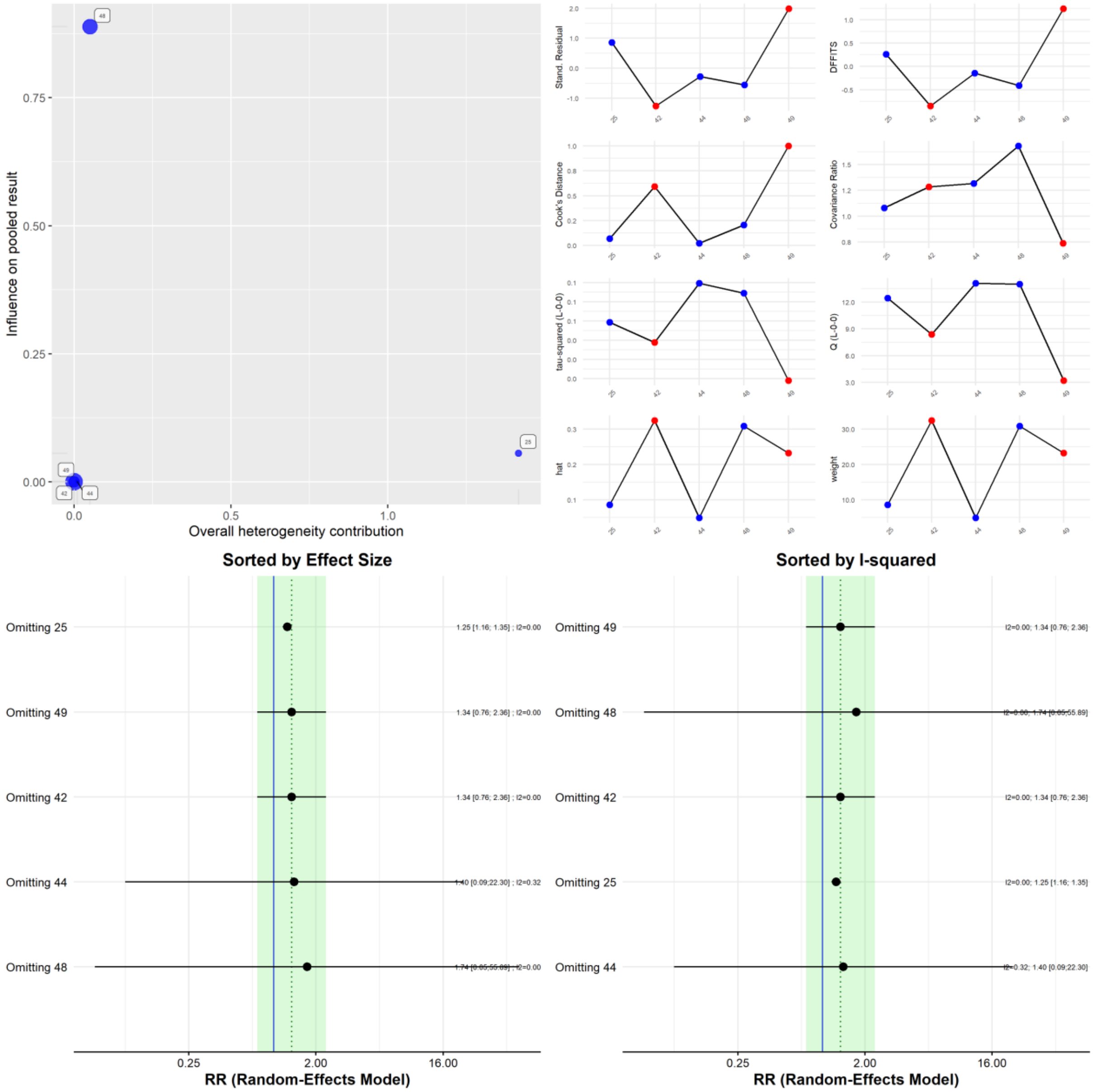


Figure VI.44. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the retention rate of crocodile shark with circle vs. J hooks. Experiments 42 and 49 were excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.45 provides the random effects model for crocodile shark, with regard to at-haulback hooking mortality. When all experiments are considered in the analysis, the RR is 1.65 (95% CIs: 0.34; 7.94). In this analysis the overall heterogeneity between studies is high (I^2=74%) and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis is represented in Figure VI.46 and experiment 42 was identified as an outlier with major influence in the results.

The analysis was therefore re-run excluding this experiment, with the results of the new pooled analysis indicated in Figure VI.47 and validation indicated in Figure VI.48. When experiment 42 is excluded, the RR is 1.16 (95% CIs: 0.55; 2.45), meaning that the at-haulback mortality of crocodile shark when using circle hooks is 16% higher than when using J hooks, but this is not significant as the 95% confidence intervals vary between a reduction of 45% and an increase of 2.45 times. We also see that the overall heterogeneity (I^2) is reduced from 74% to 10%.

Experiment	Circle hook Nr. dead at haulback	Circle hook Nr. retained	J-hook Nr. dead at haulback	J-hook Nr. retained	RR	95%-CI	Weight
25	2.000	17.000	2.000	8.000	0.47	[0.08; 2.76]	15.2%
42	69.000	811.000	2.000	365.000	15.53	[3.83; 62.99]	17.8%
45	6.035	6.035	3.995	5.015	1.25	[0.81; 1.92]	23.7%
48	41.000	473.000	9.000	189.000	1.82	[0.90; 3.67]	22.4%
49	16.000	177.000	5.000	42.000	0.76	[0.29; 1.96]	20.9%
Overall effect		**1484.035**		**609.015**	**1.65**	**[0.34; 7.94]**	**100.0%**

Heterogeneity: $I^2 = 74\%$, $\tau^2 = 1.3336$, $p < 0.01$

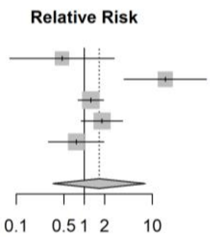


Figure VI.45. Forest plot of the random effects meta-analysis for all data in the at-haulback mortality of crocodile shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

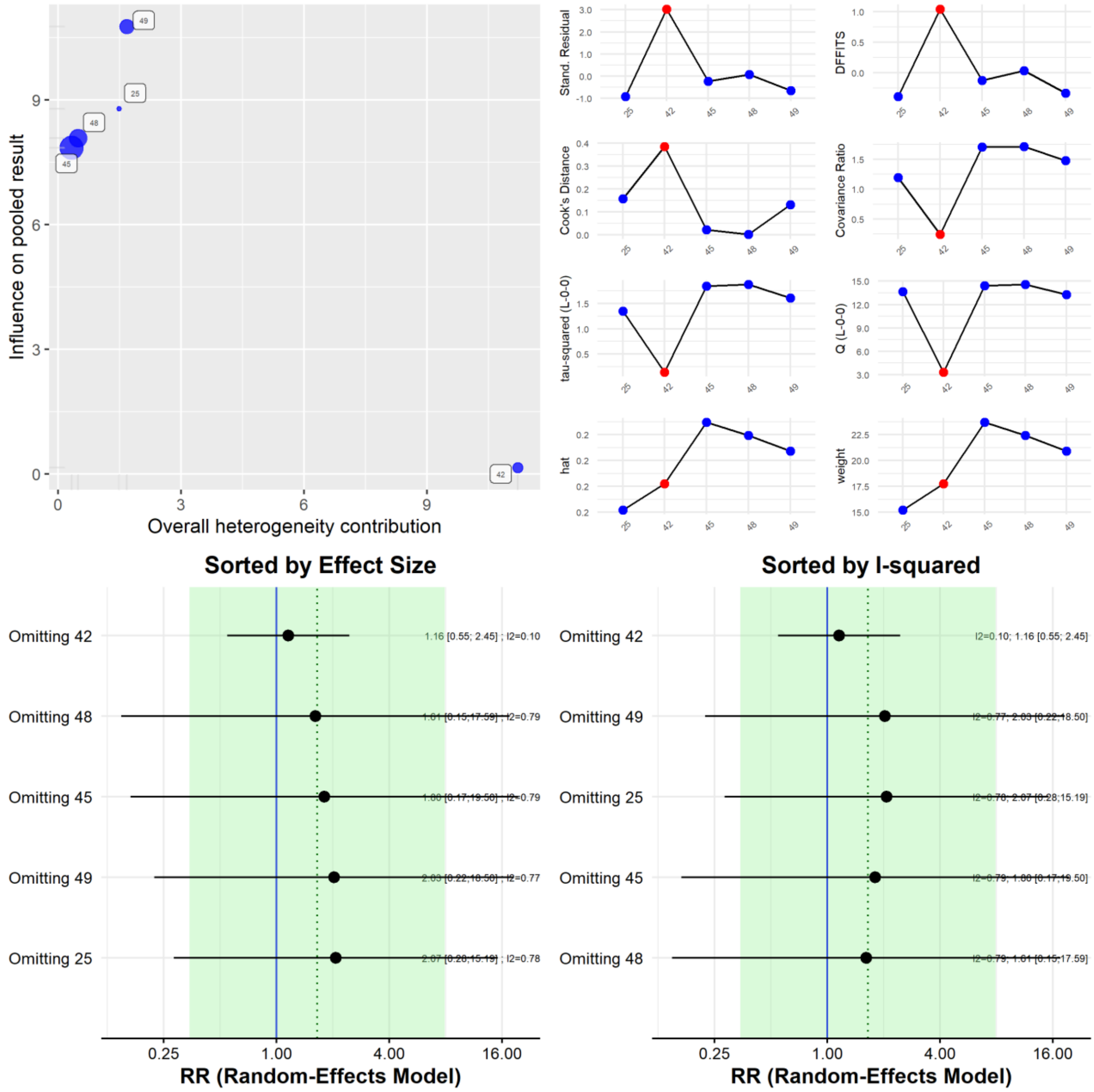


Figure VI.46. Influence analysis for the meta-analysis including all data performed for the at-haulback mortality of crocodile shark with circle vs J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

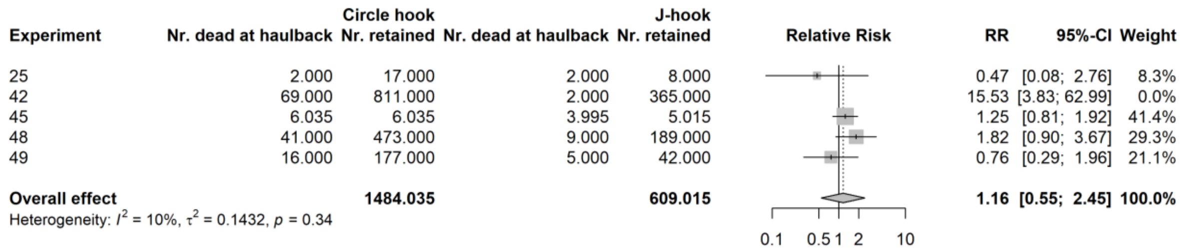


Figure VI.47. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of crocodile shark with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiment 42 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

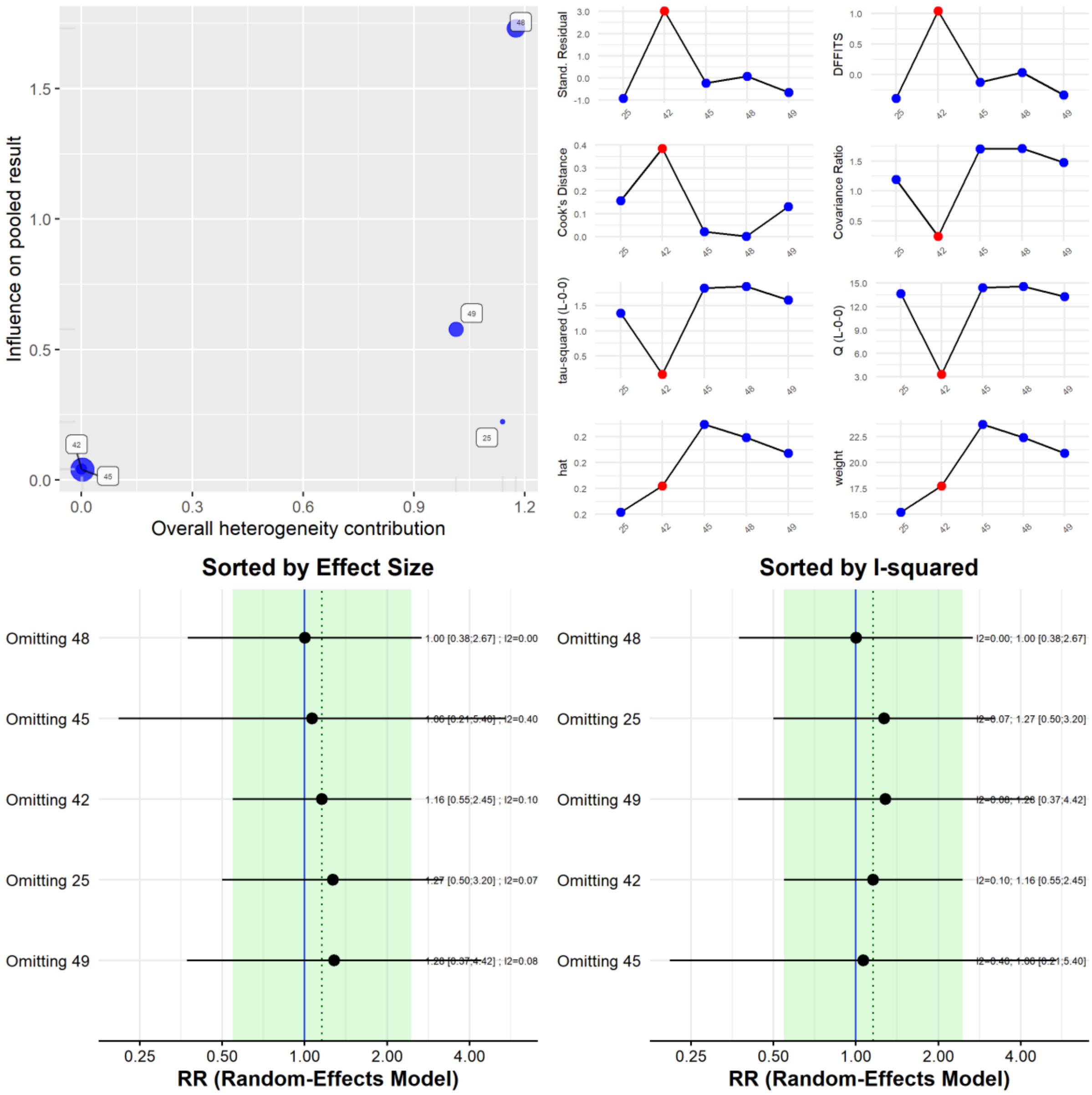


Figure VI.48. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of crocodile shark with circle vs. J hooks. Experiment 42 was excluded (it is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post-release mortality

There are no studies available with information for crocodile shark in terms of post-release mortality.

Scalloped hammerhead (SPL)

Retention rates

Figure VI.49 shows the random effects model when all data compiled are used for scalloped hammerhead. When all data are used, the RR is 0.90 (95% CIs: 0.30; 2.67). This means that on average we expect that the retention of scalloped hammerhead when using circle hooks is 10% lower than when using J hooks, but this value is not significant as the 95% confidence intervals vary between a decrease of 70% and an increase of 2.67 times. In this analysis we also see that the overall heterogeneity (I^2) is relatively low (46%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis represented in Figure VI.50 did not identify outliers with major influence in the results, and for that reason all experiments were kept.

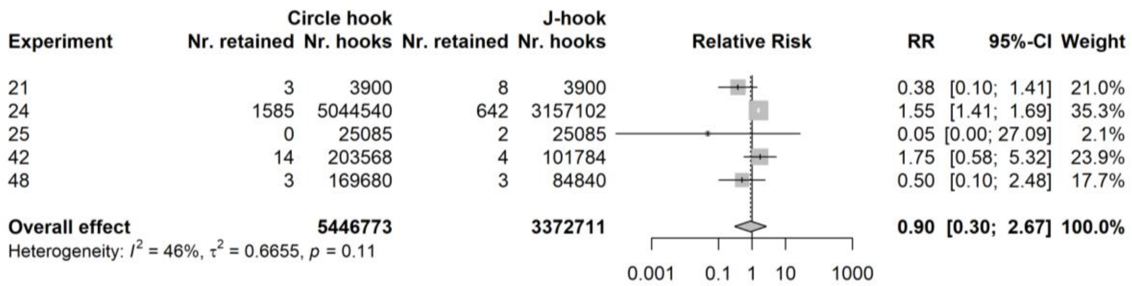


Figure VI.49. Forest plot of the random effects meta-analysis for all data in the retention rates of scalloped hammerhead with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

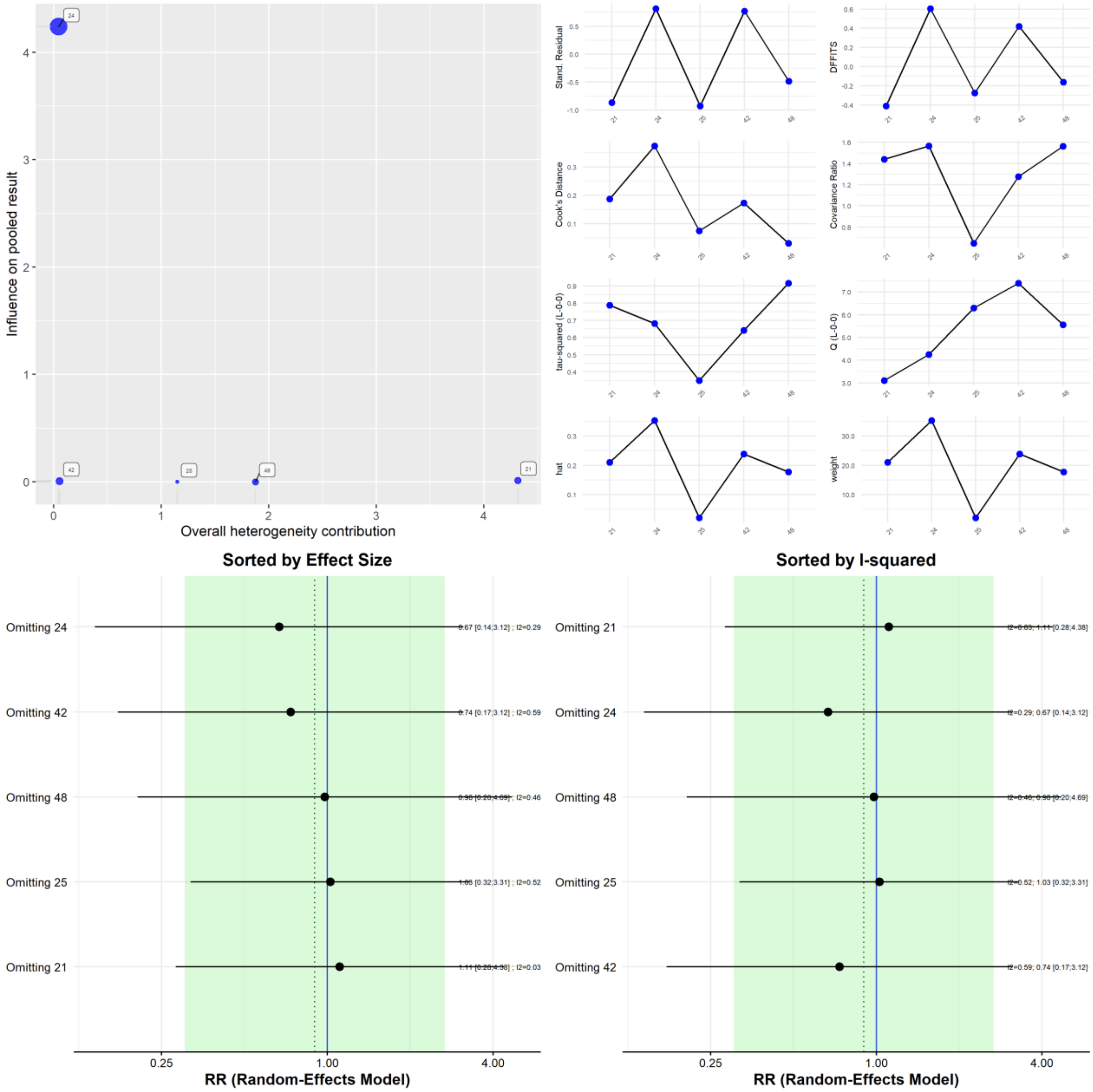


Figure VI.50. Influence analysis for the meta-analysis including all data performed for the retention rates of scalloped hammerhead with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.51 provides the random effects model for scalloped hammerhead, with regard to at-haulback hooking mortality. In this case the RR is 0.79 (95% CIs: 0.35; 1.77). This means that on average we expect that the mortality of scalloped hammerhead when using circle hooks is 21% lower than when using J hooks, but this value is not significant with the 95% confidence intervals varying between a reduction of 65% and an increase of 77%. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.52 and no major outliers were identified and therefore all experiments were kept.

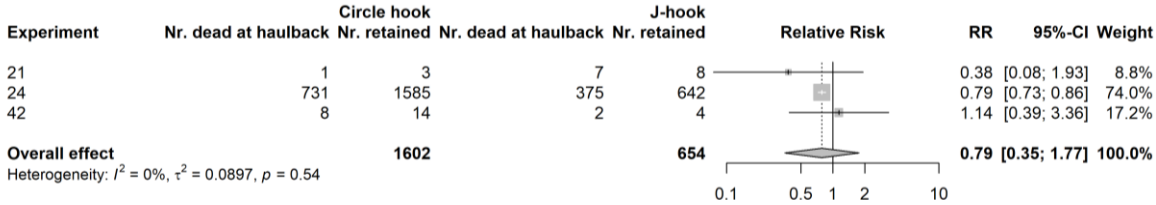


Figure VI.51. Forest plot of the random effects meta-analysis for all data in the at-haulback mortality of scalloped hammerhead with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

Post release mortality

Table VI.11 provides a summary of the available studies on post-release mortality for scalloped hammerhead shark.

Table VI.11. Summary of post-release mortality studies for scalloped hammerhead shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
SPL – Scalloped hammerhead	3	100	Purse-seine	Equatorial eastern Pacific	NA	NA	NA	Eddy et al. (2016)
	6	0.0/33.3*	Longline	Equatorial Atlantic	C	NA	Nylon	Bezerra et al. (2020)
	33	0.0	Rod and reel and bottom longline	Gulf of Mexico	C	Fish	Nylon	Wells et al. (2018)
	1	100	Handline	Red sea	C	Fish	Nylon	Spaet et al. (2017)
	1	100	Hook-and-line gear	Gulf of Mexico	NA	NA	NA	Hoffmayer et al. (2013)

*: Two tags released prematurely and the following is provided by the authors: "*Two premature releases may be related to several reasons, but premature death resulting from the stress of the capture and on-board tagging procedure appears to be the most probable cause*"

Smooth hammerhead (SPZ)

Retention rates

Figure VI.52 shows the random effects model when all data compiled are used for smooth hammerhead. When all data is used, the RR is 1.07 (95% CIs: 0.40; 2.87). This means that on average we expect that the retention of smooth hammerhead when using circle hooks is 7% higher than when using J hooks, but this is not significant with the 95% confidence intervals varying between a decrease of 60% and an increase of 2.87 times. In this analysis we also see that the overall heterogeneity (I^2) is 69% and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis represented in Figure VI.53 identified experiment 48 as an outlier with major influence in the results, however the experiment was kept in order to perform the meta-analysis (there were only three experiments available, including experiment 48).

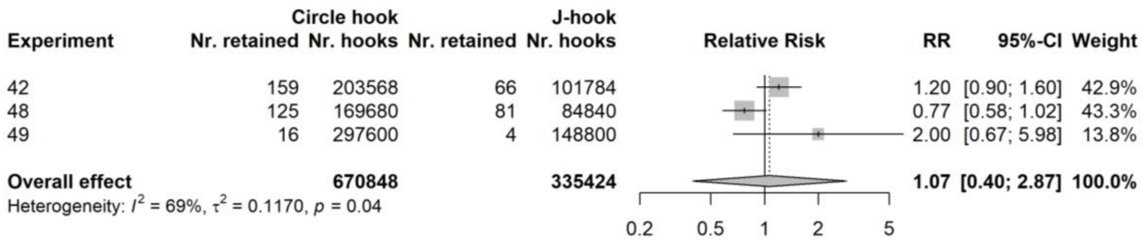


Figure VI.52. Forest plot of the random effects meta-analysis for all data in the retention rates of smooth hammerhead with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

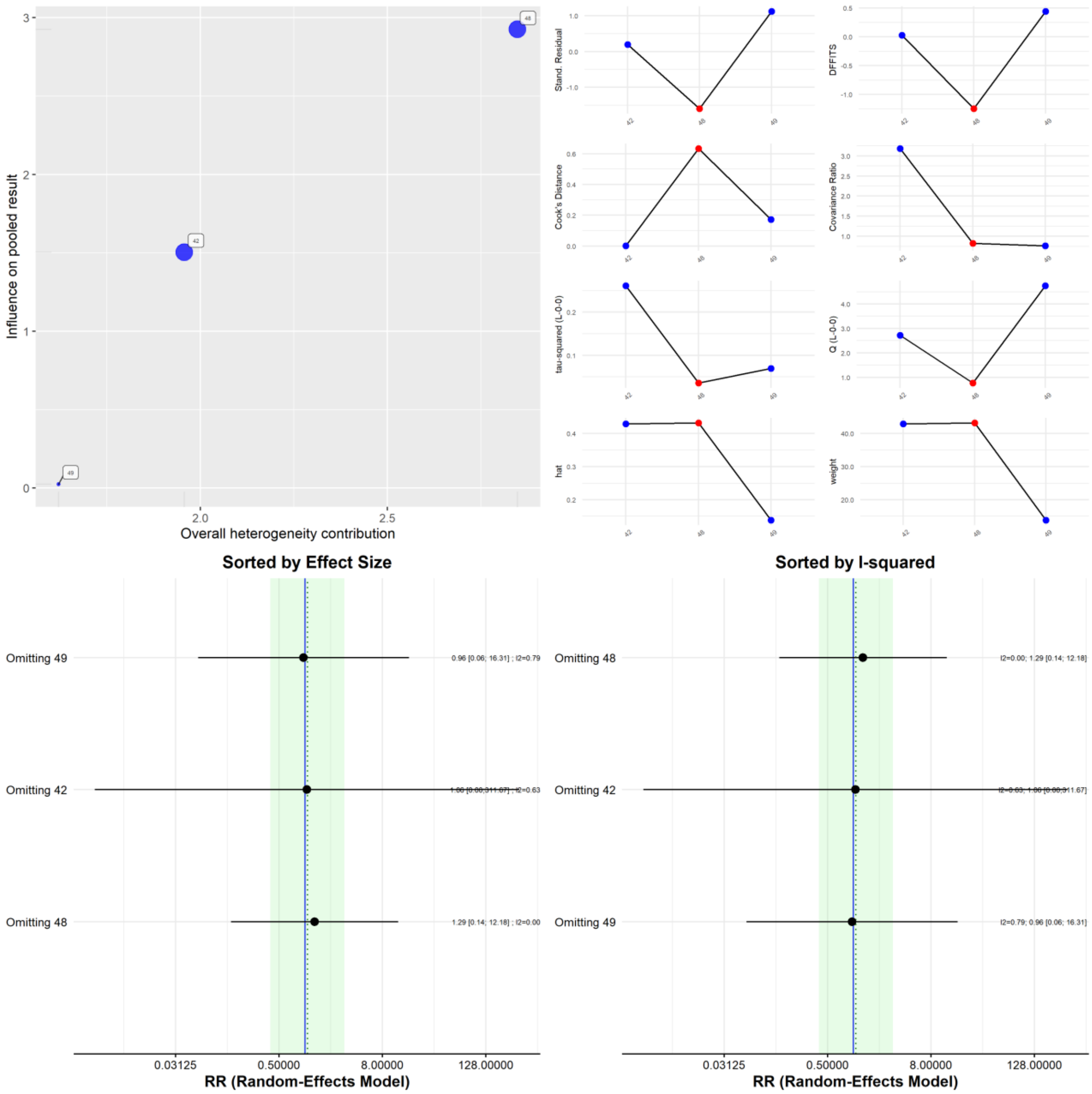


Figure VI.53. Influence analysis for the meta-analysis including all data performed for the retention rates of smooth hammerhead with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.54 provides the random effects model for smooth hammerhead, with regard to at-haulback hooking mortality. In this case the RR is at 1.19 (95% CIs: 0.35; 4.06). This means that on average we expect that the mortality of smooth hammerhead when using circle hooks is 19% higher than when using J hooks, but this is not significant as the 95% confidence intervals vary between a reduction of 65% and an increase of 4.06 times. In this analysis the overall heterogeneity between studies is low (I^2=11%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05).

The influential analysis represented in Figure VI.55 identified experiment 49 as an outlier with major influence in the results, however the experiment was kept in order to perform the meta-analysis (there were only three experiments available, including experiment 49).

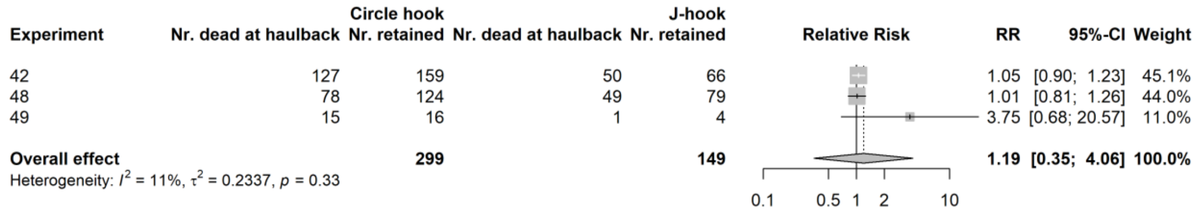


Figure VI.54. Forest plot of the random effects meta-analysis for all data in the at-haulback mortality of smooth hammerhead with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

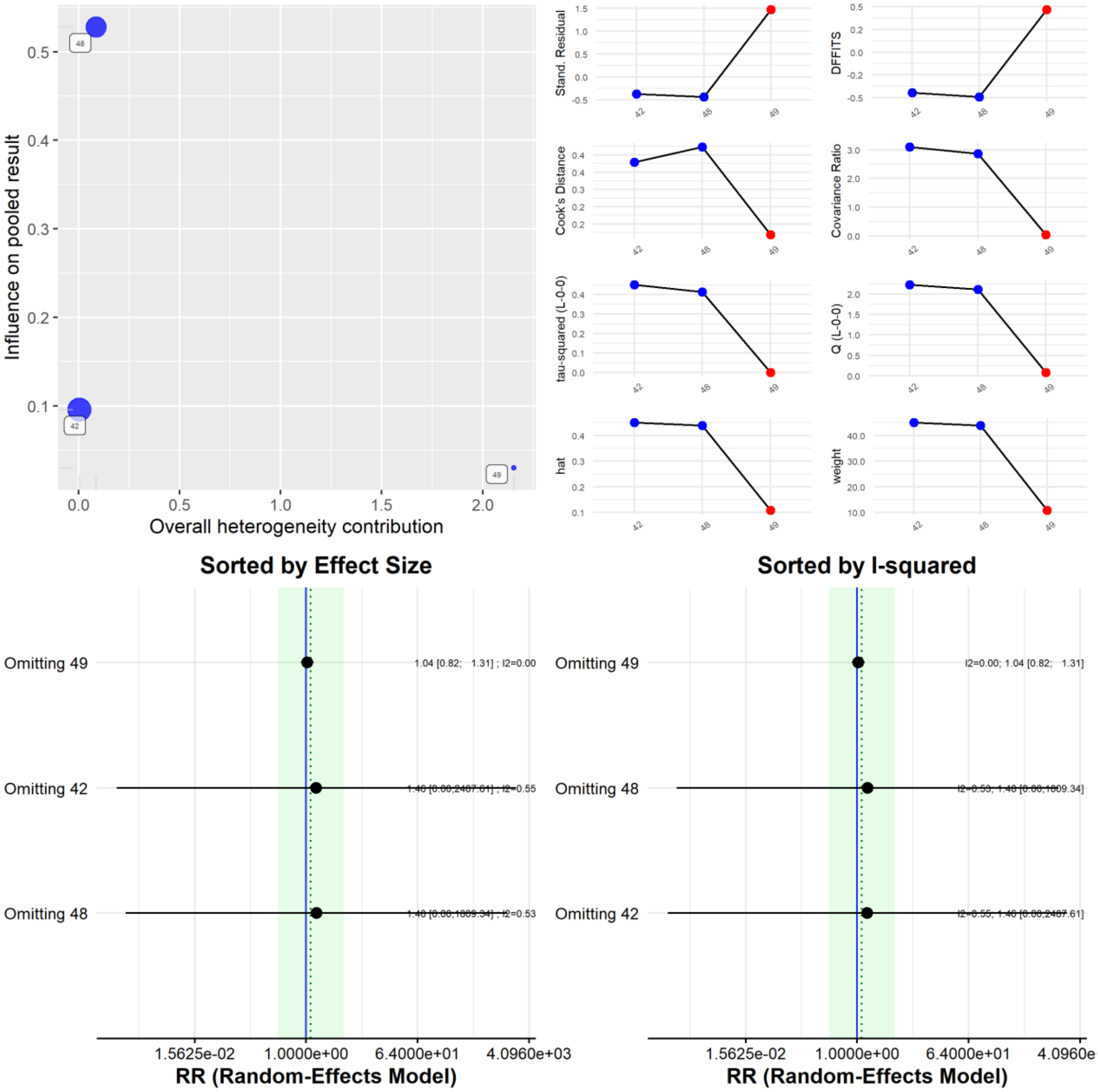


Figure VI.55. Influence analysis for the meta-analysis including all data performed for the at-haulback mortality of smooth hammerhead with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.12 provides a summary of the available studies on post-release mortality for smooth hammerhead shark.

Table VI.12. Summary of post-release mortality studies for smooth hammerhead shark with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
SPZ – Smooth hammerhead	5	60*	Rod and reel	SW Pacific	NA	Fish and squid	NA	Francis (2016)
	5	100	Longline	Equatorial Atlantic	J	Fish and squid	Wire	Santos & Coelho (2018)

*: The authors mention that 3 sharks *may* have died

Pelagic stingray (PLS)

Retention rates

Figure VI.56 shows the random effects model when all data compiled are used for pelagic stingray. When all data are used, the RR is 0.24 (95% CIs: 0.13; 0.46). This means that the retention of pelagic stingray when using circle hooks is 76% lower than when using J hooks, with 95% confidence intervals varying between decreases of 87% and 54%. In this analysis we also see that the overall heterogeneity (I^2) is high (70%) and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis represented in Figure VI.57 did not identify outliers with major influence in the results, and for that reason all experiments were kept.

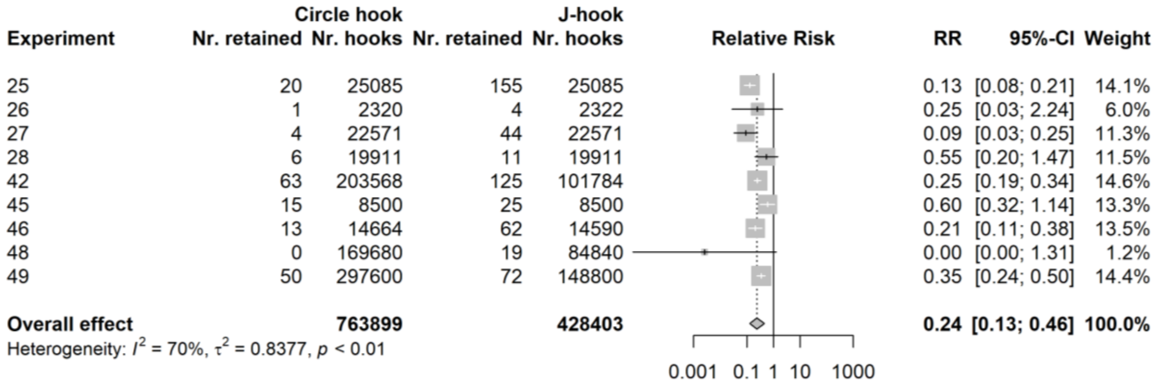


Figure VI.56. Forest plot of the random effects meta-analysis for all data in the retention rates of pelagic stingray with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

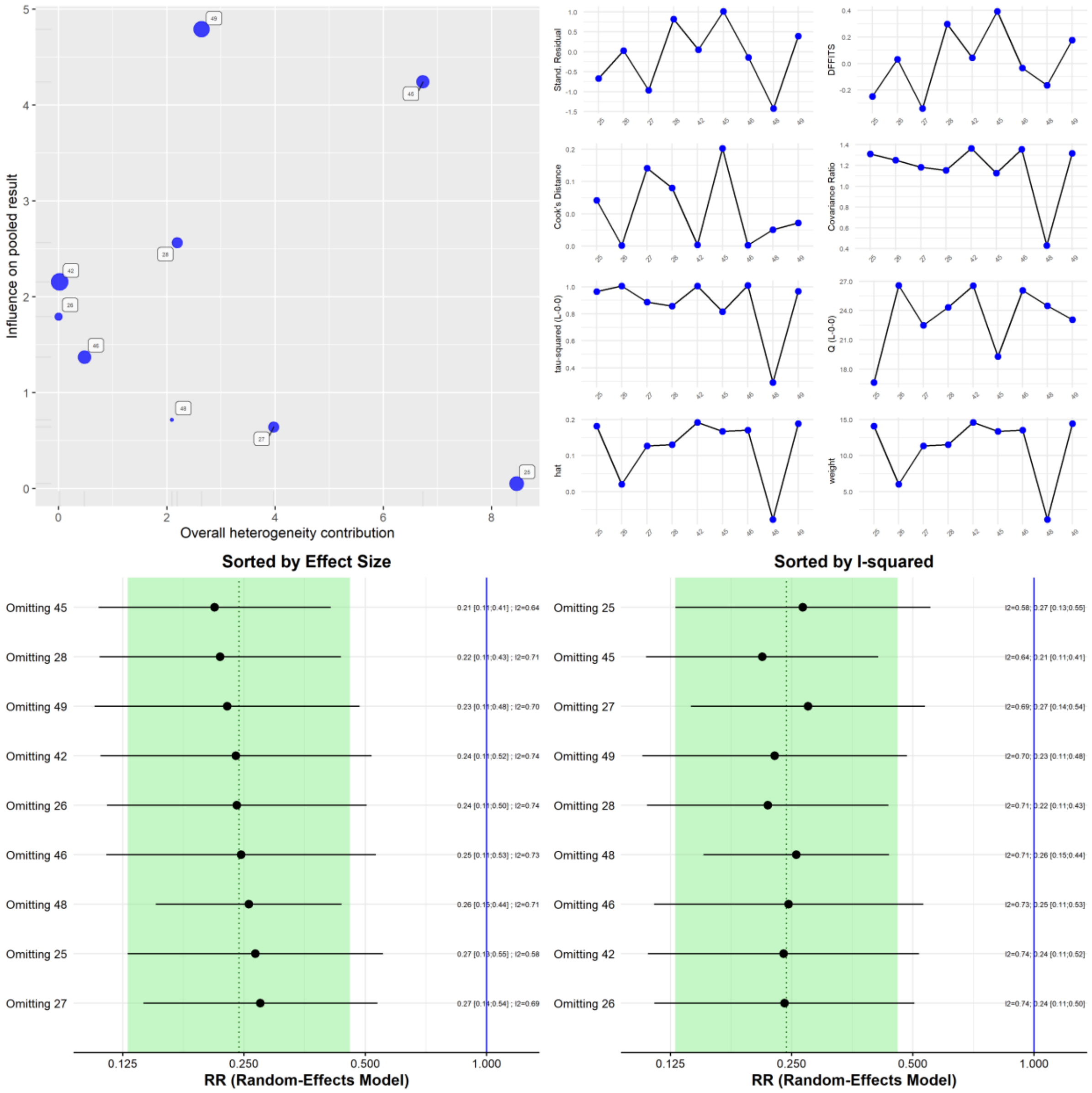


Figure VI.57. Influence analysis for the meta-analysis including all data performed for the retention rates of pelagic stingray with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

At-haulback mortality

Figure VI.58 provides the random effects model for pelagic stingray, with regards to at-haulback hooking mortality. In this case the RR is 2.88 (95% CIs: 0.00; 2108.09). This means that on average we expect that the mortality of pelagic stingray when using circle hooks is 2.88 times higher than when using J hooks, with 95% confidence intervals varying between zero and an increase of 2,108 times. It is noteworthy that for this species the CIs are extremely large, mostly due to very small sample sizes (N) in the available studies. In this analysis the overall heterogeneity between studies is practically null (I^2=4%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VI.59. In this case no major outliers were identified and therefore all experiments were kept.

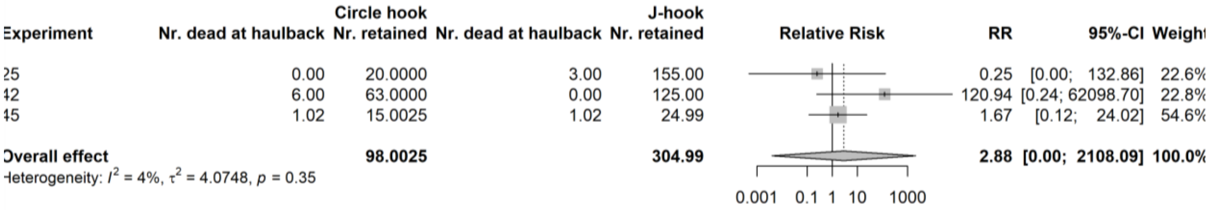


Figure VI.58. Forest plot of the random effects meta-analysis for all data in the at-haulback mortality of the pelagic stingray with circle vs. J hook (Note: J hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks).

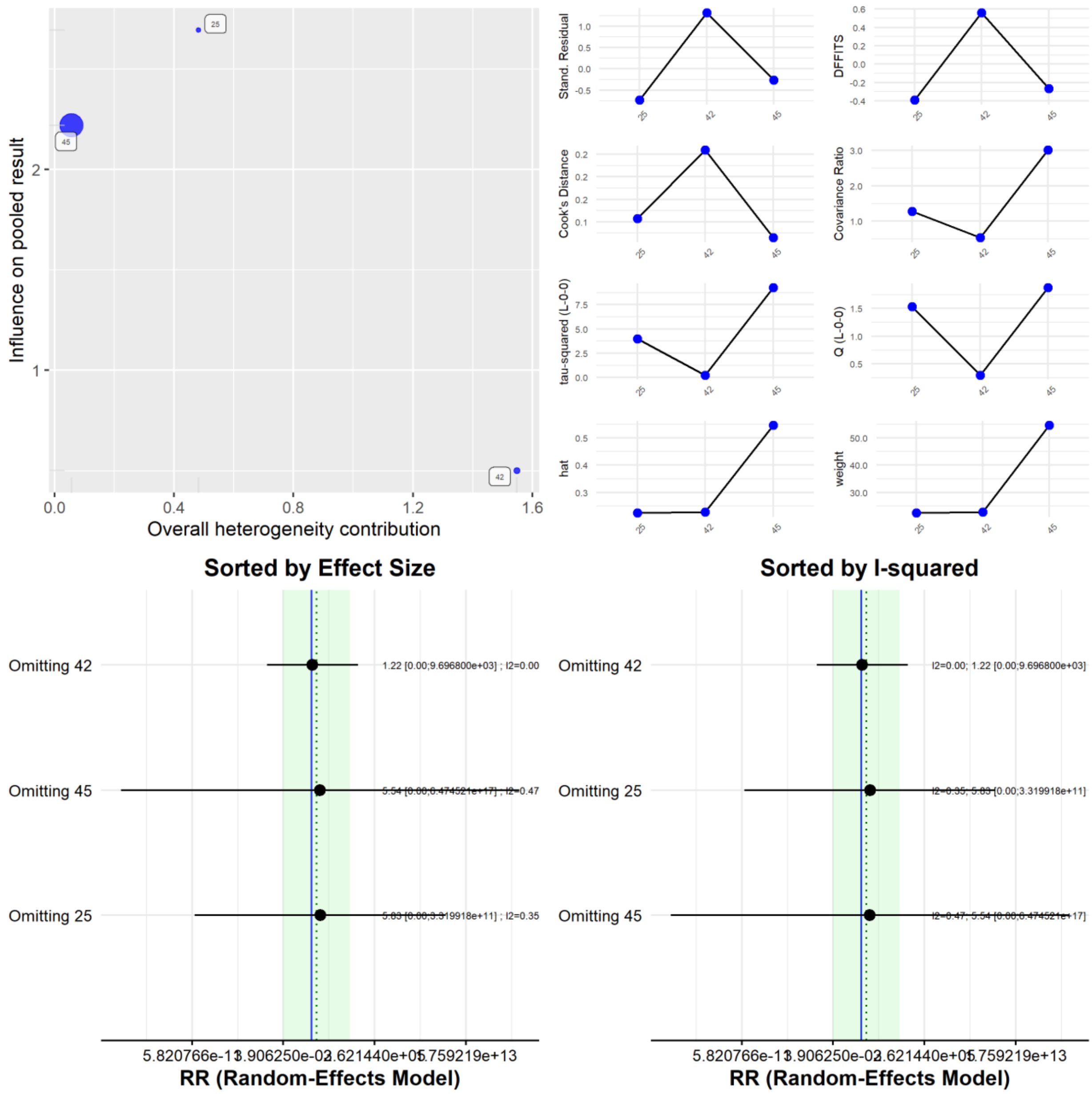


Figure VI.59. Influence analysis for the meta-analysis including all data performed for the at-haulback mortality of pelagic stingray with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Post release mortality

Table VI.13 provides a summary of the available studies on post-release mortality for pelagic stingray.

Table VI.13. Summary of post-release mortality studies for pelagic stingray with indication of gear and region, and whether factors such as hook bait and leader materials have been reported. The sample size (N) is provided. NA refers to information not provided/available in the study.

Species	N	Post-release mortality (%)	Fishery	Region	Hook type	Bait type	Leader type	Reference
PLS – Pelagic stingray	4	100*	Longline	NW Atlantic and Gulf of Mexico	NA	NA	NA	Weidner (2014)

*: The tags in this study were programmed for only day deployments.

APPENDIX VII: SPECIES-SPECIFIC ANALYSIS FOR TASK 3 – EFFECTS OF OTHER VARIABLES

In this Appendix we provide the detailed species-specific results for Task 3, specifically for the meta-analysis for retention rates and at-haulback mortality for the effects of changing other variables (i.e., bait type and leader material). In this annex we focus on the 3 species components, namely target species, desirable bycatch and unwanted bycatch.

Effects of bait on targeted species

Swordfish – Retention rates

In the specific case of swordfish, Figure VII.1 shows the random effects model when all experiments compiled are used. In that case the RR is 1.00 (95% CIs: 0.80; 1.25), which means that changing from squid to fish bait does not influence the retention of swordfish, with the 95% confidence intervals varying between reductions of 20% and increases of 25%. When using all experiments the overall heterogeneity (I^2) is very high and fails the statistical assumption of homogeneity (p-value<0.05).

The results of the validation with search for possible outliers and influence analysis are represented in Figure VII.2. Some experiments are identified in several of the diagnostics, as for example studies 15, 42, 43 and 49, but their influence was not identified at a sufficient level to exclude them (Figure VII.2 – top right panel). Experiments 42 and 49 are a large contributor to the heterogeneity while at the same not contributing too much for the pooled results (Figure VII.2 – top left panel); however, when excluding each one of those specific studies the I^2 would only decrease from 98% to 96%, which means that there is not a strong reason to exclude that study (Figure VII.2 – bottom panel). This is 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.

Experiment	Fish bait Nr. retained	Fish bait Nr. hooks	Squid bait Nr. retained	Squid bait Nr. hooks	RR	95%-CI	Weight
15	33142	2150674	17086	1282748	1.16	[1.14; 1.18]	16.5%
30	9889	463139	9256	510595	1.18	[1.15; 1.21]	16.4%
42	1675	143136	2555	162216	0.74	[0.70; 0.79]	16.2%
43	8	18240	12	18240	0.67	[0.27; 1.63]	3.3%
48	1621	127260	1222	127260	1.33	[1.23; 1.43]	16.1%
49	2133	223200	2709	223200	0.79	[0.74; 0.83]	16.3%
51	477	47432	458	47768	1.05	[0.92; 1.19]	15.3%
Overall effect		**3173081**		**2372027**	**1.00**	**[0.80; 1.25]**	**100.0%**

Heterogeneity: $I^2 = 98\%$, $\tau^2 = 0.0514$, $p < 0.01$

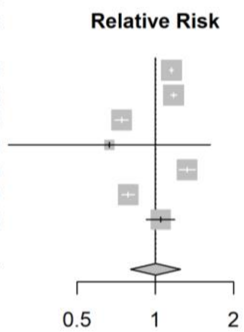


Figure VII.1. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish with fish vs squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

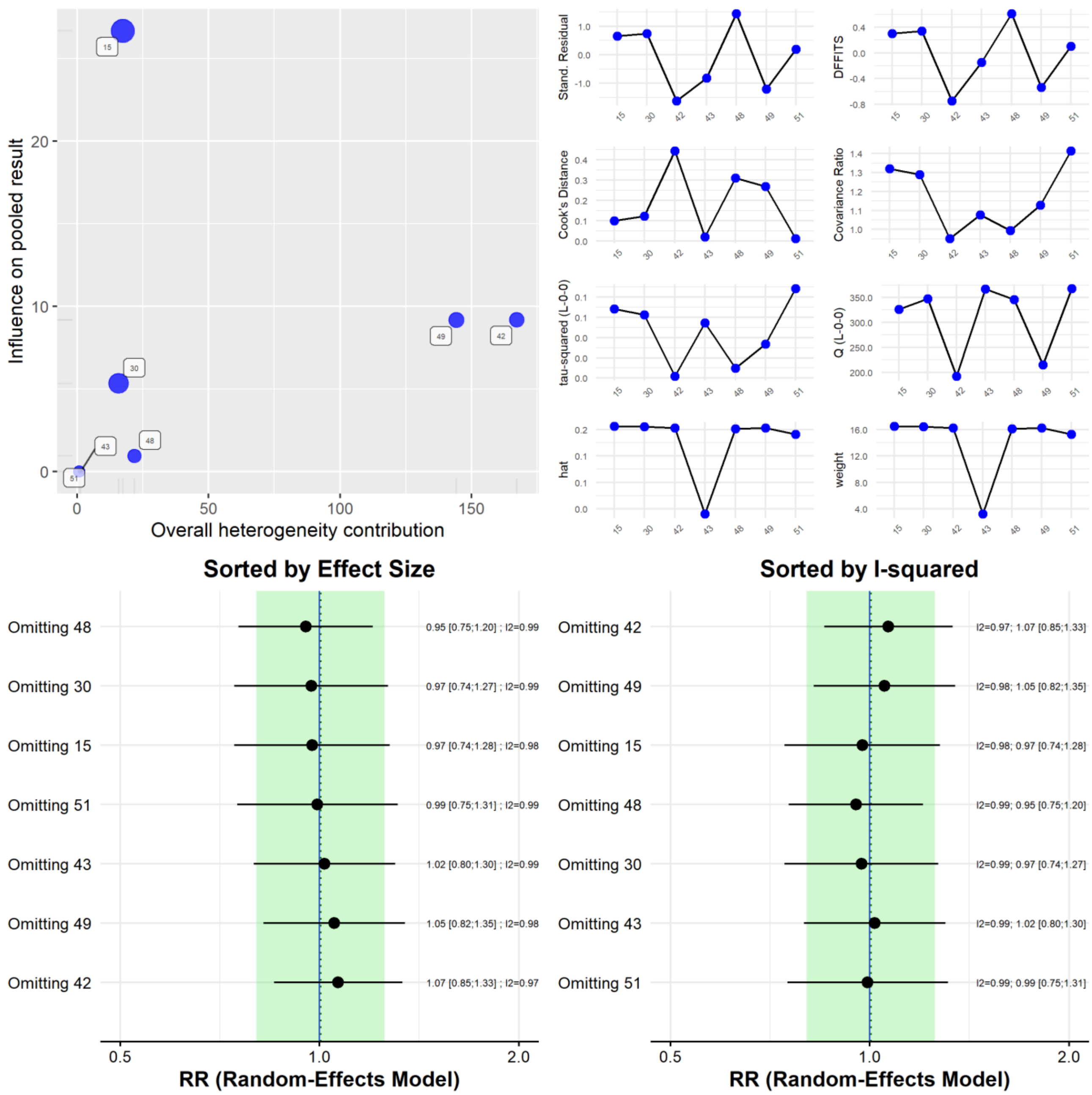


Figure VII.2. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I2 (right).

Swordfish – At-haulback mortality

With regard to the at-haulback mortality of swordfish, the random effects model considering all experiments is shown in Figure VII.3. In this case, the influence analysis that followed (Figure VII.4) identified one experiment (experiment 42) that is an outlier with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was therefore re-run excluding that study, with the results of the new pooled analysis indicated in Figure VII.5 and validation indicated in Figure VII.6.

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. In the first analysis including all studies the at-haulback mortality RR is 1.02 (95% CIs: 0.99-1.05) when changing from squid to fish bait, while after excluding the outlier the RR is 1.03 (95% CIs: 1.02-1.05). This indicates that changing bait type has a very slight effect on the at-haulback mortality of swordfish (3% higher mortality on fish bait), with the 95% confidence intervals varying between 2% and 5%.

	Fish bait		Squid bait					
Experiment	**Nr. dead at-haulback**	**Nr. retained**	**Nr. dead at-haulback**	**Nr. retained**	**Relative Risk**	**RR**	**95%-CI**	**Weight**
42	1453	1675	2206	2539		1.00	[0.97; 1.02]	34.9%
48	974	1185	1269	1591		1.03	[0.99; 1.07]	22.3%
49	1542	2073	1845	2557		1.03	[1.00; 1.07]	23.4%
51	443	476	407	456		1.04	[1.00; 1.09]	19.4%
Overall effect		**5409**		**7143**		**1.02**	**[0.99; 1.05]**	**100.0%**
Heterogeneity: $I^2 = 38\%$, $\tau^2 = 0.0002$, $p = 0.19$								

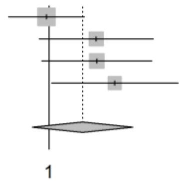


Figure VII.3. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of swordfish with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

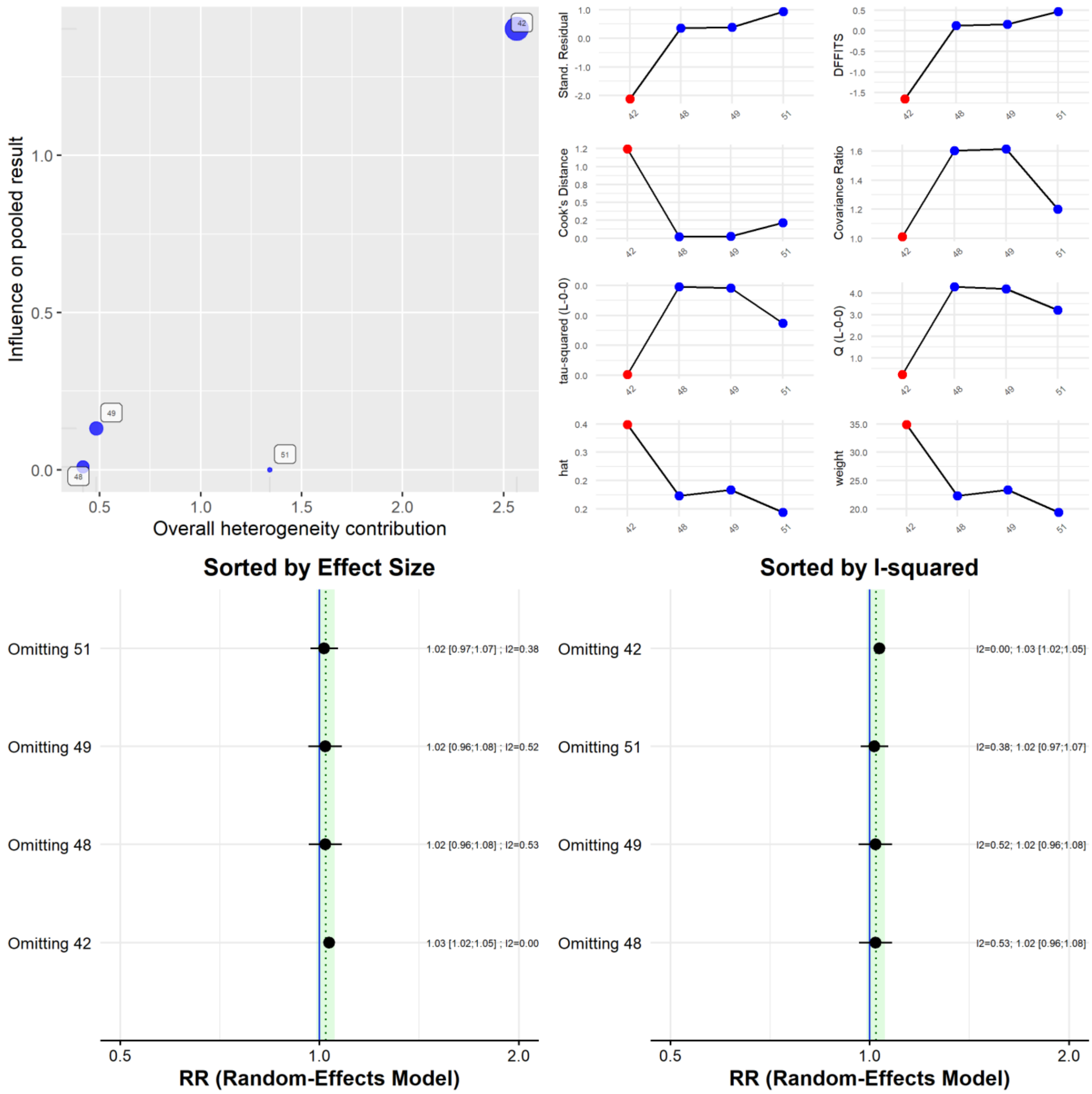


Figure VII.4. Influence analysis for the meta-analysis performed for the at-haulback mortality of swordfish with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I2 (right).

Experiment	Fish bait Nr. dead at-haulback	Fish bait Nr. retained	Squid bait Nr. dead at-haulback	Squid bait Nr. retained	RR	95%-CI	Weight
42	1453	1675	2206	2539	1.00	[0.97; 1.02]	0.0%
48	974	1185	1269	1591	1.03	[0.99; 1.07]	34.6%
49	1542	2073	1845	2557	1.03	[1.00; 1.07]	37.3%
51	443	476	407	456	1.04	[1.00; 1.09]	28.2%
Overall effect		**5409**		**7143**	**1.03**	**[1.02; 1.05]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 < 0.0001$, $p = 0.89$

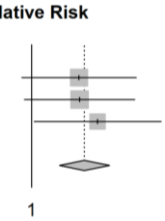


Figure VII.5. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of swordfish with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis).

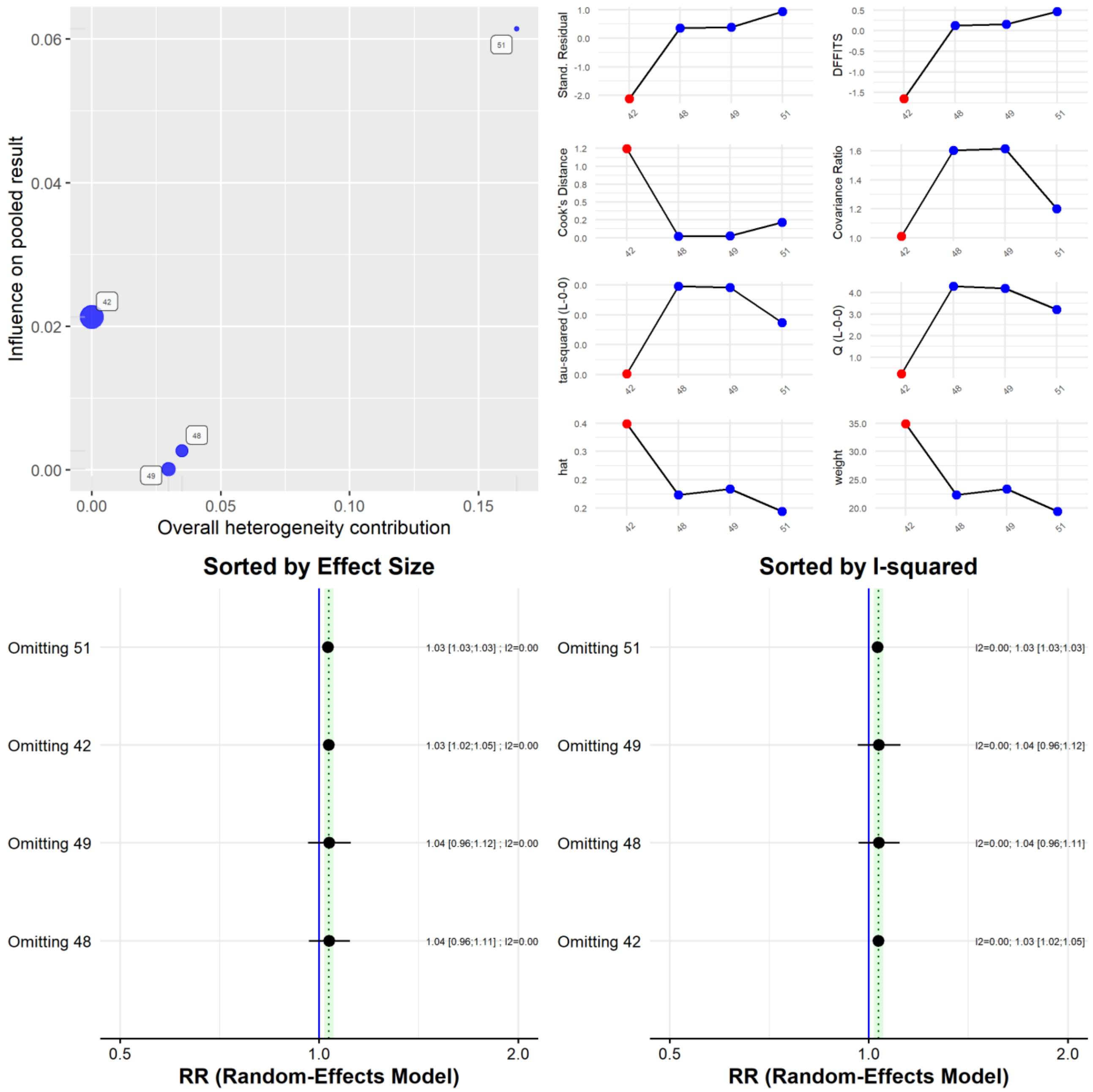


Figure VII.6. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of swordfish with fish vs. squid bait. The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye tuna – Retention rates

For bigeye tuna, the random effects model considering all experiments is shown in Figure VII.7. In this case, experiment 30 and 51 CIs do not overlap with the estimated overall RR. The influence analysis that followed (Figure VII.8 – top right panel) identified experiment 51 as an outlier. In the Baujat plot and the leave-one-out analysis (Figure VII.8 – top left panel and bottom panel) show these studies have a relatively high influence in the pooled results. The analysis was re-run excluding those 2 experiments, with the results of the new pooled analysis indicated in Figure VII.9 and validation indicated in Figure VII.10. With the exclusion of those 2 outliers, the overall heterogeneity did not change significantly (from 99% to 98%). On the other hand, the pooled analysis results changed from 0.61 (95% CIs: 0.14-2.63) to 0.52 (95% CIs: 0.15-1.81). This means that changing from squid to fish bait reduced the retention of bigeye tuna by 48%, but this value is not significant with the 95% CIs varying between a reduction of 85% and an increase of 81%.

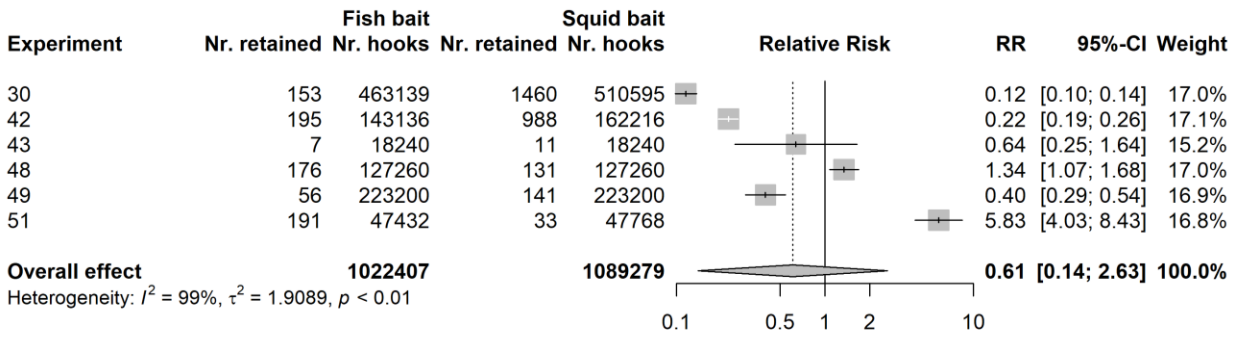


Figure VII.7. Forest plot of the random effects meta-analysis performed for the retention rates of bigeye tuna with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

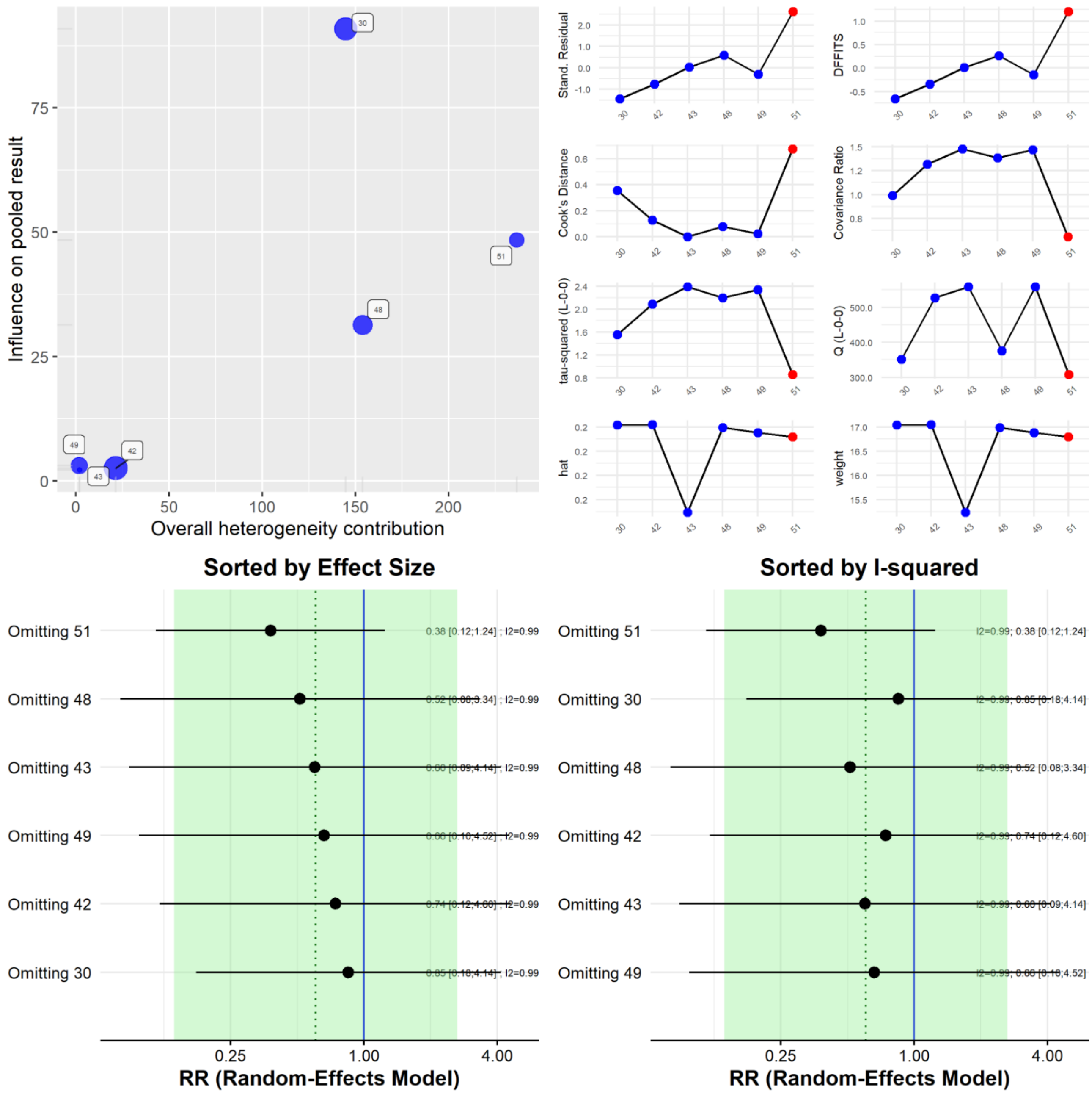


Figure VII.8. Influence analysis for validating the meta-analysis performed for the retention rates of bigeye tuna with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Fish bait Nr. retained	Fish bait Nr. hooks	Squid bait Nr. retained	Squid bait Nr. hooks	RR	95%-CI	Weight
30	153	463139	1460	510595	0.12	[0.10; 0.14]	0.0%
42	195	143136	988	162216	0.22	[0.19; 0.26]	27.3%
43	7	18240	11	18240	0.64	[0.25; 1.64]	19.4%
48	176	127260	131	127260	1.34	[1.07; 1.68]	26.9%
49	56	223200	141	223200	0.40	[0.29; 0.54]	26.4%
51	191	47432	33	47768	5.83	[4.03; 8.43]	0.0%
Overall effect		**1022407**		**1089279**	**0.52**	**[0.15; 1.81]**	**100.0%**

Heterogeneity: $I^2 = 98\%$, $\tau^2 = 0.5569$, $p < 0.01$

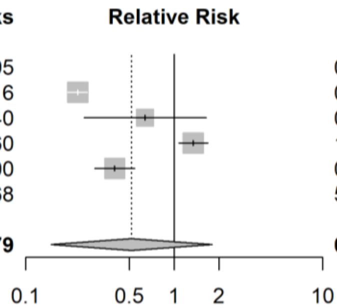


Figure VII.9. Forest plot of the random effects meta-analysis excluding 2 outliers in the retention of bigeye tuna with fish vs. squid (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). Experiments 30 and 51 were excluded (these are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

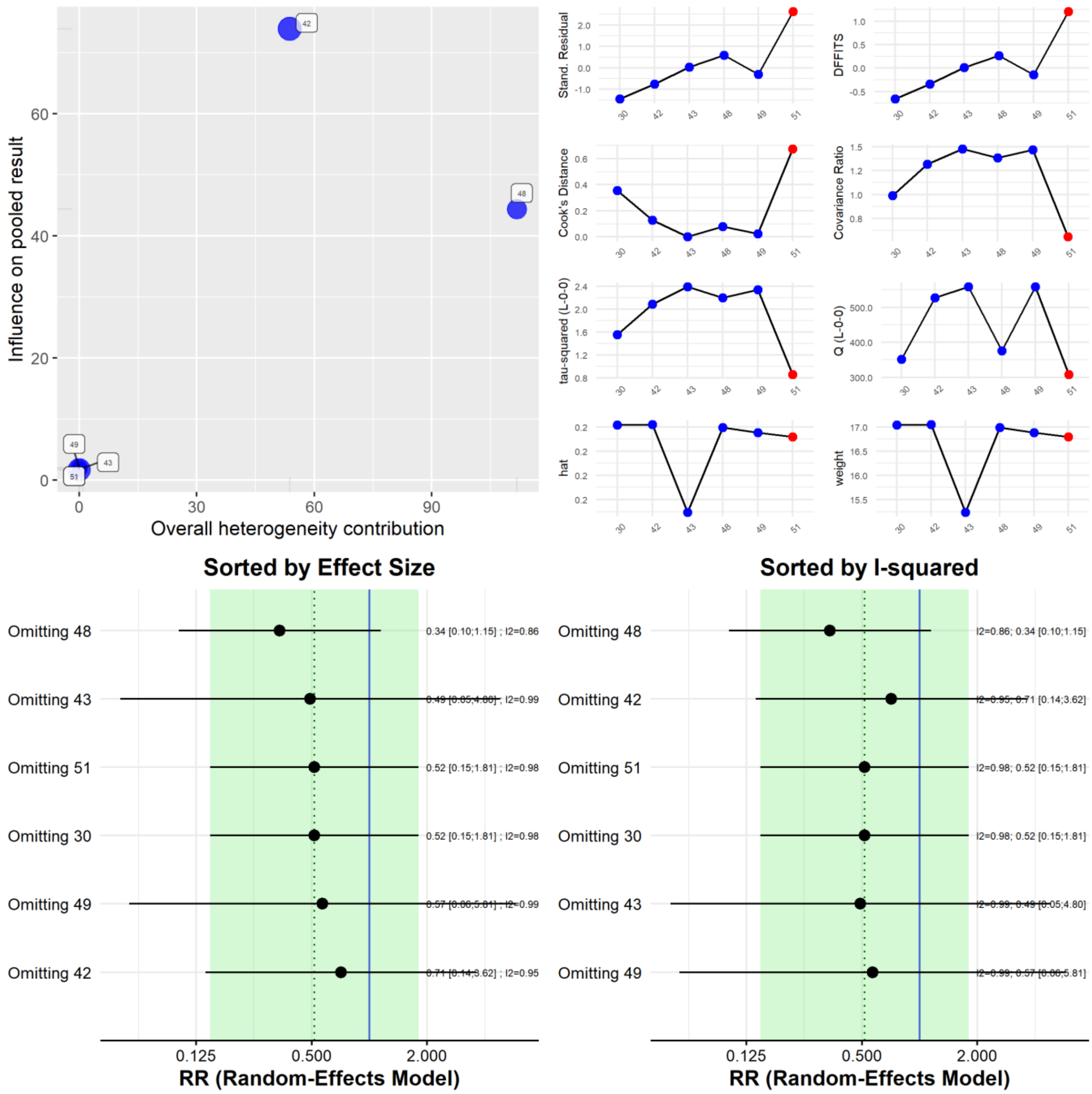


Figure VII.10. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the retention of bigeye tuna with fish vs. squid. Experiments 30 and 51 were excluded (these are still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye tuna – At-haulback mortality

In the specific case of bigeye tuna, when all experiments are used for comparing fish and squid bait the RR is calculated at 0.99 (95% CIs: 0.88; 1.12), indicating that changing from squid bait to fish bait does not lead to a change in at-haulback mortality in bigeye tuna.

Specifically, the pois estimate is a reduction of 1% but this value is not significant as the 95% CIs vary between a reduction of 12% and an increase of 12% (Figure VII.11). In this specific analysis the overall heterogeneity (I^2) is 0% 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 VII.12. For this specific case no, specific experiment is identified as a possible outlier.

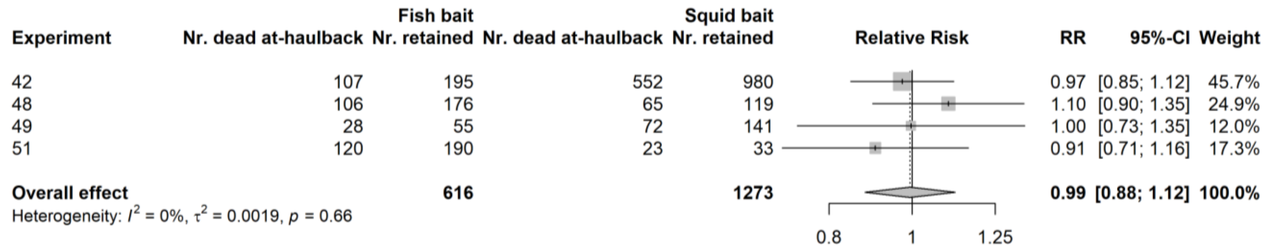


Figure VII.11. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of bigeye tuna with fish vs. squid bait. (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

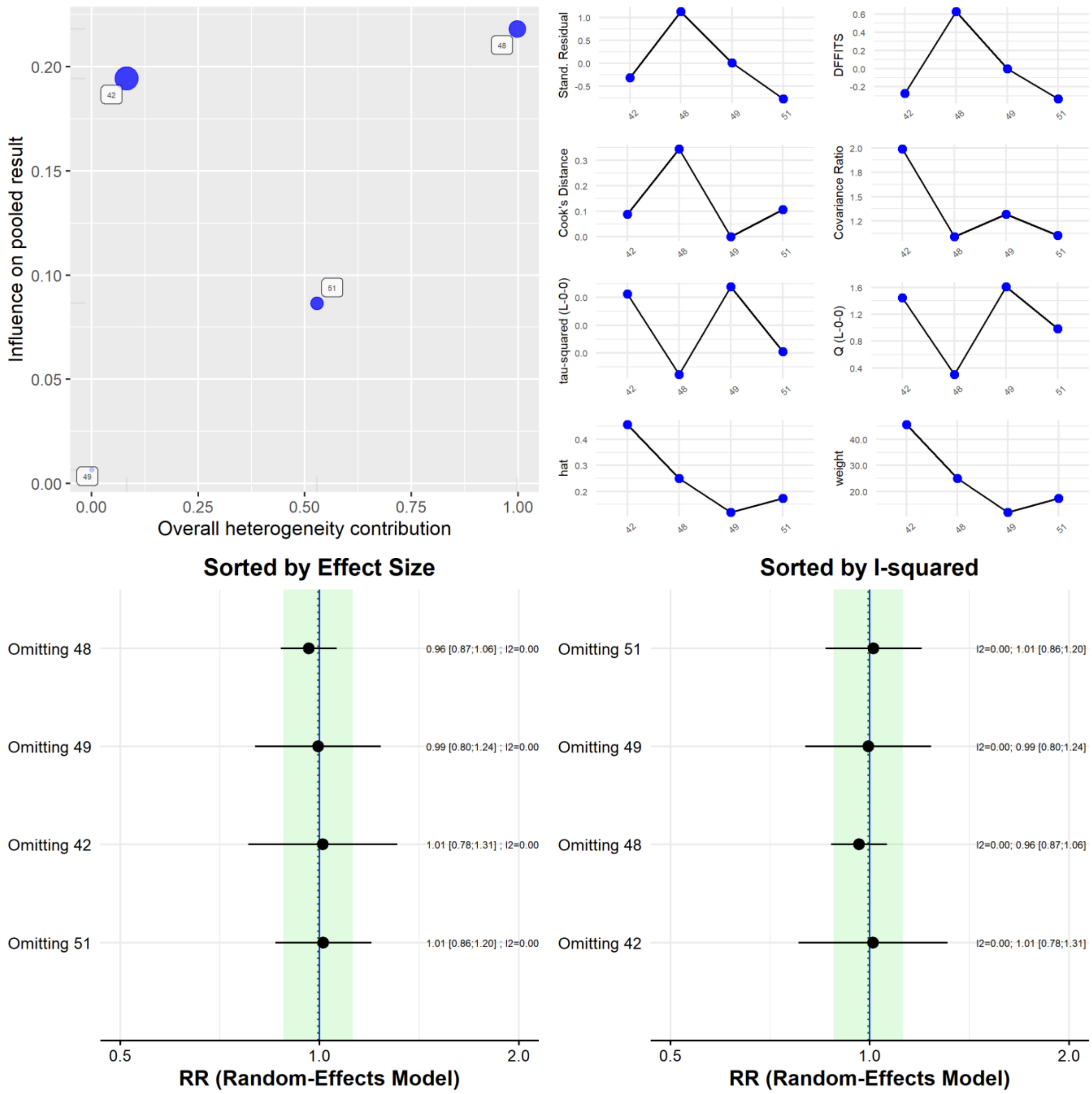


Figure VII.12. Influence analysis for the meta-analysis performed for the at-haulback mortality of bigeye tuna with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I^2 (right).

Bluefin tuna – Retention rates

With regard to the effect of bait type on the retention of bluefin tuna, only two experiments are available (experiments 30 and 43), therefore the meta-analysis was not conducted. Experiment 30 shows a decrease in the at-haulback mortality of bluefin tuna when using circle hooks (RR=0.86; 95% CIs: 0.95; 1.48). In experiment 43 using fish bait no BFT was retained, with 18240 hooks baited with fish, and only one BFT was retained when using squid bait with the same number of hooks baited with squid.

Bluefin tuna – At-haulback mortality

There were no experiments that reported on at-haulback mortality of bluefin tuna for surface longlines comparing bait type.

Yellowfin tuna – Retention rates

With regard to the retention of yellowfin tuna, the random effects model considering all experiments is shown in Figure VII.13. In this case, the influence analysis that followed (Figure VII.14) identified one experiment (experiment 51) that is an outlier with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was therefore re-run excluding that study, with the results of the new pooled analysis indicated in Figure VII.15 and validation indicated in Figure VII.16.

With the exclusion of that outlier, the heterogeneity was largely reduced, specifically from 94% when including all studies to 27% when excluding experiment 51. This exclusion also had an influence in the pooled results, in the first analysis including all studies the at-haulback mortality RR is 0.60 (95% CIs: 0.14-2.55) when changing from squid to fish bait, while after excluding the outlier the RR is 0.40 (95% CIs: 0.26 – 0.60). This indicates that using fish bait reduces the retention of yellowfin tuna by 60%, with 95% CI ranging from reductions of 40% and 74%.

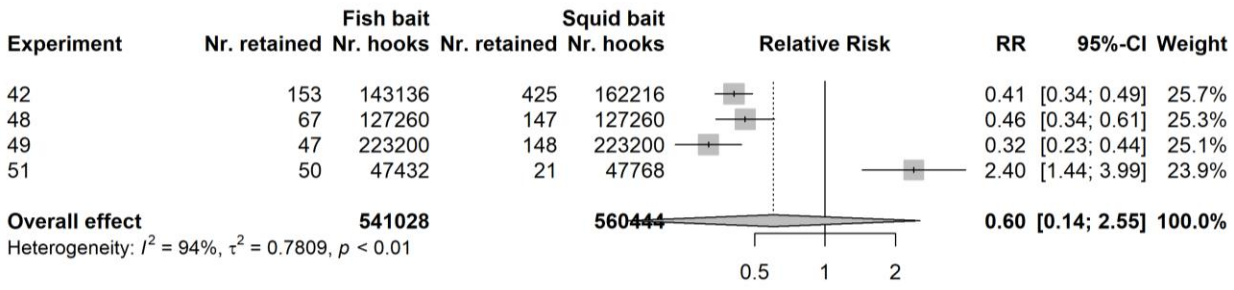


Figure VII.13. Forest plot of the random effects meta-analysis performed for the retention of yellowfin tuna with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

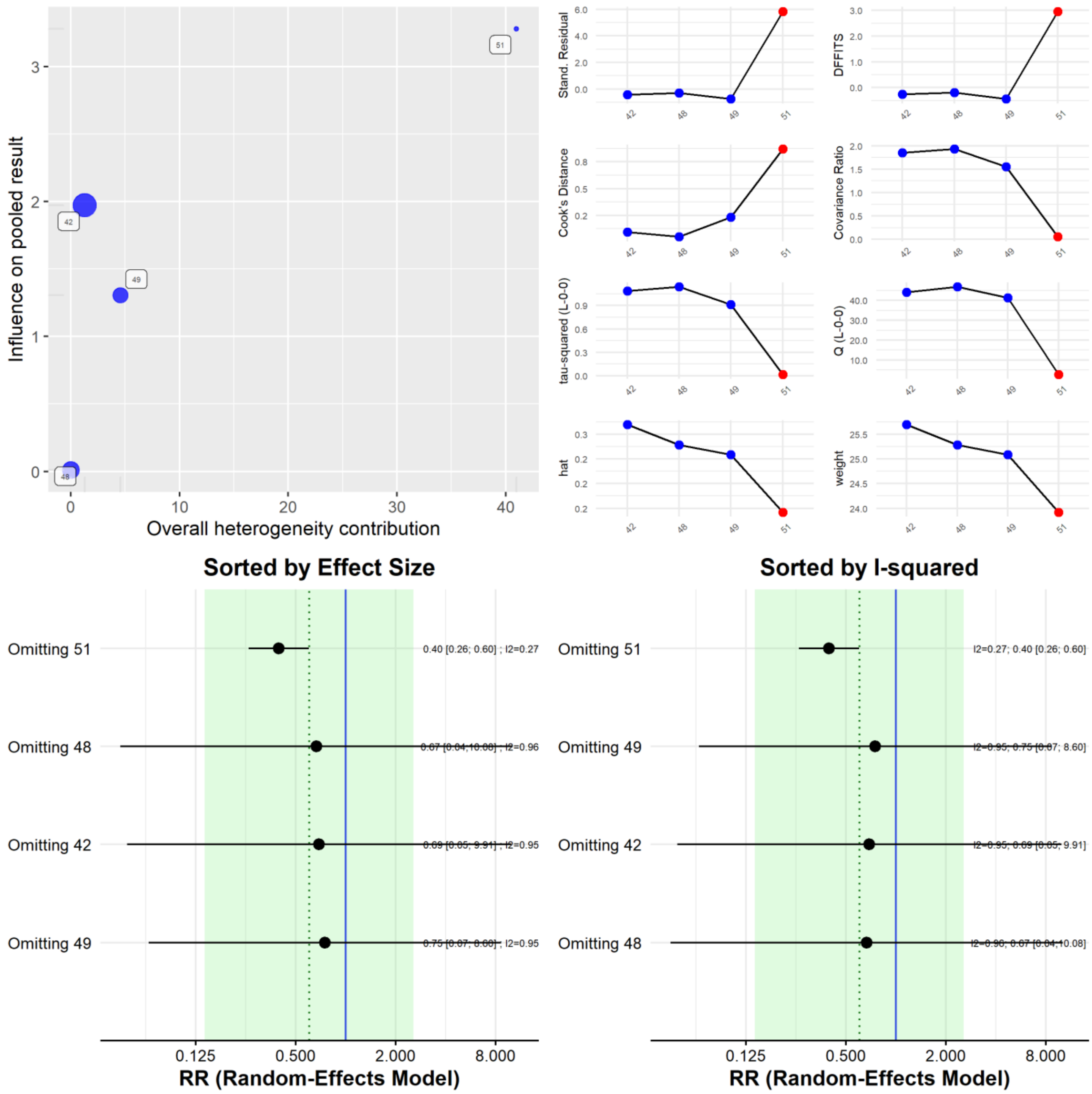


Figure VII.14. Influence analysis for the meta-analysis performed for the retention of yellowfin tuna with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

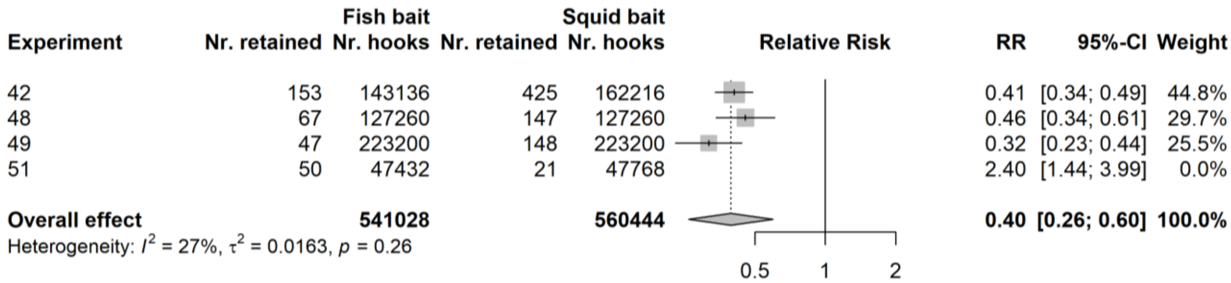


Figure VII.15. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of yellowfin tuna with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 51 (that is still represented in the plots but not considered in the analysis).

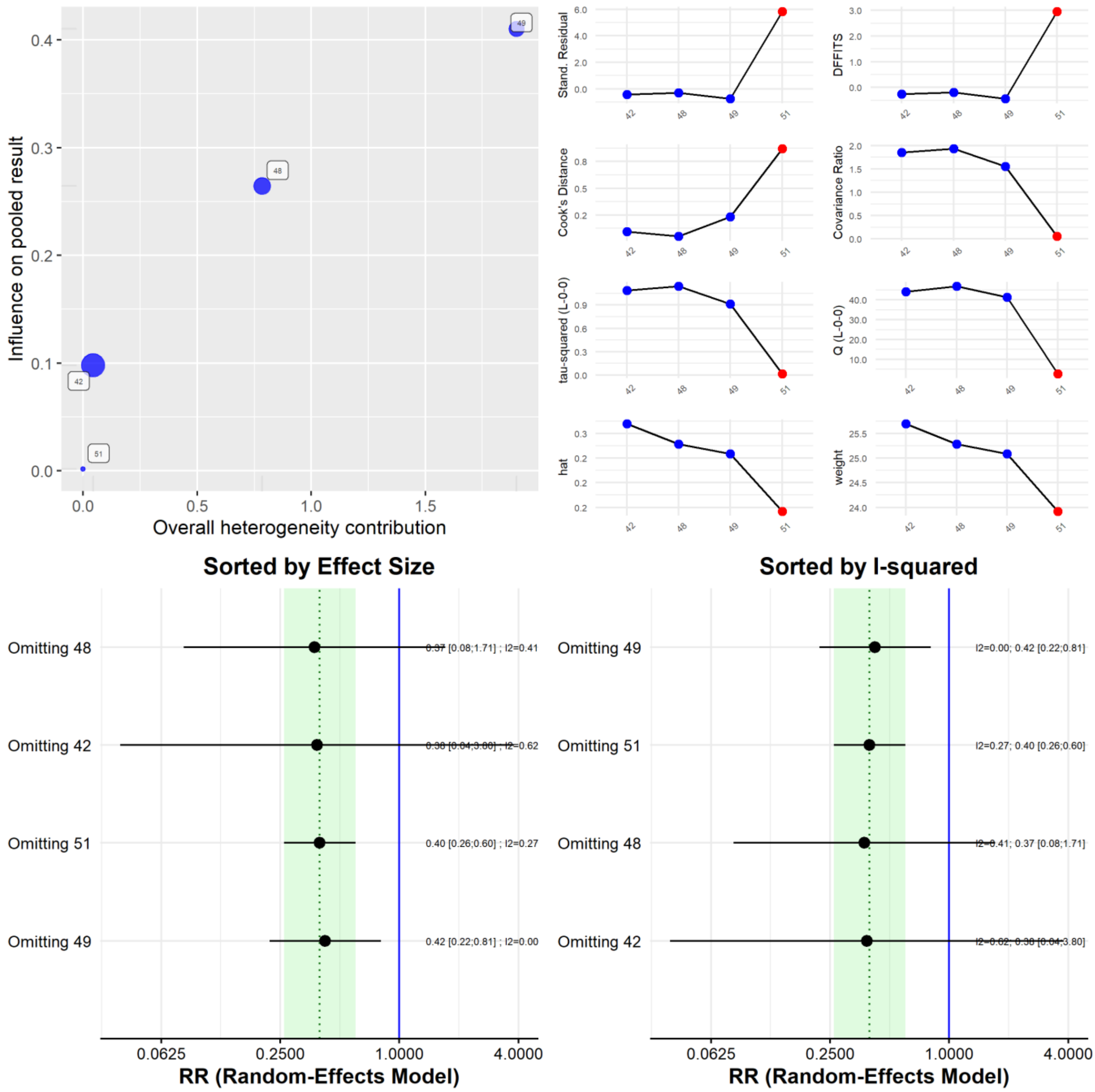


Figure VII.16. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of yellowfin tuna with fish vs. squid bait. The excluded experiment is number 51 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Yellowfin tuna – At-haulback mortality

The random effects model considering all experiments is shown in Figure VII.17 for the at-haulback mortality of yellowfin tuna. In this case, the influence analysis that followed (Figure VII.18) identified experiment 42 that is an outlier with significant leverage and as such could be considered for deletion from the pooled analysis. The analysis was re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VII.19 and validation indicated in Figure VII.20.

With the exclusion of that outlier, the heterogeneity was largely reduced, specifically from 86% when including all studies to 27% when excluding experiment 42. This exclusion also had an influence in the pooled results, in the first analysis including all studies the at-haulback mortality RR is 1.03 (95% CIs: 0.59-1.81) when changing from squid to fish bait, while after excluding the outlier the RR is 0.88 (95% CIs: 0.53 – 1.47). In both analysis changing bait type does not significantly influence the at-haulback mortality of yellowfin tuna.

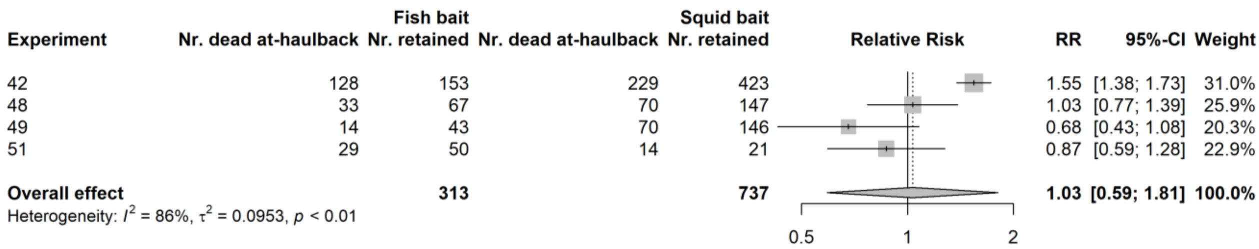


Figure VII.17. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of yellowfin tuna with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

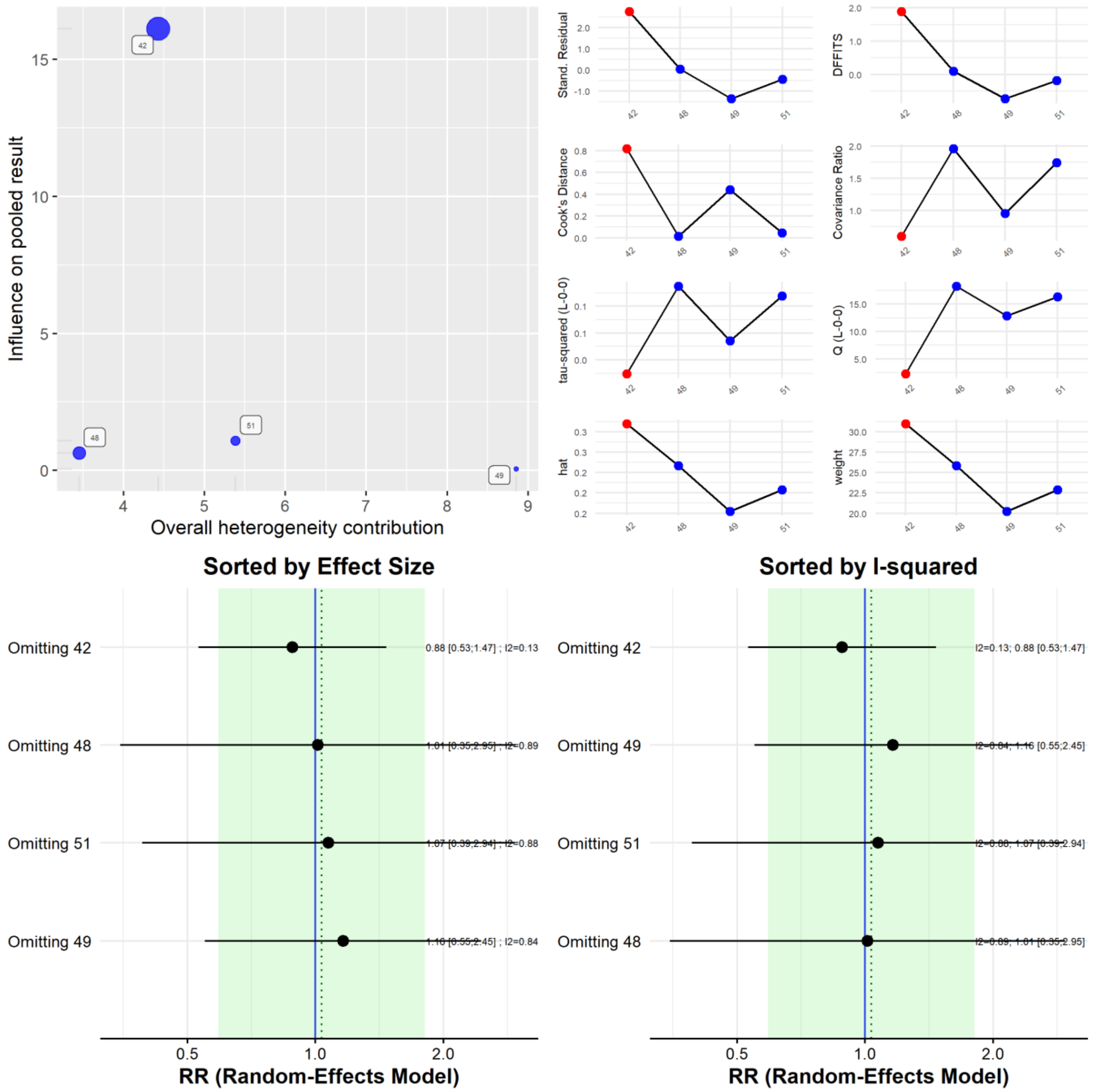


Figure VII.18. Influence analysis for the meta-analysis performed for the at-haulback mortality of yellowfin tuna with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

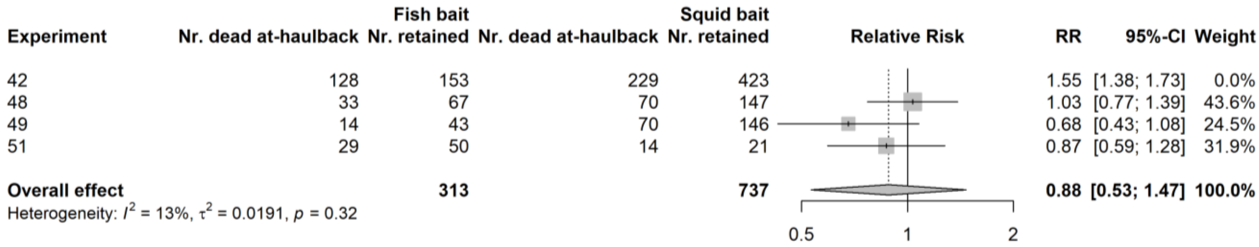


Figure VII.19. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of yellowfin tuna with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis).

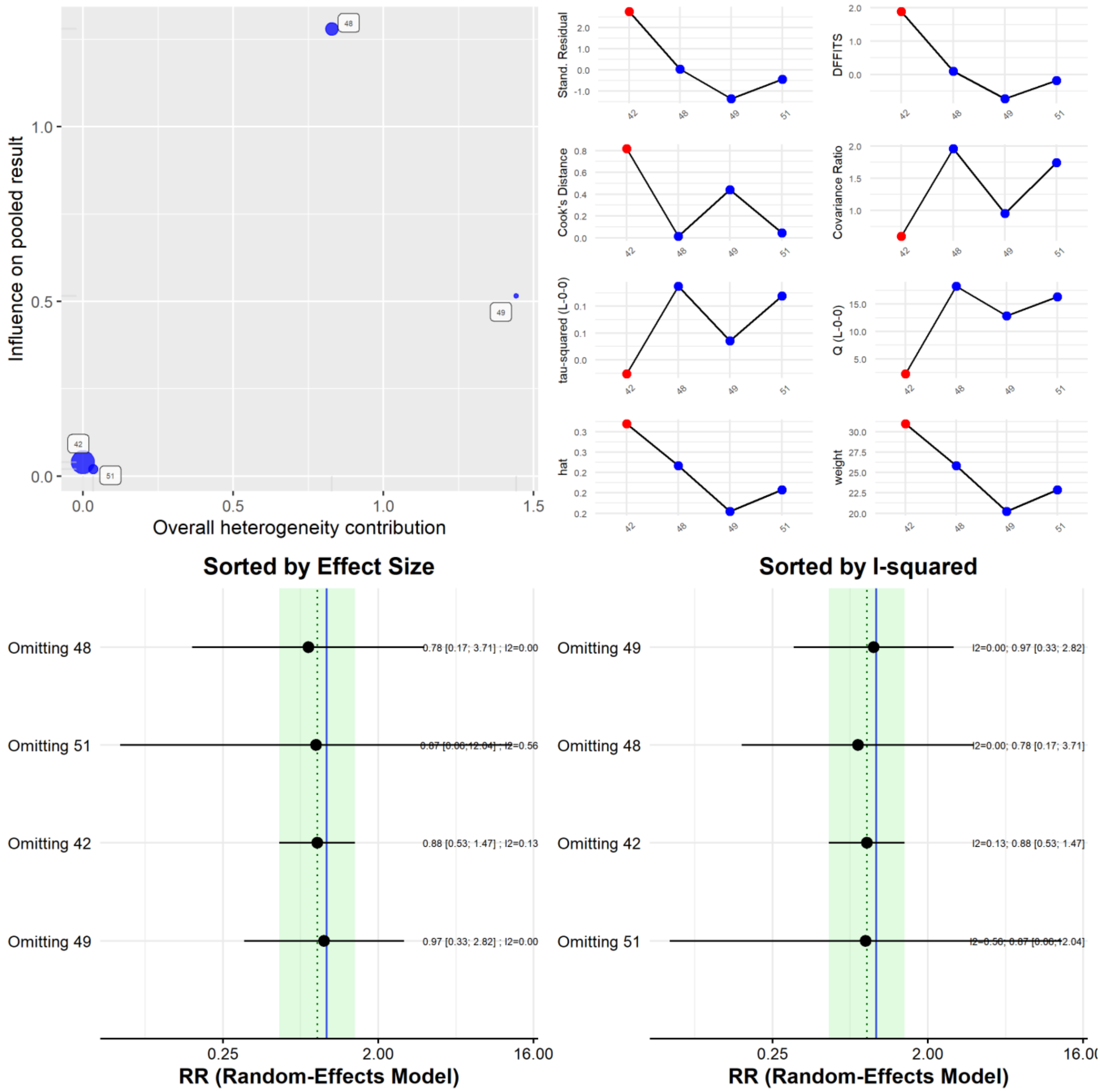


Figure VII.20. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of yellowfin tuna with fish vs. squid bait. The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Albacore tuna – Retention rates

With regard to the at-haulback mortality of albacore, the random effects model considering all experiments is shown in Figure VII.21. In this case, the influence analysis that followed (Figure VII.22) identified two experiments (experiment 30 and 49) that are outliers with influence both on the overall heterogeneity and on the pooled results. When excluding each of the experiments at a time I^2 is reduced as shown in Figure VII.22 (bottom panel). When excluding both studies, heterogeneity was completely removed, specifically from 96% when including all studies to 0% (Figure VII.23 and VII.24). In the first analysis including all studies the at-haulback mortality RR is 0.27 (95% CIs: 0.08-0.84) when changing from squid to fish bait, while after excluding the outliers the RR is 0.32 (95% CIs: 0.07-1.46).

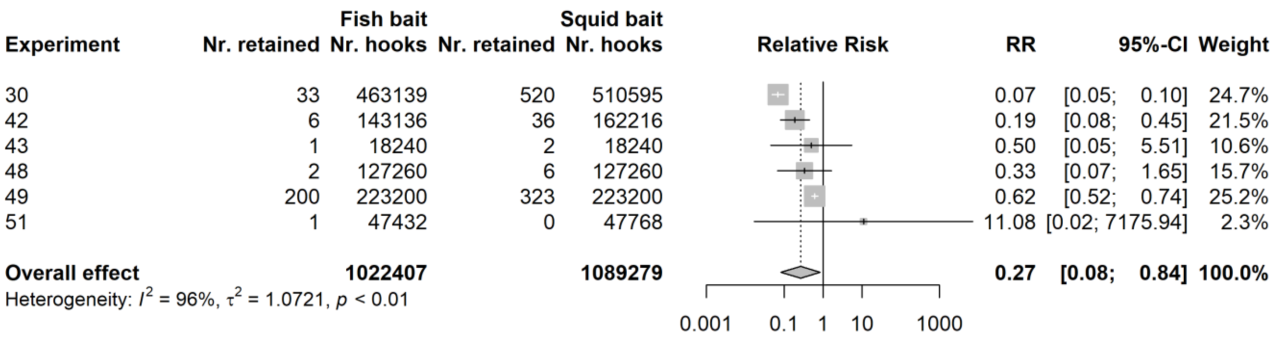


Figure VII.21. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of albacore with fish vs. squid bait.(Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

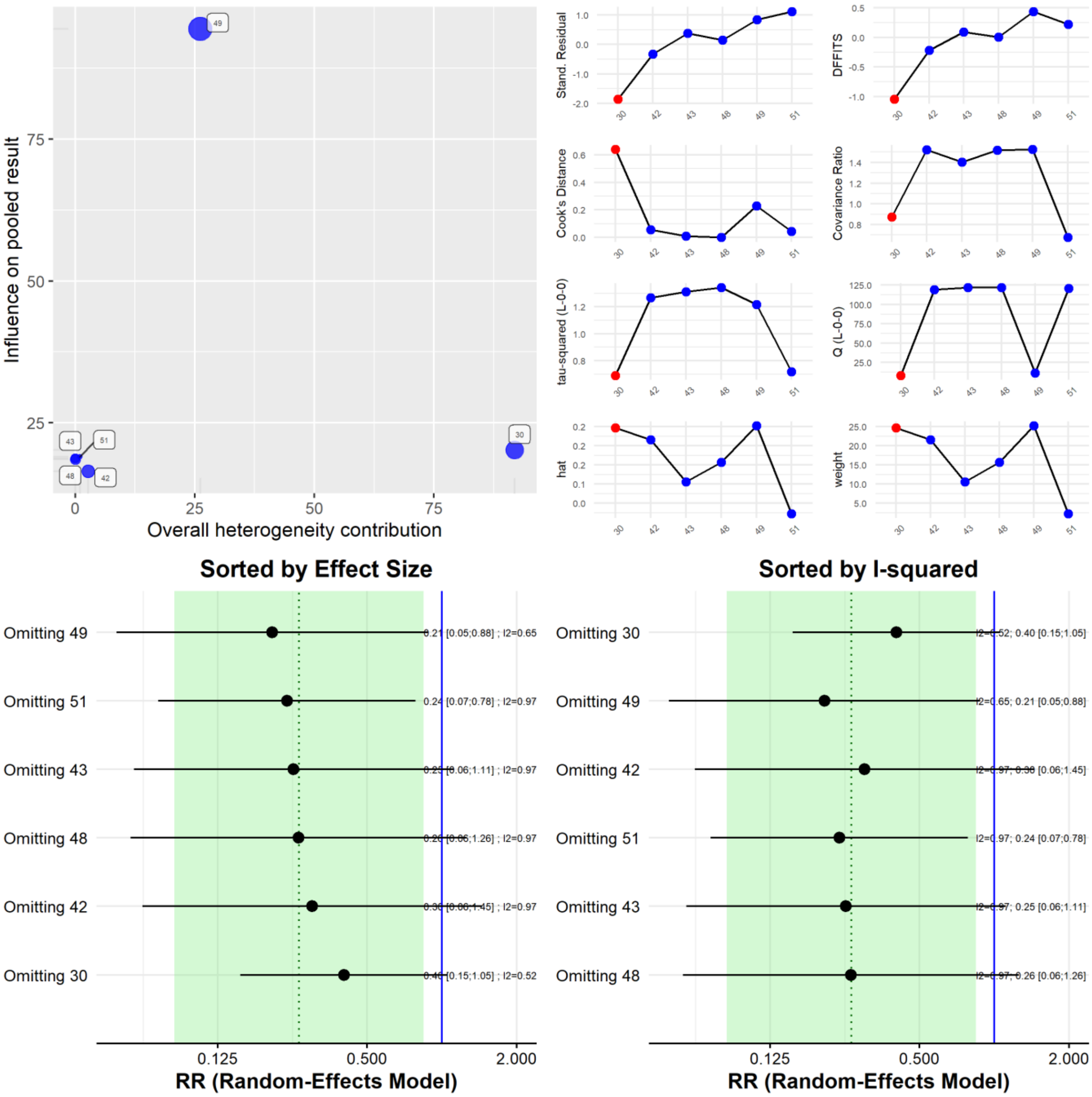


Figure VII.22. Influence analysis for the meta-analysis performed for the at-haulback mortality of albacore with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

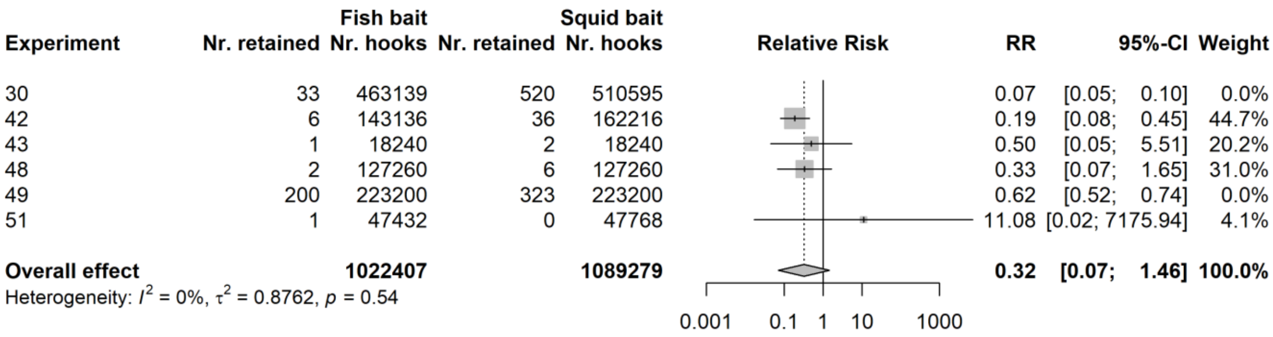


Figure VII.23. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of albacore with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiments are numbers 30 and 49 (that are still represented in the plots but not considered in the analysis).

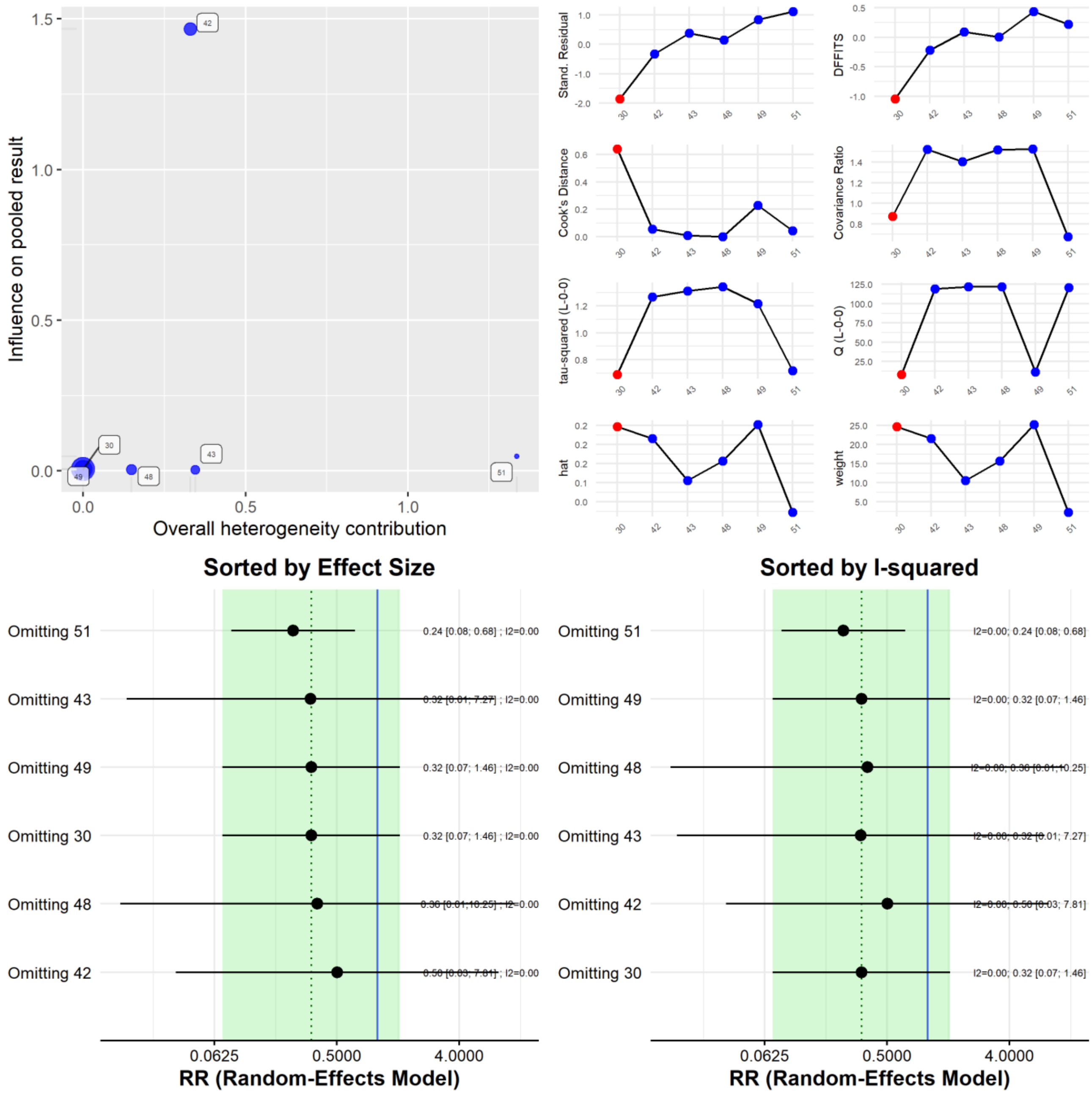


Figure VII.24. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of albacore with fish vs. squid bait. The excluded experiments are number 30 and 49 (that are still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Albacore tuna – At-haulback mortality

In the specific case of albacore, when all experiments are used for comparing fish and squid bait the RR is calculated at 1.04 (95% CIs: 0.97; 1.11), which means that changing from squid to fish bait is not significant in the at-haulback mortality of albacore (Figure VII.25). In this analysis there is no overall heterogeneity. The results of the validation with search for possible outliers and influence analysis is represented in Figure VII.26. Experiment 42 is identified in several of the diagnostics as a possible outlier, however in this case as only three experiments are available, removing the possible outliers would hinder the meta-analysis as only two studies would remain; as such, all three studies were maintained for the final analysis.

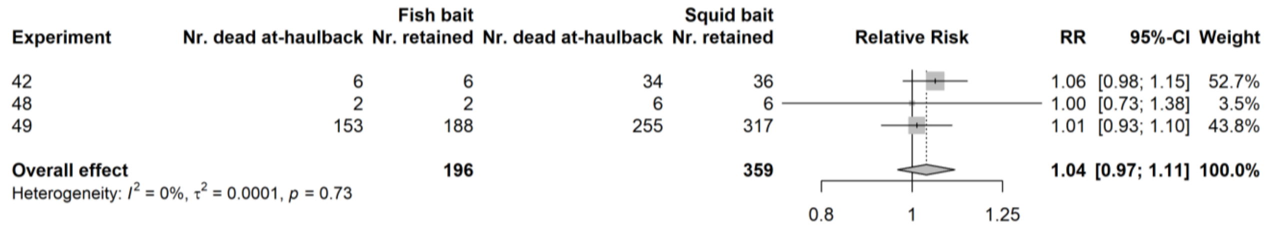


Figure VII.25. Forest plot of the random effects meta-analysis performed for the retention rates of albacore with fish vs. squid bait (Note: Squid is considered the control while fish is considered the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

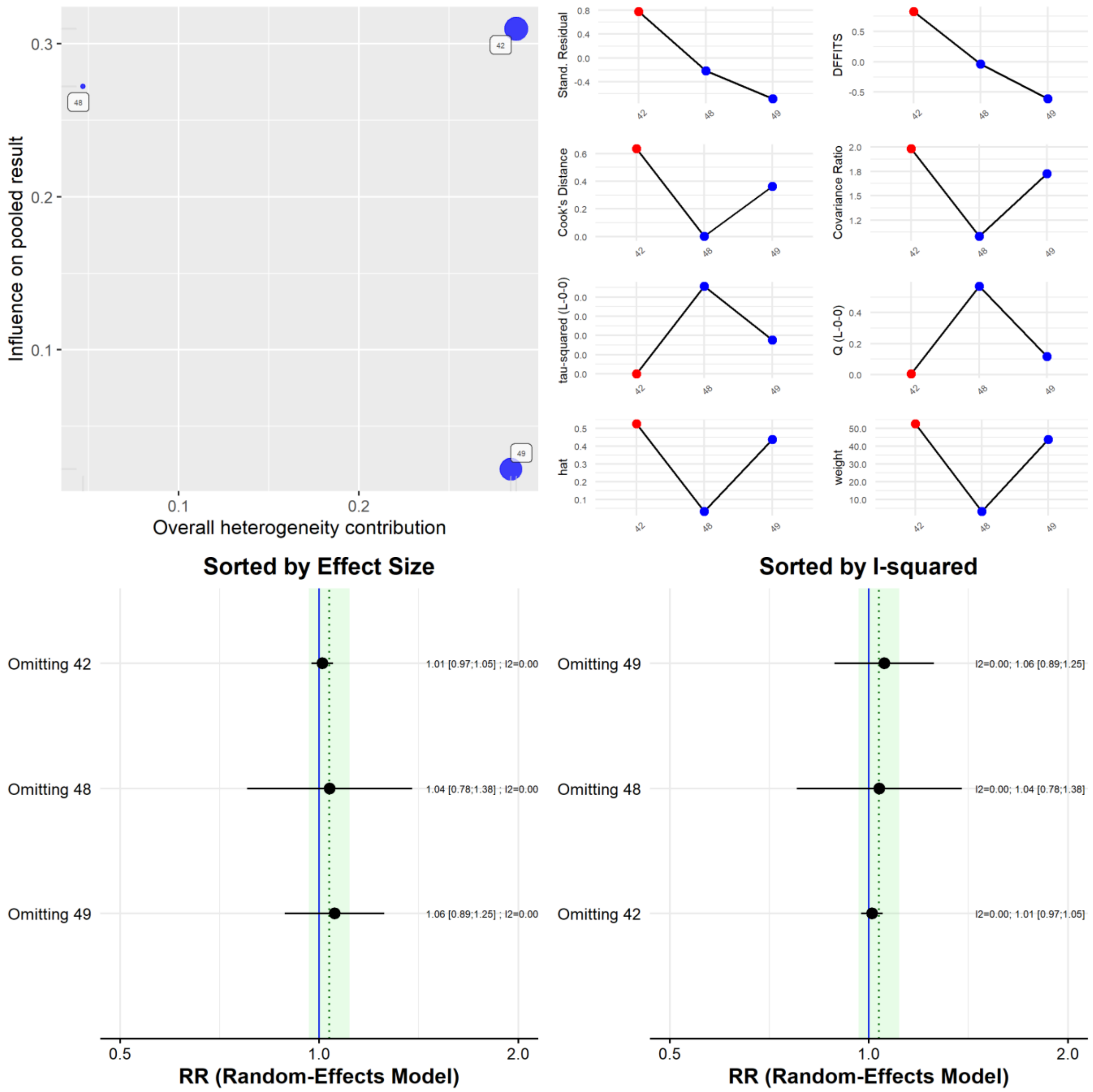


Figure VII.26. Influence analysis for validating the meta-analysis performed for the retention rates of albacore with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Effects of bait on desirable bycatch species

Blue shark – Retention rates

For the blue shark, Figure VII.27 shows the random effects model when all data compiled is used. In the specific case, when all data are used, the RR is 1.07 (95% CIs: 0.70; 1.63). In this analysis we also see that the overall heterogeneity (I^2) is very high and fails the statistical assumption of homogeneity (p-value<0.05).

We then looked for possible outliers and carried out an influence analysis, which is shown in Figure VII.28. In this case, the influence analysis identified 1 experiment (experiment 49) that is an outlier with influence on the overall results. The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VII.29 and validation indicated in Figure VII.30. With the exclusion of that outlier, the final RR estimation is 0.95 (CIs: 0.63; 1.43), meaning that we expect blue shark to be less retained (by 5%) when changing from squid to fish bait, but this is not significant as the 95% CIs vary between a reduction of 37% to an increase of 43%.

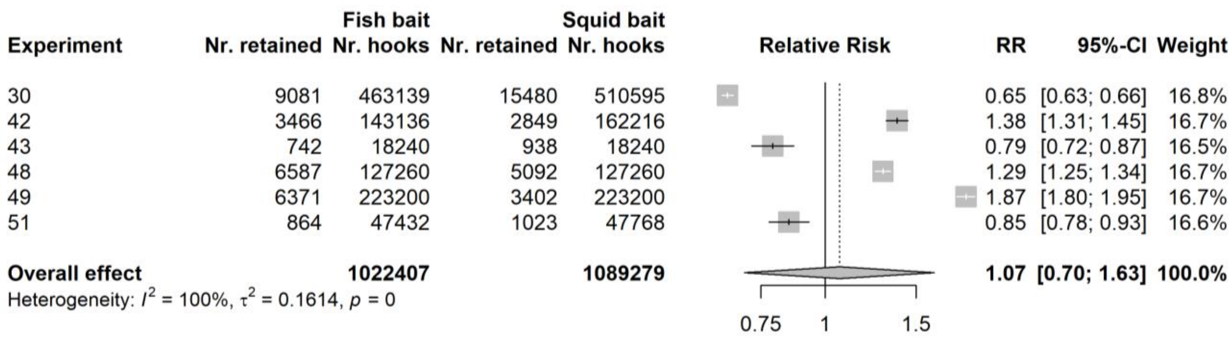


Figure VII.27. Forest plot of the random effects meta-analysis performed for the retention of blue shark with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

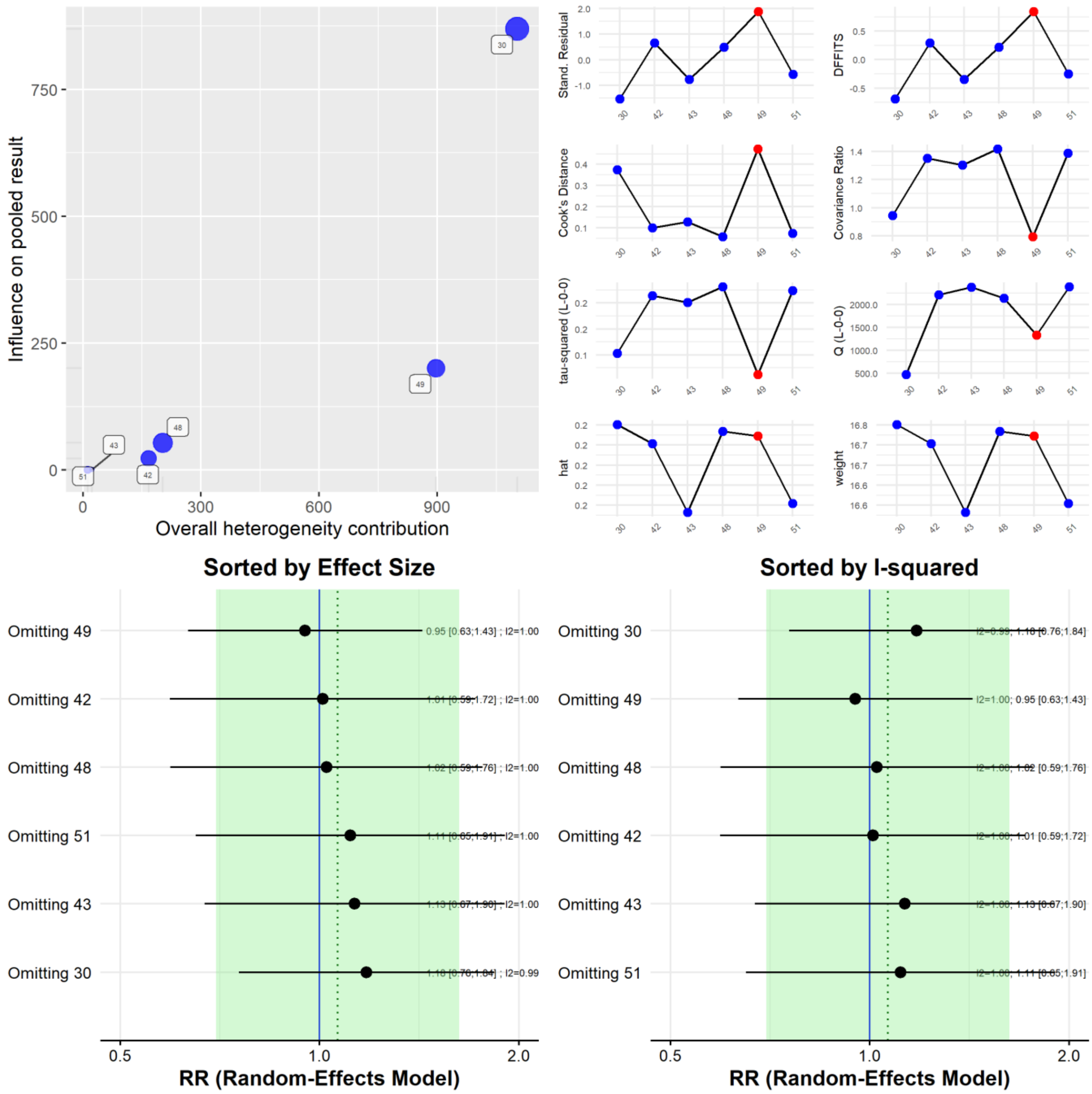


Figure VII.28. Influence analysis for the meta-analysis performed for the retention of blue shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

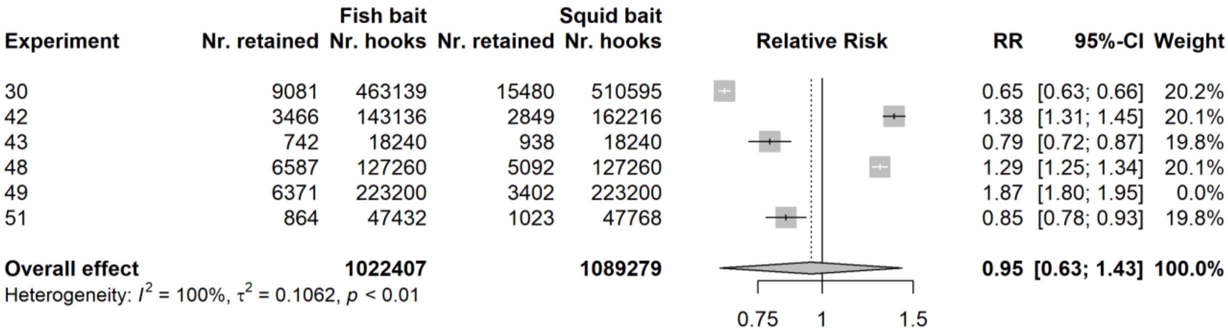


Figure VII.29. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of blue shark with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis).

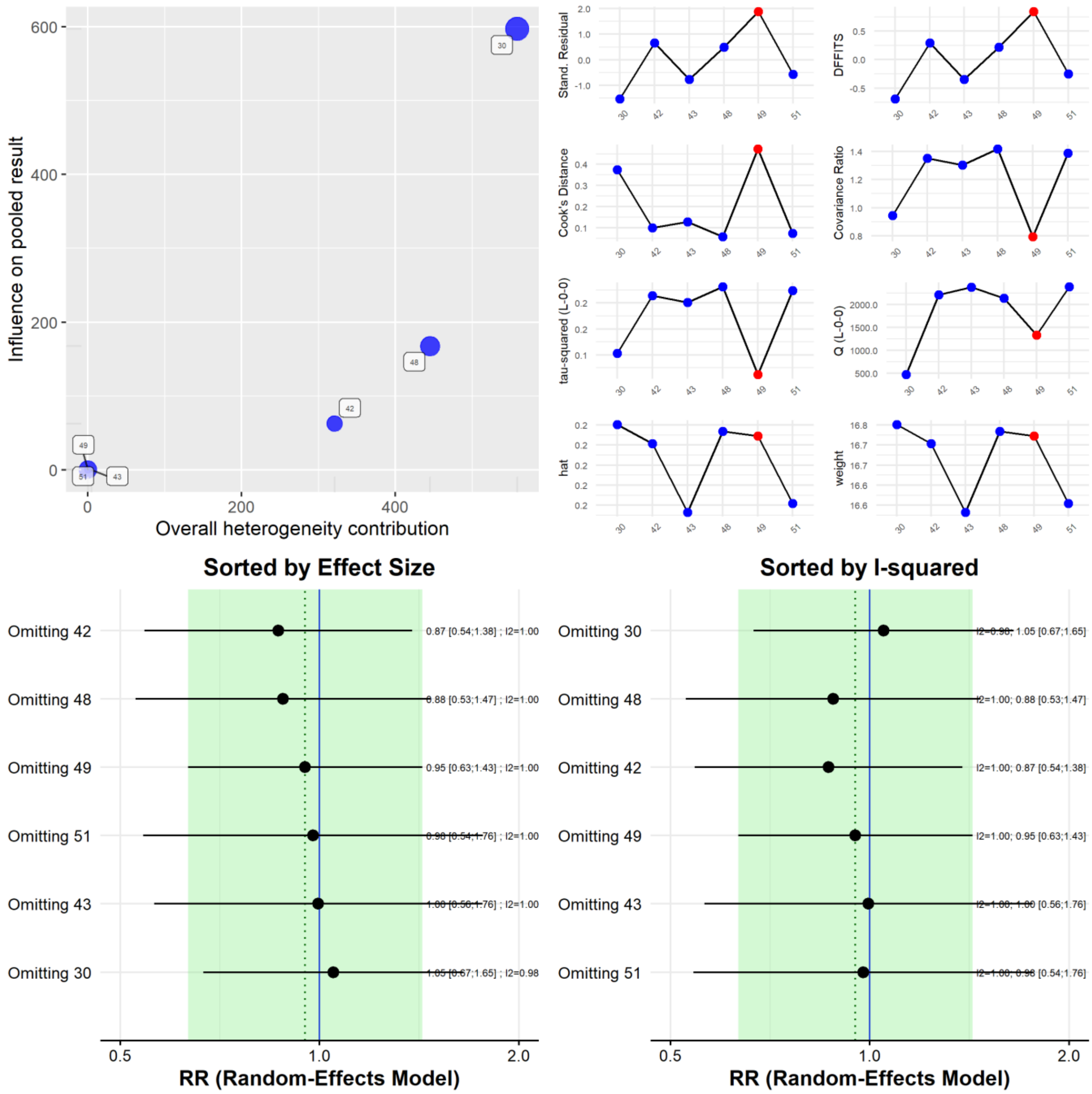


Figure VII.30. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of blue shark with fish vs. squid bait. The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Blue shark – At-haulback mortality

With regard to the at-haulback mortality of blue shark, the random effects model considering all experiments is shown in Figure VII.31. In this case, the influence analysis that followed (Figure VII.32) identified one experiment (experiment 49) 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 study, with the results of the new pooled analysis indicated in Figure VII.33 and validation indicated in Figure VII.34.

With the exclusion of that outlier, the heterogeneity was largely reduced, specifically from 70% when including all studies to 50%, and the final analysis results also changed. With the exclusion of experiment 49, the final RR estimation would change from 1.71 (CIs: 1.39; 2.11) to 1.80 (CIs: 1.35; 2.41). This indicates that changing from squid bait to fish bait leads to a significant increase in the at-haulback mortality of blue shark specifically of 80%, with the 95% CIs varying between increases of 35% and 2.41 times.

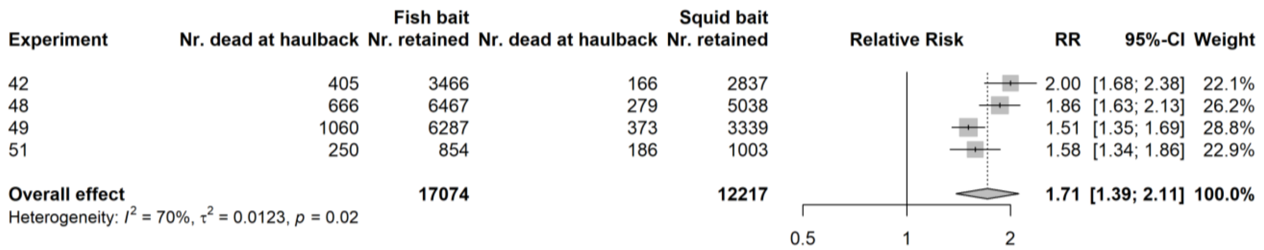


Figure VII.31. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of blue shark with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

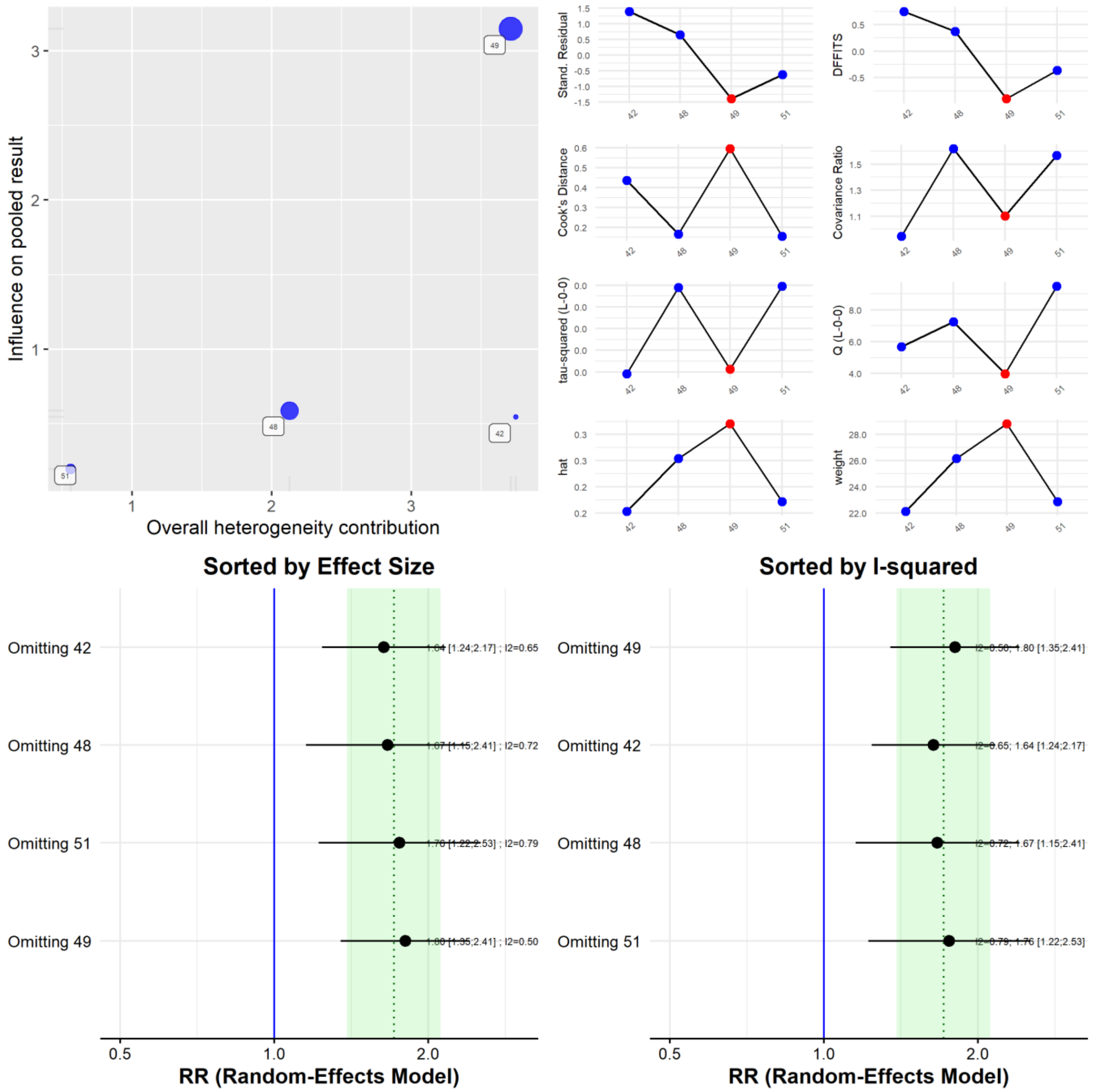


Figure VII.32. Influence analysis for the meta-analysis performed for the at-haulback mortality of blue shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Fish bait Nr. dead at haulback	Fish bait Nr. retained	Squid bait Nr. dead at haulback	Squid bait Nr. retained	RR	95%-CI	Weight
42	405	3466	166	2837	2.00	[1.68; 2.38]	30.5%
48	666	6467	279	5038	1.86	[1.63; 2.13]	37.8%
49	1060	6287	373	3339	1.51	[1.35; 1.69]	0.0%
51	250	854	186	1003	1.58	[1.34; 1.86]	31.7%
Overall effect		**17074**		**12217**	**1.80**	**[1.35; 2.41]**	**100.0%**

Heterogeneity: $I^2 = 50\%$, $\tau^2 = 0.0083$, $p = 0.14$

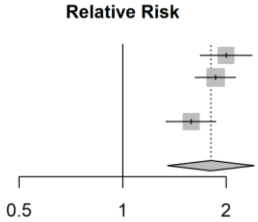


Figure VII.33. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of blue shark with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis).

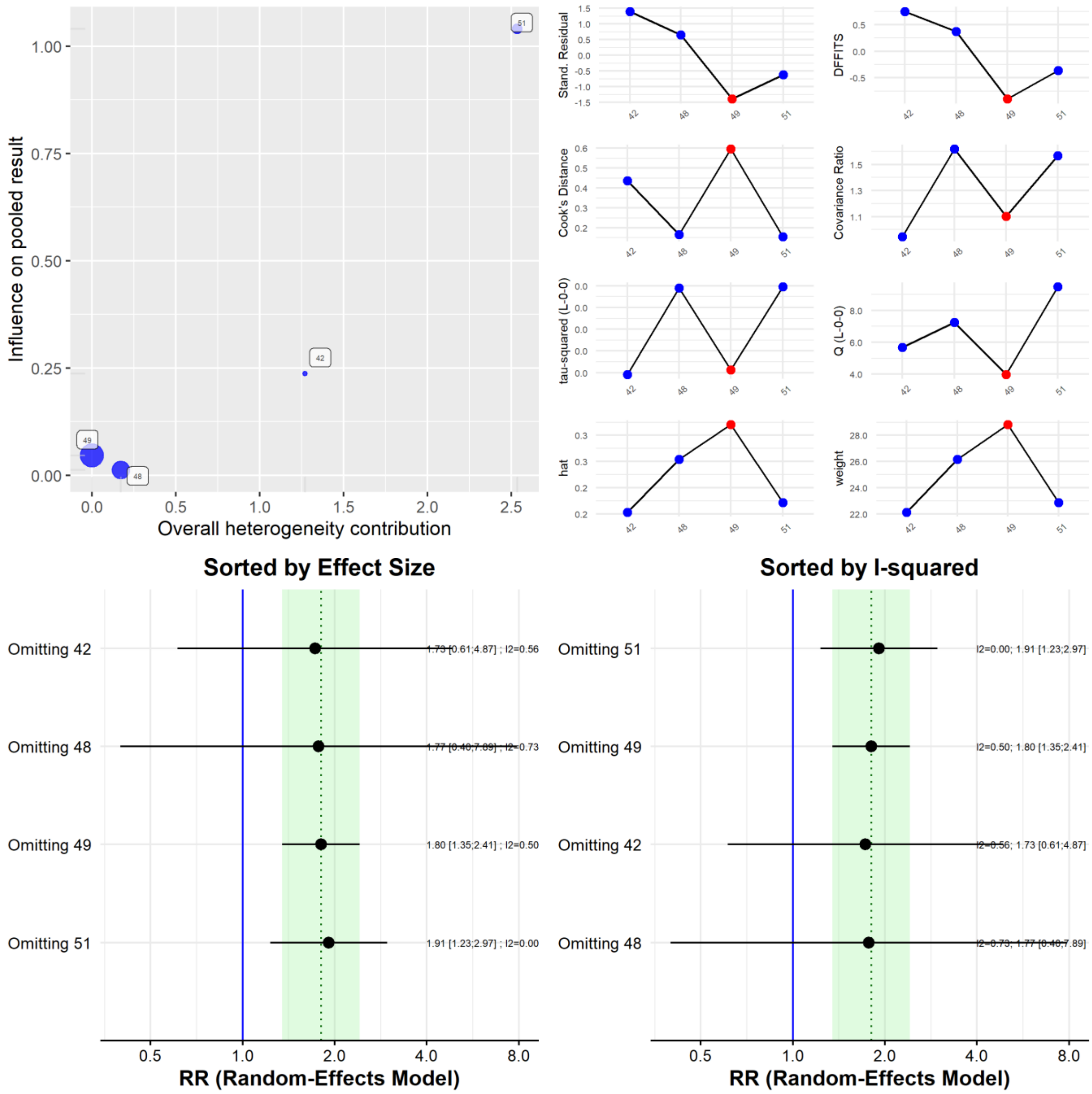


Figure VII.34. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of blue shark with fish vs. squid bait. The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Shortfin mako – Retention rates

Figure VII.35 shows the random effects model when all data compiled are used for shortfin mako. When all experiments are used in the analysis, the RR is 1.45 (95% CIs: 0.86; 2.45). In this analysis the overall heterogeneity (I^2) is very high (95%) and fails the statistical assumption of homogeneity (p-value<0.05).

The influence analysis is represented in Figure VII.36. In this case, one experiment (experiment 30) was identified as an outlier with influence in the pooled results. The analysis was therefore re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VII.37 and validation indicated in Figure VII.38. With the exclusion of that outlier, the final RR estimation is 1.26 (CIs: 0.79; 2.00), meaning that on average we expect that the retention of shortfin mako when using fish bait is 26% higher than when using squid bait, but with 95% confidence intervals varying between a reduction of 21% and an increase of 2 times. Although the point estimate indicates an increase in retention of shortfin mako when using fish bait, this increase is not significant as indicated by the confidence intervals.

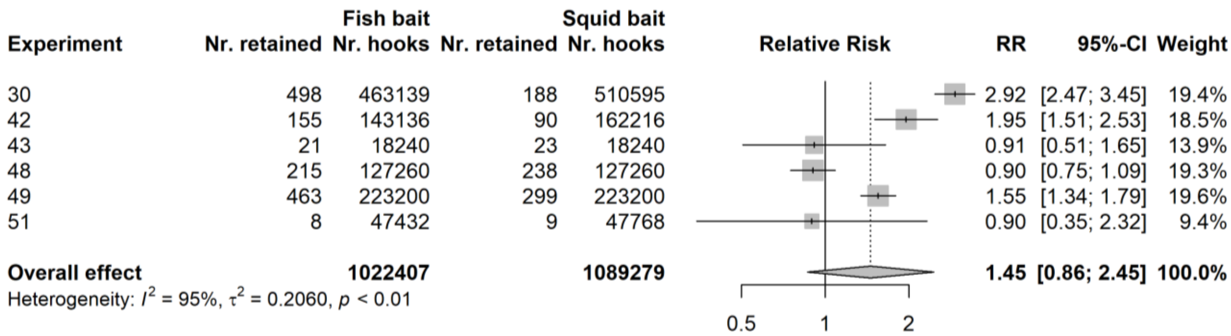


Figure VII.35. Forest plot of the random effects meta-analysis performed for the retention of shortfin mako with fish vs. squid bait Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

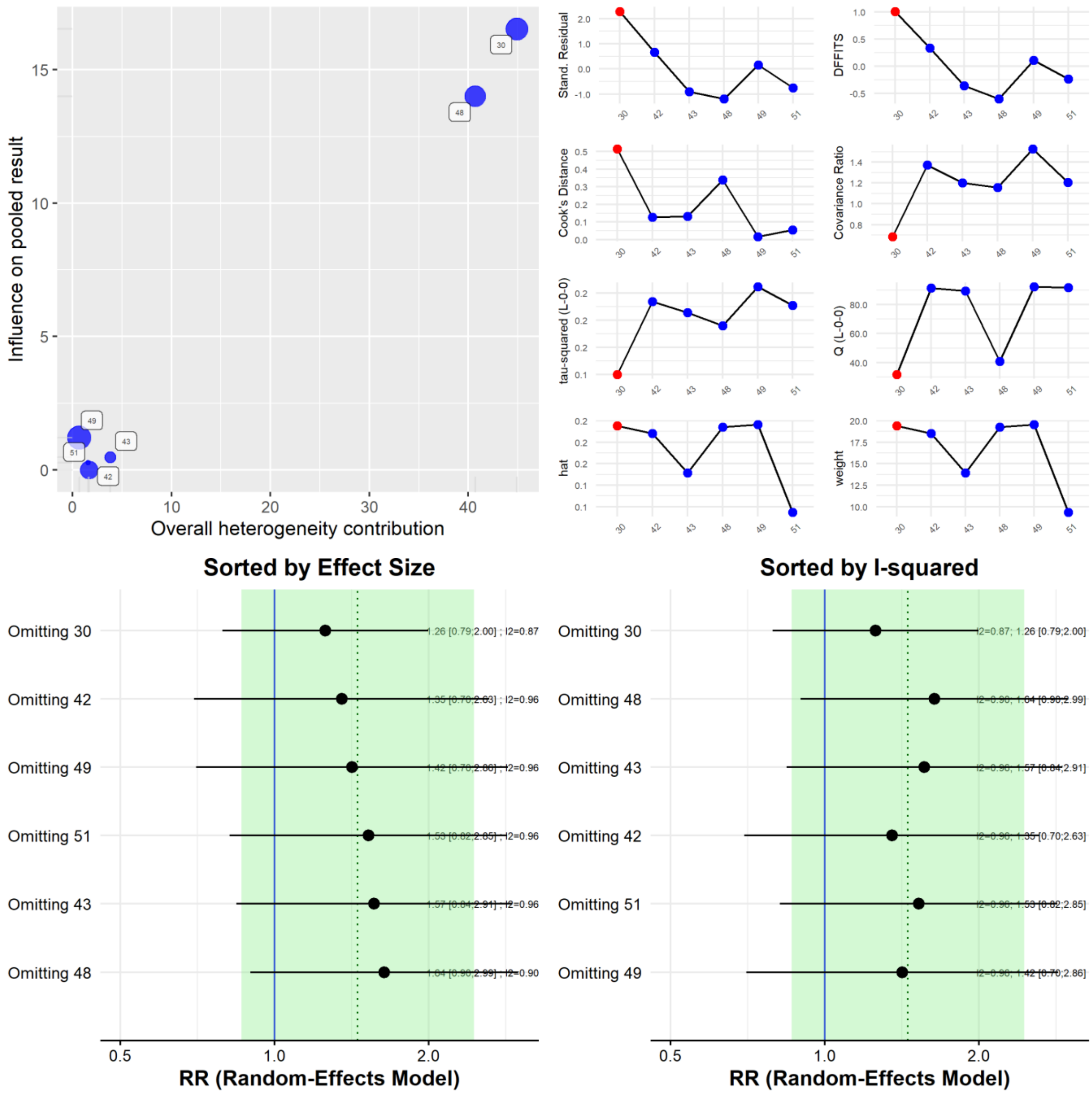


Figure VII.36. Influence analysis for the meta-analysis performed for the retention of shortfin mako with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

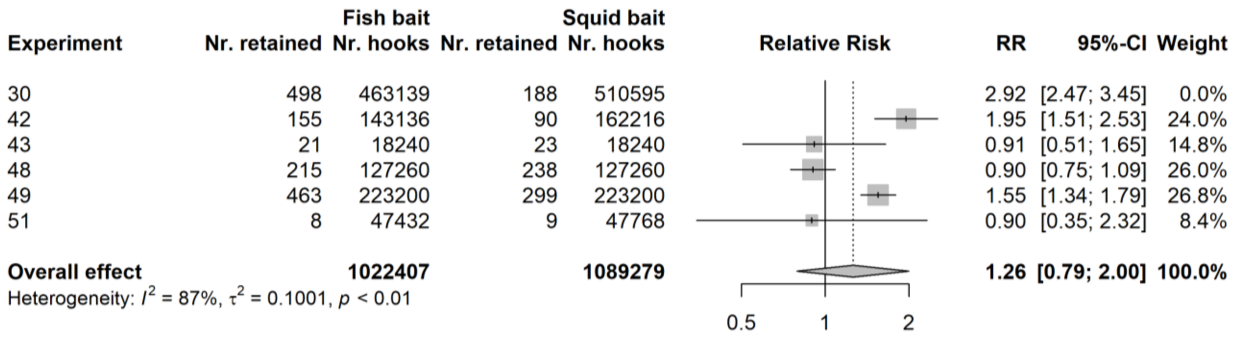


Figure VII.37. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of shortfin mako with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis).

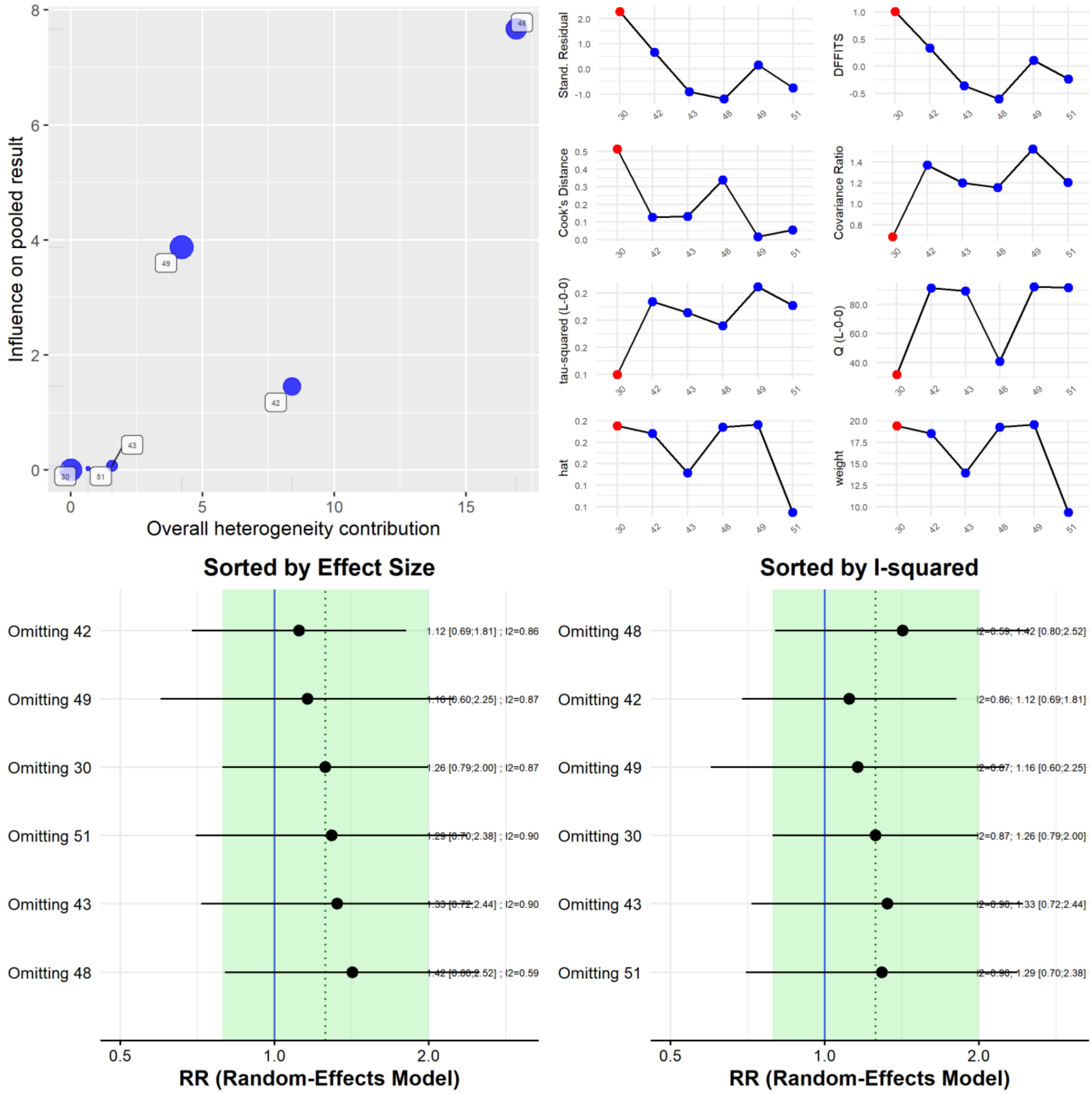
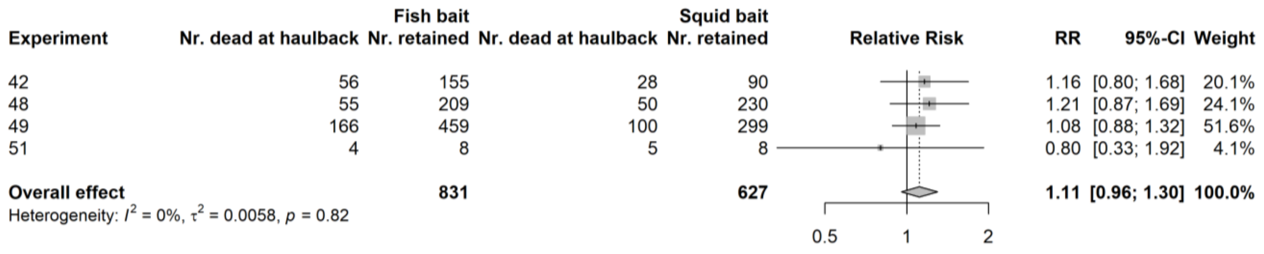


Figure VII.38. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of shortfin mako with fish vs. squid bait. The excluded experiment is number 30 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Shortfin mako – At-haulback mortality

Regarding the at-haulback mortality of shortfin mako, when all experiments are used, the RR is 1.11 (95% CIs: 0.96; 1.30) (Figure VII.39). This means that on average we expect that the at-haulback mortality of shortfin mako when using fish bait is 11% higher than when using squid bait, but with 95% confidence intervals varying between a reduction of 4% and an increase of 30% in at-haulback mortality, meaning that the increase in at-haulback mortality is not significant. In this specific analysis there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by 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 VII.40, and in this case no outliers with major influence in the pooled results were identified.



Experiment	Fish bait Nr. dead at haulback	Fish bait Nr. retained	Squid bait Nr. dead at haulback	Squid bait Nr. retained	RR	95%-CI	Weight
42	56	155	28	90	1.16	[0.80; 1.68]	20.1%
48	55	209	50	230	1.21	[0.87; 1.69]	24.1%
49	166	459	100	299	1.08	[0.88; 1.32]	51.6%
51	4	8	5	8	0.80	[0.33; 1.92]	4.1%
Overall effect		**831**		**627**	**1.11**	**[0.96; 1.30]**	**100.0%**

Heterogeneity: I^2 = 0%, τ^2 = 0.0058, p = 0.82

Figure VII.39. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of shortfin mako with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

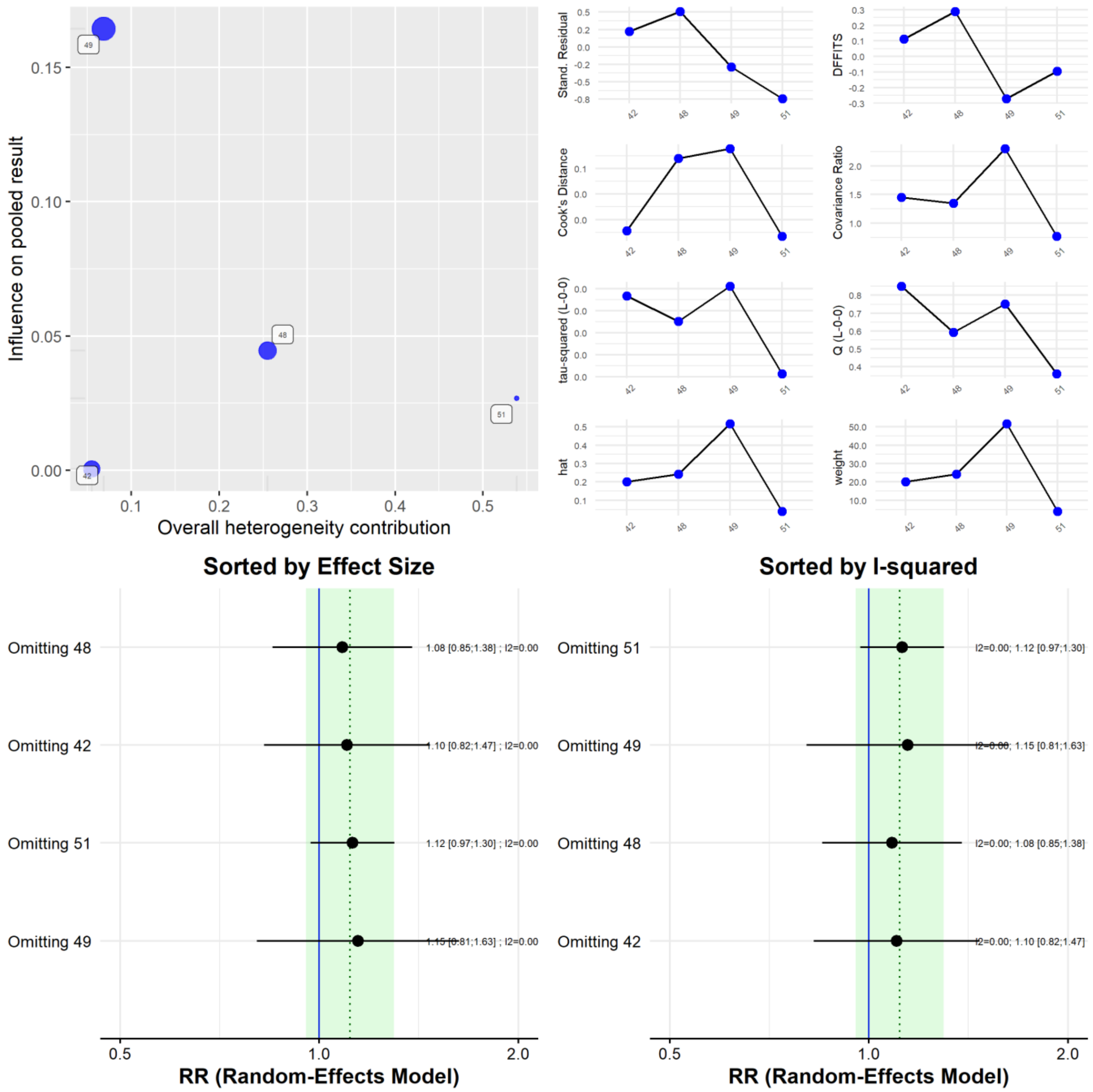


Figure VII.40. Influence analysis for the meta-analysis performed for the at-haulback mortality of shortfin mako with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Blue marlin – Retention rates

In the case of blue marlin, Figure VII.41 shows the random effects model when all data compiled is used. When all data are used, the RR is 1.48 (95% CIs: 0.62; 3.55). This means that on average we expect that the retention of blue marlin when using fish bait is 48% higher than when using squid bait, but with 95% confidence intervals varying between a reduction of

38% and an increase of 3.55 times in retention. In this specific analysis we also see that one problem when using all data (all studies), is that the overall heterogeneity (I^2) is high (87%) and fails the statistical assumption of homogeneity (p-value<0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.42 and in this case no outliers with significant leverage were identified.

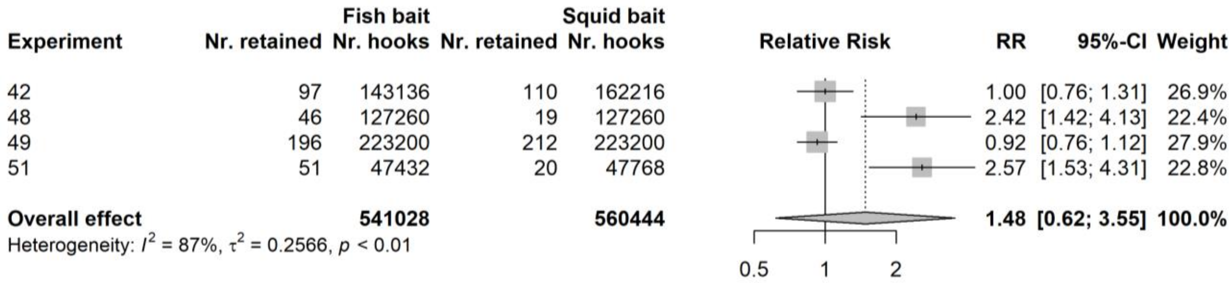


Figure VII.41. Forest plot of the random effects meta-analysis performed for the retention of blue marlin with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

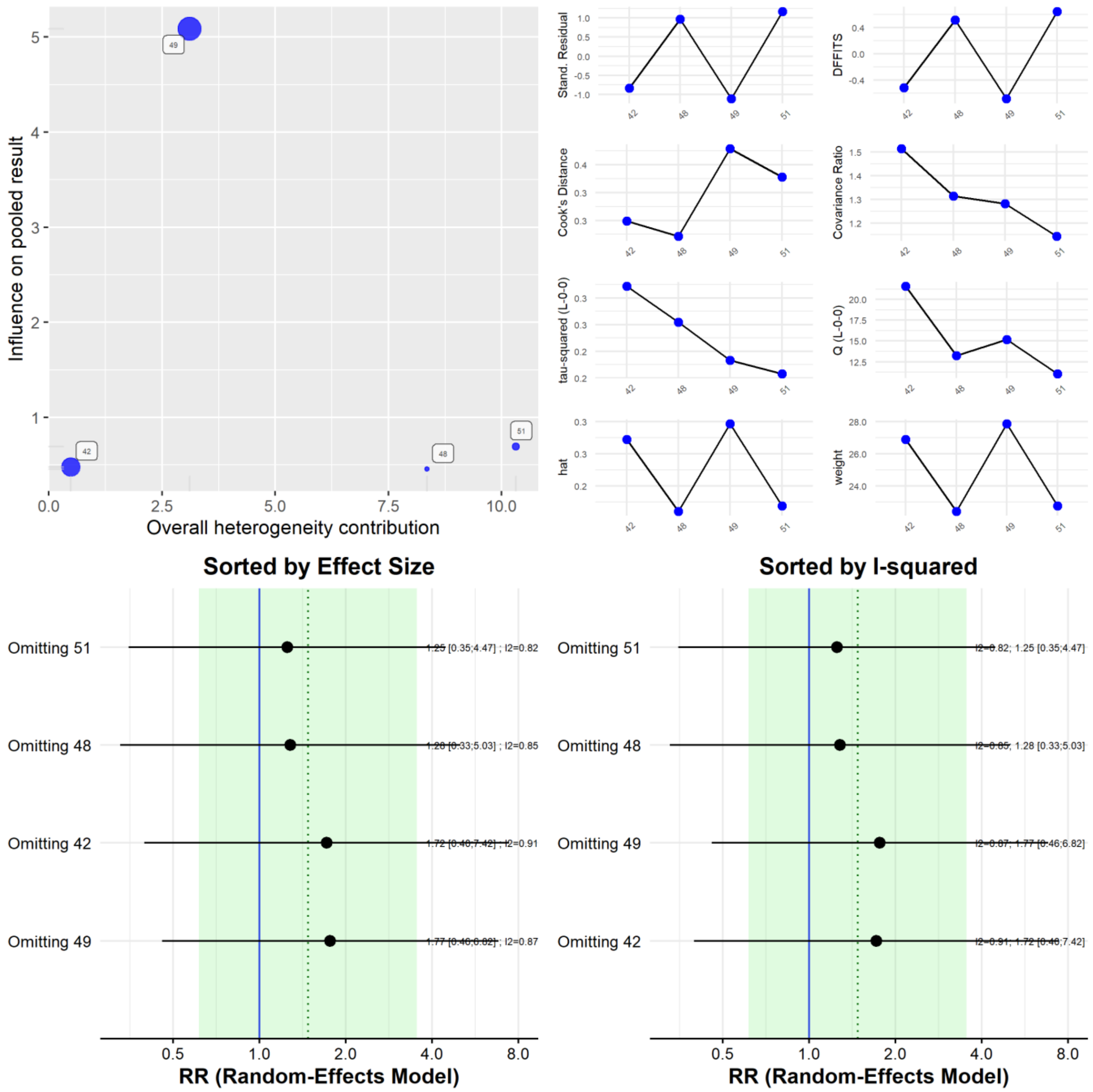


Figure VII.42. Influence analysis for the meta-analysis performed for the retention of blue marlin with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I^2 (right).

Blue marlin – At-haulback mortality

Figure VII.43 shows the random effects model for at-haulback mortality of blue marlin. When all experiments are used, the RR is 0.97 (95% CIs: 0.75; 1.25). This means that on average we expect that the at-haulback mortality of blue marlin when using fish bait is 3% lower than when using squid bait, but this is not significant with 95% confidence intervals varying between a reduction of 25% and an increase of 25%. In this analysis the overall heterogeneity is low (I^2=12%) with the meta-analysis validated by 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 VII.44, and in this case no outliers with major influence in the pooled results were identified.

Experiment	Fish bait Nr. dead at haulback	Fish bait Nr. retained	Squid bait Nr. dead at haulback	Squid bait Nr. retained	RR	95%-CI	Weight
42	62	97	69	110	1.02	[0.83; 1.25]	31.6%
48	30	46	9	19	1.38	[0.82; 2.31]	10.4%
49	93	194	114	206	0.87	[0.72; 1.05]	33.6%
51	37	51	16	20	0.91	[0.69; 1.20]	24.3%
Overall effect		**388**		**355**	**0.97**	**[0.75; 1.25]**	**100.0%**

Heterogeneity: $I^2 = 12\%$, $\tau^2 = 0.0178$, $p = 0.33$

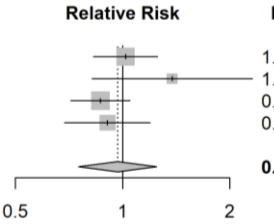


Figure VII.43. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of blue marlin with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

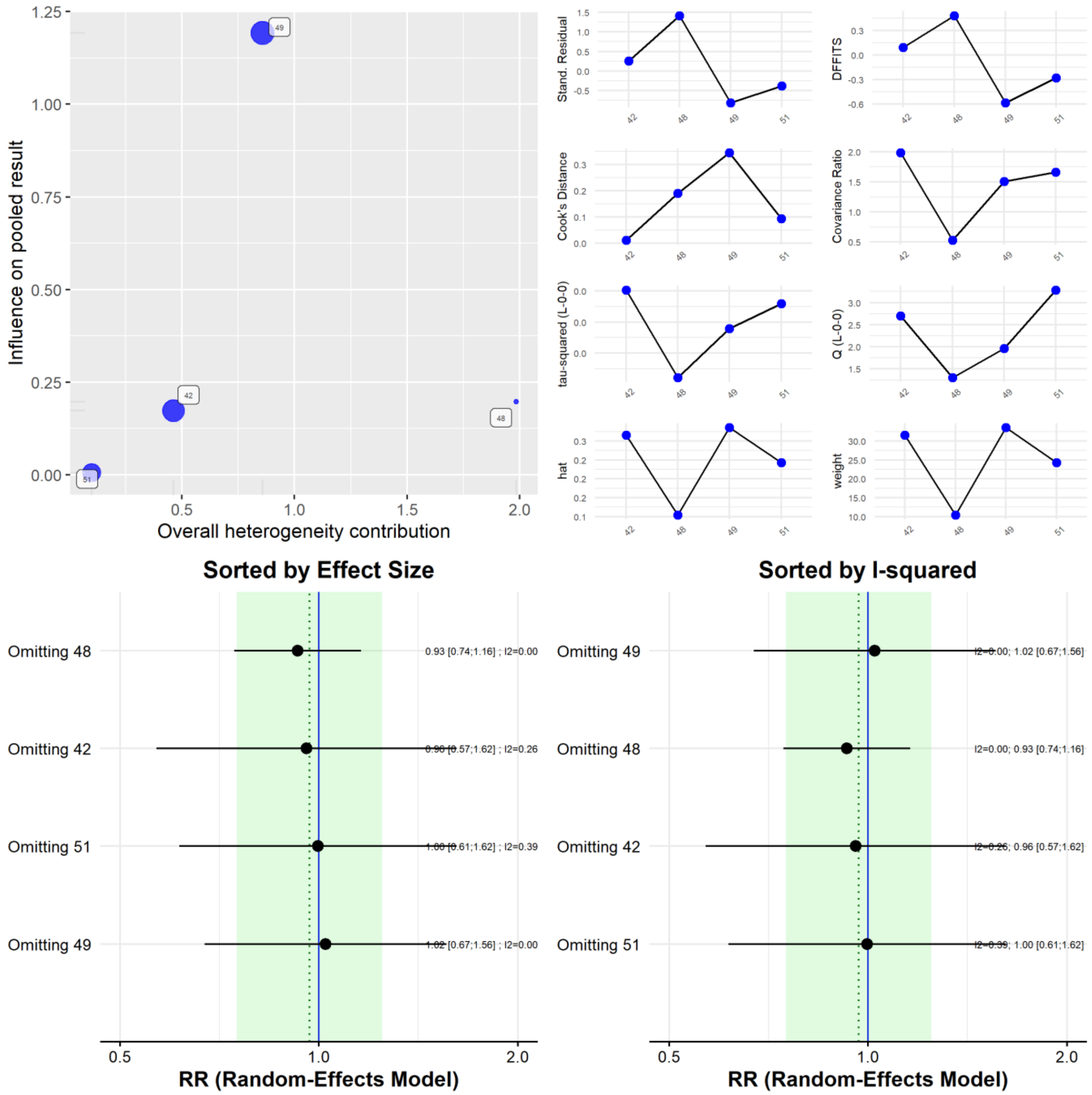


Figure VII.44. Influence analysis for the meta-analysis performed for the at-haulback mortality of blue marlin with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I^2 (right).

Atlantic sailfish – Retention rates

Figure VII.45 shows the random effects model for retention of Atlantic sailfish when all data compiled are used. When all data is used, the RR is 0.64 (95% CIs: 0.09; 4.32). In this analysis the overall heterogeneity (I^2) is very high (90%) and fails the statistical assumption of homogeneity (p-value<0.05).

We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.46. In this case, the influence analysis identified one experiment (experiment 51) that is an outlier with 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 VII.47 and validation indicated in Figure VII.48. With the exclusion of that outlier, the final RR estimation is 0.35 (CIs: 0.20; 0.62), meaning that there is a 65% decrease in retention of Atlantic sailfish when using fish bait, with the 95% confidence intervals varying between reductions of 28% and 80%. In the case of the new pooled analysis there is no overall heterogeneity (I^2=0%), with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05).

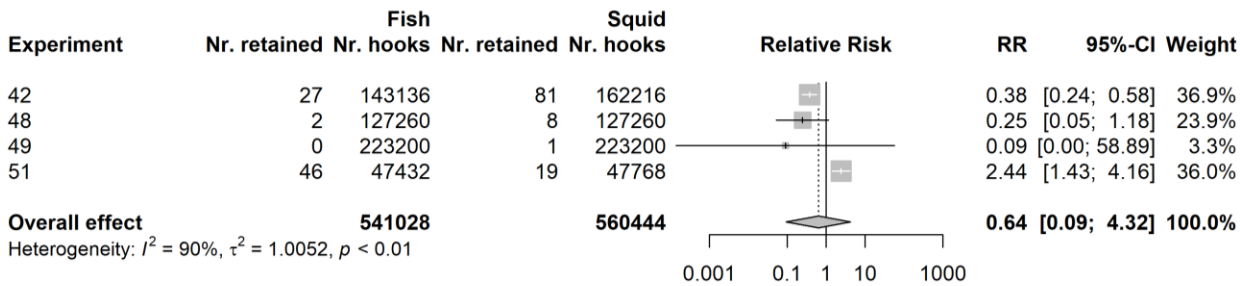


Figure VII.27. Forest plot of the random effects meta-analysis performed for the retention of Atlantic sailfish with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

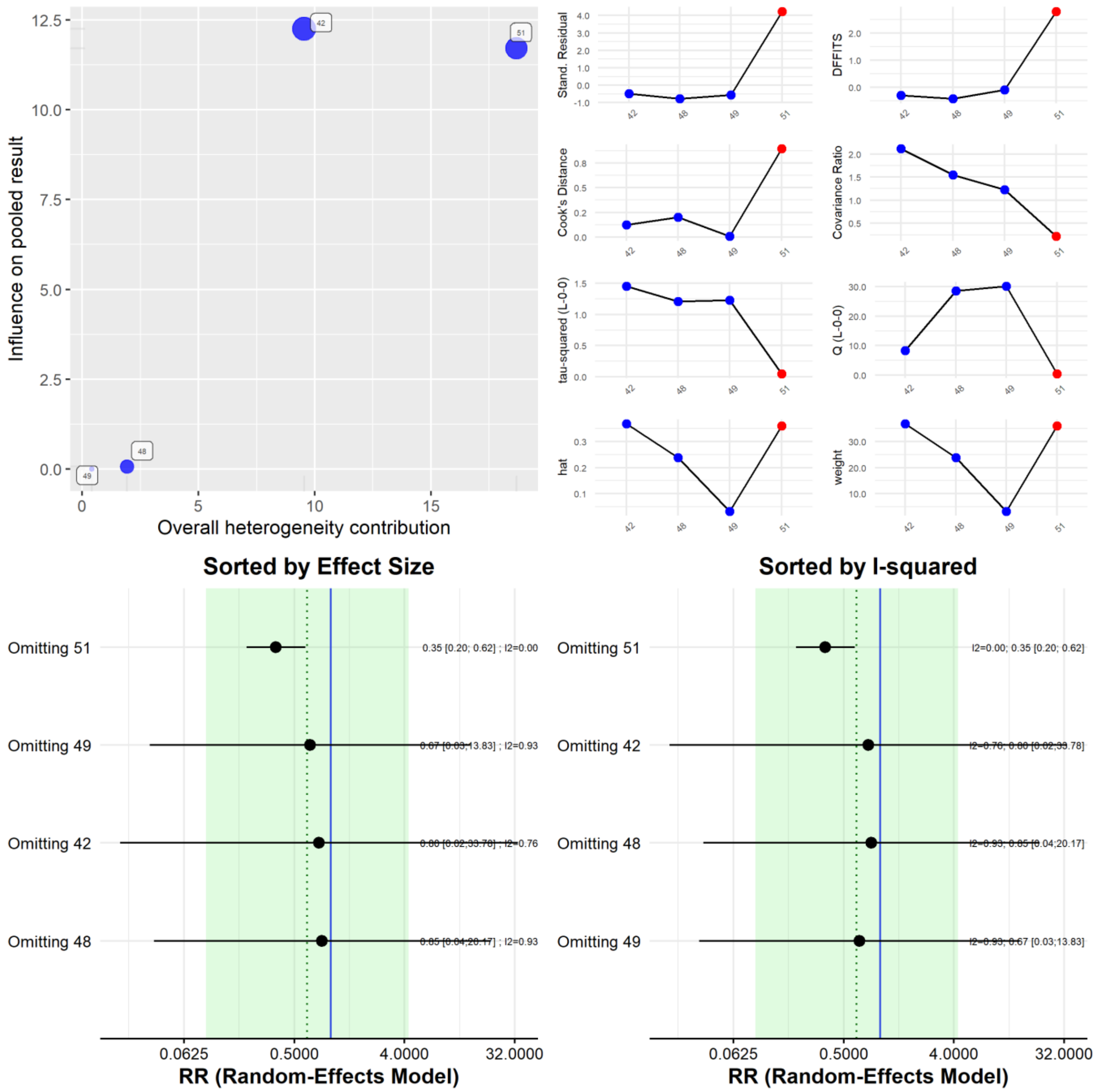


Figure VII.28. Influence analysis for the meta-analysis performed for the retention of Atlantic sailfish with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Fish Nr. retained	Fish Nr. hooks	Squid Nr. retained	Squid Nr. hooks	RR	95%-CI	Weight
42	27	143136	81	162216	0.38	[0.24; 0.58]	86.7%
48	2	127260	8	127260	0.25	[0.05; 1.18]	12.6%
49	0	223200	1	223200	0.09	[0.00; 58.89]	0.8%
51	46	47432	19	47768	2.44	[1.43; 4.16]	0.0%
Overall effect		**541028**		**560444**	**0.35**	**[0.20; 0.62]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0483$, $p = 0.81$

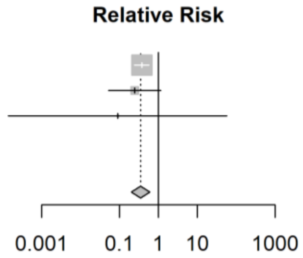


Figure VII.29. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of Atlantic sailfish with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 51 (that is still represented in the plots but not considered in the analysis).

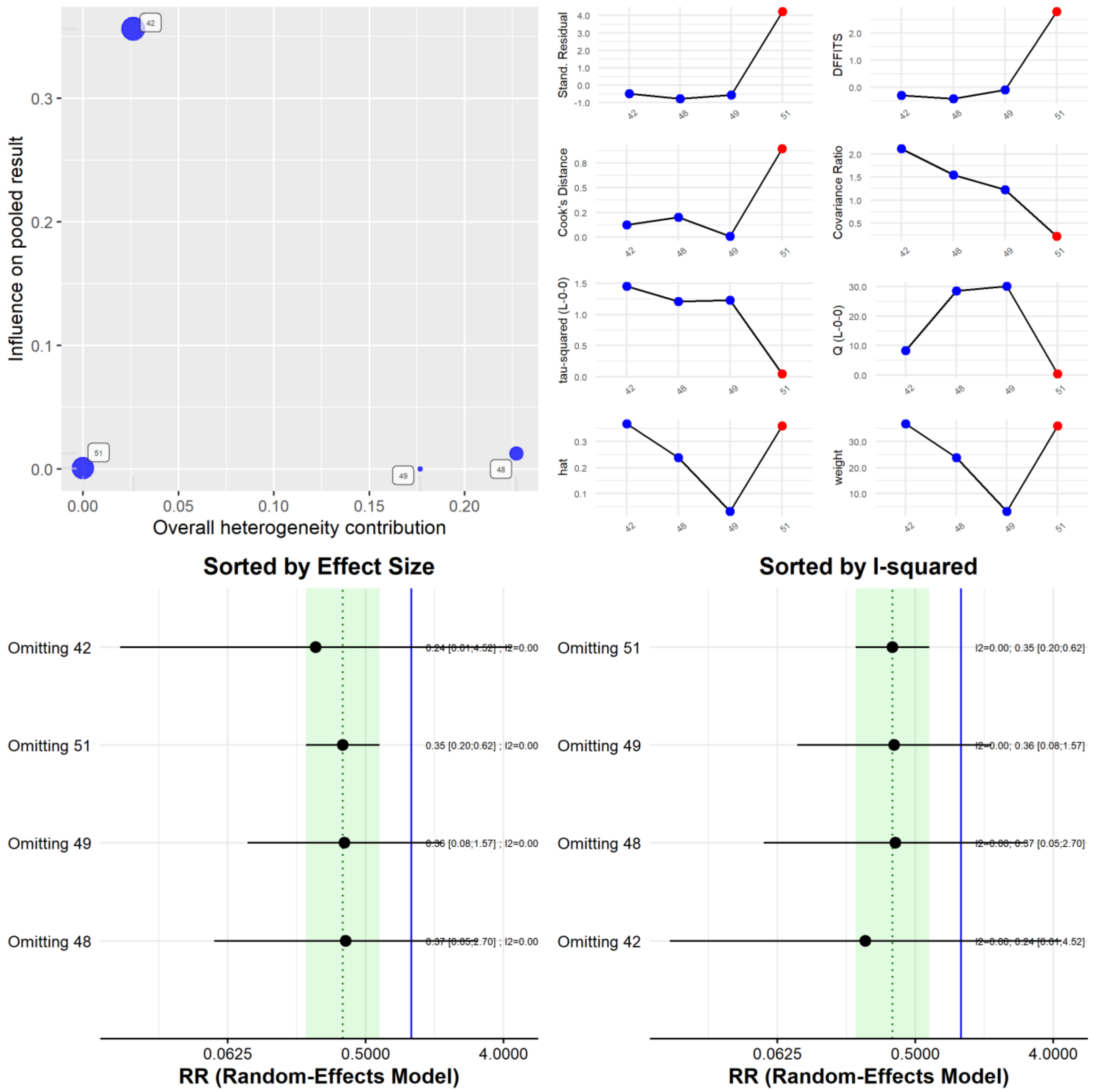


Figure VII.30. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of Atlantic sailfish with fish vs. squid bait. The excluded experiment is number 51 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Atlantic sailfish – At-haulback mortality

With regard to the at-haulback mortality of the Atlantic sailfish, the random effects model considering all experiments is shown in Figure VII.31. The RR is 1.05 (95% CIs: 0.71; 1.56), meaning that on average we expect that the at-haulback mortality of Atlantic sailfish when using fish bait is 5% higher than when using squid bait, but this increase is not significant as the 95% confidence intervals vary between a reduction of 29% and an increase of 56%. In this case there is no overall heterogeneity (I2=0%), with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05). The influence analysis is shown in Figure VII.32 and there were no outliers with significant leverage identified.

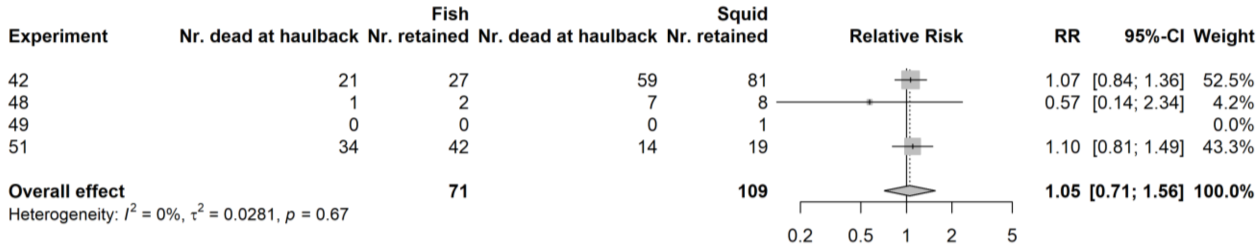


Figure VII.31. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of Atlantic sailfish with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

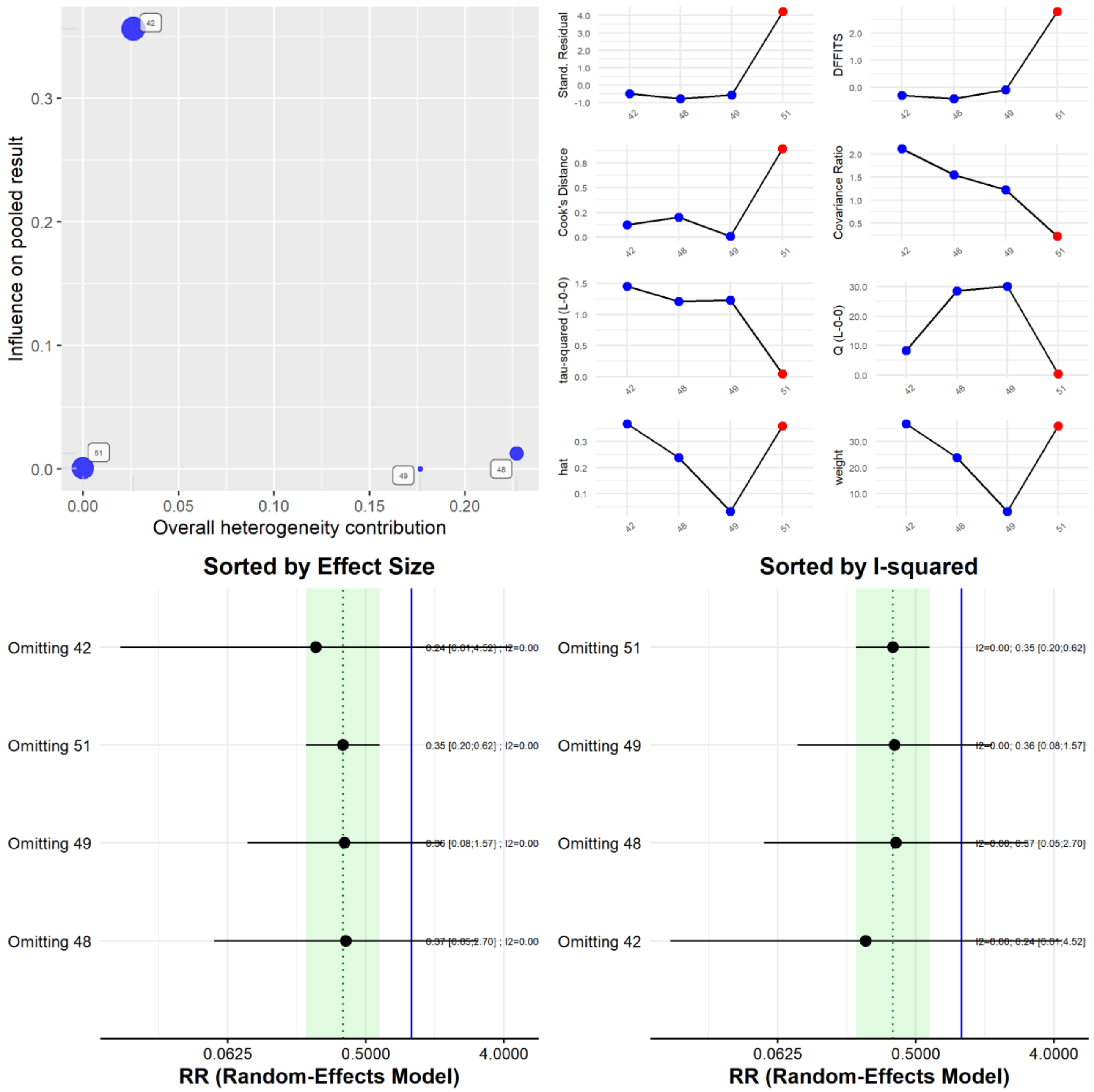


Figure VII.32. Influence analysis for the meta-analysis performed for the at-haulback mortality of Atlantic sailfish with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

White marlin – Retention rates

Figure VII.33 shows the random effects model for retention of white marlin when all data compiled are used. When all data are used, the RR is 0.82 (95% CIs: 0.09; 7.98). In this specific analysis we also see that the overall heterogeneity (I^2) is very high (93%) and fails the statistical assumption of homogeneity (p-value<0.05).

We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.34. In this case, the influence analysis identified one experiment (experiment 42) that is an outlier with influence on the results. The analysis was therefore re-run excluding that experiment, with the results of the final pooled analysis indicated in Figure VII.35 and validation indicated in Figure VII.36. With the exclusion of that outlier, the final RR estimation is 1.45 (CIs: 0.20; 10.53). This indicates that on average we expect that the retention of white marlin when using fish bait is 45% higher than when using squid bait, however this is not significant as the 95% confidence intervals vary between a reduction of 80% and an increase of 10.53 times in retention.

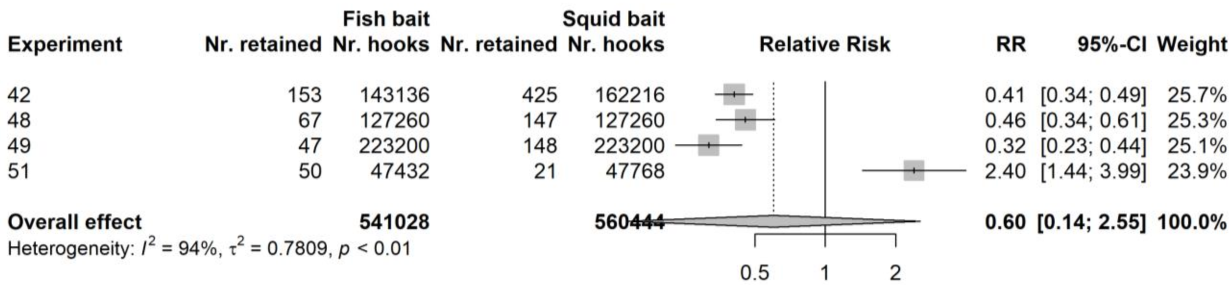


Figure VII.33. Forest plot of the random effects meta-analysis performed for the retention of white marlin with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

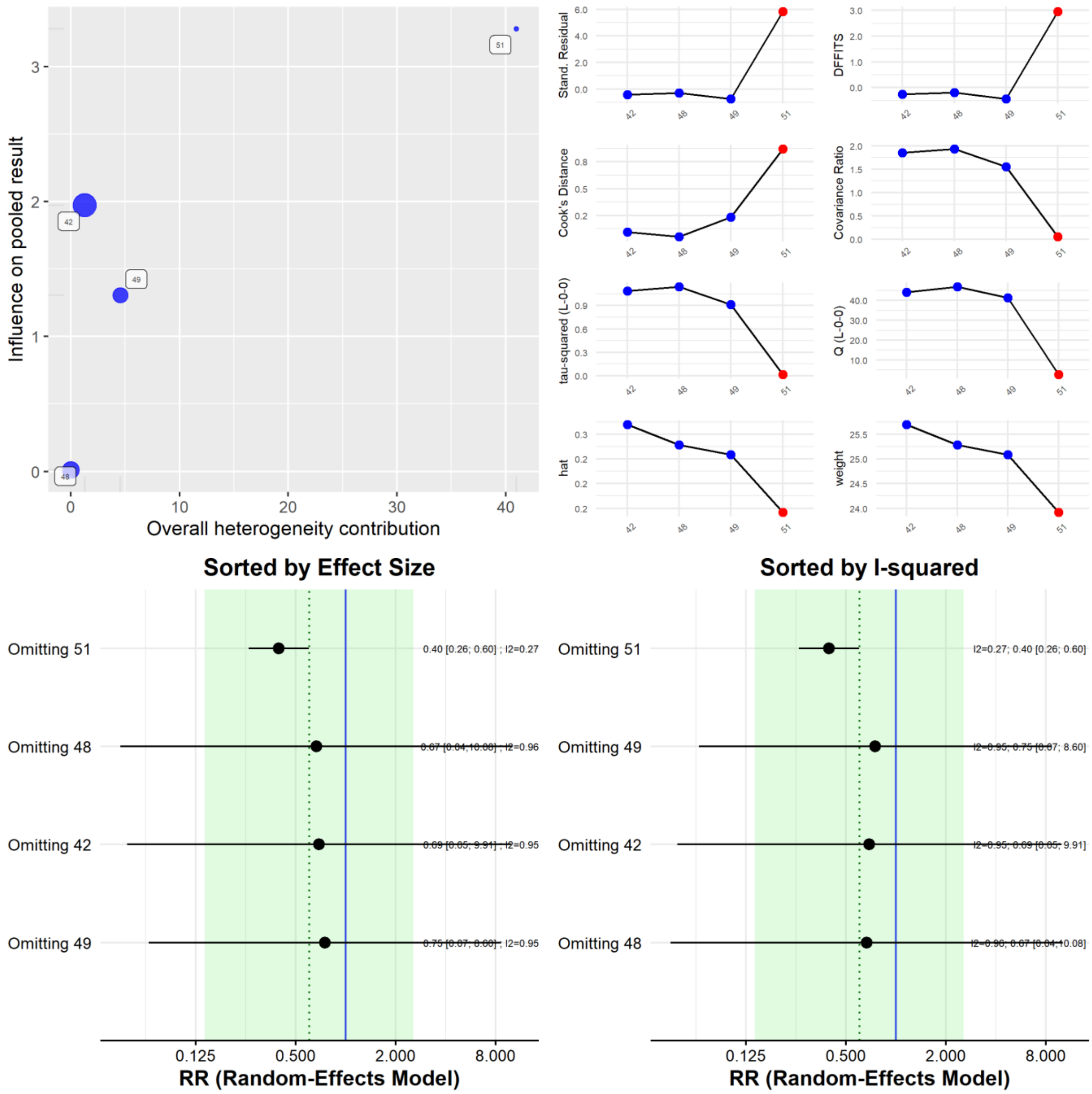


Figure VII.34. Influence analysis for the meta-analysis performed for the retention of white marlin with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

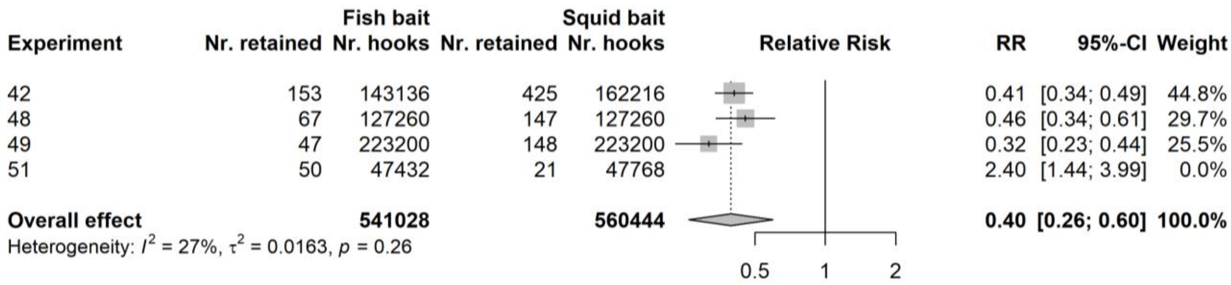


Figure VII.35. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of white marlin with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 51 (that is still represented in the plots but not considered in the analysis).

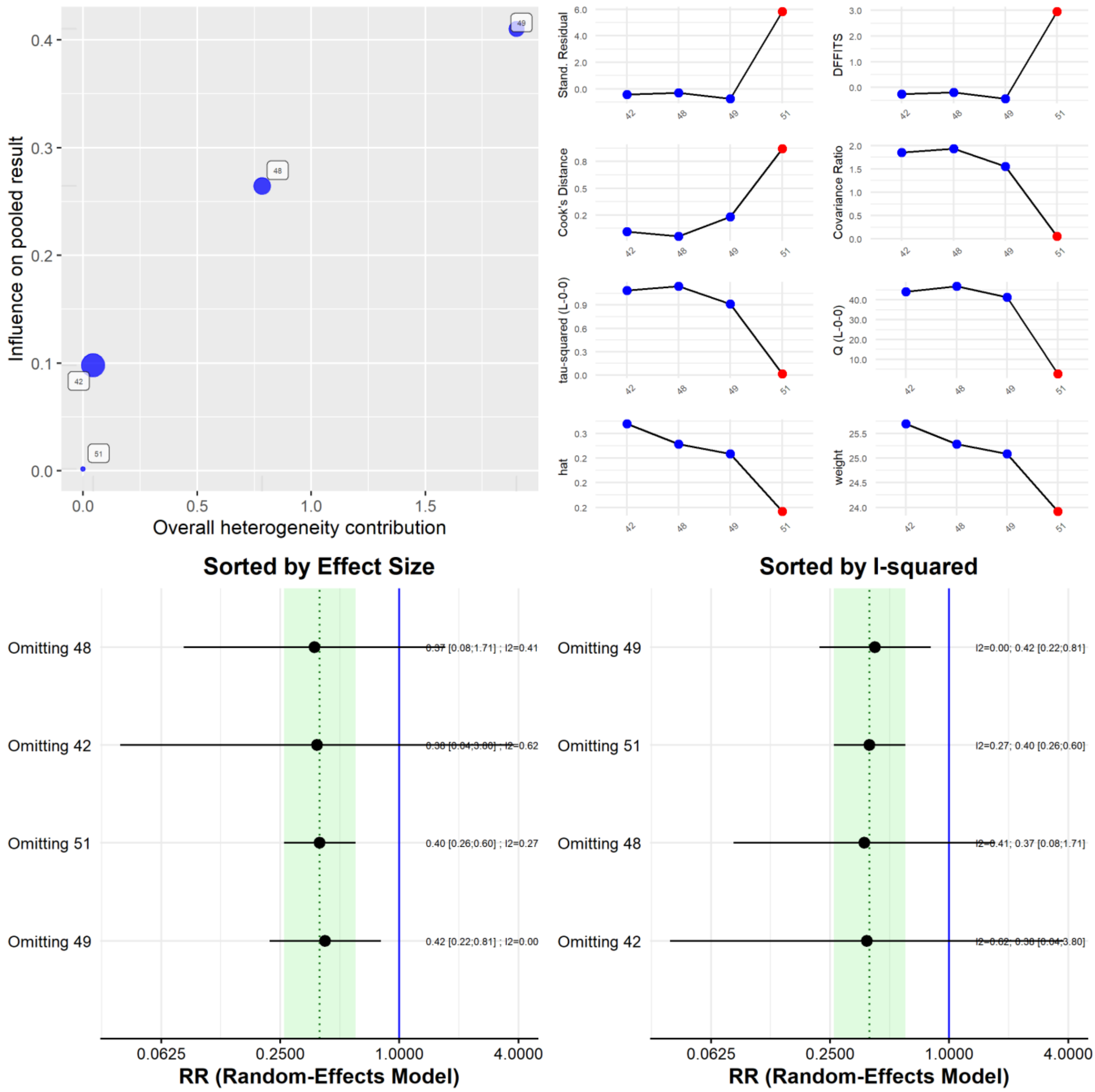


Figure VII.36. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of white marlin with fish vs. squid bait. The excluded experiment is number 51 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

White marlin – At-haulback mortality

With regard to the at-haulback mortality of white marlin, the random effects model considering all experiments is shown in Figure VII. 37. In this case, the influence analysis that followed (Figure VII.38) identified one experiment (experiment 42) 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 study, with the results of the new pooled analysis indicated in Figure VII.39 and validation indicated in Figure VII.40.

With the exclusion of that outlier, the heterogeneity was largely reduced, specifically from 30% when including all studies to 0%, and the pooled analysis results also changed. With the exclusion of experiment 42, the final RR estimation would change from 1.16 (CIs: 0.97; 1.39) to 1.09 (CIs: 0.98; 1.20). This indicates that changing from squid bait to fish bait leads to an increase in the at-haulback mortality of white marlin, although not significant.

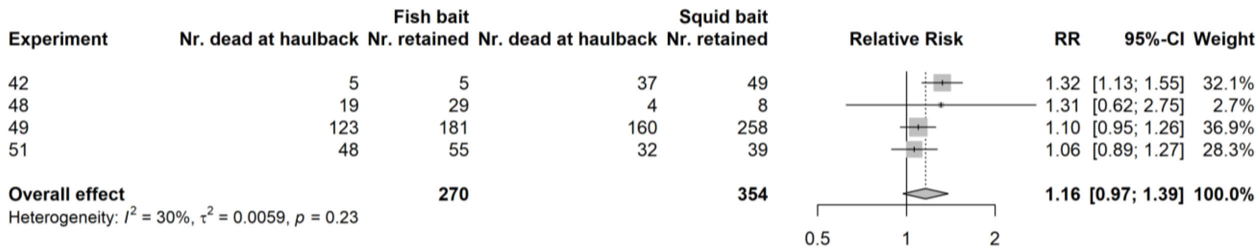


Figure VII.37. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of white marlin with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

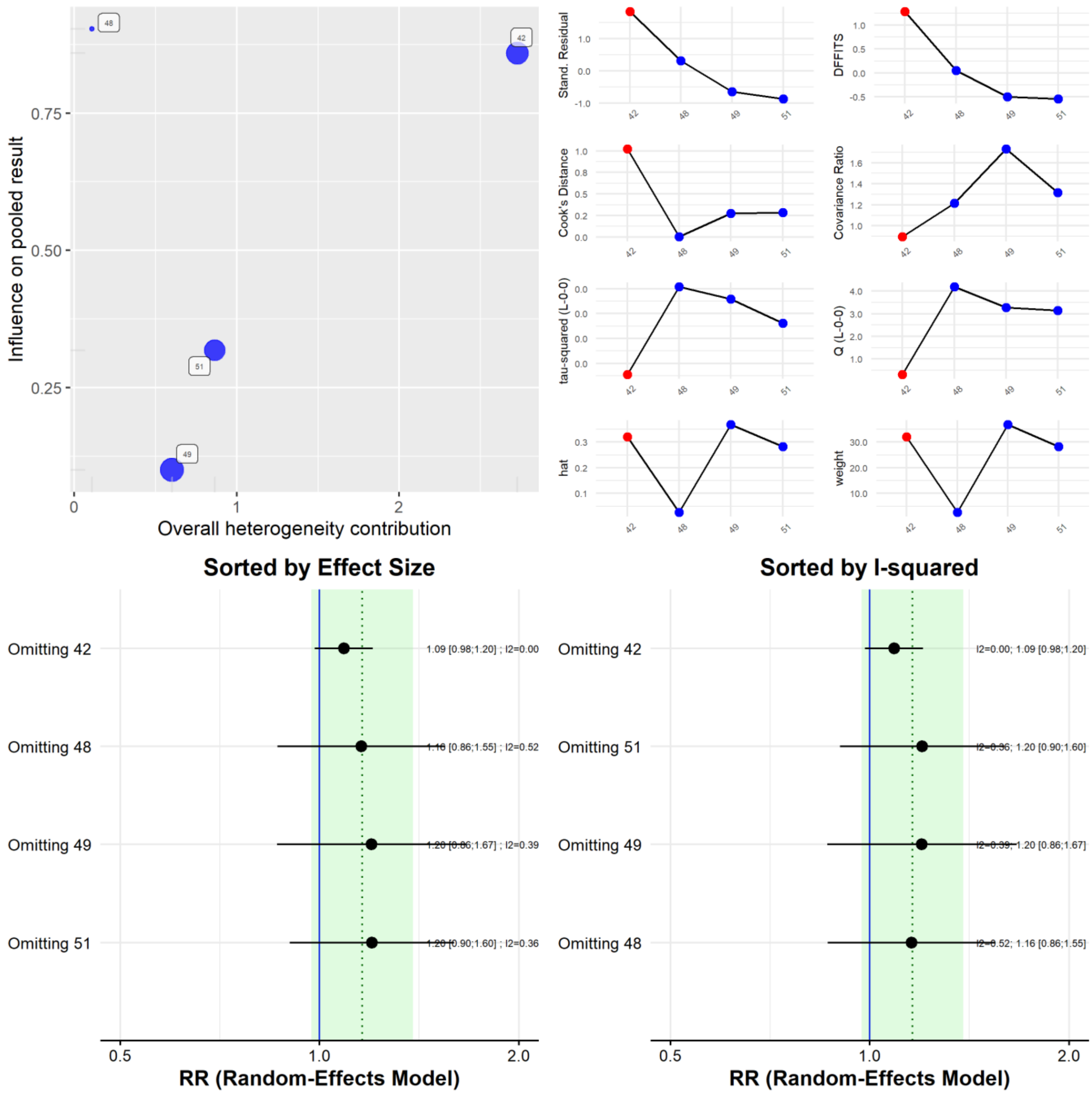


Figure VII.38. Influence analysis for the meta-analysis performed for the at-haulback mortality of white marlin with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

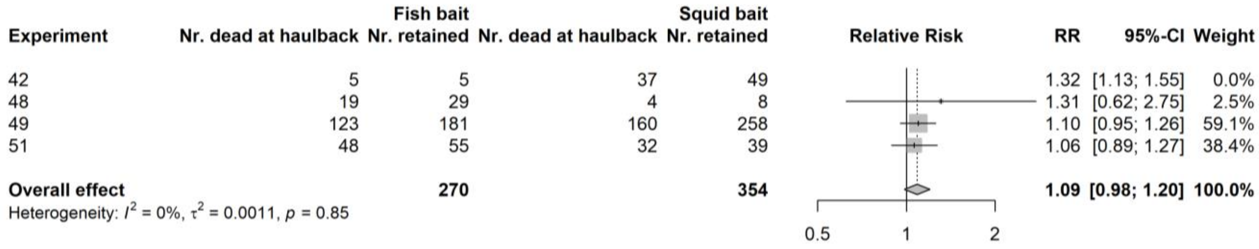


Figure VII.39. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of white marlin with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis).

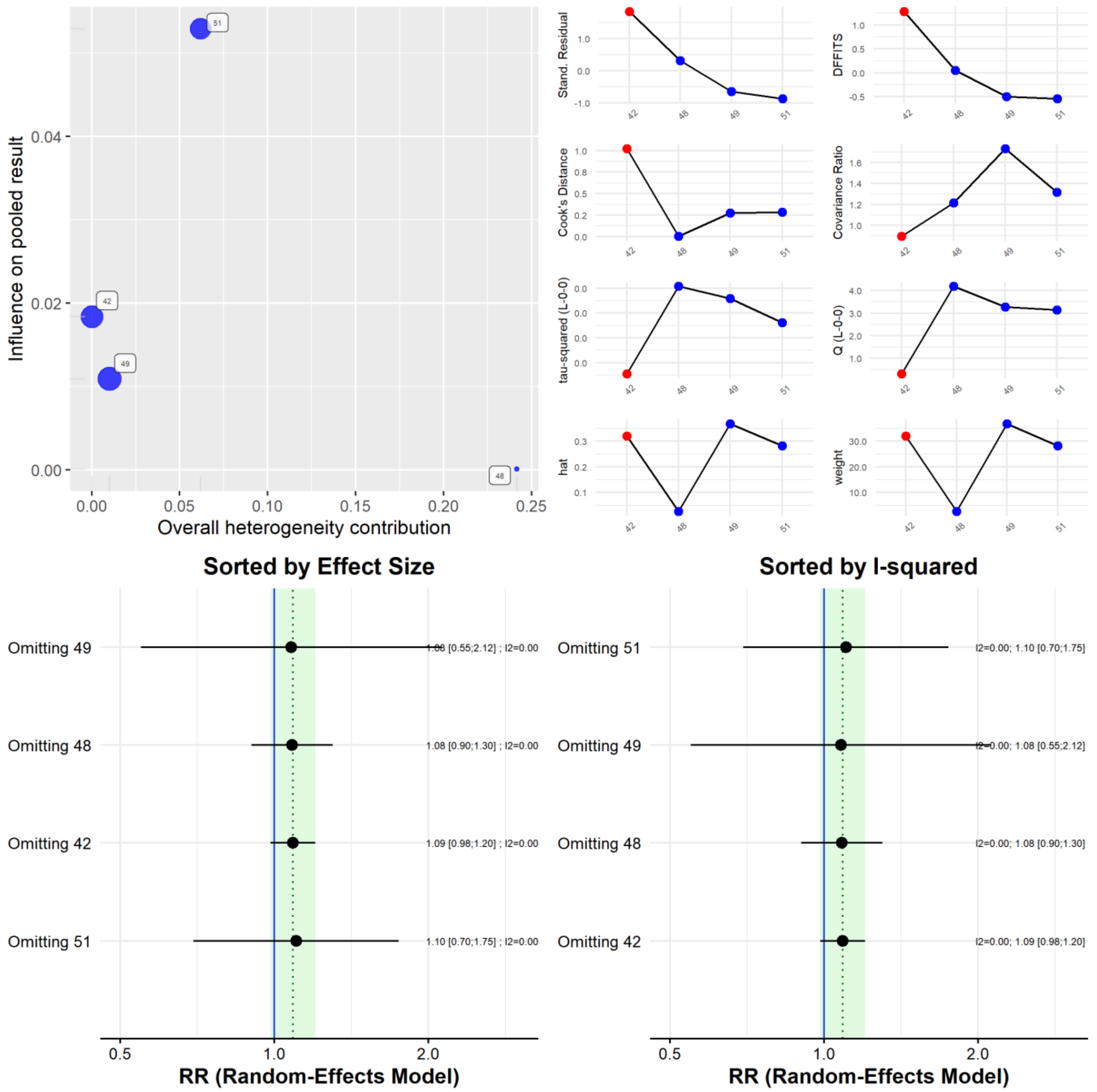


Figure VII.40. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of white marlin with fish vs. squid bait. The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Effects of bait on unwanted bycatch species

Loggerhead sea-turtle – Retention rates

Figure VII.41 shows the random effects model for retention of loggerhead sea turtle when all data compiled are used. When all data is used, the RR is 0.23 (95% CIs: 0.15; 0.38). This means that we expect that the retention of loggerhead sea turtle when using fish bait is 77% lower than when using squid bait, with 95% confidence intervals varying between reductions of 62 % and 85% in retention. We also see that the overall heterogeneity I^2 is high (70%) and fails the statistical assumption of homogeneity (p-value<0.05). The influence analysis is represented in VII.42 and in this case the influence analysis did not identify outliers and therefore all experiments were considered in the analysis.

	Fish bait		Squid bait				
Experiment	**Nr. retained**	**Nr. hooks**	**Nr. retained**	**Nr. hooks**	**RR**	**95%-CI**	**Weight**
14	11	12150	27	12150	0.41	[0.20; 0.82]	11.7%
15	27	2150674	182	1282748	0.09	[0.06; 0.13]	13.6%
30	24	463139	143	510595	0.19	[0.12; 0.29]	13.4%
42	0	143136	10	162216	0.01	[0.00; 5.69]	0.7%
43	4	18240	18	18240	0.22	[0.08; 0.66]	9.1%
48	8	127260	14	127260	0.57	[0.24; 1.36]	10.5%
49	54	223200	206	223200	0.26	[0.19; 0.35]	14.1%
51	0	47432	3	47768	0.03	[0.00; 17.64]	0.7%
52	9	22335	27	22370	0.33	[0.16; 0.71]	11.3%
53	1	30000	1	30000	1.00	[0.06; 15.99]	2.9%
54	10	35340	67	35760	0.15	[0.08; 0.29]	12.0%
Overall effect		**3272906**		**2472307**	**0.23**	**[0.15; 0.38]**	**100.0%**

Heterogeneity: $I^2 = 70\%$, $\tau^2 = 0.4881$, $p < 0.01$

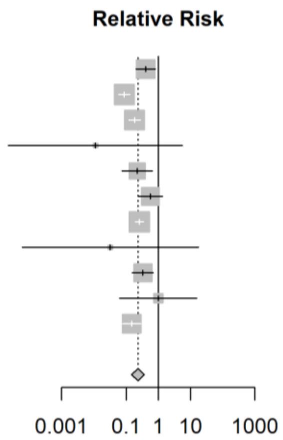


Figure VII.41. Forest plot of the random effects meta-analysis performed for the retention of loggerhead sea turtle with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

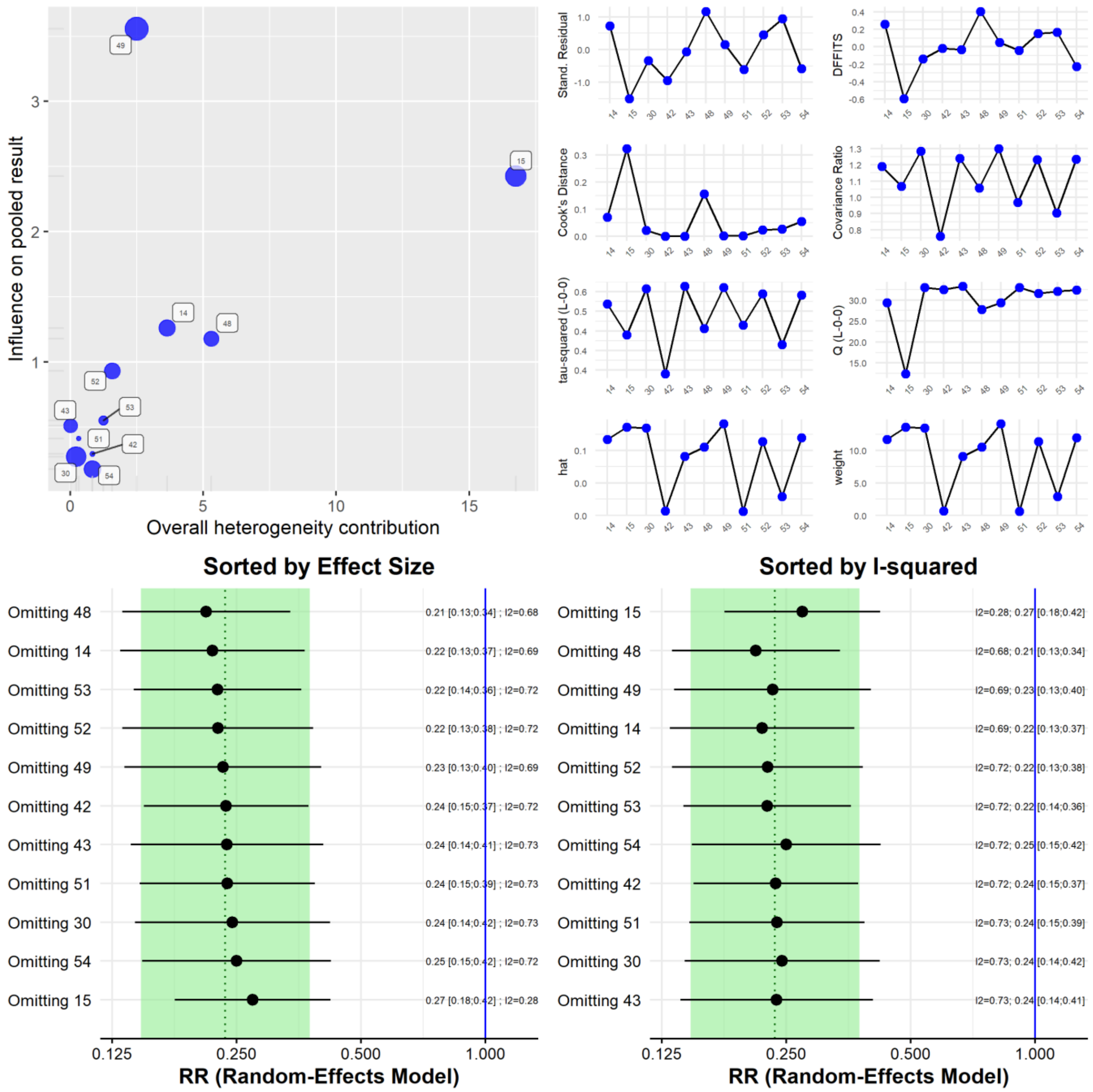


Figure VII.42. Influence analysis for the meta-analysis performed for the retention of loggerhead sea turtle with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Loggerhead sea turtle – At-haulback mortality

Figure VII.43 shows the random effects model for at-haulback mortality of loggerhead sea turtle when all data compiled are used. When all data are used, the RR is 1.25 (95% CIs: 0.24; 6.62). This means that we expect that the at-haulback mortality of loggerhead sea turtle when using fish bait is 25% higher than when using squid bait, but this value is not significant as the

95% confidence intervals vary between a reduction of 76 % and an increase of 6.62 times. In this specific analysis there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.44. In this case, the influence analysis did not identify outliers and therefore all experiments were considered in the analysis.

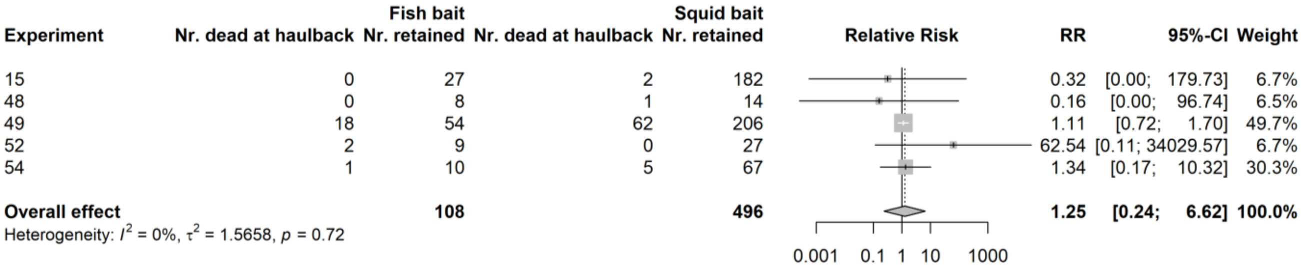


Figure VII.43. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of the loggerhead sea-turtle with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

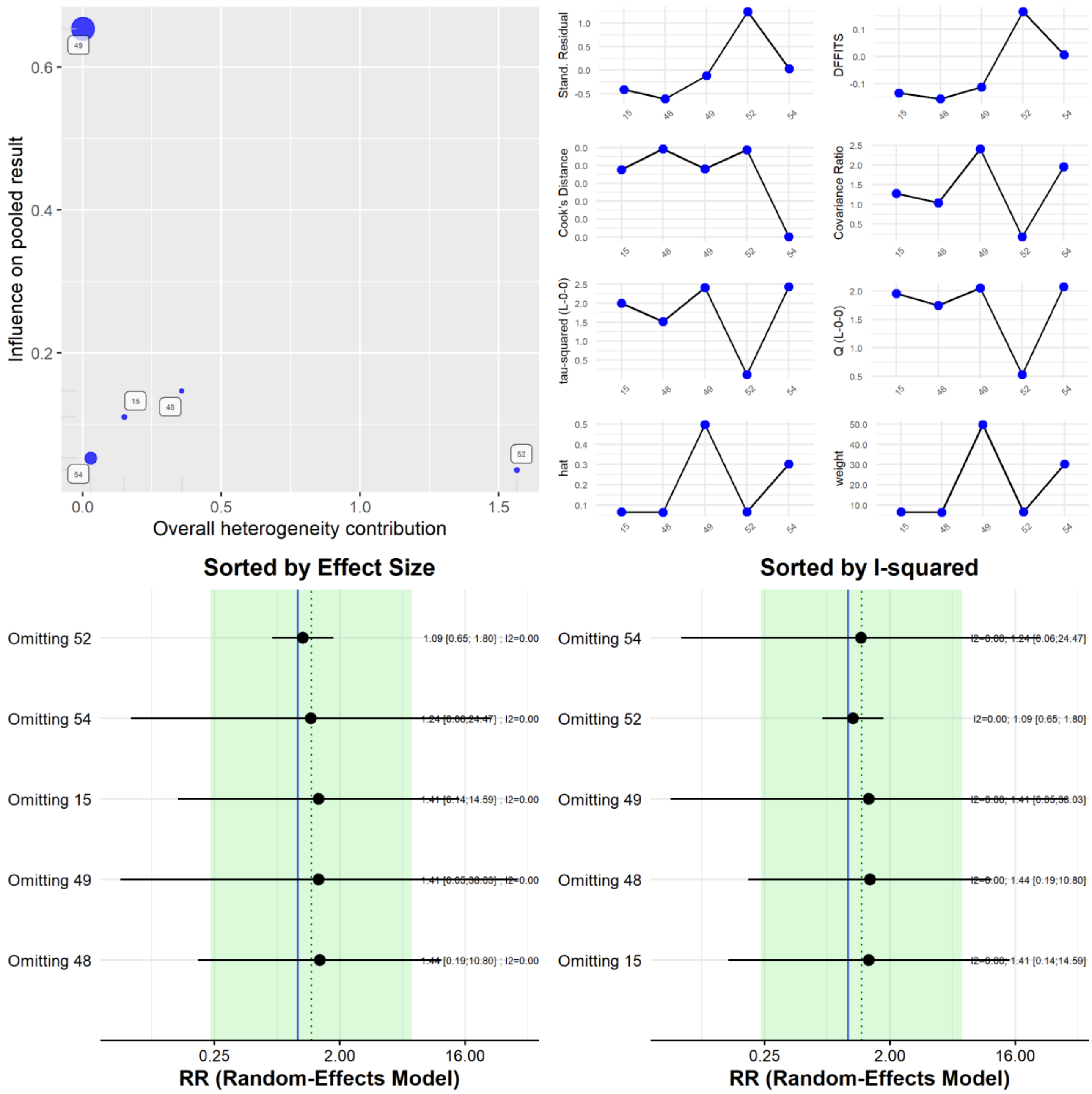


Figure VII.44. Influence analysis for the meta-analysis performed for the at-haulback mortality of the loggerhead sea-turtle with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Leatherback sea turtle – Retention rates

Figure VII.45 shows the random effects model for retention of leatherback sea turtle when all data compiled are used. When all data are used, the RR is 0.53 (95% CIs: 0.26; 1.06). This means that on average we expect that the retention of leatherback sea turtle when using fish bait is 47% lower than when using squid bait, but this is not significant as the 95% confidence intervals vary between a reduction of 74% and an increase of 6% in retention. The overall heterogeneity (I^2) is high (84%) and fails the statistical assumption of homogeneity (p-value<0.05). In the influence analysis, that is represented in Figure VII.46, there was no identification of possible outliers and therefore all experiments were considered in the analysis.

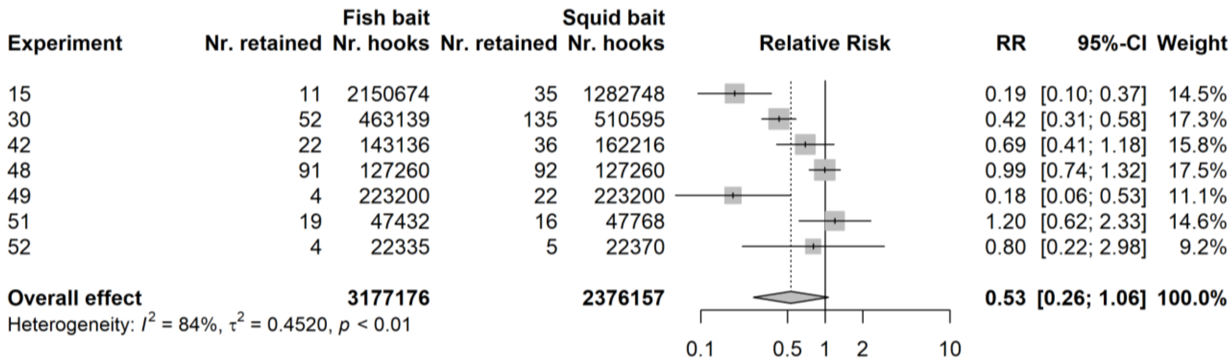


Figure VII.45. Forest plot of the random effects meta-analysis performed for the retention of leatherback sea-turtle with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

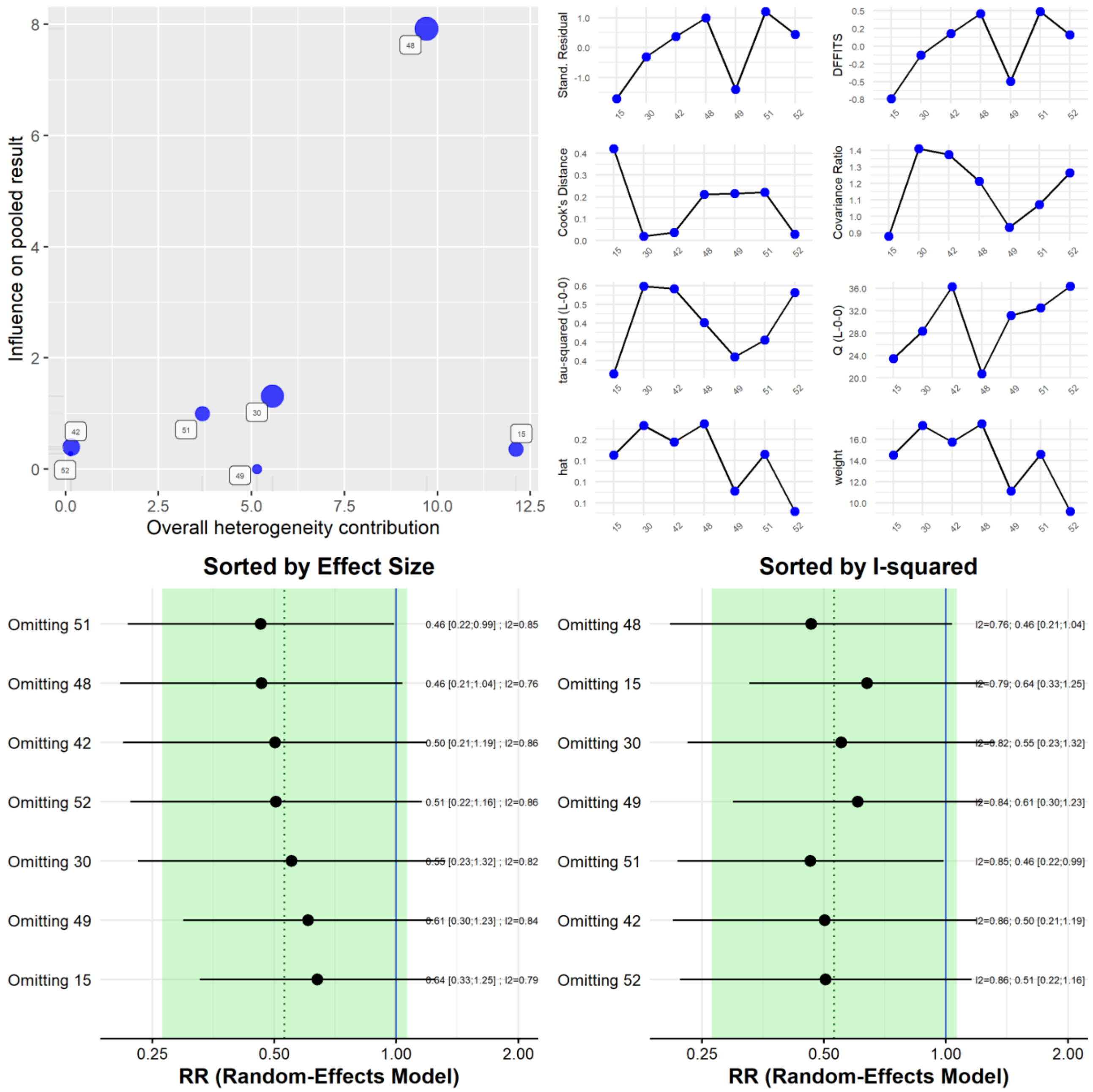


Figure VII.46. Influence analysis for the meta-analysis performed for the retention of leatherback sea-turtle with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Leatherback sea turtle – At-haulback mortality

Figure VII.47 shows the random effects model for at-haulback mortality of leatherback sea turtle when all data compiled are used. When all data are used the RR is 0.63 (95% CIs: 0.16; 2.56). This means that we expect that the at-haulback mortality of leatherback sea turtle when using fish bait is 37% lower than when using squid bait, but with 95% confidence intervals varying between a reduction of 84% and an increase of 2.56 times. In this specific analysis there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05). The influence analysis (Figure VII.48) did not identify outliers and therefore all experiments were considered in the analysis.

	Fish bait		Squid bait				
Experiment	**Nr. dead at haulback**	**Nr. retained**	**Nr. dead at haulback**	**Nr. retained**	**RR**	**95%-CI**	**Weight**
42	0	22	2	36	0.08	[0.00; 43.29]	4.3%
48	5	91	9	92	0.56	[0.20; 1.61]	59.2%
49	1	4	4	22	1.38	[0.20; 9.33]	32.3%
51	0	19	1	16	0.08	[0.00; 47.98]	4.2%
Overall effect		**136**		**166**	**0.63**	**[0.16; 2.56]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.5066$, $p = 0.68$

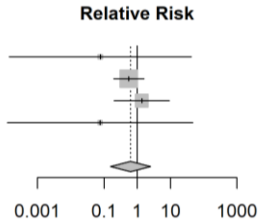


Figure VII.47. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of leatherback sea turtle with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

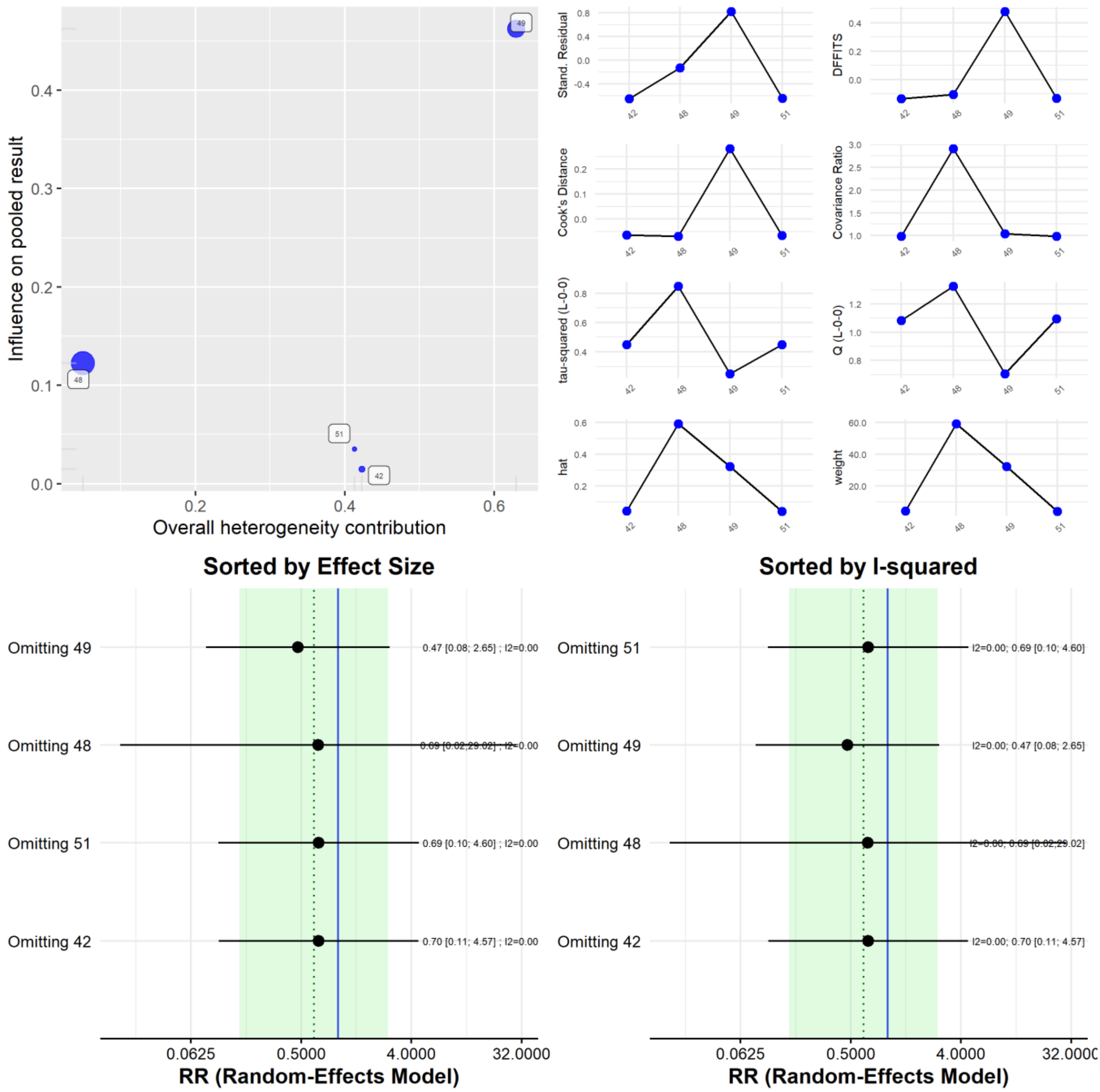


Figure VII.48. Influence analysis for the meta-analysis performed for the at-haulback mortality of leatherback sea turtle with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Olive ridley sea turtle – Retention rates

Figure VII.49 shows the random effects model for retention of olive ridley sea turtle when all data compiled are used. When all data is used, the RR is 1.01 (95% CIs: 0.04; 27.42). This means that on average we expect that the retention of olive ridley sea turtle when using fish bait is 1% higher than when using squid bait. However, this is not significant as the 95%

confidence intervals vary between a reduction of 96% and an increase of 27 times in retention. In this specific analysis we also see that the overall heterogeneity (I^2) is very high (95%) and fails the statistical assumption of homogeneity (p-value<0.05). In the influence analysis, represented in Figure VII.50, there was the identification of experiment 51 as an outlier; however, this experiment was kept in the analysis as there were only three experiments available (including experiment 51).

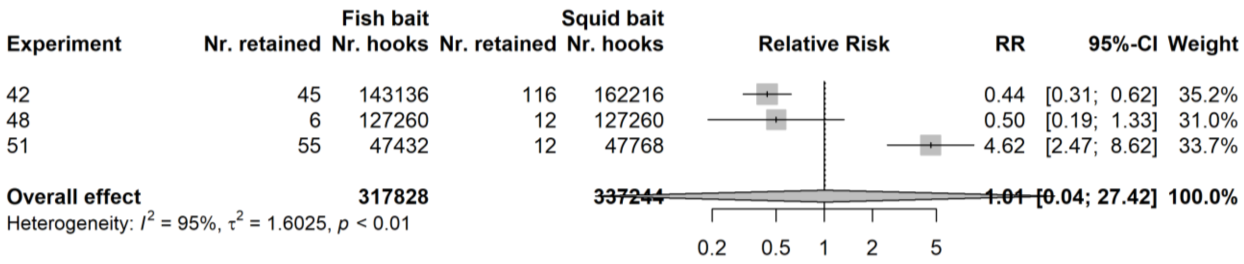


Figure VII.49. Forest plot of the random effects meta-analysis performed for the retention of olive ridley sea turtle with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

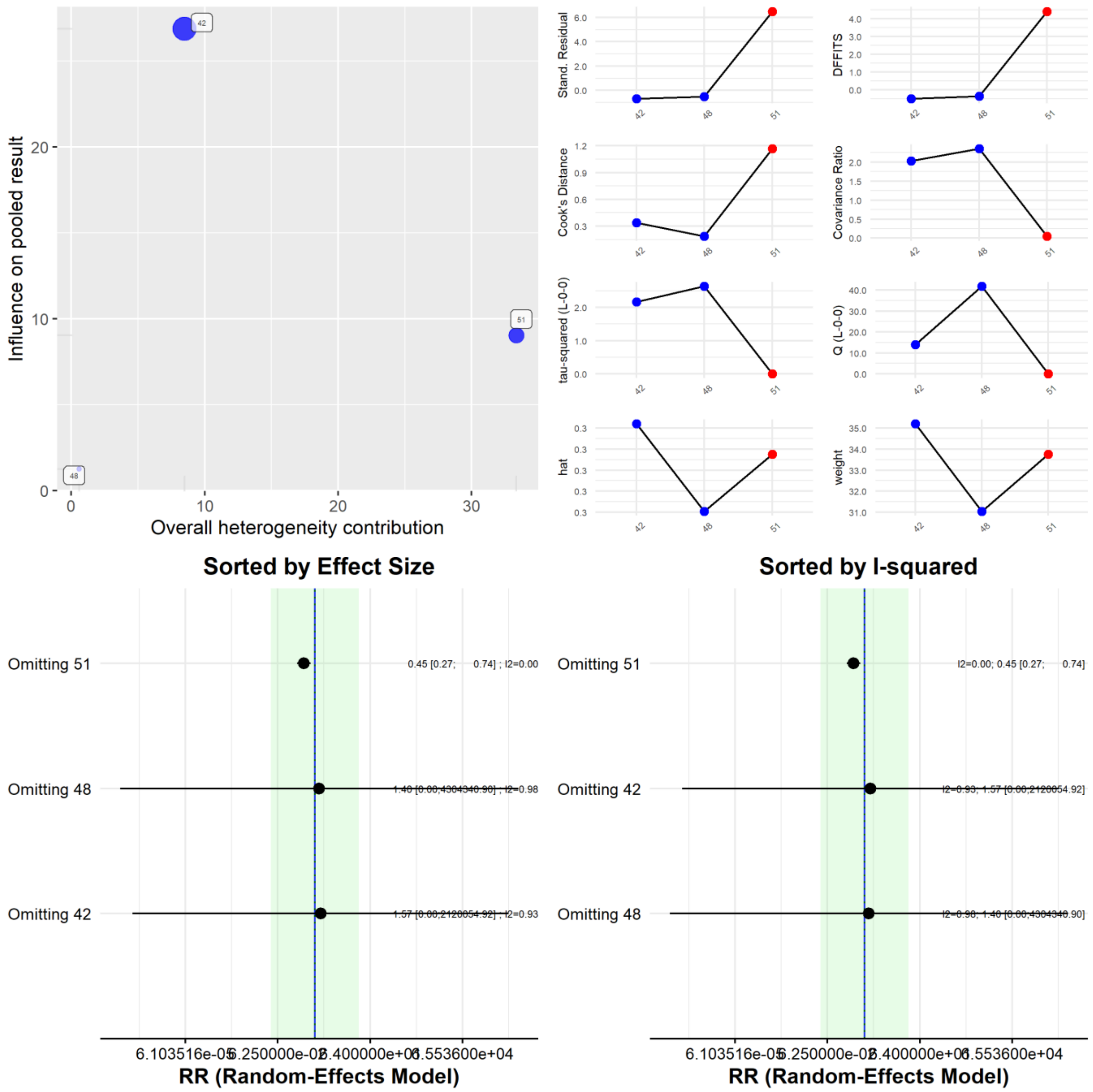


Figure VII.50. Influence analysis for the meta-analysis performed for the retention of olive ridley sea turtle with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Olive ridley sea turtle – At-haulback mortality

Figure VII.51 shows the random effects model for at-haulback mortality of olive ridley sea turtle when all data compiled are used. when all data are used, the RR is 1.43 (95% CIs: 0.53; 3.88). This means that we expect that the at-haulback mortality of olive ridley sea turtle when using fish bait to be 43% higher than when using squid bait, but this is not significant with the 95% confidence intervals varying between a reduction of 47% and an increase of 3.88 times. In this specific analysis there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.52. In this case, the influence analysis did not identify outliers and all experiments were considered in the analysis.

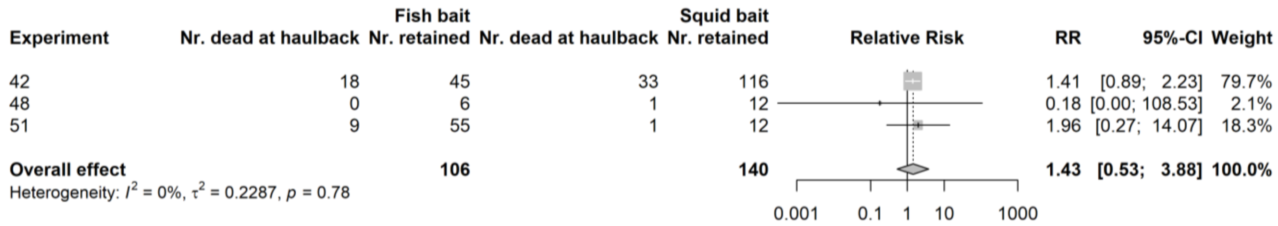


Figure VII.51. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of olive ridley sea turtle with fish vs. squid bait (Note: Squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

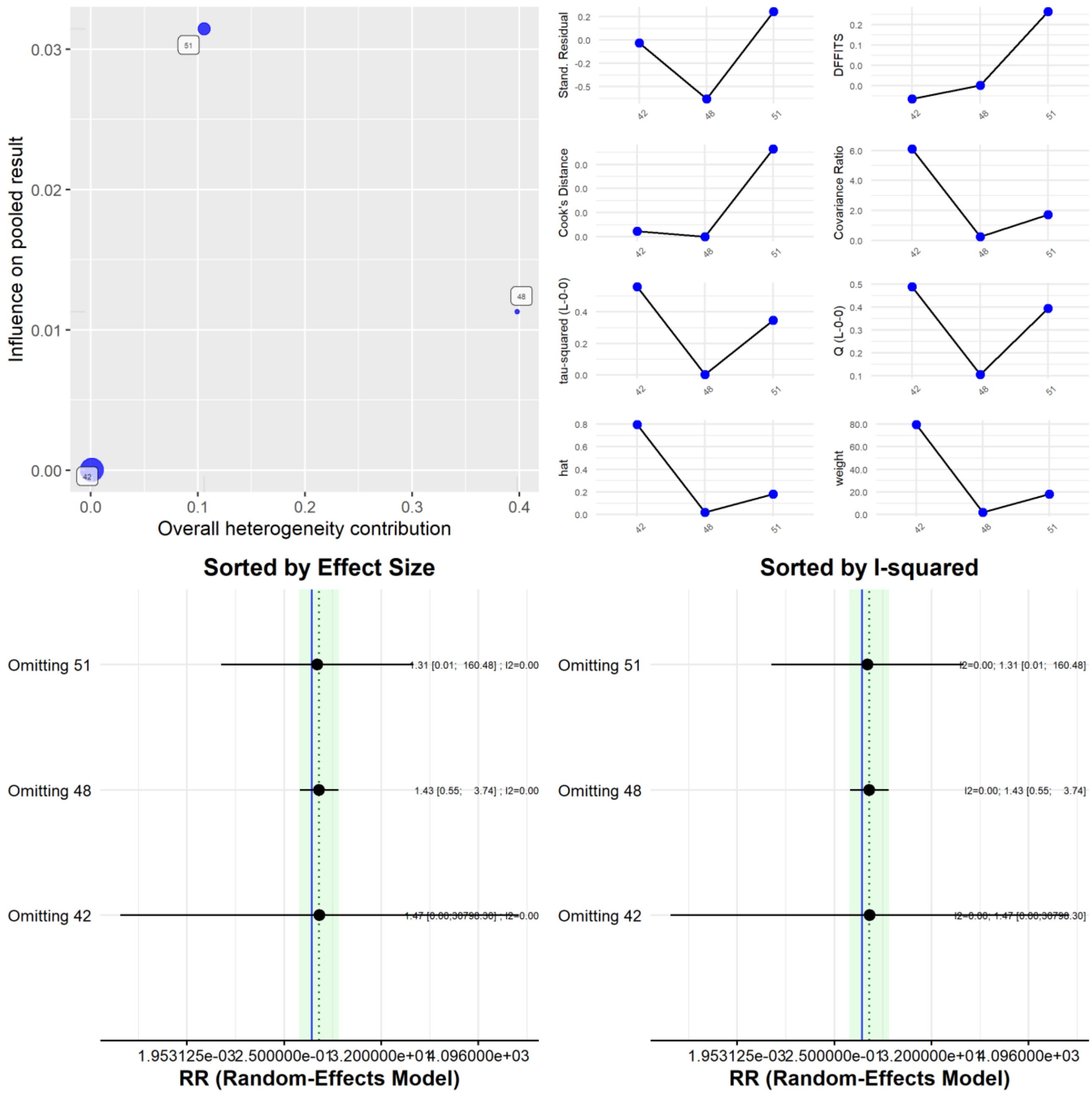


Figure VII.52. Influence analysis for the meta-analysis performed for the at-haulback mortality of olive ridley sea turtle with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Kemp's ridley sea turtle – Retention rates

For the comparisons between bait type, there were only two experiments that reported on retention of Kemp's ridley sea turtle for surface longlines and sample sizes were very small. As such, it was not possible to conduct the meta-analysis. Experiment 42 reported 2 specimens retained in 162,216 hooks baited with squid and none in 143,136 hooks baited with fish (RR=

0.05; 95% CIs: 0.00; 30.70). Experiment 48 reported 2 specimens retained in 127,260 hooks baited with squid and none in 127,260 hooks baited with fish (RR= 0.05; 95% CIs: 0.00; 27.09).

Kemp's ridley sea turtle – At-haulback mortality

For the comparisons between bait type, there were only two experiments (42 and 48) that reported on at-haulback mortality of Kemp's ridley sea turtle for surface longlines. In both experiments, no turtle retained suffered any at-haulback mortality.

Green sea turtle – Retention rates

For the comparisons between bait type, there were no experiments that reported on retention of green sea turtle for surface longlines.

Green sea turtle – At-haulback mortality

For the comparisons between bait type, there were no experiments that reported on at-haulback mortality of green sea turtle for surface longlines.

Oceanic whitetip – Retention rates

Figure VII.53 shows the random effects model for retention of oceanic whitetip when all data compiled are used. When all data is used, the RR is 0.82 (95% CIs: 0.52; 1.31). The overall heterogeneity between studies (I^2) is 46% and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influence analysis is represented in Figure VII.54 and identified one experiment (experiment 42) that is an outlier with 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 VII.55 and validation indicated in Figure VII.56. With the exclusion of that outlier, the final RR estimation is 0.70 (CIs: 0.41; 1.22) and the overall heterogeneity (I^2) is 0%. This analysis indicates that on average we expect that the retention of oceanic whitetip when using fish bait is 30% lower than when using squid bait, however this is not significant as the 95% confidence intervals vary between a reduction of 59% and an increase of 22% in retention.

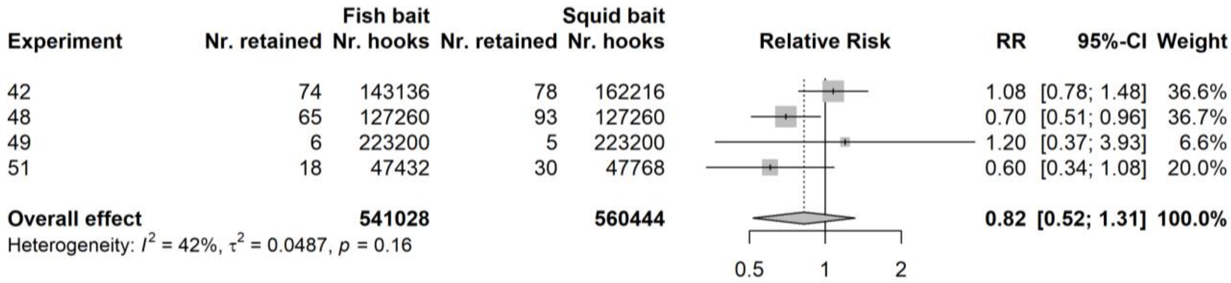


Figure VII.53. Forest plot of the random effects meta-analysis performed for the retention of oceanic whitetip shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

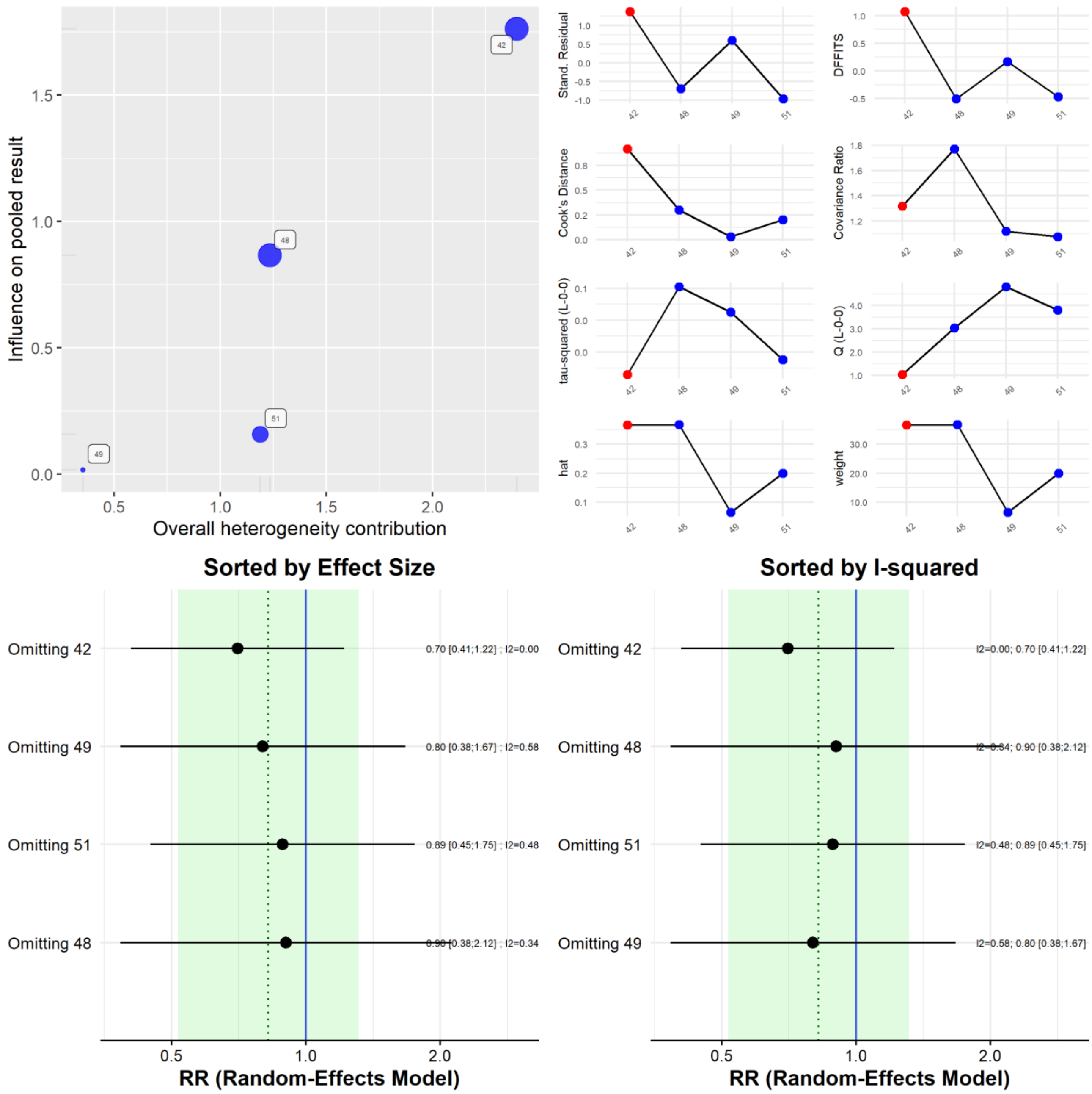


Figure VII.54. Influence analysis for the meta-analysis performed for the retention of oceanic whitetip shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

	Fish bait		Squid bait				
Experiment	Nr. retained	Nr. hooks	Nr. retained	Nr. hooks	RR	95%-CI	Weight
42	74	143136	78	162216	1.08	[0.78; 1.48]	0.0%
48	65	127260	93	127260	0.70	[0.51; 0.96]	61.2%
49	6	223200	5	223200	1.20	[0.37; 3.93]	9.1%
51	18	47432	30	47768	0.60	[0.34; 1.08]	29.7%
Overall effect		**541028**		**560444**	**0.70**	**[0.41; 1.22]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0329$, $p = 0.60$

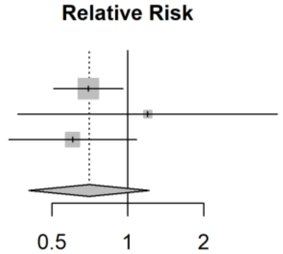


Figure VII.55. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of oceanic whitetip shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis).

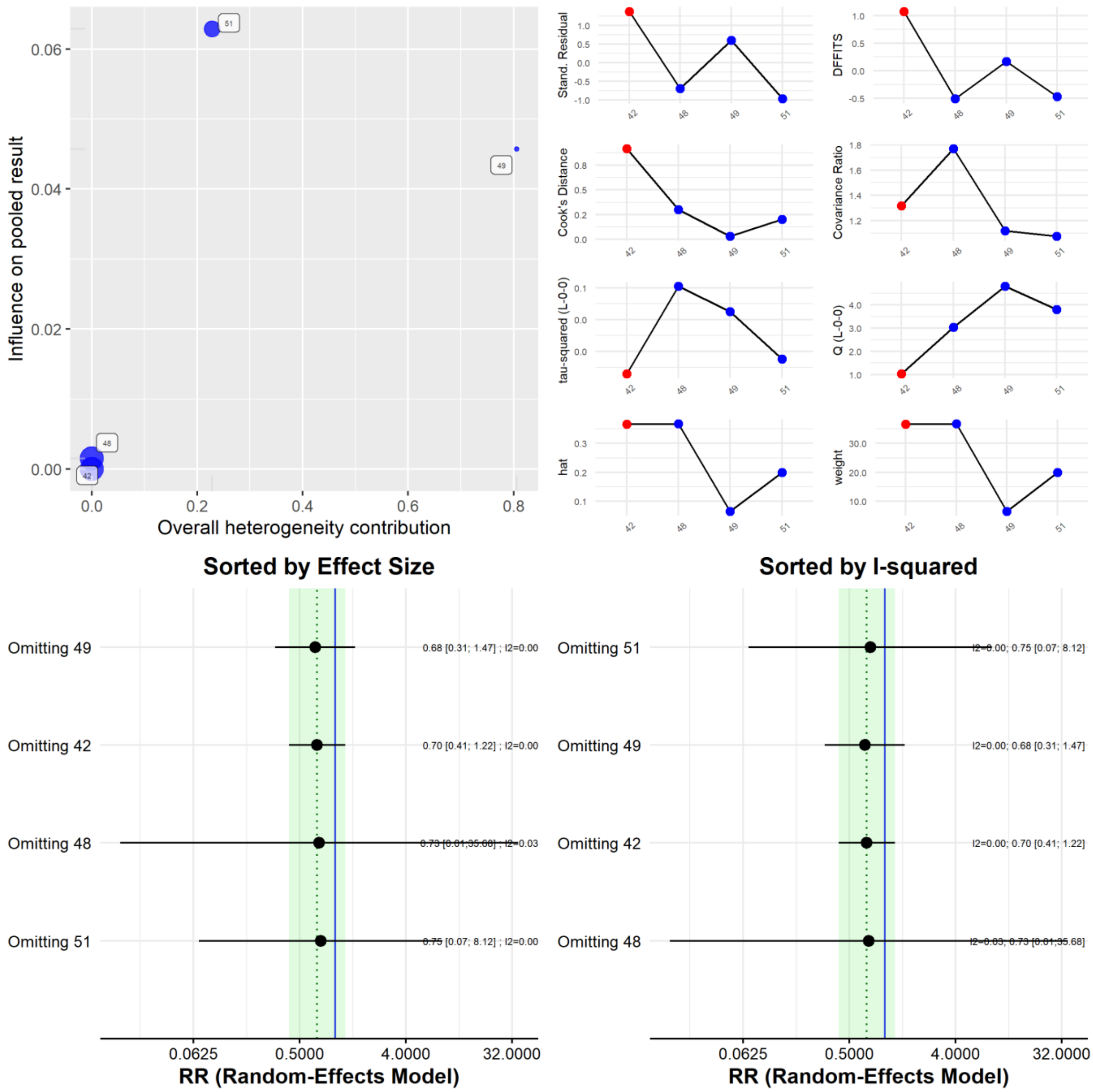


Figure VII.56. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of oceanic whitetip shark with fish vs squid bait. The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave-one-out method sorted by effect size (left) and I^2 (right).

Oceanic whitetip – At-haulback mortality

Figure VII.57 shows the random effects model for at-haulback mortality of oceanic whitetip when all data compiled are used. When all data are used, the RR is 1.24 (95% CIs: 1.07; 1.44). This means that we expect that the at-haulback mortality of oceanic whitetip when using fish bait is 24% higher than when using squid bait, with 95% confidence intervals varying between an increase of 7% and 44%. In this specific analysis there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.58. In this case, the influence analysis did not identify outliers and all experiments were considered in the analysis.

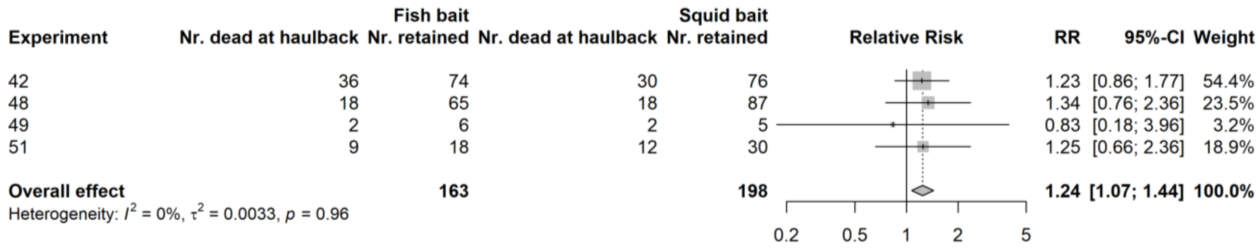


Figure VII.57. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of oceanic whitetip shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

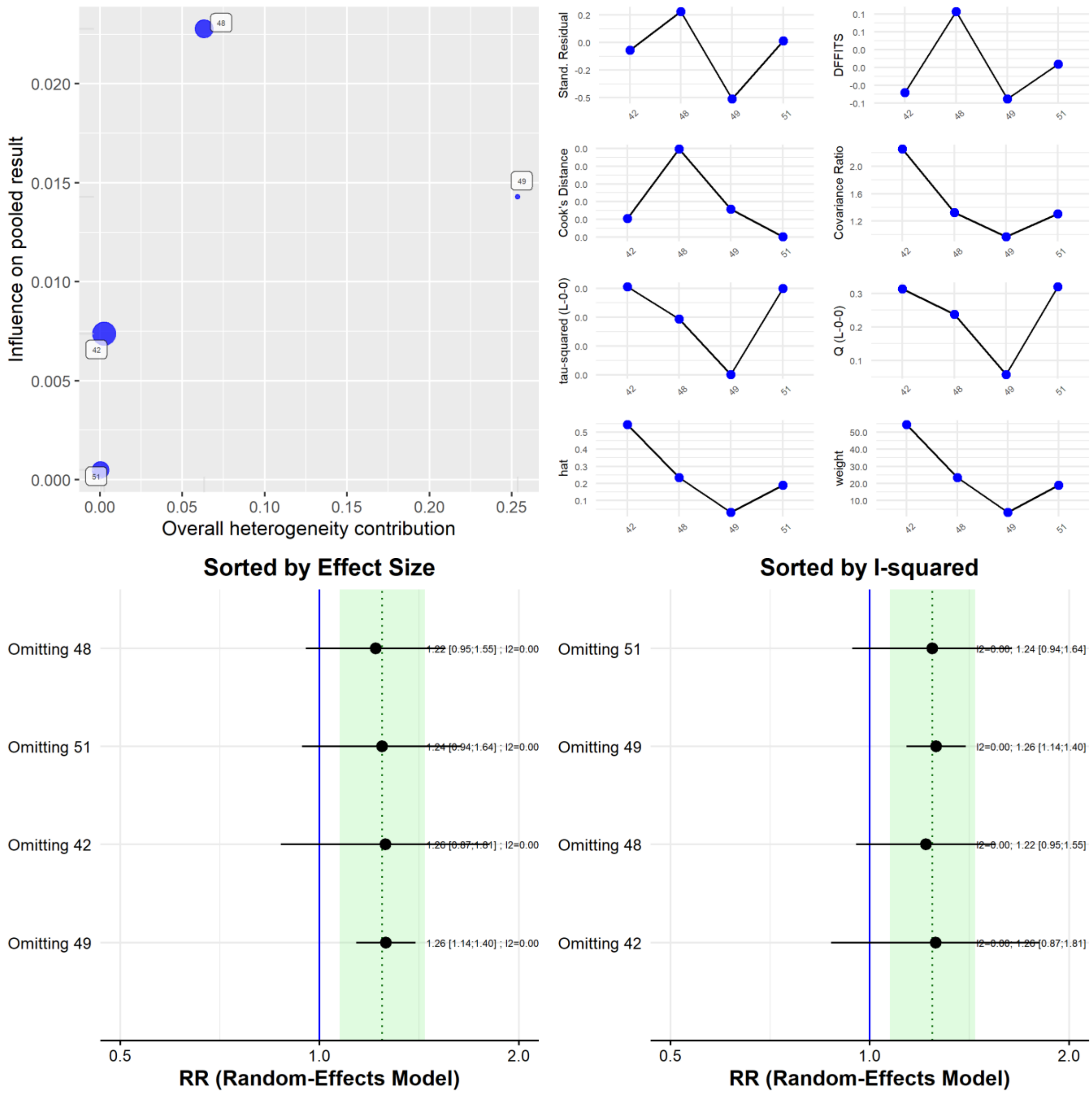


Figure VII.58. Influence analysis for the meta-analysis performed for the at-haulback mortality of oceanic whitetip shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Porbeagle – Retention rates

For the comparisons between bait type, there were only two experiments that reported on retention of porbeagle for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 30 reported 257 specimens retained in 510,595 hooks baited with squid and 1046 in 463,139 hooks baited with fish (RR= 4.49; 95% CIs: 3.91; 5.14). This single experiment seems to indicate that the retention rate is higher when fish bait is used. Experiment 49 reported 1 specimen retained in 223,200 hooks baited with squid and none in 223,200 hooks baited with fish (RR= 0.09; 95% CIs: 0.00; 58.89).

Porbeagle – At-haulback mortality

For the comparisons between bait type, there was only one experiment (experiment 49) that reported on at-haulback of porbeagle for surface longlines. As such, it was not possible to conduct the meta-analysis. In this experiment, only one porbeagle was retained (with squid baited hooks) and it suffered at-haulback mortality.

Silky shark – Retention rates

Figure VII.59 shows the random effects model for retention of silky shark when all data compiled are used. When all data are used, the RR is 1.48 (95% CIs: 0.64; 3.41). The overall heterogeneity between studies is 64% and fails the statistical assumption of homogeneity (p-value<0.05). The influence analysis for that analysis using all studies is represented in Figure VII.60 and identified two experiments (experiment 42 and 48) that are outliers with influence on the pooled results. Since only four experiments were available, excluding the two experiments (experiment 42 and 48) would hinder the meta-analysis. As such, the analysis was re-run excluding experiment 48 which had more effects in the heterogeneity, with the results of the new pooled analysis indicated in Figure VII.61 and validation indicated in Figure VII.62. With the exclusion of that outlier, the final RR estimation was 1.97 (CIs: 1.01; 3.86) and the overall heterogeneity (I^2) dropped to 0%. This analysis indicates that on average we expect that the retention of silky shark when using fish bait is 97% higher than when using squid bait, and this is statistically significant as the 95% confidence intervals vary between increases of 1% and 3.86 times.

	Fish bait		Squid bait					
Experiment	**Nr. retained**	**Nr. hooks**	**Nr. retained**	**Nr. hooks**	**Relative Risk**	**RR**	**95%-CI**	**Weight**
42	207	143136	112	162216		2.09	[1.66; 2.64]	45.1%
48	16	127260	20	127260		0.80	[0.41; 1.54]	28.5%
49	4	223200	4	223200		1.00	[0.25; 4.00]	11.7%
51	9	47432	4	47768		2.27	[0.70; 7.36]	14.8%
Overall effect		**541028**		**560444**		**1.48**	**[0.64; 3.41]**	**100.0%**

Heterogeneity: I^2 = 64%, τ^2 = 0.1558, p = 0.04

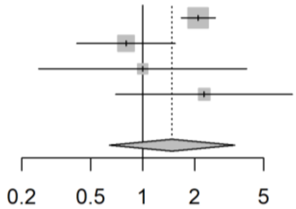


Figure VII.59. Forest plot of the random effects meta-analysis performed for the retention of silky shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

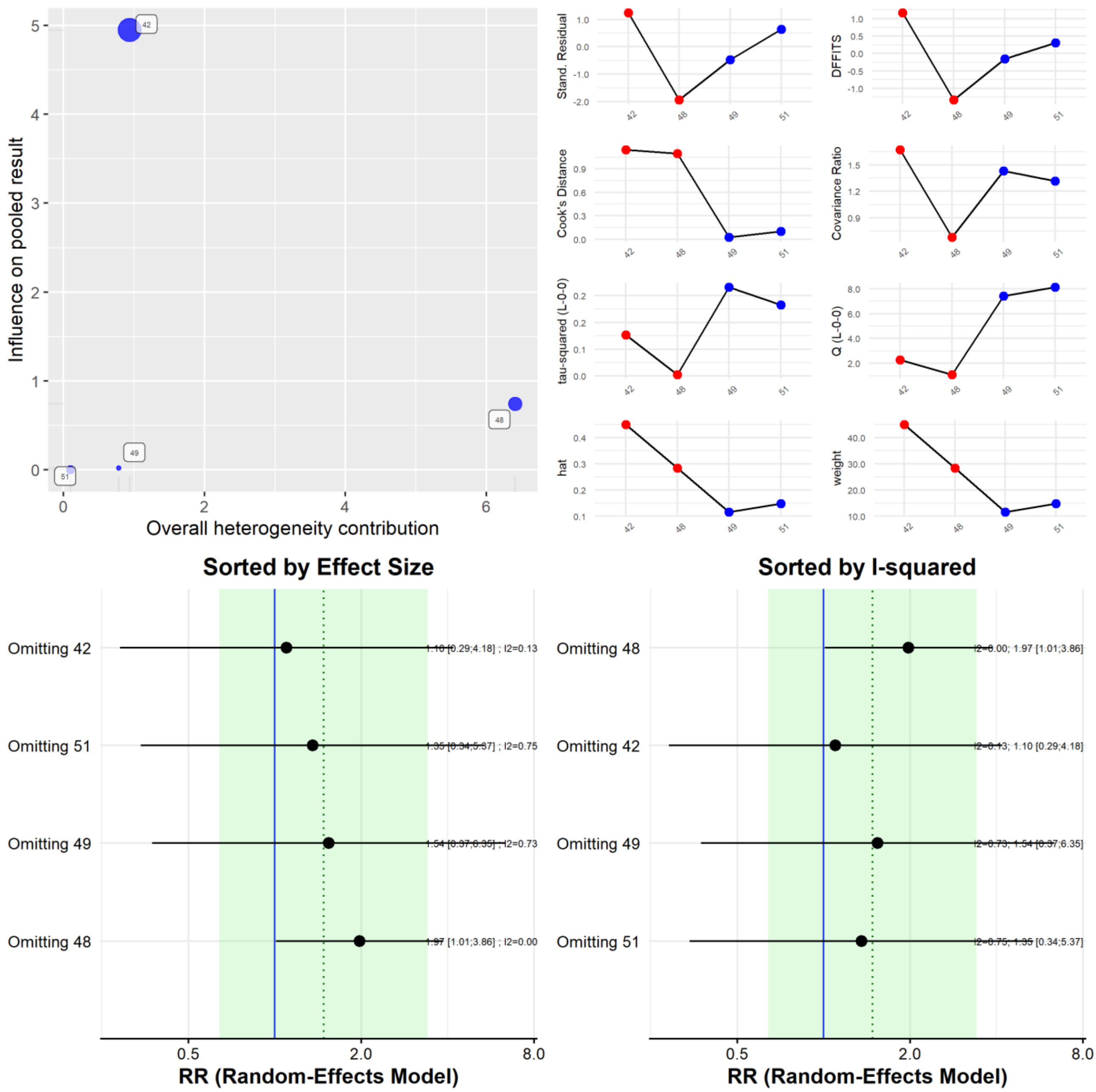


Figure VII.60. Influence analysis for the meta-analysis performed for the retention of silky shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

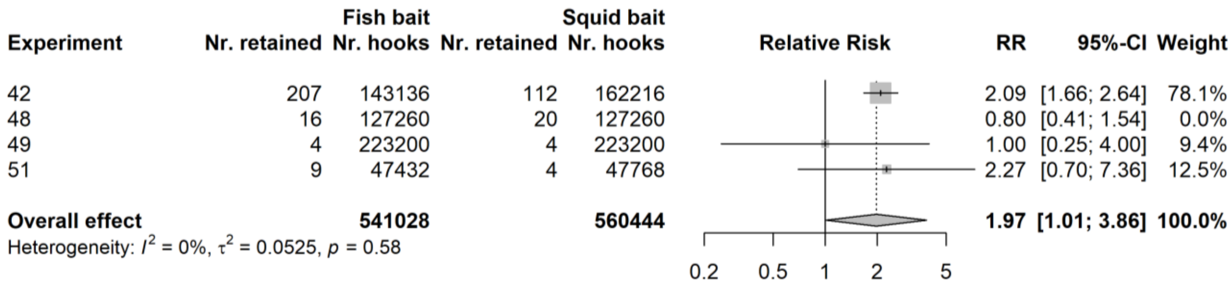


Figure VII.61. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of silky shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 48 (that is still represented in the plots but not considered in the analysis).

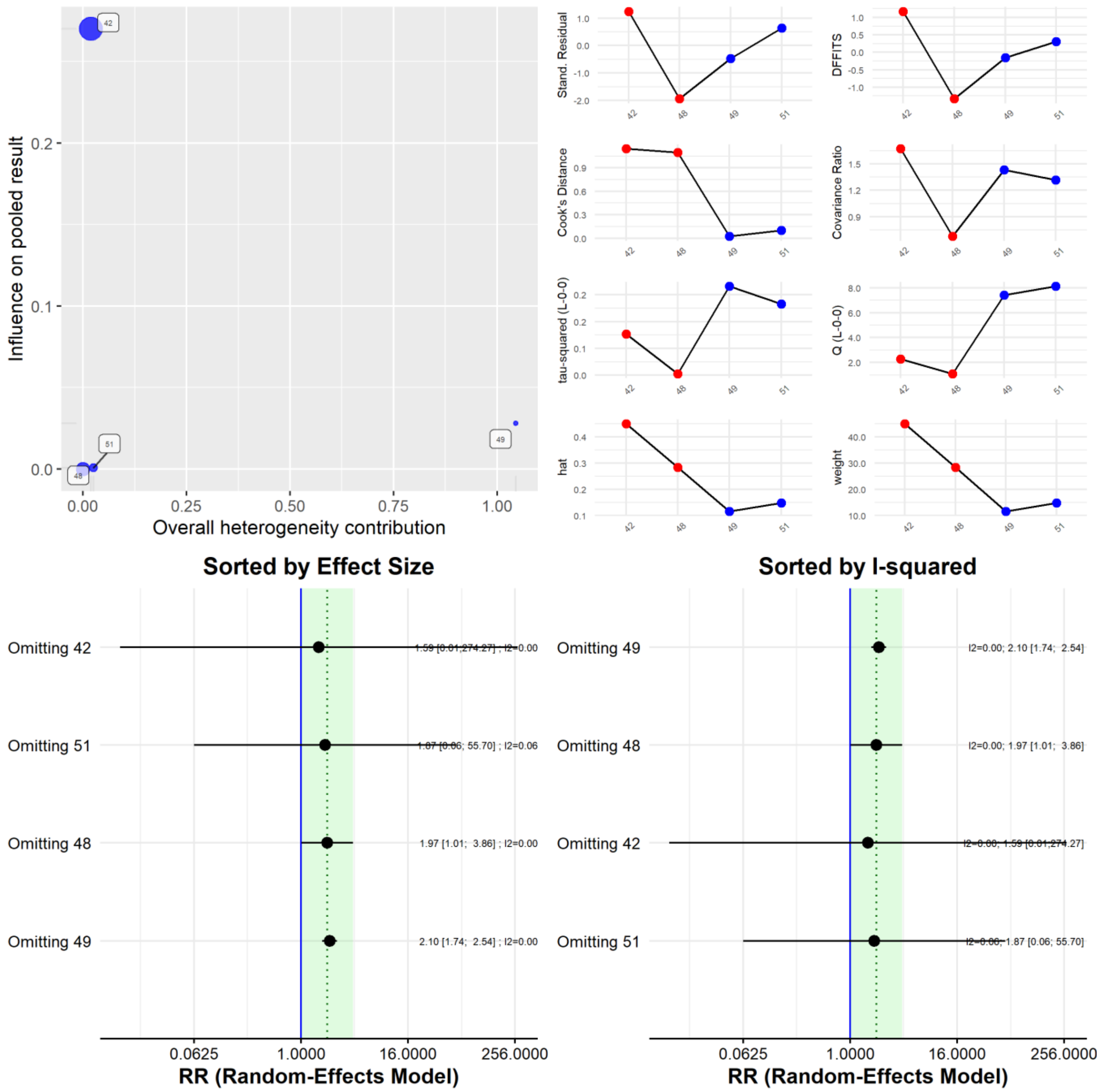


Figure VII.62. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of silky shark with fish vs. squid bait. The excluded experiment is number 48 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Silky shark – At-haulback mortality

Figure VII.63 shows the random effects model for at-haulback mortality of silky shark when all data compiled are used. When all data are used, the RR is 0.88 (95% CIs: 0.45; 1.74). In this analysis the overall heterogeneity between studies is 67% and fails the statistical assumption of homogeneity (p-value<0.05). We then carried out an influence analysis, that is represented in Figure VII.64. Again, the influence analysis identified two experiments (experiment 42 and 48) that are outliers with influence on the pooled results. Since only four experiments were available, excluding the two experiments (experiment 42 and 48) would hinder the meta-analysis. As such, the analysis was re-run excluding experiment 48, with the results of the new pooled analysis indicated in Figure VII.65 and validation indicated in Figure VII.66. With the exclusion of that outlier, the final RR estimation is 0.69 (CIs: 0.52; 0.92) and the overall heterogeneity (I^2) is reduced to 0%. This analysis indicates that on average we expect that the at-haulback mortality of silky shark when using fish bait is 31% lower than when using squid bait, and this is statistically significant as the 95% confidence intervals vary between reductions of 8% and 48%.

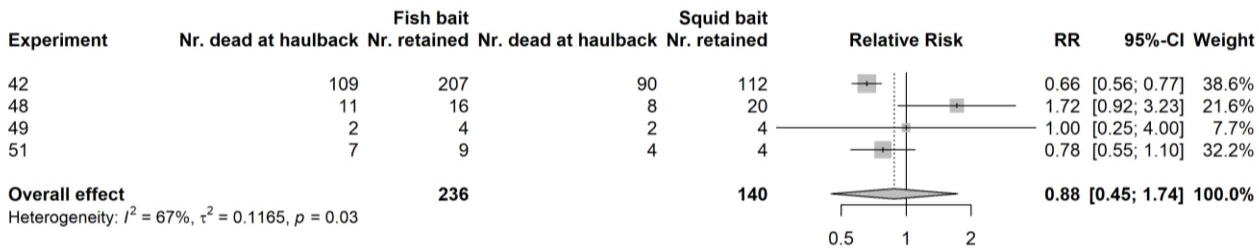


Figure VII.63. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of silky shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

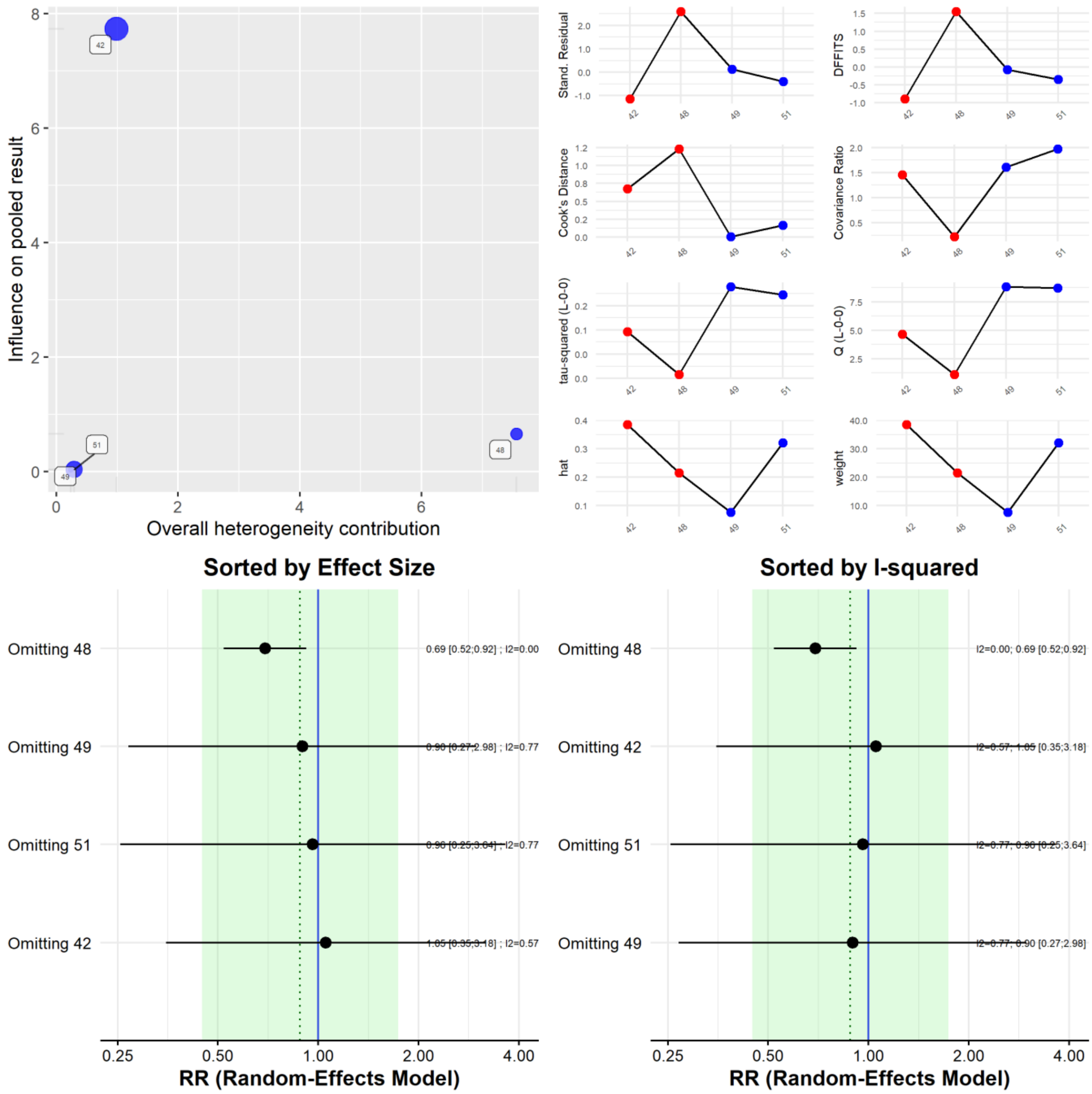


Figure VII.64. Influence analysis for the meta-analysis performed for the at-haulback mortality of silky shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Fish bait Nr. dead at haulback	Fish bait Nr. retained	Squid bait Nr. dead at haulback	Squid bait Nr. retained	RR	95%-CI	Weight
42	109	207	90	112	0.66	[0.56; 0.77]	71.2%
48	11	16	8	20	1.72	[0.92; 3.23]	0.0%
49	2	4	2	4	1.00	[0.25; 4.00]	2.1%
51	7	9	4	4	0.78	[0.55; 1.10]	26.7%
Overall effect		**236**		**140**	**0.69**	**[0.52; 0.92]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0082$, $p = 0.57$

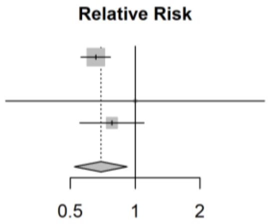


Figure VII.65. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality of silky shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait). The excluded experiment is number 48 (that is still represented in the plots but not considered in the analysis).

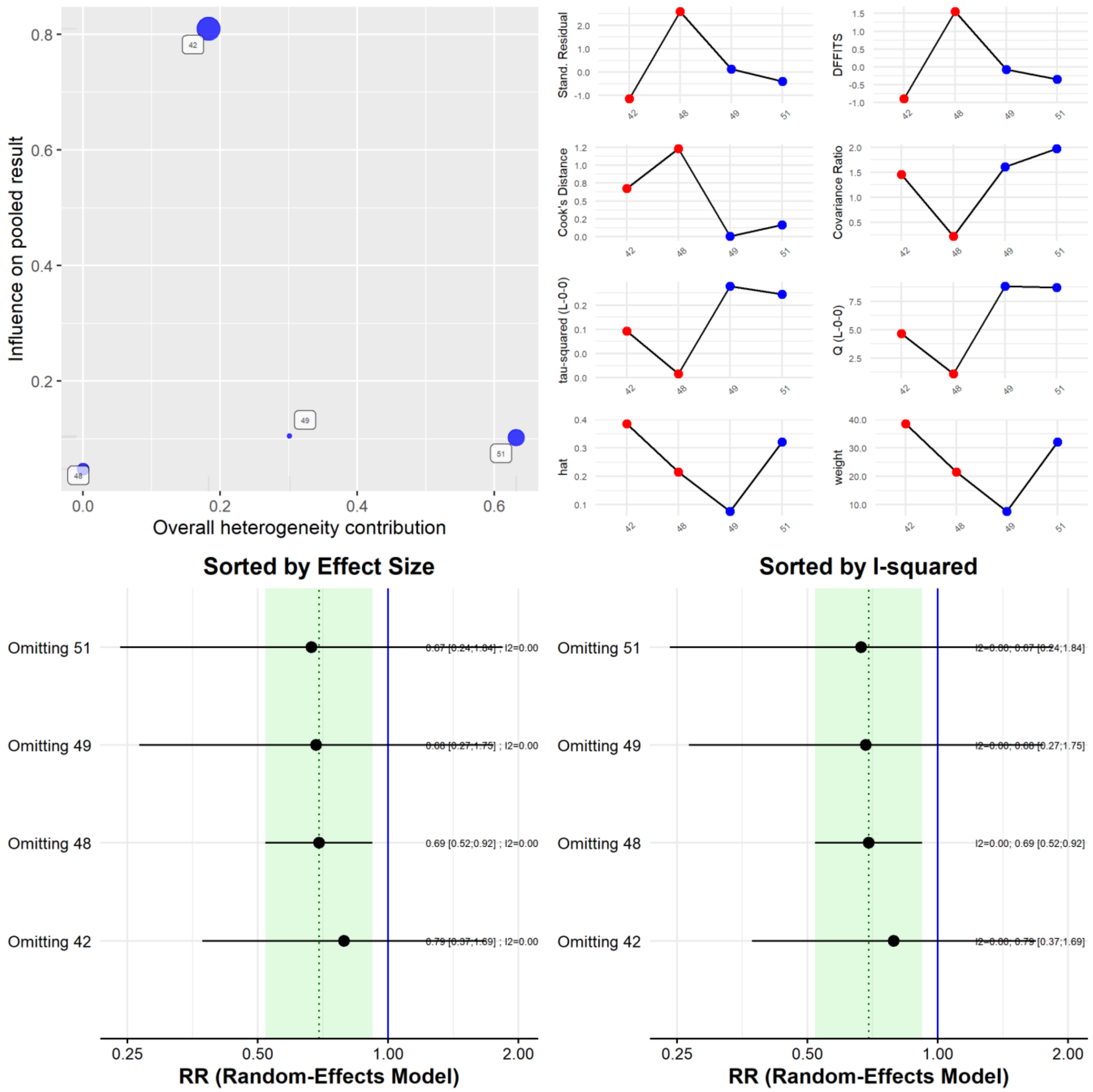


Figure VII.66. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality of silky shark with fish vs. squid bait. The excluded experiment is number 48 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye thresher – Retention rates

Figure VII.67 shows the random effects model for retention of bigeye thresher when all data compiled are used. When all data are used, the RR is 1.16 (95% CIs: 0.74; 1.82). This means that on average we expect that the retention of bigeye thresher when using fish bait is 16%

higher than when using squid bait. However, this value is not significant as the 95% confidence intervals vary between a reduction of 26% and an increase of 82%. In this specific analysis we also see that the overall heterogeneity (I^2) is 46% and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The search for possible outliers was carried out an influence analysis, that is represented in Figure VII.68. In this case, the influence analysis did not identify outliers with significant influence on the pooled results.

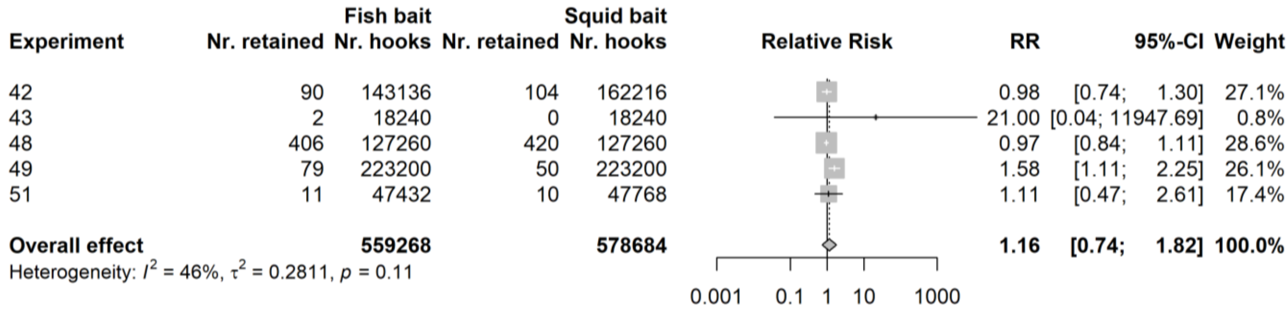


Figure VII.67. Forest plot of the random effects meta-analysis performed for the retention rates of bigeye thresher shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

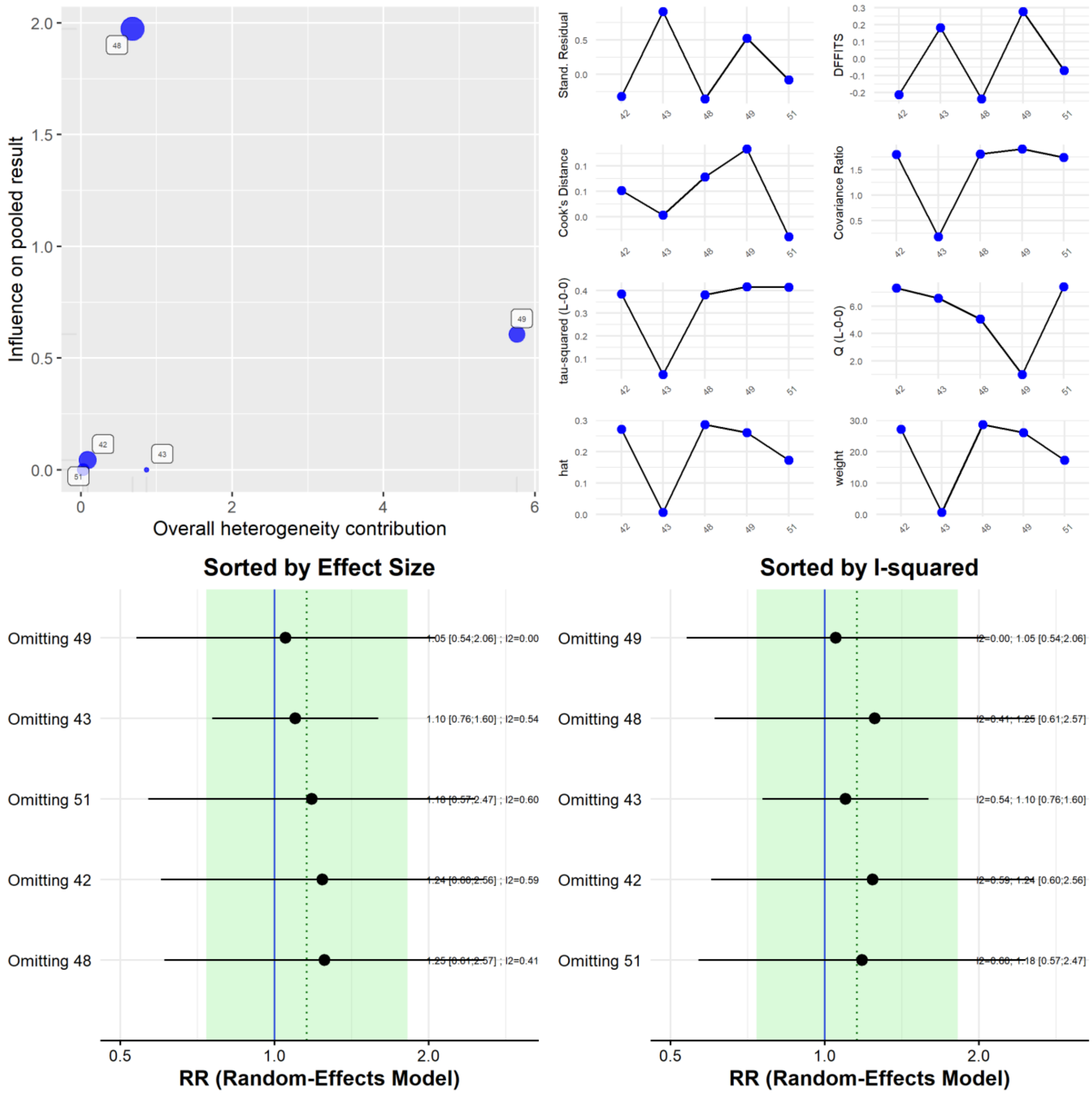


Figure VII.68. Influence analysis for the meta-analysis performed for the retention rates of bigeye thresher shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye thresher – At-haulback mortality

Figure VII.69 shows the random effects model for at-haulback mortality of bigeye thresher when all data compiled are used. When all data are used, the RR is 1.06 (95% CIs: 0.80; 1.39). This means that we expect that the at-haulback mortality of bigeye thresher when using fish bait is 6% higher than when using squid bait, but this is not significant as the 95% confidence intervals vary between a decrease of 20% and an increase of 39%. In this specific analysis the overall heterogeneity is low (I^2=28%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VII.70 and in this specific case no major outliers were identified and therefore all experiments were kept.

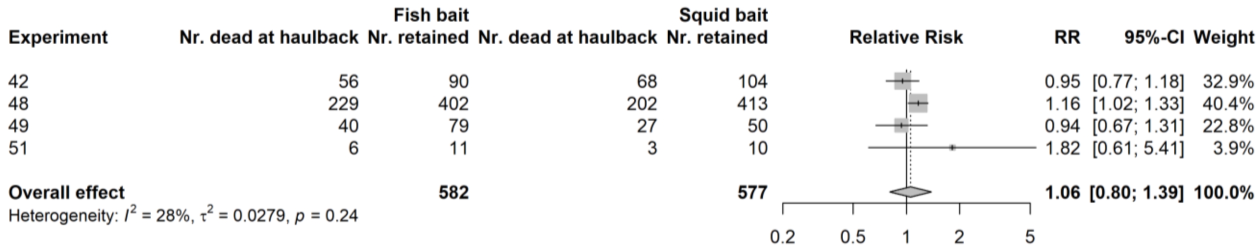


Figure VII.69. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of bigeye thresher shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

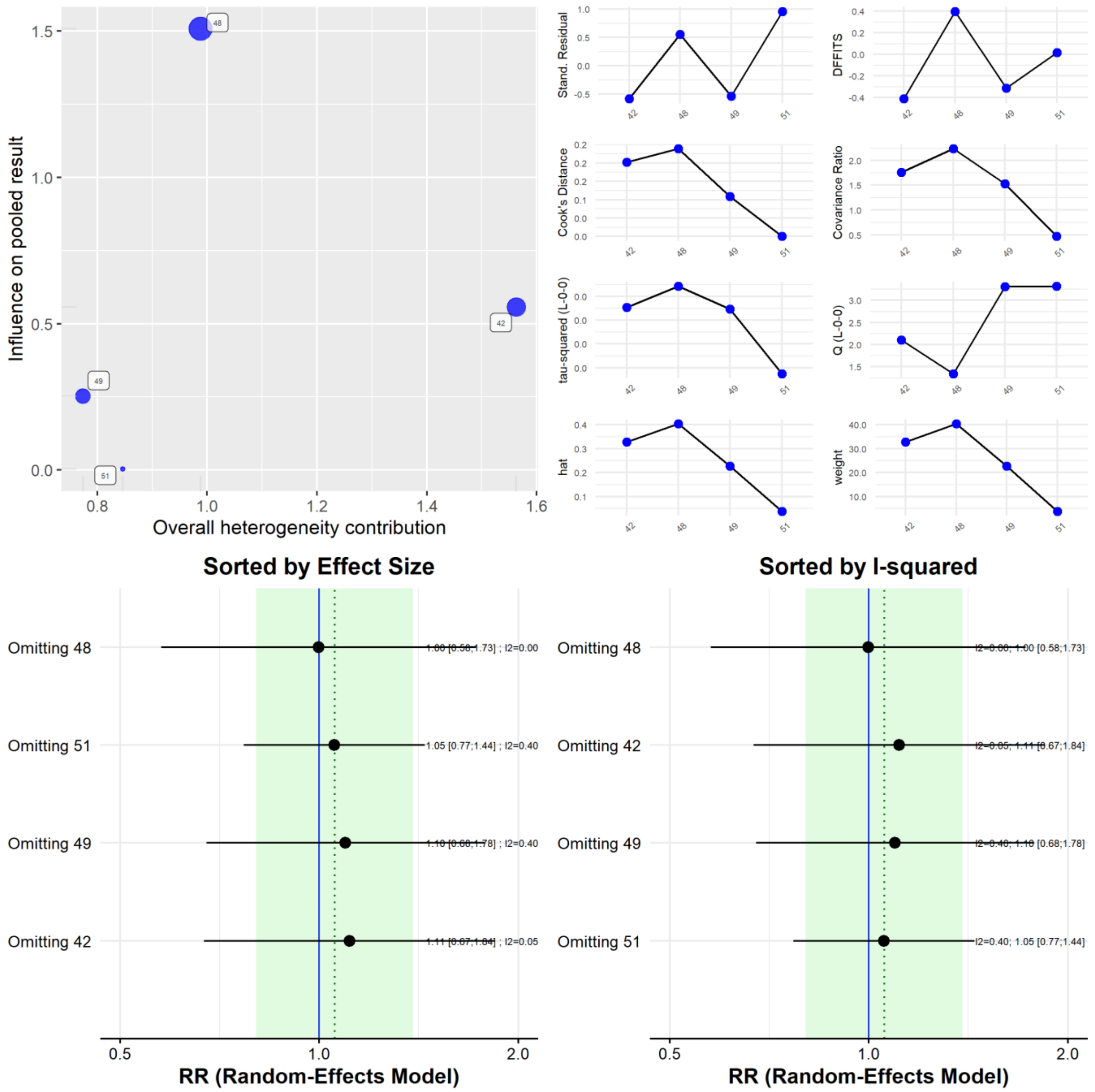


Figure VII.70. Influence analysis for the meta-analysis performed for the at-haulback mortality of bigeye thresher shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Longfin mako – Retention rates

Figure VII.71 shows the random effects model for retention of longfin mako when all data compiled are used. When all data are used, the RR is1.59 (95% CIs: 0.01; 380.27). This means that on average we expect that the retention of longfin mako when using fish bait is 59% higher than when using squid bait. However, this is not significant as the 95% confidence intervals vary between a reduction of 99% and an increase of 380 times. In this specific analysis we also see that the overall heterogeneity (I^2) is very high (98%) and fails the statistical assumption of homogeneity (p-value<0.05). The influential analysis is shown in Figure VII.72. Two experiments (experiment 42 and 49) were identified as outliers with influence on the pooled results. However, since only three experiments were available, the exclusion of experiments 42 and 49 would hinder the meta-analysis and therefore they were kept in the analysis.

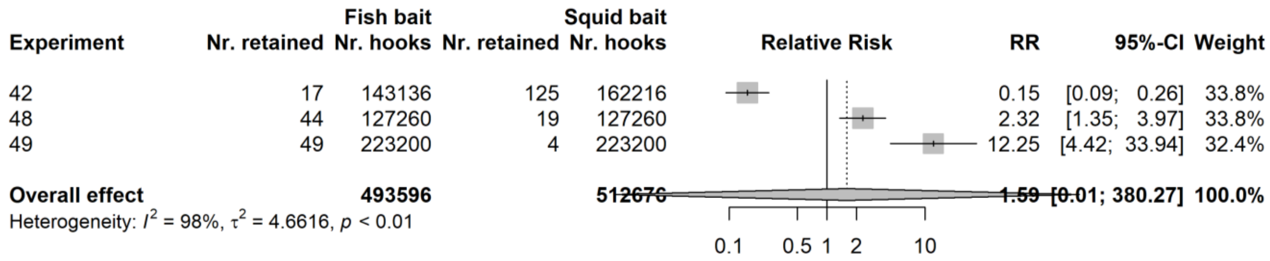


Figure VII.71. Forest plot of the random effects meta-analysis performed for the retention rates of longfin mako shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

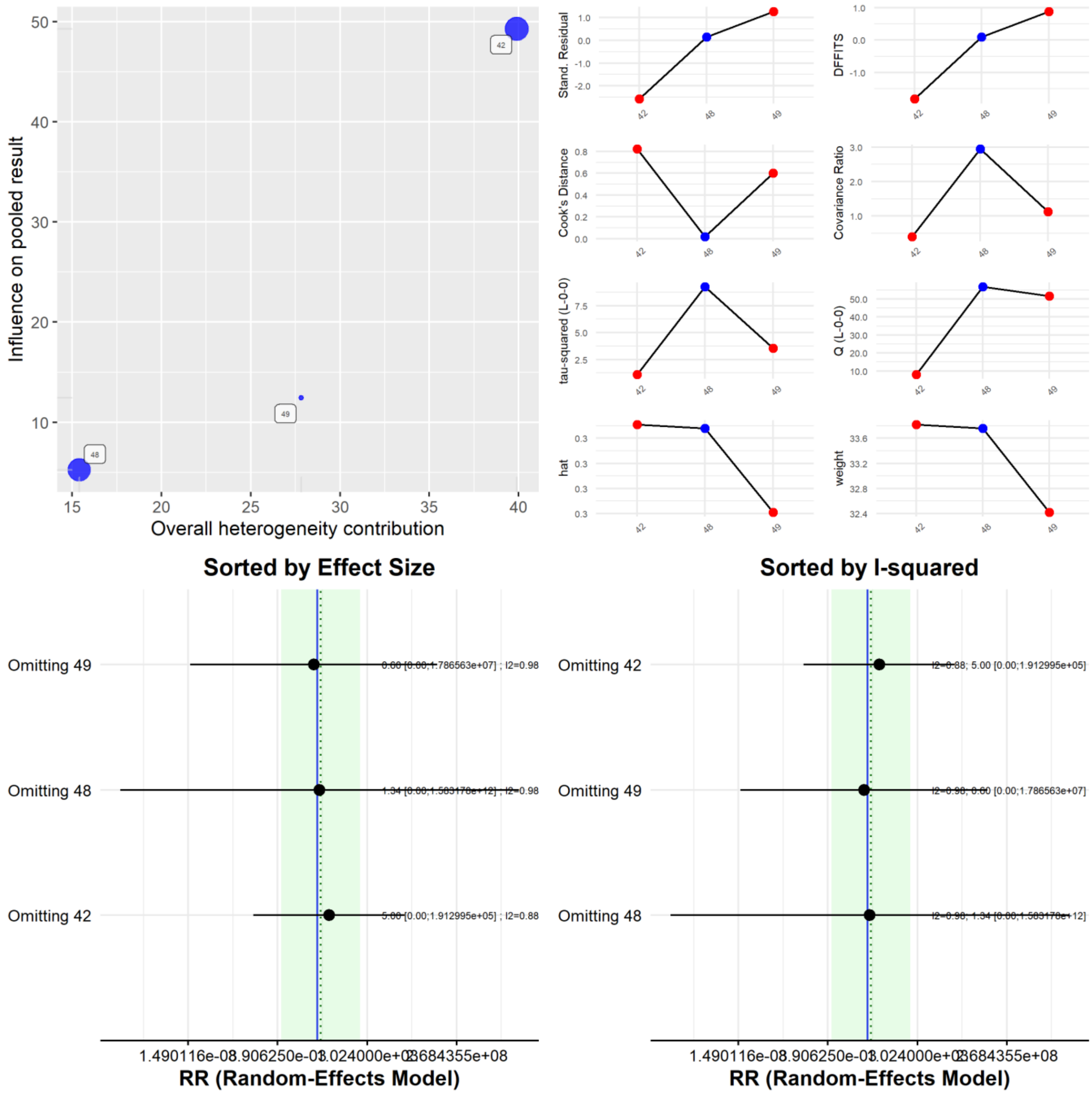


Figure VII.72. Influence analysis for the meta-analysis performed for the retention rates of longfin mako shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Longfin mako – At-haulback mortality

Figure VII.73 shows the random effects model for at-haulback mortality of longfin mako when all data compiled are used. When all data are used, the RR is 1.02 (95% CIs: 0.02; 45.25). This means that on average we expect that the at-haulback mortality of longfin mako when using fish bait is 2% higher than when using squid bait, but this is not significant as the

95% confidence intervals vary between a decrease of 98% and an increase of 45 times. In this specific analysis the overall heterogeneity is 35% and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influential analysis is shown in Figure VII.74. In this specific case one outlier was identified (experiment 49) but the experiment was kept in order to perform the meta-analysis, given that there are only three studies available.

	Fish bait		Squid bait					
Experiment	**Nr. dead at haulback**	**Nr. retained**	**Nr. dead at haulback**	**Nr. retained**	**Relative Risk**	**RR**	**95%-CI**	**Weight**
42	6	17	14	42		1.06	[0.49; 2.29]	47.0%
48	13	44	0	14		41.88	[0.09; 20486.29]	9.1%
49	11	49	2	4		0.45	[0.15; 1.36]	43.9%
Overall effect		**110**		**60**		**1.02**	**[0.02; 45.25]**	**100.0%**

Heterogeneity: $I^2 = 35\%$, $\tau^2 = 2.2166$, $p = 0.21$

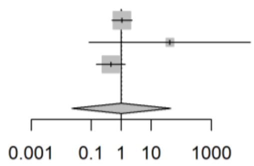


Figure VII.73. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of longfin mako shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

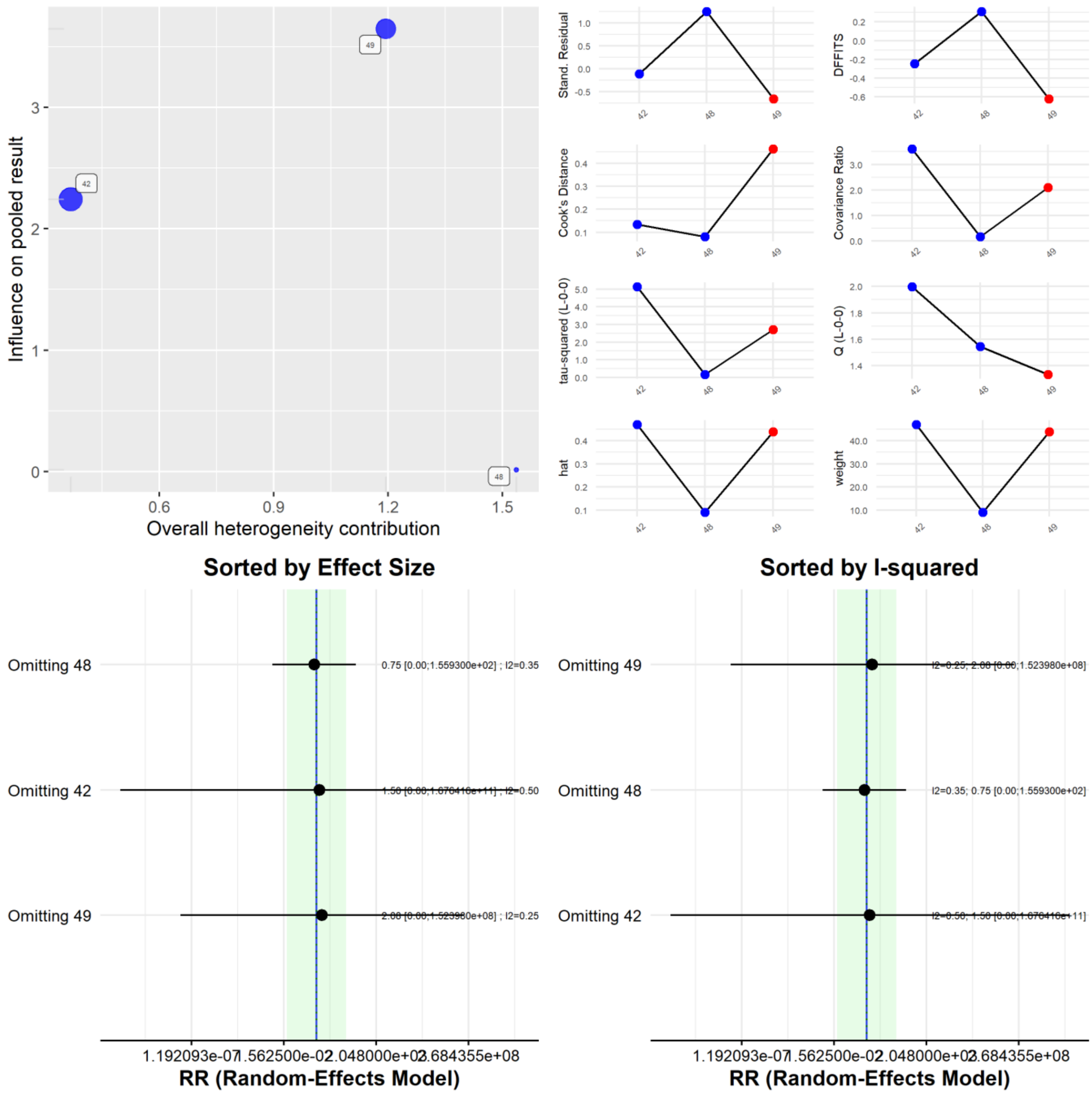


Figure VII.74. Influence analysis for the meta-analysis performed for the at-haulback mortality of longfin mako shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Crocodile shark – Retention rates

Figure VII.75 shows the random effects model for retention of crocodile shark when all data compiled are used. When all data are used, the RR is 0.72 (95% CIs: 0.10; 5.42). In this specific case the overall heterogeneity is very high (I^2=99%) and fails the statistical assumption of homogeneity (p-value<0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure 3VII.76. In this case, the influence analysis identified one experiment (experiment 42) that is an outlier with 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 VII.77 and validation indicated in Figure VII.78. With the exclusion of that outlier, the final RR estimation is 1.26 (95% CIs: 0.35; 4.51) and the overall heterogeneity (I^2) decreases to 81%. This analysis indicates that on average we expect that the retention of crocodile shark when using fish bait is 26% higher than when using squid bait, however this is not significant as the 95% confidence intervals vary between a reduction of 65% and an increase of 4.51 times.

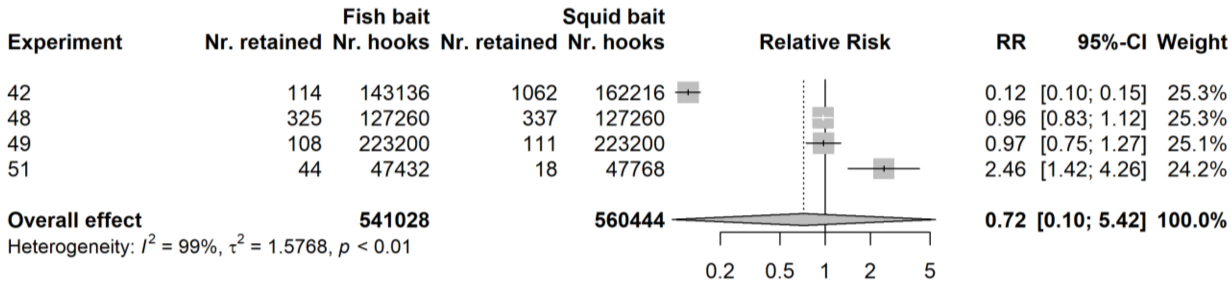


Figure VII.75. Forest plot of the random effects meta-analysis performed for the retention rates of the crocodile shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

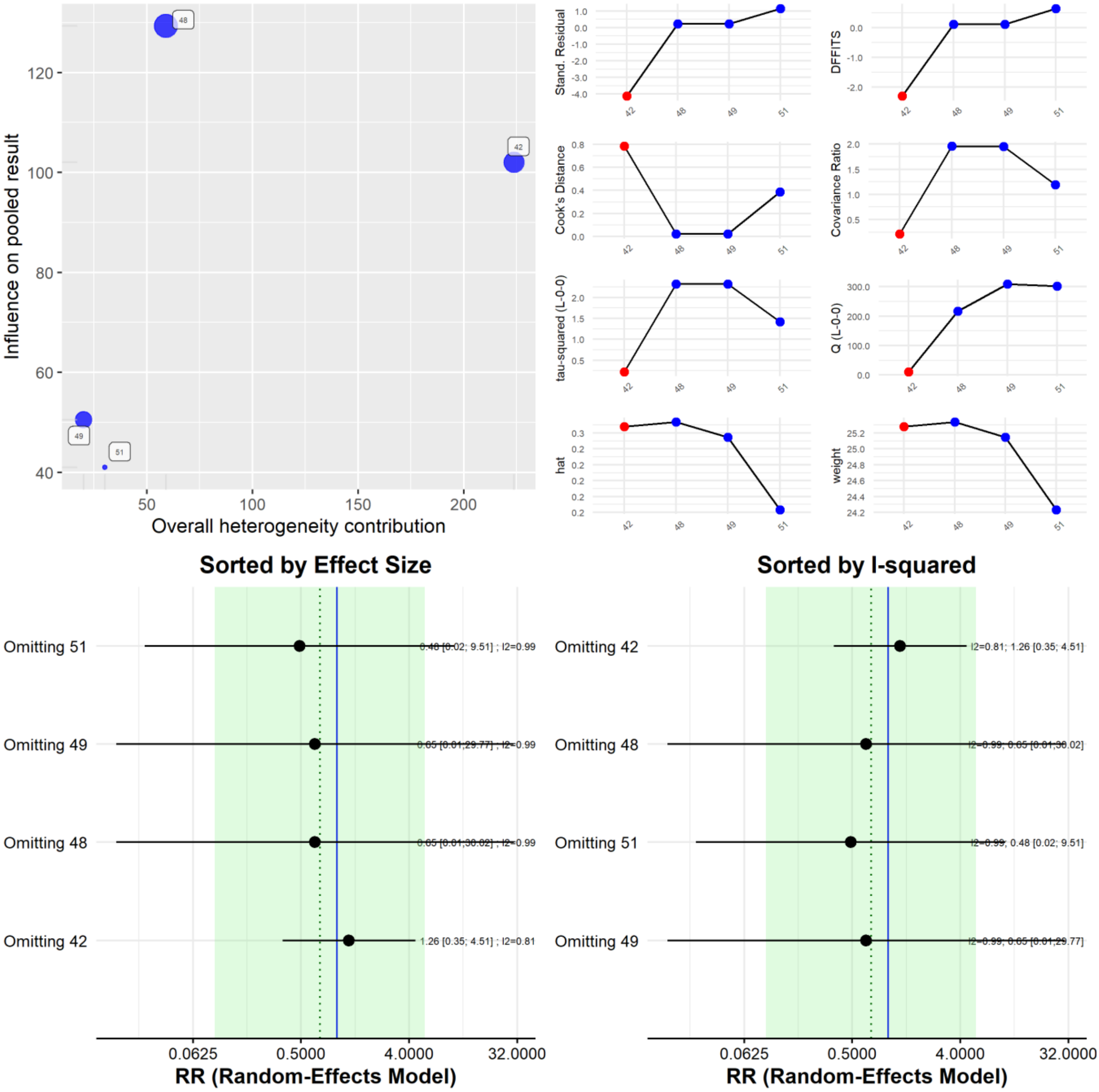


Figure VII.76. Influence analysis for the meta-analysis performed for the retention rates of the crocodile shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

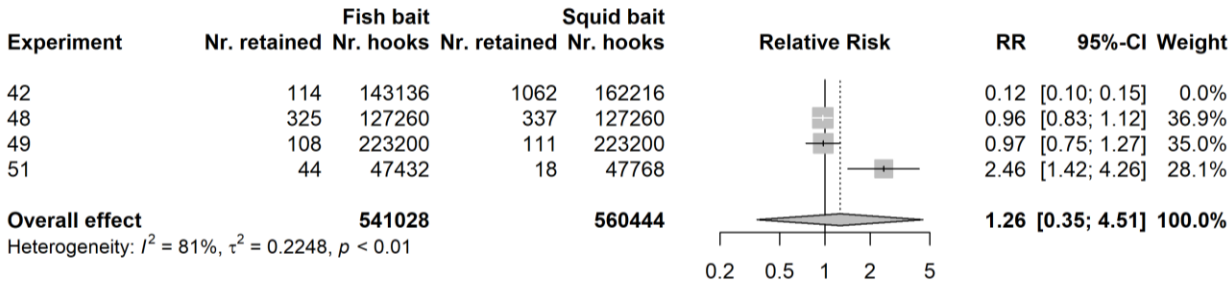


Figure VII.77. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of the crocodile shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates is higher with fish bait). The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis).

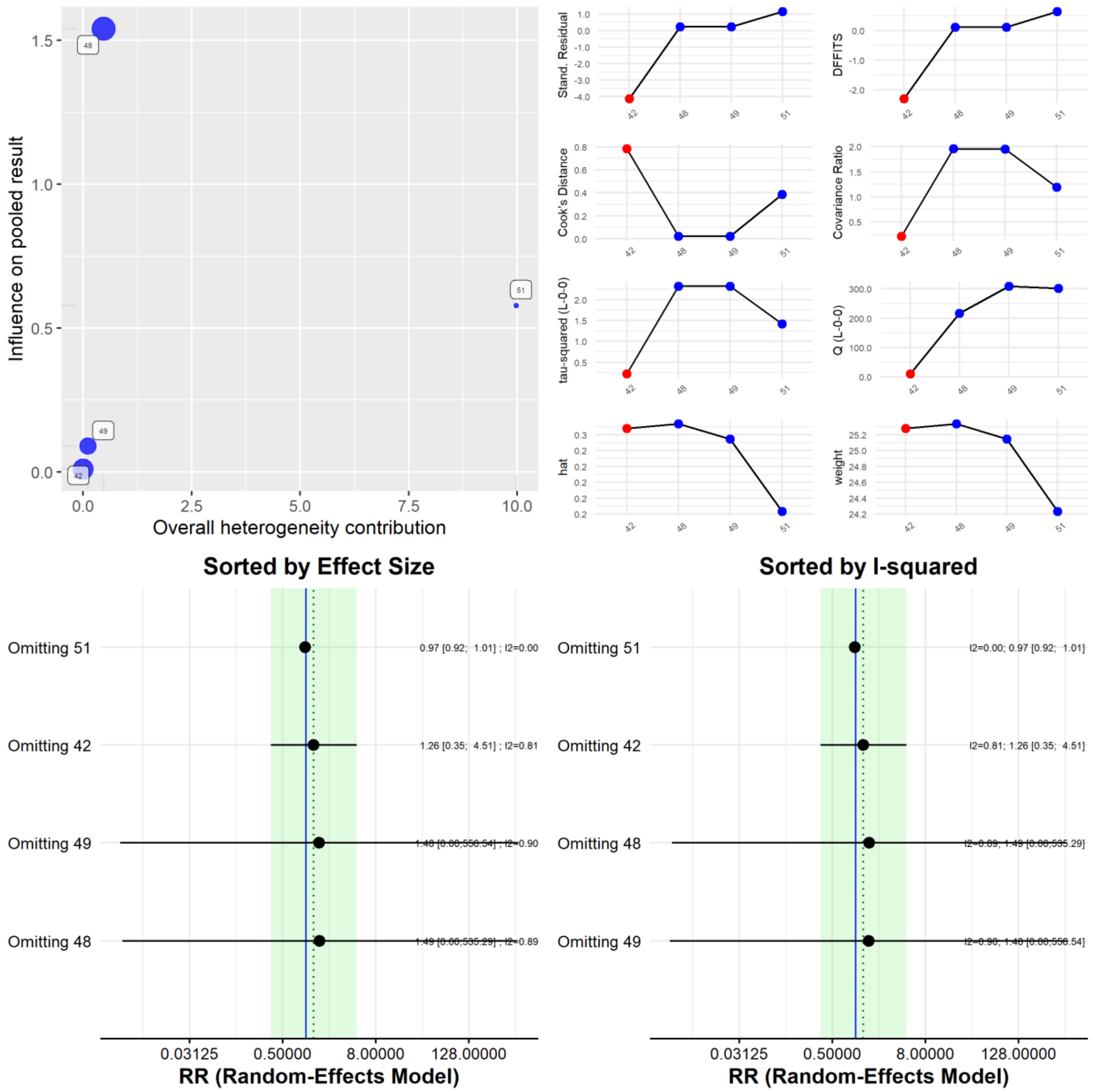


Figure VII.78. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rates of the crocodile shark with fish vs. squid bait. The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Crocodile shark – At-haulback mortality

Figure VII.79 shows the random effects model for at-haulback mortality of crocodile shark when all data compiled are used. When all data are used, the RR is 1.48 (95% CIs: 0.24; 9.26). In this specific case we also see that the overall heterogeneity is very high (I^2=94%) and fails the statistical assumption of homogeneity (p-value<0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.80. In this case, the influence analysis identified one experiment (experiment 42) that is an outlier with 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 VII.81 and the validation indicated in Figure VII.82. With the exclusion of that outlier, the final RR estimation is 0.88 (95% CIs: 0.32; 2.40) and the overall heterogeneity (I^2) is reduced from 94% to 13%. This analysis indicates that on average we expect that the at-haulback mortality of crocodile shark when using fish bait is 12% lower than when using squid bait, however this is not significant as the 95% confidence intervals vary between a reduction of 68% and an increase of 2.4 times.

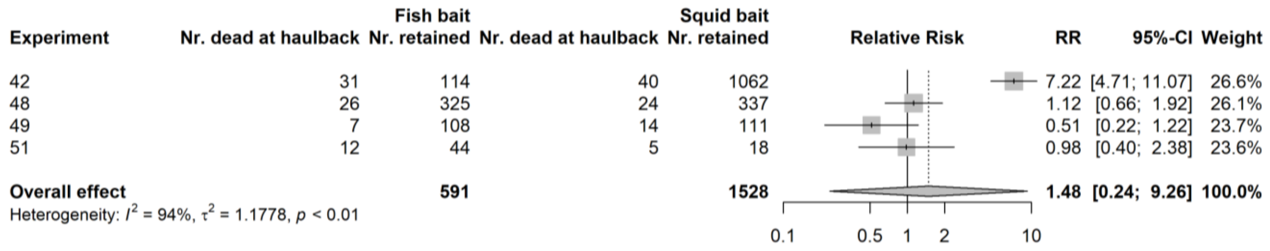


Figure VII.79. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of the crocodile shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

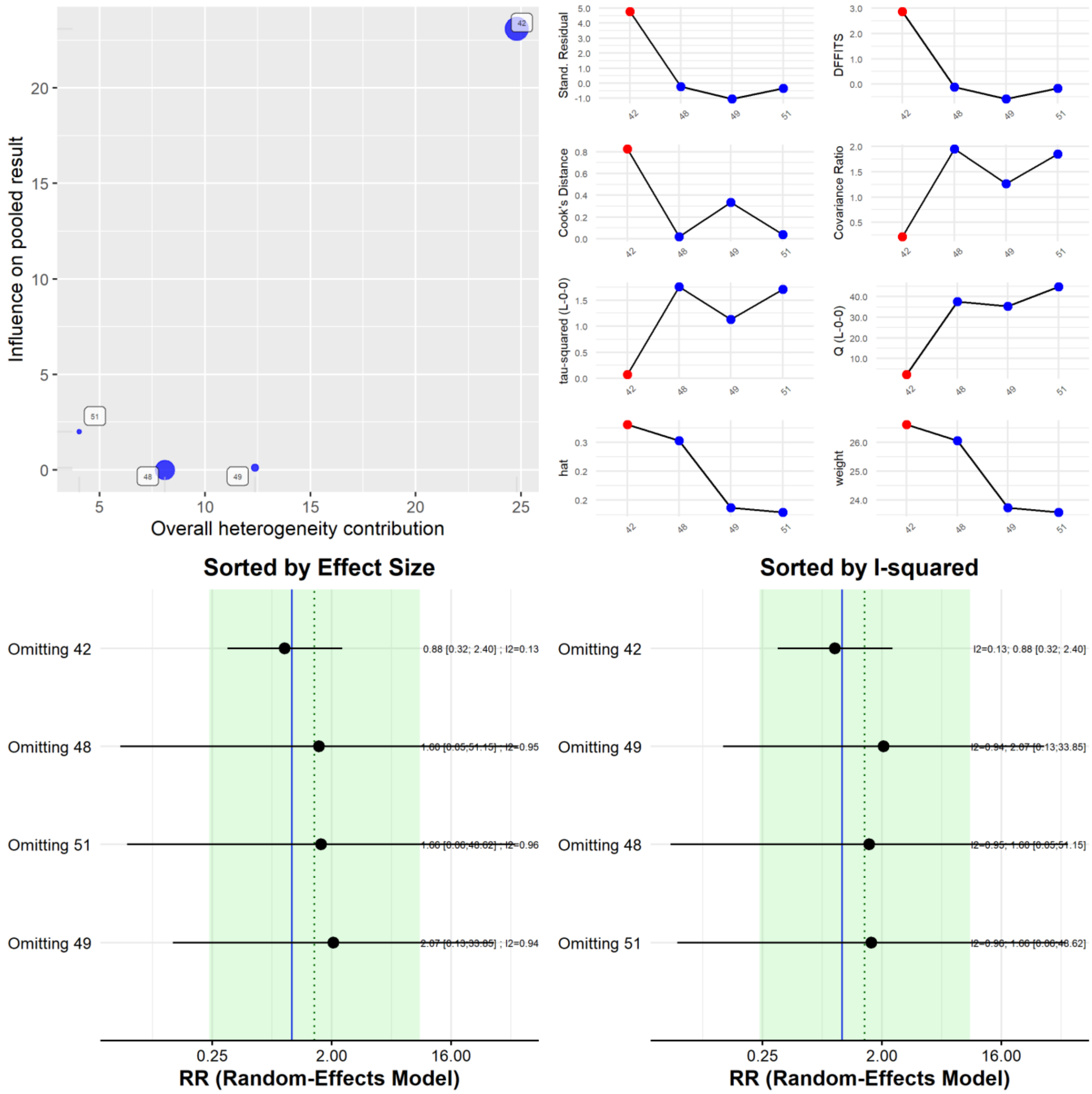


Figure VII.80. Influence analysis for the meta-analysis performed for the at-haulback mortality rates of the crocodile shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Fish bait Nr. dead at haulback	Fish bait Nr. retained	Squid bait Nr. dead at haulback	Squid bait Nr. retained	RR	95%-CI	Weight
42	31	114	40	1062	7.22	[4.71; 11.07]	0.0%
48	26	325	24	337	1.12	[0.66; 1.92]	48.1%
49	7	108	14	111	0.51	[0.22; 1.22]	26.4%
51	12	44	5	18	0.98	[0.40; 2.38]	25.5%
Overall effect		**591**		**1528**	**0.88**	**[0.32; 2.40]**	**100.0%**

Heterogeneity: $I^2 = 13\%$, $\tau^2 = 0.0743$, $p = 0.32$

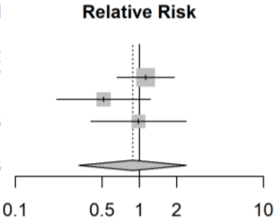


Figure VII.81. Forest plot of the random effects meta-analysis excluding 1 outlier in the at-haulback mortality rates of the crocodile shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait). The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis).

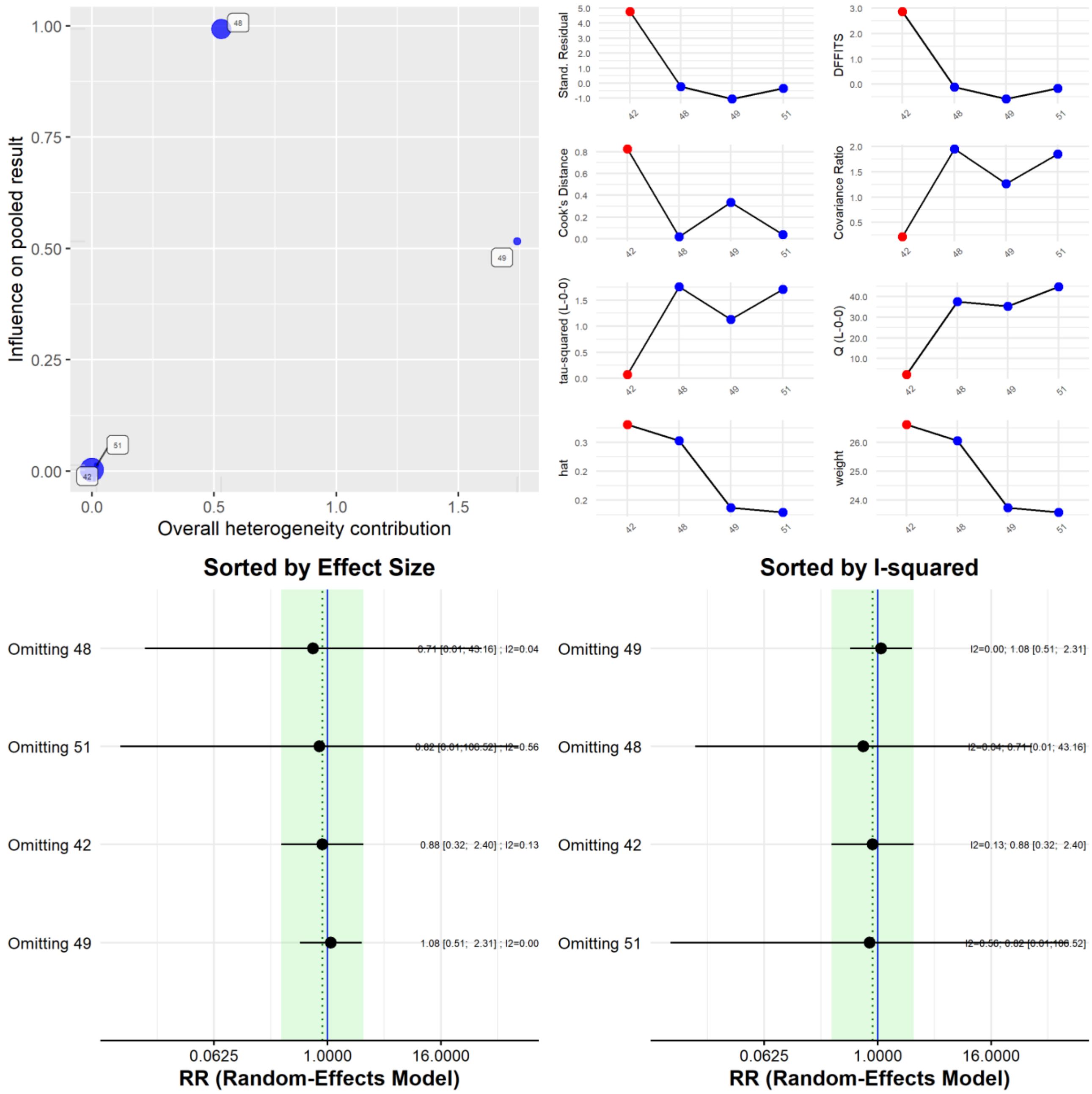


Figure VII.82. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the at-haulback mortality rates of the crocodile shark with fish vs. squid bait. The excluded experiment is number 42 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Scalloped hammerhead – Retention rates

For the comparisons between bait type, there were only two experiments that reported on retention of scalloped hammerhead for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 42 reported 4 specimens retained in 162,216 hooks baited with squid and 14 specimens retained in 143,136 hooks baited with fish (RR= 3.97; 95% CIs: 1.31; 12.05). Experiment 48 reported 4 specimens retained in 127,260 hooks baited with squid and 2 specimens retained in 127,260 hooks baited with fish (RR= 0.50; 95% CIs: 0.09; 2.73).

Scalloped hammerhead – At-haulback mortality

For the comparisons between bait type, there was only one experiment (experiment 42) that reported on at-haulback of scalloped hammerhead for surface longlines. As such, it was not possible to conduct the meta-analysis. In this experiment, 2 specimens out of 4 retained with squid baited hooks and 8 specimens out of 14 retained with fish baited hooks suffered at-haulback mortality (RR= 1.14; 95% CIs: 0.39; 3.36).

Smooth hammerhead – Retention rates

Figure VII.83 shows the random effects model for retention of smooth hammerhead when all data compiled are used. When all data are used, the RR is 1.17 (95% CIs: 0.18; 17.17). In this specific case the overall heterogeneity is very high (I^2=91%) and fails the statistical assumption of homogeneity (p-value<0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.84. In this case, the influence analysis identified one experiment (experiment 49) that is an outlier with 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 VII.85 and validation indicated in Figure VII.86. With the exclusion of that outlier, the final RR estimation is 1.12 (95% CIs: 0.21; 5.94) and the overall heterogeneity is 93%. This analysis indicates that on average we expect that the retention of smooth hammerhead when using fish bait is 12% higher than when using squid bait, however this is not significant as the 95% confidence intervals vary between a reduction of 79% and an increase of 5.94 times.

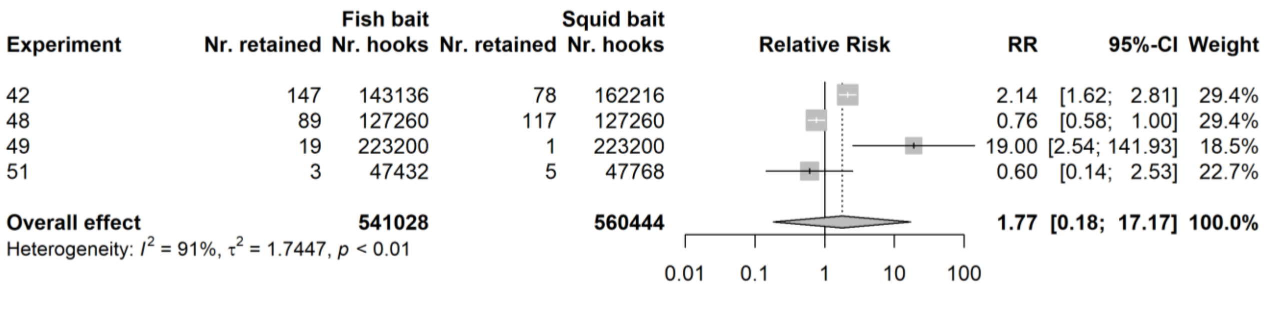


Figure VII.79. Forest plot of the random effects meta-analysis performed for the retention of the smooth hammerhead shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

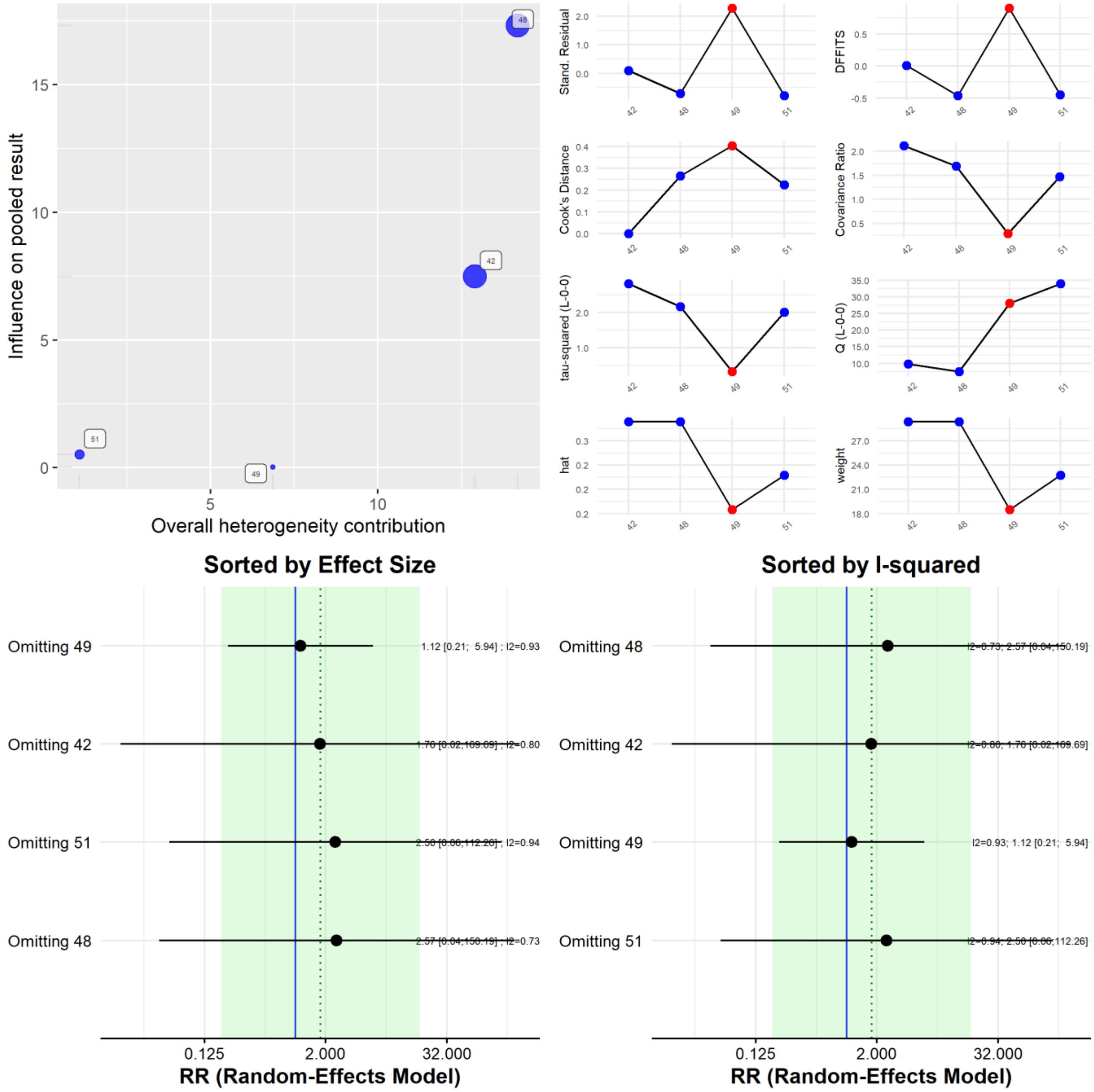


Figure VII.80. Influence analysis for the meta-analysis performed for the retention of the smooth hammerhead shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

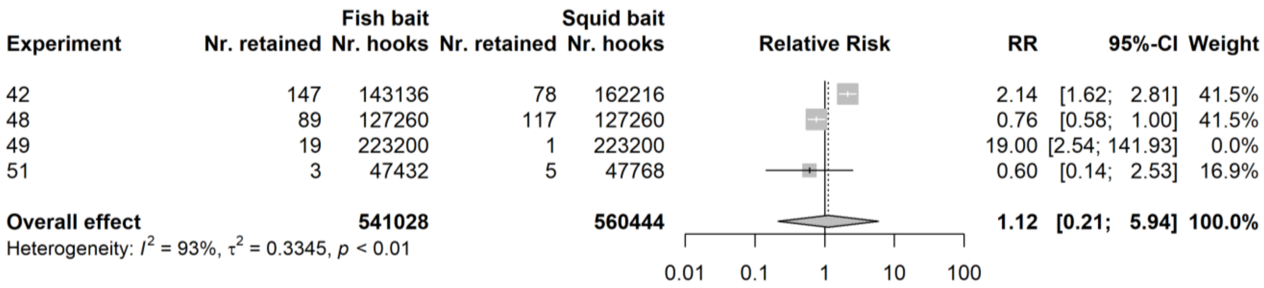


Figure VII.81. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention of the smooth hammerhead shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis).

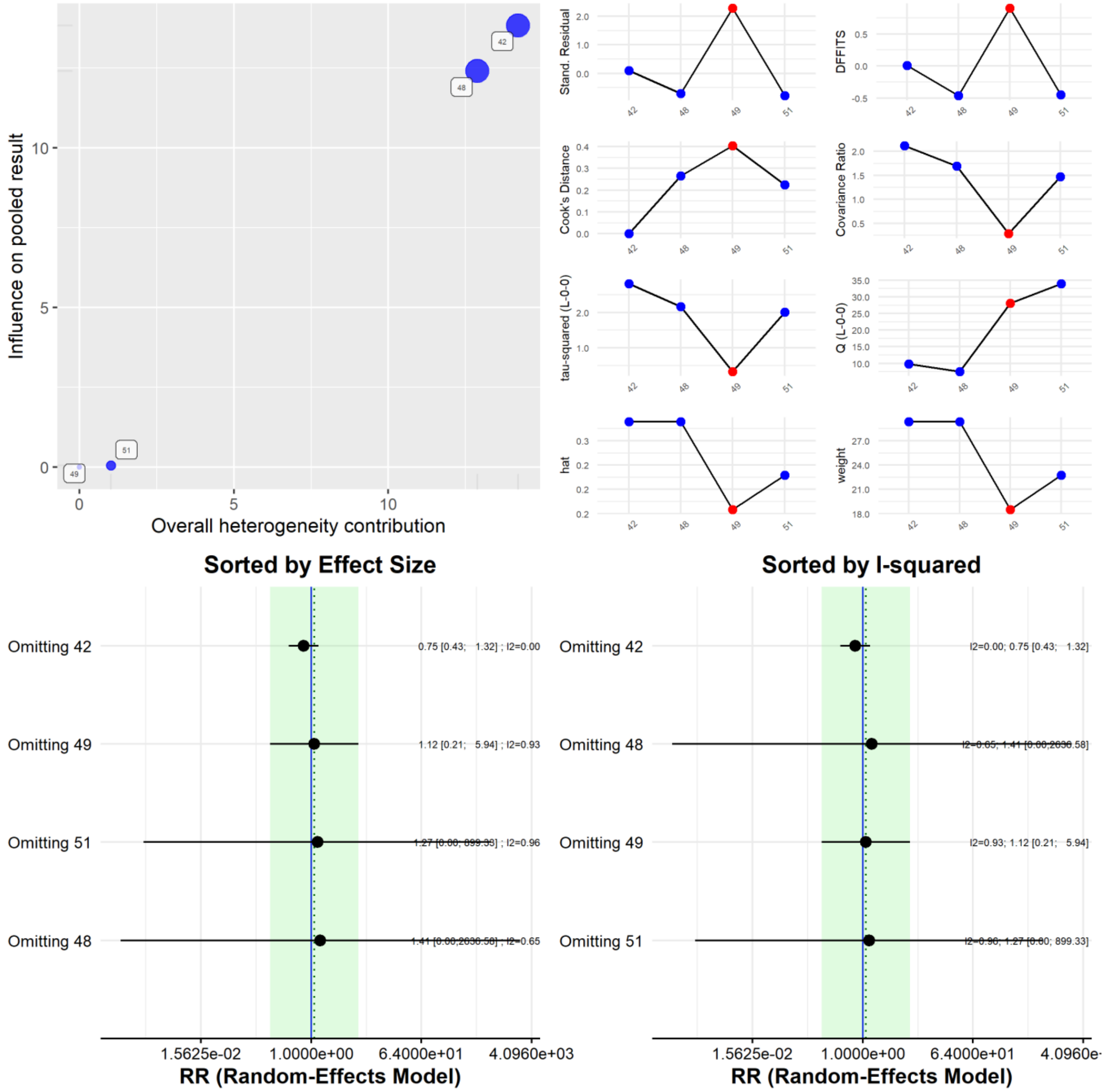


Figure VII.82. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention of smooth hammerhead shark with fish vs. squid bait. The excluded experiment is number 49 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Smooth hammerhead – At-haulback mortality

Figure VII.83 shows the random effects model for at-haulback mortality of smooth hammerhead when all data compiled are used. When all data are used, the RR is 0.89 (95% CIs: 0.72; 1.11). This means that on average we expect that the at-haulback mortality of smooth hammerhead when using fish bait is 11% lower than when using squid bait, but this is not significant with 95% confidence intervals varying between a reduction of 28% and an increase of 11%. In this specific case see that the overall heterogeneity is low (I^2=14%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). The influence analysis is represented in Figure VII.84. In this case, the influence analysis did not identify outliers with major influence on the pooled results.

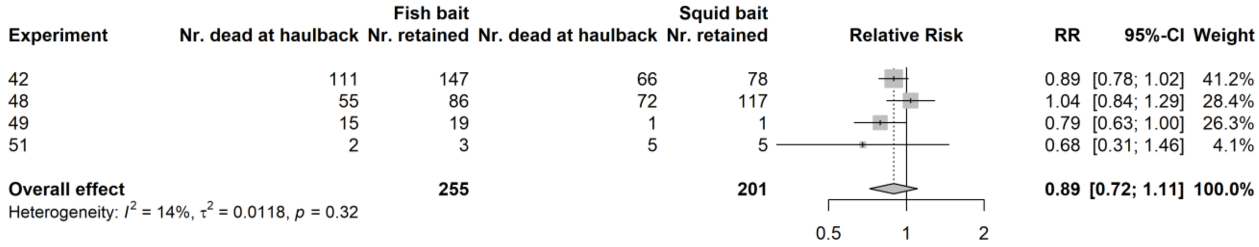


Figure VII.83. Forest plot of the random effects meta-analysis performed for the at-haulback mortality of the smooth hammerhead shark with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates at-haulback mortality is higher with fish bait).

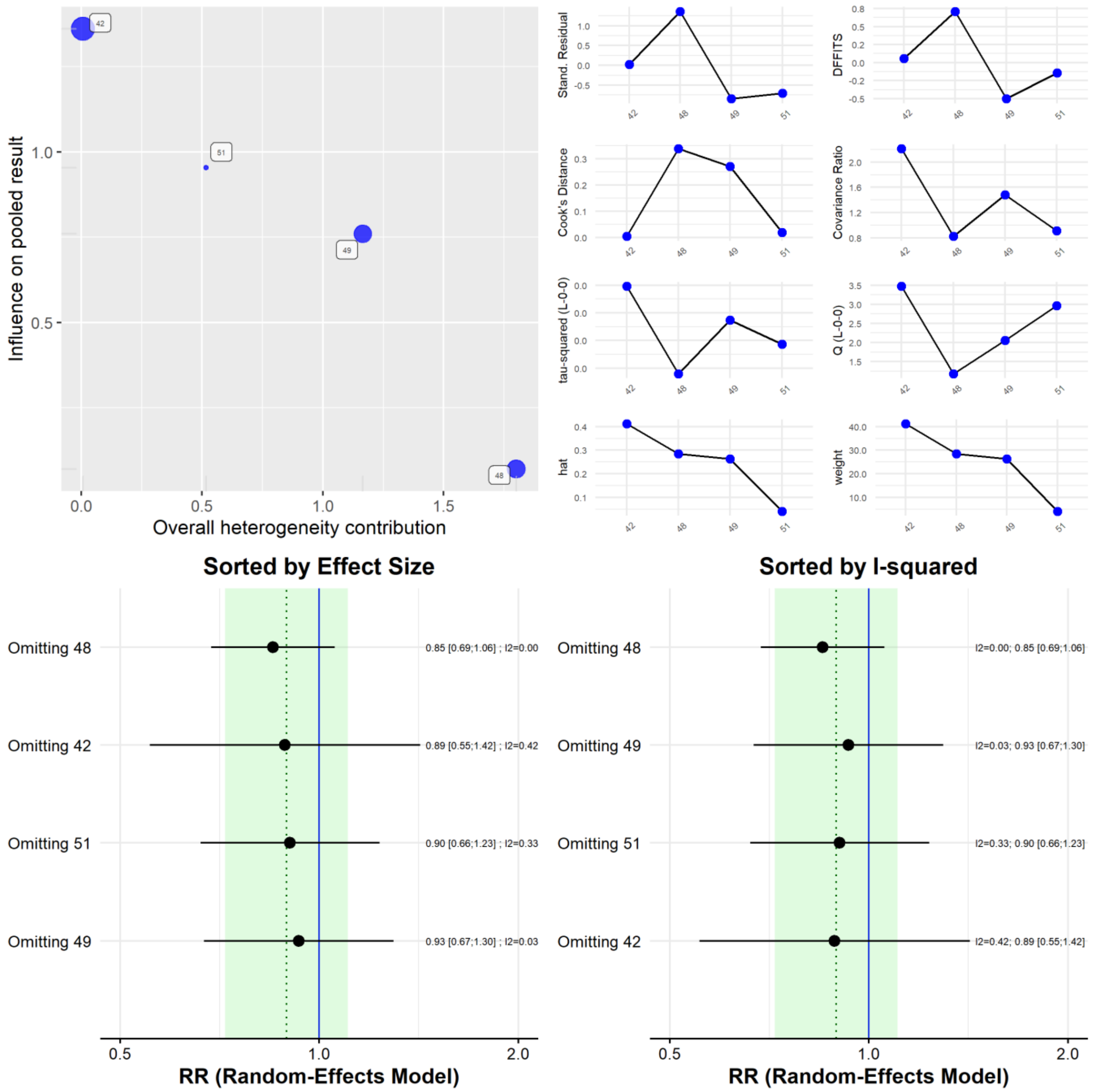


Figure VII.84. Influence analysis for the meta-analysis performed for the at-haulback mortality of the smooth hammerhead shark with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Pelagic stingray – Retention rates

Figure VII.85 shows the random effects model for retention of pelagic stingray when all data compiled is used. When all data are used, the RR is 1.07 (95% CIs: 0.54; 2.12). The overall heterogeneity is high (I^2=87%) and fails the statistical assumption of homogeneity (p-value<0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.86. In this case, the influence analysis identified two experiments (experiment 42 and 51) that are outliers with influence on the pooled results. The analysis was therefore re-run excluding those experiments, with the results of the new pooled analysis indicated in Figure VII.87 and validation indicated in Figure VII.88. With the exclusion experiment 42 and 51, the final RR estimation is 1.26 (95% CIs: 0.83; 1.93) and the overall heterogeneity (I^2) is reduced to 0%. This analysis indicates that on average we expect that the retention of pelagic stingray when using fish bait is 26% higher than when using squid bait, however this is not significant as the 95% confidence intervals vary between a reduction of 17% and an increase of 93% in retention.

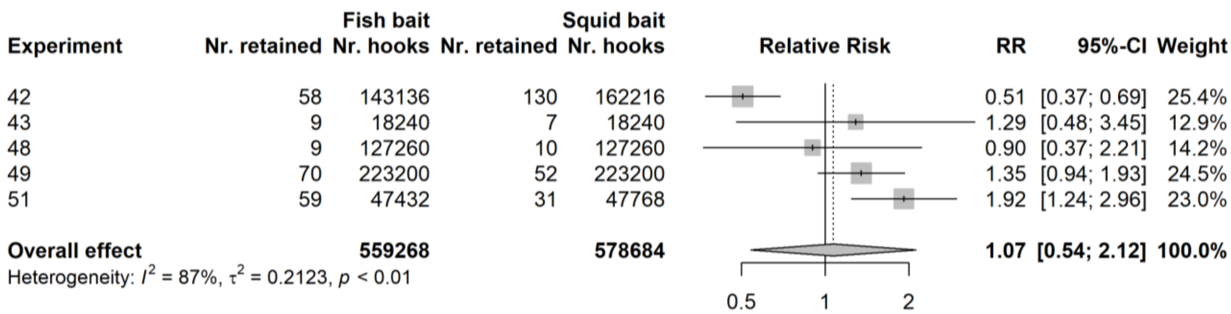


Figure VII.85. Forest plot of the random effects meta-analysis performed for the retention of the pelagic stingray with fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait).

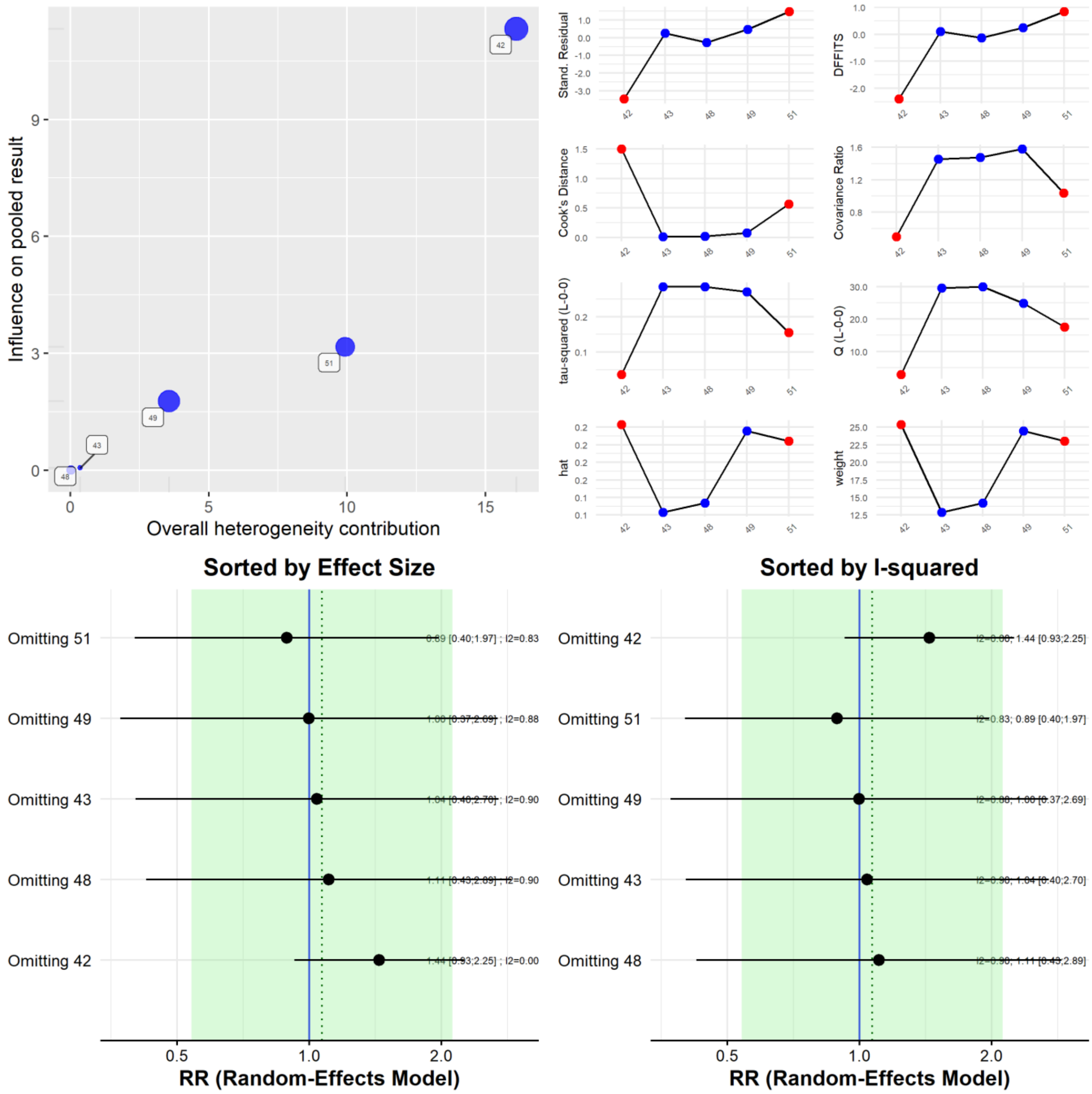


Figure VII.86. Influence analysis for the meta-analysis performed for the retention of the pelagic stingray with fish vs. squid bait. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Experiment	Fish bait Nr. retained	Fish bait Nr. hooks	Squid bait Nr. retained	Squid bait Nr. hooks	RR	95%-CI	Weight
42	58	143136	130	162216	0.51	[0.37; 0.69]	0.0%
43	9	18240	7	18240	1.29	[0.48; 3.45]	11.9%
48	9	127260	10	127260	0.90	[0.37; 2.21]	14.2%
49	70	223200	52	223200	1.35	[0.94; 1.93]	74.0%
51	59	47432	31	47768	1.92	[1.24; 2.96]	0.0%
Overall effect		**559268**		**578684**	**1.26**	**[0.83; 1.93]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0086$, $p = 0.72$

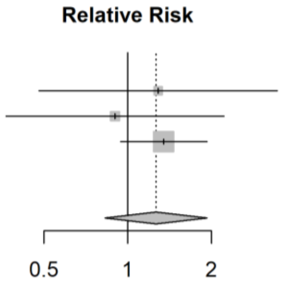


Figure VII.87. Forest plot of the random effects meta-analysis excluding 2 outliers in the retention of the pelagic stingray fish vs. squid bait (Note: squid is considered the control and fish the experimental bait; a relative risk (RR) >1 indicates retention is higher with fish bait). The excluded experiments are numbers 42 and 49 (that are still represented in the plots but not considered in the analysis).

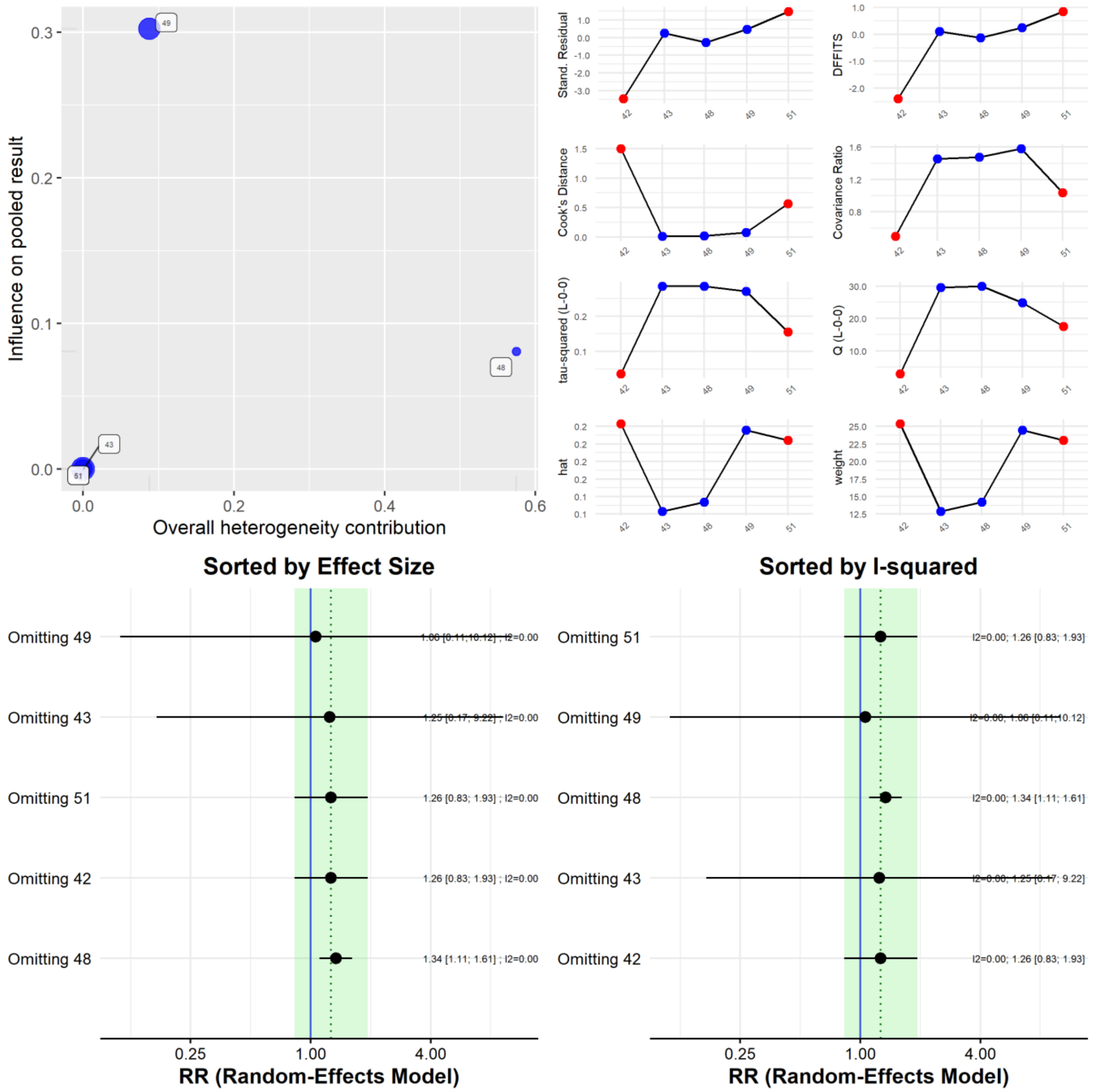


Figure VII.88. Influence analysis for the meta-analysis after excluding 2 outliers, performed for the retention of the pelagic stingray with fish vs. squid bait. The excluded experiments are numbers 42 and 49 (that are still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Pelagic stingray – At-haulback mortality

For the comparisons between bait type, there was only one experiment (experiment 42) that reported on at-haulback of pelagic stingray for surface longlines. As such, it was not possible to conduct the meta-analysis. In this experiment, 4 specimens out of 130 retained with squid baited hooks and 2 specimens out of 58 retained with fish baited hooks suffered at-haulback mortality (RR= 1.12; 95% CIs: 0.21; 5.95).

Effects of leader type on targeted species

Swordfish – Retention rates

In the case of swordfish, when all experiments are used for comparing nylon and wire leaders the RR is 0.87 (95% CIs: 0.67; 1.13), which means that changing from nylon leader to wire leader would lead to a decrease in retention of SWO, although not significant, with 95% confidence intervals varying between reductions of 33% and increases of 13% (Figure VII.89. In this specific analysis the overall heterogeneity (I^2) is 48% 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 VII.90. Experiments 50 and 51 are identified in several of the diagnostics as possible outliers, however in this case as only three experiments are available, removing the possible outliers would hinder the meta-analysis as only two studies would remain. As such, all available studies were used.

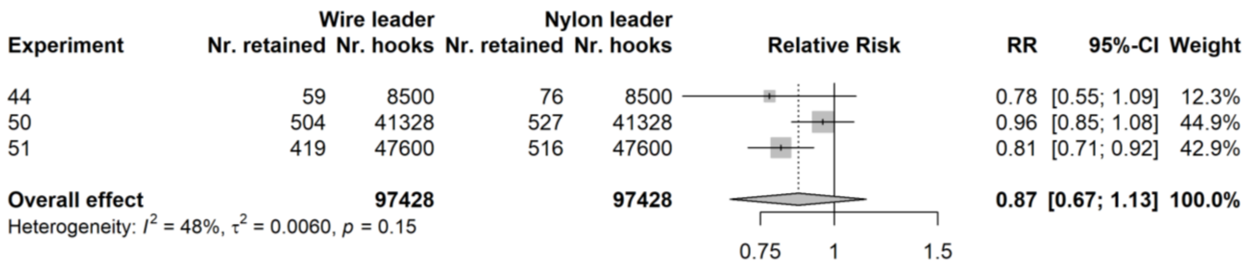


Figure VII.89. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish with wire vs. nylon leader (Note: Nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

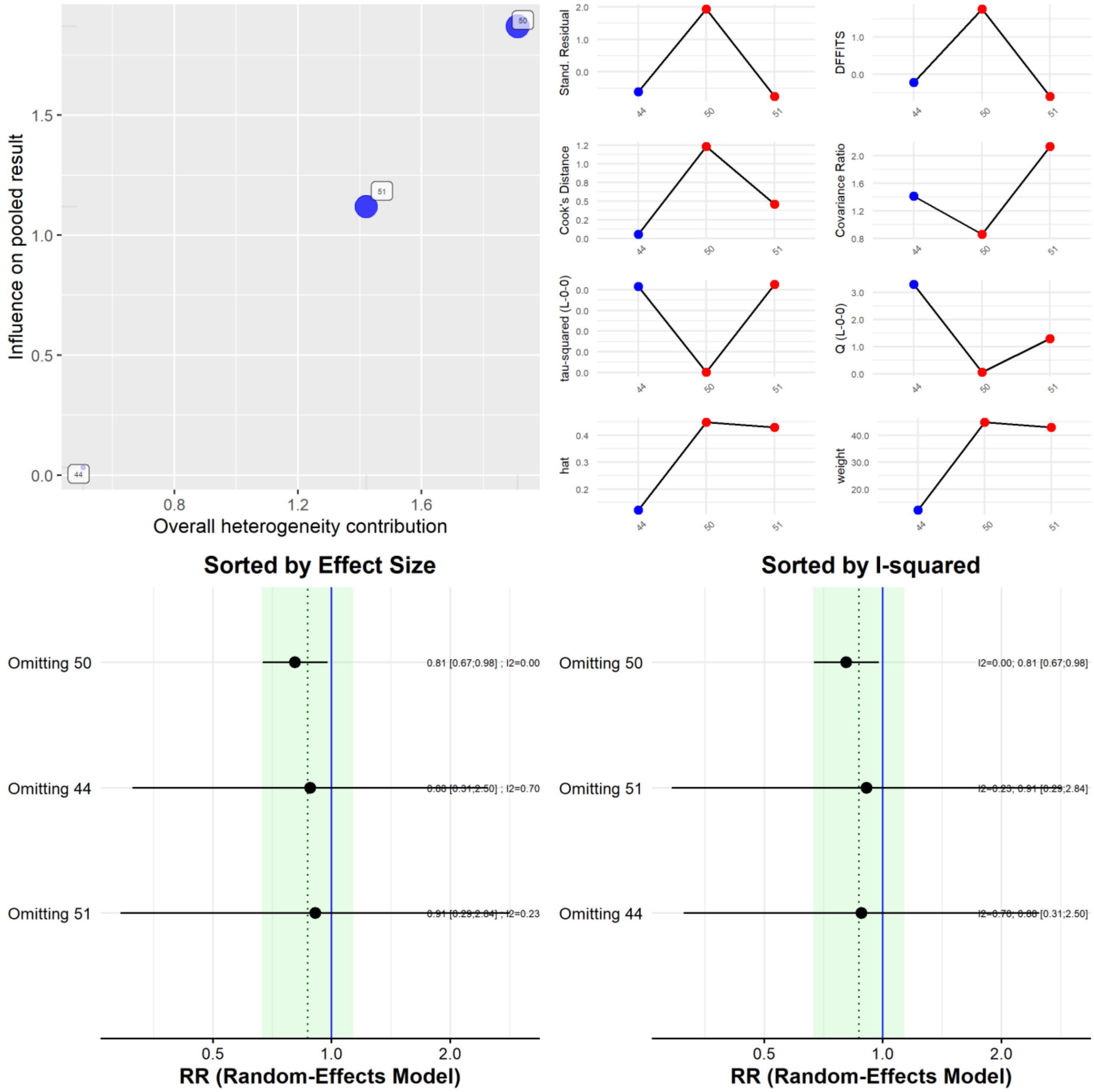


Figure VII.90. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Swordfish – At-haulback mortality

With regard to the effect of leader type on the at-haulback mortality of swordfish, only two experiments were available (experiments 50 and 51), so the meta-analysis was not conducted. Experiment 50 shows a significant decrease in the at-haulback mortality of swordfish when using wire leaders (RR=0.87; 95% CIs: 0.80; 0.93), while experiment 51 indicated there are no differences in the at-haulback mortality (RR=0.99; 95% CIs:0.95; 1.04).

Bigeye tuna – Retention rates

In the case of bigeye tuna, when all experiments are used for comparing nylon and wire leaders the RR is 0.76 (95% CIs: 0.11; 5.45), which means that although the point estimate indicates a reduction in retention when using nylon leader, this reduction not significant as indicated by the confidence intervals (Figure VII.91). In this specific analysis the overall heterogeneity (I^2) is 81% and fails 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 VII.92. Experiments 50 and 51 are identified in several of the diagnostics as possible outliers, however in this case as only three experiments are available, removing the possible outliers would hinder the meta-analysis as only two studies would remain.

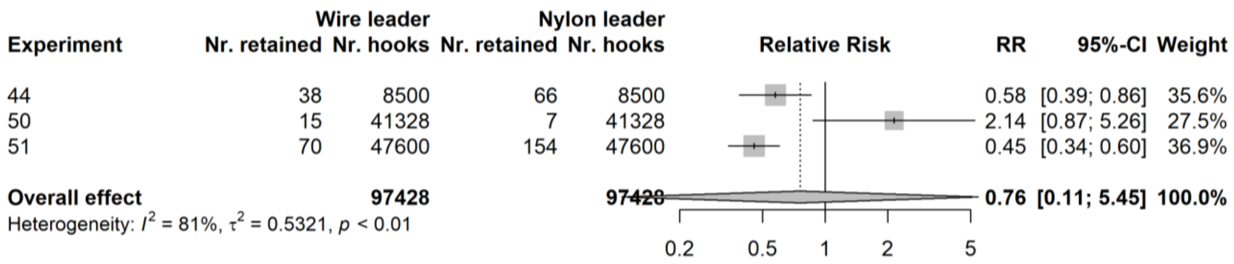


Figure VII.91. Forest plot of the random effects meta-analysis performed for the retention rates of bigeye tuna with wire vs. nylon leader (Note: Nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

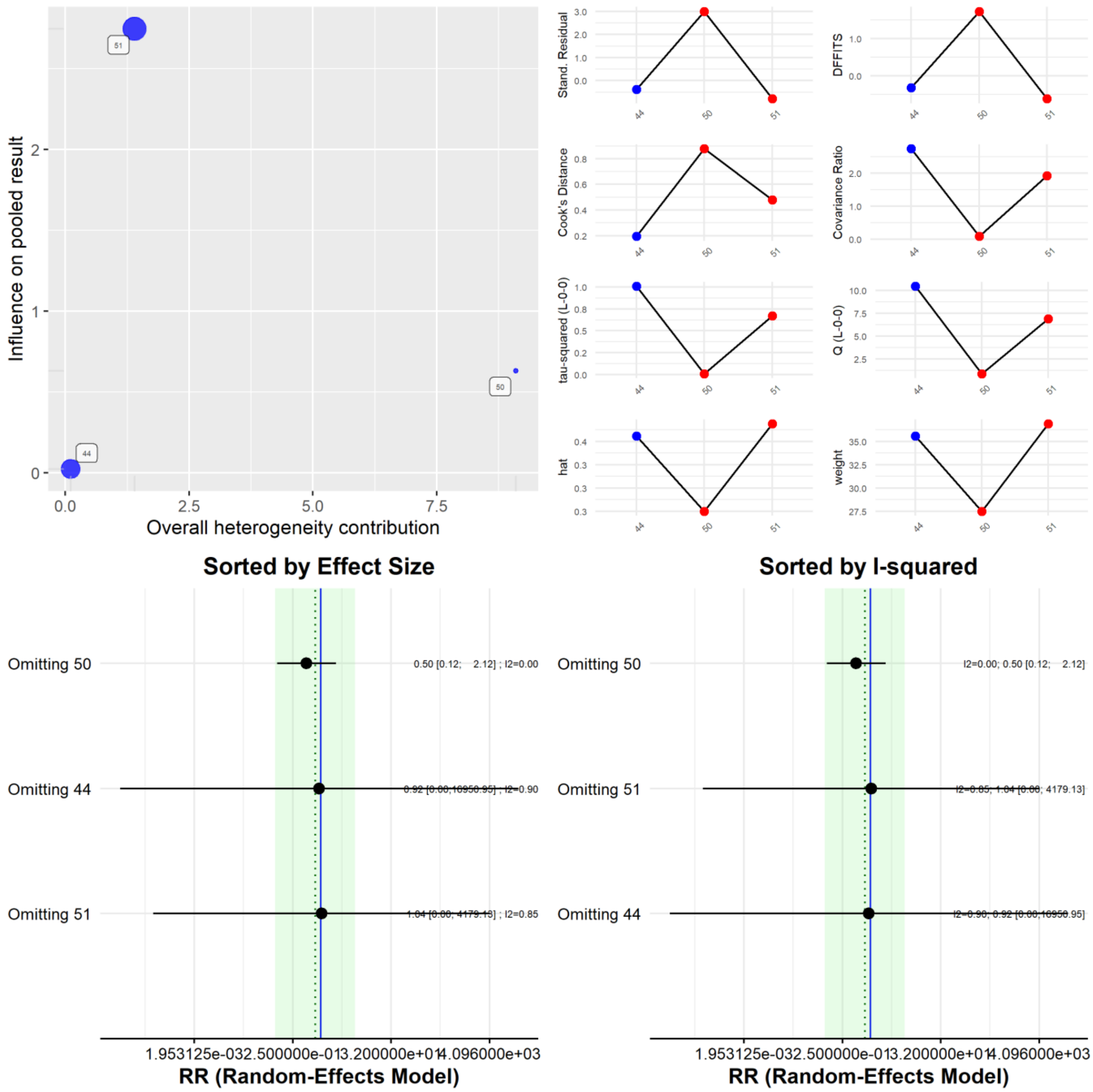


Figure VII.92. Influence analysis for validating the meta-analysis performed for the retention rates of bigeye tuna with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye tuna – At-haulback mortality

With regard to the effect of leader type on the at-haulback mortality of bigeye tuna, only two experiments were available (experiment 50 and 51), so the meta-analysis was not conducted. Both experiments indicate there is a non-significant decrease in at-haulback mortality of bigeye tuna when changing to wire leaders. Experiment 50 shows a decrease in the at-haulback mortality of swordfish when using wire leaders (RR=0.58; 95% CIs: 0.22; 1.53), this study has a low sample size, information on at-haulback fate is only available for 22 individuals (15 retained on nylon leaders and 7 on wire leaders) of these 9 were dead at-haulback (5 when using nylon leaders and 4 when using wire leaders). Experiment 51 RR is of 0.95 (95% CIs:0.76; 1.18).

Bluefin tuna – Retention rates

For the comparisons between leader type, there were no experiments that reported on retention of bluefin tuna for surface longlines.

Bluefin tuna – At-haulback mortality

For the comparisons between leader type, there were no experiments that reported on at-haulback mortality of bluefin tuna for surface longlines.

Yellowfin tuna – Retention rates

For yellowfin tuna retention when all experiments are used for comparing nylon and wire leaders the RR is 0.34 (95% CIs: 0.02; 5.78), which means that although the point estimate indicates a reduction in retention of yellowfin tuna when using nylon leader, this reduction not significant (Figure VII.93). In this analysis the overall heterogeneity is 86% and fails 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 VII.94. Experiment 51 is identified in several of the diagnostics as a possible outlier, however in this case as only three experiments are available, removing the possible outliers would hinder the meta-analysis as only two studies would remain.

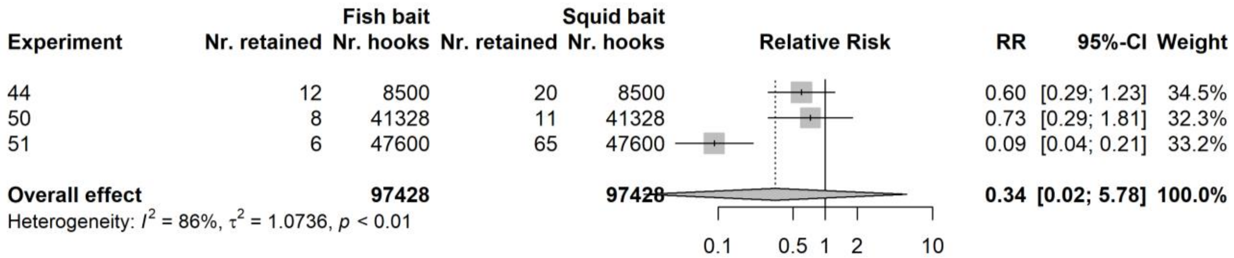


Figure VII.93.Forest plot of the random effects meta-analysis performed for the retention rates of yellowfin tuna with wire vs. nylon leader (Note: Nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

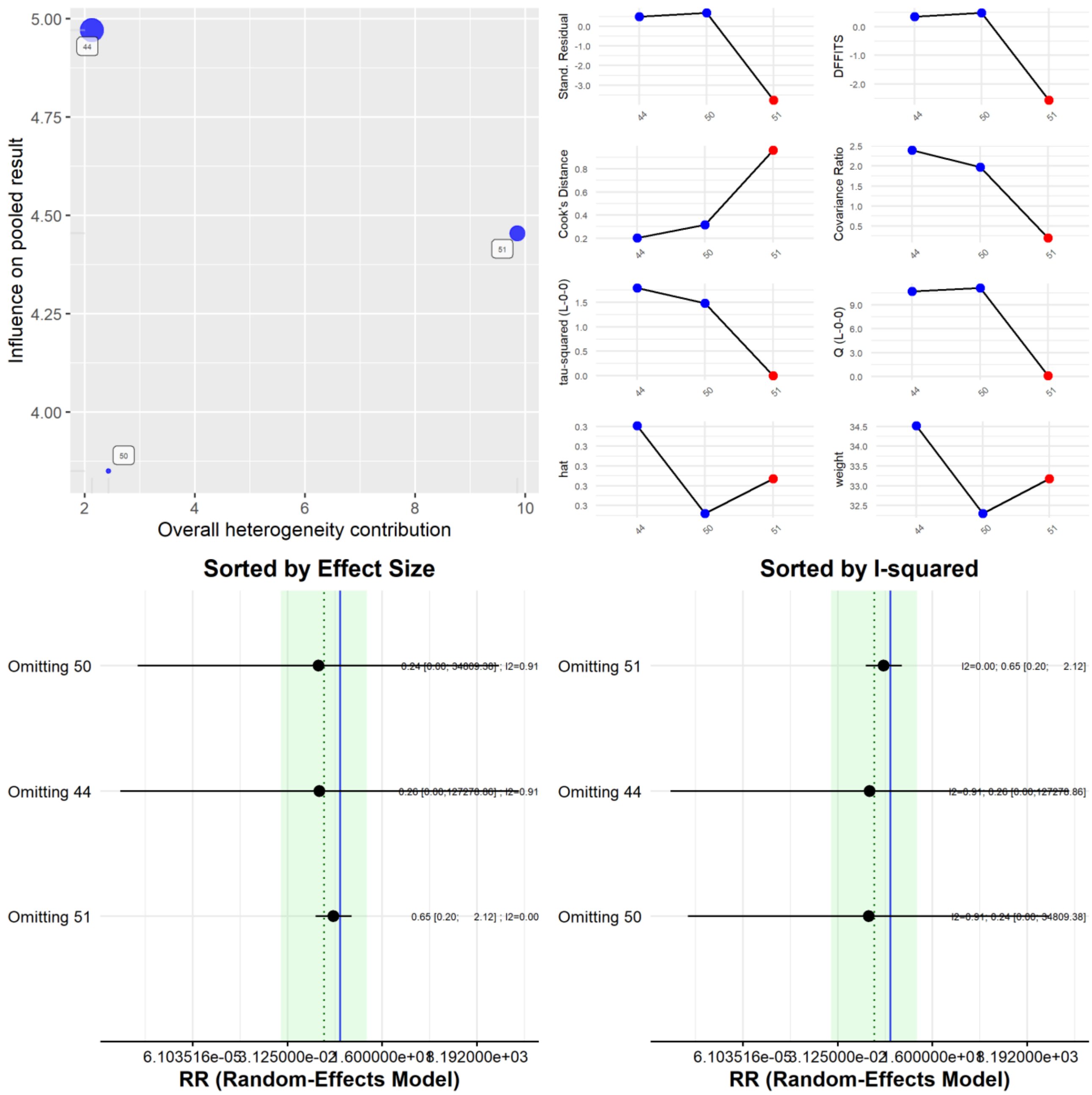


Figure VII.94. Influence analysis for validating the meta-analysis performed for the retention rates of yellowfin tuna with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Yellowfin tuna – At-haulback mortality

With regard to the effect of leader type on the at-haulback mortality of yellowfin tuna, only two experiments were available (experiment 50 and 51), so the meta-analysis was not conducted. One experiment indicates there is a non-significant decrease in at-haulback mortality of yellowfin tuna when changing to wire leaders while the other indicates there is a non-significant increase. For experiment 50, 2 individuals were dead at-haulback (out of 8 retained) when using wire leaders, for nylon leaders 4 individuals were dead at-haulback out of 9 retained (RR=0.56; 95% CIs: 0.14; 2.29). In experiment 51 the RR is 1.14 (95% CIs: 0.83; 1.56), 22 individuals were dead at-haulback (out of 33 retained) when using wire leaders, for nylon leaders 38 individuals were dead at-haulback out of 65 retained.

Albacore tuna– Retention rates

For albacore retention when all experiments are used for comparing nylon and wire leaders the RR is 0.44 (95% CIs: 0.05; 5.41), which means that although the point estimate indicates a reduction in retention of albacore when using nylon leader this reduction is not significant as indicated by the confidence intervals (figure VII.95). In this analysis there is no overall heterogeneity (0%) and the analysis 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 VII.96. None of the experiments are identified as potential outliers.

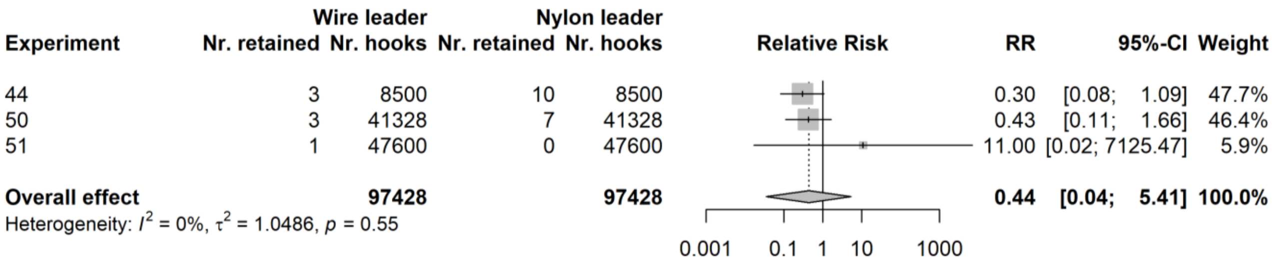


Figure VII.95. Forest plot of the random effects meta-analysis performed for the retention rates of albacore with wire vs. nylon leader (Note: Nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

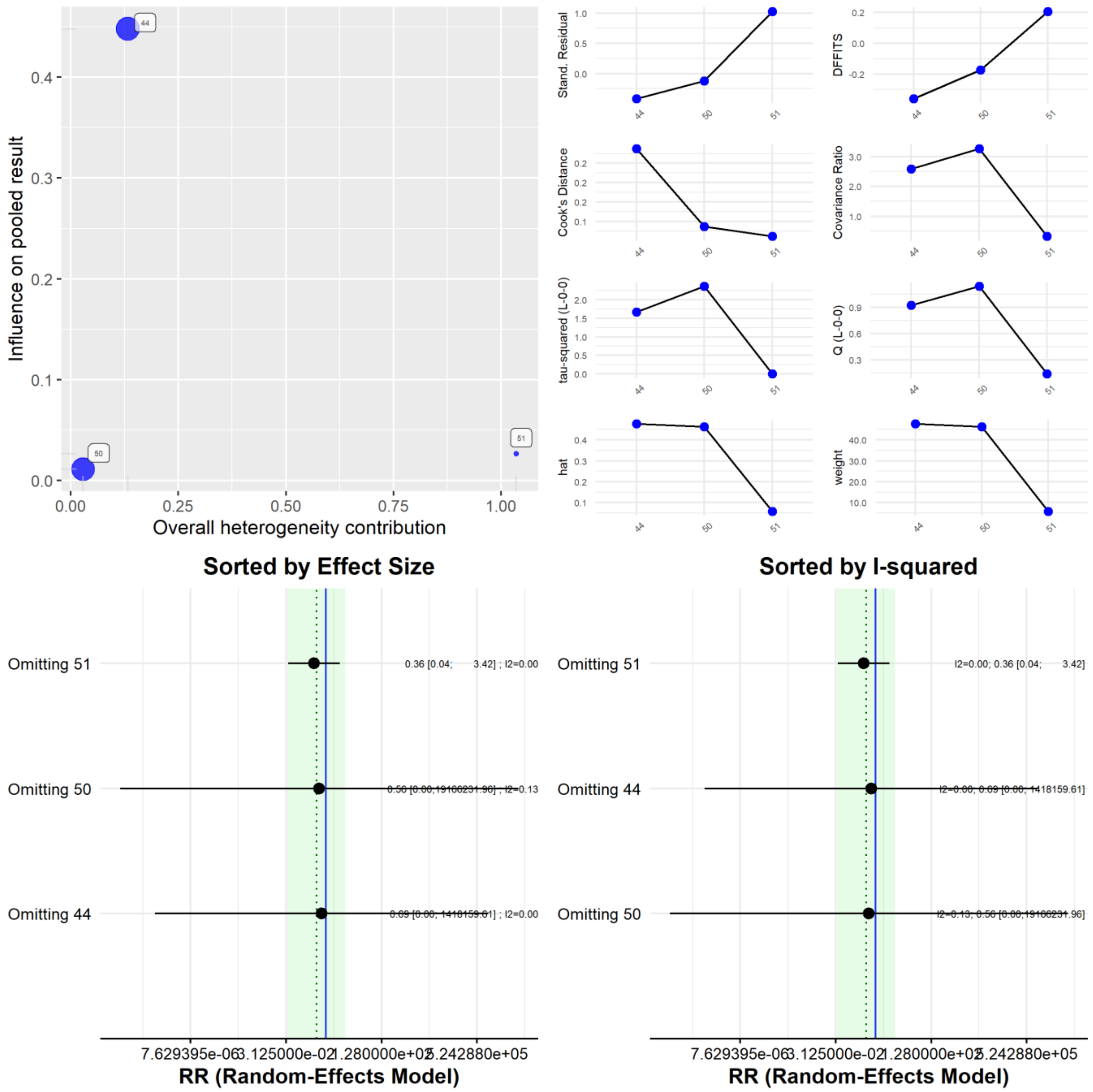


Figure VII.96. Influence analysis for validating the meta-analysis performed for the retention rates of albacore with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Albacore tuna- At-haulback mortality

With regards to the effect of leader type on the at-haulback mortality of albacore, only two experiments were available (experiment 45 and 50), so the meta-analysis was not conducted. For experiment 45, 3 individuals were dead at-haulback (out of 30 retained) when using wire leaders, for nylon leaders 9 individuals were dead at-haulback out of 100 retained (RR=1.09;

95% CIs: 0.31; 3.80). In experiment 50 the RR is 0.58 (95% CIs: 0.10; 3.21), 1 individual was dead at-haulback (out of 3 retained) when using wire leaders, for nylon leaders 4 individuals were dead at-haulback out of 7 retained.

Effects of leader type on desirable bycatch species

Blue shark – Retention rates

In the case of blue shark, changing from nylon leader to wire leader would lead to an increase in retention, with 95% confidence intervals varying between increases of 11% and 93% (Figure VII.97). In this specific analysis the overall heterogeneity (I^2) is 54% 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 VII.98. As in some of the previous cases, some possible outliers were identified (study 50 and 51); however, as only 3 studies are available, those possible outliers were not excluded from the analysis as it would hinder the meta-analysis.

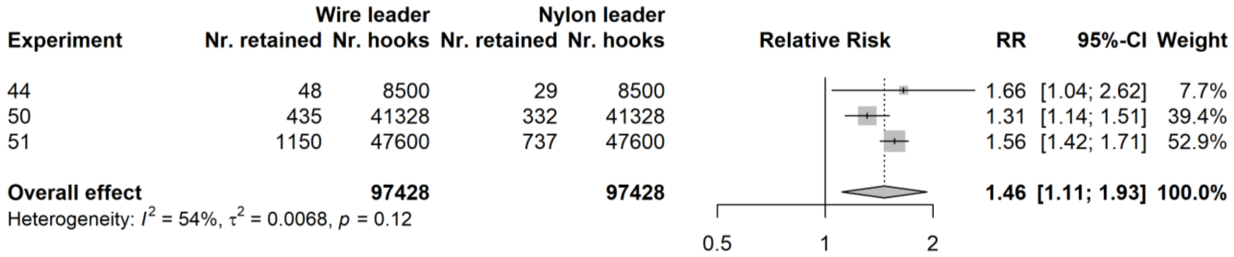


Figure VII.97.Forest plot of the random effects meta-analysis performed for the retention rates of blue shark with wire vs. nylon leader (Note: nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

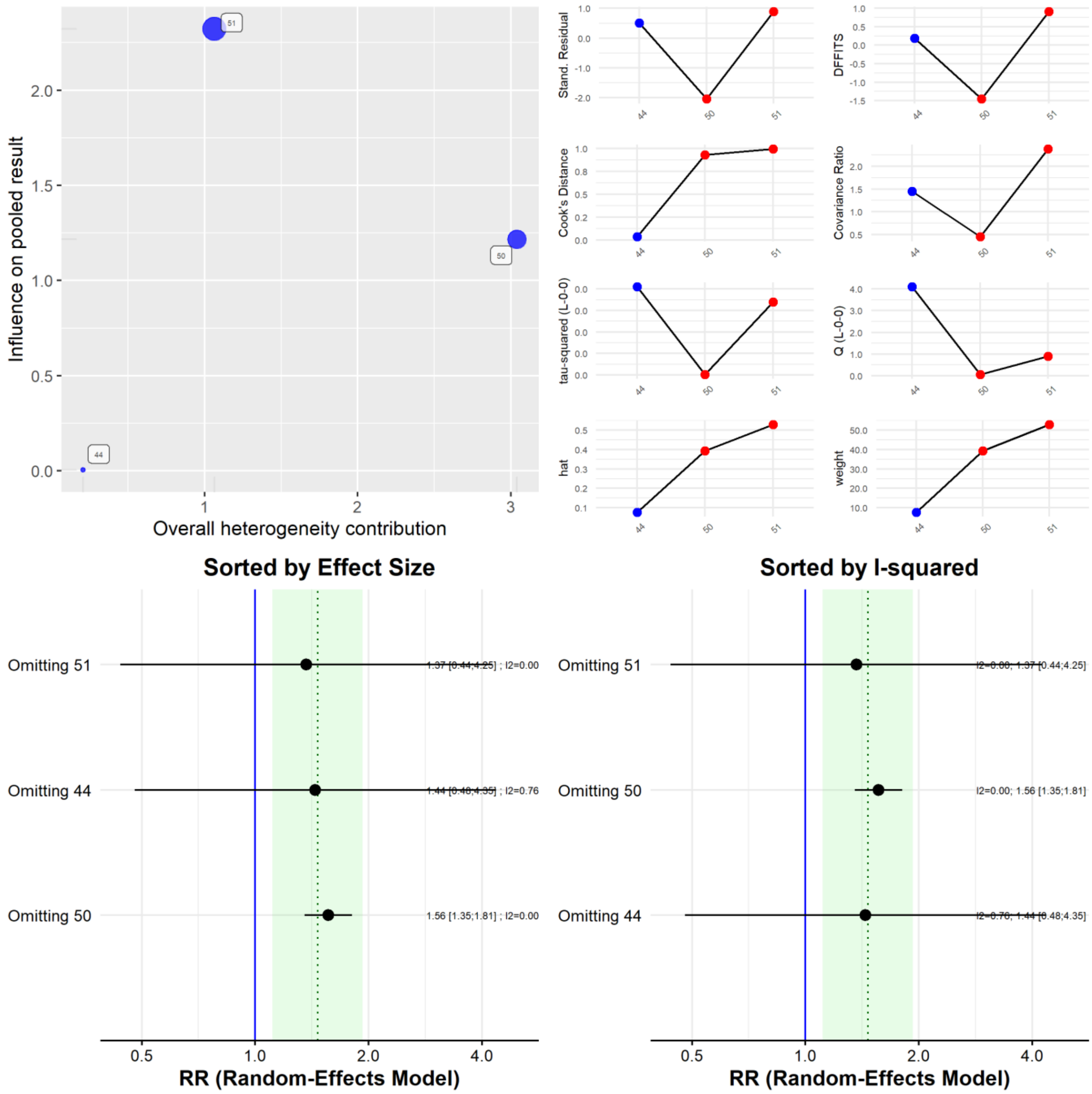


Figure VII.98. Influence analysis for validating the meta-analysis performed for the retention rates of blue shark with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Blue shark – At-haulback mortality

With regard to the at-haulback mortality of blue shark, the random effects model considering all experiments is shown in Figure VII.99. Changing from nylon leader to wire leader would lead to a decrease in retention of 12%, but this is not significant with the 95% confidence intervals varying between decreases of 34% and increases of 17% (RR=0.88; 95%

CIs:0.66; 1.17). In this specific analysis there is no overall heterogeneity (I^2=0%) with the meta-analysis validated by the statistical assumption of homogeneity (p-value>0.05). The influence analysis is represented in Figure VII.100. For this case no particular study 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.

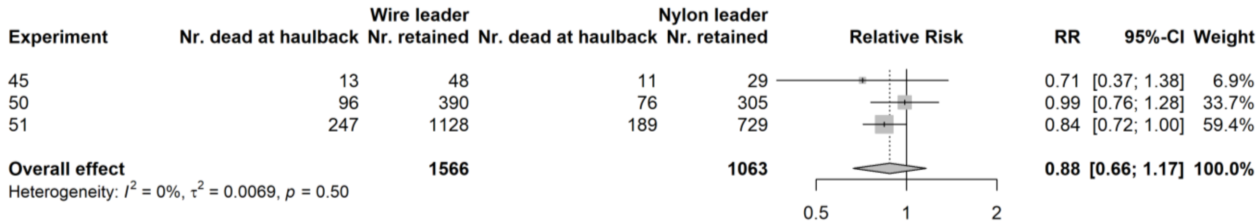


Figure VII.99.Forest plot of the random effects meta-analysis performed for the at-haulback mortality of blue shark with wire vs. nylon leader (Note: nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates at-haulback mortality is higher with wire leaders).

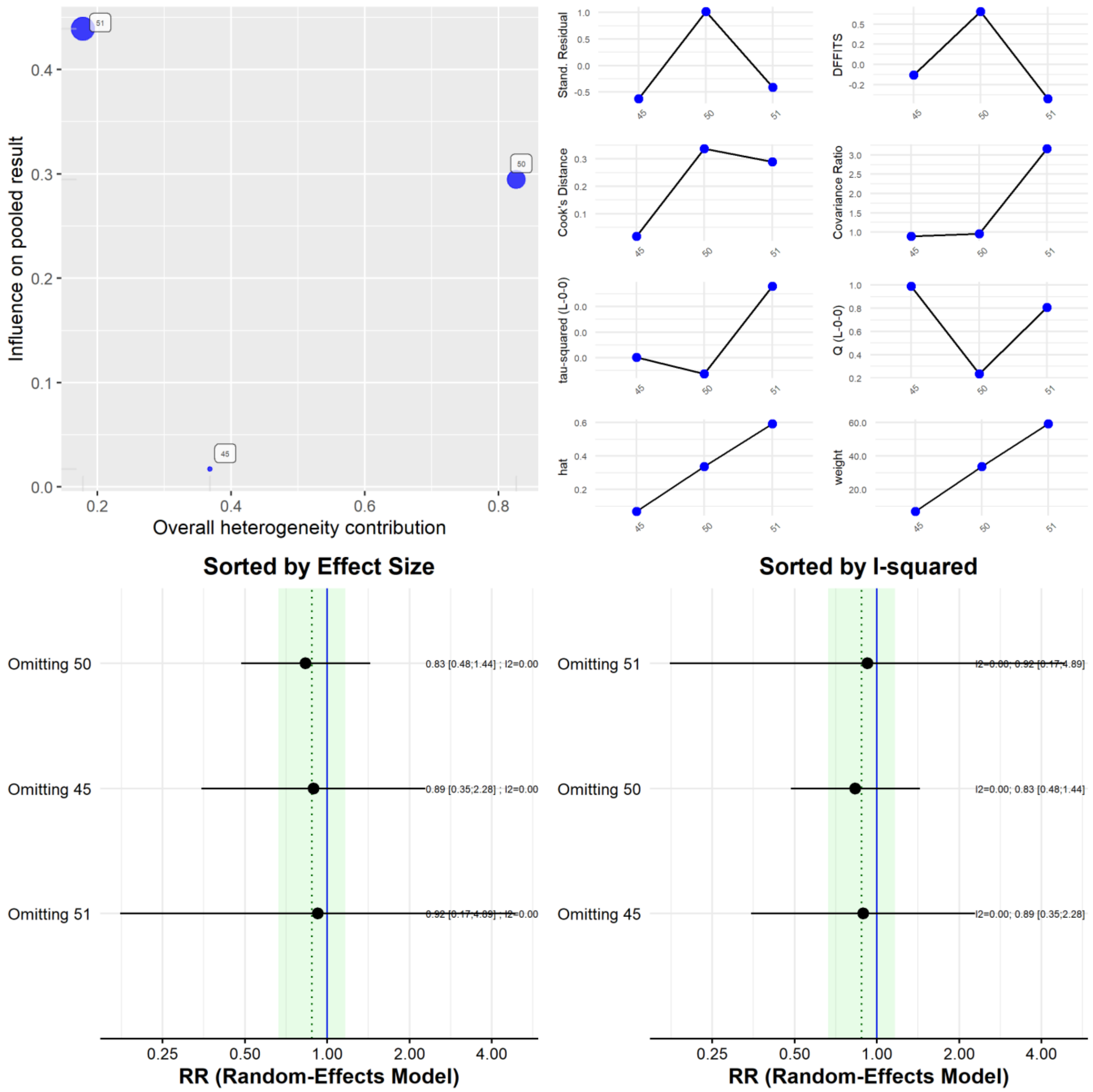


Figure VII.100. Influence analysis for validating the meta-analysis performed for the at-haulback mortality of blue shark with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Shortfin mako – Retention rates

In the specific case of shortfin mako, there were only two experiments (experiment 50 and 51) available that reported retention rates with each leader type. As such, it was not possible to perform the meta-analysis. Experiment 50 shows an increase in the at-haulback mortality of shortfin mako when using wire leaders (RR=1.17; 95% CIs: 0.54; 2.52). In experiment 51 using wire leaders also lead to an increase in retention (RR=4.67; 95% CIs: 1.34; 16.24).

Shortfin mako – At-haulback mortality

As mentioned above, there were only two experiments (experiments 50 and 51) available that reported mortalities for each leader type, which hinders the meta-analysis. Experiment 50 shows that 2 out of 10 individuals retained with wire leaders died and 1 out of 11 individuals retained with nylon leaders died (RR=2.20; 95% CIs: 0.23; 20.72). In experiment 51, 7 out of 13 individuals retained with wire leaders died and 2 out of 3 individuals retained with nylon leaders died (RR=0.81; 95% CIs: 0.31; 2.08).

Blue marlin – Retention rates

Figure VII.101 shows the random effects model for retention of blue marlin. In this case, when all data are used, the RR is 0.63 (95% CIs: 0.41; 0.97), meaning that the retention of blue marlin when using wire leaders is 37% lower than when using nylon leaders, and the 95% confidence intervals vary between reductions of 3% and 59%. In this specific analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.102. In this case, no outliers with significant leverage were identified and all experiments were used.

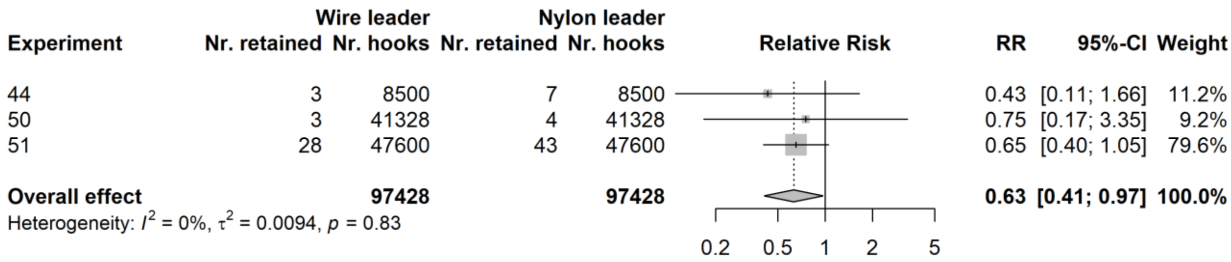


Figure VII.101. Forest plot of the random effects meta-analysis performed for the retention rates of blue marlin with wire vs. nylon leader (Note: nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

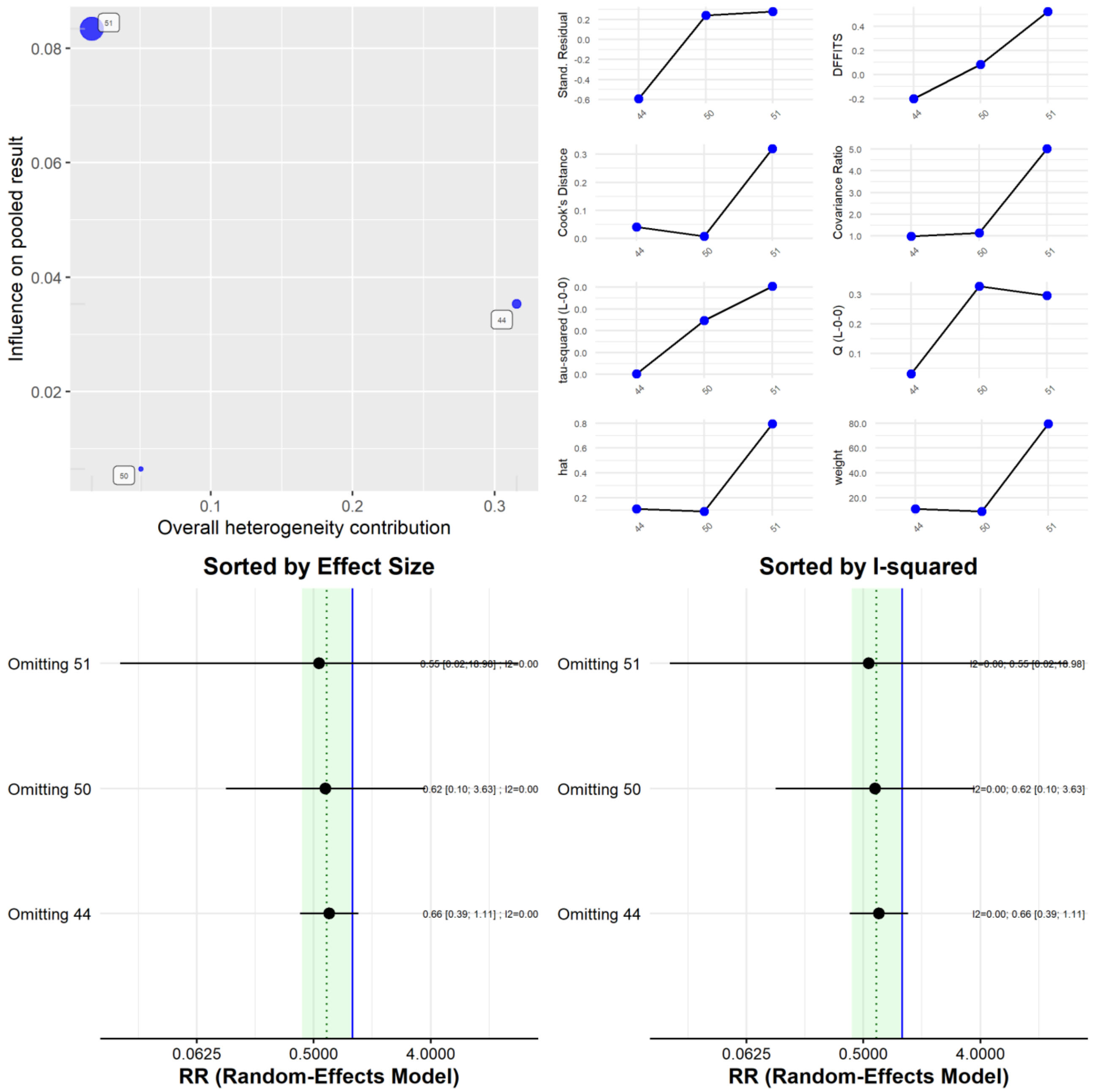


Figure VII.102. Influence analysis for validating the meta-analysis performed for the retention rates of blue marlin with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Blue marlin – At-haulback mortality

For blue marlin there were only two experiments (experiments 50 and 51) available that reported mortalities for each leader type, which hinders the meta-analysis. Experiment 50 shows that 2 out of 3 individuals retained with wire leaders died and 1 out of 3 individuals retained with nylon leaders died (RR=2.00; 95% CIs: 0.33; 11.97). In experiment 51, 18 out of

28 individuals retained with wire leaders died and 35 out of 43 individuals retained with nylon leaders died (RR=0.79; 95% CIs: 0.58; 1.08).

Atlantic sailfish – Retention rates

With regard to the effect of leader type on the retention of Atlantic sailfish, only two experiments were available (experiment 50 and 51), so the meta-analysis was not conducted. Both experiments indicate there is a non-significant increase in retention of Atlantic sailfish when changing to wire leaders. For experiment 44 the RR is calculated at 1.25, with 95% confidence intervals varying between a decrease in retention of 51% and an increase in retention of 3.17 times with wire leaders. For experiment 51 the RR is calculated at 1.10, with 95% confidence intervals varying between a decrease in retention of 33% and an increase in retention of 78% with wire leaders.

Atlantic sailfish – At-haulback mortality

With regard to the effect of leader type on the at-haulback mortality of Atlantic sailfish, there was only one experiment (experiment 51) with data available for surface longlines, and so the meta-analysis was not conducted. In this experiment 28 out of 33 individuals retained with wire leaders died and 20 out of 28 individuals retained with nylon leaders died (RR=1.19; 95% CIs: 0.90; 1.56), meaning that the effects are not significant.

White marlin – Retention rates

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on retention of white marlin in surface longlines. In this experiment, 49 individuals were retained in 47,600 hooks with wire leaders and 45 individuals were retained in 47,600 hooks with nylon leaders (RR=1.09; CIs: 0.73; 1.63), meaning that there are no significant effects.

White marlin – At-haulback mortality

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on at-haulback mortality of white marlin in surface longlines. In this experiment, 40 out of 49 individuals retained with wire leaders died and 40 out of 45 individuals retained with nylon leaders died (RR=0.92; 95% CIs: 0.78; 1.09), again meaning that the effects were not significant.

Effects of leader type on unwanted bycatch species

Loggerhead sea turtle – Retention rates

For the comparisons between leader type, there were only two experiments that reported on retention of loggerhead sea turtle for surface longlines and the sample sizes were very small. As such, it was not possible to conduct the meta-analysis. Experiment 50 reported 1 specimen retained in 41,328 hooks with wire leaders and none in 41,328 hooks with nylon leaders (RR= 11.00; 95% CIs: 0.02; 7125.46). Experiment 51 reported 4 specimens retained in 47,600 hooks with nylon leaders and 1 specimen retained in 47,600 hooks with wire leaders (RR= 0.25; 95% CIs: 0.03; 2.24).

Loggerhead sea turtle – At-haulback mortality

For the comparisons between leader types there were only two experiments (experiments 50 and 51) that reported on at-haulback mortality of loggerhead sea turtle for surface longlines and therefore the meta-analysis was not conducted. In both experiments all turtles retained suffered no at-haulback mortality both with wire and nylon leaders.

Leatherback sea turtle – Retention rates

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on retention of leatherback sea turtles for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 51 reported 16 specimens retained in 47,600 hooks with nylon leaders and 19 specimens retained also with 47,600 hooks with wire leaders (RR= 1.19; 95% CIs: 0.61; 2.31).

Leatherback sea turtle – At-haulback mortality

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on at-haulback mortality of loggerhead sea turtle for surface longlines and therefore the meta-analysis was not conducted. In this experiment, 1 out of 16 leatherback sea turtles retained with nylon leaders died. The 19 individuals retained with wire leaders were alive at the time of haulback (RR= 0.08; 95% CIs: 0; 47.98).

Olive ridley sea turtle – Retention rates

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on retention of olive ridley sea turtle for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 51 reported 41 specimens retained in 47,600 hooks with nylon leaders and 26 specimens retained also in 47,600 hooks with wire leaders (RR= 0.63; 95% CIs: 0.39; 1.04).

Olive ridley sea turtle – At-haulback mortality

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on at-haulback mortality of olive ridley sea turtle for surface longlines and for that reason it was not possible to conduct the meta-analysis. In this experiment, 9 out of 41 olive ridley sea turtles retained with nylon leaders died, and 1 individual out of 26 retained with wire leaders died (RR= 0.18; 95% CIs: 0.02; 1.30)

Kemp's ridley sea turtle – Retention rates

For the comparisons between leader type, there were no experiments that reported on retention of Kemp's ridley sea turtle for surface longlines.

Kemp's ridley sea turtle – At-haulback mortality

For the comparisons between leader type, there were no experiments that reported on at-haulback mortality of Kemp's ridley sea turtle for surface longlines.

Green sea turtle – Retention rates

For the comparisons between leader type, there were no experiments that reported on retention of green sea turtle for surface longlines.

Green sea turtle – At-haulback mortality

For the comparisons between leader type, there were no experiments that reported on at-haulback mortality of green sea turtle for surface longlines.

Oceanic whitetip – Retention rates

For the comparisons between leader type, there were only two experiments (experiments 50 and 51) that reported on retention of oceanic whitetip for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 50 reported 1 specimen retained in 41328 hooks with nylon leaders and 7 specimens retained in 41328 hooks with wire leaders (RR= 7.00; 95% CIs: 0.86; 56.89). Experiment 51 reported 33 specimens retained in 47,600 hooks with nylon leaders and 15 specimens retained also in 47,600 hooks with wire leaders (RR= 0.45; 95% CIs: 0.25; 0.84).

Oceanic whitetip – At-haulback mortality

For the comparisons between leader type, there were only two experiments (experiments 50 and 51) that reported on at-haulback mortality of oceanic whitetip for surface longlines and for that reason it was not possible to conduct the meta-analysis. In experiment 50, there was only one specimen retained with nylon leaders and it survived. Regarding wire leaders, 2 individuals out of 7 retained with wire leaders died (RR= 3.25; 95% CIs: 0.01; 1335.77). In experiment 51, 14 individuals out of 33 retained with nylon leaders died, and 7 individuals out of 15 retained with wire leaders died (RR= 1.10; 95% CIs: 0.56; 2.15).

Porbeagle – Retention rates

For the comparisons between leader type, there was only one experiment (experiment 50) that reported on retention of porbeagle for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 50 reported no retentions in 41,328 hooks with nylon leaders and 2 specimens retained also in 41,328 hooks with wire leaders (RR= 21.00; 95% CIs: 0.04; 11947.92).

Porbeagle – At-haulback mortality

For the comparisons between leader type, there were no experiments that reported on at-haulback mortality of porbeagle for surface longlines.

Silky shark – Retention rates

Figure VII.103 shows the random effects model for retention of silky shark. When all data are used, the RR is 1.18 (95% CIs: 0.20; 6.95), meaning that the retention of silky shark when using wire leaders is 18% higher than when using nylon leaders. However, this is not significant as the 95% confidence intervals vary between a reduction of 80% and an increase of 6.95 times. In this analysis, the overall heterogeneity between studies is I^2=50% and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.104. In this case, experiment 52 was identified as an outlier with significant leverage on the pooled results. However, since there were only three experiments available (including experiment 52), the experiment was kept in order to perform the meta-analysis.

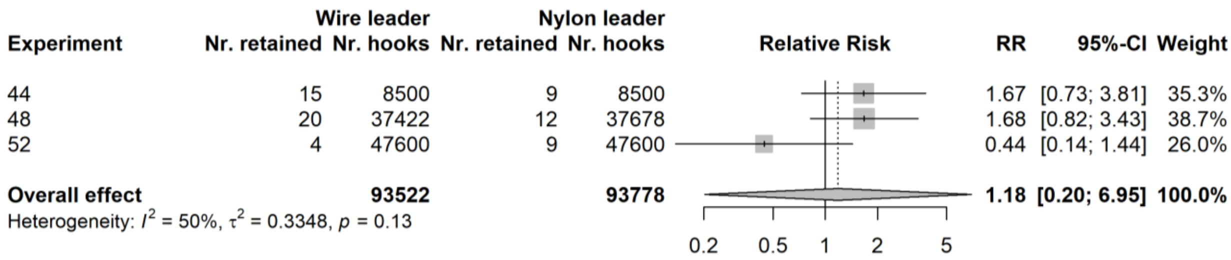


Figure VII.103. Forest plot of the random effects meta-analysis performed for the retention rates of silky shark with wire vs. nylon leader (Note: nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

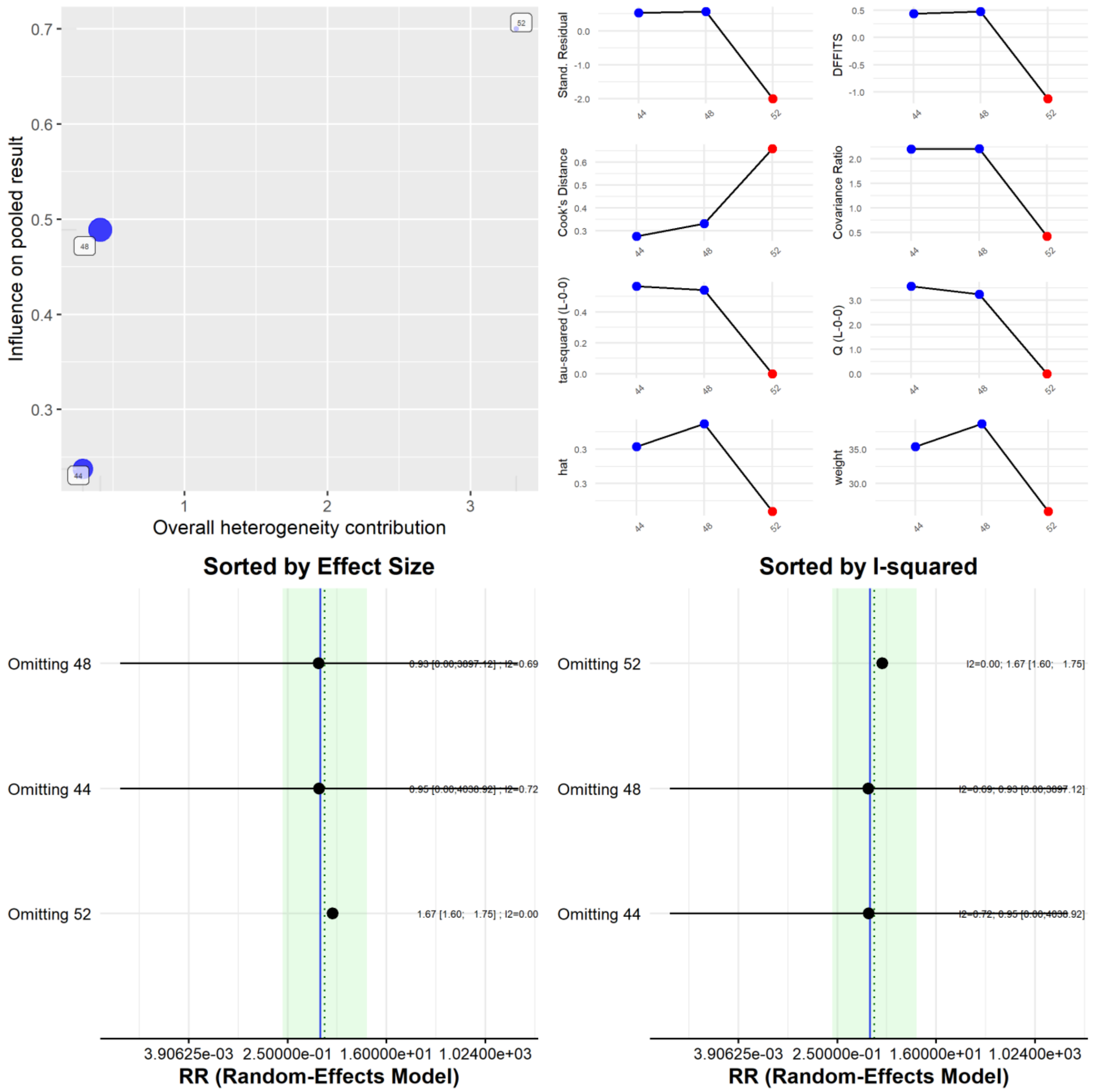


Figure VII.104. Influence analysis for validating the meta-analysis performed for the retention rates of silky shark with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Silky shark – At-haulback mortality

For the comparisons between leader type, there were only two experiments (experiments 45 and 51) that reported on at-haulback mortality of silky shark for surface longlines and for that reason it was not possible to conduct the meta-analysis. In experiment 45, 9 specimens out of 9 retained with nylon leaders died, and 9 individuals out of 15 retained with wire leaders died

(RR=0.60; 95% CIs: 0.40; 0.91). In experiment 51, 7 individuals out of 9 retained with nylon leaders died, and 4 individuals out of 4 retained with wire leaders died (RR= 1.28; 95% CIs: 0.91; 1.81).

Bigeye thresher – Retention rates

For the comparisons between leader type, there were only two experiments (experiments 50 and 51) that reported on retention of bigeye thresher for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 50 reported 9 specimens retained in 41,328 hooks with nylon leaders and 1 specimen retained in 41,328 hooks with wire leaders (RR= 0.11; 95% CIs: 0.01; 0.88). Experiment 51 reported 12 specimens retained in 47,600 hooks with nylon leaders and 9 specimens retained in 47,600 hooks with wire leaders (RR= 0.75; 95% CIs: 0.32; 1.78).

Bigeye thresher – At-haulback mortality

For the comparisons between leader type, there were only two experiments (experiments 50 and 51) that reported on at-haulback mortality of bigeye thresher for surface longlines and for that reason it was not possible to conduct the meta-analysis. In experiment 50, 5 out of 8 specimens retained with nylon leaders died, and 1 individual out of 1 retained with wire leaders died (RR= 1.59; 95% CIs: 0.94; 2.69). In experiment 51, 6 individuals out of 12 retained with nylon leaders died, and 3 individuals out of 9 retained with wire leaders died (RR=0.67; 95% CIs: 0.23; 1.97).

Longfin mako – Retention rates

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on retention of longfin mako for surface longlines. As such, it was not possible to conduct the meta-analysis. That was experiment 5a, that reported 5 specimens retained in 41,328 hooks with nylon leaders and 5 specimens retained in 41,328 hooks with wire leaders (RR=1.00; 95% CIs: 0.29; 3.45).

Longfin mako – At-haulback mortality

For the comparisons between leader type, there was only one experiment (experiment 51) that reported on at-haulback mortality of longfin mako for surface longlines and for that reason it was not possible to conduct the meta-analysis. In experiment 51, 5 out of 5 specimens retained with nylon leaders died, and 2 individuals out of 2 retained with wire leaders died (RR= 1.00; 95% CIs: 0.72; 1.39).

Crocodile shark – Retention rates

Figure VII.105 shows the random effects model for retention of crocodile shark. When all data are used, the RR is 0.73 (95% CIs: 0.16; 3.37), meaning that the retention of silky shark when using wire leaders is 27% lower than when using nylon leaders. However, 95% confidence intervals vary between a reduction of 84% and an increase of 3.37 times. In this analysis there is no overall heterogeneity between studies (I^2=0%) and the meta-analysis is validated by the statistical assumption of homogeneity (p-value>0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.106. In this case, no outliers with significant leverage on the pooled results were identified.

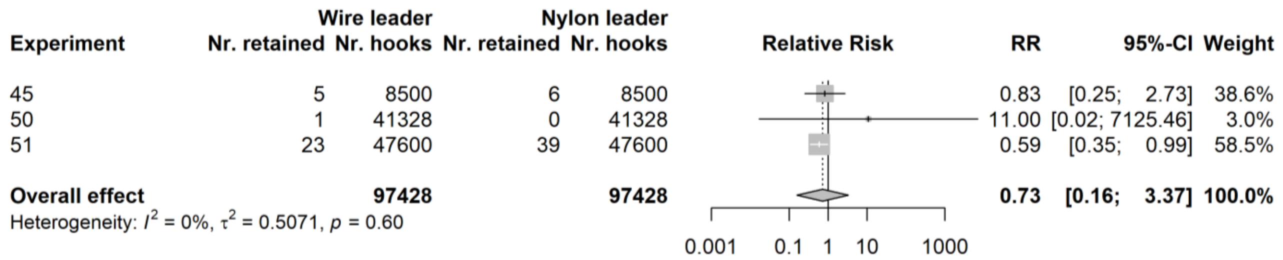


Figure VII.105. Forest plot of the random effects meta-analysis performed for the retention rates of the crocodile shark with wire vs. nylon leader (Note: nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

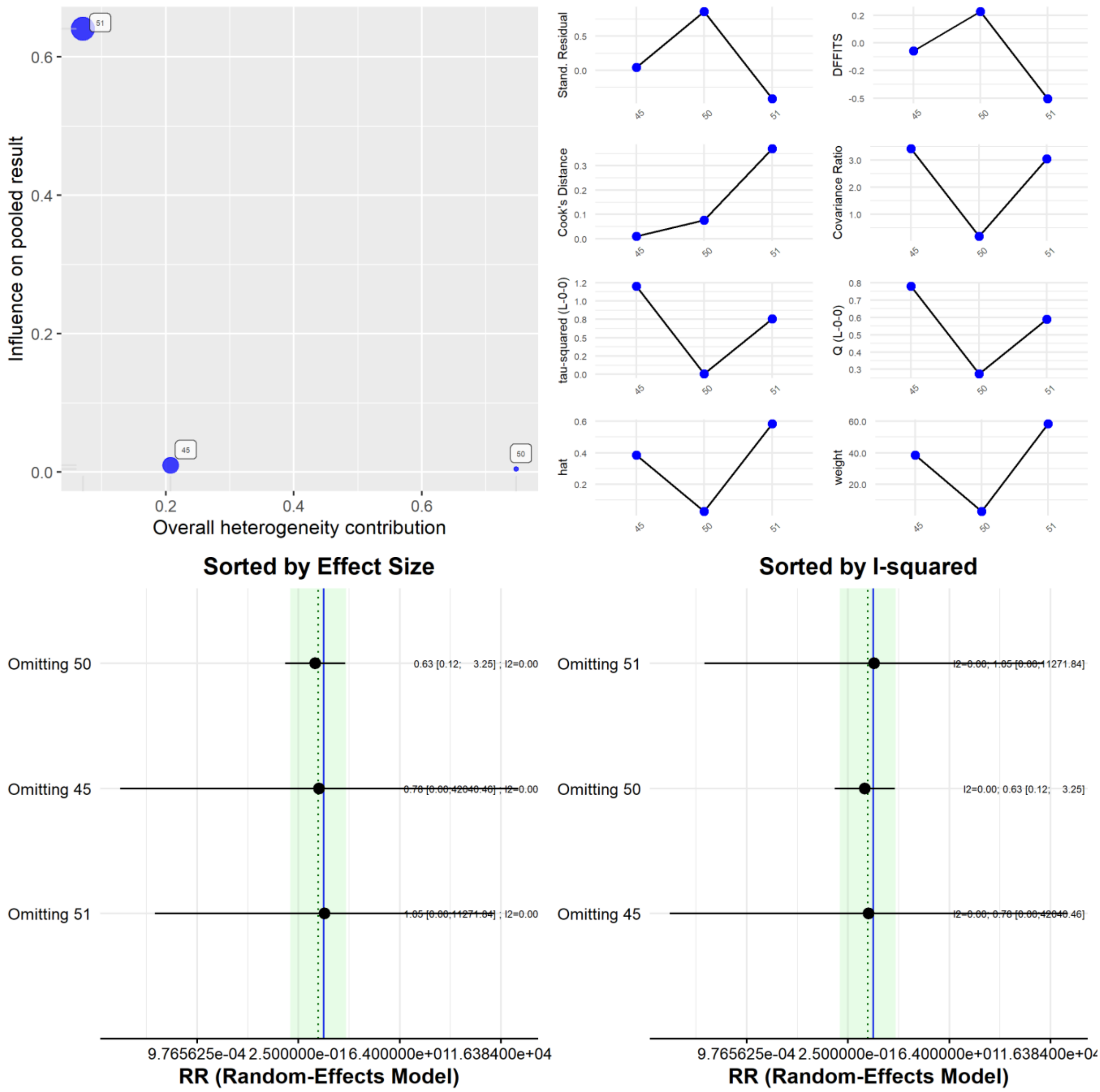


Figure VII.106. Influence analysis for validating the meta-analysis performed for the retention rates of the crocodile shark with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Crocodile shark – At-haulback mortality

For the comparisons between leader type, there were only two experiments (experiments 45 and 51) that reported on at-haulback mortality of crocodile shark for surface longlines and for that reason it was not possible to conduct the meta-analysis. In experiment 45, 5 out of 6 specimens retained with nylon leaders died, and 5 individuals out of 5 retained with wire leaders died (RR= 1.20; 95% CIs: 0.84; 1.71). In experiment 51, 7 individuals out of 39 retained with nylon leaders died, and 10 individuals out of 23 retained with wire leaders died (RR=2.42; 95% CIs: 1.07; 5.48).

Scalloped hammerhead – Retention rates

For the comparisons between leader type, there were no experiments that reported on retention of scalloped hammerhead for surface longlines.

Scalloped hammerhead – At-haulback mortality

For the comparisons between leader type, there were no experiments that reported on at-haulback mortality of scalloped hammerhead for surface longlines.

Smooth hammerhead – Retention rates

For the comparisons between leader type, there were only two experiments (experiments 50 and 51) that reported on retention of smooth hammerhead for surface longlines. As such, it was not possible to conduct the meta-analysis. Experiment 50 reported no retentions in 41,328 hooks with nylon leaders and 3 specimens retained in 41,328 hooks with wire leaders (RR= 31.00; 95% CIs: 0.06; 16833.00). Experiment 51 reported 2 specimens retained in 47,600 hooks with nylon leaders and 6 specimens retained in 47,600 hooks with wire leaders (RR= 3.00; 95% CIs: 0.61; 14.86).

Smooth hammerhead – At-haulback mortality

For the comparisons between leader type, there were only two experiments (experiments 50 and 51) that reported on at-haulback mortality of smooth hammerhead for surface longlines and for that reason it was not possible to conduct the meta-analysis. Experiment 50 reported no retention with nylon leaders, and 3 individuals out of 3 retained with wire leaders died. In experiment 51, 2 individuals out of 2 retained with nylon leaders died, and 5 individuals out of 6 retained with wire leaders died (RR=0.84; 95% CIs: 0.59; 1.19).

Pelagic stingray – Retention rates

Figure VII.107 shows the random effects model for retention of pelagic stingray. When all data are used, the RR is 0.38 (95% CIs: 0.01; 13.53), meaning that the retention of pelagic stingray when using wire leaders is 62% lower than when using nylon leaders. However, 95%

confidence intervals vary between a reduction of 99% and an increase of 1353% in retention with wire leaders. In this specific analysis, there overall heterogeneity between studies is I^2=92% and fails the statistical assumption of homogeneity (p-value<0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VII.108. In this case, experiment 51 was identified as an outlier with significant leverage on the pooled results. However, since there were only three experiments available (including experiment 51), the experiment was kept in order to perform the meta-analysis.

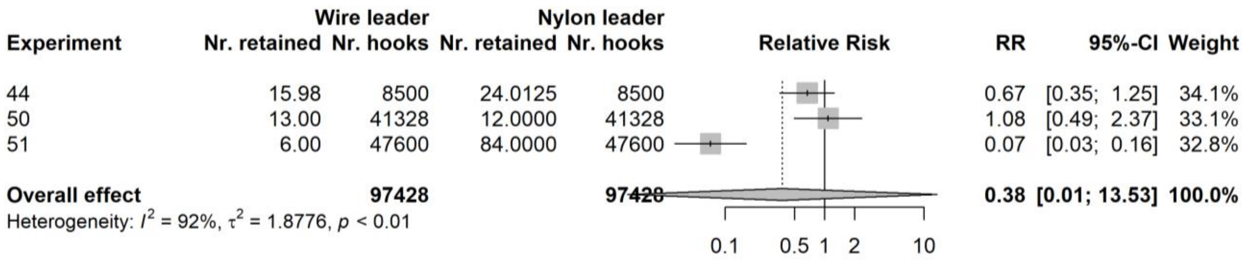


Figure VII.107. Forest plot of the random effects meta-analysis performed for the retention rates of the pelagic stingray with wire vs. nylon leader (Note: nylon leaders are considered the control while wire leaders are considered the experimental leader; a relative risk (RR) >1 indicates retention is higher with wire leaders).

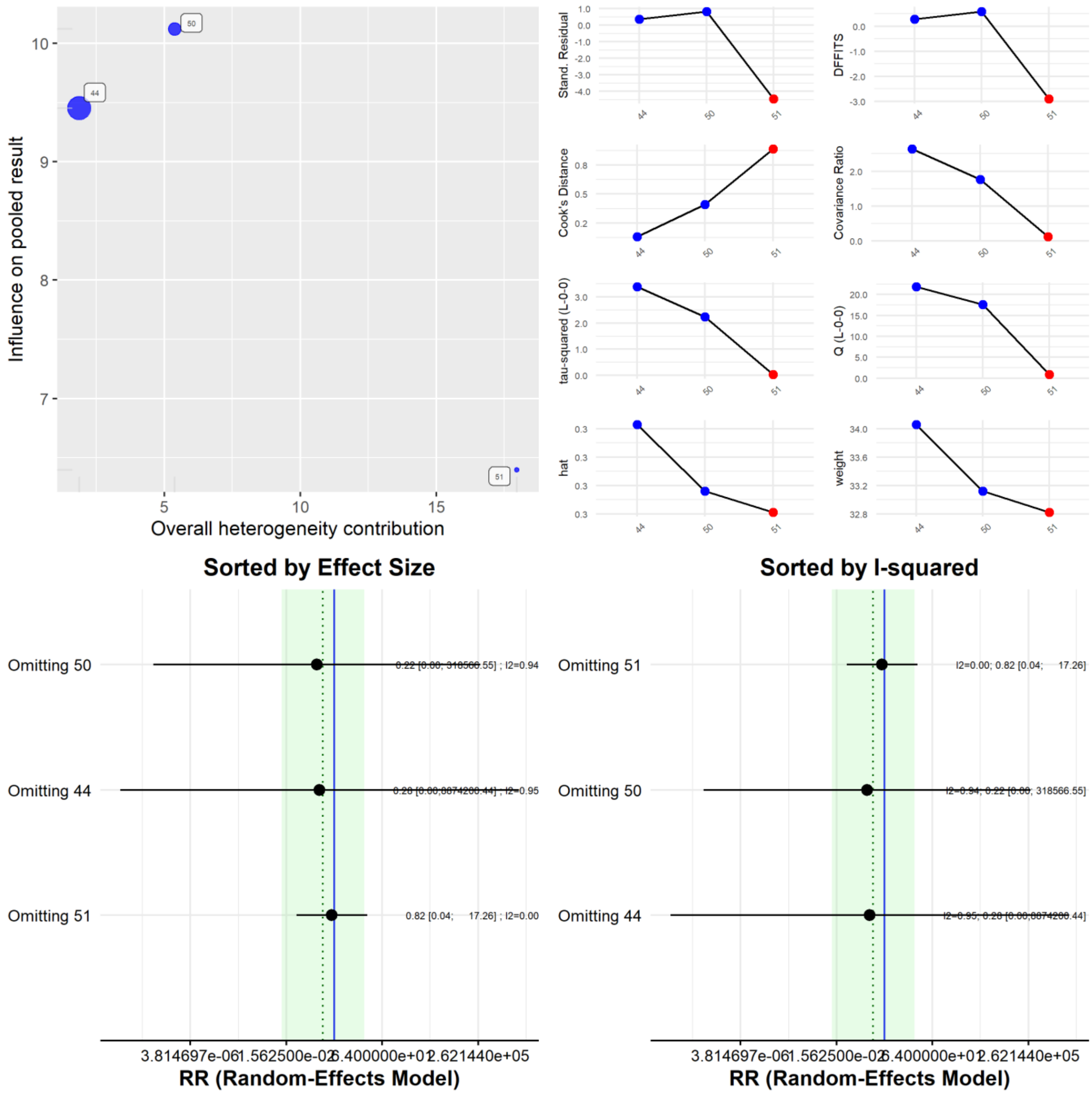


Figure VII.108. Influence analysis for validating the meta-analysis performed for the retention rates of the pelagic stingray with wire vs. nylon leader. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Pelagic stingray – At-haulback mortality

For the comparisons between leader type, there was only one experiment (experiment 45) that reported on at-haulback mortality of pelagic stingray for surface longlines and for that reason it was not possible to conduct the meta-analysis. In experiment 45, 1 specimen out of

24 retained with nylon leaders died, and 1 individual out of 16 retained with wire leaders died (RR=1.38; 95% CIs: 0.09; 21.2)

APPENDIX VIII: SPECIES-SPECIFIC ANALYSIS FOR TASK 4 – EFFECTS OF HOOK DEPTH

In this Appendix we provide the detailed species-specific results for Task 4 specifically for the meta-analysis for retention rates and at-haulback mortality for the effects of changing hook types in deep setting longlines. As in previous appendices, here we also focus on the 3 species components, namely target species, desirable bycatch, and unwanted bycatch.

Deep setting longlines – changing J to circle hooks

Yellowfin tuna – retention rates

In the case of the yellowfin tuna, for the effects of changing hook type (from J hook to circle hook) on the retention rates, the RR is 0.69 (95% CIs: 0.08; 5.93) (Figure VIII.1), suggesting that there is no significant effect of changing hook type. In this 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 VIII.2. 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, study 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.

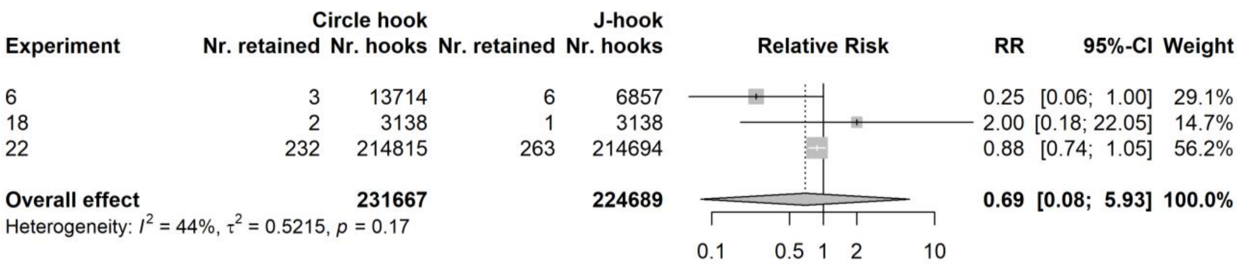


Figure VIII.1. Forest plot of the random effects meta-analysis performed for the retention rates of yellowfin tuna for the deep-set longlines with circle vs. J hooks (Note: J hooks are considered the control while circle hooks are considered the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

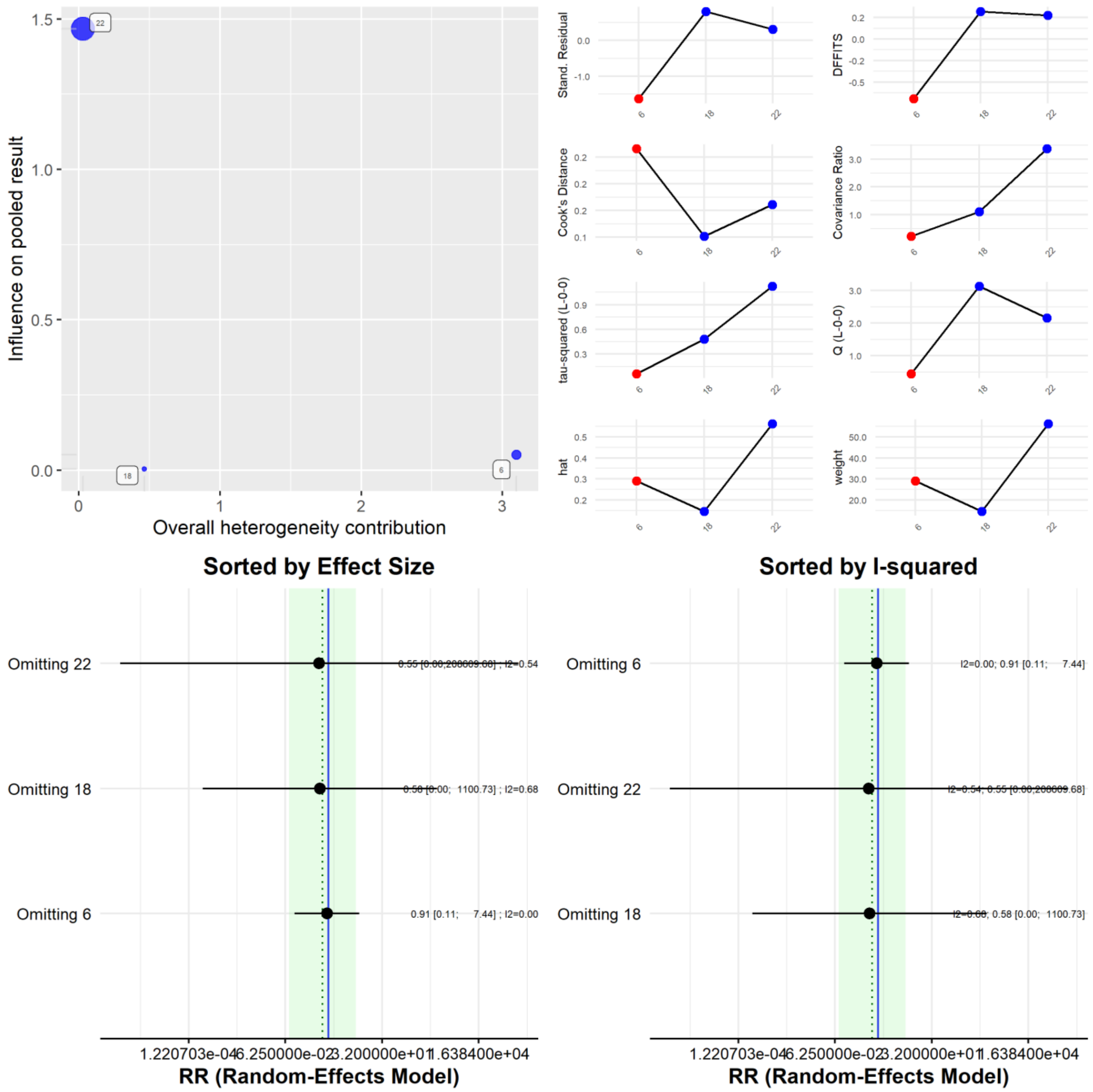
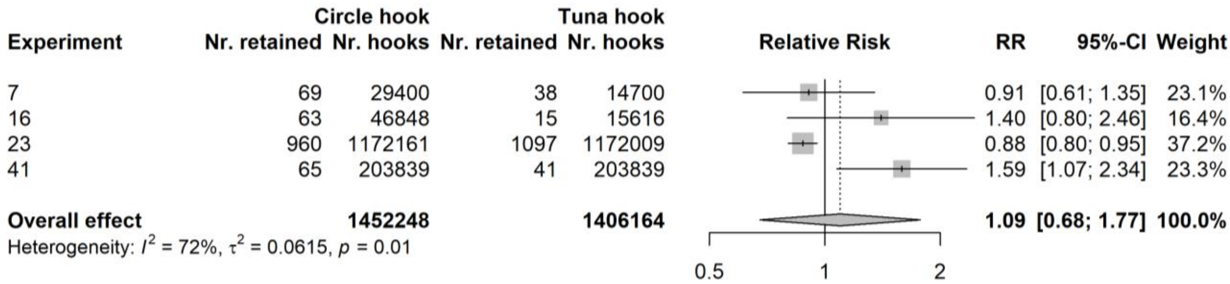


Figure VIII.2. Influence analysis for validating the meta-analysis performed for the retention rates of yellowfin tuna with circle vs. J hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – Leave one-out method sorted by effect size (left) and I^2 (right).

Deep setting longlines – changing tuna to circle hooks

Yellowfin tuna – Retention rates

In the case of yellowfin tuna retention in deep-setting longlines when changing from tuna to circle hooks, when all experiments are used the RR is 1.09 (95% CIs: 0.68; 1.77), which means that changing from tuna to circle hooks does not significantly influence the retention of yellowfin tuna (Figure VIII.3). In this specific analysis the overall heterogeneity (I^2) is relatively high (72%) and fails 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 VIII.4. Experiments 23 and 41 are identified in several of the diagnostics as possible outliers, however in this case as only four experiments are available, removing those two possible outliers would hinder the meta-analysis as only two studies would remain.



Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	Tuna hook Nr. retained	Tuna hook Nr. hooks	RR	95%-CI	Weight
7	69	29400	38	14700	0.91	[0.61; 1.35]	23.1%
16	63	46848	15	15616	1.40	[0.80; 2.46]	16.4%
23	960	1172161	1097	1172009	0.88	[0.80; 0.95]	37.2%
41	65	203839	41	203839	1.59	[1.07; 2.34]	23.3%
Overall effect		**1452248**		**1406164**	**1.09**	**[0.68; 1.77]**	**100.0%**

Heterogeneity: $I^2 = 72\%$, $\tau^2 = 0.0615$, $p = 0.01$

Figure VIII.3. Forest plot of the random effects meta-analysis performed for the retention rates of yellowfin tuna for the deep-set longlines with tuna vs. circle hooks (Note: Tuna hooks are considered the control while circle hooks are considered the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

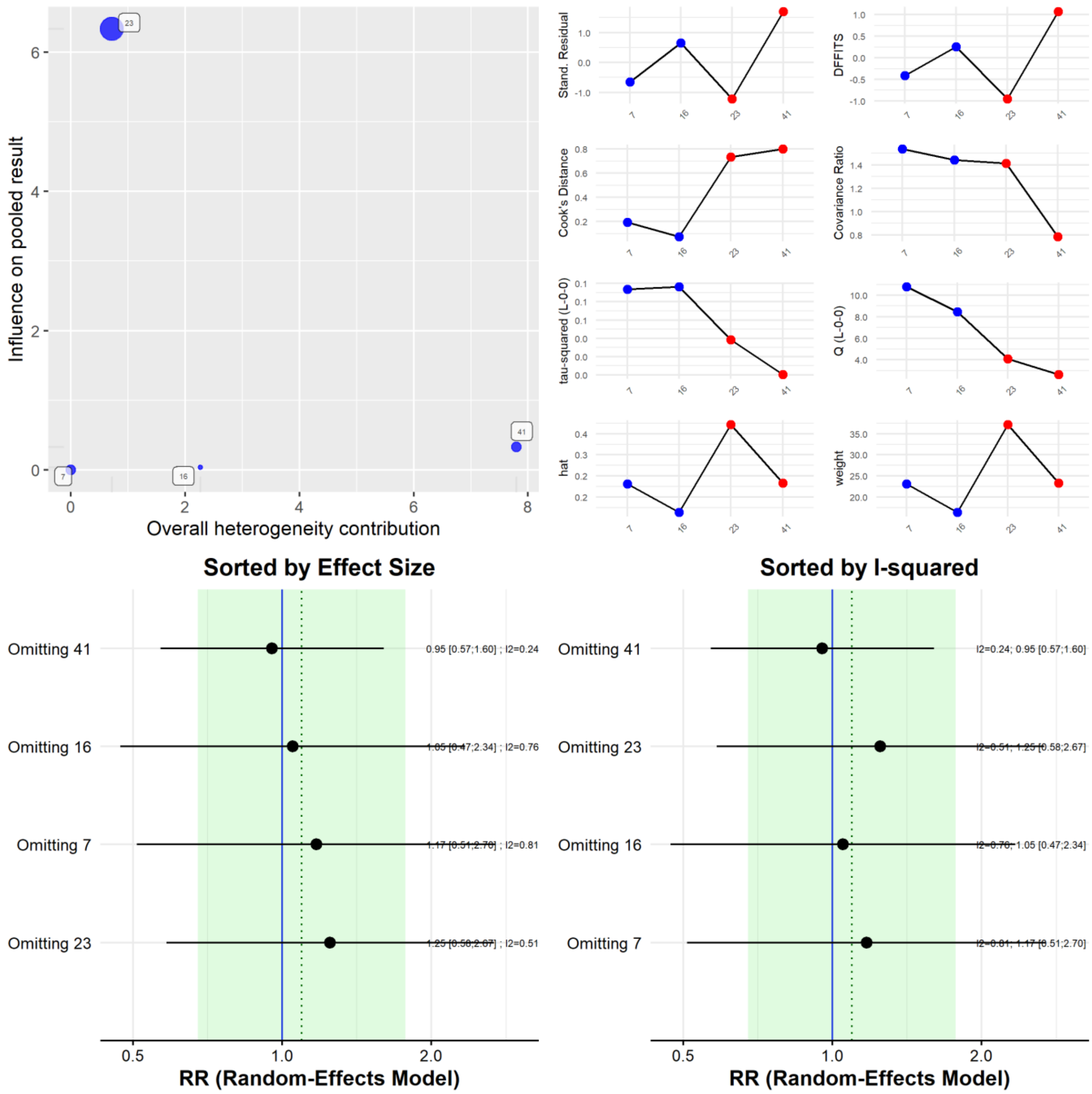


Figure VIII.4. Influence analysis for validating the meta-analysis performed for the retention rates of yellowfin tuna with tuna vs. circle hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Yellowfin tuna- At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of yellowfin tuna, only two experiments were available (experiments 23 and 41), so the meta-analysis was not conducted. For experiment 23, 396 individuals were dead at-haulback (out of 960 retained) when using circle hooks, for tuna hooks 509 individuals were dead at-haulback out of 1097 retained (RR=0.89; 95% CIs: 0.81; 0.98). In experiment 41, the RR is 0.99 (95% CIs: 0.76; 1.30), 44 individuals were dead at-haulback (out of 65 retained) when using circle hooks, for tuna hooks 28 individuals were dead at-haulback out of 41 retained. Both experiments indicate there is a reduction in at-haulback mortality of yellowfin tuna when using circle hooks instead of tuna hooks however this is not significantly different for experiment 51.

Swordfish – Retention rates

Figure VIII.5 shows the random effects model when all compiled experiments that reported on swordfish retention for deep-setting pelagic longline when comparing tuna with circle hooks are used. When all experiments are used, the RR is 0.87 (95% CIs: 0.36; 2.13), which means that the retention of swordfish decreases by 13% when using circle hooks compared with tuna hooks, however this reduction is not significant as 95% confidence intervals vary between reductions of 64% and increases in retention of 213%. In this analysis, one problem when using all experiments, is that the overall heterogeneity (I^2) is very high (95%) failing the statistical assumption of homogeneity (p-value<0.05).

The results of the validation with search for possible outliers and influence analysis are represented in Figure VIII.6. Two experiments (experiments 23 and 41) are identified in several of the diagnostics (Figure VIII.6 – top right panel. These experiments are relatively large contributors to both the overall heterogeneity and to the pooled results (Figure VIII.6 – top left panel). Excluding each specific experiment one at a time would decrease the I^2 from 95% to 70% (still failing the statistical assumption of homogeneity), excluding those studies would lead to a change in the point estimate of the RR, but not to a degree to have a significant difference in retention when changing hook type (Figure VIII.6 – bottom panel).

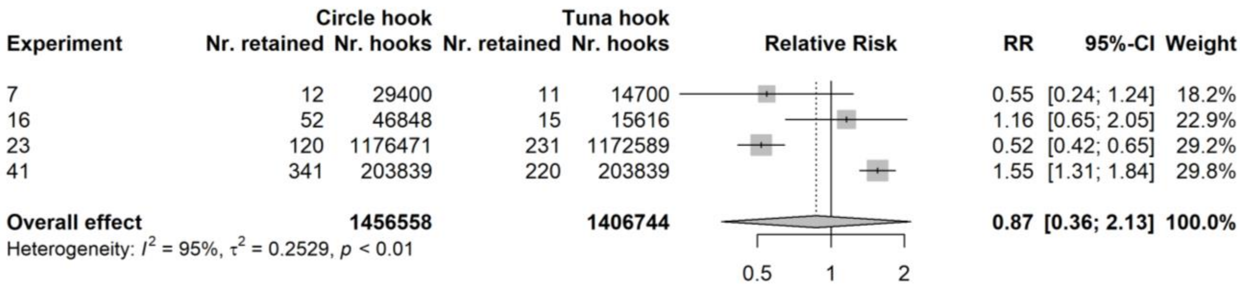


Figure VIII.5. Forest plot of the random effects meta-analysis performed for the retention rates of swordfish in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

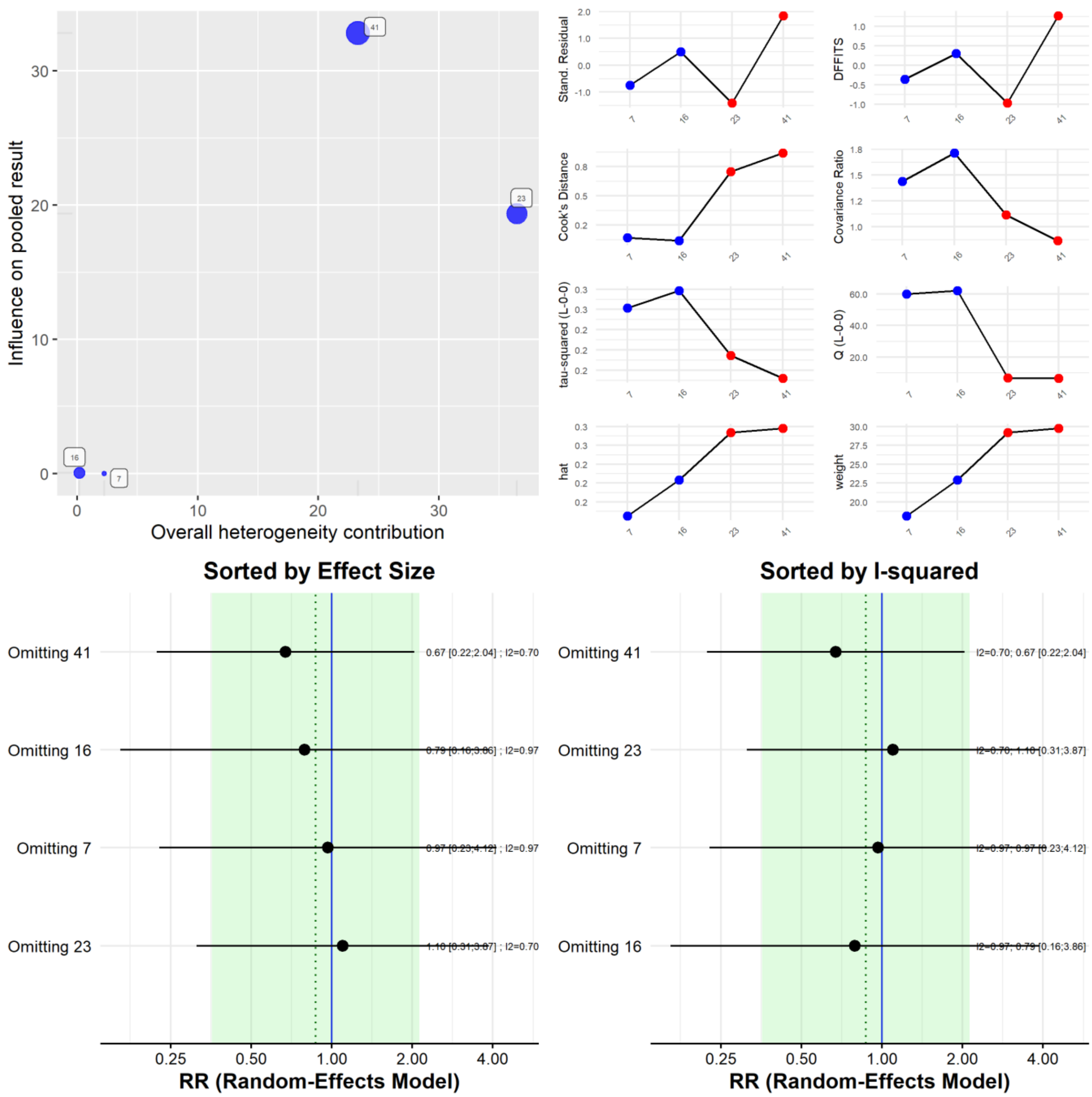


Figure VIII.6. Influence analysis for validating the meta-analysis performed for the retention rates of swordfish in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Swordfish – At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of swordfish, only two experiments were available (experiments 23 and 41), so the meta-analysis was not conducted. One experiment indicates there is a decrease in at-haulback mortality of swordfish when using circle hooks, while the other indicates that there is no effect of hook in the at-haulback mortality. For experiment 23, 49 individuals were dead at-haulback (out of 120 retained) when using circle hooks, for tuna hooks 128 individuals were dead at-haulback out of 231 retained (RR=0.74; 95% CIs: 0.58; 0.94). In experiment 41, the RR is 1.00 (95% CIs: 0.93; 1.08), 283 individuals were dead at-haulback (out of 341 retained) when using circle hooks, for tuna hooks 182 individuals were dead at-haulback out of 220 retained.

Bigeye tuna – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention bigeye tuna, the random effects model considering all experiments is shown in Figure VIII.7. The influence analysis that followed (Figure VIII.8) identified experiment 41 as an outlier with significant leverage. The analysis was re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VIII.9 validation indicated in Figure VIII.10. With the exclusion of this outlier, the heterogeneity was largely reduced, specifically from 83% when including all experiments to 39%. The pooled analysis results changed from an RR of 1.05 (95% CIs:0.82-1.34) to 0.99 (95% CIs:0.73-1.34). In both analysis changing hook type did not significantly influence retention of bigeye tuna.

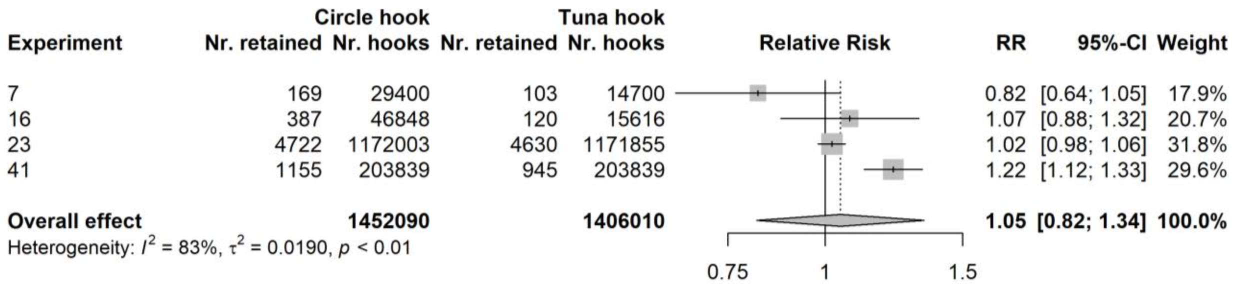


Figure VIII.7. Forest plot of the random effects meta-analysis performed for the retention rates of bigeye tuna in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

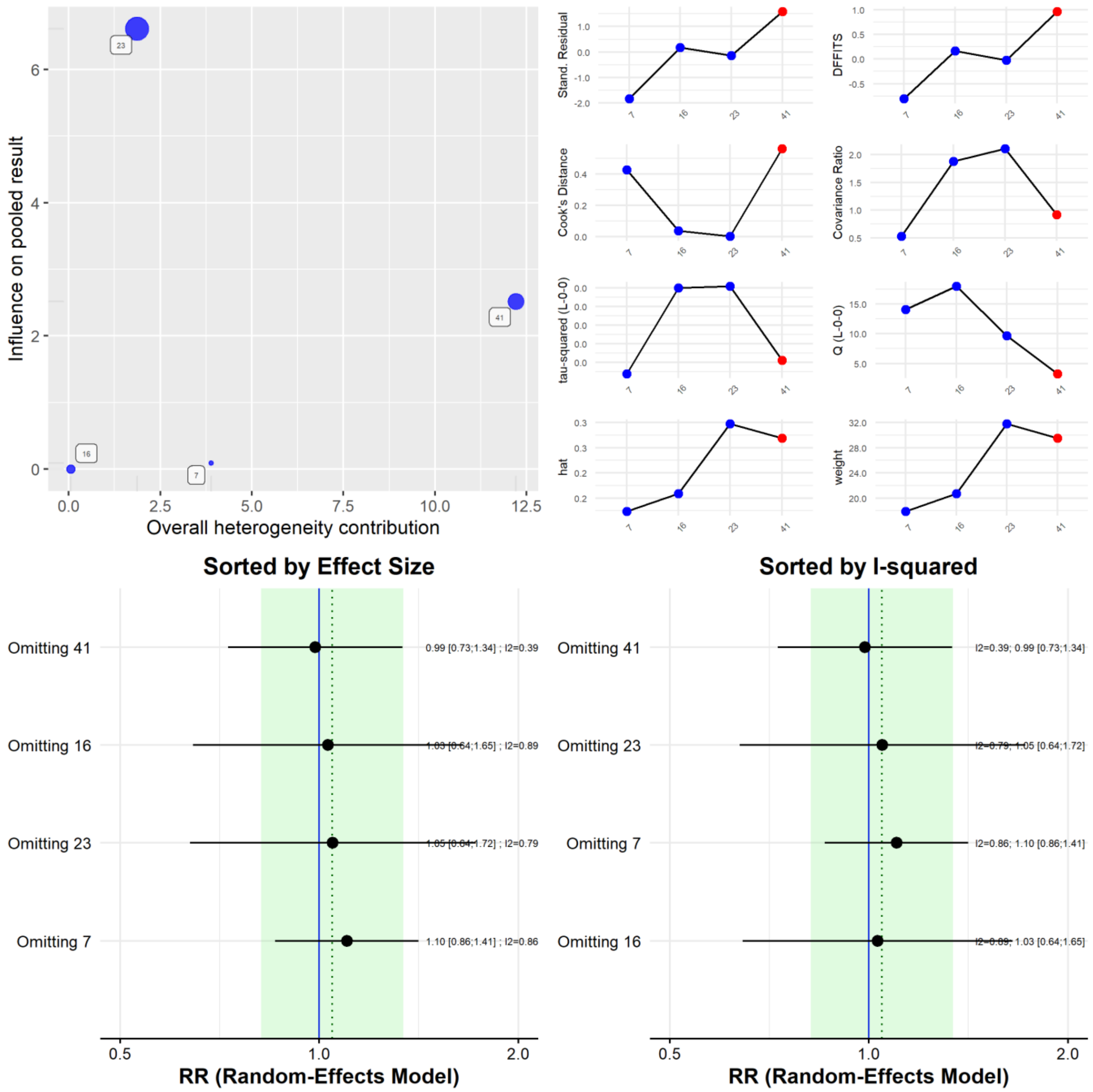


Figure VIII.8. Influence analysis for validating the meta-analysis performed for the retention rates of albacore in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

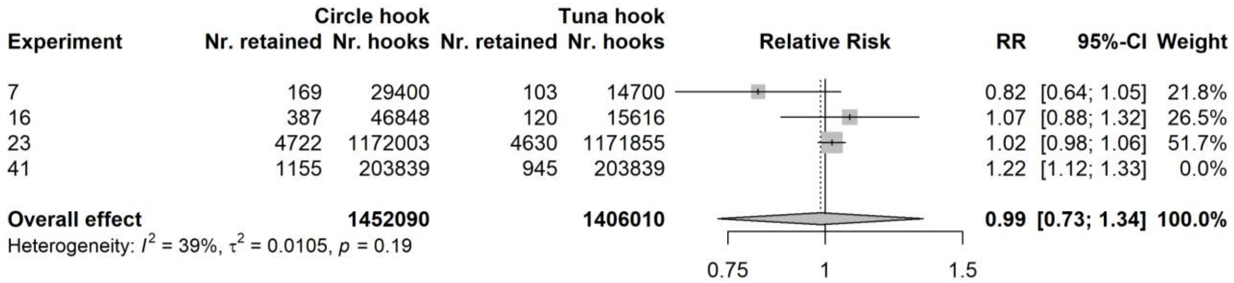


Figure VIII.9. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of albacore in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates at-haulback mortality is higher with circle hooks). Experiment 41 was excluded (this is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis).

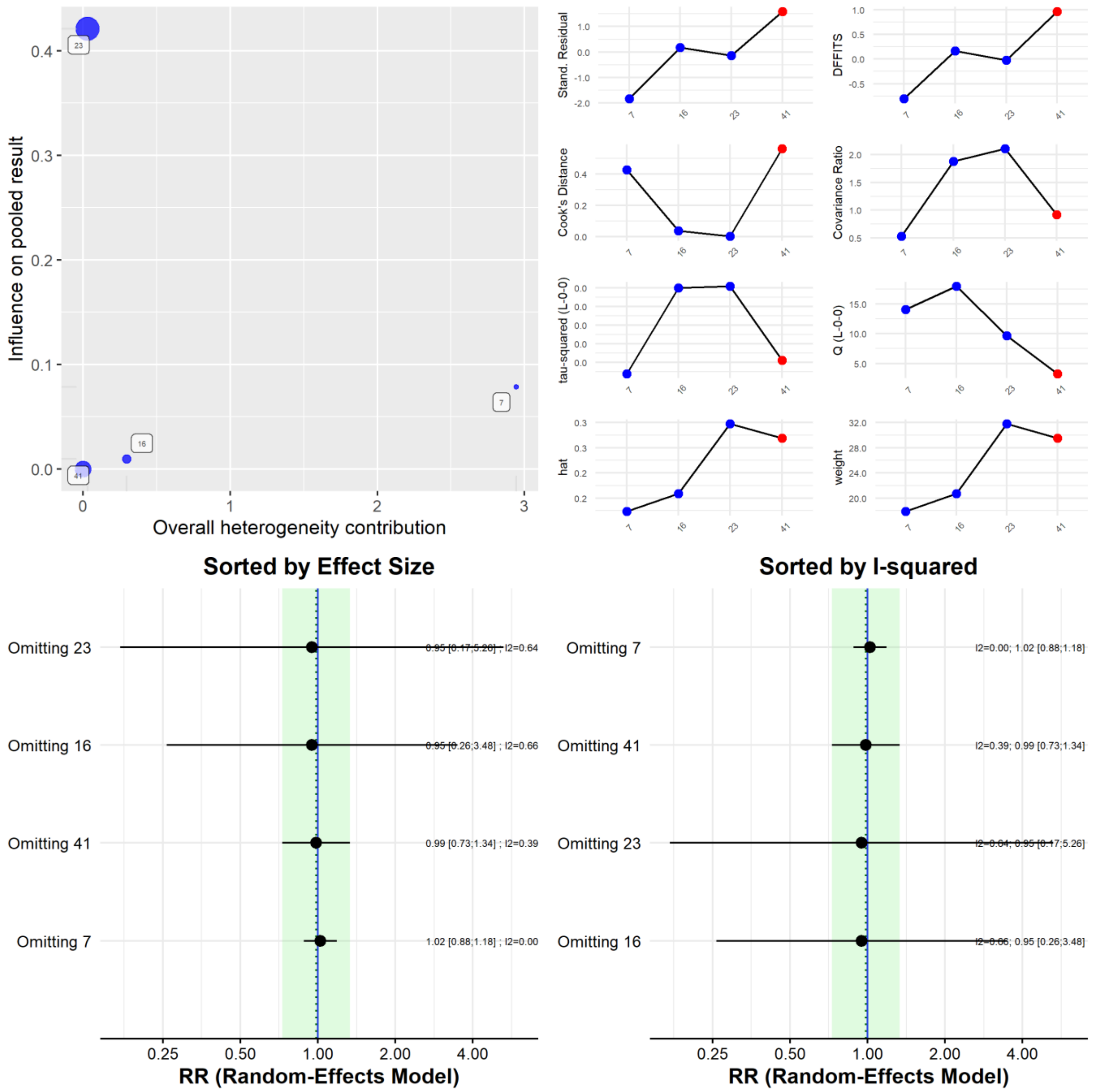


Figure VIII.10. Influence analysis for the meta-analysis after excluding 1 outlier, performed for the retention rates of albacore in deep-setting longlines with circle vs. tuna hooks. Experiment 41 was excluded (this is still represented in the plots but not considered in the analysis – 0% weight in the final pooled analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye tuna – At-haulback mortality

With regards to the effect of changing from tuna to circle hooks on the at-haulback mortality of bigeye tuna, only two experiments were available (experiments 23 and 41), so the meta-analysis was not conducted. One experiment indicates there is an increase in at-haulback mortality of bigeye tuna when using circle hooks, while the other indicates there is a decrease. For experiment 23, 1044 individuals were dead at-haulback (out of 4722 retained) when using circle hooks, for tuna hooks 843 individuals were dead at-haulback out of 4630 retained (RR=1.21; 95% CIs: 1.21; 1.32). In experiment 41, the RR is 0.92 (95% CIs: 0.85; 1.00), 584 individuals were dead at-haulback (out of 1155 retained) when using circle hooks, for tuna hooks 517 individuals were dead at-haulback out of 945 retained.

Bluefin tuna – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of bluefin tuna.

Bluefin tuna – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of bluefin tuna.

Albacore – Retention rates

Figure VIII.11 shows the random effects model when all compiled experiments that compared tuna and circle hook on albacore retention for deep-set longlines. When all experiments are used, the RR is 0.97 (95% CIs: 0.37; 2.55). In this analysis the overall heterogeneity (I^2) is 71% and fails the statistical assumption of homogeneity (p-value<0.05). In this particular case no specific experiment is identified as a potential outlier Figure VIII.12 (top-right panel), however removing experiment 16, which has a large influence in the overall heterogeneity estimation (Figure VIII.12 top-left panel) would result in a low heterogeneity (Figure VIII.12 bottom panel) that does not fail the statistical assumption of homogeneity. As such, the final model used was by removing this experiment, leading to a final RR estimation and confidence intervals of RR=0.82 (95% CIs:0.16; 4.18). The final model is shown in Figure VIII.13 and validation in Figure VIII.14.

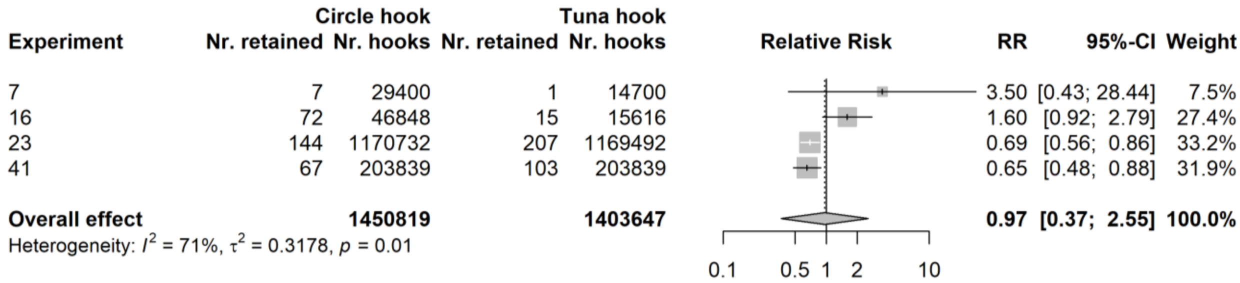


Figure VIII.11. Forest plot of the random effects meta-analysis performed for the retention rates of albacore in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

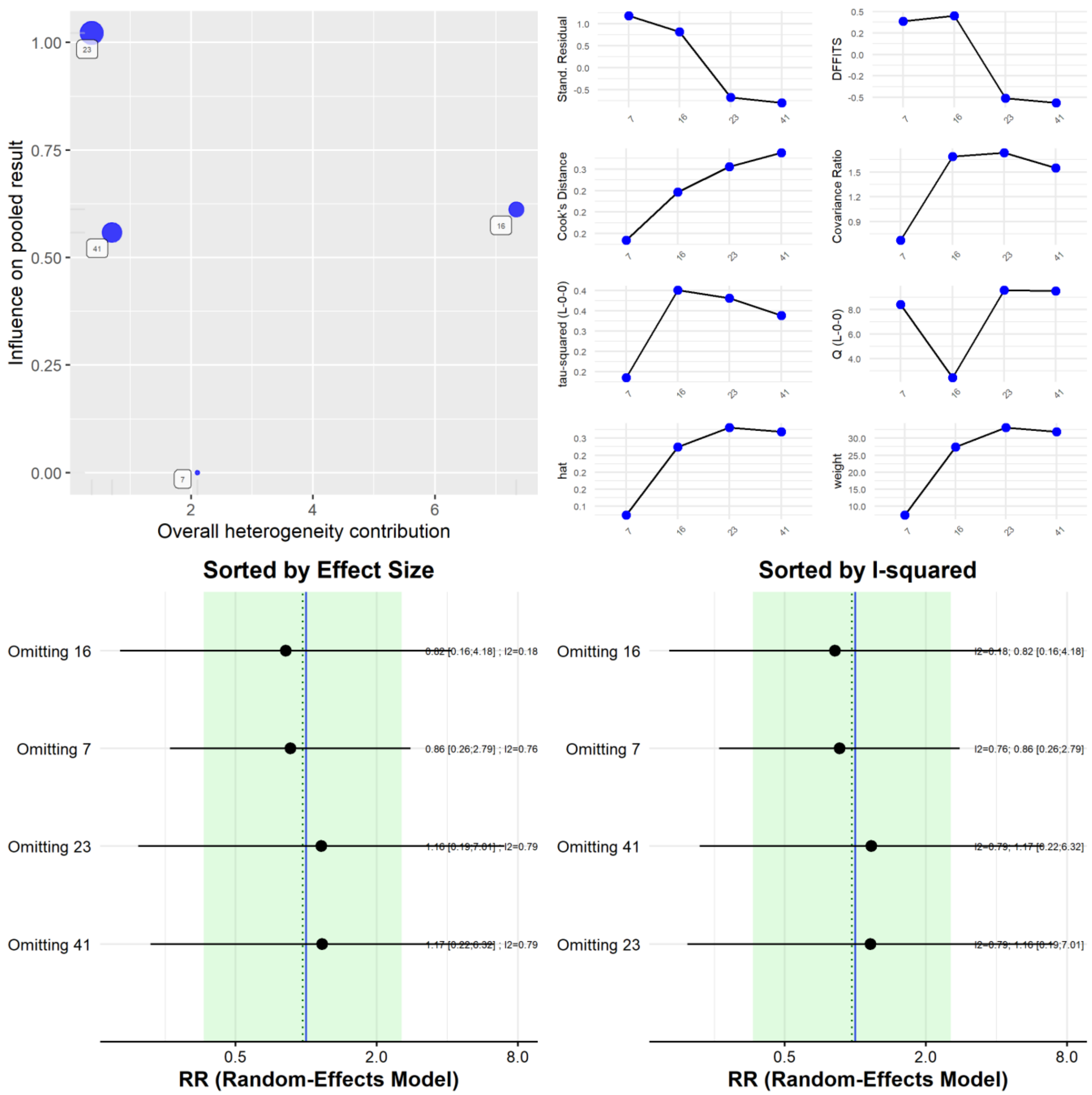


Figure VIII.12. Influence analysis for validating the meta-analysis performed for the retention rates of albacore in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

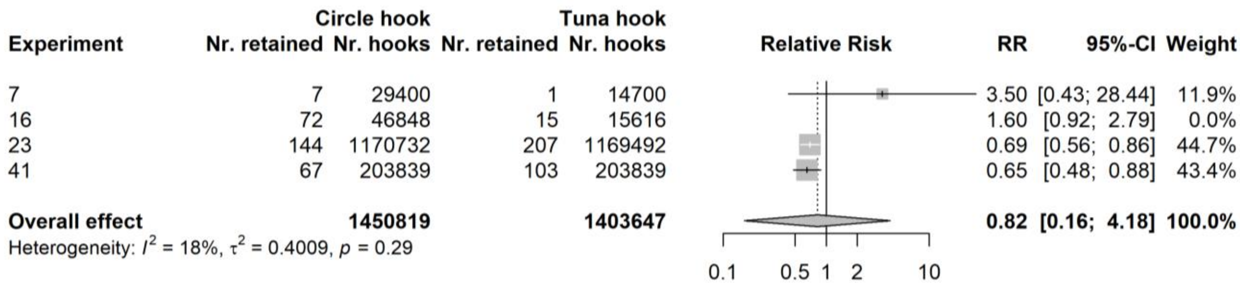


Figure VIII.13. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of albacore tuna with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). The excluded experiment is number 16 (that is still represented in the plots but not considered in the analysis).

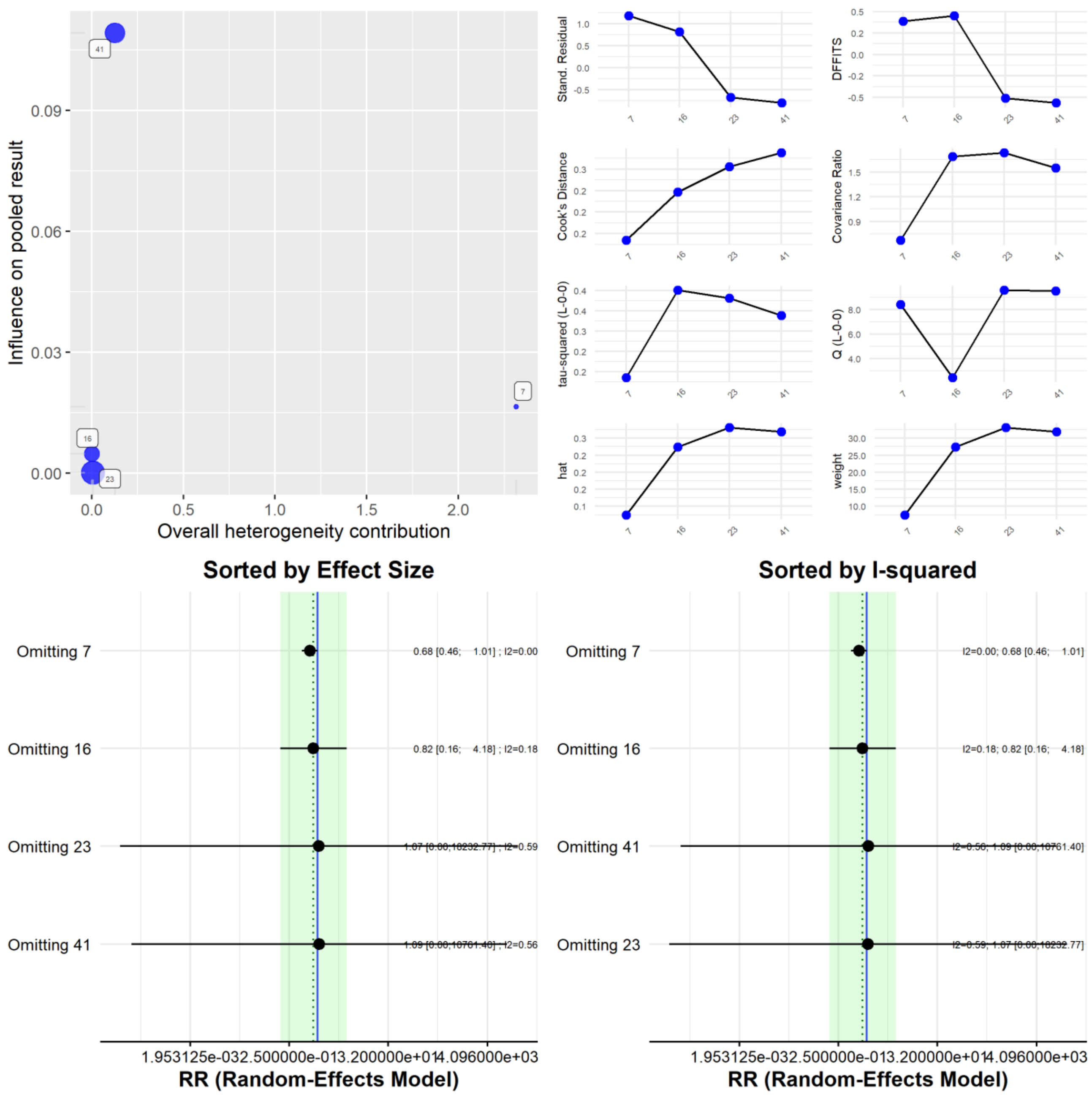


Figure VIII.14. Influence analysis for validating the meta-analysis excluding 1 outlier performed for the retention rates of albacore in deep-setting longlines with circle vs. tuna hooks. The excluded experiment is number 16 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Albacore – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of albacore.

Blue shark- Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention blue shark, the random effects model considering all experiments is shown in Figure VIII.15. The influence analysis that followed identified experiment 23 as an outlier with significant leverage (Figure VIII.16). The analysis was re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VIII.17 and validation indicated in Figure VIII.18. With the exclusion of this outlier, the heterogeneity was reduced from 82% when including all experiments to 0%. The pooled analysis results changed from an RR of 0.97 (95% CIs:0.67-1.40) to 1.07 (95% CIs:0.53-2.18). In both analysis changing hook type did not significantly influence the retention of blue shark.

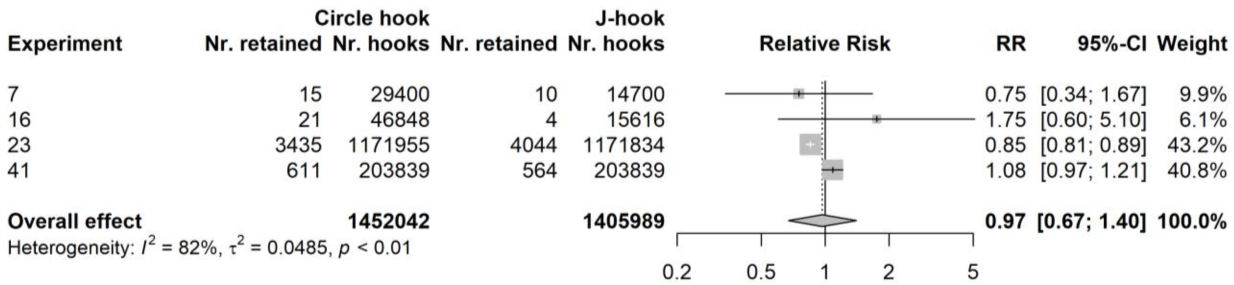


Figure VIII.15. Forest plot of the random effects meta-analysis performed for the retention rates of blue shark in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

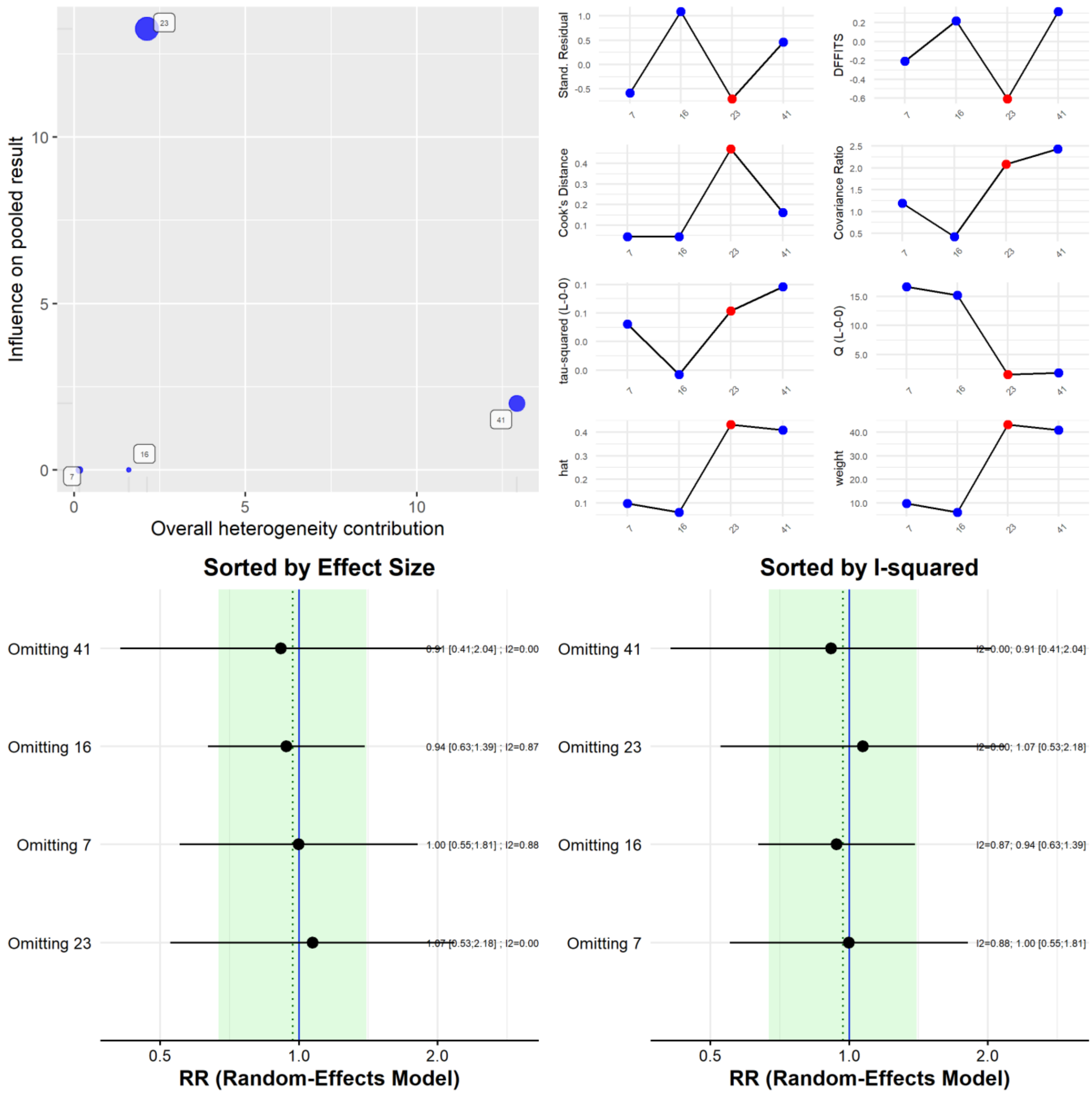


Figure VIII.16. Influence analysis for validating the meta-analysis performed for the retention rates of blue shark in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

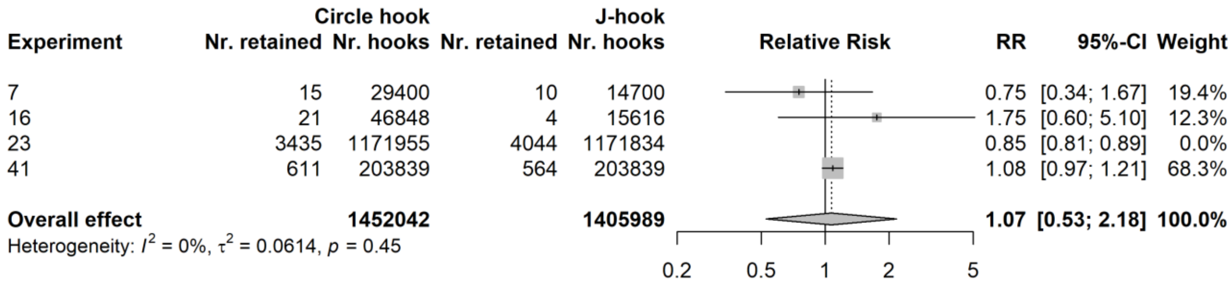


Figure VIII.17. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of blue shark with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). The excluded experiment is number 23 (that is still represented in the plots but not considered in the analysis).

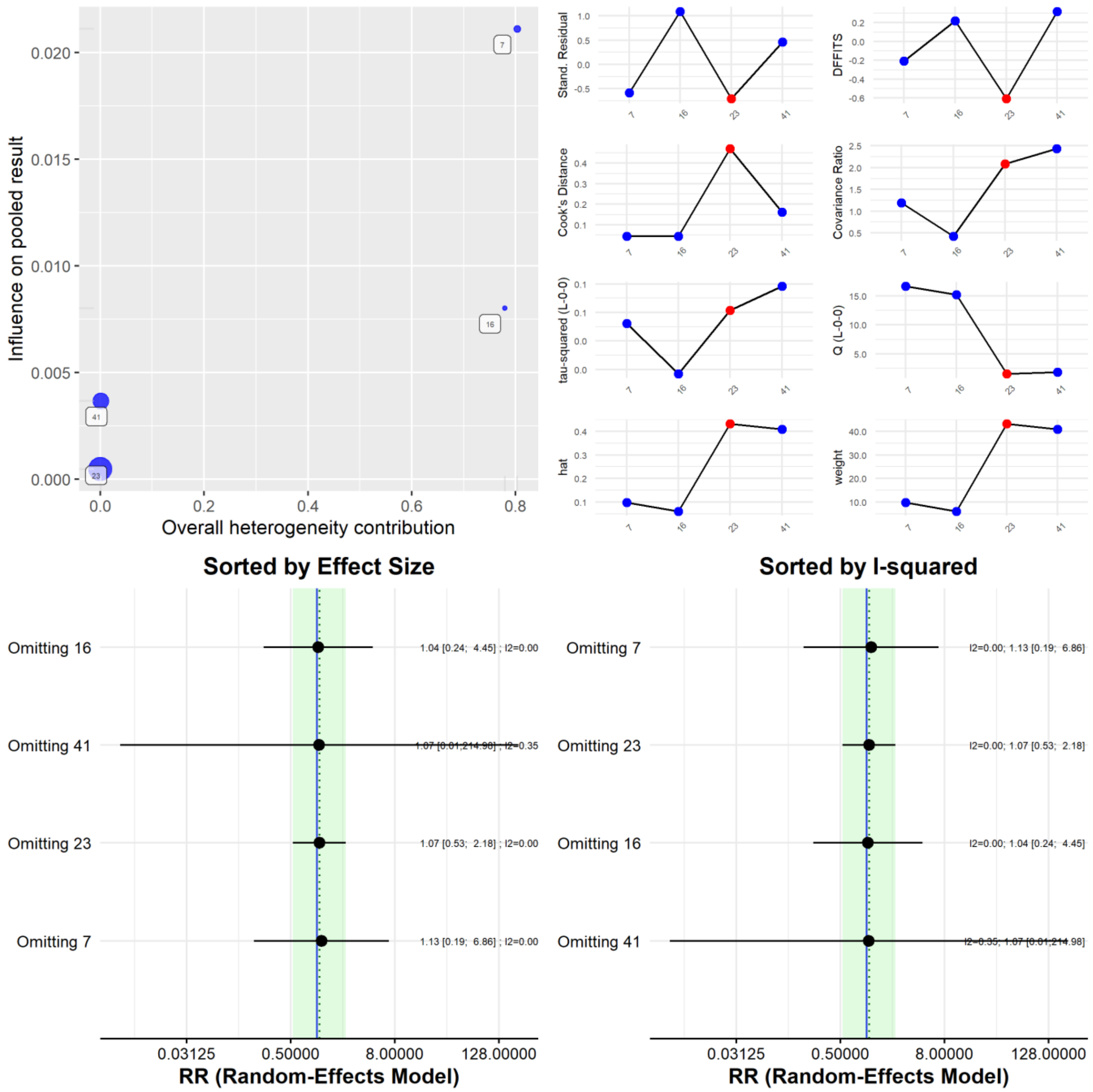


Figure VIII.18. Influence analysis for validating the meta-analysis excluding 1 outlier performed for the retention rates of blue shark in deep-setting longlines with circle vs. tuna hooks. The excluded experiment is number 23 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Blue shark – At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of blue shark, only two experiments were available (experiments 23 and 41), so the meta-analysis was not conducted. For experiment 23, 89 individuals were dead at-haulback out of

3435 retained when using circle hooks, while for tuna hooks 93 individuals were dead at-haulback out of 4044 retained (RR=1.13; 95% CIs: 0.85; 1.50). In experiment 41, the RR was calculated at 1.03 (95% CIs: 0.87; 1.22), and 195 individuals were dead at-haulback out of 611 retained when using circle hooks, while for tuna hooks 175 individuals were dead at-haulback out of 564 retained.

Shortfin mako – Retention rates

With regards to the effect of changing from tuna to circle hooks on the retention mortality of shortfin mako, only one experiment was available (experiment 7), so the meta-analysis was not conducted. Moreover, sample size was very small. For experiment 7, only 1 shortfin mako was retained when using 14700 tuna hooks and for circle hooks no retentions were recorded in 29400 hooks (RR=0.05; 95% CIs: 0; 29.44).

Shortfin mako – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of shortfin mako.

Blue marlin – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of blue marlin.

Blue marlin – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of blue marlin.

Atlantic sailfish – Retention

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of Atlantic sailfish.

Atlantic sailfish – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of Atlantic sailfish.

White marlin – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of white marlin.

White marlin – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of white marlin.

Loggerhead sea turtle – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention of loggerhead sea turtle, only one experiment was available (experiment 41), so the meta-analysis was not conducted. Moreover, the sample size was very small. For experiment 41, only 1 loggerhead was retained when using 203,839 tuna hooks and for circle hooks no retentions were recorded in 203,839 hooks (RR=0.09; 95% CIs: 0; 58.89).

Loggerhead sea turtle – At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of loggerhead sea turtle, only one experiment was available (experiment 41), so the meta-analysis was not conducted. For experiment 41, only 1 (out of 1) loggerhead was retained and died when using tuna hooks and for circle hooks no retentions were recorded.

Leatherback sea turtle – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention of leatherback sea turtle, only one experiment was available (experiment 41), so the meta-analysis was not conducted. In this experiment, 14 leatherback sea turtles were retained when using 203,839 tuna hooks, and 15 leatherback sea turtles were retained when using 203,839 circle hooks (RR=1.07; 95% CIs: 0.52; 2.22).

Leatherback sea turtle – At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of leatherback sea turtle, only one experiment was available (experiment 41), so the meta-analysis was not conducted. For experiment 41, 4 specimens died (out of 14 retained) when using tuna hooks and for circle hooks 2 specimens died (out of 15 retained) (RR= 0.47; 95% CIs: 0.1; 2.16).

Olive ridley sea turtle – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention of olive ridley sea turtle, the random effects model considering all experiments is shown in Figure VIII.19. The influence analysis that followed (Figure VIII.20) identified experiment 41 as an outlier with significant leverage. The analysis was re-run excluding that experiment, with the results of the new pooled analysis indicated in Figure VIII.21 and validation indicated in Figure VIII.22. With the exclusion of this outlier, the pooled analysis results changed from an RR of 0.35 (95% CIs:0.04-2.92) to 0.16 (95% CIs:0.02-1.67). In both analyses, changing hook type did not significantly influence retention of olive ridley sea turtle.

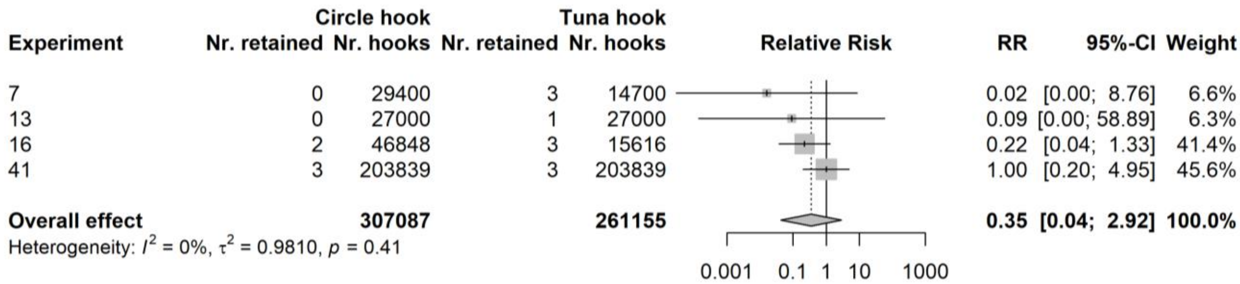


Figure VIII.19. Forest plot of the random effects meta-analysis performed for the retention rates of olive ridley sea turtle in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

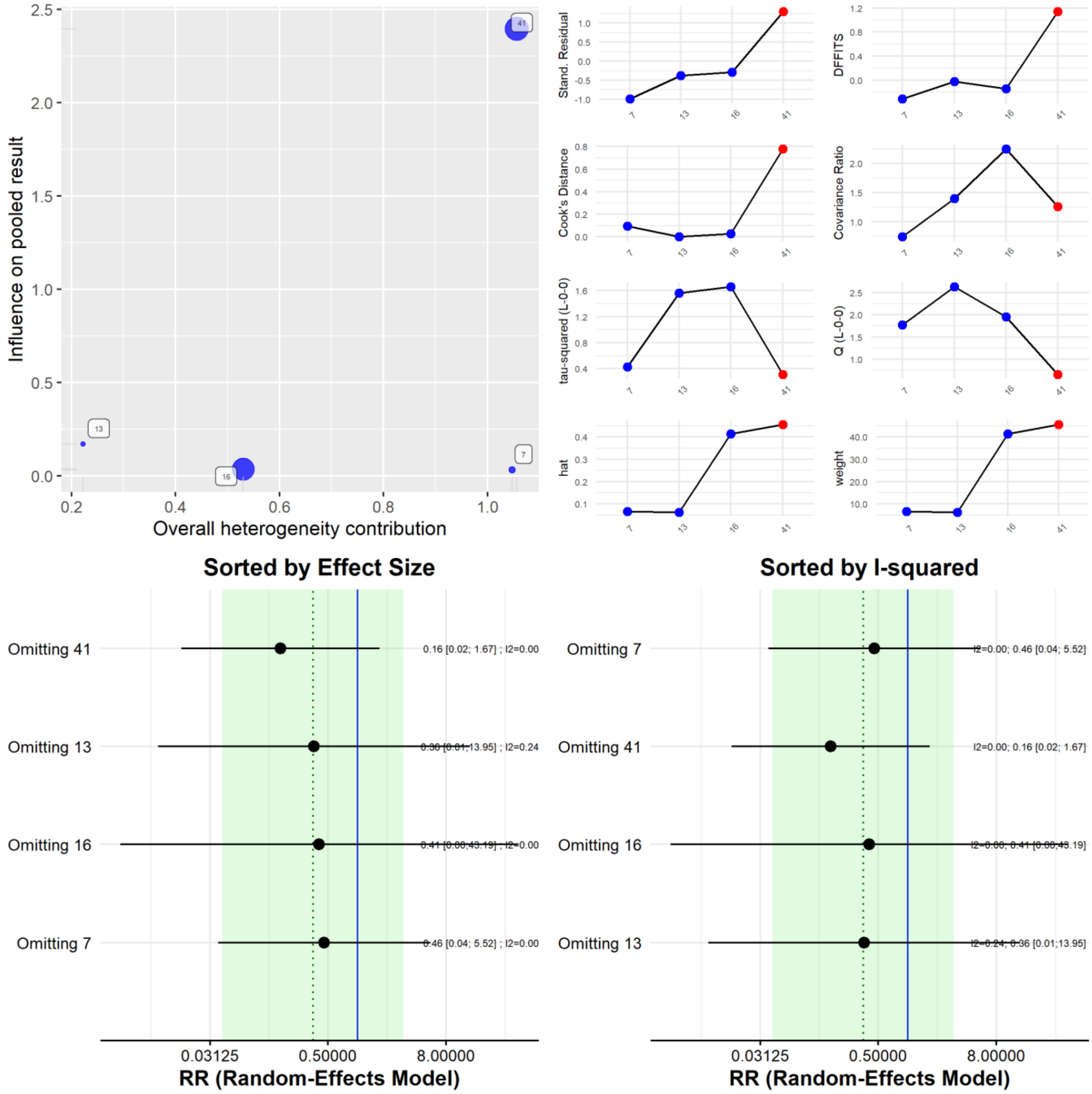


Figure VIII.20. Influence analysis for validating the meta-analysis performed for the retention rates of olive ridley sea turtle in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I² (right).

Experiment	Circle hook Nr. retained	Circle hook Nr. hooks	Tuna hook Nr. retained	Tuna hook Nr. hooks	RR	95%-CI	Weight
7	0	29400	3	14700	0.02	[0.00; 8.76]	8.9%
13	0	27000	1	27000	0.09	[0.00; 58.89]	8.4%
16	2	46848	3	15616	0.22	[0.04; 1.33]	82.7%
41	3	203839	3	203839	1.00	[0.20; 4.95]	0.0%
Overall effect		**307087**		**261155**	**0.16**	**[0.02; 1.67]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.3123$, $p = 0.72$

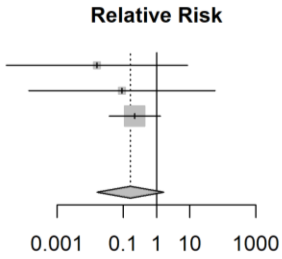


Figure VIII.21. Forest plot of the random effects meta-analysis excluding 1 outlier in the retention rates of olive ridley sea turtle with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks). The excluded experiment is number 41 (that is still represented in the plots but not considered in the analysis).

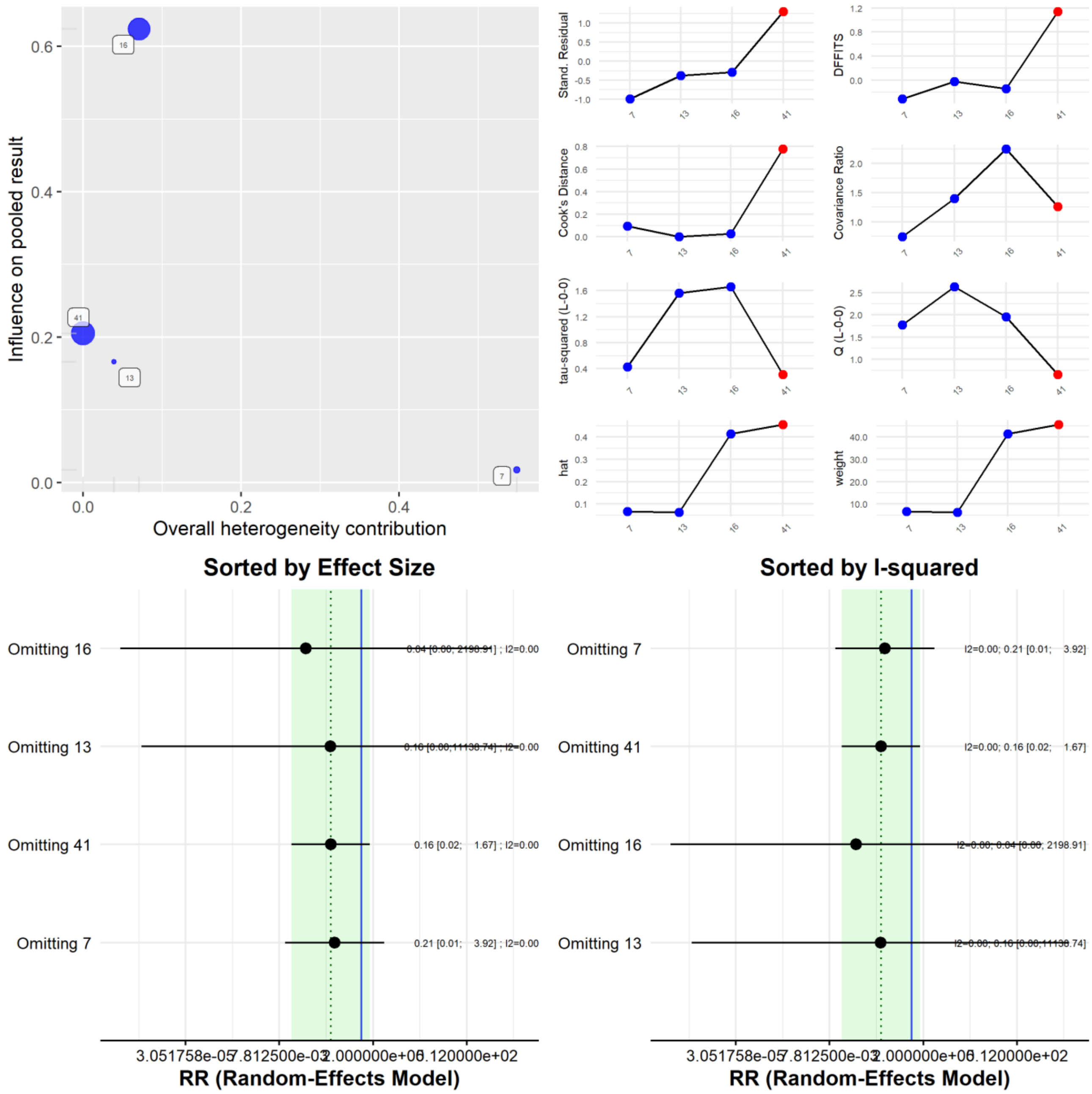


Figure VIII.22. Influence analysis for validating the meta-analysis excluding 1 outlier performed for the retention rates of olive ridley sea turtle in deep-setting longlines with circle vs. tuna hooks. The excluded experiment is number 41 (that is still represented in the plots but not considered in the analysis). Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Olive ridley sea turtle – At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of olive ridley sea turtle, only two experiments were available (experiment 7 and 41), so the meta-analysis was not conducted. For experiment 7, 1 specimen died (out of 3 retained) when using tuna hooks and for circle hooks there were no retentions recorded. For experiment 41, 3 specimens died (out of 3 retained) when using tuna hooks and for circle hooks 3 specimens died (out of 3 retained) (RR=1.00; 95% CIs: 0.75; 1.33).

Kemp's ridley sea turtle – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of Kemp's ridley sea turtle.

Kemp's ridley sea turtle – at-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of kemp's ridley sea turtle.

Green sea turtle – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of green sea turtle.

Green sea turtle – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of green sea turtle.

Oceanic whitetip – Retention rates

With regards to the effect of changing from tuna to circle hooks on the retention of oceanic whitetip, only two experiments were available (experiments 7 and 16), so the meta-analysis was not conducted. In experiment 7, 6 specimens were retained when using 14700 tuna hooks, and 8 specimens were retained when using 29400 circle hooks (RR=0.67; 95% CIs: 0.23; 1.92). In experiment 16, 7 specimens were retained when using 15616 tuna hooks, and 4 specimens were retained when using 46848 circle hooks (RR=0.19; 95% CIs: 0.06; 0.65).

Oceanic whitetip – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of oceanic whitetip.

Porbeagle – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of porbeagle.

Porbeagle – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of porbeagle.

Silky shark – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of silky shark.

Silky shark – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of silky shark.

Bigeye thresher – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention of bigeye thresher, the random effects model considering all experiments is shown in Figure XVIII.23. In this specific case, we calculate the RR at 0.87 (95% CIs: 0.28; 2.67). This means that on average we expect that the retention of bigeye thresher when using circle hooks is 13% lower than when using tuna hooks, but with 95% confidence intervals varying between a reduction of 72% and an increase of 267% in retention. In this specific case we also see that the overall heterogeneity value is 66% (p-value=0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VIII.24. In this case, the influence analysis identified one experiment (experiment 16) that is an outlier with influence on the pooled results. Since there were only three experiments available, this experiment was kept in order to perform the meta-analysis.

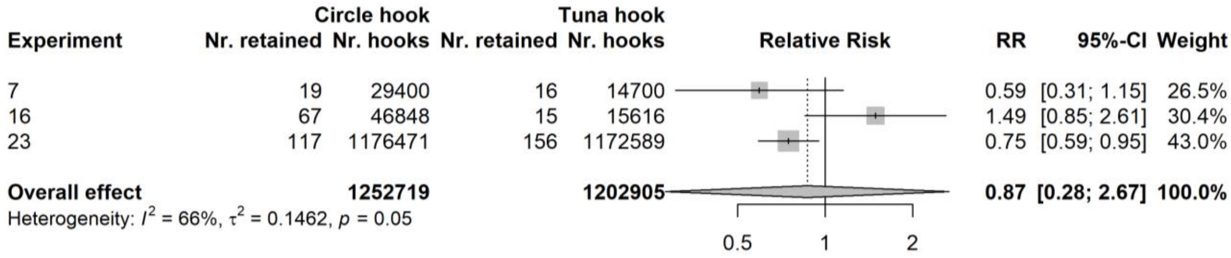


Figure VIII.23. Forest plot of the random effects meta-analysis performed for the retention rates of the bigeye thresher shark in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

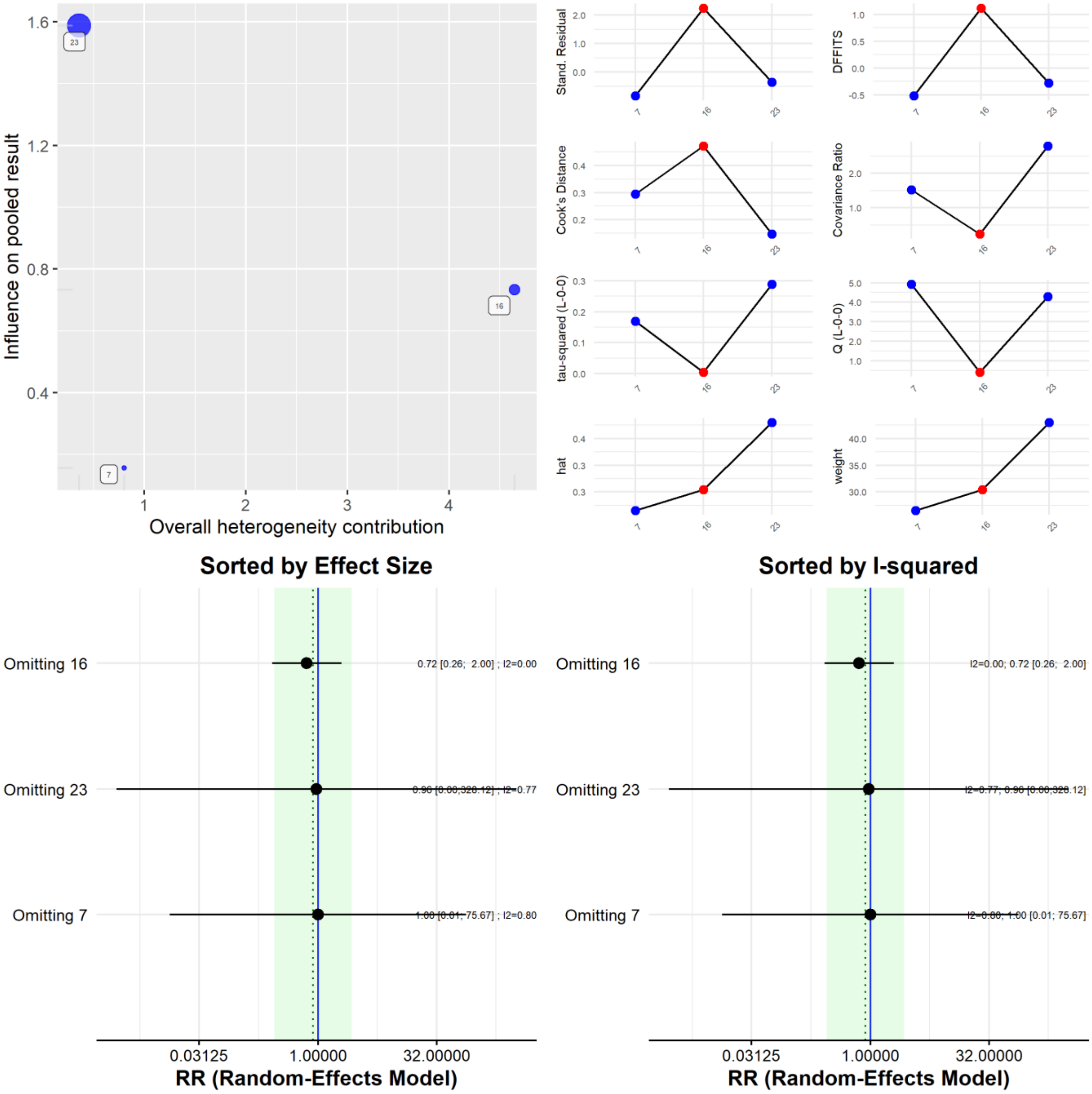


Figure VIII.24. Influence analysis for validating the meta-analysis performed for the retention rates of the bigeye thresher shark in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

Bigeye thresher – At-haulback mortality

With regard to the effect of changing from tuna to circle hooks on the at-haulback mortality of bigeye thresher, only one experiment was available (experiment 23), so the meta-analysis was not conducted. For this experiment, 26 specimens died (out of 156 retained) when using tuna hooks and for circle hooks 15 specimens died (out of 117 retained) (RR=0.77; 95% CIs: 0.43; 1.39).

Longfin mako – Retention rates

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on retention of longfin mako.

Longfin mako – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of longfin mako.

Crocodile shark – Retention rates

With regards to the effect of changing from tuna to circle hooks on the retention of crocodile shark, only two experiments were available (experiments 7 and 16), so the meta-analysis was not conducted. In experiment 7, 4 specimens were retained when using 14700 tuna hooks, and 3 specimens were retained when using 29400 circle hooks (RR=0.38; 95% CIs: 0.08; 1.68). In experiment 16, 13 specimens were retained when using 15616 tuna hooks, and 126 specimens were retained when using 46848 circle hooks (RR=3.23; 95% CIs: 1.83; 5.72).

Crocodile shark – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of crocodile shark.

Scalloped hammerhead – Retention rates

With regards to the effect of changing from tuna to circle hooks on the retention of scalloped hammerhead, only two experiments were available (experiments 7 and 16), so the meta-analysis was not conducted. In experiment 7, 1 specimen was retained when using 14700 tuna hooks, and there were no retentions in 29400 circle hooks (RR=0.05; 95% CIs: 0.00; 29.44). In experiment 16, 1 specimen was retained when using 15616 tuna hooks, and 1 specimen was retained when using 46848 circle hooks (RR=0.33; 95% CIs: 0.02; 5.33).

Scalloped hammerhead – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of scalloped hammerhead.

Smooth hammerhead – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention of smooth hammerhead, only two experiments were available (experiments 7 and 16), so the meta-analysis was not conducted. In experiment 7, 1 specimen was retained when using 14700 tuna hooks, and 1 specimen was retained when using 29400 circle hooks (RR=0.50; 95% CIs: 0.03; 7.99). In experiment 16, 2 specimens were retained when using 15616 tuna hooks, and no retentions were recorded when using 46848 circle hooks (RR=0.02; 95% CIs: 0.00; 9.03).

Smooth hammerhead – At-haulback mortality

For the comparisons between tuna and circle hooks for the deep-set longlines there were no experiments that reported on at-haulback mortality of smooth hammerhead.

Pelagic stingray – Retention rates

With regard to the effect of changing from tuna to circle hooks on the retention of pelagic stingray, the random effects model considering all experiments is shown in Figure VIII.25. In this case, the RR is 0.52 (95% CIs: 0.10; 2.75). This means that on average we expect that the retention of pelagic stingray when using circle hooks is 48% lower than when using tuna hooks, but with 95% confidence intervals varying between a reduction of 90% and an increase of 2.75 times. In this specific case we also see that the overall heterogeneity value is 66% (p-value=0.05). We then looked for possible outliers and carried out an influence analysis, that is represented in Figure VIII.26. In this case, the influence analysis identified one experiment (experiment 23) that is an outlier with influence on the pooled results. Since there were only three experiments available, this experiment was kept in order to perform the meta-analysis.

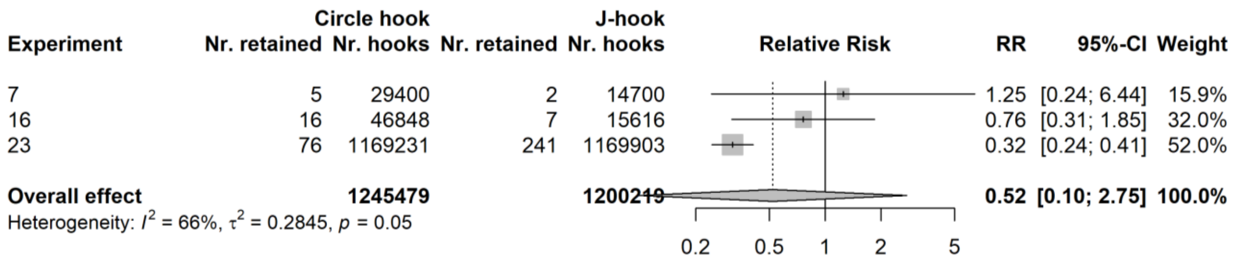


Figure VIII.25. Forest plot of the random effects meta-analysis performed for the retention rates of pelagic stingray in deep-setting longlines with circle vs. tuna hooks (Note: Tuna hooks are considered the control and circle hooks the experimental hook; a relative risk (RR) >1 indicates retention is higher with circle hooks).

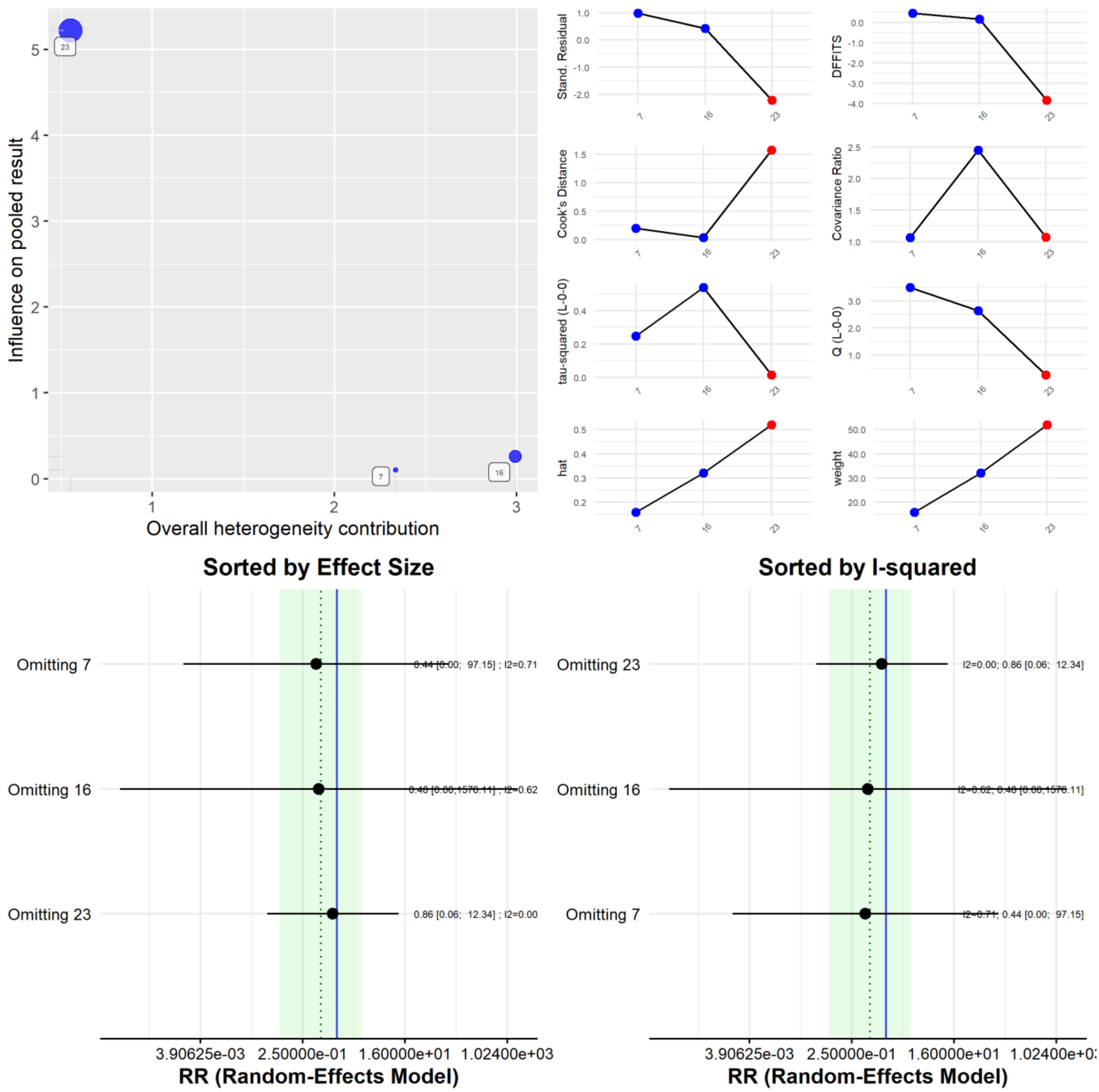


Figure VIII.25. Influence analysis for validating the meta-analysis performed for the retention rates of pelagic stingray in deep-setting longlines with circle vs. tuna hooks. Top left panel – Baujat plot; top right panel – influence diagnostics; bottom panel – leave-one-out method sorted by effect size (left) and I^2 (right).

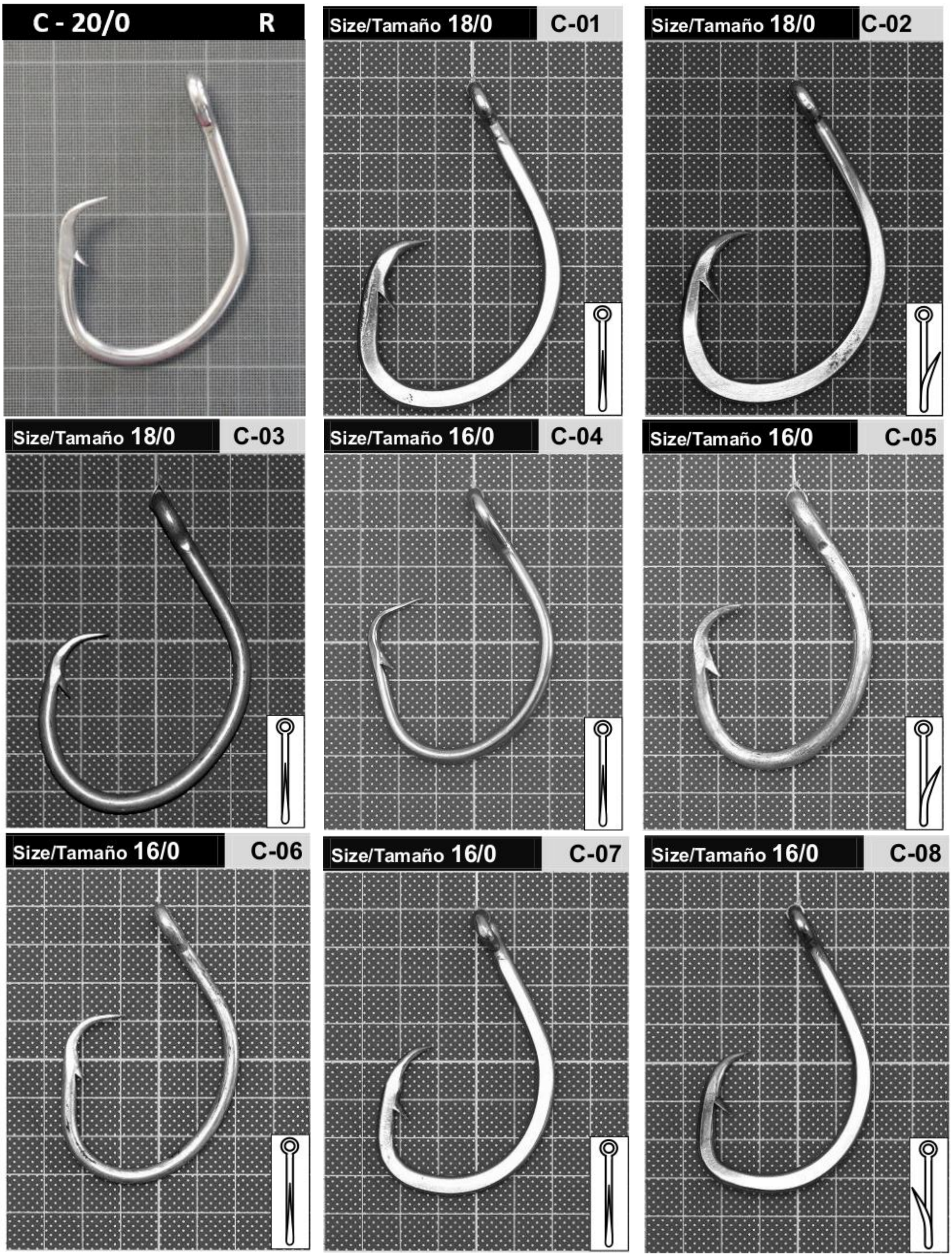
Pelagic stingray – At-haulback mortality

With regards to the effect of changing from tuna to circle hooks on the at-haulback mortality of pelagic stingray, only one experiment was available (experiment 23), so the meta-analysis was not conducted. For this experiment, 3 specimens died (out of 241 retained) when using tuna hooks and for circle hooks 1 specimen died (out of 76 retained) (RR=1.06; 95% CIs: 0.11; 10.01).

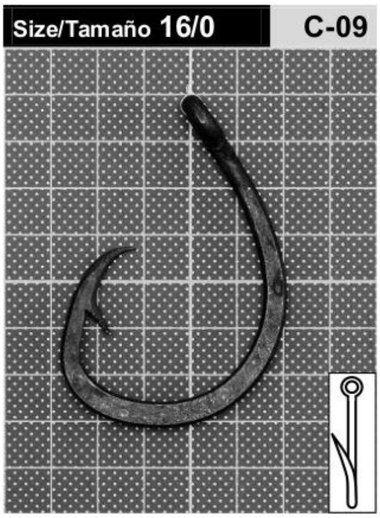
APPENDIX IX: CATALOGUE OF HOOKS

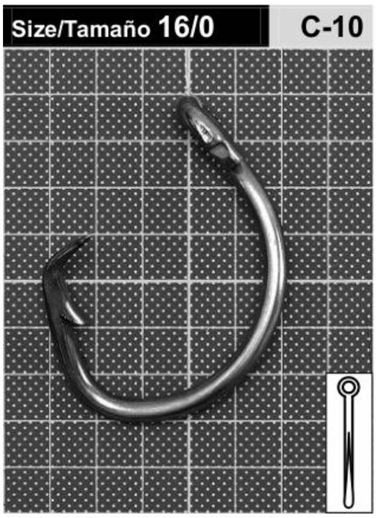
Catalogue of hooks used in pelagic longline considered in this study. Note: For each picture the size of each square side is 10 mm. For several hooks the letter **B** or **R** in the right part of the black banner at the top of the picture refers respectively to pictures published in **B**everly and Park (2009) and unpublished pictures provided by **R**omanov. All other pictures are extracted from the Mituhasi and Hall (2011) catalogue.

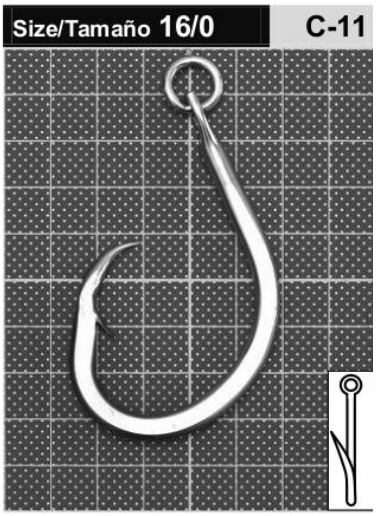
CIRCLE HOOKS

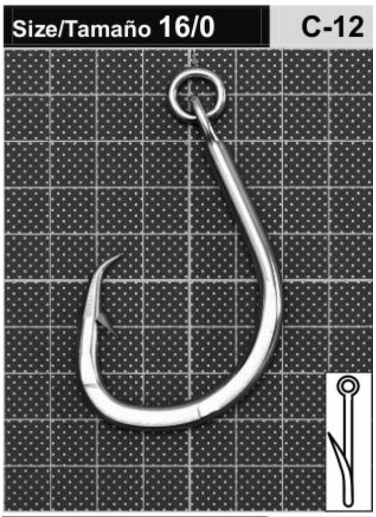


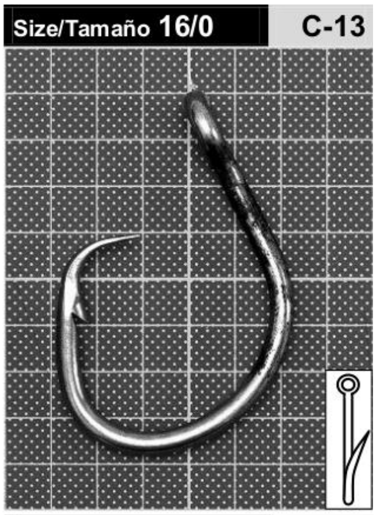
CIRCLE HOOKS

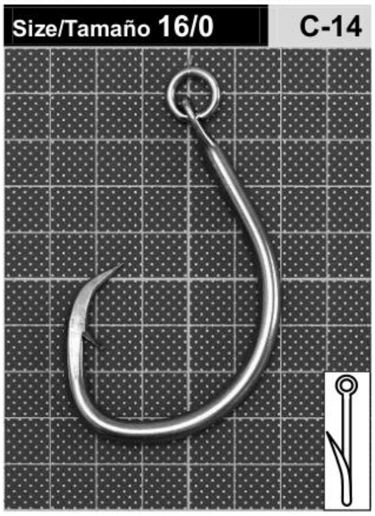


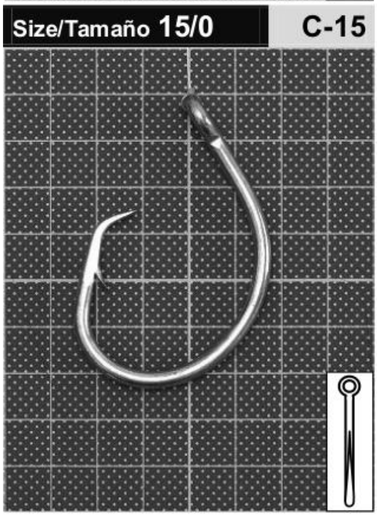


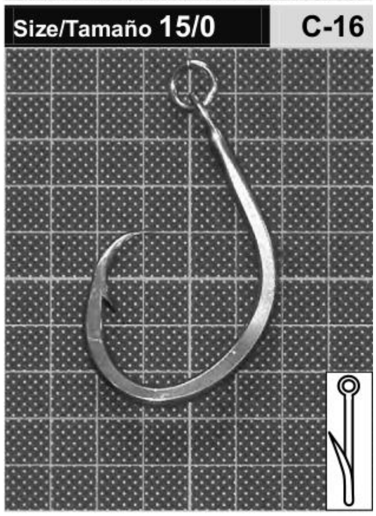






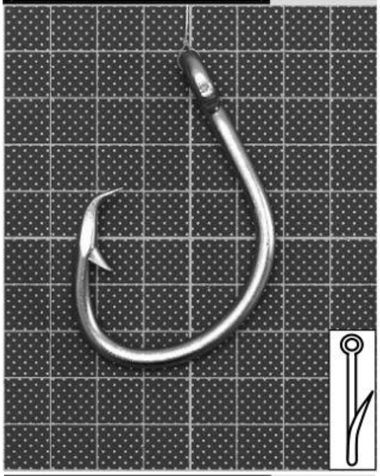




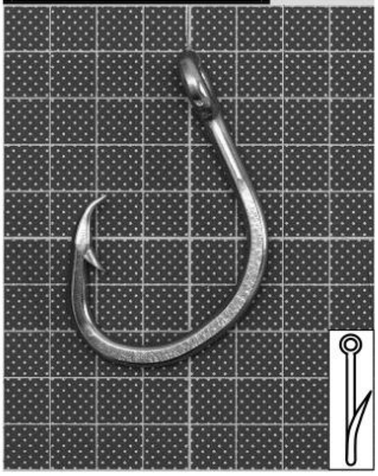


CIRCLE HOOKS

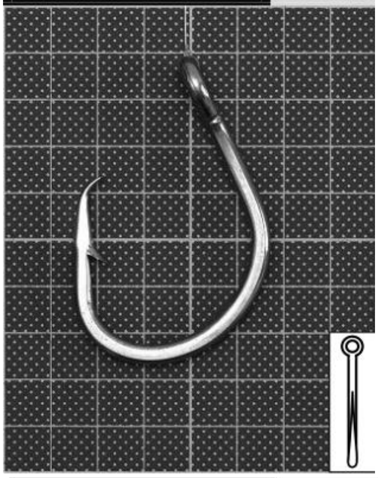
Size/Tamaño 15/0 C-17



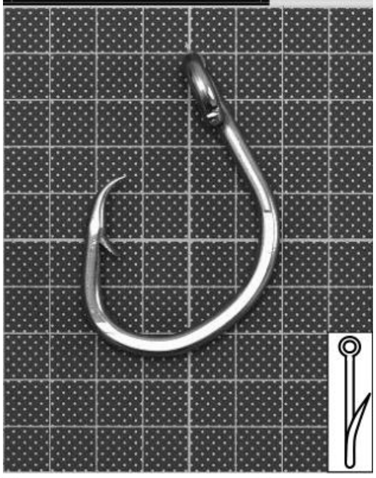
Size/Tamaño 15/0 C-18



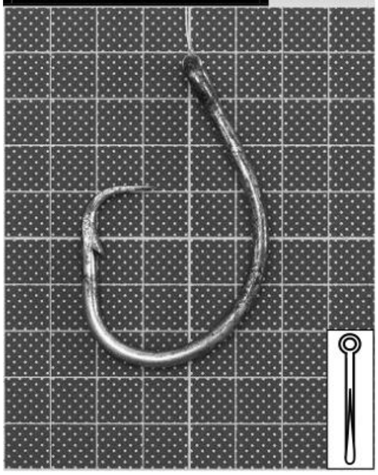
Size/Tamaño 15/0 C-19



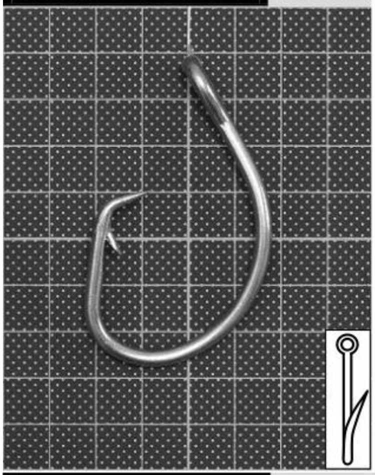
Size/Tamaño 15/0 C-20



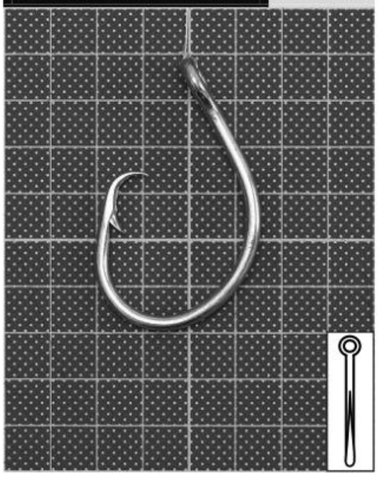
Size/Tamaño 15/0 C-21



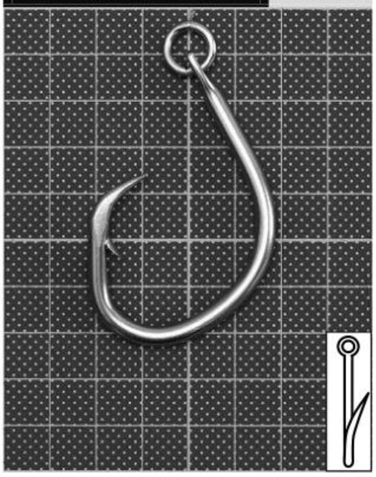
Size/Tamaño 15/0 C-22



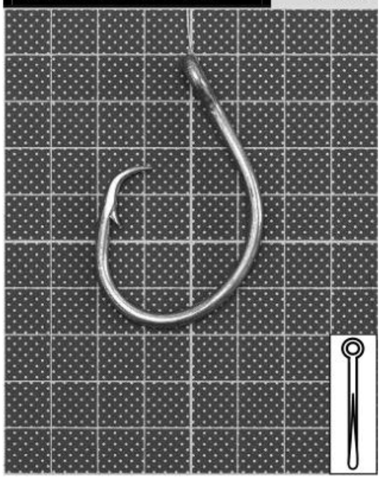
Size/Tamaño 14/0 C-23



Size/Tamaño 14/0 C-24

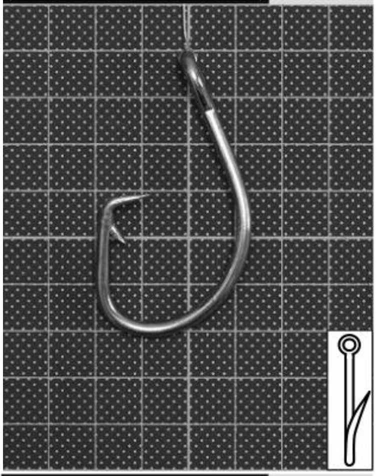


Size/Tamaño 14/0 C-25



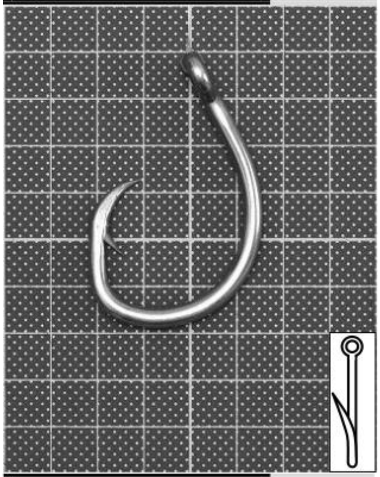
CIRCLE HOOKS

Size/Tamaño 14/0 C-26



C - 14/0 R

Size/Tamaño 13/0 C-27



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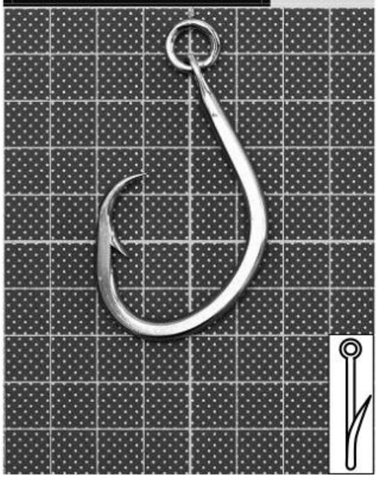

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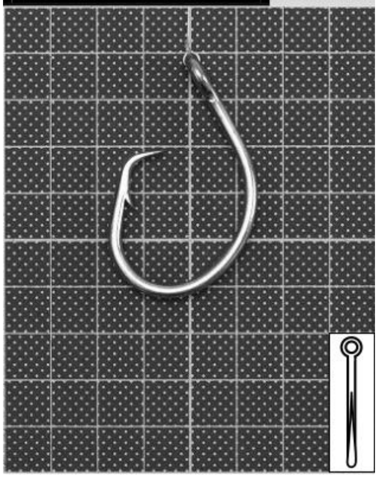

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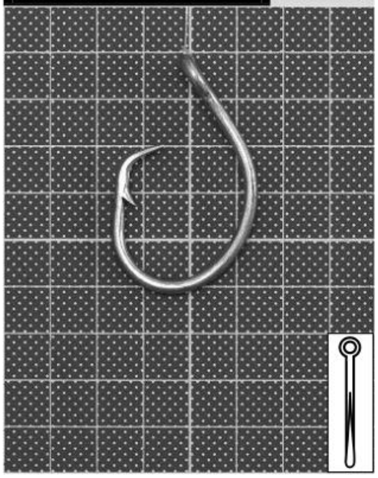

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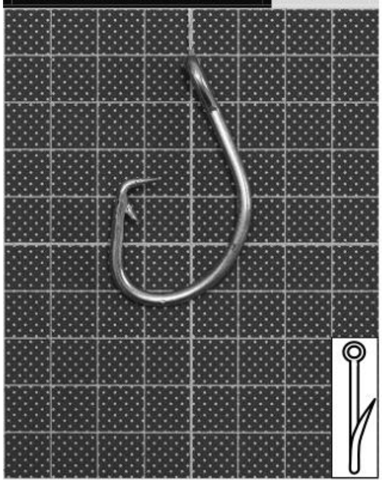

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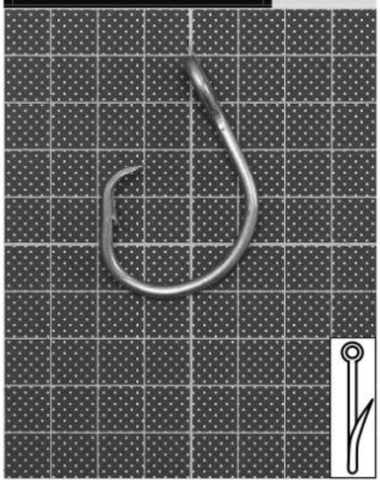
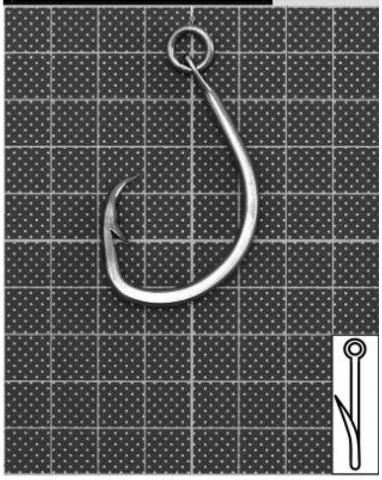


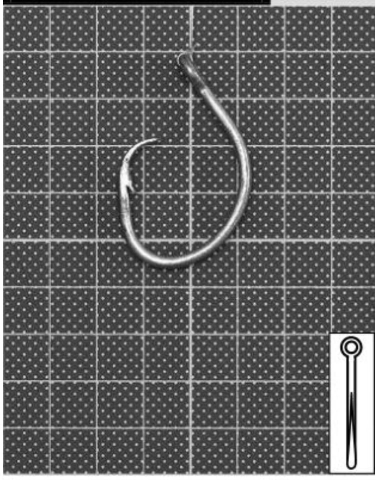
C - 13/0 R

CIRCLE HOOKS

Size/Tamaño 12/0 C-33

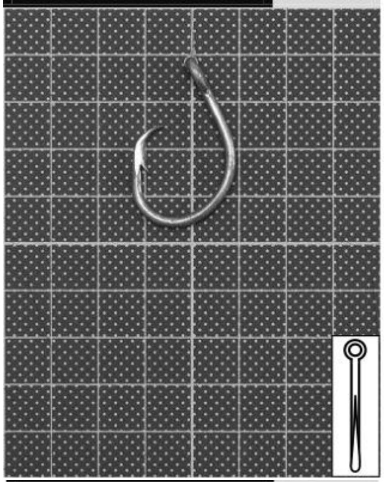


Size/Tamaño 12/0 C-34

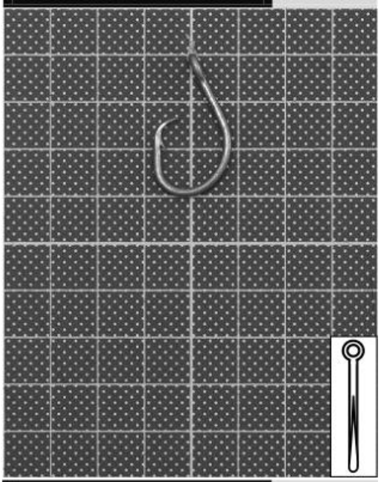


C - 12/0 R

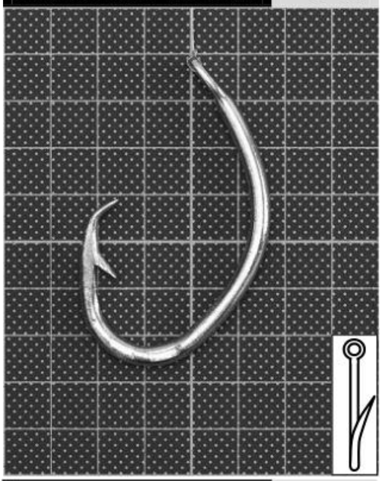
Size/Tamaño 10/0 C-35



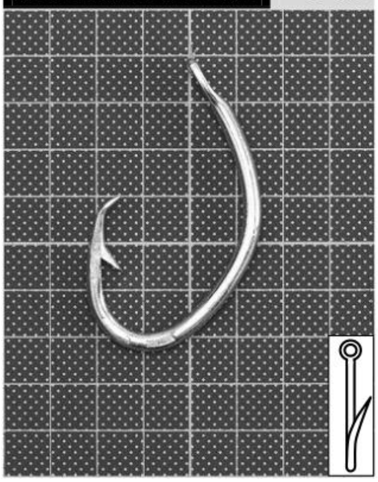
Size/Tamaño 9/0 C-36



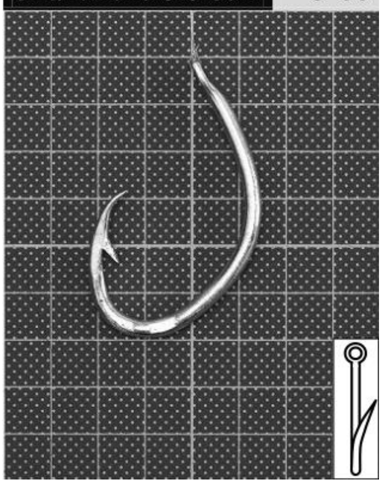
Size/Tamaño 4.0 sun C-37



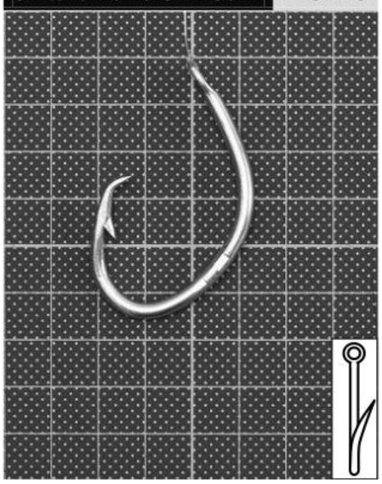
Size/Tamaño 3.8 sun C-38



Size/Tamaño 3.6 sun C-39

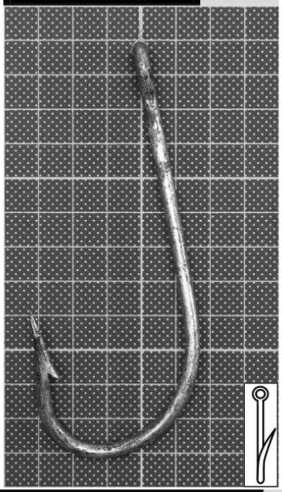


Size/Tamaño 3.4 sun C-40

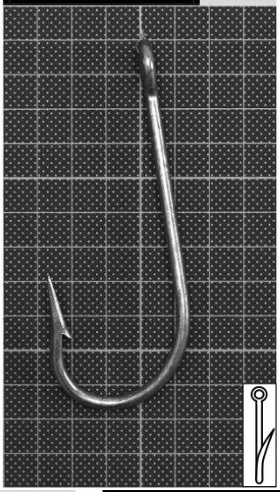


J HOOKS

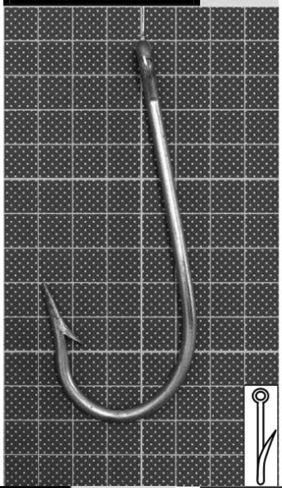
Size/Tamaño 2/0 J-01



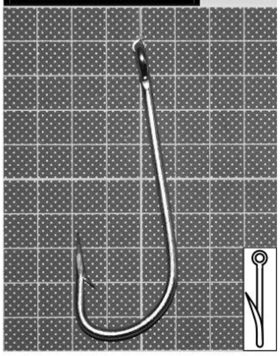
Size/Tamaño 1/0 J-02



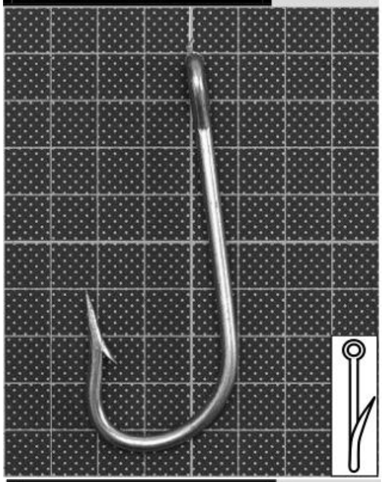
Size/Tamaño 1/0 J-03



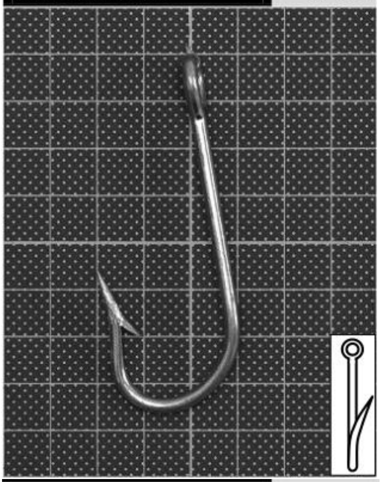
Size/Tamaño No. 2 J-04



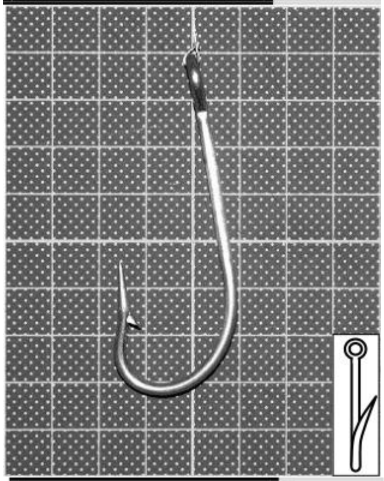
Size/Tamaño 2 J-05



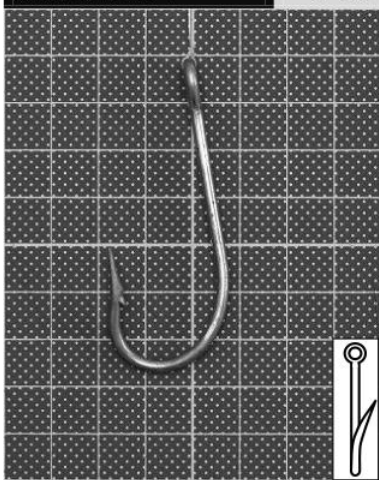
Size/Tamaño 3 J-06



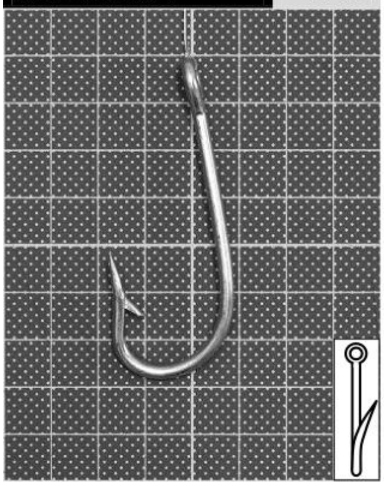
Size/Tamaño 3 J-07



Size/Tamaño 4 J-08



Size/Tamaño 4 J-09



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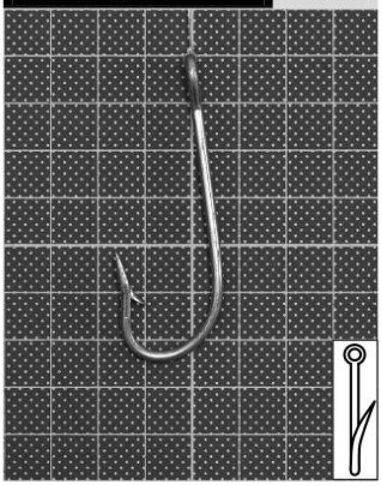
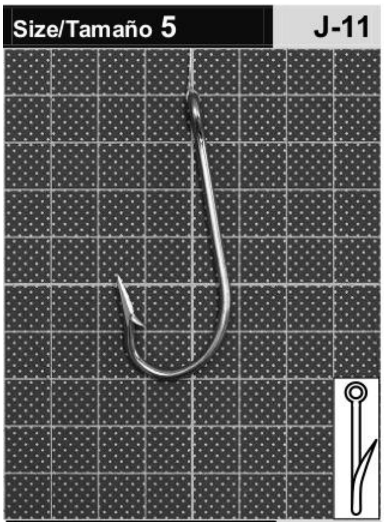
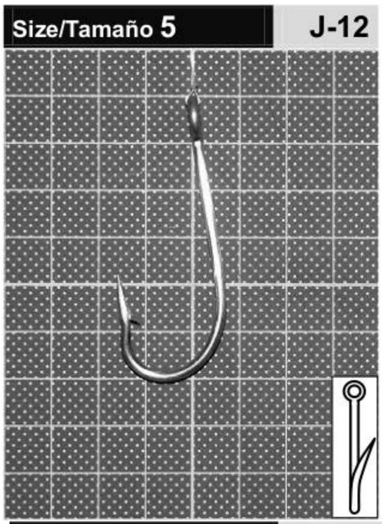


J HOOKS


Size/Tamaño 5
J-11


Size/Tamaño 5
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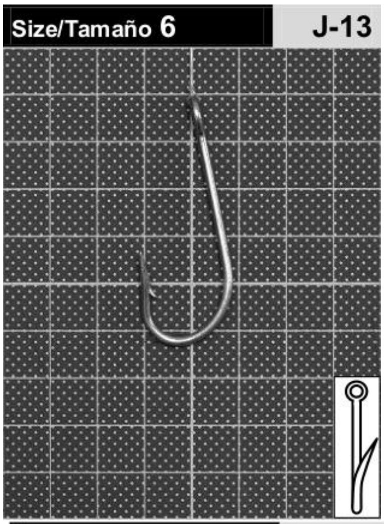
Size/Tamaño 6
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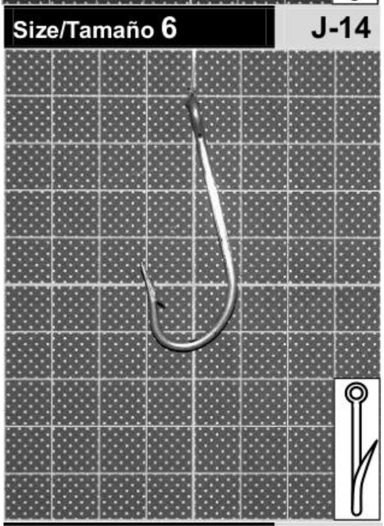
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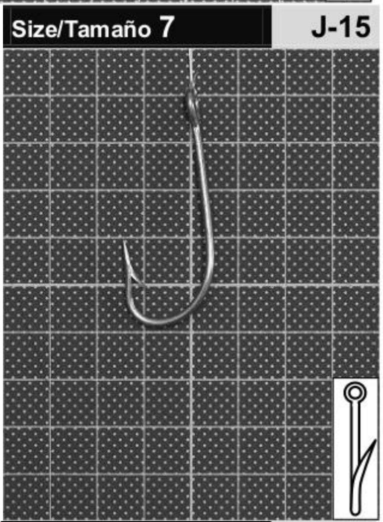
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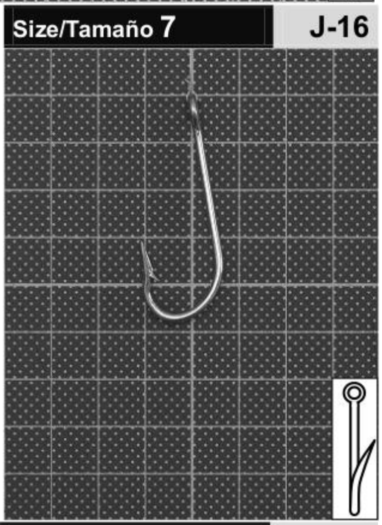
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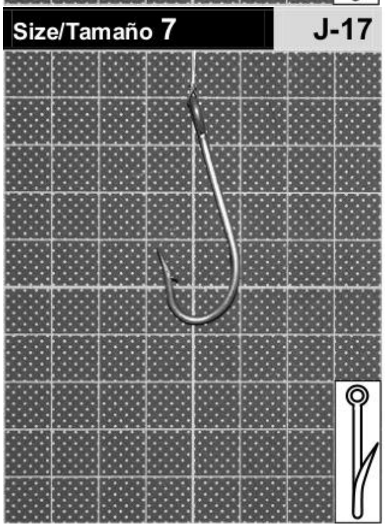
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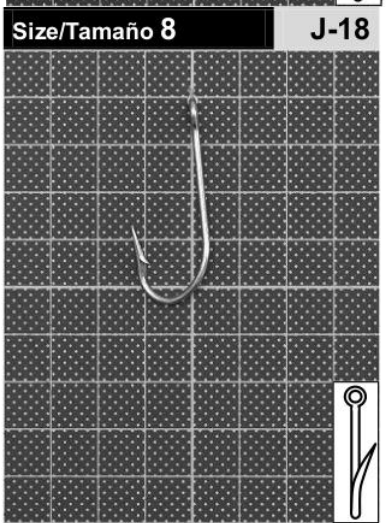
Size/Tamaño 8
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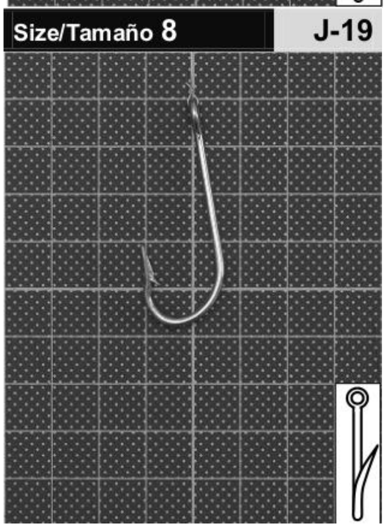
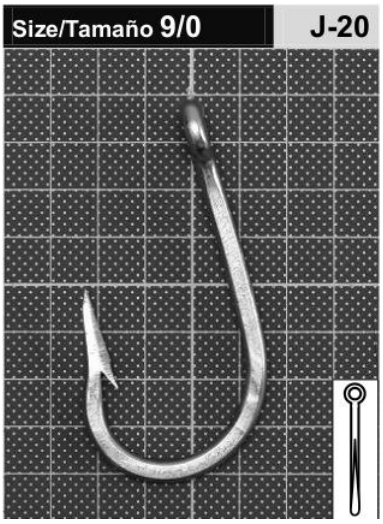

Size/Tamaño 8
J-19

J HOOKS


Size/Tamaño 9/0
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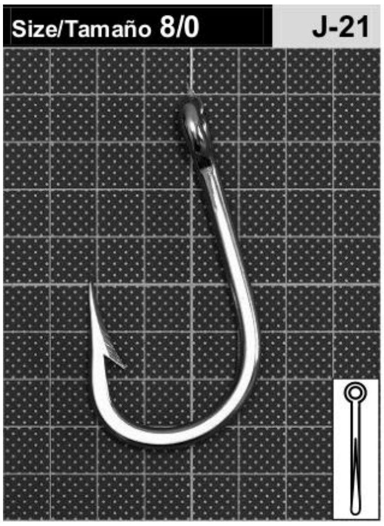
Size/Tamaño 8/0
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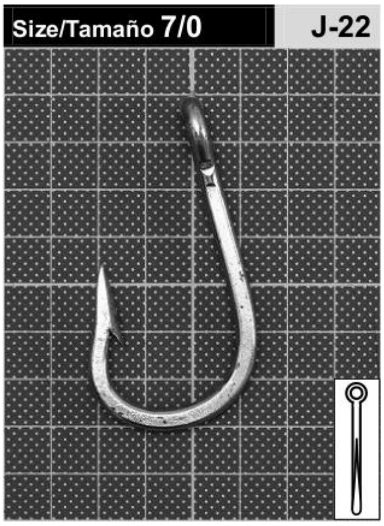
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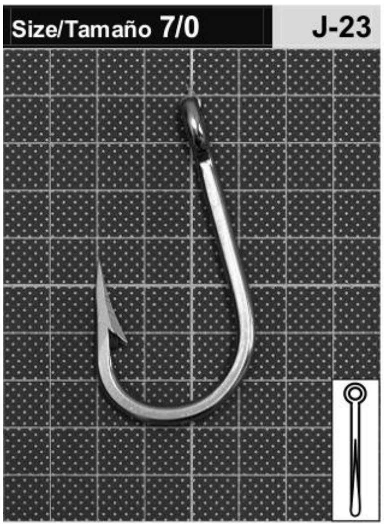
Size/Tamaño 7/0
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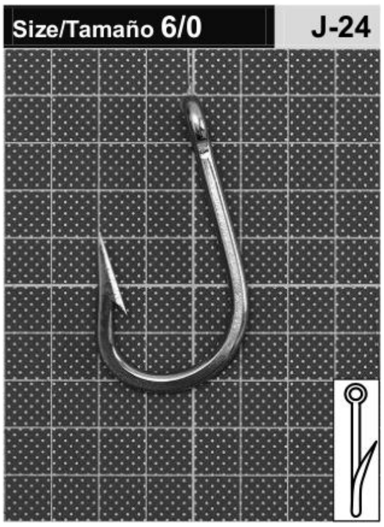
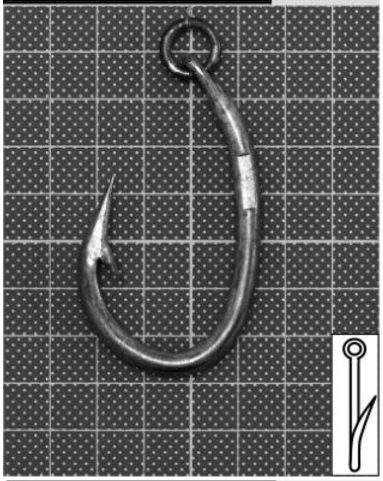

Size/Tamaño 6/0
J-24

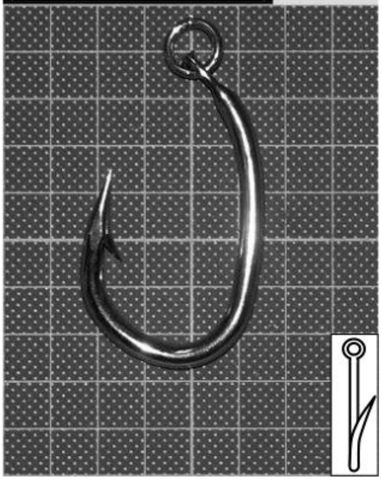

J – 9/0
R

TUNA HOOKS

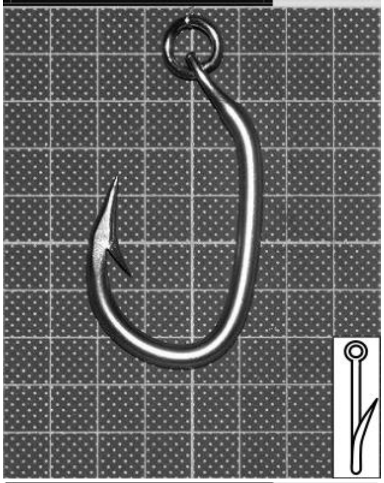
Size/Tamaño 40 T-01



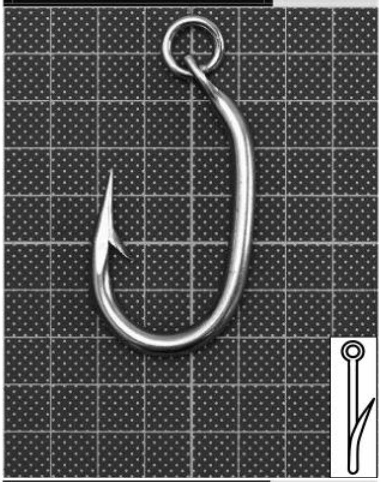
Size/Tamaño 10/0 T-02



Size/Tamaño 9/0 T-03



Size/Tamaño 38 T-04



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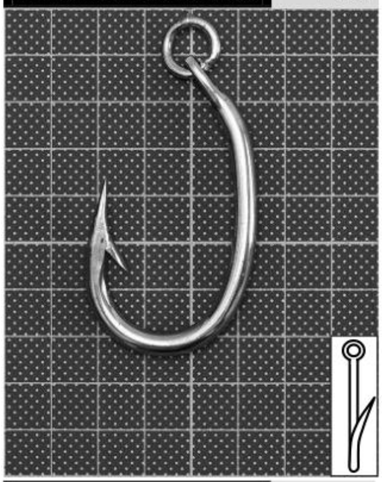
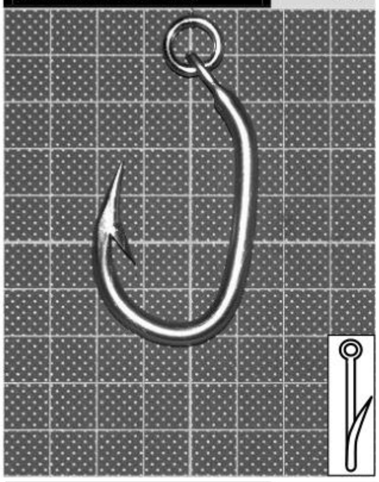
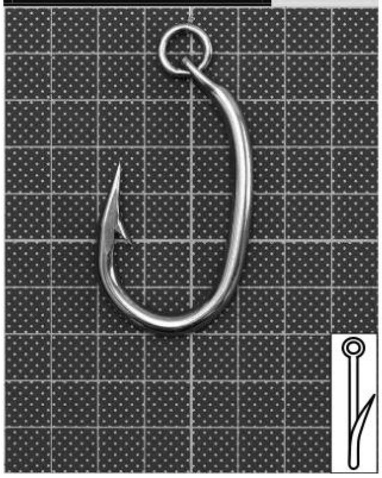


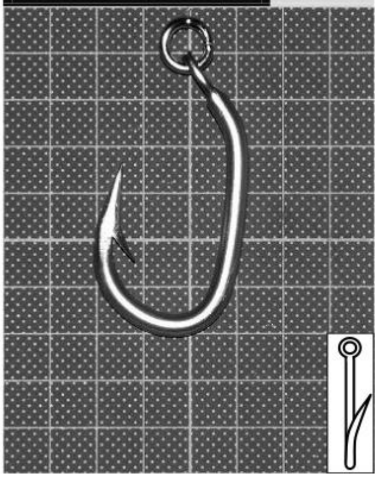
Size/Tamaño 8/0 T-06



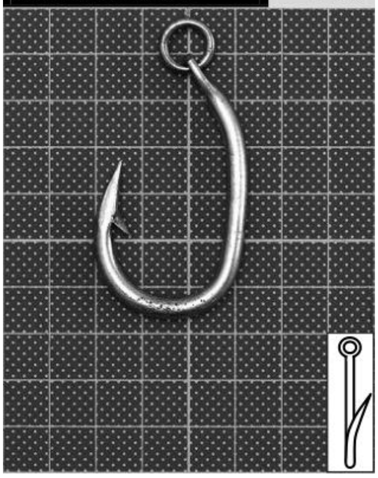
Size/Tamaño 36 T-07



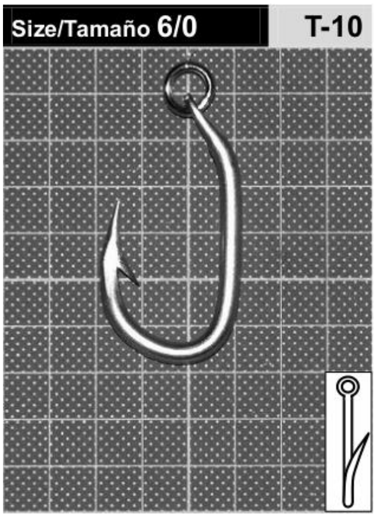
Size/Tamaño 7/0 T-08

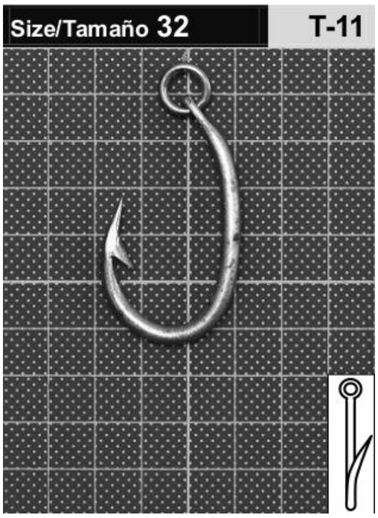


Size/Tamaño 34 T-09



TUNA HOOKS



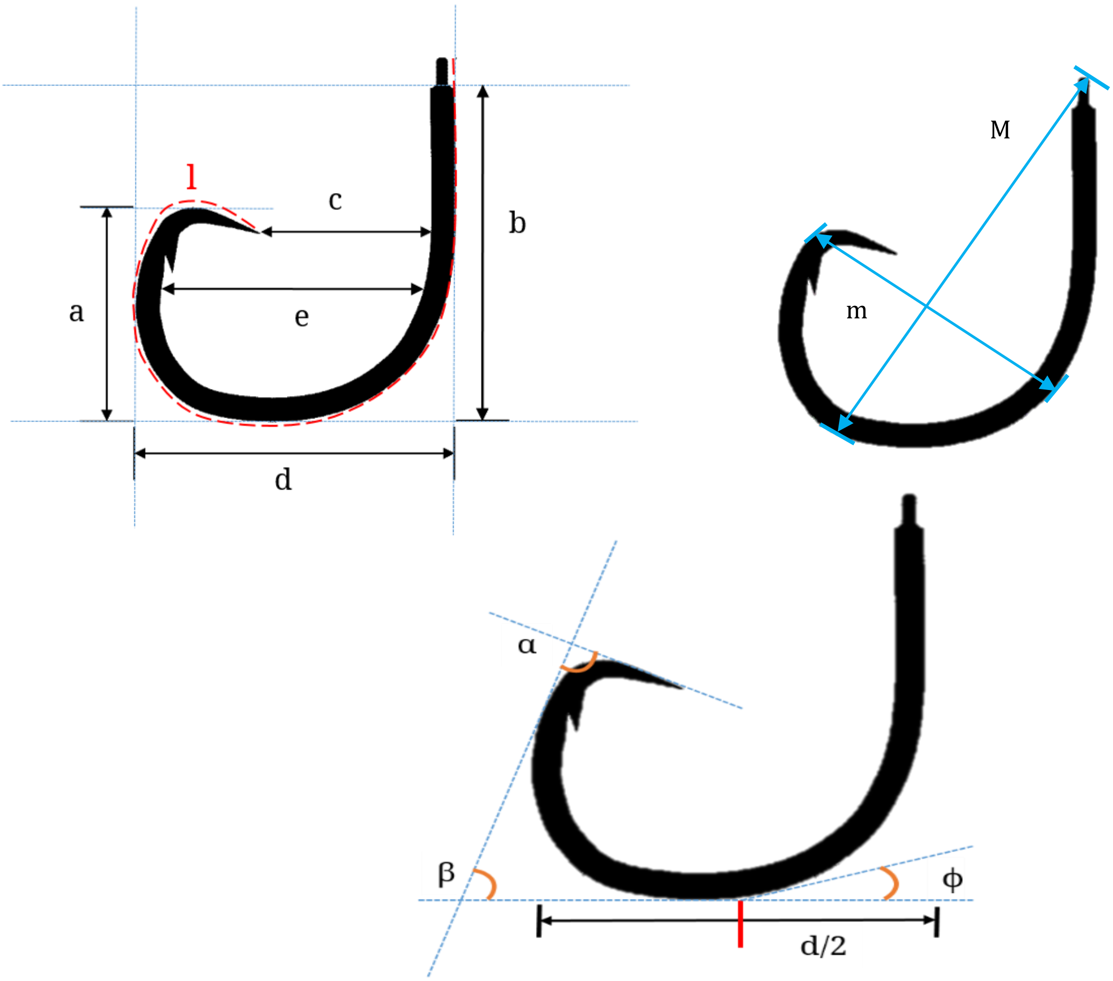


TERACIMA HOOKS

APPENDIX X: MEASUREMENTS OF HOOKS

Measurements of hook variables describing the shape of different hook size and type used in pelagic longlining, including figures with the specific measurements.

SHAPE AND SIZE VARIABLES COLLECTED ON THE HOOK



Measures

a	Front length (mm)
b	Straight total length (mm)
c	Minimum inner width (mm)
d	Straight total width (mm)
e	Maximum inner width (mm)
L	Total length (mm)
m	Minimum total width (mm)
M	Maximum total width (mm)

α tilt of the point and barb (°)

β tilt of the tangent of the bend on the front part of the hook (°)

ϕ tilt of the tangent of the bend on the shank side of the hook (°)

CIRCLE HOOKS

PHOTO ID	HOOK ID	a	b	c	e	d	L	m	M	α	β	ϕ
C01	18/0	49	65	28	50	64	177	50	87	132	54	26
C02	18/0	49	66	29	51	64	177	51	87	137	48	26
C03	18/0	50	57	26	51	62	179	54	87	133	59	21
C04	16/0	46	44	23	44	51	153	49	74	121	71	22
C05	16/0	46	44	24	43	54	154	47	74	133	60	25
C06	16/0	45	46	20	44	54	156	45	74	130	58	26
C07	16/0	41	54	25	41	51	147	43	77	140	58	24
C08	16/0	39	55	25	40	51	145	41	77	131	60	24
C09	16/0	41	47	24	45	55	150	44	69	133	43	20
C10	16/0	45	36	28	47	60	147	50	70	122	68	18
C11	16/0	41	57	19	38	50	157	42	82	136	59	24
C12	16/0	39	56	24	39	48	152	40	75	133	61	22
C13	16/0	49	54	20	45	56	168	51	82	128	67	22
C14	16/0	40	54	26	42	54	156	45	85	138	63	20
C15	15/0	38	40	19	40	44	131	35	59	134	48	26
C16	15/0	37	49	19	37	46	140	39	75	144	52	23
C17	15/0	39	44	22	40	47	141	41	67	130	57	19
C18	15/0	37	41	24	37	44	130	41	70	132	63	17
C19	15/0	40	40	23	37	43	130	40	65	130	62	20
C20	15/0	39	38	20	38	45	131	38	64	139	56	20
C21	15/0	41	45	18	36	45	138	43	70	124	65	27
C22	15/0	38	42	20	36	48	132	40	70	122	54	26
C23	14/0	33	36	16	35	37	125	34	58	116	54	31
C24	14/0	34	46	18	38	43	143	37	68	131	61	23
C25	14/0	41	38	16	34	39	120	34	61	130	51	20
C26	14/0	32	41	16	28	37	116	31	61	115	66	28
C27	13/0	33	38	19	32	42	116	34	57	133	63	21
C28	13/0	35	43	17	31	40	126	34	67	139	62	26
C29	13/0	33	35	14	31	38	109	31	52	116	47	31
C30	13/0	32	33	13	30	35	110	29	50	133	51	21
C31	13/0	28	34	15	25	34	100	27	54	117	59	27
C32	13/0	30	37	17	33	35	113	34	54	139	61	11
C33	12/0	27	38	18	30	36	109	31	59	135	66	20
C34	12/0	28	28	12	27	32	94	26	44	131	55	24
C35	10/0	22	24	10	19	24	72	21	35	135	65	21
C36	9/0	17	21	7	14	17	56	16	29	125	70	20
C37	4.0 sun	36	38	26	40	50	128	38	67	135	57	29
C38	3.8 sun	32	36	25	37	47	119	35	63	129	54	30
C39	3.6 sun	31	40	24	33	43	110	31	58	155	60	33
C40	3.4 sun	30	37	20	31	41	105	31	55	130	54	32
C 12/0R	12/0	28	29	14	27	33	98	29	47	121	56	16
C 13/0R	13/0	28	38	15	27	36	110	31	55	119	67	26
C 14/0R	14/0	36	41	19	33	41	124	37	61	122	63	17
C 16/0R	16/0	44	52	23	40	52	156	46	77	131	63	22
C 20/0R	20/0	56	66	36	54	67	197	61	98	117	71	23

J HOOKS

PHOTO ID	HOOK ID	a	b	c	e	d	L	m	M	α	β	ϕ
J01	2/0	45	99	40	43	51	192	53	123	180	79	30
J02	1/0	40	86	34	36	41	165	47	106	180	83	20
J03	1/0	44	90	36	39	43	174	51	110	173	88	26
J04	2	33	72	25	25	32	135	34	87	180	79	27
J05	2	35	66	24	26	33	135	38	84	169	84	27
J06	3	32	59	22	25	29	121	34	76	163	81	32
J07	3	30	58	20	20	29	117	31	73	180	72	31
J08	4	28	53	21	21	27	108	30	67	180	79	25
J09	4	28	52	19	21	28	106	30	66	180	82	29
J10	5	24	52	17	19	23	99	25	64	180	86	31
J11	5	24	50	19	21	24	97	26	62	180	90	30
J12	5	25	50	19	20	24	98	26	62	180	84	25
J13	6	21	43	15	16	20	85	22	53	180	81	30
J14	6	21	42	15	16	20	82	23	53	180	87	30
J15	7	19	42	16	18	21	80	21	53	180	85	37
J16	7	18	39	13	15	18	75	20	49	180	84	28
J17	7	18	38	13	14	17	73	20	47	180	85	25
J18	8	16	35	12	14	15	65	18	42	180	93	29
J19	8	18	40	14	15	18	75	19	49	180	85	24
J20	9/0	45	64	31	31	42	147	45	83	180	77	23
J21	8/0	38	56	29	30	38	132	39	66	180	76	22
J22	7/0	38	51	25	29	38	128	38	71	180	69	21
J23	7/0	36	51	26	28	34	124	39	69	180	77	17
J24	6/0	37	46	24	26	34	117	39	63	180	74	11
J 9/0	9/0	42	63	29	32	41	146	39	82	180	68	16

TUNA HOOKS

PHOTO ID	HOOK ID	a	b	c	e	d	L	m	M	α	β	ϕ
T01	4.0 sun	41	61	24	28	37	138	45	73	180	68	13
T02	10/0	41	60	26	27	37	137	45	72	180	70	10
T03	9/0	39	61	25	25	36	140	43	74	180	73	5
T04	3.8 sun	38	59	26	26	33	133	42	72	180	83	21
T05	3.8 sun	38	58	27	27	36	132	42	72	180	75	18
T06	8/0	36	56	24	24	32	128	40	68	180	74	0
T07	3.6 sun	36	56	24	24	31	124	39	66	180	78	8
T08	7/0	35	56	23	23	31	127	40	69	180	75	0
T09	3.4 sun	32	52	23	23	31	119	37	64	180	61	0
T10	6/0	33	51	21	21	29	115	38	62	180	78	0
T11	3.2 sun	31	49	22	22	29	109	34	60	180	70	0

TERACIMA HOOKS

PHOTO ID	HOOK ID	a	b	c	e	d	L	m	M	α	β	ϕ
Ter 3.0R	3.0 sun	32	35	20	27	34	105	33	56	180	57	17
Ter 3.2B	3.2 sun	40	42	27	34	44	130	42	68	180	55	20
Ter 3.4B	3.4 sun	39	43	25	32	41	123	38	63	161	71	14
Ter 3.6B	3.6 sun	42	46	26	34	43	133	41	67	165	70	15
Ter 3.8B	3.8 sun	37	38	22	29	37	115	36	59	168	70	20
Ter 3.8R	3.8 sun	40	43	24	32	40	126	39	63	169	70	17

APPENDIX XI: ONLINE QUESTIONNAIRE

Below we provide the questionnaire and additional Excel file requesting information on the hook type and hooking location.

Description

As part of a study dealing with the evaluation of the effects of hooks' shape & size on the catchability, yields and mortality of target and by-catch species, we are analysing technical and biological reasons explaining the supposed practical effects of the circle hooks with respect to other shapes of hooks.

To this end, we would like to know if you collect/have collected data concerning pelagic longline fisheries, in order to study the relationship between the hook type and the hooking location and to link the latter with the at-vessel fish status. In the case where the study concerns you, you will receive a web link which leads you to an excel file to fill in and return to us by e-mail, if you wish to collaborate.

Thank you for your time and consideration.

* Required

Section 1

1.
What is your name? *

2.
What is your email address?

3.
What institution or organization do you belong to? *

4.
Have you implemented / are you in the process of implementing a longline fishery observer program or experimental pelagic longline trials? *

- Yes
- No

Section 2: Data collected concern / will concern

5.
Longline characteristics (number of sets, setting time, hauling time ...)

- Yes
- No

6.
Fishing gear used and its dimensions (several options can be selected)

- No
- Mainline
- Branchline and leader
- Floatline

- Hook (type and size)
- Bait type

7.
Target species (several options can be selected)
- No
- Species
- Individual's length
- Individual's weight
- Sex
- Other:

8.
Bycatch species (several options can be selected)
- No
- Species
- Individual's length
- Individual's weight
- Sex
- Other:

9.
Did you collect at-haulback status (dead or alive) and/or hooking location for TARGET species? *
- At-haulback status only
- Hooking location only
- Both
- None

10.
Did you collect at-haulback status (dead or alive) and/or hooking location for BYCATCH species? *
- At-haulback status only
- Hooking location only
- Both
- None

Section 3: At-haulback status and hooking location collected

11.
Collected for (several options can be selected) *
- Turtles
- Sharks and rays
- Marine mammals
- Marine birds
- Tunas
- Swordfish
- Billfishes
- Other finfishes
- Other:

12.
How detailed is the hooking location reported?
- Only External vs Internal
- Detailed (lip/mouth/jaw/throat/gut/fin...)

13.

Concerning marine turtle interactions, are individuals transferred to a marine rescue centre when injured?

- Yes
- No

14.
If yes, could you submit us the contact information (web link, e-mail address...)

15.
Are these data already published in (a) grey literature reports? If yes, could you submit us the reference(s)?

Section 4: Sharing data

16.
Would you agree to share the data concerning hooking location and/or at-haulback status via an excel file to return by e-mail?

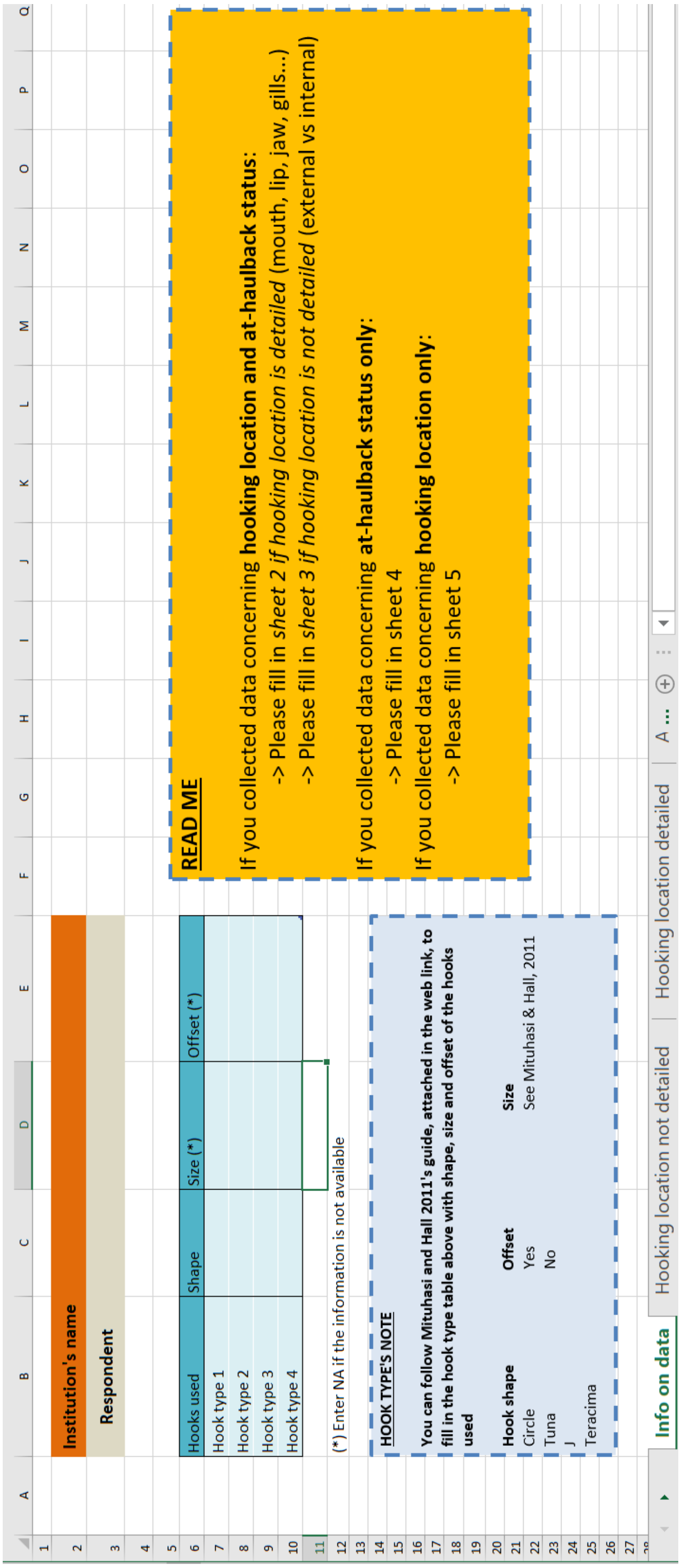
- Yes
- No

Section 5: Excel file to fill in

Please find the following link of the excel file to fill in and return to yoluene.massey@ird.fr:
https://drive.google.com/open?id=1b0Hp-juBshBES1c65UXLZOKapzptIDcW

Thank you for your fruitful contribution!

EXCEL FILE TO FILL IN



SPECIE'S NOTE

Concerning sharks, the first table on top refers to **all shark species taken together**, the following tables refer to seven major common pelagic shark species.

Concerning turtles, there is only one table to fill in and it refers to **all marine turtles species taken together**.

SHARKS (ALL)	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

TURTLES	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Carcharhinus falciformis	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Prionace glauca	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Carcharhinus longimanus	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Isurus oxyrinchus	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Isurus paucus	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Alopias pelagicus	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Alopias superciliosus	*Hook type 1*		*Hook type 2*		*Hook type 3*		*Hook type 4*	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
External								
Internal								

Info on data | **Hooking location not detailed** | Hooking location detailed | A ...

SPECIE'S NOTE

Concerning **sharks**, the first table on top refers to **all shark species taken together**, the following tables refer to seven major common pelagic shark species.

Concerning **turtles**, there is only one table to fill in and it refers **to all marine turtles species taken together**.

SHARKS (ALL)	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
Mouth								
Lip								
Jaw								
Gills								
Throat								
Gut								
Fin								

TURTLES (ALL)	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
Beak								
Mouth								
Beak								
Gut								
Fin								

Carcharhinus falcifor	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
Mouth								
Lip								
Jaw								
Gills								
Throat								
Gut								
Fin								

Isurus paucus	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
Mouth								
Lip								
Jaw								
Gills								
Throat								
Gut								
Fin								

Prionace glauca	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
Mouth								
Lip								
Jaw								
Gills								
Throat								
Gut								
Fin								

Alopias pelagicus	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
Hooking location	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
Mouth								
Lip								
Jaw								
Gills								
Throat								
Gut								
Fin								

Carcharhinus longim	Hook type 1		Hook type 2		Hook type 3		Hook type 4	

Alopias superciliosus	Hook type 1		Hook type 2		Hook type 3		Hook type 4	

Info on data | Hooking location not detailed | **Hooking location detailed** | A ...

SPECIE'S NOTE

Concerning **sharks**, the first table on top refers to **all shark species taken together**, the following tables refer to seven major common pelagic shark species.

Concerning **turtles**, there is only one table to fill in and it refers **to all marine turtles species taken together**.

	Hook type 1		Hook type 2		Hook type 3		Hook type 4	
SHARKS (ALL)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
	Hook type 1		**Hook type 2**		**Hook type 3**		**Hook type 4**	
TURTLES (ALL)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
	Hook type 1		**Hook type 2**		**Hook type 3**		**Hook type 4**	
Carcharhinus falciformis	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
	Hook type 1		**Hook type 2**		**Hook type 3**		**Hook type 4**	
Prionace glauca	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
	Hook type 1		**Hook type 2**		**Hook type 3**		**Hook type 4**	
Carcharhinus longimanus	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)
	Hook type 1		**Hook type 2**		**Hook type 3**		**Hook type 4**	
Isurus oxyrinchus	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)	Alive (n)	Dead (n)

... | Hooking location detailed | **At-haulback status only** | Hooking location only

SPECIE'S NOTE

Concerning **sharks**, the first table on top refers to **all shark species taken together**, the following tables refer to seven major common pelagic shark species.

Concerning **turtles**, there is only one table to fill in and it refers to **all marine turtles species taken together**.

SHARKS (ALL)	*Hook type 1*	*Hook type 2*	*Hook type 3*	*Hook type 4*
Mouth				
Lip				
Jaw				
Gills				
Throat				
Gut				
Fin				

TURTLES (ALL)	*Hook type 1*	*Hook type 2*	*Hook type 3*	*Hook type 4*
Beak				
Mouth				
Beak				
Gut				
Fin				

Carcharhinus falciformis	*Hook type 1*	*Hook type 2*	*Hook type 3*	*Hook type 4*
Mouth				
Lip				
Jaw				
Gills				
Throat				
Gut				
Fin				

Isurus paucus	*Hook type 1*	*Hook type 2*	*Hook type 3*	*Hook type 4*
Mouth				
Lip				
Jaw				
Gills				
Throat				
Gut				
Fin				

Prionace glauca	*Hook type 1*	*Hook type 2*	*Hook type 3*	*Hook type 4*
Mouth				
Lip				
Jaw				
Gills				
Throat				
Gut				
Fin				

Alopias pelagicus	*Hook type 1*	*Hook type 2*	*Hook type 3*	*Hook type 4*
Mouth				
Lip				
Jaw				
Gills				
Throat				
Gut				
Fin				

... Hooking location detailed | At-haulback status only | **Hooking location only**

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