Collect. Vol. Sci. Pap. ICCAT, 82(2), SCRS/2025/034: 1-17 (2025)

POST-RELEASE MORTALITY OF SHORTFIN MAKO IN THE ATLANTIC OCEAN USING SATELLITE TELEMETRY

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SUMMARY

*This paper presents data from 128 tags used to determine the post-release mortality (PRM) of the shortfin mako (*Isurus oxyrinchus*). The tags include 14 sPATs, 21 Mk10-PATs, and 63 miniPATs from Wildlife Computers; 16 PSATLIFE tags from Lotek Wireless; and 14 X-Tags from Microwave Telemetry. Sharks were tagged during multiple research and commercial fishing trips aboard pelagic longliners in different areas of the Atlantic Ocean. To maximize tag comparability for the PRM analysis, we set the mortality threshold at 28 days. The overall PRM rate for shortfin mako sharks caught by pelagic longliners was 29.4%. Operational factors, such as in-water or onboard tagging and hook removal, may play a critical role in improving post-release survival rates.*

RÉSUMÉ

*Ce document présente les données de 128 marques utilisées pour déterminer la mortalité après la remise à l'eau (PRM) du requin-taupe bleu (*Isurus oxyrinchus*). Les marques comprennent 14 sPAT, 21 Mk10-PAT, et 63 miniPAT de Wildlife Computers ; 16 marques PSATLIFE de Lotek Wireless ; et 14 X-Tags de Microwave Telemetry. Les requins ont été marqués au cours de multiples campagnes de recherche et sorties de pêche commerciale à bord de palangriers pélagiques dans différentes zones de l'océan Atlantique. Afin de maximiser la comparabilité des marques pour l'analyse PRM, nous avons fixé le seuil de mortalité à 28 jours. Le taux global de PRM pour les requins-taupes bleus capturés par les palangriers pélagiques était de 29,4%. Les facteurs opérationnels, tels que le marquage dans l'eau ou à bord et le retrait des hameçons, peuvent jouer un rôle essentiel dans l'amélioration des taux de survie après la remise à l'eau.*

RESUMEN

Este documento presenta datos de 128 marcas utilizadas para determinar la mortalidad posterior a la liberación (PRM) del marrajo dientuso (Isurus oxyrinchus). *Las marcas incluyen 14 sPATs, 21 Mk10-PATs y 63 miniPATs de Wildlife Computers; 16 marcas PSATLIFE de Lotek Wireless; y 14 X-Tags de Microwave Telemetry. Los tiburones fueron marcados durante múltiples mareas de investigación y pesca comercial a bordo de palangreros pelágicos en diferentes zonas del océano Atlántico. Para maximizar la comparabilidad de las marcas en el análisis de PRM, fijamos el umbral de mortalidad en 28 días. La tasa global de PRM de los marrajos dientusos capturados por palangreros pelágicos fue del 29,4 %. Los factores operativos, como el marcado en el agua o a bordo y la retirada del anzuelo, pueden desempeñar un papel fundamental en la mejora de las tasas de supervivencia tras la liberación.*

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KEYWORDS

Post-release mortality; Isurus oxyrinchus;
Shortfin mako; longline fisheries; Atlantic Ocean; satellite tagging

1. Introduction

Fishing represents one of the earliest productive activities developed by humans and has progressively evolved into a global industry centered on the capture and commercialization of aquatic resources. Over time, it has become the primary driver of mortality for numerous fish species, both through the targeted exploitation of commercially valuable stocks and the incidental capture of non-target species resulting from the use of non-selective fishing gear. Particularly for pelagic and oceanic species, longline fisheries are responsible for a large number of global catches, and also one of the most important sources of mortality (Bonfil 1994; Camhi et al. 2008; Clarke et al. 2014). As such, a comprehensive understanding of species interactions and the underlying causes of mortality within these fisheries is essential for the development of effective management strategies (Anónimo, 2013; Campana et al., 2015; Musyl & Gilman, 2018).

Once a shark is hooked on a longline, it is subjected to varying degrees of physical injury (e.g., hook-related wounds, abrasion from the leader) and physiological stress (e.g., elevated metabolic rates, exhaustion, impaired ventilation, and increased cortisol levels). These effects can be exacerbated by the way the fishing crew handles the animal during hauling and release procedures (Skomal, 2007; Ellis et al., 2017; Mandelman et al., 2022). Numerous studies have demonstrated that hooking mortality in sharks is influenced by a complex interplay of factors, including individual characteristics such as size, sex, behavior, and physiological condition, as well as environmental and operational variables such as season, geographic location, water temperature, and specific fishing practices (e.g., soak time, hook type, and handling methods) (Coelho et al., 2012, 2013; Gallagher et al., 2014; Ellis et al., 2017; Mandelman et al., 2022). Moreover, these findings underscore that estimates of hooking mortality are likely to differ among fishing fleets, as gear configurations and fishing practices can vary significantly across fishing fleets. These variations include differences in hook type and size, soak duration, fishing depth (e.g., shallow vs. deep sets), and geographic distribution of fishing effort (Domingo et al., 2014).

Hooking mortality provides valuable information for fisheries management. Understanding whether sharks survive or perish by the time the fishing gear is retrieved can help evaluate management strategies, such as regulating the size of retained individuals or prohibiting the retention of certain species. (Coelho et al. 2013; Clarke et al. 2014; Ellis et al. 2017). Post-release mortality, on the other hand, represents the probability of a shark dying due to causes related to the fishing event after being caught and released alive (Campana et al. 2015). Therefore, the combination of both hooking and post-release mortality is indicative of total fishing induced mortality (F), which at the same time represents one of the major parameters estimated needed in stock assessments.

In 2013 the Shark Research and Data Collection Program (SRDCP) was created by ICCAT's Shark Species Group. The main objective of this project is the development and coordination of research and science-related initiatives in order to provide grounded scientific advice for the sustainable management and conservation of sharks in the Atlantic Ocean. During the 2014 inter-sessional meeting, the Shark Working Group updated the SRDCP, which was framed within the 2015-2020 SCRS Strategic Plan. The initial implementation of this Research Programme focused on the biology, ecology and fisheries aspects of the shortfin mako shark (*Isurus oxyrinchus*) that are relevant to its stock assessment. Within the ICCAT/SRDCP, two specific studies using satellite telemetry were developed for the shortfin mako: 1) a study aimed at gathering and providing information on stock boundaries, movement patterns and habitat use in the Atlantic; and 2) a study focused on the assessment of post-release mortality. This document is intended to update previous results from the post-release mortality study (Domingo et al. 2018, Miller et al. 2020) by including more recently deployed tags from ICCAT as well as other deployments form independent research projects.

2. Methods

2.1 Tag acquisition

Shark Research and Data Collection Program (SRDCP)

Two models of tags were used: MiniPAT and Survivorship PAT (sPAT) tags built by Wildlife Computers (WC). The former model was used to address the objective 1 of the SRDCP, and the latter to address the objective 2 (see Introduction). The first tag acquisition process was completed during 2015, and the tags were then distributed to the participating Institutes in late 2015. In this first project phase, a total of 9 miniPATs and 14 sPATs were acquired. Additionally, in late 2016, 12 additional miniPATs were acquired for deployment during 2017-2018, during the second phase of the project. As such, for the second phase of the project a total of 13 miniPATs were available for deployment in 2017-2018. In the third phase of the project, 20 miniPATs were acquired for deployment on shortfin mako as well as silky shark. The 20 miniPATs acquired during the fourth phase of the project are planned to be deployed on shortfin mako as well as other pelagic species such as the porbeagle, silky shark and oceanic whitetip. For full details of all the tags acquired during the project, their allocation for deployment and their current deployment status, please refer to **Table 1** of document SCRS/2019/090.

Other Projects

The scientists and institutes involved in this study had other ongoing projects and initiatives that also included the deployment of satellite telemetry tags on shortfin makos. This information was made available to the group and used to complement the PRM analysis.

2.2 Tagging procedure

A total of 128 tags from three manufacturers (Wildlife Computers: 14 sPATs, 21 Mk10-PATs and 63 miniPATs; Lotek Wireless: 16 PSATLIFE; Microwave Telemetry: 14 X-Tag) were deployed on shortfin mako sharks during this study. Sharks were tagged during several research trips and commercial fishing trips in different areas of the Atlantic Ocean, including the Northeast Atlantic (NEA), Northwest Atlantic (NWA), Southeast Atlantic (SEA), Southwest Atlantic (SWA), and the Equatorial Atlantic (EqA), defined as the area within the 10N-10S latitudinal range (**Figure 1**).

Sharks were either hoisted alongside the vessel or brought on board for tagging. Most tags were affixed to the dorsal musculature of the shark, and close the first dorsal fin base, with a plastic Domeier-type (n = 94) or a stainless-steel anchor (n = 24), although in six individuals the tag was secured directly to de first dorsal fin by a monofilament loop crimped to tag. Tagging operations lasted for a maximum of 5 minutes and did not produce any additional injuries or damage to the specimens. Before attachment, tags were tested for accurate data collection. All sPATs and PSATLIFE tags were pre-programmed to detach 30 and 28 days after deployment, respectively (see below), whereas Mk10-PATs, miniPATs and X-tags were programmed to record information for periods between 30 and 351 days. In order to preserve the physical integrity of the tags, all tag types had a safety release mechanism that would initiate a premature detachment if depth exceeded 1400, 1700 or 1800 m (depending on tag model).

All tagged animals were sexed and their fork length (FL) measured or estimated, when possible. Male maturity status (juveniles or adult) was determined based on the size and calcification of the claspers. For all females and all males for which maturity status could not be determined in situ, individuals were assigned into the juvenile or adult category based on the median sizes-at-maturity published for the southern (174 cm FL, females: 246 cm FL, Cabanillas-Torpoco et al. 2024[13]) and northern (males: 182 cm FL, females: 280 cm FL, Natanson et al. 2020) hemispheres.

Date and time were recorded, and the geographic tagging location (latitude and longitude) was determined by Global Positioning System (GPS). Whenever possible, for each tagged individual additional information was recorded, including hooking location, hook type, whether the hook was removed or not prior to release, branchline material (monofilament or wire/stainless-steel). In previous analysis (Domingo et al. 2018; Miller et al. 2020), animal condition was also considered (Perfect: no visual damage; Moderate: superficial damage; Severe: damage could affect survival and Unknown). However, the group concluded that considerable subjectivity existed among observers when qualitatively assessing the condition of individual sharks. Moreover, the incorporation of tag

[13] Converted to FL from TL using Mas et al. (2014) conversion equation.

deployments from other research projects into the analysis hindered comparability due to the use of differing assessment criteria or, in some cases, the complete absence of condition data. Consequently, animal condition was not considered in the present study.

2.3 Data analysis

In order to be able to compare as many tags as possible for the PRM analysis, we set the mortality threshold at 28 days (maximum deployment duration from PSATLIFE tags). Therefore, all sharks with deployments equal or larger to 28 days were assumed to have survived the negative effects of the fishing interaction. Once popped-off sPATS sent a tag report describing the reason for detachment (scheduled, premature, unknown), together with daily minimum and maximum depths recorded throughout the entire deployment. In all other tag models, different data products, including depth and temperature time series at predefined sampling rates, percentage of time spent at pre-defined depth and temperature bins, and light intensity curves can be obtained, as well as summary of the reason for detachment. This information can then be used to infer mortality or survival events. As mentioned before, all sharks with deployments equal or larger to 28 days were assumed to have survived the negative effects of the fishing interaction. On the other hand, tags that were detached prematurely due to reaching depths in excess of 1700 m (Sinker) or that had recorded a constant depth for at least one day before detachment (Sitter, indicative of dead sharks lying dead in the bottom but shallower than 1700m) can both be attributed to post-release mortality events. Lastly, tags can also detach prematurely for unknown reasons, float to surface and transmit (Floater), or directly fail to transmit any data. In these cases, no definite conclusion regarding mortality or survival can be inferred and therefore were left out of the post-release mortality analysis.

Post-release mortality was assessed against shark's size, sex, hook fate (removed or not) and geographical region. All statistical analyses for this paper were carried out with the R language (R Core Team, 2024, R version 4.4.1 (2024-06-14 ucrt). Plots and maps were created using libraries *ggplot2* (Wickham, 2016), *ggspatial* (Dunnington 2023), *sf* (Pebesma E. 2018; Pebesma & Bivand 2023), and *sp* (Pebesma & Bivand 2005; Bivand & Gomez-Rubio 2013). Interactive plots of depth-temperature time series and daily min-max depth time series were constructed using the library *plotly* (Sievert 2020).

3. Results and Discussion

3.1 Tag performance

To enhance the sample size and complement the data obtained from the 30 shortfin mako sharks equipped with survival tags (14 sPAT and 16 PSATLIFE), we incorporated data from an additional 98 individuals tagged with miniPAT, Mk10-PAT, and X-Tag devices, which were originally deployed to investigate habitat use and movement patterns. While this approach provides a larger and more representative sample, it may also introduce bias into post-release mortality (PRM) estimates, as habitat-use tags are typically deployed on sharks in better condition, avoiding individuals with compromised health.

Unexpectedly, however, overall PRM rates were higher in sharks fitted with habitat-use tags (**Figure 1**). On the other hand, Miller et al. (2020) found no significant differences between transmitter groups (post-release vs. habitat use), supporting the use of habitat-use transmitters for PRM analyses. Our findings further emphasize that external visual assessments of a shark's condition are highly subjective and unreliable for predicting its likelihood of surviving interactions with fisheries.

The miniPAT was the tag model most used, followed by Mk10-PAT, PSATLIFE, sPAT, and X-Tag (Figure 2). Premature releases occurred in all tag models but were more frequent in miniPAT and Mk10-PAT models. Conversely, the sPAT and PSATLIFE tag models had the largest occurrence of complete deployments, albeit this is likely a consequence of their shorter deployment durations. Tag failures occurred in three tag models, with the highest frequency observed for the X-tags (15.4%) (**Figure 2**). The effect of anchor type on tag performance could not be assessed properly as most tag models were placed using only one type of anchor (**Figure 3**). Only in the case of miniPATs were more than one anchor type used. Out of 37 miniPATs deployed 62.2% detached prematurely for some reason. Although with considerably smaller sample sizes, miniPAT tags secured with a monofilament loop or with a stainless-steel dart showed premature release rates of 40% and 100% respectively.

3.2 General Results

In total, 128 satellite tags were deployed between 2011 and 2022 by seven nations: Brazil (n = 3), Canada (n = 49), EU-Portugal (n = 36), EU-Spain (n = 3), South Africa (n = 10), Uruguay (n = 20), and the USA (n = 7). Regionally, 31 tags were deployed in the NEA, 56 in the NWA, 11 in the EqA, 10 in the SEA, and 20 in the SWA (**Figure 4**).

Of the 128 tags deployed, five failed to transmit any data, resulting in 123 tags available for PRM analysis. Of these, 45 (37%) detached on the scheduled date, 76 (62%) detached prematurely, and two (1%) terminated early due to the tagged sharks being captured by fishing gear. The primary causes of premature detachment were the activation of the safe-release mechanism after exceeding the programmed depth threshold (n = 25) and extended periods at a constant depth, either near the surface or on the bottom (n = 47). In four cases, the cause of detachment could not be determined.

3.3 Information on tagged sharks

A total of 57 males, 50 females and 16 unsexed individuals were successfully monitored in this study. Male sharks ranged in size from 80 to 240 cm FL (mean ± s.d., 148.7 ± 35.5 cm FL), while females ranged from 80 to 220 cm FL (150.5 ± 36.8 cm FL).

The size distribution of tagged sharks varied across geographic regions. In general, individuals larger than 200 cm fork length were rare (n = 8; 6.5%) and were mostly tagged in the NW Atlantic. Similarly, smaller sharks (<100 cm FL; n = 17; 13.8%), were primarily tagged in the NW Atlantic (n = 15) and, to a lesser extent, in the NE Atlantic (n = 2) (**Figure 5**). Overall, 79.7% (n = 98) of the tagged sharks measured between 100 and 200 cm FL.

With respect to maturity status, all tagged females were juveniles, and the majority of males were also classified as juveniles (84.2%, *n* = 48).

3.4 Post-release mortality

3.4.1 Generalities

Overall, the fate of the tagged sharks (survival or mortality) was determined in 87% of cases (n = 107), while the outcome remained inconclusive for the remaining 13% (n = 16). Among the former, 77 sharks survived the post-release event, while 30 died, resulting in an overall PRM rate of 28%.

Mortality events occurred between 0 and 25 days after release, with 59.4% of all deaths occurring within the first 24 hours and 84.4% within the first 10 days (**Figure 6**). Additionally, five sharks presumably died and sank to the bottom after 31, 36, 47, 78, and 93 days. Since these events occurred beyond the 28-day threshold, they were considered unrelated to fishery interactions.

Our overall PRM estimate for shortfin mako sharks (29.4%) aligns well with previous reports. Campana et al. (2015) estimated a post-release mortality rate of 30–33% for shortfin makos caught by pelagic longliners in the NW Atlantic (off Canada), while more recently, Bowlby et al. (2020) reported a PRM rate of 28% for the same fishery.

In the SE Pacific, Abascal et al. (2011) found that 1 out of 9 sharks (11%) died within 30 days after capture and release by a pelagic longliner. Similarly, Francis et al. (2023) reported a PRM rate of 12.3% for shortfin makos caught on pelagic longlines in the Southwestern Pacific; however, if ingested tags (considered mortality events by the authors) were excluded, the PRM rate would drop to 5.3%. In SE Australia, a meta-analysis by Musyl & Gilman (2019) estimated an overall PRM rate of 25.4% for shortfin makos.

Campana et al. (2015) also observed that most mortality events occurred within a few days after release, with 69% (20 out of 29 sharks) occurring within the first five days and 10% beyond 30 days. Similarly, French et al. (2015) reported that 100% of mortality events in shortfin makos caught by recreational fisheries occurred within 24 hours of release.

Our findings are consistent with previous observations in two key aspects: the majority of PRM events occurred within the first week after release, yet some were also detected beyond the typical 28–30 day threshold.

3.4.2 Geographic regions

The geographical distribution of PRM is closely linked to fishing fleets and, in many cases, their operational practices. Consequently, certain patterns that may appear region-specific could be influenced or masked by these factors.

PRM rates varied across the different regions analyzed (**Figure 7**). The highest overall PRM rate was recorded in the NEA (44.8%), followed by the EqA (33.3%), NWA (30%), and SEA (12.5%). No PRM events were observed in the SWA.

3.4.3 Fishing Fleets

PRM rates also varied among fishing fleets (**Figure 8**). The highest overall PRM rate was recorded in the EU-Spain fleet (66.7%), although the sample size was very small. This was followed by EU-Portugal (42.4%), Canada (31.0%), USA (14.3%), and South Africa (12.5%). No PRM events were observed among sharks tagged by the fleets of Brazil, and Uruguay.

3.4.4 Tagging mode

Post-release mortality appeared to be influenced by the tagging method. PRM events occurred in 14.3% of sharks tagged in the water (N = 21), compared to nearly 40% of those tagged on board (**Figure 9**).

Sharks tagged in water typically experience shorter handling times, are less likely to sustain handling-related injuries, and encounter fewer ventilation or respiratory restrictions. These conditions may reduce physiological stress and consequently improve post-release survival. While Campana et al. (2015) did not find a significant effect of tagging method (onboard vs. in-water) on post-release mortality (PRM) for shortfin mako sharks, our findings suggest potential context-specific differences. Notably, all sharks tagged onboard in Uruguay and Brazil (n = 19; 15.4%) exhibited a PRM of 0%, despite the expectation of higher mortality associated with onboard tagging. In contrast, Francis et al. (2023) reported a PRM of 15.7% for 57 shortfin mako sharks caught by pelagic longliners in the Southwest Pacific, all of which were tagged in water. These contrasting results underscore the complexity of the factors influencing PRM and suggest that the tagging method alone may not fully account for the observed variability. Further investigation is needed to understand how local handling practices, environmental conditions, or the condition of the shark at the time of capture may influence the outcomes.

Some potential drawbacks of the in-water tagging method include the challenges of safely removing the hook and drag gear from the shark, as well as the increased risk of improper tag attachment.

3.4.5 Hook type and Hook fate

Hook type (J vs. circle hooks) showed some differences in PRM; however, the results were somewhat contrasting when also considering whether the hook was removed or left in place (**Figure 10**). Information on hook removal was available for 80 individuals, of which 45 retained the hook and 35 had it removed.

Our analysis revealed that hook-related mortality varied depending on both hook type and removal status. When the hook was not removed, mortality was higher for circle hooks compared to J hooks (34.5% vs. 15.4%, respectively). Conversely, when the hook was removed, mortality was 10% for circle hooks but increased to 44.4% for J hooks (**Figure 10**). This difference may be attributed to the handling required for hook removal and the specific location where the hook was embedded.

These findings are relevant when considering recommendations for hook type selection, as post-release mortality contributes to overall mortality rates. Some studies suggest that using circle hooks may significantly increase total mortality in shortfin mako sharks due to post-capture release (Semba et al., 2018).

It is also important to recognize that, particularly in the case of shortfin makos, removing a hook from a live shark is a high-risk procedure that not all crew members may be willing or able to perform.

3.4.6 Hooking location and leader material

Hooking location was recorded for 81 sharks whose post-release fate could be determined (**Figure 11**). Among these, 95% were hooked in the mouth, while the remaining 5% were deep- or gut-hooked (two with circle hooks and two with J hooks).

PRM was notably higher in deep-hooked sharks, with 75% mortality (3 out of 4), compared to 28.9% (22 out of 54) in sharks hooked in the mouth. Additionally, PRM rates varied depending on the leader material used. Mortality was higher with wire leaders (44.1%) compared to monofilament leaders (23.0%) (**Figure 12**)

3.4.7 Size and Sex comparisons

Post-release mortality was similar between sexes, though slightly higher in males (35.4%) than in females (28.3%) (**Figure 13**). Larger individuals exhibited lower post-release mortality rates compared to smaller ones. Among sharks measuring 180 cm FL or more, mortality was recorded in only 3 out of 25 individuals (12.0%), while for those under 180 cm FL, it occurred in 29 out of 84 individuals (34.5%).

Based on the mean sizes at maturity reported for males from both southern and northern populations (Natanson et al., 2020; Cabanillas-Torpoco et al., 2024), PRM rates differed between juveniles and adults, with values of 33.3% and 44.4%, respectively (**Figure 13**). However, it is important to note that the number of tagged adults was considerably lower than that of juveniles, which may limit the robustness of these estimates and should be considered when interpreting the observed differences.

Adult female shortfin mako sharks appear to be rare throughout the Atlantic (Coelho et al., 2025), emphasizing the need for further research to better understand their distribution and accurately estimate their PRM.

3.5 Other considerations

Although satellite tagging has provided valuable PRM estimates (e.g., Musyl et al., 2011; Campana et al., 2015; Musyl & Gilman, 2018, 2019; Bowlby et al., 2020), fully understanding the causes of this mortality remains challenging. Mortality is likely multifactorial and cumulative.

Based on post-capture survival data, PRM is estimated at 29.4%. When factoring in hooking mortality (26–35%) (Coelho et al., 2012; Schultz, 2022), total fishing-related mortality in shortfin makos could reach 55.4–64.4%. These figures underscore the need to assess whether non-retention measures are truly effective or if alternative, more effective managements strategies should be explored.

4. Final Remarks

- The overall PRM rate for shortfin mako sharks caught by pelagic longliners was 29.4%, assuming mortality observed after 28 days is not related to fishery interactions.

- Mortality events occurred between 0 and 25 days post-release, with 59.4% occurring within the first 24 hours and 84.4% within the first 10 days.

- Five late mortality events were recorded beyond the 28-day threshold (31 to 93 days post-release). If these are considered fishery-related, the PRM would be somewhat larger.

- Other unaccounted variables or a cumulative multifactorial impact likely influence PRM, warranting further investigation in future studies.

- Operational factors such as hook removal or not and the use of degradable hooks are critical for improving post-release survival rates.

Acknowledgments

This study was carried out as part of a cooperative work conducted by the ICCAT Shark species group integrated in the ICCAT Shark Research and Data Collection Program (SRDCP). The authors are grateful to all fishery observers and longline skippers from the Nations involved in this study. Tags from additional sources have been contributed and deployed with several national Projects, specifically: Project "LL-Sharks: Mitigação das capturas de tubarões na pescaria de palangre de superfície (Ref: 31-03-05-FEP-44, funded by PROMAR)", Project "MAKO-WIDE - "A wide scale inter-hemispheric and inter-disciplinary study aiming the conservation of the shortfin mako shark in the Atlantic Ocean (Ref: FAPESP/19740/2014)", funded by FCT (Portuguese Foundation for Science and Technology) and FAPESP (São Paulo Research Foundation, Brazil), and Project SAFEWATERS SC7 (The provision of advice on the conservation of pelagic sharks associated to fishing activity under EU Sustainable Fisheries Partnership Agreements in the Atlantic Ocean) under the Framework Contract MARE/2012/21, funded by the European Commission. Additional satellite tags were acquired by NOAA in US-Uruguay and US-Portugal-Uruguay collaboration initiatives. Rui Coelho is supported by an Investigador-FCT contract from the Portuguese Foundation for Science and Technology (FCT) supported by the EU European Social Fund and the Programa Operacional Potencial Humano (Ref: IF/00253/2014). Catarina C. Santos is supported by an FCT Doctoral grant (Ref: SFRH/BD/139187/2018). Fisheries and Oceans Canada supported and undertook all Canadian tagging.

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Table 1. Post-Release Mortality estimates of shortfin mako sahrks (*Isurus oxyrinchus*) reported in the literature. LL: longline, R&R: Rod and Reel.

Reference	N	PRM	95%LCI	95%UCI	FishGear	Observations
Abascal et al. 2011	9	**0.444**	0.177	0.749	LL	NE Pacific
Bowlby et al. 2021	104	**0.358**	0.259	0.479	LL	
Bowlby et al. 2021 - with M estimation	104	**0.339**	0.246	0.453	LL	M = 0.101 (0.016–0.659)
Campana et al. 2015	26	**0.313**	NA	NA	LL	s.e.= 0.18
SCRS_2025_034 (this study)	109	**0.294**	0.203	0.374	LL	
Bowlby et al. 2020	15	**0.280**	0.140	0.390	LL	
Musyl & Gilman 2019	NA	**0.254**	0.137	0.420	LL	
Musyl et al. 2011	2	**0.167**	0.01	0.806	LL	Central Pacific
Francis et al. 2023	57	**0.157**	0.039	0.253	LL	SE Pacific In-water tagging
French et al. 2015	30	**0.100**	0.033	0.268	R&R	SE Indian

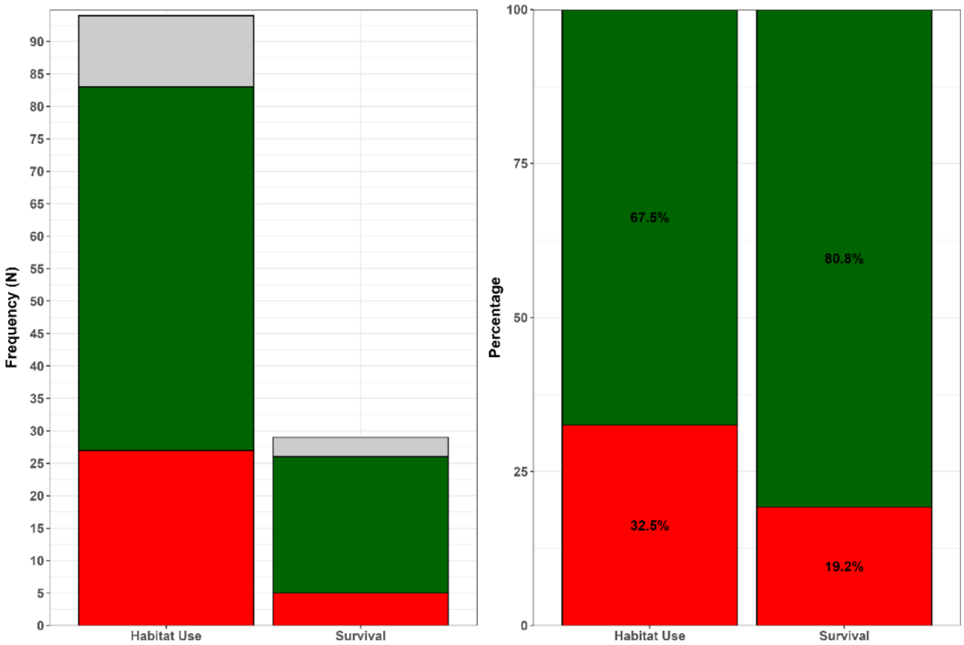

Figure 1. Fate frequency (red: death; green: survival; grey: unknown) of shortfin mako sharks tagged and released with electronic tags with the main objective of studying their habitat use (miniPAT, Mk10-PAT, X-Tag) and post-release mortality (sPAT, PSATLIFE). The left panel shows the fate frequency in number of sharks and the right panel shows the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear. Two tags were not considered here as both sharks were caught by fishing vessels, abruptly ending the deployment.

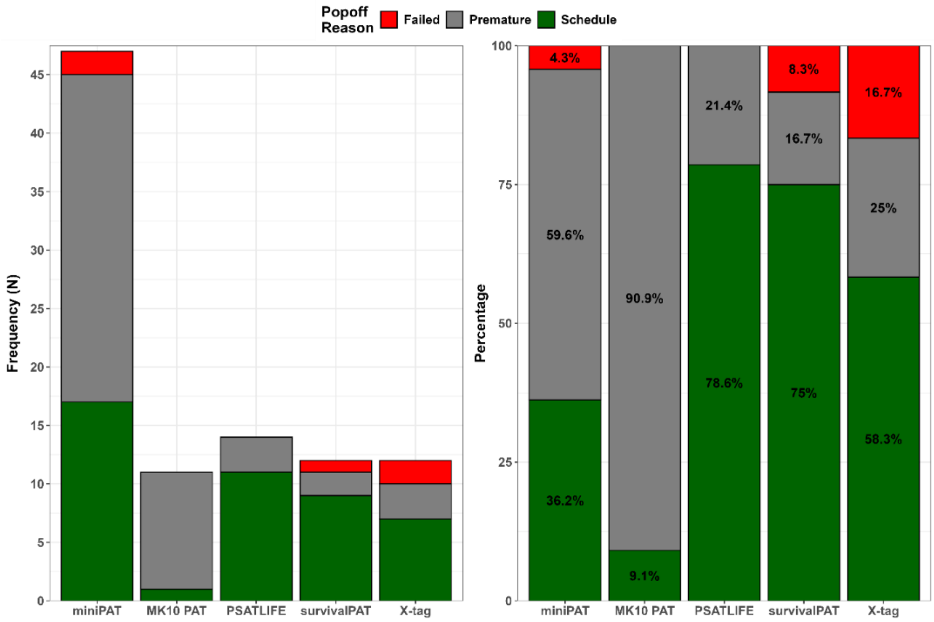

Figure 2. Pop-off reason frequency by archival tag type used for the post-release analysis of the shortfin mako. The left panel shows the frequency of events in number of tags and the right panel shows the overall percentage of each pop-off reason. Sharks that died, hence prompting the release mechanism prematurely, were not considered in this plot.

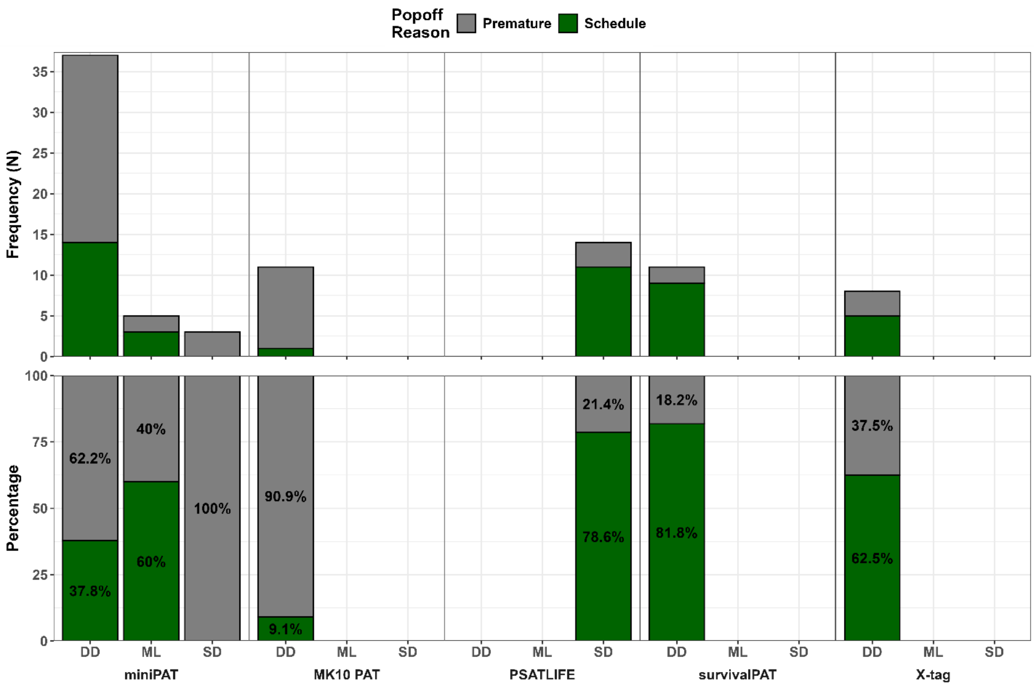

Figure 3. Tag performance (Complete deployment vs. premature release) in relation to tag model and anchor type (DD: Domeier Dart; ML: Monofilament Loop; SD: Steel Dart). The upper panel shows the frequency of events in number of tags and the right panel shows the overall percentage of each pop-off reason. Sharks that died, hence prompting the release mechanism prematurely, were not considered in this plot.

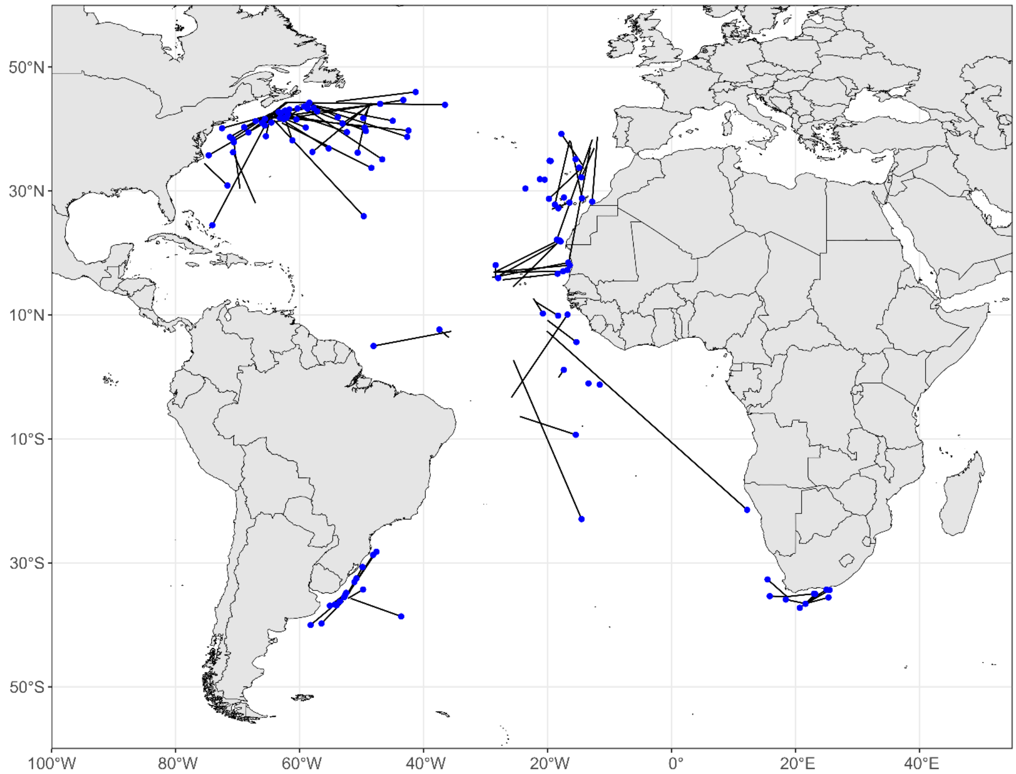

Figure 4. Minimum distances covered by shortfin mako sharks tagged for the post-release mortality analysis. The black line denotes the minimum distance connecting the tagging (line origin) and pop-off locations (blue dots). Note that some distances covered are not readily visible at the scale of the map.

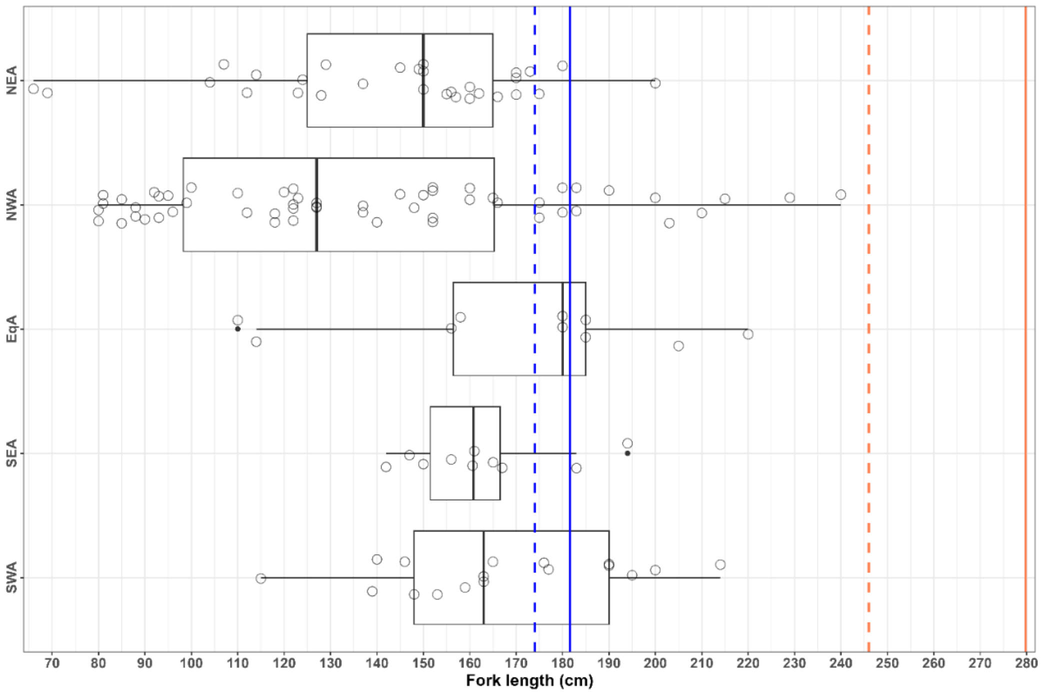

Figure 5. Size distribution of tagged shortfin mako sharks by region. Vertical lines indicate the size-at-median maturity for males (blue) and females (orange) published for the North Atlantic (solid lines, males: 182 cm FL, females: 280 cm FL, Natanson et al. 2020) and South Atlantic (dashed lines, males: 174 cm FL, females: 246 cm FL, Cabanillas-Torpoco et al. 2024). BRA: Brazil; CAN: Canada; EU.SPA: Spain; EU.PRT: Portugal; SAF: South Africa; URY: Uruguay; USA: United States of America.

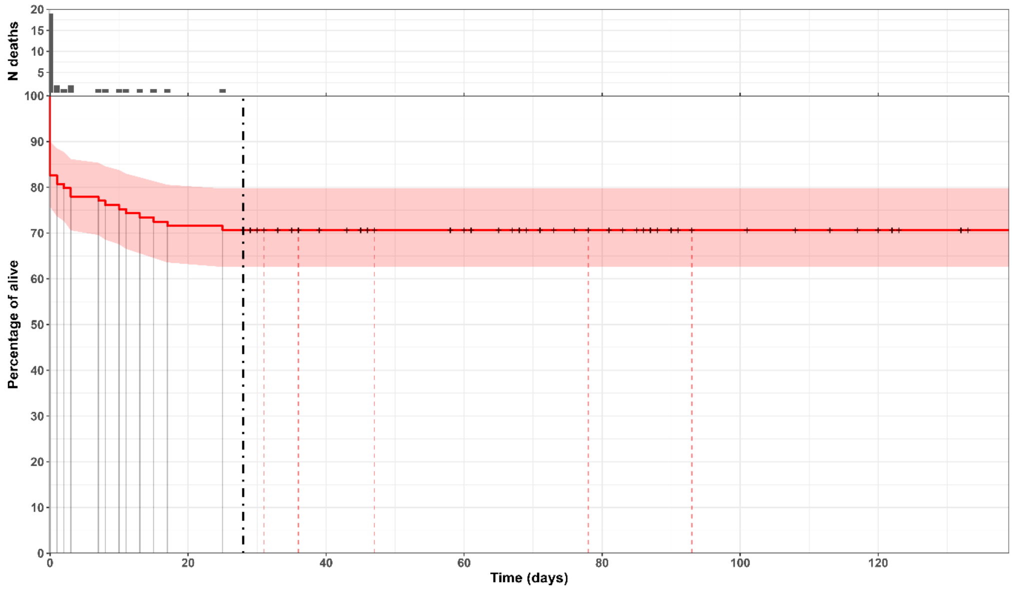

Figure 6. Percentage of alive shortfin mako sharks tagged as a function of time after tagging (days at liberty). The upper panel shows the frequency of mortality events as a function of days at liberty in one-day bins. The lower panel shows the estimates (solid red line) and 95% confidence intervals (shaded bands) for the survivorship of shortfin mako based on the non-parametric Kaplan-Meier estimator. Black broken vertical line depicts the 28-day threshold after which sharks were considered to have survived the interaction with the fishing gear. Grey solid vertical lines indicate mortality events in time. Red dashed vertical lines indicate three events of suspected delayed mortality after 31, 36, 47, 78, and 93 days. Grey crosses indicate censored observations. Note that the x-axis was truncated at 140 days to aid visualization (the longest deployment duration was 225 days).

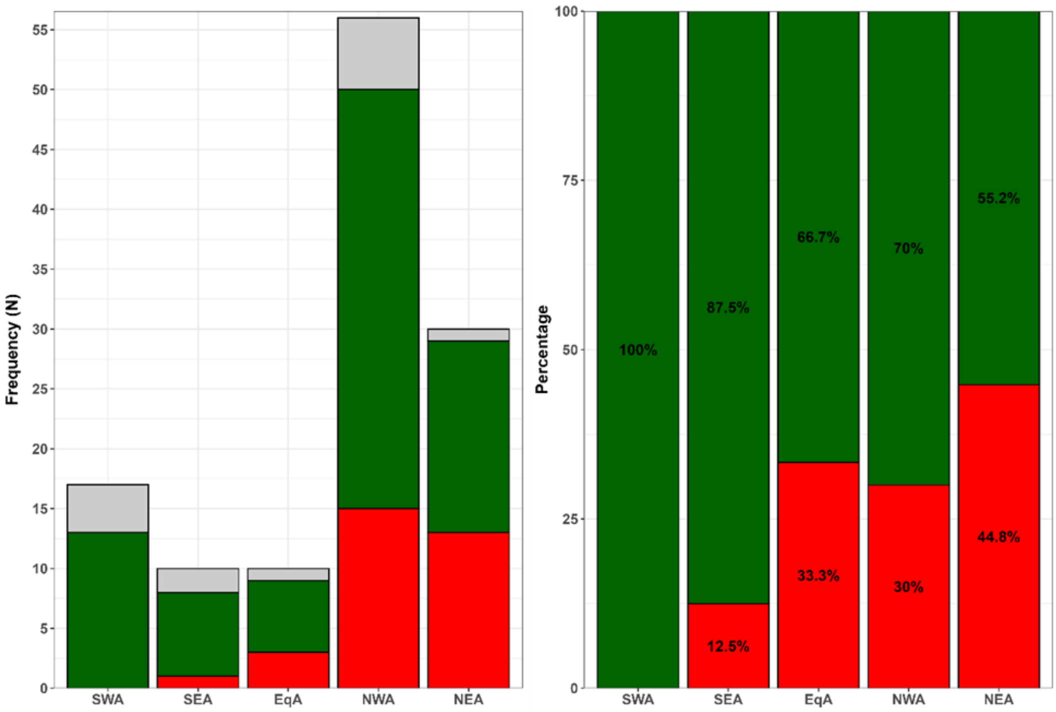

Figure 7. Fate frequency (red: death; green: survival; grey: unknown) of shortfin mako sharks tagged at each mayor tagging region. The left panel shows the fate frequency in number of sharks and the right panel shows the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.

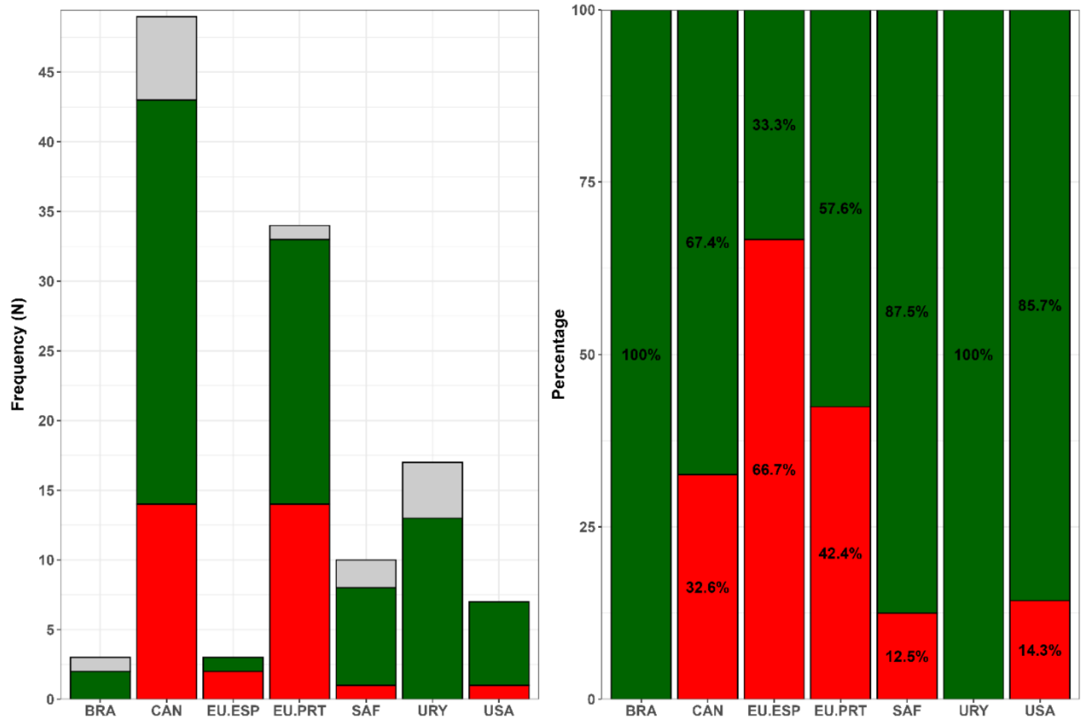

Figure 8. Fate frequency (red: death; green: survival; grey: unknown) of tagged shortfin mako sharks captured by different longline fishing fleets in the Atlantic Ocean. The left panel shows the fate frequency in number of sharks and the right panel shows the overall percentage of survival and mortality events (excluding unknown fates). BRA: Brazil; CAN: Canada; EU.SPA: Spain; EU.PRT: Portugal; SAF: South Africa; URY: Uruguay; USA: United States of America. All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.

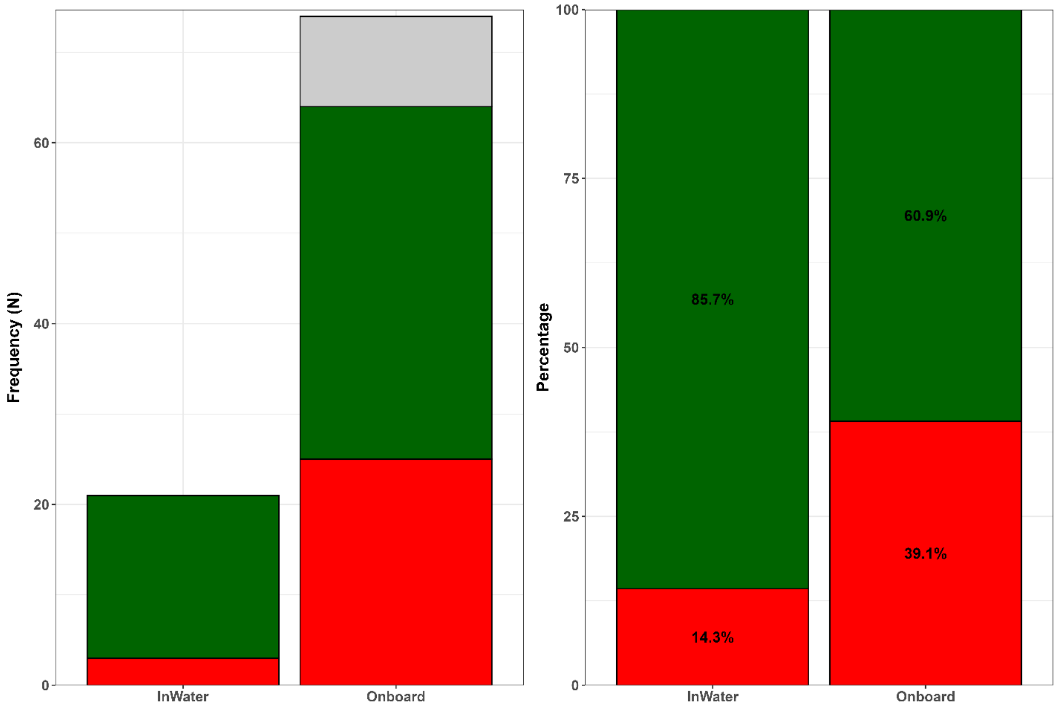

Figure 9. Fate frequency (red: death; green: survival; grey: unknown) of tagged shortfin mako sharks in relation to the tagging mode (i.e. whether the sharks was tagged in the water or onboard). The left panel shows the fate frequency in number of sharks, and the right panel shows the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.

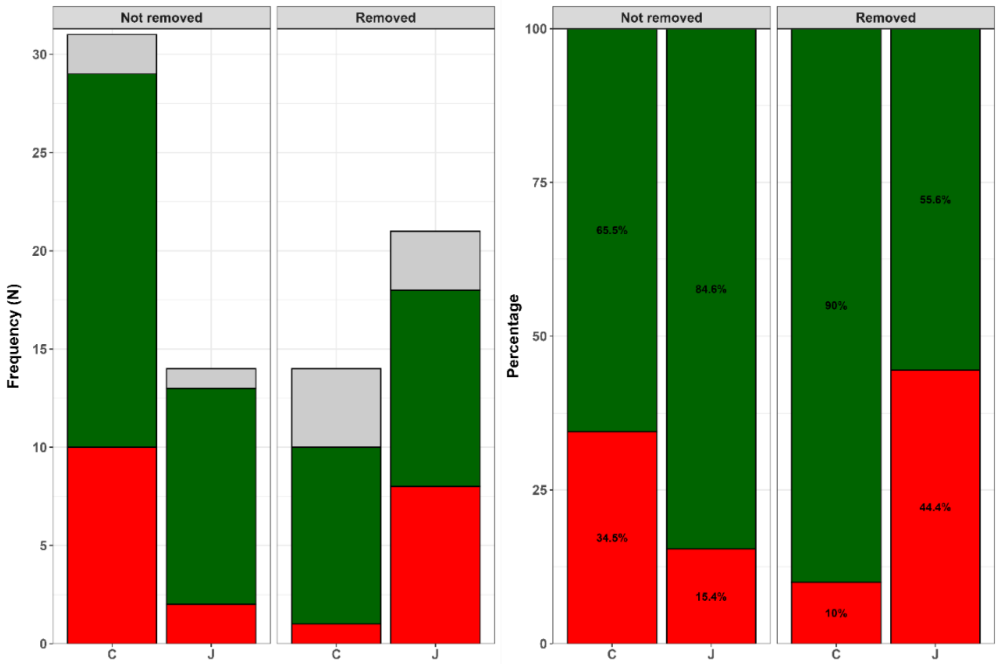

Figure 10. Fate frequency (red: death; green: survival; grey: unknown) of tagged shortfin mako sharks in relation to the hook type (C: circular hook; J: 'J' hook) and the hook fate (i.e. whether the hook was removed or not before releasing the shark). The left panel shows the fate frequency in number of sharks, and the right panel shows the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.

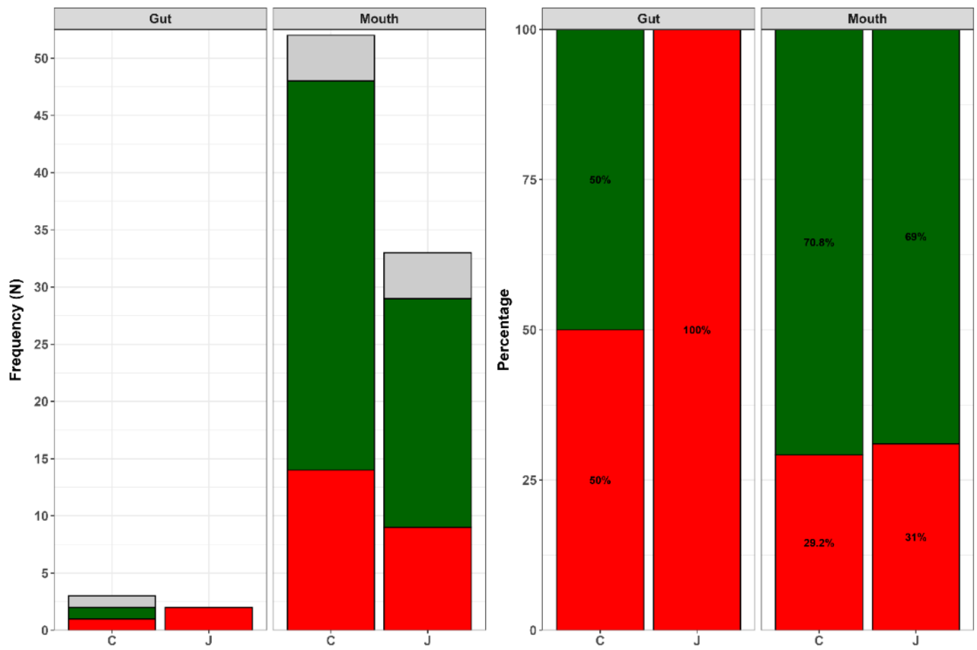

Figure 11. Fate frequency (red: death; green: survival; grey: unknown) of tagged shortfin mako sharks in relation to the hook type (C: circular hook; J: 'J' hook), and the hook location. The left panels show the fate frequency in number of sharks, and the right panels show the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.

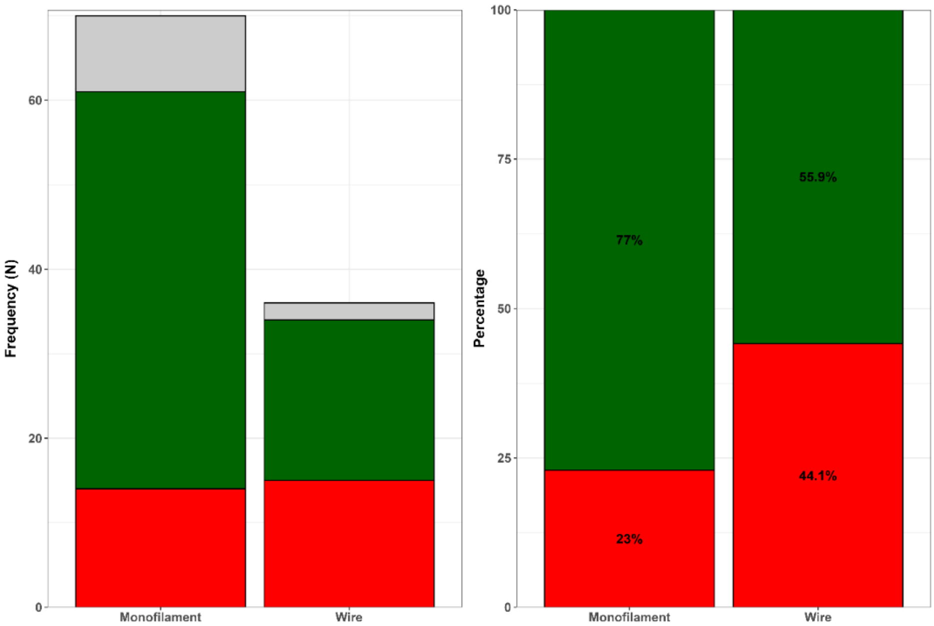

Figure 12. Fate frequency red: death; (green: survival; grey: unknown) of tagged shortfin mako sharks in relation to the branchlie leader material. The left panel shows the fate frequency in number of sharks, and the right panel shows the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.

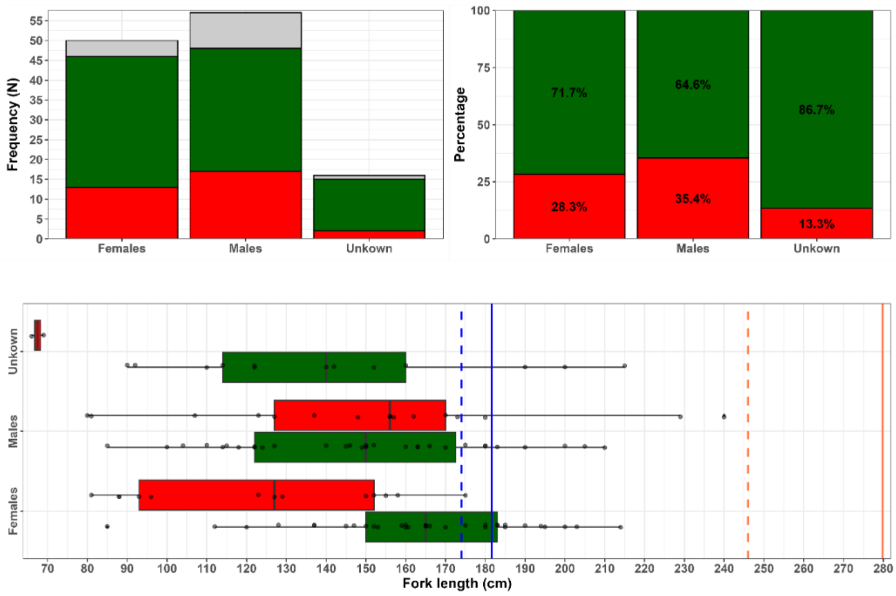

Figure 13. Fate frequency (red: death; green: survival; grey: unknown) of tagged shortfin mako sharks in relation sex. The left upper panel shows the fate frequency in number of sharks, and the right upper panel shows the overall percentage of survival and mortality events (excluding unknown fates). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear. The lower panel shows the size distribution of tagged shortfin mako sharks by sex. Sharks are grouped according to their fate (green: survival; red: death). Vertical lines indicate the size-at-median maturity for males (blue) and females (orange) published for the North Atlantic (solid lines, males: 182 cm FL, females: 280 cm FL, Natanson et al. 2020) and South Atlantic (dashed lines, males: 174 cm FL, females: 246 cm FL, Cabanillas-Torpoco et al. 2024). All individuals that survived past the 28-day threshold were considered to have survived the interaction with the fishing gear.