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Measurement of lactate as an indicator of stress in *Rhizoprionodon longurio* and *Sphyrna lewini* during shark tagging

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Abstract. Lactate is considered one of the main metabolic indicators of stress in sharks because it is closely related to the anaerobic metabolism that occurs during exhaustive exercise. The objective of this study was to evaluate the effect of the tagging process by measuring blood lactate levels in 2 species of sharks. Lactate levels were measured in 17 juvenile sharks, including *Rhizoprionodon longurio* (n = 8) and *Sphyrna lewini* (n = 9), captured as bycatch using small pelagic purse seine gear. The results showed that both handling time (P = 0.0012) and species (P = 0.022) significantly affected blood lactate levels, according to the generalized linear model. On the other hand, the differences between species were explained by the higher sensitivity of *R. longurio*, which showed a greater tendency to present higher lactate values compared to *S. lewini* (P = 0.0088). For both species, handling time should remain between 15 to 25 min, from capture during seine closure to release, to reduce the probability of mortality. This study has corroborated that the tagging technique in sharks causes high blood lactate levels as a function of handling time and species. However, it is recommended that future studies work with a larger sample in conjunction with post-capture monitoring in order to conclusively establish that lactate is an indicator of animal welfare in relation to handling time and species.

Key words: marine ecosystem, marine conservation, fishery management, shark, vulnerability, physiology, capture, tagging.

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Introduction

Shark tagging, such as acoustic (Espinoza et al. 2015, Madrigal-Mora et al. 2024), satellite (Elliott et al. 2022), and conventional tagging (Bartes et al. 2021), has been a useful tool for conservation purposes in its different modalities. Fish tagging represents a physical stress caused by handling and capture, which provokes a physiological adaptive response of escape or confrontation that activates the hypothalamic-pituitary-interrenal axis (De los Santos 2017). First, the organism displays a primary response involving the release of cortisol, which leads to a secondary response with elevations in lactate due to the alteration of the metabolism. Generally, this secondary response may appear within minutes or up to an hour after exposure to stress. In the final phase, the secondary response may trigger a tertiary response associated with chronic stress. This occurs when the animal is not able to reach homeostasis, which can affect growth, reproduction, and the immune system, and can even result in death (Aguilar 2018). During an acute stress situation, oxygen consumption and anaerobic metabolism increase, resulting in plasma hyperlactatemia. This occurs because lactate is produced as a by-product of glycolysis (Murray et al. 2015, Aguilar 2018). The baseline lactate value reported by Brooks

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et al. (2012) and Gallagher et al. (2014) in unstressed sharks ranges between 0 and 1 mmol·L^{-1}.

Research on shark tagging is recent in Panama; satellite tags have been used for *Rhincodon typus* (Guzman et al. 2018, Guzman et al. 2022) and conventional spaghetti tags for juvenile sharks and rays (Rodríguez-Arriatti 2023). In Panama, there are few studies focused on the impact of fishing activities on shark populations, despite the fact that catches obtained with different fishing gears include mainly juveniles (Vega et al. 2008, Rodríguez-Arriatti et al. 2021). Tagging research on the Panamanian Pacific coasts has focused on determining shark movement patterns and residency time in different sites, laying the groundwork for conservation efforts. Specifically, this study aimed to provide information on sharks of great ecological importance and in critical conservation status caught in the Eastern Tropical Pacific (ETP) by purse seine nets, due to the lack of information available on this fishing gear and the species involved.

If the stress caused by handling during tagging is prolonged, and the organism has a low homeostatic capacity, a lethal event could be triggered in the elasmobranch (De los Santos 2017). Mortality of certain shark species can be influenced by the handling time and species-specific susceptibility. According to Gallagher et al. (2014), each species has a particular degree of response to stress, some being more vulnerable to the impact of handling. For example, the hammerhead shark (*Sphyrna mokarran*) is notably more sensitive to stress than the blacktip shark (*Carcharhinus limbatus*), or bull shark (*Carcharhinus leucas*), which makes recaptures difficult and further threatens these endangered species (Gallagher et al. 2014). Hoolihan et al. (2011) concluded that the blue shark (*Prionace glauca*) undergoes behavioral changes post-tagging due to the trauma of capture and handling, the tagging procedure, and the wearing of the tags. In a subsequent study, Hays et al. (2016) highlighted the need for the addition of ethical regulations for vulnerable megafauna species that may be sensitive to stress associated with capture, handling, and tagging. Therefore, it is imperative to investigate the welfare of sharks during the tagging procedure.

In their study with mako sharks (*Isurus oxyrinchus*), Marshall et al. (2012) found that lactate could be a potential indicator of mortality in 16–20% of cases compared to other blood markers (Na^+, Ca^{2+}, Cl^-, Mg^{2+}, and glucose). Mohan et al. (2020) pointed out that in immediate deaths observed in *C. limbatus*, there was a significant increase in lactate (median of 2.8 mmol·L^{-1} in survivors and 5.9 mmol·L^{-1} in individuals in which immediate mortality was observed). Therefore, through this biomarker, it is possible to evaluate the impact of events considered hostile, such as capture, and to identify possible stress factors (e.g., time or species), which can help us assess the probability of survival, resilience, or risk of death of the animal (Jerome et al. 2017, Aguilar 2018). In addition, it should be taken into consideration that all scientific studies should ensure the refinement of techniques to reduce the stress associated with handling and capture. In this context, the objectives of the study were to measure blood lactate levels after handling in 2 species of sharks (*Rhizoprionodon longurio* and *Sphyrna lewini*), and compare these lactate levels by handling time and species.

Materials and methods

Study area

Sampling was carried out at multiple locations along the ETP coast (Table 1) during October 2022. This is characterized by the rainy season with warm atmospheric temperatures around 27.5 °C (González and D'Croz 2007).

Data collection

Seventeen individuals of *R. longurio* (n = 8) and *S. lewini* (n = 9) were collected, including both females and males. These sharks were caught as bycatch in the purse seine fishery for small pelagics in which the target species are *Opisthonema libertate* and *Cetengraulis mysticetus*. These industrial vessels used purse seine nets of 627.9 m long by 54.6 m high, with a mesh opening of 2.54 cm. Each shark was tagged using spaghetti tags (T-Bar FD-68B FF, Floy FD-68B FF, Floy Tag & Mfg., Inc., Seattle, USA). A blood sample was taken from each shark with a caudal peduncle puncture using 1-mL syringes and 25-G needles. Lactate was measured with a portable Accutrend Plus meter (Roche Diagnostics, Basel, Switzerland). Handling time ranged from 10 to 35 min. This time started when the shark was sighted in the purse seine net and ended when the shark was released into the sea, including the time during which the shark was caught with a small net and brought aboard. While sharks were aboard, the following data were recorded: species, total length (TL), sex, maturity stage, and capture coordinates using a W84 GPS (Garmin, Ltd., Olathe, USA).

When the shark was on board, the conventional tag was attached, and the blood sample was collected. The average manipulation time was 4 min. On the other hand, the fighting time, which refers to the interval from first sighting to total seine closure, ranged from 5 to 30 min. It is important to emphasize that the percentage of encirclement was approximately 90% and, during this phase, the net (bag) became saturated with organisms, which confirmed successful capture. This definition of fighting time differs from that described by Brownscombe et al. (2016), who based their observations on fish caught with hook-and-line fishing gear and defined fighting time as the interval between a shark taking the hook and when it was physically immobilized. Lastly, the soaking time of the net was approximately 40 min to 120 min.

Statistical analysis

The normality and homoscedasticity of the variables handling time (minutes), body measurement (cm), and blood lactate concentration (mmol·L^{-1}) were analyzed using Shapiro–Wilk and Levene's tests, respectively. The relationship between lactate concentration for each shark species as a function of its size and the handling time was determined using a univariate general linear model (GLM) (considering species, sex, size, and handling time by lactate concentration), and multivariate GLM with a logarithmic distribution (lactate concentration by species and handling time), together with the values of the McFadden's pseudo-R^2 (R^2_{MF}), which were calculated with the 'MASS' and 'Performance' packages and the GLM trend prediction profiler.

The Kaplan–Meier method was employed to determine the range of handling time that could cause a lethal increase in lactate in both species. According to IBM Corporation (2024), this method employs a calculation based on mortality tables to estimate the hazard or survival function at the times when events occur. This model is based on calculating the conditional probabilities associated with each instant and using the cumulative product of these probabilities to determine the survival rate at each point in time. Statistical differences between lactate concentration by species and handling time were determined with the Wilcoxon, Pearson's Chi-square, and Wald's Chi-square tests. Significant differences were evaluated with a value of $P < 0.05$. All analyses were performed in Jump Pro v. 14.0, R. v. 4.4.0. (R Core Team 2024), and RStudio v. 2024.09.1+394 (Posit Team 2024).

Results

A total of 17 peripheral blood samples were collected from juvenile sharks of *R. longurio* (n = 8) and *S. lewini* (n = 9). The study population had a median TL of 54 cm. The

Table 1. Information on fishing catches sampled during October 2022 in Puerto Caimito.

Fishing area	Latitude (N)	Longitude (W)	Species	Sex
Cerro Tigre	8°29′37.7406″	79°44′17.2788″	*Sphyrna lewini*	Female
Cerro Tigre	8°29′37.7406″	79°44′17.2788″	*Sphyrna lewini*	Female
Isla Chaman	8°45′0.5394″	79°36′16.9806″	*Rhizoprionodon longurio*	Female
Isla Verde	8°44′44.6994″	79°40′30.6012″	*Rhizoprionodon longurio*	Male
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Rhizoprionodon longurio*	Male
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Rhizoprionodon longurio*	Female
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Rhizoprionodon longurio*	Male
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Sphyrna lewini*	Female
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Sphyrna lewini*	Female
Isla Chaman	8°46′ 38.28″	79°36′22.2006″	*Rhizoprionodon longurio*	Female
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Rhizoprionodon longurio*	Female
Isla Chaman	8°46′38.28″	79°36′22.2006″	*Rhizoprionodon longurio*	Male
Isla Chaman	8°43′14.0412″	79°39′6.3612″	*Sphyrna lewini*	Female
Isla Chaman	8°43′14.0412″	79°39′6.3612″	*Sphyrna lewini*	Female
Isla Chaman	8°43′14.0412″	79°39′6.3612″	*Sphyrna lewini*	Male
Isla Chaman	8°43′14.0412″	79°39′6.3612″	*Sphyrna lewini*	Female
Chame	8°39'54.18″	79°38'13.8582″	*Sphyrna lewini*	Female

Table 2. General characteristics of the shark population under study. In parentheses is the percentage of *n*. $\bar{x}$: mean; Me: median; SD: standard deviation; $S\bar{x}$: standard error; IQR: interquartile range. All individuals captured were juveniles.

General characteristics	*Sphyrna lewini* *n* = 9 (%)	*Rhizoprionodon longurio* *n* = 8 (%)	Total *N* = 17 (%)
Sex			
Male	1 (11.11)	4 (50.00)	5 (29.41)
Female	8 (88.89)	4 (50.00)	12 (70.59)
Total length (TL) (cm)			
45–49	0 (0.00)	5 (62.50)	5 (29.41)
50–54	2 (22.22)	3 (37.50)	5 (29.41)
55–59	3 (33.33)	0 (0.00)	3 (17.65)
60–64	3 (33.33)	0 (0.00)	3 (17.65)
65–69	1 (11.12)	0 (0.00)	1 (5.88)
$\bar{x}$ (±SD)	58.39 (4.34)	49.62 (1.38)	54.26 (5.53)
$S\bar{x}$	1.44	0.49	1.34
Me (IQR)	56.00 (54.75–62.25)	49.00 (48.62–50.88)	54.00 (49.00–58.00)
Lactate concentration (mmol·L^{-1})			
1.0–2.9	4 (44.44)	2 (25.00)	6 (35.29)
3.0–4.9	5 (55.56)	2 (25.00)	7 (41.18)
5.0–6.9	0 (0.00)	1 (12.50)	1 (5.88)
7.0–8.9	0 (0.00)	2 (25.00)	2 (11.77)
>9.0	0 (0.00)	1 (12.50)	1 (5.88)
$\bar{x}$ (±SD)	2.88 (0.99)	5.11 (3.05)	3.93 (2.42)
$S\bar{x}$	0.33	1.08	0.59
Me (IQR)	3.10 (2.25–3.35)	4.85 (2.12–8.20)	3.10 (2.25–5.60)
Handling time (min)			
Low (≤10)	1 (11.11)	1 (12.50)	2 (11.76)
Medium (10.1–19.9)	2 (22.22)	2 (25.00)	4 (23.53)
High (≥20)	6 (66.67)	5 (62.50)	11 (64.71)
$\bar{x}$ (±SD)	21.33 (5.85)	21.12 (8.77)	21.23 (7.13)
$S\bar{x}$	1.95	3.10	1.73
Me (IQR)	21.00 (17.50–5.00)	20.00 (12.75–29.50)	21.00 (16.00–26.50)

median lactate concentration was 3.10 mmol·L^{-1} for *S. lewini* and 4.85 mmol·L^{-1} for *R. longurio*. Only one specimen of *S. lewini* reported a lactate value of 1 mmol·L^{-1}. Most sharks (65%) had high handling times, with a median of 21 min for both species (Table 2). The time values and body measurements showed normal distributions and homogeneous variances ($P > 0.05$) based on Shapiro–Wilk and Levene's tests, respectively. In contrast, lactate concentration values showed non-parametric behavior, with non-normal distribution ($P = 0.0097$). The correlation of lactate concentration with species, sex, body size, and handling time showed a R^2_{MF} value of 0.608 ($P = 0.0031$), indicating that 61% of the variability in blood lactate concentration was explained by the variables. The univariate GLM revealed significant dependence of lactate concentration with respect to shark species ($R^2_{MF} = 0.272$, $P = 0.022$) and handling time ($R^2_{MF} = 0.474$, $P = 0.0012$). The relationship with body size was marginally significant ($R^2_{MF} = 0.216$, $P = 0.0497$) and no significant relationship was found with sex ($R^2_{MF}= 0.081$, $P = 0.223$). The multivariate model showed that time is the variable that most contributes ($P = 0.0015$) to blood lactate concentration (Fig. 1).

The median handling time, when the increase in blood lactate levels was observed, was 21 min (range 15–25 min) for both species. This means, when the handling time threshold was exceeded, lactate levels increased, which increased the probability of mortality in the animal. According to the Kaplan–Meier analysis, there was no difference in the median handling time ($\chi^2 = 0.037$, $P = 0.84$) between the 2 shark species (Fig. 2). However, for the evaluation of blood lactate levels by species, it was observed that *R. longurio* tended to have higher lactate levels than those of *S. lewini* ($\chi^2 = 6.86$, $P = 0.0088$) at different handling times (Fig. 3).

Discussion

This study confirmed that an increase in shark handling time during the tagging process led to elevated blood lactate level in sharks (Fig. 1). To avoid reducing the chances of survival for both species analyzed, handling time should be limited to between 15 min and 25 min, measured from the initial sighting of the animals in the net until their release. Prolonged handling time could trigger their death (Fig. 2) (Aguilar 2018). Murray et al. (2015) observed that dogfish sharks (*Scyliorhinus canicula*) exposed to 40 min of handling showed higher blood lactate concentrations compared to those handled for only 15 min. The results found by Fuller et al. (2020) for the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) indicate that, despite the use of hooks for capture, the results were consistent with those obtained in this study. In the investigation by Fuller et al. (2020), lactate concentrations were obtained by a commercial lactate measuring device, and it was found that levels increased significantly at handling times between 45 min and 60 min, reaching values between 4 mmol·L^{-1} and 8 mmol·L^{-1}. The results of the Kaplan–Meier analysis in this study, combined with the findings of Fuller et al. (2020), suggest that increased handling time is associated with a higher risk of shark mortality. This is due to the negative effects associated with elevated lactate levels, as previously documented (Dumetz et al. 2008, Marshall et al. 2012, Jerome et al. 2017).

In this study, *R. longurio* showed a greater increase in blood lactate concentration compared to *S. lewini* (Fig. 3). The average lactate concentrations for *S. lewini* (3.10 mmol·L^{-1}) and *R. longurio* (4.85 mmol·L^{-1}) suggest high levels compared to the indicator values reported by

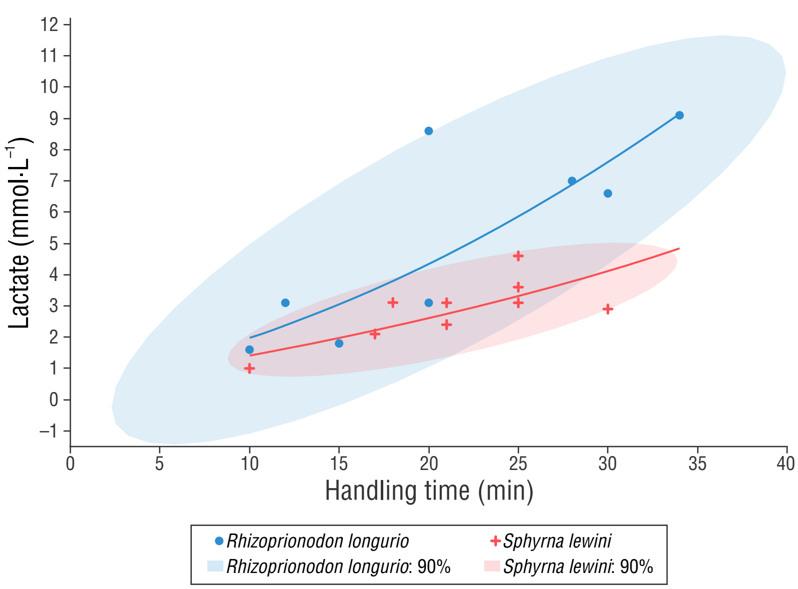

Figure 1. Multivariate analysis with Pseudo-R^2_{MF}, which shows the significant dependence of lactate measurements as a function of species and handling time ($R^2_{MF}= 0.630$, $P = 0.0046$).

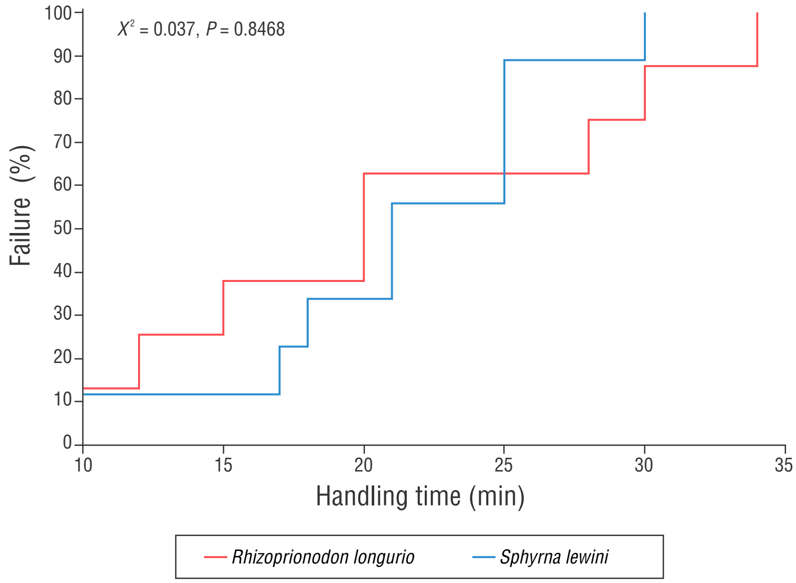

Figure 2. Kaplan–Meier analysis of lactate concentration by manipulation time for each individual, where the median manipulation time is 21 min.

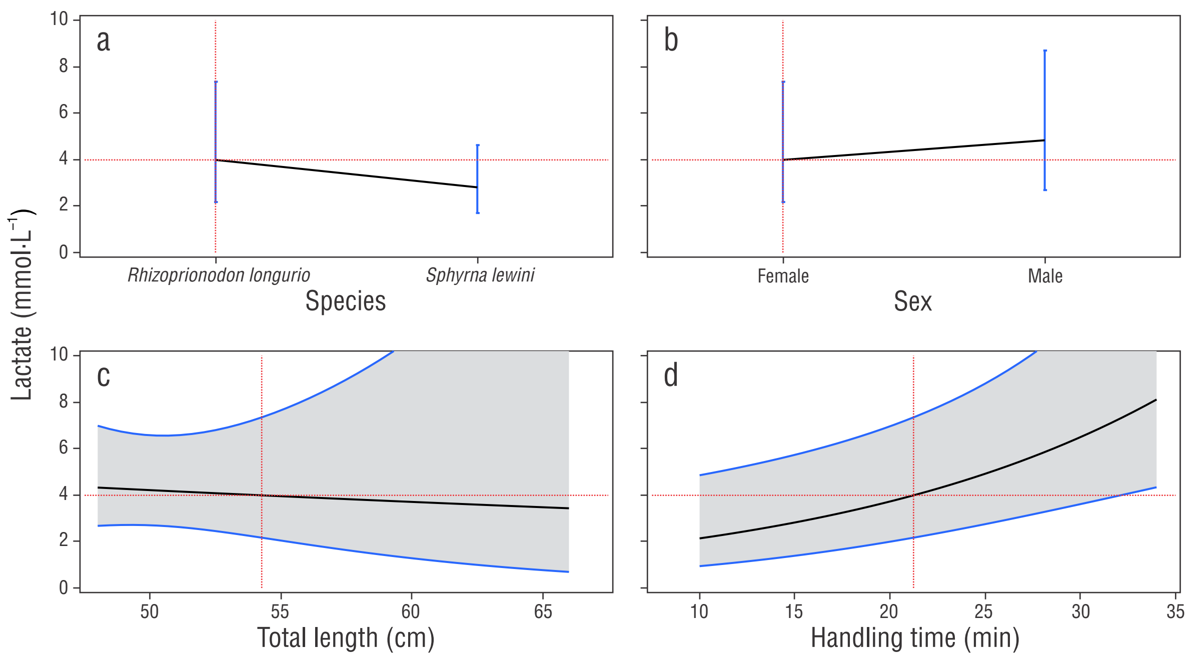

Figure 3. Trend prediction profiler of lactate (mmol·L^{-1}) per species.

Brooks et al. (2012) and Gallagher et al. (2014), who noted that the range of lactate concentrations in unstressed sharks ranged from 0 mmol·L^{-1} to 1 mmol·L^{-1}.

When comparing the values from this study with those reported by Fuller et al. (2020), which were described previously, the range of lactate in *R. terraenovae* was 2 mmol·L^{-1} to 6 mmol·L^{-1}. Ecologically and biologically, the species most similar to *S. lewini* is *C. limbatus*. Mohan et al. (2020) reported a mean of 2.8 mmol·L^{-1} for *C. limbatus* in surviving adult sharks and a value of 5.9 mmol·L^{-1} for those with immediate mortality. During the juvenile stage, *S. lewini* occupies a benthic habit (Klimley 1983, Torres-Rojas et al. 2010), so its lactate values may be more comparable with genera with benthic habitats such as shark species of the genus *Rhizoprionodon*. Giesy et al. (2025) determined that anthropogenic factors, such as intensive fishing, pollution, and the destruction of habitat and their interactions, may have a greater impact on benthic species, like nurse sharks

(*Ginglymostoma cirratum*), than capture and handling stress. In this sense, benthic species are more susceptible to physiological stress, which was reflected in elevated lactate levels (0.7 mmol·L^{-1} to 22.1 mmol·L^{-1}) (Giesy et al. 2025) compared to their pelagic counterparts that inhabit areas farther away from human influence. Regardless of the causes, this indicates that *R. longurio* and *S. lewini* undergo changes in their metabolism when manipulated, either due to species-specific metabolic reactions (Jerome et al. 2017), to the methodology used, or to other variables not analyzed in this study.

Conclusions

This study demonstrates that the conventional shark tagging technique increases blood lactate levels, an indicator of stress, depending on handling time and species. The tested individuals of *R. longurio* had higher blood lactate concentrations compared to those of *S. lewini*. Based on the results, handling time should be less than 25 min. We hope this critical range serves as a practical guideline for future studies using this tagging technique on these species. The fact that the shark is out of its environment will affect its physiological functions. It is prudent to take into account that the team should capture the shark as quickly as possible, both to prevent the shark from getting exhaustive exercise in order to escape and to prevent it from getting injured by the net or the boat. It is also necessary to carry out the manipulation during the tagging in such a way that the animal does not exhaust its energies or increase its blood lactate to critical ranges and to release the organisms under post-capture surveillance to maximize the likelihood of survival. Monitoring should be carried out in the short, medium, and long term to assess the survival rate, especially for sharks with a critical conservation status, thus strengthening conservation efforts.

English translation by authors.

Declarations

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Conflict of interest

The authors declare they have no conflict of interest.

Author contributions

Conceptualization: AP; Data curation: JP; Formal analysis: JP; Funding acquisition: YA and AP; Investigation: AP; Methodology: AP and AQ; Project administration: AP; Resources: AP; Software: JP; Supervision: AQ; Validation: AP, AQ; Visualization: AP, JP; Writing–original draft: AP, AQ, YA, JP; Writing–review and editing: JP, YA, AP.

Data availability

The data for this study are available from the corresponding author by reasonable request.

Use of AI tools

The authors, who are responsible for the content of this publication, employed DeepL and ChatGpt to conduct spelling and grammar checks.

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