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Shark Bycatch Mortality In Commercial Long-Line Fishery

By Xinlin Lyu

AUTHOR BIOGRAPHY

Xinlin (Cheryl) Lyu is a current junior student, attending The Pennington School (New Jersey, US). She endeavors to study marine biology and conservation in college.

ABSTRACT

Apex marine predators, such as sharks, are critical to ecosystem health and resilience, and their removal can seriously disrupt ocean food webs. Long-line fisheries are one source of anthropogenic shark mortality, and the likelihood of bycatch can be affected by several factors: physical traits (e.g., maturity, body shape) & physiological changes (e.g., blood pH, K+ levels, susceptibility to acidosis); sharks' active zones & behavior on the line; and technical aspects of a catch (e.g., hook type, gear removal, soak time). Future directions of conservation are explored to mitigate sharks' bycatch mortality and offer insight into ways to improve conservation. This paper groups future conservation improvements into three categories: communication with fishermen, systematic solutions (e.g., setting laws and improving current MPAs), and project-based solutions (developing specific projects to help mitigate shark bycatch or mortality). Then, the paper ends by acknowledging potential limitations in current-day studies done on shark bycatch mortality.

Keywords: *shark post-release mortality (PRM), shark at vessel mortality (PRM), shark bycatch, commercial long-line fishery, shark mortality, shark conservation, causes of shark mortality, bycatch mitigation, elasmobranch conservation, shark physiology*

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Sharks are an important part of marine ecosystems and play a key role in ecosystem function despite their relatively low abundance compared to most other marine taxa (Mukherji et al., 2026). Two separate studies (Shipley et al., 2023; Vidal et al., 2023) have shown that sharks affect multiple factors in an ecosystem, including nutrient and energy flow, environmental change, connections between the neritic zone and the deep sea, as well as overall ecosystem health.

Many species of sharks are considered apex predators, and their removal can severely disrupt the ecosystem. Fisher et al. (2021) showed that the extinction of wolves in Yellowstone in the late 19th century led to prey overpopulation and vegetation loss due to overgrazing. It also led to the disappearance of some less competitive species (e.g., beavers). In marine environments, shark populations are sensitive to fishing pressure due to their slow growth and low fecundity, and have largely declined across species (Whitney et al., 2021). In fact, studies estimate that ⅔ of the elasmobranch species are threatened with extinction, primarily due to overfishing with longline fisheries accounting for 52% of global shark catch (Worm et al., 2013). And most sharks caught in these vessels are discarded as bycatch (i.e., non-target species). Thus, determining the risk factors of shark mortality in longline fisheries and finding ways to reduce shark mortality can help mitigate the effects of longline fisheries on the declining shark population.

Whitney et al. (2021) suggested that shark mortality due to commercial fisheries can be split into two groups: direct targeting, where shark species are directly fished for, and bycatch mortality, where sharks are captured unintentionally. Whitney et al. (2021) identified two different types of bycatch mortality: at vessel mortality (AVM) and post-release mortality (PRM). Factors that risk shark mortality in longline commercial fisheries are: (1) physiological aspects of a shark after capture and how the physical aspects of a shark can affect PRM; (2) factors that determine sharks' behavior on the line and how it determines likelihood of capture; (3) how technical aspects of fisheries operation can affect mortality.

PHYSICAL AND PHYSIOLOGICAL ASPECTS OF A SHARK AFFECT ITS LIKELIHOOD OF CAPTURE, PRM & ATM

Physical aspects of sharks affect the chances of capture and mortality

Physical aspects of sharks influence mortality, such as morphologies of the mouth (Murua et al., 2021), specialized body parts, size (Afonso & Hazin, 2014), and maturity. Two studies (Murua et al., 2021; Fauconnet et al., 2024) suggest that mouth morphologies can affect the likelihood of getting hooked on the line. Fauconnet et al. (2024) suggest that, when circle hooks slip in the jaw, it is easier to get caught in the soft tissue of deep-sea sharks; it is also harder to get out due to the mouth morphology of deep-sea sharks. The same team suggested that the percentage of deep hooking (hooks that are caught deeper in a shark's throat or gut) on both circle and

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J-shaped hooks in the study may be due to sharks' feeding behavior, suction feeding ability, and size, which led to the conclusion that circle hooks may not effectively reduce shark bycatch; as circle hooks are designed to prevent swallowing and are more likely to hook to the mouths of bony fish. Apart from mouth morphology, Afonso & Hazin (2014) identified that shark size can also impact survival between species. Scott et al. (2023) speculate that the smaller shark size in their study (150cm FL) may be one factor that causes mortality times at AVM to be shorter. However, data from Afonso & Hazin (2014) showed that the AVM rate for adult tiger sharks (37.5%) is higher than for juvenile tiger sharks (7.6–9.1%), suggesting that both species and life stage interactively affect survival odds. This variation suggests that with different species and circumstances, mortality rates vary significantly. So, more data and experiments are needed in this area to better understand the relationship between age and sharks' susceptibility to mortality. It is also important to note that sharks' maturity affects their movement pattern and affects their sensitivity toward capture stress, both affecting the risk of bycatch mortality.

Physiological aspects of a shark correlate with mortality

Studies (Whitney et al., 2021; Hutchinson et al., 2021) demonstrate that levels of blood pH, lactate, K+, breathing mode (i.e., ram ventilation vs. buccal pumping), and acidosis (respiratory and metabolic) affect a shark's mortality. It was suggested that respiratory acidosis occurs because of the high carbon dioxide levels in the blood due to poor ventilation when caught on a hook, and metabolic acidosis is caused by increased buildup of lactic acid in the blood due to anaerobic muscle activity. A separate study by Hutchinson et al. (2021) came to a similar conclusion that metabolic and respiratory acidosis are key drivers in shark mortality. This is evident particularly in ram ventilation sharks, as they often struggle hard to force oxygenated water through their gills, which results in acidosis and also causes more stress that can increase PRM (Whitney et al., 2021). Furthermore, high potassium levels in specifically blacktip, sandbar, tiger, and blacknose sharks in their study are shown to correlate with mortality; it may also be a response to metabolic acidosis, where muscle cells will transfer cations outside to maintain blood pH (Whitney et al., 2021). However, Na+ (another monovalent electrolyte) is shown not to be associated with mortality in the same study. Whitney et al. (2021) put vessel data collected into a decision tree to determine thresholds for PRM. They suggested that due to the overlap of sharks that died and those that survived, there was not a clear threshold, which led to predictions that were very high in sandbar species (99%) but lower in blacktip (68%) and spinner sharks (69%). Although there were often no distinctive cut-off points, thresholds that are established in this study should be repeated in others to improve understanding of factors that affect an individual's species' mortality.

Stress affects shark's behavior on the line & shark's active zone affects susceptibility to capture

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Different spatial and temporal scales affect mortality. On a finer scale, how sharks react to being hooked and brought to the fishing vessels can substantially influence the level of stress they experience. On a broader scale, natural movements and home ranges affect the likelihood of an individual shark encountering a fishery.

Stress experienced by shark species is likely to affect their behavior on the line, and species that struggle more on the line are exposed to higher chances of mortality (Whitney et al., 2021). A study observed that Caribbean reef sharks exhibit sudden bursts of movement, suggesting it was an escape behavior, which is likely due to metabolic stress (Prohaska et al., 2025); however, despite being handled identically, small tooth sawfish were observed to exhibit lower stress levels overall compared to the Caribbean reef shark, which is potentially due to their low metabolic scope (Prohaska et al., 2025). Similarly, variation of data in results of different species of sharks in the study by Whitney et al. (2021) led them to hypothesize that mortality rates in their study are likely due to different physiology and behavior that affects species' sensitivity towards capture stress. This variation between responses of sharks is likely due to their sensitivity towards capturing stress, which is affected by their physiology. However, more research has yet to be done to understand the specific behavior of shark species while on the hook. Knowledge in this area can aid in understanding the interaction between shark behavior and capture mortality risk.

Bizzarro et al. (2017) and Baremore et al. (2021) suggest that the location of sharks can be determined by many factors, including environmental conditions, age, habitat availability, and distribution of prey. Areas with overlapping shark and fishery activity raise the likelihood of incidental catch. According to Bizzarro et al. (2017), shark movement can be categorized into 2 types: Short-term movement and long-term movement/migration. The same study suggests short-term movements of near-shore sharks are influenced by tidal cycles as they determine an area's salinity, temperature, amount of dissolved oxygen, etc. Long-term movements are shown to be influenced by seasonal variations, prey abundance, or reproduction (Bizzarro et al., 2017). Furthermore, age variations can also impact a shark's movement pattern. Baremore et al. (2021) show that there is variation in movement in different levels of maturity of Caribbean reef sharks, suggesting that they had ontogenetic shifts in habitat use (mature females exhibit residence behavior, while juveniles are more active around movement corridors--- the south western reef area used for travel route of all sharks).

TECHNICAL ASPECTS AFFECT SHARKS' ATM AND PRM

The technical aspects that affect shark mortality can be separated into 3 main groups: Soak time & water temperature, trailing gear & hook type, and damage caused by handling & gear removal.

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DURATION OF TIME SPENT IN WARMER WATERS AND SOAK TIMES CAN INFLUENCE LEVELS OF ACIDOSIS

Several studies suggest warmer waters influence the level of acidosis a species experiences by speeding up metabolism, causing faster rates of acidosis (Whitney et al., 2021; Afonso & Hazin, 2014; Scott et al., 2023; Hutchinson et al., 2021); furthermore, metabolic and respiratory acidosis are reactions that are dependent on temperature (Hutchinson et al., 2021). Afonso & Hazin (2014) also showed that warmer waters increase physiological stress in some species of shark and seemed to make them more susceptible to getting captured on fishing gear. This explains the higher PRM of blacktip sharks near Madeira Beach and Key West (Florida, US) compared to other studies, due to their warmer temperature (Whitney et al., 2021). Interestingly, Hutchinson et al. (2021) showed that poikilothermic species are less effective physiologically in clearing up lactic acid buildup. This suggests that the susceptibility to acidosis should be assessed individually because susceptibility may vary between species. Research also showed that shorter soak times reduce the PRM in species like Oceanic whitetip sharks, tiger sharks, and across other species (Afonso & Hazin 2014). A separate study noticed the same pattern, and Scott et al. (2023) suggest adjusting soak times based on seasonal restrictions, and soak time restrictions can help reduce PRM in such species. Future studies should aim at identifying species of sharks with which PRM correlates to mortality, and work on ways to shorten soak times.

LENGTH OF TRAILING GEAR AND HOOK CAN AFFECT PRM RATES

Hutchinson et al. (2021) show that a longer trailing gear is found to increase the chances of PRM for the big eye thresher shark. In the same study, removal of trailing gear to ideally less than 1m is shown to improve the chances of PRS to up to 40% over 365 days. Thus, suggesting that removing more trailing gear using a de-hooker or cutting the line showed the best survival results (Hutchinson et al., 2021). The behavior of shark species can also affect the length of the trailing gear. Species that surface or struggle a lot, such as thresher sharks, can be seen from far away, and a fisherman usually cuts the line as soon as they see the shark resulting in longer trailing gear (Hutchinson et al., 2021); sharks that may be hard to identify or only surface as the vessel nears are spotted nearer to the vessel, so their trailing gear will be much shorter than those that have been spotted further out (Hutchinson et al., 2021). Since longer trailing gear results in higher mortality, this suggests that species that struggle more on the line are likely to have higher PRM.

Studies have shown that hook types have an impact on sharks' ATM, PRM, and vessel conditions based on their hook type and leader material (Baremore et al., 2021; Afonso & Hazin 2014). Looking at circle and J hooks, Afonso & Hazin (2014) show that circle hooks cause less ATM tiger sharks than J hooks. In the study with ships that used only longline gear with circle hooks, tiger sharks had an AVM of 8-18%, and with vessels that used both circle and J-shaped hooks, had an ATM of 30.9%. However, in a different study, the results are different for deep-sea sharks. More studies should be done to better understand this discrepancy (Fauconnet et al., 2024). PR offshore behavior, such as yo-yo diving patterns (vertical, wide-ranging, erratic movement), may be due to the shark's response to hooking stress. Incorrect or damage caused by removing hooking gear may also impact mortality rates (Afonso & Hazin, 2014).

HANDLING DAMAGE AND GEAR REMOVAL OFTEN CAUSES PRM OR DELAYED MORTALITY

Hutchinson et al. (2021) show that handling damage and damage due to gear removal can result in delayed mortality and PRM. Separate studies also show that handling methods can cause yo-yo diving patterns and other behavioral patterns, which can lead to mortality depending on the species (Afonso & Hazin 2014; Bowlby et al., 2021). Hutchinson et al. (2021) shows the type of harm inflicted on sharks from direct handling or with hooks from lowest survival rate to highest: jaw damage (occurs when fishers cut through the cartilage of the jaw to attain/remove a hook and can also be caused by removal of hook), part removal (removing part of the shark to get the hook), removing gear, and de-hooking. Hutchinson et al. (2021) saw that when a thresher shark's tail is hooked, 67% of the time the tip of the tail will be removed to retrieve the hook (part removal), even if thresher sharks rely on their tail to stun prey. The same study also suggested that damage caused by direct handling and gear removal can be mitigated by successfully communicating with fishers. Effective communication with fishers will aid in implementing more suitable conservation measures.

FUTURE DEVELOPMENT OF CONSERVATION MEASURES

This section proposes solutions to the three factors in the sections above that affect mortality in sharks. Solutions of potential ways to mitigate long-line commercial fishery in sharks are classified into three categories: communication with fishermen, systematic restrictions, and other project-based solutions.

Communication with fishermen is essential as they directly interact with shark species (Hutchinson et al., 2021). Fishermen's attitude, knowledge, and support are what make conservation possible (Afonso & Hazin, 2014; Varela et al., 2025). More studies should be done looking at the fishermen's willingness to incorporate new changes to improve shark survival. A study by Varela et al. (2025) shows that most fishermen in the Santiago Island, Cabo Verde region demonstrate knowledge of why sharks are decreasing (96% of fishermen believe the shark abundance decrease is because of fisheries); and 51% will stop catching sharks if it were a legal obligation rather than other alternatives. Thus, increasing fishermen's knowledge of the ecological roles of sharks will be vital for their cooperation. Furthermore, restricting and developing better handling methods and banning the removal of specialized parts of sharks, because their specialized body parts are usually vital to the shark's survival, requires communication with the fishermen as well. Working with fishermen to find alternative jobs to fishing, like tourism, creates a mutually beneficial relationship with the fishermen and the ecosystem, allowing them to help sustain and preserve it.

Apart from direct communication with fishermen, systematic restrictions are also necessary for the future of shark conservation. Current MPA sections of protection can be reviewed in the MPA guideline (Grorud-Colvert et al., 2021). Better adaptations to the MPA methods are essential to the protection of migratory sharks, as 85% of animals spend their time outside the MPA's (Sequeira et al., 2025). Apart from protecting areas that have the most marine activity, it is also important to incorporate areas of high shark mortality or mortality of megafauna into MPAs. Recognizing places with high shark mortality and identifying the reasons for mortality can improve fishing regulations, which will help prevent shark mortality caused by fisheries. Murua et al. (2021) suggest that when assessing mortality in an area, one should consider multiple aspects like availability, encounterability, the possibility of a species encountering fishing gear within its depth, susceptibility, selectivity, and PRM. To reduce encounterability including more MPA areas that protect the depth-specific zones that are important to an endangered shark species, may help mitigate bycatch. Similarly, for migratory species, instead of protecting a region of the ocean, MPA's should focus on implementing protection of depth zones (eg., 0-200m) that are vital sites for breeding, feeding, or other activities. More data provided by long-term tracking SAT tags of migratory sharks, as well as fine-scale PSAT tags of non-migratory sharks or their prey, on the movement patterns of different sharks may allow a clearer perspective to refine MPA areas and provide insight into future areas of shark conservation.

Project-based solutions explore ways to help mitigate the amount of shark mortality. Kajiura et al. (2024) conducted a study that shows sharks can theoretically sense a zinc/graphite deterrent from about 58.5cm away. Sharks are electroreceptive, and weak electric fields are common components of individual shark deterrents. While electric-field emitting shark deterrents have been in use for decades (Kajiura et al., 2024), many are marketed for individual use for recreational anglers or water users due to various restrictions, such as cost, availability, and size. Despite the restriction, large-scale commercial products that implement designs to reduce bycatch are not unprecedented. TED's (Turtle Excluder Devices) had been designed based on turtles' responses to capture. A hole at the top of the net utilized turtles' tendency to float to the surface when caught, which is contrary to that of fish (which is to swim down). Researchers were able to exclude turtles 97% of the time from shrimp trawl nets (National Oceanic and Atmospheric Administration, 2025). The cost of the zinc deterrent mentioned in the study is significantly less than that of other deterrents in the past. However, repairing gear for long-line fisheries could take a lot of time, as a set of longlines can have over 1000 hooks (Kajiura et al., 2024) Trials conducted in Florida (US), showed that zinc/graphite treatment reduced catch by 62.3%-69.5% compared to the controls, which used hooks without treatment (Kajiura et al., 2024). However, the same study suggests that further testing should be conducted to understand the limitations of this, as well as noting that the effectiveness of the treatment of species seemed to vary by species. Treatment to species like Atlantic shark nose shark, and other species in their study was proven to be effective; however, the treatment did not work well for dogfish (>650 sharks per 1000 hook- hours). Kajiura et al. (2024) suggest that the ineffectiveness of the treatment towards dogfish may be due to competition within a school. This has been echoed in separate studies, which showed shark deterrents seemed to be less effective when there was competition or tight food sources (Stoner and Kaimmer 2008; Jordan et al., 2011; Robbins et al., 2011; O'Connell et al., 2015).

KEY TAKEAWAYS AND LIMITATIONS OF CURRENT RESEARCH

Generally, data availability remains a key challenge in understanding bycatch mortality in sharks (Hutchinson et al., 2021; Scott et al., 2023). Dulvy et al. (2017) list the challenges in shark and ray conservation, some of which include: undermanagement of shark fishing mortality, managing shark migration, sharks as food security in places with poverty, etc. All these challenges listed are likely to affect the results from various studies that are discussed. Many studies have conducted a detailed analysis of satellite use and how to identify mortality after release (Benson et al., 2018; Clarke et al., 2021; Grorud-Colvert et al., 2021; Fisher et al., 2021; Tate et al., 2021), however, tagging and tracking individuals can still be challenging. Due to funding and other reasons, current research is mainly available in developed countries, resulting in a biased understanding of shark mortality, as many of the places that rely heavily on shark fisheries are in developing countries. Furthermore, as suggested by Whitney et al. (2021), different PRM rates vary for different species, gear, hook, and location, so the effects could be difficult to quantify. Finally, shark conservation can be limited in places where hunting sharks is part of their culture, where drawing the line between conservation and people's culture is something that needs to be determined in future studies.

Shark conservation is important because sharks have direct and indirect impacts on the ecosystem. More studies need to be conducted to get a better understanding of the factors that affect shark mortality. Shark bycatch mortality can be influenced by a shark's physical and physiological conditions, their behavior, and technical aspects of the catch, but different species' responses may vary significantly. Finally, future conservation methods should focus on the mitigation of shark bycatch through enhancing communications with fishermen, systematic regulations, and project-based conservation.

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