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Review Article

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MONITORING PROPOSAL OF THE SCHOOL SHARK G*ALEORHINUS GALEUS* (LINNAEUS, 1758)

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Abstract. The ongoing global environmental challenges have led to a decline in biodiversity, placing numerous species, both terrestrial and aquatic, at risk. Among the affected ecosystems, the aquatic environment holds particular significance due to its complex and interconnected nature. This paper presents a comprehensive proposal for the monitoring of the school shark (*Galeorhinus galeus*), a species currently classified as near-threatened, primarily due to its susceptibility to various environmental stressors. The paper outlines the species' habitat preferences, dietary habits, and distinctive biological traits. Furthermore, it proposes a detailed framework for population monitoring and critically examines conservation strategies aimed at ensuring the long-term viability of the school shark.

Key words: biodiversity, monitoring, environment, stressor, school shark.

INTRODUCTION

In light of the escalating threats to marine biodiversity, safeguarding and monitoring apex predators such as the school shark (*Galeorhinus galeus*) assume critical importance. The school shark, first described by Linnaeus in 1758, is a species with a wide global distribution and a pivotal role in marine ecosystems. As the sole representative of the genus Galeorhinus, adults can reach lengths of up to 3.5 meters and exhibit a distinctive grey-brown or grey-greenish coloration on their dorsum. Their diet predominantly comprises pelagic fish such as herring, sardines, and mackerel (Compagno 1984; Ebert et al. 2013).

Despite their ecological significance, school sharks face numerous threats, including overfishing, habitat degradation, and climate change. Their low reproductive rates and slow growth further heighten their vulnerability (Stevens 2006). Additionally, the high market value of their meat, fins, and oil has exacerbaopulation declines (Last and Stevens 2009).

This study aims to outline the methodologies for monitoring school shark populations to better understand their behavior, migration patterns, and habitat preferences. The research employs direct observation, tagging and tracking techniques, and analysis of fishing data. Recent studies emphasize the importance of long-term monitoring with frequency adjusted based on resource availability (Ebert et al. 2013). A comprehensive understanding of the school shark's

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ecology is crucial for devising effective conservation and management strategies, essential for preserving the balance of marine ecosystems amid current environmental challenges.

MATERIAL AND METHODS

Information about the species

Systematic affiliation

Order: Carcharhiniformes
Family: Triakidae

Legal status and threat of the species

IUCN Red List – NEAR THREATENED species
CITES – regulation of international trade in this species; export and import permits

Regional regulations

European Union: Conservation measures for the school shark have been introduced, including restrictions on fishing and trade since 2010 to safeguard the species (Council Regulation (EU) No 40/2013).

Australia: Fishing and trade of school sharks are regulated, with a ban on commercial shark fishing in Queensland and catch limits implemented in Western Australia (Queensland Department of Agriculture and Fisheries, 2016; Australian Fisheries Management Authority, 2014).

South Africa: A ban on commercial shark fishing, including the school shark, was implemented in 2013 along the South African coast as part of the National Plan of Action for Shark Conservation (South African Department of Environmental Affairs, 2013; National Plan of Action for the Conservation and Management of Sharks).

California, USA: A ban on commercial shark fishing, which includes the school shark, has been enforced in California to protect local shark populations (California Department of Fish and Wildlife, 2011; Shark Fin Law, AB 376).

Description of the species

The school shark (*Galeorhinus galeus*) belongs to the order Sharks Carcharhiniformes and the Triakidae family. Some other species in this family are the white-bellied shark (*Carcharhinus plumbeus*), the river shark (*Glyphis* spp.), and the small-toothed shark (*Mustelus* spp.). It is the only representative of the genus *Galeorhinus*. Sharks of the Triakidae family share some common features, such as slender bodies, five pairs of gill slits, long dorsal fins, and cone-shaped teeth (Ebert et al. 2013).

Size: Adult school sharks usually reach a length of two to three meters, although some can exceed 3.5 meters. Males are usually slightly smaller than females (Nelson 2006).

Body structure: The school shark has a slender, elongated body that is relatively tall in cross-section. This is the typical body structure of sharks, which provides them with high efficiency of movement when swimming (Klimley 2003).

Head shape: The head is relatively large compared to the rest of the body. The snout is long and conical with clearly defined angles at the end of the jaw (Klimley 2003).

Skin: Smooth and covered with small, fine scales, placed close together. On the back and sides of the body, the skin takes on a distinctive grey-brown or grey-greenish colour,

which gradually changes to a lighter colour on the flanks and white or cream on the belly, which helps to mask the surroundings (Carrier et al. 2018).

Fins: Two distinctive dorsal fins. The first dorsal fin is noticeably larger. The caudal fin is long and slender (Klimley 2003).

Teeth: Sharp, triangular located in several rows in both jaws (Klimley 2003).

Identification: The school shark (*Galeorhinus galeus*) can be confused with other shark species (Fig. 1).

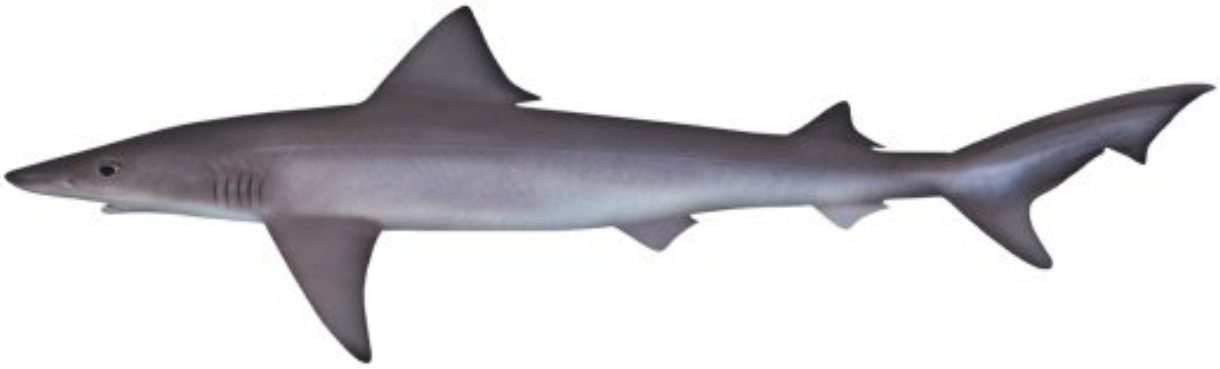

Fig. 1. Illustration of the school shark (https://www.dpi.nsw.gov.au)

Species with which the school shark may be confused include:

– **The dusky shark** (*Carcharhinus obscurus*) (Lesueur, 1818): Similar in size and body shape, with a grey-brown back and lighter belly. The dusky shark has a more rounded snout and a larger second dorsal fin compared to the school shark (Ebert et al. 2013) (Fig. 2).

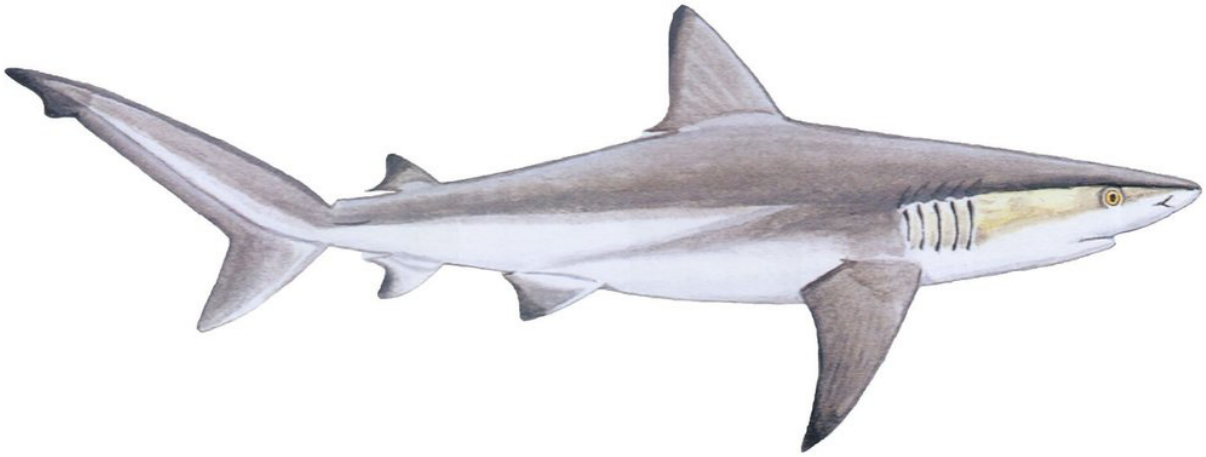

Fig. 2. Illustration of the dusky shark (copyright Marc Dando)

– **The sandbar shark** (*Carcharhinus plumbeus*) (Eduard Rüppell, 1837): Similar in size with a similar body shape and coloration, with a grey-brown back and lighter belly (Ebert et al. 2013). However, the sandbar shark has a more prominent and rounded snout, and its first dorsal fin is taller and more upright than that of the school

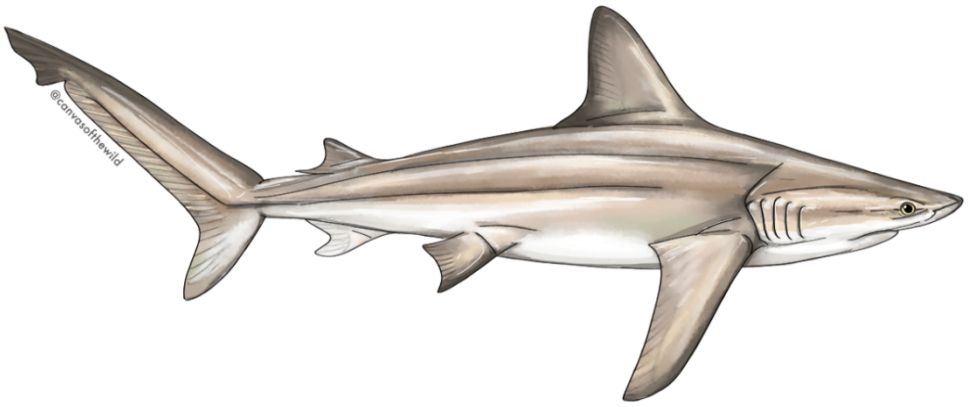

Fig. 3. Illustration of the sandbar shark (copyright Canvas of the Wild)

– **The silky shark** (*Carcharhinus falciformis*) (Johann Jakob von Engelhardt, 1841): This species also resembles the school shark in body shape and size. Both species have long first dorsal fins and a conical snout (Castro 2011). However, the silky shark has a more slender body, a smaller second dorsal fin, and a lighter overall coloration. Additionally, the silky shark's pectoral fins are longer and more pointed compared to the school shark (Fig. 4).

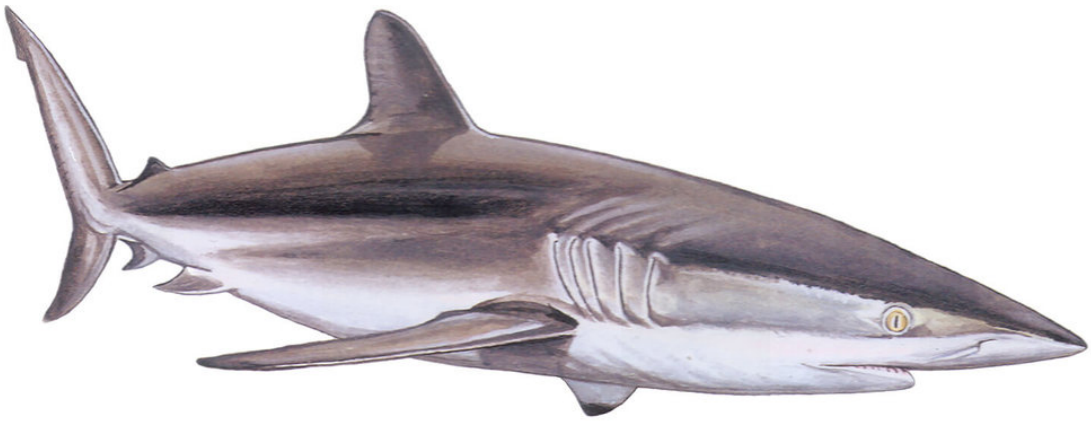

Fig. 4. Illustration of the silky shark (copyright Marc Dando)

Biology of the species

Nutrition: The diet of the school shark consists mainly of fish such as herring, sardines, and mackerel, but also includes squid, crustaceans, and other marine invertebrates. It is considered an opportunistic species that adapts its diet based on the availability of food in a given area (Compagno 1984).

Reproduction: The school shark is an ovoviviparous species, meaning that the embryos develop inside the mother's body, but are nourished by a yolk sac rather than through a placental connection, as seen in viviparous species (Compagno 1984). During gestation, the embryos remain in egg-like cases within the mother, but the eggs hatch internally before birth. The mother then gives birth to live young, which are fully formed and independent at birth. Female school sharks typically give birth to litters of 6 to 52 pups after a gestation period that can last up to 12 months (Stevens and McLoughlin 1991).

Activity: This species is primarily nocturnal but can also be found during the day. It undertakes long migrations both along the coasts and in the open sea in search of food and suitable habitats (Olsen 1984).

Lifespan: It is estimated that the school shark can live between 20 and 30 years, although some sources suggest it may live even longer. Exact figures are difficult to determine due to variations in survey methods and limited information (Last and Stevens 2009).

Areas of occurrence

Atlantic Ocean: Present in the northern, central, and southern regions. It is found along the coasts of Europe, including the Mediterranean Sea, and extends to the coasts of North America, including Canada and the United States, as well as South America.

Indian Ocean: Found around the African coast, from the Red Sea to southern Africa. It also occurs along the coasts of the Indian subcontinent, Indonesia, Australia, and other adjacent regions.

Pacific Ocean: Occurs in the northern, central, and southern regions. It is found along the coasts of North America, South America, East Asia, Australia, and various islands of Oceania. The species is found both in the open sea and along continental shelves, including offshore coral reefs, lagoons, and estuaries. It typically prefers the pelagic zone in waters of moderate depth.

Habitat requirements:

- A pelagic species, it prefers marine waters with significant salinity at depths of up to several hundred meters. It is also found near the coasts, particularly in continental shelf regions, especially in areas of moderate depth that provide access to a variety of food sources (Compagno 1984; Ebert et al. 2013).
- Juveniles often migrate to lagoons and estuaries where they can find shelter and abundant food (Stevens 2006; Last and Stevens 2009).
- Seasonal migrations occur in search of food and suitable habitats. The species can travel long distances, including transoceanic migrations facilitated by ocean currents. In the Northern Hemisphere, migrations generally take place from spring to autumn, while in the Southern Hemisphere, they occur from late summer to early winter (Compagno 1984; Ebert et al. 2013).
- Temperature Range: Found in waters with temperatures ranging from 10°C to 22°C, depending on the region (Compagno 1984).

Distribution of the species

- Along the Eastern Atlantic Coasts: found from Norway and Britain to southern Africa. Found in the Mediterranean Sea and around the Canary Islands and the Azores (Compagno 1984; Ebert et al. 2013).
- In the Pacific: found both on the west coast of North America, from Alaska to Mexico, and on the east coast of South America, from Chile to Peru. It is also presented in the Central and North Pacific regions, including Hawaii (Stevens 2006; Last and Stevens 2009).
- In the Indian Ocean: present along the coasts from South Africa through Mozambique, Madagascar, India, Sri Lanka, the Maldives and Indonesia (Compagno 1984; Ebert et al. 2013).
- Australia: found along the northern coasts and along the east coast, including the Great Barrier Reef (Last and Stevens 2009).
- New Zealand: found on both the northern and southern coasts (Ebert et al. 2013).

Indicators and assessment of the conservation status of the species

Population status indicator

Table 1. School shark population status indicators

Indicator	Measurement	Measurement method/definition
Relative abundance	individuals/m²	number of captured individuals of school shark per unit area of fishing ground
Age structure	descriptive index	based on measurements of the total length of captured sharks using the standard method (direct method), identification of individuals in distinct age classes: adults (ADULT), juveniles (JUV) before reaching sexual maturity, and young individuals in their first year of life (YOY)
Species composition in shark assemblage	%	determination of the proportion of school shark individuals in the total number of captured sharks

Table 2. Valuation of school shark population status indicators

Indicator	Assessment		
	FV	U1	U2
Relative abundance	>0.005	0.001–0.005	<0.001
Age structure	all age categories present	one age category missing	only one age category present
Species proportion in shark assemblage	>1%	0.1–1%	<0.1%

FV – proper state, U1 – unsatisfactory state, U2 – poor state.

Assessment of population status

The population status rating is determined by the lowest of the ratings of the three indicators. Indicators of habitat condition:

- Scale and range of measurements – pH, chemical concentrations, pollution levels.
- Biodiversity – identification of other aquatic species present with them and their abundance and density.
- Physical and geographic features – structure and distribution of habitats, condition of vegetation (to determine food resources, often fish refuge).

For each school shark area (aquatic habitat, geographic area or entire ecosystem), an appropriate scale should be selected, depending on the size of the study area. Appropriate values, will be in the range of water temperature 15–20 degrees Celsius. Data collection is carried out through field surveys, water sampling, biological surveys, i.e. observation of aquatic species, and analysis of histological data to check organ structure and identify potential diseases or pathogens, as well as analysis of historical data.

Habitat condition assessment

After selecting the appropriate evaluation criteria, the condition of a specific aquatic habitat will be determined based on this.

Conservation prospects

The conservation prospects of the school shark species, are currently of concern. The species is classified by the International Union for Conservation of Nature (IUCN) as “threatened with extinction” globally.

The school shark has a low reproductive capacity and is slow to develop, making it particularly vulnerable to fishing pressure and environmental changes. There are several factors that contribute to the decline of the school shark population. These include:

– Overfishing: The school shark is often an unwanted bycatch It is also fished intentionally in some regions because of the market value of its meat, fins and oil. Excessive fishing without proper regulation can lead to population declines.
– Habitat conversion: the school shark inhabits a variety of habitats, including coastal and pelagic marine waters. Changes in habitat structure and quality, such as coral reef degradation, water pollution or loss of feeding grounds, can affect food availability and living space for this species.
– Climate change: Changes in marine water thermals and ocean acidification can affect the ecosystems in which the school shark lives. disrupting migration, reproduction, reducing food availability, among other things.

Many countries and organizations are taking measures to protect sharks

Catch limits: Many countries and organizations have implemented catch limits to ensure the sustainable management of shark populations. In Australia, strict catch limits have been established for various shark species to prevent overfishing and promote sustainable fishing practices (NSW Department of Primary Industries, 2020). Similarly, the National Marine Fisheries Service (NMFS) in the United States has set catch limits for sharks to regulate their populations and prevent overharvesting (NMFS 2021).

Creation of protected areas: Protected areas are crucial for shark conservation. For instance, the Galápagos Marine Reserve in Ecuador is a designated protected area where shark fishing is strictly prohibited, providing a sanctuary for various shark species (Galápagos National Park Service, 2018). The Bahamas has also established protected areas that ban shark fishing, contributing to the preservation of its shark populations (Baum et al. 2007).

Education and shark awareness: For example: Shark Week organized by Discovery Channel promotes awareness about sharks and their conservation. Educational projects led by NGOs like Shark Trust and Shark Savers educated the public about ecological role of sharks and the threats they face.

It is also worth noting that the protection of the school shark and other shark species is important for the balance of marine ecosystems. Sharks play an important role in regulating the populations of other species and maintaining the health of ocean ecosystems.

Therefore, it is necessary to regulate the school shark fishery and protect its habitat.

The assessment of the species’ conservation prospects is equal to the future status of the population: it is assessed as adequate if the current FV status remains unchanged or the current U1 status improves. The prospects are assessed as unsatisfactory if the current U1 status does not change or the current FV status deteriorates. If the predicted status deteriorates to a U2 rating or the current U2 status does not improve, then the outlook should be assessed as poor.

Overall assessment

The assessment is based on evaluations of key parameters, including population status, habitat condition, and conservation prospects. The overall rating is determined by the lowest rating among these parameters.

Description of monitoring studies

Selection of monitoring plots

School sharks are a partially migratory species. They tend to move on a large scale, covering oceanic and coastal areas. However, migration routes are still under study and all their details are unknown, and such monitoring would add valuable information.

The migrations studied so far are along the coasts, in winter towards warmer waters and in summer towards cooler areas. And in accordance with sea currents.

The positions would be distributed in:

– Europe, where they move from Mediterranean waters to the Atlantic.
– In the United States along the coast of California.
– Australia and New Zealand: between the northern and southern parts of these countries, depending on seasonal changes in water temperature and food availability.
– South Africa: along the coasts of South Africa, Mozambique and other nearby countries.
– South America: along the coasts of Brazil, Argentina, Chile and other countries in the region.

Because of commercial fishing, the study could use data obtained from these fisheries in the Mediterranean and eastern Atlantic: along the southern and eastern coasts of Australia, it is caught mainly for meat.

A worthwhile monitoring proposal would also be the implementation of artificial intelligence methods for forecasting and determining trends in school shark migration and feeding grounds.

Method of conducting research

– Direct observations: from ship decks, observations from airplanes, or the use of underwater methods such as diving or the utilization of underwater robots.
– Tagging and tracking: Tagging of school sharks using markers, tags, or transponders enables tracking of their movements and migrations.
– Analysis of fishing data, such as commercial fishing records or data from fishing monitoring programs, regarding the number and distribution of school sharks in a given area.

Fig. 5. Photo of tagging method (ocearch.org)

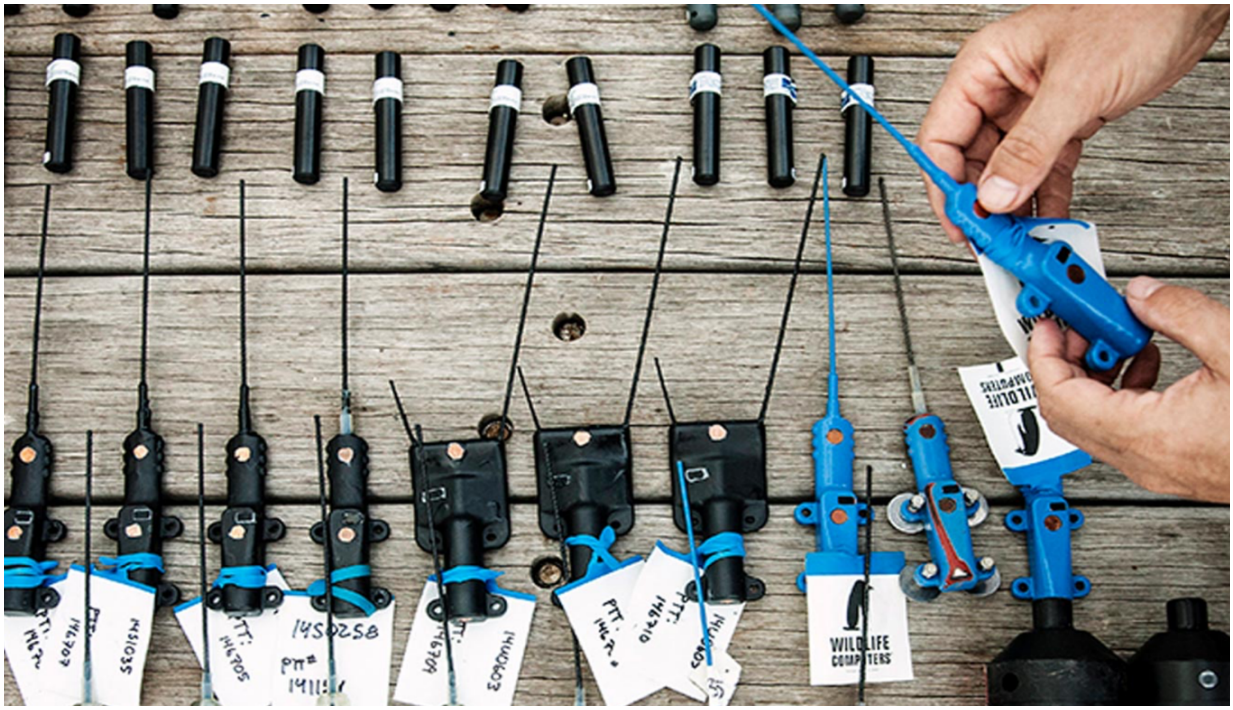

Fig. 6. Photo of tagging method (ocearch.org)

Fig. 7. Photo of shark research team (copyright Christopher Brown, Sharktagging.com)

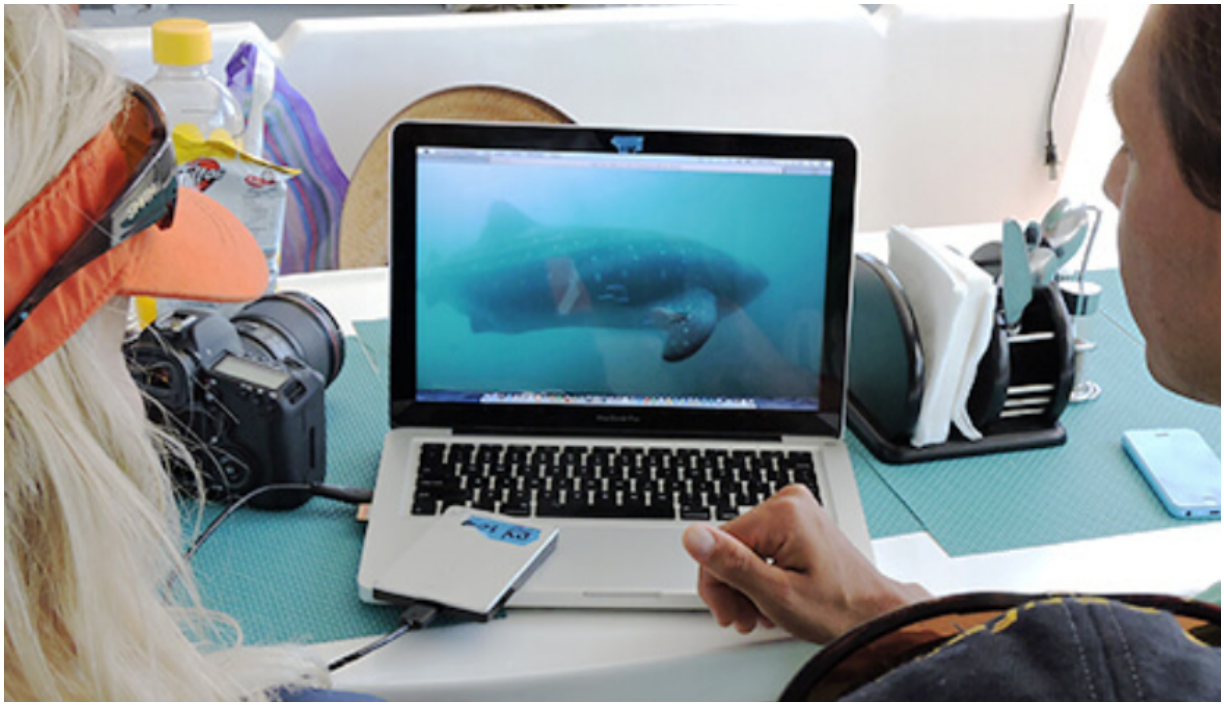

Fig. 8. Photo of data analysis method (sharks.org)

Study duration and frequency

– The monitoring of the school shark should be conducted over an extended period to enable the analysis of population trends. It is suggested to regularly repeat the studies at predetermined intervals to ensure data comparability.
– The frequency of studies may vary depending on the available resources. This could encompass annual, seasonal, or even more detailed short-term studies aimed at comprehending specific aspects of the biology or ecology of the school shark.

Equipment and materials

Depending on the applied monitoring method, various types of equipment and materials will be required. These will include:

– Equipment for direct observation. For example: dive masks, snorkel equipment, waterproof binoculars, underwater cameras.
– Devices for tagging and labeling sharks. For example: identification tags and labels, waterproof markers, suction cups or straps for attaching tags.
– Transponders or acoustic tags. For example: RFID transponders, tags for tracking location and movement, acoustic tags.

RFID transponders:

– Frequency: Typically operate at 125 kHz (low frequency), 13.56 MHz (high frequency), or 860–960 MHz (ultra-high frequency).
– Range: Can vary significantly; low-frequency RFID typically has a short range (a few centimeters), while ultra-high frequency RFID can reach up to several meters.
– Battery life: Passive RFID tags do not have a battery and are powered by the reader's signal. Active RFID tags, which contain a battery, can have a battery life ranging from a few months to several years, depending on usage.

– Durability: Tags must be waterproof and resistant to saltwater corrosion if used in marine environments.

RFID transponders are essentialin marine biology to track shark movements and behaviors (Heupel and Simpfendorfer 2005; Hussey et al. 2015).

Acoustic tags:

– Frequency range: Typically operate in the range of 30–300 kHz. The specific frequency depends on the model and manufacturer.
– Transmission interval: Can be set to different intervals, such as every 30 seconds to several minutes, to conserve battery life.
– Detection range: Depending on water conditions, acoustic tags can be detected at ranges from a few hundred meters to several kilometers.
– Battery life: Varies based on the size of the tag and the transmission interval; some can last from several months to over five years.
– Environmental resistance: Tags should be robust enough to withstand high pressure, temperature variations, and salinity levels in oceanic environments.

As described by Heupel and Simpfendorfer (2005), acoustic tags are essential tools for evaluating marine protected areas. Hussey et al. (2015) also highlight the panoramic view into the underwater world provided by aquatic animal telemetry.

– Satellite tags for monitoring movements and migrations.
– Apparatus for collecting and analyzing biological samples, such as DNA samples or tissue samples.
– Computers and software for data analysis and processing.
– Diving equipment, dry suits, wetsuits, fins, and tanks.

OBSERVATION RECORD FORM

Observation card at the site	
Species name:	Common name, scientific name, author according to currently valid nomenclature
Date and time of observation:	Exact information regarding the time and date of observation – this will allow for determining migration trends and seasonal changes
Geographic coordinates:	Enter the geographic coordinates of the location (GPS)
Location name:	Name of the monitored location
Weather conditions:	Information about atmospheric and oceanic or marine conditions, air and water temperature, wind speed and direction, sea state, visibility
Number and size of gray sharks:	Number and length of individuals' bodies, specific size categories can be used, e.g., small, large, medium
Behavior of gray sharks:	Description of behavior, feeding, swimming, interactions with humans or other animals, agitation, curiosity
Habitat characteristics, environment:	Brief description of the habitat considering the surroundings
Additional notes:	Any additional observations that might be relevant to the study
Observer:	Name and surname of the monitoring executor
Is monitoring required in subsequent years / at what time interval:	Determination of the next useful observation

Species conservation status in the studied area				
parameter	indicators	indicator value and description	evaluation	
Population	relative abundance	provide number + species occurs abundantly, sparsely	e.g. U2	U1
	age structure	YOY 0% JUV 0% ADULT 100% One individual observed	XX	
	species composition within a shark assemblage	e.g. rare species	U1	
Habitat	EFI+/other	indicates good/poor habitat quality	FV	U1
	hydromorphological quality	e.g. high vegetation, lack of accompanying organisms, low visibility, moderate water conditions	U1	
	flow characteristics	e.g. good water circulation and flow, moderately stagnant water	U1	
Preservation prospects	here, a brief forecast of population status, existing conditions, trend projections, consideration of plans and changes that may affect the species			U2
Overall assessment	U2			

List of the most important current and predicted impacts, which pose threats to species A, B, and C, categorized as strong, moderate, and weak interactions.

Current interactions				
code	activity name	intensity	impact	description
x	commercial shark fishing	A	/	exploitation of the school shark in the fishing industry, meat trade, finning, cosmetic and culinary industry
y	unsustainable fishing, bycatch	B	/	intensive and uncontrolled fishing, school shark caught during the fishing of other species
z	destruction of habitats due to waste such as fishing nets and others, ghost nets	C	/	fishing nets lost at sea, known as „ghost nets," which destroy coral reefs or entangle sharks, causing immobilization or starvation

Additional Information	
Other natural information	Other animal and plant species observed during monitoring work; endangered and rare species
Alien and other species observed with school shark	Observed alien and invasive species (indicate abundance on a scale of: few, moderately abundant, very abundant) or not found
Other comments	Any information to help interpret the results, e.g., weather anomalies, comments on the methodology, suggestions for changes or lack thereof
Photographic documentation, cartography	Appendices to the database, photos from the site, boundaries of the site marked on the relevant cartographic base

DISCUSSION

The results of monitoring studies on the school shark (*Galeorhinus galeus*) provide valuable insights into ecosystems, migration patterns, and population status. Research by Compagno (1984) and Ebert et al. (2013) has shown that understanding the behavior and habitat preferences of this species is crucial for effective management and conservation strategies. These

studies highlight how the school shark adapts to various ecological conditions, from coastal regions to deeper ocean environments, as seen in its preference for areas with moderate depths and specific temperature ranges.

Analysis of such research reveals significant variability in the school shark's behavior and habitat preferences across different global regions. For instance, Stevens (2006) and Last and Stevens (2009) have documented how these sharks migrate over large distances, indicating a need for international cooperation in conservation efforts. The migratory patterns observed underscore the importance of understanding and protecting migratory routes to prevent bycatch and ensure sustainable populations.

The adaptation of the school shark to diverse ecological conditions, from shallow coastal areas to deeper pelagic zones, reflects broader patterns observed in other pelagic species. Compagno (1984) note that such adaptability highlights the need for a comprehensive approach to research and conservation, incorporating data from various regions to effectively address the challenges facing this species.

In summary, integrating findings from various studies emphasizes the importance of continued monitoring and international collaboration. Identifying key migratory routes and understanding habitat preferences will be crucial for mitigating bycatch and supporting the conservation of the school shark and associated species within its ecosystem.

CONCLUSIONS

To ensure the conservation of the school shark (*Galeorhinus galeus*), it is imperative to implement stringent fisheries regulations. This includes establishing and enforcing catch limits and enacting fishing bans in critical habitats where the species is particularly vulnerable. Effective monitoring of fishing activities and rigorous enforcement of regulations are essential to curbing illegal fishing practices and preventing the trade of products derived from this species.

Special attention must be given to sustainable fishing practices to mitigate bycatch, where sharks are inadvertently captured. Additionally, safeguarding critical habitats that serve as breeding and feeding grounds for the school shark is crucial for its conservation.

Public education and awareness initiatives regarding the school shark and broader shark conservation are vital. Providing accurate information to local communities, fishermen, and relevant organizations can facilitate the recovery of shark populations and promote the adoption of more sustainable fishing practices.

The protection of the school shark represents a significant effort towards preserving the biodiversity of oceanic and marine ecosystems.

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PROPOZYCJA MONITORINGU ŻARŁACZA SZAREGO (REKINA SZAREGO)

Streszczenie. Trwające globalne wyzwania środowiskowe doprowadziły do spadku różnorodności biologicznej, narażając na ryzyko wiele gatunków, zarówno lądowych, jak i wodnych. Wśród dotkniętych ekosystemów środowisko wodne ma szczególne znaczenie ze względu na jego złożony i wzajemnie powiązany charakter. Niniejszy artykuł przedstawia kompleksową propozycję monitoringu rekina szarego (*Galeorhinus galeus*), gatunku obecnie klasyfikowanego jako bliski zagrożenia, głównie ze względu na jego podatność na różne stresory środowiskowe. Ukazano preferencje siedliskowe gatunku, nawyki żywieniowe i charakterystyczne cechy biologiczne. Ponadto zaproponowano szczegółowe ramy monitorowania populacji i przeanalizowano strategie ochrony mające na celu zapewnienie długowieczności rekina szarego.

Słowa kluczowe: bioróżnorodność, monitoring, środowisko, stresor, rekin szary.