



Tracking the Gentle Giant: Whale Shark Conservation through Satellite Science

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ABSTRACT

The whale shark (*Rhincodon typus*), the world's largest fish, has become a flagship species for global marine conservation owing to its immense size, filter-feeding ecology, and gentle behaviour toward humans. Despite its charismatic status, the species has been classified as Endangered on the IUCN Red List since 2016, with the Indo-Pacific population estimated to have declined by 50–79%. Historical targeted fishing, bycatch in tuna fisheries, illegal trade in fins and liver oil, plastic pollution, and vessel strikes continue to threaten the species, even as international protections under CITES and CMS have expanded. Over the past decade, satellite-tracking research in Indonesia's Bird's Head Seascape and Coral Triangle has tagged more than 70 individuals, revealing that whale sharks cross at least 13 national maritime boundaries and spend substantial portions of their lives in international waters beyond the reach of any single nation's protection. Long-term photo-identification work in Mozambique, by contrast, has documented an alarming and unexplained decline exceeding 85% at a once-thriving aggregation site, underscoring that cessation of direct fishing does not guarantee recovery. Emerging tools biologging cameras, citizen-science photo-matching, and artificial intelligence are expanding understanding of whale shark behaviour and movement. This review synthesises recent findings on whale shark population status, threats, and tracking research, and argues that effective long-term conservation must extend beyond isolated marine protected areas to encompass migratory corridors, high-seas governance, and sustained collaboration with local fishing communities.

KEYWORDS

Whale shark; *Rhincodon typus*; satellite tracking; marine conservation; Indo-Pacific; endangered species; bycatch; CITES

Introduction

On a warm morning in Cenderawasih Bay, Indonesia, a fisherman lowers his bagan lift-net into the sea and waits for the catch. After some time, a large shadow, almost the size of a school bus, moves beneath the fishing platform. The animal is not dangerous; instead, its presence is considered a good sign by local fishers. Fishers in this region have long known that whale sharks often approach their nets to feed on anchovies that escape from them. This close relationship between local fishermen and whale sharks has become an important part of marine conservation research, helping scientists collect valuable information about *Rhincodon typus*, the largest fish species in the world (Himawan et al., 2015; Meyers et al., 2020).

The whale shark is well known for its extraordinary size. Some individuals have been reliably recorded at nearly 19 metres in length, making it the largest living fish and the largest non-mammalian animal on Earth (Compagno, 2001; Rowat & Brooks, 2012). Despite this size, the whale shark is a filter-feeding animal, filtering plankton, fish eggs, krill and small schooling fishes from seawater through its specialised gill structures, processing thousands of litres of seawater every hour (Motta et al., 2010; Rowat & Brooks, 2012). Its calm, harmless nature draws divers and tourists worldwide, making it an important flagship species for marine conservation (Gallagher & Hammerschlag, 2011; Rowat & Brooks, 2012) and supporting tourism economies in the Philippines, Mexico and Western Australia.

However, the whale shark also illustrates how populations of large marine animals can decline over time. Whale sharks are believed to live for more than 100 years, grow slowly, mature late, and reproduce at a low rate, making population recovery extremely slow after declines (Pierce & Norman, 2016; Rigby et al., 2019). Identifying the

major causes of population decline and prioritising conservation actions have therefore become central concerns in marine megafauna conservation research.

A Species Assessed as Endangered

The whale shark has been classified as Endangered on the IUCN Red List of Threatened Species since 2016, a status maintained in the latest assessment (Pierce & Norman, 2016; Rigby et al., 2019). Globally, the population is estimated to have declined by at least 50% over the last three generations a period that, depending on the generation length used, may represent approximately 75–120 years. The level of decline, however, is not uniform across regions. The Indo-Pacific region, home to a major share of the global population, has experienced a particularly severe decline of about 50–79%, driven by historical targeted fishing, accidental capture, and mounting pressure on key habitats. The Atlantic population, by comparison, has declined less and remains categorised as Vulnerable, though its trend continues to be a concern (Rigby et al., 2019). Whale sharks are currently protected under several international agreements. The species has been listed in Appendix II of CITES since 2002, regulating international commercial trade in whale shark products (CITES, 2002), and in Appendix II of CMS, with some populations in Appendix I reflecting the long migratory distances whale sharks travel between national waters (CMS, 2017; Pierce & Norman, 2016).

More than 45 countries have introduced national laws prohibiting the capture or trade of whale sharks, yet these measures have not eliminated threats. A proposal submitted before the 2025 CITES Conference of the Parties (CoP20) highlighted continuing problems such as illegal retention of bycaught whale sharks, trade in fins, liver oil and meat in parts of Asia, and increasing mortality from vessel collisions,

recommending that the species be transferred to the stricter Appendix I (CITES, 2025).

The Threats Converging on the World's Biggest Fish

For much of the twentieth century, direct fishing was the principal threat to whale sharks. Fisheries in the Philippines, Taiwan, India and the Maldives targeted the species for meat, fins and liver oil the latter valued as a source of squalene once common in cosmetics and supplements. Although many of these fisheries have since been closed or restricted, illegal fishing and unreported catches persist in some areas, including parts of China, sustained by continuing demand for whale shark products (Rowat & Brooks, 2012; Pierce & Norman, 2016). Bycatch remains a harder threat to control. Whale sharks often associate with tuna schools and are accidentally captured in purse-seine and gillnet fisheries; although many regulations require their release, some individuals are retained or die from capture and handling (Rowat & Brooks, 2012; Pierce & Norman, 2016).

Plastic pollution is an emerging concern: because whale sharks filter enormous volumes of seawater, they may inadvertently ingest microplastics and larger debris alongside their natural food, raising concern over long-term health effects, though the population-level impact remains difficult to measure (Germanov et al., 2018). Satellite-tracking data combined with global shipping records show that around 92% of whale sharks' horizontal range and nearly 50% of their vertical range overlap with areas of heavy vessel traffic. Because animals injured or killed by ships often sink rather than reach shore, many vessel-related deaths likely go unrecorded, suggesting the true toll of ship strikes is substantially underestimated (Womersley et al., 2022).

What a Decade of Satellite Tracking Has Revealed

Some of the most significant recent whale shark research has taken place in Indonesia, home to the Bird's Head Seascape and the Coral Triangle critical habitats for the Indo-Pacific population. A collaboration involving the Elasmobranch Institute Indonesia, Konservasi Indonesia, Conservation International, and university researchers from Australia and Indonesia has tracked whale sharks by satellite for more than a decade (Putra et al., 2026). More than 70 whale sharks were tagged, with tags remaining active for an average of over 400 days and, in one case, nearly 990 days producing one of the largest satellite-tracking datasets available for the species. Research published in *Frontiers in Marine Science* in 2026 found that whale sharks in the region cross at least 13 national maritime boundaries, with males spending approximately 40% of their lives outside any national jurisdiction (Putra et al., 2026).

The research also illuminated whale shark aggregation ecology. While aggregations are typically seasonal elsewhere, Cenderawasih Bay and Saleh Bay were found to support year-round feeding aggregations, and newborn whale sharks recorded in Saleh Bay suggest it may serve as an important nursery habitat. These findings are informing conservation planning, including Indonesia's efforts with local communities to establish a marine protected area dedicated to whale sharks, and contributed to a seamount-protection resolution adopted at the March 2026 CMS Conference of the Parties (Putra et al., 2026). A separate study of 115 whale shark stranding records collected in Indonesia over 13 years found that reported strandings rose considerably from 2020 onward, likely reflecting greater public awareness and reporting rather than a proportional rise in actual mortality. Nonetheless, the study identified concerning patterns: juveniles accounted for a large share of

strandings, and stranding timing and location appeared linked to regional oceanographic conditions warranting systematic, ongoing monitoring rather than reactive response alone.

Findings from other regions have been less encouraging. At Praia do Tofo in southern Mozambique, a 15-year photo-identification study of more than 700 individuals (2005–2019) documented a continuing, serious decline in local sightings. Larger juveniles and adults particularly individuals longer than about seven metres showed the steepest decline, falling by roughly 99%, with overall sightings down about 87% and estimated abundance down 89% (Auditore et al., 2025). Researchers found no strong evidence that environmental shifts or redistribution could fully account for this decline, raising concern that it reflects a genuine regional population collapse rather than a change in distribution an important counterpoint to the more encouraging Indonesian findings.

New technology is also deepening behavioural understanding. In 2026, researchers from the Australian Institute of Marine Science reported findings from small cameras mounted on tagged whale sharks' fins, directly observing feeding behaviour previously inferred only indirectly. The study identified 36 distinct feeding behaviours, revealing a far wider foraging strategy than previously assumed including active searching throughout the water column and near the seafloor, not just surface plankton feeding (Barry et al., 2026). Citizen science and artificial intelligence are further transforming monitoring: AI-based systems can match the unique spot patterns in photographs submitted by divers and tourists to identify individual whale sharks, greatly expanding the geographic reach of data collection beyond professional research teams (Arzoumanian et al., 2005).

Turning Knowledge into Protection

Translating scientific knowledge into effective long-term conservation remains difficult. Marine protected areas around key aggregation sites including Ningaloo Reef in Western Australia, the Bird's Head Seascape in Indonesia, and Isla Holbox in Mexico continue to form the backbone of conservation efforts (Rowat & Brooks, 2012; Pierce & Norman, 2016). Ningaloo Marine Park, in particular, is often cited as a model for combining conservation with tourism through rules governing tourist location and behaviour during swim-with-whale-shark activities; a 2025 review in *Frontiers in Conservation Science* highlighted this as a useful approach for reducing disturbance while sustaining tourism (Hammerton et al., 2025).

Yet satellite-tracking studies reveal an important limitation of protected-area-based conservation: whale sharks do not remain within protected boundaries throughout their lives, instead crossing national borders and moving into international waters. Protecting isolated aggregation sites alone therefore cannot fully safeguard the species (Putra et al., 2026). Effective conservation planning must instead connect feeding and nursery habitats with migratory corridors spanning multiple countries and the high seas a far more complex undertaking that depends on international cooperation and still-developing frameworks for governing high-seas areas (Womersley et al., 2022; Putra et al., 2026). Local community involvement has also proven essential. In Indonesia, the same fishers whose bagan nets attract whale sharks have become valuable research partners, providing access to fishing grounds, local knowledge, and sighting information (Himawan et al., 2015); similar partnerships have emerged in tourism-dependent regions. Recent reviews of shark conservation more broadly emphasise the need for interdisciplinary approaches that address not only biology and population status but also interactions

with fisheries, human activities, and management, while highlighting persistent gaps in understanding the combined effects of multiple pressures and the social and economic dimensions of conservation (Queiroz et al., 2019; Dulvy et al., 2021).

The Road Ahead

Research over the past two years has substantially expanded understanding of whale shark conservation, yet the species' future remains uncertain. Satellite tracking has clarified migration routes, likely nursery areas, and the extent of time spent in international waters, while long-term monitoring has shown that populations do not automatically recover once direct fishing pressure eases the steep decline documented in Mozambique demonstrates that halting targeted fishing alone may be insufficient to restore populations (Putra et al., 2026).

New technologies are simultaneously creating better monitoring opportunities: biologging cameras are yielding direct behavioural data, artificial intelligence is enabling analysis of citizen-submitted photographs, and genetic and genomic tools are opening new avenues for population study (Auditore et al., 2025). Policy responses are also advancing, including the proposed strengthening of CITES protections, plans for a new whale shark-focused marine protected area in Indonesia, and CMS actions targeting connected marine habitats (CITES, 2025; CMS, 2026; Putra et al., 2026) signalling that conservation policy is gradually catching up with the scientific evidence.

Three major gaps remain. First, conservation must extend beyond individual aggregation sites to encompass migration routes and international waters. Second, modern threats such as vessel collisions and plastic pollution must be addressed alongside long-standing threats like fishing and illegal trade. Third, sustained

cooperation with local communities, fishermen, and citizen scientists must be maintained, given the importance of these partnerships for collecting data across vast areas.

Conclusion

Whale sharks take decades to reach maturity, and their populations may require even longer to recover from serious declines. The conservation decisions made during the present decade may therefore not show their full effects for many years to come, making this a particularly consequential period. Researchers now possess better data, a clearer understanding of the major threats, and improved conservation technologies than ever before yet the window of opportunity to prevent further population decline remains limited. Bridging the gap between site-based protection and the migratory, transboundary reality of whale shark life history, while sustaining the community partnerships that make long-term monitoring possible, will be essential to securing the future of the world's largest fish.

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