

THE IN A HURRY SERIES

Sharks

in a Hurry

The ocean's most misunderstood predator

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The Whole Thing in One Page

Say shark and the mind supplies one animal: large, grey, triangular, coming towards you. It is mostly a great white, enlarged by film, carrying the motives of a murderer and the senses of a guided missile. That animal has become so familiar that it hides the subject.

There are more than 500 living shark species. The biggest, the whale shark, filters small prey from seawater. Some lanternsharks can fit along a human forearm. Angelsharks flatten against the seabed. Greenland sharks move through cold darkness on a lifespan measured in centuries. Hammerheads widen the front of the head, while cookiecutter sharks remove neat plugs of flesh from animals much larger than themselves. A few species sometimes injure people. Most could not, would not, or never come near them.

Their common body is neither primitive nor perfected. Cartilage is reinforced where force demands it. Teeth are replaced through life. Toothlike denticles cover the skin. Fins, an oil-rich liver and body shape manage lift and sinking without a gas-filled swim bladder. Each arrangement has costs. A dense, fast shark can accelerate well but must work to stay up. A more buoyant deep-water shark may cruise cheaply and turn slowly. There is no single shark design because there is no single shark job.

The senses work the same way. Smell finds chemicals carried by moving water, not blood from an unlimited distance. Vision, hearing and the lateral line supply other parts of the scene. Close to an animal, pores around the head detect weak electric fields generated by muscles and nerves. No sense makes a shark omniscient. Hunting is the assembly of incomplete signals into a decision about whether a meal is worth the effort and risk.

That decision ranges from filtering plankton to ambushing seals, crushing shellfish, taking squid in darkness and scavenging a carcass. Sharks can be top predators, mid-level hunters, prey, competitors and carriers of nutrients between habitats. Their ecological effects depend on species, size and place. Removing one population can matter greatly without proving that every shark controls an entire food web.

Their deepest vulnerability lies in time. Some lay eggs. Others bear live young through several different systems, including yolk, uterine secretions, unfertilised eggs and placenta-like connections. Many large or deep-water species mature late and produce few young. Industrial fishing can remove adults in hours that a population needs decades to replace.

That is now the dominant encounter between sharks and humans. A 2024 global analysis put the lower bound on fishing deaths at 76 million sharks in 2012 and 80 million in 2019, despite widespread anti-finning rules. The rules addressed waste, but whole sharks could still be landed and sold.

Conservation therefore has to name the species, population, fishery and replacement rate. The same word that makes every shark look dangerous makes unequal declines hard to see.

The shark in the film is a predator facing us. The sharks in the ocean are a lineage facing a faster predator with nets, hooks, engines and markets. Understanding begins when both images are put back at their proper scale.

That is the book.

Why You Should Care

In 1971, the Dutch physiologist Ad Kalmijn hid a flatfish beneath sand and inside a chamber of seawater gel. A small shark could neither see it nor follow a direct trail of food through the water. It still turned towards the buried animal and struck at its position. When Kalmijn replaced the fish with electrodes producing a similar weak field, the shark struck those. When he added an electrically insulating sheet, the response disappeared.

The experiment revealed a world you do not inhabit. Every working muscle and nerve produces a faint electric field. Sharks and rays carry pores called ampullae of Lorenzini around the snout and head, connected to gel-filled canals that register such fields at close range. A fish hidden in sediment is still physically present to them. The sea has information in it that your body cannot read.

That is the first reason to care. Sharks force you to abandon the human

version of the ocean. To you, open water is visually empty. To a shark it contains odour filaments twisted by turbulence, low-frequency vibrations, water displacement, contrast, pressure changes and electrical gradients. These signals do not form a supernatural radar. They form a different reality, partial and noisy, in which food has to be found before energy runs out.

The second reason is engineering. A shark has no bony skeleton and no gas-filled swim bladder, yet some cross ocean basins, some hover over reefs and some rest on the bottom while pumping water across their gills. The solution is distributed across the animal: mineralised cartilage, an oil-rich liver, body density, paired fins, tail shape, skin texture, muscle and behaviour. Change one component and the rest of the package changes with it. Sharks are a lesson in how evolution works with trade-offs rather than best designs.

The third reason is fear, because this is one of the cleanest cases in which a vivid hazard defeats a rational denominator. The International Shark Attack File confirmed 65 unprovoked bites worldwide in 2025, nine fatal. Those are real injuries and deaths, and they deserve more than jokes about coconuts. They are also reports produced by the overlap between sharks and millions of people swimming, surfing, diving and fishing. A count without exposure cannot tell you that sharks became more aggressive, and the word unprovoked classifies the human action before the bite, not the shark's intention.

Then comes the reversal. While people measure sharks mainly by the damage they can do to us, industrial fishing measures them by what can be sold or by whether they happen to be on a hook. A global reassessment published in 2021 placed 391 of 1,199 assessed sharks, rays and chimaeras in threatened categories. A separate indicator built from 57 abundance series for 18 oceanic shark and ray species estimated a 71 per cent decline from 1970 to 2018. Those results have different species, denominators and methods, so they must not be fused into one slogan. Together they establish a hard asymmetry: the feared encounter is rare, while removal by fishing is routine.

Sharks matter without being saints. Some bite. Some populations are abundant enough to support managed fisheries; others are not. Their ecological effects vary, and protecting a species does not remove every risk at a beach. The reward for getting the subject right is better than reassurance. You gain a new sensory world, a working body model, a cleaner way to think about rare danger and a test for conservation claims that sound compassionate but never identify what is being conserved.

The animal becomes less monstrous when it becomes more specific. It also becomes more interesting.

The Core Ideas

The word shark hides a lineage

Movement is one of the clearest places where the word shark hides diversity. A whale shark crossing an ocean, a reef shark circling a home range and a deep-water dogfish shifting along a slope are solving different problems. Routes can reflect temperature, oxygen, prey, mating, pupping sites and learned familiarity with a place. Many species also separate day and night activity or move vertically through the water column. These tracks should not be read as one built-in programme. Individuals of the same species can use different routes, and conditions can alter a pattern from one year to the next. Experiments with bonnethead sharks support the conclusion that at least some sharks can use the Earth's magnetic field as part of a map-like sense, but that result does not establish a universal navigation system. Vision, smell, current, temperature, bottom features and memory may all contribute. Social behaviour is equally variable. Some sharks repeatedly associate with particular individuals or assemble around food, shelter or breeding opportunities; others spend much of their time apart. Solitary and social are therefore descriptions of context, not permanent personality types.

Put a whale shark beside a dwarf lanternshark and the word connecting them begins to look suspicious. One can exceed the length of a bus and

filters tiny animals from seawater. The other is among the smallest living sharks and carries light-producing organs along its underside. Add a flattened angelshark buried in sand, a thresher using an elongated tail around schooling fish, a blunt-headed bull shark moving into rivers and a Greenland shark living in deep cold water, and the familiar outline dissolves.

Sharks belong to the cartilaginous fishes, Chondrichthyes. Their closest living company consists of rays and skates, together called batoids, and the more distant chimaeras. The sharks themselves form a branch containing more than 500 described living species. The total shifts as new species are described, old names are merged or split, and genetic work rearranges families. That is why a rounded number is more honest than a permanent-looking exact count.

They occupy coral reefs, continental shelves, the open ocean, polar water, river mouths, deep slopes and the seabed. Some stay within a limited home range. Others cross ocean basins. Most are smaller than the cinematic shark, and many spend much of life beyond easy human observation. Even large species can change jobs as they grow. A juvenile may eat fish and crustaceans in shallow nursery habitat before the adult moves offshore and takes larger prey. Several families are concentrated in deep water, where darkness, low temperature and scattered food select for forms rarely seen alive at the surface. Others gather predictably at reefs, seamounts or seasonal feeding sites. Visibility to people is not a measure of abundance or importance.

The variety is not decorative. It means that almost every sentence beginning sharks are requires a test. Sharks are top predators: some are, while many are mid-level hunters, scavengers, filter feeders or prey for larger animals. Sharks must keep swimming: some pelagic species depend heavily on forward motion to ventilate their gills, while many bottom-living sharks can rest and pump water through the mouth or spiracles. Sharks reproduce slowly: the claim captures serious vulnerability in many large and deep-water species, yet smaller coastal species can mature and reproduce faster. Sharks live in the sea: bull sharks and river sharks make even that

boundary untidy.

The great white dominates because it combines size, visible teeth, surface encounters and a shape that reads clearly from a distance. It is also unusually well filmed. Yet it represents one branch of one order. Whale sharks and basking sharks are closer to the title's predator in ancestry than in daily practice. Hammerheads alter the geometry of the head and its sensory field. Wobbegongs turn camouflage into an ambush. Cookiecutters make a living by taking small circular pieces from larger animals, while also eating squid, fish and crustaceans.

Classification matters because biology and policy happen below the level of the icon. A ban that protects one hammerhead species may leave a similar-looking relative difficult to identify at sea. A recovery in one reef does not describe pelagic sharks elsewhere. A bite by a white, tiger or bull shark does not reveal the behaviour of hundreds of species that never produce such incidents. The plural is the first correction. Before asking what sharks do, ask which shark, at what size, in which water.

The body is a set of trade-offs, not a primitive fish

The skeleton is the usual insult. Bony fishes have bone; sharks have cartilage; therefore sharks are pictured as earlier, softer versions waiting for evolution to finish the job. The comparison mistakes material for performance.

Shark cartilage is organised and reinforced. Much of its surface is covered by small mineralised tiles called tesserae, and regions carrying high loads can be heavily calcified. Vertebral centra record growth in layered mineralised tissue. The skeleton supports muscles, transmits force and bends where swimming requires it. It does not need to imitate mammalian bone to work. Nor is cartilage automatically light enough to solve buoyancy. Whole-body density depends on several tissues, especially the liver and its oils.

Most bony fishes can adjust gas in a swim bladder and approach neutral buoyancy without continuous lift from movement. Sharks lack that device.

They combine a large oil-rich liver, relatively low-density tissues, body form and hydrodynamic forces from fins and tail. The result is a continuum rather than one solution. Comparative work across species found larger livers and greater buoyancy associated with deeper habitats, where economical steady movement can be valuable. Denser, more streamlined sharks may pay more to remain up but gain advantages during acceleration. A shark that sinks is not malfunctioning. Negative buoyancy can be part of the design.

The tail then has to do more than push backwards. In many sharks its upper lobe is longer than the lower, and the angle of thrust interacts with body and pectoral fins to produce forward force, pitch control and lift. Fin shape varies with work. Long narrow fins suit efficient cruising; broader shapes can favour manoeuvring. Some makos and white sharks retain metabolic heat in parts of the swimming muscles, eyes or viscera through counter-current blood vessels. That regional warming supports performance in cool water, but it raises the cost of the body and is confined to particular lineages.

The skin is armour and flow surface. Each dermal denticle has a toothlike structure, with a hard outer layer and a pulp cavity. Denticle size, direction and ridging vary across the body and among species. They can resist abrasion, deter fouling and alter water close to the skin. Experiments on shark skin and synthetic replicas show hydrodynamic effects, but not one universal percentage of drag reduction. A fixed denticle in a laboratory channel, a flexible patch on a swimming body and a different species are different measurements.

The mouth completes the package. Teeth develop in rows and move into use as older teeth are lost. Their shapes match tasks: cutting, gripping, crushing or holding small prey. Many sharks can project the upper jaw during a strike, extending the bite beyond the resting outline of the head. Suction, head movement and body momentum can matter as much as tooth sharpness.

Even breathing varies. Water must cross the gills, but it can arrive through forward motion, active pumping or a mixture that changes with speed.

Spiracles behind the eyes help some bottom dwellers draw water while the mouth is occupied or close to sediment. The shark body is therefore not a fossilised answer. It is a negotiated package. Strength, flexibility, lift, speed, manoeuvrability, ventilation and energy use pull in different directions, and each species settles the argument differently.

The ocean reaches a shark as overlapping signals

Smell gets the publicity because it travels well in a story. Pour blood into the sea, wait for a distant shark to turn, and the animal appears to possess a chemical telescope. Water does not carry odour that neatly. A chemical source is stretched, broken and folded by current and turbulence into intermittent filaments. A shark crossing the plume may detect a substance, lose it, turn, meet it again and use changes through time to search. Sensitivity cannot remove the need for transport.

The nostrils are sensory openings, not breathing holes. Water moves across folded olfactory tissue, where dissolved chemicals bind to receptors. Tests on several shark and ray species found impressive sensitivity to amino acids, often around parts per billion, but they did not support the idea that every shark shares one extraordinary threshold or can identify a meal from an arbitrary distance. Large olfactory organs also did not map cleanly onto greater sensitivity. Detection says a chemical is present. It does not state where the source is, whether it is edible or whether pursuing it is worthwhile.

Other channels narrow the problem. Hearing in fishes is largely sensitivity to particle motion, with the inner ear registering low-frequency vibration and acceleration. The lateral-line system runs through canals and pores along the head and body, detecting nearby water movement. It can reveal a struggling animal, another body passing close by or flow over an obstacle. Vision supplies contrast, movement and shape, with eyes adapted to different light environments. A deep-water shark and a surface hunter do not receive the same useful picture.

Then comes the electric sense. The ampullae of Lorenzini are small pores linked to conductive gel-filled canals, concentrated around the head. They

detect weak electric fields generated by living tissue. Kalmijn's experiments showed small sharks and rays locating buried flatfish and attacking electrodes that simulated the prey's field, even when sight, odour and ordinary mechanical cues were controlled. At close range, that signal can provide direction when a fish is hidden beneath sand or the final strike has disturbed the water.

Electroreception has also been proposed as part of navigation because moving through the Earth's magnetic field can induce electrical signals. Experiments support magnetic sensitivity in some sharks, but the route from detection to a general ocean map is still being worked out. The safe claim is narrower: these animals can detect electric fields, and at least some use electromagnetic information in orientation. It is not a licence to turn every migration into a solved compass story.

Hammerheads make the geometry visible. Spreading the head separates the nostrils and distributes electroreceptors and eyes across a wider front. Depending on species and task, that can alter sampling, visual overlap, manoeuvring and the area searched close to the bottom. It does not prove that the strangest-looking head is superior in every situation. Its value depends on speed, habitat, prey and the sensory task being solved.

A hunting shark therefore does not switch on one master sense. It combines channels whose ranges and reliability change as it approaches. Odour may announce something upstream. Sound or water movement may indicate activity. Vision may classify a moving outline. Electrical and tactile cues may finish localisation. The order is not fixed, and signals can conflict. Understanding the shark begins by asking what information could physically reach it at that distance, in that current, light and noise. The animal is perceptive. It is not all-seeing.

Predation is an energy decision, not a personality

A predator in a film wants one thing. A predator in water has a balance sheet. Searching uses energy. Chasing costs more. A struggling prey animal can injure eyes, gills or mouth. A missed attack reveals the hunter and may scatter the remaining food. The meal must repay those costs often enough for the strategy to persist.

That arithmetic produces sharks that barely resemble one another at dinner. Whale sharks and basking sharks collect dense patches of plankton and small nekton. A feeding whale shark can swim forwards with its mouth open or use suction, while filtering structures retain prey as water leaves. One supported model is cross-flow filtration, in which water moves largely along the filter surface rather than forcing every particle directly through a mesh, reducing clogging. The largest shark is therefore built around abundance at the smallest scale.

At the other extreme, a white shark approaching a seal near the surface may use depth, countershading and a burst of speed to shorten the chase. Even here, the famous behaviour belongs to particular places, seasons, prey and age classes. White sharks also eat fish, rays, squid, carrion and other animals. A filmed breach is a useful example of ambush, not the species' permanent state.

Hammerheads pin or manipulate rays. Port Jackson sharks crush hard prey with broad rear teeth. Wobbegongs wait on the bottom and expand the mouth rapidly, drawing nearby fish in with water. Threshers can use the long upper tail lobe to strike schooling prey. Cookiecutter sharks attach with specialised lips and remove plugs using their lower teeth, leaving marks on tuna, whales, other sharks and even underwater equipment. Stable-isotope work suggests that the visible plugs may not represent the whole diet; small prey can contribute substantially. The scar is easier to notice than the squid.

Jaws themselves are mobile tools. In many species the upper jaw is not fused rigidly to the skull. Muscles and ligaments can project it during capture, changing reach and bite geometry. Teeth then divide labour.

Narrow points grip slippery fish. Serrated triangles cut large pieces. Flattened teeth crush shells. Repeated replacement keeps a functional edge without requiring one permanent set.

Ecology becomes untidy when these methods meet a food web. A large shark can suppress prey through consumption, alter where prey feed through risk, remove sick animals, scavenge carrion and carry nutrients between habitats. A small shark may be eaten by a larger shark, marine mammal or bony fish. Juveniles and adults of one species can occupy different positions. A 2024 review therefore described sharks as predators, competitors, facilitators, nutrient transporters and food. The list is useful because it prevents apex predator from swallowing the group.

Strong indirect effects have been measured in some systems, and weakened or disputed in others. Shark Bay, for example, has supplied influential evidence that tiger-shark presence changes the behaviour and habitat use of large grazers. That does not establish a universal chain in which fewer sharks automatically create one predictable collapse. Food webs contain alternative prey, competitors, fishing effects, habitat change and local history. The honest ecological question is not whether sharks are important. It is which species performs which function, at what abundance, and whether another organism can replace it.

Predation is neither cruelty nor virtue. It is a sequence of information, movement, capture and digestion constrained by risk. Once that mechanism is visible, the shark stops being a personality with teeth and becomes an animal solving a recurrent economic problem: spend less than the meal returns.

Every offspring is expensive, but not in the same way

Shark reproduction begins with internal fertilisation. Males carry paired claspers, extensions of the pelvic fins that transfer sperm. From there, the group branches into an unusually broad set of ways to provision embryos.

Some species lay eggs enclosed in tough cases fixed to rock, weed or the

seabed. The cases often called mermaid's purses protect an embryo supplied by yolk while allowing water exchange. Other sharks retain embryos and give birth to live young. That phrase hides several systems. An embryo may depend mainly on a yolk sac, receive nutrient-rich uterine secretions, consume additional unfertilised eggs, or connect to the mother through a yolk-sac placenta. Recent comparative work indicates that live bearing and its variants evolved repeatedly across sharks and rays rather than appearing once as a straight march towards complexity.

Each route moves cost between mother, embryo, time and risk. An egg case leaves development in the environment but allows the female to distribute investment across places and dates. Retaining embryos protects them from some external hazards while occupying the uterus and extending the interval before the next litter. Feeding embryos inside the mother can produce larger young, but those nutrients have to come from somewhere. White-shark embryos, for example, receive lipid-rich uterine secretions during early gestation and later consume nutrient eggs. The sensational description of sharks eating in the womb turns a provisioning system into theatre and then mistakes the theatre for the whole group.

Litter size varies from one or two young to many dozens. Gestation can last months or well over a year. Maturity may arrive quickly in some small species and after many years in large or cold-water sharks. Females of some populations return to particular nursery areas or breeding regions, a pattern that can help researchers find them and fisheries encounter them. A protected nursery is valuable only if the animals survive the rest of their route.

The Greenland shark supplies the extreme anchor and the necessary warning about estimates. Researchers radiocarbon-dated proteins laid down early in the eye lenses of 28 females. Their model supported a lifespan of at least 272 years. The largest individual's age was estimated near 392 years, with uncertainty of roughly 120 years on either side, and sexual maturity was estimated around 150 years. The finding is extraordinary without converting a probability distribution into a birthday. It

describes one cold-water species, not a hidden rule for sharks.

At population level, the decisive quantity is replacement. A species with early maturity, frequent litters and many surviving young can absorb more mortality than one whose females mature late, reproduce intermittently and produce a few pups. Body size often correlates with slower life history, and deep-water species can be especially vulnerable, but there are exceptions in both directions. Slow is a distribution, not an identity.

Adult females carry unusual weight in that calculation because losing one removes her future reproduction as well as the animal herself. This is why a fishery that appears numerically modest can still be severe if it selects large mature females, aggregates at breeding sites or catches animals before they reproduce. It is also why recovery can continue long after fishing pressure falls. The surviving population has to grow through its own calendar.

Sharks have invested in offspring for hundreds of millions of years without one reproductive formula. The common thread is that young are not produced at the speed of small schooling fishes. For many species, especially the large, migratory and deep-living ones, industrial mortality operates on a human timetable while replacement remains stubbornly biological.

Survival through deep time required continual change

Sharks are often granted an age and denied a history. They are said to have existed before trees or dinosaurs, followed by the claim that they have barely changed. The first idea contains a truth about ancestry. The second erases most of evolution.

The cartilaginous-fish branch reaches back more than 400 million years, but the first shark depends on what the word means. Isolated toothlike scales and spines can mark early chondrichthyan relatives without proving that the whole animal had a modern shark body. Better-preserved Devonian forms show combinations of features that do not fit living categories cleanly. The

familiar package of jaws, fins, vertebral organisation and body proportions was assembled through branching experiments, not unveiled complete.

Preservation distorts the view. Cartilage usually decays, while mineralised teeth, denticles and fin spines survive. The fossil record therefore contains vast numbers of durable mouth parts and far fewer complete animals. Teeth can identify diet, size and relationship, but they cannot reveal every soft tissue, fin outline or reproductive system. A lineage may look static because the evidence keeps presenting the same hard component.

Palaeozoic seas contained many cartilaginous fishes that were neither modern sharks nor direct ancestors of them. Some familiar shark-shaped forms disappeared. Other lineages survived mass extinctions and radiated into new opportunities. The modern shark branch, often called neoselachians in the fossil literature, became increasingly recognisable during the Mesozoic, while living orders diversified over long spans rather than at one birth date. Reef expansion, new prey, changes in the open ocean and repeated extinctions altered which designs paid.

The Cenozoic added marine mammals, modern tuna-like fishes, expanded coastal habitats and enormous predators. Megatooth sharks culminated in *Otodus megalodon*, known chiefly from teeth and some vertebrae. Its maximum size remains reconstructed rather than measured from a complete skeleton. Chemical evidence from teeth places it at a high trophic position, and overlap with early white sharks may have created competition in some waters. That remains one possible part of extinction, alongside changing prey, climate and nursery habitat. A single dramatic cause is not established.

Megalodon did not shrink into the great white. Fossils from the Pacific support a white-shark lineage associated with broad-toothed mako-like forms, including teeth that become more strongly serrated through time. Megalodon belongs to a different family. Similar triangular cutting teeth can evolve in separate lineages facing similar prey. Shape is evidence, but convergence can make it a trap.

Deep time also records losses before industrial fishing. A 2024 analysis of shark functional traits across the past 66 million years found broad ecological variety through much of the Cenozoic followed by long decline, with living sharks occupying less functional space than many past assemblages. The reconstruction depends heavily on teeth and inferred body size, so it should not be treated as a complete census of ancient jobs. It still breaks the museum image of a lineage passing unchanged through catastrophe.

Their endurance came from variation, dispersal and repeated replacement of forms, not immunity. The species alive now are the thin surviving tips of a branching history. Past survival proves that sharks can persist through enormous environmental change when some lineages find workable routes. It says nothing about whether a particular population can withstand hooks and nets removing breeding adults faster than it can replace them.

Industrial mortality outruns some replacement clocks

A hook set for tuna does not become harmless when a shark takes it. A trawl aimed at another catch still kills what cannot escape. A gill net does not ask whether the animal has a market. Shark fishing therefore begins with a distinction between target catch and bycatch, then becomes more complicated when an accidental catch can be retained and sold.

Sharks supply meat, fins, liver oil, skin, cartilage and teeth. Uses vary by country and fishery, and fins are neither the sole market nor an irrelevant one. Finning means removing fins and discarding the body at sea. It wastes the carcass and can make species identification and mortality accounting difficult. Requiring fins to remain naturally attached until landing can reduce that practice and improve enforcement. It does not stop a whole shark being landed, processed and sold.

That difference explains a result that sounds paradoxical. A global analysis published in 2024 assembled fisheries and trade information and estimated that shark fishing mortality rose from at least 76 million animals in 2012 to

80 million in 2019. About 25 million of the 2019 total were from threatened species. Anti-finning rules had spread and finning declined in some settings, yet total mortality did not fall. Coastal fisheries and expanding markets for meat and other products helped keep whole animals valuable. The estimates are lower bounds with uncertainty, not a global body count read from one ledger.

Threat is also distributed unevenly. The 2021 global reassessment covered 1,199 sharks, rays and chimaeras. It placed 391 species, or 32.6 per cent, in threatened categories; allowing for data-deficient species produced an estimated 37.5 per cent. Those are chondrichthyan figures, not shark-only totals. Overfishing affected all 391 threatened species, while habitat loss, climate change and pollution compounded risk for some. Tropical and subtropical coastal species carried disproportionate danger.

Management succeeds when it reaches the mortality mechanism. Catch limits require data and enforcement. Prohibitions can protect species whose biology cannot support fishing. Gear changes, hook practices and rapid release can reduce some bycatch deaths, though effects vary by species and fishery. Seasonal or spatial closures work when they cover breeding, nursery or aggregation sites and do not shift effort into equally important habitat. Marine protected areas can support reef sharks that remain within their boundaries, while a wide-ranging oceanic shark may spend most of life outside one.

International trade controls address another link. Listing a species under CITES Appendix II does not ban all trade. Exporting states must find that trade is legal and will not be detrimental to survival, and shipments must be documented. Domestic catch and consumption still depend on fisheries law. FAO's shark plan supplies a voluntary framework, and its policy use of shark often includes rays, skates and chimaeras. A broad word can help administration while obscuring species-level outcomes.

Recovery is possible and slow. Some populations respond after fishing mortality is cut, habitat is protected and enough breeders remain. Others stop declining but stay depleted for years because the replacement clock

cannot accelerate. United States sandbar-shark management illustrates the distinction: directed fishing was largely prohibited outside a research fishery in 2008, overfishing later ceased, yet the stock remained overfished. Ending the rate of loss is not the same event as rebuilding abundance.

The causal loop closes here. Shark began as a word hiding more than 500 species. Conservation fails when it keeps using the word at that resolution. The useful unit is a species and population, with a sex and age structure, moving through particular fisheries and markets at a known or bounded replacement rate. The animal that frightens people is generic. The animal that recovers or disappears never is.

How It Actually Works

A body assembled in pieces

Three policies often collapse into one word: protection. A finning rule governs what happens to a shark already caught, often by requiring fins to remain naturally attached or by controlling fin-to-carass ratios. A catch rule governs whether, where, when or how many sharks may be taken. A trade rule, including a CITES listing, requires international shipments of listed species to be legal, traceable and compatible with the species' survival. None automatically substitutes for the others. A fins-attached rule can improve identification and reduce the incentive to discard bodies at sea while total mortality remains high. A trade permit can improve scrutiny while domestic catch continues. A no-take rule can fail when monitoring and enforcement are weak. The useful question is which source of mortality the measure reaches, how compliance is checked and what happens across the animal's whole range.

Conservation numbers need their denominator. The widely quoted 71.1 per cent decline is an estimated change in relative abundance for 18 oceanic shark and ray species between 1970 and 2018; it is not a census of every shark species or every sea. A separate global Red List reassessment concluded that more than one-third of assessed sharks, rays and chimaeras

were threatened with extinction, with overfishing as the dominant pressure. These findings reinforce one another without measuring the same thing. One tracks abundance in a defined oceanic group across time. The other classifies extinction risk across a much wider taxonomic set. Coastal recoveries under strong management can coexist with severe global decline, just as a protected nursery can coexist with mortality along a migration route. Scale, species and reference period must travel with the number.

More than 400 million years ago, vertebrate life was learning what jaws could do. The first cartilaginous fishes emerged within that experiment, but the boundary between an early shark and a shark-like relative is blurred by both evolution and preservation. A tiny tooth, scale or fin spine can establish that a chondrichthyan was present. It cannot supply the outline of the animal that carried it.

One Devonian fish called *Gladbachus* helps because more of it survived. Its anatomy combines features later divided among modern sharks and other early jawed fishes. The skull, jaws, shoulder region and fin supports show that the shark body was assembled through a sequence of changes rather than inherited intact from the first member of the branch. The result was already successful, but it was not yet the familiar grey torpedo.

Cartilage created a biased archive. Teeth and denticles mineralise and survive readily; most of the skeleton does not. A beach or quarry can therefore contain thousands of clues from mouths and almost no complete bodies. Palaeontologists reconstruct lineages from tooth shape, microscopic tissues, rare articulated skeletons and the positions of fossils in dated rock. Every new complete specimen can rearrange a family tree previously built from fragments.

The Palaeozoic workshop

The Carboniferous seas held a profusion of cartilaginous fishes. Some were streamlined hunters. Others carried fin spines, crushing tooth plates, strange ornaments or dental arrangements with no modern equivalent. Popular accounts often label the whole collection sharks, but many sit outside the living shark branch. They are better understood as experiments around the chondrichthyan design space.

This matters because deep time is usually told backwards. Start with a great white, look for older animals with triangular teeth, and a straight ancestry appears. Start with the fossils and the picture branches. Features now bundled together arrived at different times. Body shape, jaw suspension, tooth replacement, fin control and sensory anatomy could change independently, then become recombined.

The end-Permian extinction around 252 million years ago destroyed most marine species and cleared ecological space on a scale difficult to imagine. Cartilaginous-fish lineages passed through, but survival did not preserve every form. The Triassic and Jurassic oceans were repopulated by mixtures of old survivors and emerging groups. Hybodonts, a long-lived branch with stout fin spines and varied teeth, shared the water with early representatives of the modern shark radiation. They lasted into the Cretaceous and then disappeared. The winner was not one eternal shark. It was a shifting set of lineages.

Tooth replacement itself left a misleading abundance. One animal could shed thousands of teeth, each durable enough to enter the record. A rare lineage living near a productive deposit may therefore look common, while a widespread soft-bodied feature leaves nothing. Counts of fossil teeth are ecological evidence only after deposition, transport, breakage and repeated replacement have been considered.

The modern shark becomes recognisable

By the Jurassic, sharks with increasingly modern combinations of jaws, teeth, fins and vertebrae were spreading through marine habitats. Many living orders have roots in the Mesozoic, but their present species arrived much later. Cow sharks preserve some anatomical features that look old beside other living groups. Carpet sharks include bottom dwellers and the future whale-shark line. Mackerel sharks developed powerful swimming bodies and, in several lineages, regional warming. Ground sharks eventually became the largest living order, including reef sharks, tiger sharks, catsharks and hammerheads.

The Cretaceous brought extensive shallow seas and abundant bony fishes, marine reptiles and invertebrates. Sharks diversified as pursuit hunters, bottom feeders, crushers and scavengers. Teeth track the shift because their geometry records function. Narrow points help hold slippery prey. Broad cutting edges remove flesh. Low rounded crowns crush hard shells. Yet similar diets can produce similar teeth in unrelated animals, so shape has to be combined with tissue structure, age and associated fossils.

The end-Cretaceous extinction 66 million years ago removed non-bird dinosaurs, ammonites and large marine reptiles. Sharks suffered losses too. Surviving lineages entered oceans in which mammals soon expanded and new communities formed. This is the beginning of the Cenozoic story, not an empty stage on which an unchanged shark continued swimming.

Geography kept dividing the survivors. Opening and closing seaways changed migration and gene flow. Shallow nurseries appeared, vanished or shifted with sea level. Deep-water habitats selected for low-energy lives far from surface productivity, while warmer shelves repeatedly generated small benthic species. The modern catalogue was built through isolation as well as conquest.

Giants after the dinosaurs

Megatooth sharks had appeared before the Cenozoic giant most people know. Over time, species in the *Otodus* lineage developed larger, more robust and more strongly serrated teeth. *Otodus megalodon* lived from roughly 20 million to 3.5 million years ago. Its teeth occur in deposits around the world, and vertebrae survive at a few sites. No complete skeleton fixes its outline or maximum length. Reconstructions use proportions borrowed from living analogues, which is why confident pictures differ.

It was enormous and occupied a high trophic position. Marine mammals supplied rich prey, and bite marks and associated fossils show interaction with whales. Zinc isotopes in fossil teeth indicate that megatooth sharks and early white sharks occupied comparably high positions in some food webs. Competition is therefore plausible where ranges and prey overlapped. It is not a verdict on extinction. Cooling seas, changing whale communities, loss of warm nursery habitat and other predators may all have contributed.

The white shark was developing on another branch. Fossils from Peru include *Carcharodon hubbelli*, with teeth intermediate in serration between broad-toothed mako-like sharks and the living great white. The evidence supports close ancestry within that line rather than descent from megalodon. Two large hunters could converge on triangular cutting teeth because flesh presents the same mechanical problem.

The Cenozoic also produced sharks that do not fit the giant-hunter story: deep-water forms with large oily livers, small luminous sharks, filter feeders, specialised ray hunters and benthic ambush predators. Functional diversity rose and fell as climates, coastlines and prey changed. The surviving set is one late sample of a much larger history.

Gigantism was no free prize. A huge hunter needed enough concentrated prey, suitable nursery water and a body that could travel between them. Once those conditions changed, size could turn from advantage into dependency. Megalodon's extinction is interesting because a formidable adult still belonged to a population whose young, prey and habitat set limits

it could not bite through.

Sharks as food, tools and neighbours

Long before a fin became a warning symbol, people used sharks. Coastal communities caught them for meat, oil, skin and teeth. Dried or salted flesh could be stored. Liver oil supplied fuel and other products. Rough skin worked as an abrasive and, when processed, as shagreen. Teeth became cutting edges, weapons, ornaments and ritual objects in different cultures. The relationship was practical, local and varied.

Fear existed too, especially where large sharks shared fishing grounds and surf zones with people. Sailors and fishers knew that blood, struggling catch and discarded offal could attract animals. Stories enlarged what direct observation could not settle. A shark seen at the surface supplied a fin and a mouth; the rest could be filled with intention.

European natural histories grouped many sharks under names meaning sea dog or dogfish. Specimens arrived damaged, dried or dismembered. Illustrators copied earlier illustrators. Teeth known as tongue stones were once treated as curious mineral objects before anatomical comparison tied them to sharks and helped establish that fossils were remains of former life. The shark therefore contributed to a larger intellectual change: stone objects in rock could record animals no longer present.

During the nineteenth and early twentieth centuries, expanding fisheries, museums and public aquaria put more shark bodies before scientists and audiences. Taxonomy improved as whole specimens could be compared, but the largest species still received disproportionate attention. Sport anglers made a large shark proof of conquest. Newspapers made a bite a story with a clear villain. The animal was becoming both better known and more narrowly imagined.

At a landing beach, however, the categories remained practical. Fishers sorted animals by flesh quality, size, gear damage, danger on deck and sale price. A scientist might separate species by teeth and fin placement while a trader combined several under one market name. That gap between

biological and commercial identity still weakens catch records. A label can preserve a product while erasing the animal it came from.

One species takes the screen

Peter Benchley's novel *Jaws* appeared in 1974. Steven Spielberg's film followed in 1975 and turned a white shark into a moving plot mechanism: unseen approach, repeated attack, escalating pursuit. The dorsal fin could announce danger before the animal appeared, and John Williams's two-note theme supplied intention to empty water. The film worked because it made an environment itself feel hostile.

Its cultural power is beyond dispute. Its biological effect is harder to isolate. Shark tournaments and trophy fishing existed before it. Commercial fishing had larger engines than cinema, driven by food, trade and bycatch. The film strengthened the great-white template and provided language for later policy debates, but a straight claim that one movie caused global shark depletion asks evidence to do too much.

The more defensible consequence is compression. *Jaws* made the rare surface encounter feel like the normal relationship between humans and sharks. It attached active malice to a predator whose motives in bite incidents are often unknown. It also generated fascination. Some researchers, photographers and conservationists trace their interest to the same image they later tried to correct. A monster can recruit its own debunkers.

Television repeated the useful parts: teeth, speed, breach, blood, cage. The difficulty is structural. A small deep-water catshark does not carry a thriller. A filter-feeding basking shark crossing green water may be magnificent, but it lacks a chase. Public knowledge therefore became richest where the lineage was least representative.

Learning to follow a moving animal

For much of history, a shark was known at capture. Length, sex, stomach contents, teeth and reproductive organs could be measured, but the living route before the net remained hidden. Tagging changed the unit of observation from specimen to journey.

A conventional tag asks for a second encounter. Mark an animal with a number, release it, and learn distance and time when somebody catches or finds it again. Acoustic tags transmit coded signals to receivers fixed along reefs, coasts or river mouths. Satellite-linked tags can report position when a fin reaches the surface or detach on schedule and send stored depth, temperature and light data. Accelerometers and cameras reveal bursts, turns and prey encounters at finer scales. None gives a complete life. Each trades duration, precision, sample size and disturbance.

Photo-identification uses stable markings or fin shapes where individuals can be recognised. Genetics reveals connections among breeding populations and can estimate relatedness, movement and effective population size. Baited remote underwater video stations compare presence and relative abundance without putting a diver beside the bait.

Environmental DNA can detect traces shed into water, though detection does not directly state how many animals were present.

These methods dismantled several easy assumptions. Coastal sharks can make long offshore movements. Individuals may return to the same seasonal sites. Nursery habitat can be separated from adult feeding grounds by hundreds or thousands of kilometres. A boundary that protects one life stage may miss the next. The animal on a local reef can belong to a population governed by distant fishing mortality.

Age is another reconstruction. Vertebral bands can record growth, but their timing must be validated and may change with species and age.

Bomb-produced radiocarbon has supplied time markers for some long-lived fishes. Eye-lens proteins helped date Greenland sharks because their central layers form early and remain metabolically stable. Each method

works only after its biological clock has been tested.

The industrial ocean

Industrial fishing converted encounter into coverage. Longlines could set thousands of baited hooks. Gill nets intercepted animals moving through coastal water. Trawls collected bottom species and juveniles along with their targets. Refrigeration, stronger synthetic gear, hydraulic handling and global transport made distant catches marketable. A shark did not need to be the intended quarry to enter the supply chain.

Demand for fins became the most visible trade because the product could be valuable, dried and transported. Finning at sea also produced unforgettable evidence: a live or dead body discarded after the fins were removed. Campaigns were right to attack the waste. The focus became too narrow when finning, fin trade and all shark mortality were treated as the same event.

Whole sharks were landed for meat and other products before and after finning rules. In some fisheries, retention made economic use of an animal already caught. In others, new markets could increase incentive. Reported landings missed discards, illegal catch and small-scale fisheries. Trade records followed products that might be processed, re-exported or labelled under broad categories. The global total had to be estimated by combining incomplete systems.

On deck, the population consequence could hinge on a brief choice. Release a live shark, retain it, discard it dead, or cut the line with gear attached. Survival after release then depends on species, capture depth, handling, temperature and injury. A rule written around landed catch can miss animals that died before reaching port. Mortality follows the animal, while administration often follows the product.

The biological mismatch appeared first in large coastal and oceanic species. Long life, late maturity, wide movement and aggregation around predictable places made some populations easy to catch and slow to rebuild. The 71 per cent oceanic abundance decline estimated from 1970 to 2018 did not

include every shark or every population. It was an indicator based on 18 oceanic shark and ray species. Its scale was still enough to show that industrial reach had overtaken replacement.

Regulation catches up

The policy response arrived through several doors. National fisheries introduced catch limits, protected species, gear rules and spatial closures. Regional organisations responsible for tuna and other highly migratory fisheries began adding shark measures. FAO developed its International Plan of Action in the late 1990s, asking fishing states to assess and manage sharks in the broad chondrichthyan sense. The plan was voluntary, so adoption and execution varied.

Finning bans spread, and fins-naturally-attached rules made enforcement stronger where used. CITES listings brought selected species into international trade controls. These measures improved identification, reporting and legal leverage. They did not create one global conservation system. A shark can cross jurisdictions, be caught under one rule, landed under another and consumed without crossing an international border.

Evidence from the 2012 to 2019 period then exposed the gap between visible regulation and total deaths. Finning declined in many places, yet estimated mortality rose to at least 80 million sharks in 2019. The lesson was not that regulation fails. Rules aimed at one practice can succeed at that practice while leaving the main population outcome unchanged.

Where mortality is cut far enough, rebuilding can begin. No-take reefs can benefit relatively resident species. Well-enforced national protection can reduce landings. Science-based fisheries can sustain some faster-growing populations. Wide-ranging, slow-breeding species need measures that follow them through routes and fleets.

The social problem is part of the mechanism. Small-scale fishers may depend on mixed catches and lack safe storage, alternative gear or bargaining power. Industrial fleets can move effort when one area closes. Consumers may buy shark meat under names that do not reveal species. A

workable rule therefore needs biological precision and a route through incentives, identification and enforcement.

The next phase is less cinematic than a fin ban. It is species identification, stock assessment, observer coverage, traceable trade, enforceable catch limits, safer gear and enough restraint to let biological time pass.

How we know

Shark knowledge is built from evidence that sees different slices. Living bodies supply anatomy, physiology and controlled sensory experiments. Fisheries samples reveal age, growth, diet and reproduction, but they are biased towards animals and places that gear catches. Tags and receivers map selected movements; a route outside receiver range can look like disappearance. Cameras, diver surveys and environmental DNA improve detection while measuring presence or relative abundance more readily than total population.

Teeth dominate deep time because cartilage rarely survives. Rare articulated fossils correct trees built from isolated parts, while isotope chemistry adds clues about diet and water. Modern relationships come from anatomy and DNA, and the names change as evidence improves.

Bite files depend on reporting and case classification. Catch and trade totals miss illegal, discarded and poorly recorded animals, so global mortality is modelled with ranges and lower bounds. Red List categories assess extinction risk, not head counts. The result is a subject with strong mechanisms and uneven census. Confidence should rise when independent methods agree, and narrow when one memorable species or one visible fishery is asked to represent the whole lineage.

What People Get Wrong

“The great white is the shark”

It has the silhouette, the exposed teeth and the film career, so one species has become the measuring stick for the group. Documentaries then reinforce the choice because white sharks gather at some predictable sites, hunt visible prey near the surface and tolerate cameras well enough to produce dramatic footage.

The correction is numerical and functional. More than 500 living shark species include filter feeders, bottom ambushers, shell crushers, small deep-water hunters and animals restricted to narrow regions. Most are far smaller than a white shark. Many never encounter a swimmer, and several lineages spend their lives in water people rarely enter. Even the white shark changes diet and habitat with age and place.

This matters because the icon distorts both fear and protection. Human bite risk is concentrated in a few species and circumstances. Extinction risk is concentrated elsewhere too, including obscure deep-water and coastal species with no publicity. A generic shark campaign can attract attention, but research and rules must eventually name the animal. Its dominance also narrows curiosity: a luminous deep-water shark or a suction-feeding carpet shark can appear like a deviation when both are ordinary outcomes of the lineage. The great white is a remarkable shark. It is a poor average.

“Sharks have not changed since before the dinosaurs”

The sentence flatters them by turning survival into perfection. A recognisable streamlined body also makes a fossil tooth feel like evidence that the same animal has crossed hundreds of millions of years without revision.

The chondrichthyan branch is ancient, but living sharks are recent tips on a branching tree. Early forms combined traits that are separated in modern

groups. Whole lineages of shark-like fishes flourished and vanished. Modern orders diversified at different times, and their species continued changing through the Cenozoic. Megatooth sharks disappeared. White sharks developed on another line. Recent work even suggests that the range of shark ecological forms has contracted during the past ten million years.

Fossil bias helps the myth. Teeth preserve repeatedly while cartilage usually decays, so the record keeps showing durable feeding tools rather than complete changing bodies. The correction matters because ancient does not mean invulnerable. Deep-time persistence was achieved by variation and turnover. Extinction removed many successful forms along the way. A present population with a small range and slow replacement cannot call on the survival of distant relatives, any more than one old family guarantees every living member a future.

“Cartilage is an inferior skeleton”

School comparisons invite a ladder: invertebrate, cartilaginous fish, bony fish, mammal. Bone appears later in the lesson and is treated as an upgrade. The shark then becomes a half-finished fish held together by soft gristle.

Its skeleton is no such thing. Cartilage is reinforced by mineralised tiles, with heavier calcification where loads demand it. Vertebrae and jaw regions can be stiff and strong, while other parts bend during swimming. Muscles attach and transmit force through an organised framework. Bone is one structural material among several, not a certificate of advancement.

Nor does cartilage alone make sharks float. Buoyancy emerges from liver oil, tissue density, body form, fins and movement. Different species settle that balance differently, from relatively buoyant deep-water cruisers to denser fast accelerators. The important question is performance under a given load, not whether the material matches ours. A flexible support can be useful in one region and costly in another, which is why reinforcement is distributed. Calling cartilage primitive hides the engineering trade-offs that

made the group successful and turns a working material into a rung on an imaginary ladder.

“One drop of blood brings sharks from miles away”

A precise drop and an immense distance make a perfect fact. They also remove the ocean from the story. Odour cannot reach an animal until moving water carries the molecules there, and turbulence breaks a plume into irregular filaments rather than a straight chemical road.

Sharks can be sensitive to dissolved amino acids and other compounds. Experiments across several species have found responses around parts per billion, but thresholds differ with chemical, animal, condition and method. Detecting a trace does not reveal its source direction, identify it as food or compel an attack. A shark may cross a plume, sample changes as it moves, combine them with current and other senses, and decide that pursuit is not worth the cost.

The correction matters because sensory ability is often converted into intention. Blood in water does not summon every nearby shark, and smell is not a remote targeting system. Baiting can attract sharks under controlled conditions because quantity, current and repeated release create a detectable plume; that does not validate the one-drop story. Ask how the signal travelled, how concentrated it remained and what other information was available. Physics comes before appetite.

“A bite means the shark was hunting a person”

The injury is intentional in the narrow mechanical sense: the animal closes its jaws. Motive is harder. Bite files can describe place, species, activity and wound. They rarely recover the shark's internal decision.

Several mechanisms are plausible. A shark may investigate an unfamiliar object with its mouth, respond to splashing or captured fish, defend space at close range, redirect feeding behaviour, or treat a surface silhouette as possible prey. Visual modelling found that, from below and at the resolution

of a juvenile white shark, some swimmers, paddling surfers and pinnipeds can produce ambiguous motion and shape cues. That supports mistaken identity for some incidents. It does not prove it for all.

The term unprovoked adds another trap. It means the human did not initiate contact under the reporting system; it does not mean investigators established predatory intent. The correction preserves two truths. Shark bites can be catastrophic and deserve serious prevention. Some involve feeding behaviour, while others may not. Management choices differ if the mechanism is prey attraction, poor visibility, fishing activity, seasonal overlap or a local aggregation. Explaining every one as a hunt invents evidence and makes species-specific risk harder to manage.

“Megalodon became the great white”

The story seems visible in the teeth. Both animals carried large triangular cutting blades with serrated edges, so the giant ancestor appears to shrink into its modern descendant after the climate changed.

Fossils place them on separate branches. *Otodus megalodon* belongs to the megatooth sharks. The great white sits within the mackerel-shark family, and specimens such as *Carcharodon hubbelli* support a transition from broad-toothed mako-like forms towards the living white shark. Similar prey can favour similar cutting geometry in unrelated lineages. Convergence is common because flesh keeps presenting the same problem.

The two may still have interacted. Tooth chemistry suggests comparable high trophic positions in some overlapping settings, making competition plausible among several proposed pressures on megalodon. Plausible is not proven, and competition does not make one species the other's child. The correction is larger than a family-tree detail. It also blocks the comforting idea that extinction merely reduced a giant into a smaller survivor. Megalodon ended; the white shark was already its own history. Fossil teeth are powerful evidence, but familiar shapes can mislead when function is mistaken for ancestry.

“Stopping finning solves the shark problem”

Finning is so wasteful and visually brutal that it has become shorthand for every shark death. The shorthand helped create laws, but it also made success easy to misread.

Finning means removing fins and discarding the carcass at sea. Requiring the fins and carcass to reach port together can reduce that practice, improve species identification and make enforcement easier. A whole shark can still be caught, landed and sold for fins, meat, oil or other products. Sharks also die as bycatch where fins were never the main reason for setting the gear.

The global evidence exposes the distinction. The estimated lower bound was 76 million animals in 2012. By 2019 it had reached 80 million while anti-finning rules became widespread. The result does not show that those rules were useless. It shows that reducing waste is not the same outcome as reducing deaths. Conservation has to reach total fishing mortality through species protection, catch limits, bycatch reduction, trade controls and enforcement suited to the fishery. It must also distinguish sustainable catch from depletion rather than treating every use as identical. A fin can reveal the problem. It cannot define all of it.

Use It

Name the animal before judging the claim

Treat shark as the beginning of a question, never the answer. Ask for species, population, size, sex, place and season. A claim about white sharks at a seal colony cannot travel automatically to blacktip reef sharks, and a trend in an oceanic index cannot describe every coast.

This habit catches two opposite errors. Sensational reporting enlarges the behaviour of a few large species until it covers the group. Advocacy sometimes does the same with vulnerability or ecological importance. Both gain force by dropping resolution.

When the exact species is unknown, make the uncertainty visible rather

than replacing it with a generic animal. Fishery products may be sold under market names, fins may be detached, and a brief sighting may support only a family-level identification. The correct response is then a bounded claim. Precision is not pedantry here. It is the difference between protecting a declining population and congratulating yourself for protecting an icon elsewhere.

Separate hazard, exposure and probability

A large shark is capable of severe harm. That is hazard. Risk also depends on whether people and that species share water, how often and under what conditions. That is exposure. A yearly bite count combines both with reporting, classification and chance.

Use this distinction whenever a headline says bites are rising or a beach is safe. More surfers, warmer days, clearer reporting, prey movement or a local shark aggregation can change incidents without any change in aggression. Fewer reports can follow bad weather or closed beaches while the animals remain present.

The practical question is local and conditional: which species occurs here, what activities overlap with it, what time and visibility increase contact, and which warning system has evidence? Do not use low global totals to dismiss a victim or high-profile incidents to infer a worldwide trend. A rare event can deserve serious prevention without becoming a common event. Hazard sets the possible consequence. Exposure supplies the denominator.

Follow the signal through water

Before explaining shark behaviour, draw the physical route from source to animal. Odour needs current. Sound needs a frequency and medium that carry it. A visual outline needs light and contrast. Water movement weakens with distance. Electric fields are strongest close to their source.

This prevents magical biology. A shark cannot smell what has not reached its olfactory tissue, and extreme sensitivity cannot identify direction by itself. One logged tag ping shows only that the animal entered detection range at

that moment. A cage, bait trail, struggling fish and boat engine create several signals at once, so behaviour beside them should not be treated as untouched nature.

The lens is useful beyond senses. Fishing pressure also travels through routes: gear is deployed, animals encounter it, some die at capture, some die after release, some are retained, products enter markets. Policy claims should trace the same chain. Ask where the signal or mortality begins, what carries it, where it can be interrupted and what remains unmeasured.

Price the meal

Replace aggression with a budget. What energy might the prey return? How much searching and pursuit does it require? Can it damage the hunter? Is there a cheaper option nearby? Does the shark have enough information to classify it before contact?

This model explains why large predators often ignore available animals. A healthy seal can be dangerous. A dense fish school may repay a specialised strike. A carcass offers energy without pursuit. A whale shark needs an unusually rich patch of small prey because filtering empty water is still work. The same shark can choose differently with hunger, age, experience and habitat.

Use the budget when reading footage. A short clip usually begins after attraction, editing and selection have already occurred. Repeated close passes may be investigation, feeding opportunity or habituation to bait. A failed strike can be more informative than a successful one because it exposes constraints. The question is not whether a shark is bold or cruel. It is what action paid under those conditions.

Read the replacement clock

Population decline means little without the rate at which losses can be replaced. Find age at maturity, reproductive interval, litter size, juvenile survival, adult survival and movement between populations. Then ask which ages and sexes the fishery removes.

This avoids the loose claim that all sharks are slow. Some small species can reproduce faster than large coastal or deep-water sharks. It also avoids the opposite mistake of calling a catch sustainable because many animals remain. A population can look numerous while losing mature females or juveniles before reproduction. Wide movement can replenish a local site temporarily while draining another.

Recovery has two stages that headlines often merge. Overfishing ends when current fishing mortality falls below the relevant threshold. An overfished population has rebuilt only when abundance or biomass returns to the target. The first can happen through a rule change. The second must wait for births and survival. Biological time is not a bureaucratic deadline.

Separate the routes from sea to market

When somebody says shark fishing, split the event. Was the shark targeted or caught incidentally? Was it alive at release? Was the whole body retained? Were fins removed at sea? Which products were sold, under what name, and did they cross a border?

Each route calls for different evidence and policy. A finning ban addresses carcass discard. Fins-naturally-attached rules improve identification and enforcement. A CITES Appendix II listing regulates international trade through legal and non-detriment findings. None sets a domestic catch limit by itself. Bycatch reduction may depend on gear, depth, soak time, handling and fleet behaviour rather than consumer demand.

The distinction also protects against moral shortcuts. Using a landed animal fully can reduce waste without proving the catch sustainable. A legal trade can still be poorly monitored. A prohibited species may still die before release. Follow mortality first, product second and paperwork third. Conservation succeeds only if the number and identity of animals removed match what populations can replace.

The limits

Sharks cannot supply one rule for ecosystems. Some exert strong top-down or behavioural effects; others are mid-level consumers, scavengers or prey. Removing a large predator may reshape a particular food web, but the direction and size depend on alternative prey, competitors, fishing, habitat and history. Do not turn a good case study into an ocean law.

Their senses also resist translation. Researchers can measure thresholds, nerves and responses, yet the combined experience of odour, movement, vision and electricity remains inaccessible. A model of what a juvenile white shark can visually distinguish is not a recording of what one thought before a bite.

Conservation has conflicts. Shark protection can impose costs on fishers, change catches of other species and alter how coastal communities manage safety. Some shark populations may support carefully controlled use; others cannot. No single choice follows from admiring the animals.

Finally, absence from a survey is not proof of absence, and a local increase is not automatically a global recovery. Tags miss routes, catch data miss discards, trade labels combine species and fossils favour teeth. The correct response is calibrated confidence, not permanent doubt.

The one thing to keep

Keep the scale right.

A fin at the surface is a few seconds of one animal's life. A film turns those seconds into a species, then turns the species into a lineage and the lineage into an intention. Conservation can make the same mistake in reverse, replacing the monster with a harmless guardian and calling the correction complete.

The durable picture is harder and better. More than 500 species occupy different depths, coasts and food webs. Their bodies combine cartilage, oil, fins, skin, teeth and movement into different compromises. Their senses collect signals that water must carry. Their feeding decisions balance energy

and injury. Their young arrive through several reproductive systems and at radically different rates. Their history contains invention, extinction and replacement. Their present condition ranges from managed abundance to acute danger.

That scale changes the first question. Do not ask whether sharks are dangerous, ancient, important or threatened. Ask which shark, in which population, doing what, on what evidence and against which denominator. The answer can still be frightening. It can also support fishing, protection, beach management or uncertainty. What disappears is the permission to let one vivid image decide before the animal has been identified.

Humans meet sharks through an extreme asymmetry of attention. One bite can become international news. Millions of fishing deaths remain an estimate assembled years later from incomplete records. The difference is not proof that bites do not matter. It is proof that visibility and scale are separate properties.

Once that is understood, the dorsal fin loses its power to stand for everything beneath it. You see an animal with a body, a history and a replacement clock, moving through water full of signals and through human systems full of hooks, markets and rules. Misunderstanding begins by enlarging the encounter. Understanding begins by restoring the lineage.

Terms

Chondrichthyes. The vertebrate class containing sharks, rays, skates and chimaeras. Its members have predominantly cartilaginous skeletons, paired fins and internal fertilisation, though their bodies and ecologies vary widely.

Elasmobranch. A shark, ray or skate. Elasmobranchii excludes chimaeras and is useful when research covers sharks and batoids together, as much conservation and sensory work does.

Selachimorpha. The living shark branch, distinct from batoids. Taxonomic ranks and names vary among classifications, but the term marks sharks in the narrower biological sense used by this book.

Batoid. A ray or skate, usually with enlarged pectoral fins joined to the head and gill openings underneath. Batoids are the closest living relatives of sharks.

Holocephalan. A chimaera or ratfish, belonging to the other living chondrichthyan branch. Holocephalans have upper jaws fused to the skull and tooth plates rather than replaceable rows.

Teleost. A member of the enormous radiation containing most living bony fishes. Comparisons with teleosts clarify shark traits such as swim-bladder absence, jaw suspension and reproductive investment.

Dermal denticle. A small toothlike structure covering shark skin. Denticles protect the body and can affect flow, abrasion and fouling; their form varies by species and body region.

Tessera. One of the mineralised tiles reinforcing much shark cartilage. Tesserae show why describing the skeleton as soft gristle misses the distributed stiffness required for loading and movement.

Heterocercal tail. A tail in which the vertebral column extends into a larger upper lobe. Common in sharks, it contributes thrust and interacts with fins and body angle to control lift.

Spiracle. An opening behind the eye that can draw water towards the gills. It is especially useful to bottom-living sharks feeding or resting with the mouth near sediment.

Ram ventilation. Moving forwards so water enters the mouth and crosses the gills. Some active pelagic sharks rely heavily on it, while others switch between ram ventilation and pumping.

Buccal pumping. Actively moving water over the gills using the mouth and pharynx. It allows many sharks to ventilate while stationary, disproving the claim that all must keep swimming.

Ampullae of Lorenzini. Electroreceptive organs formed by sensory pores linked to conductive canals, mainly on the head. They register faint electrical

signals and assist close-range prey localisation and, in some species, orientation.

Lateral line. A system of canals and sensory cells that detects local water motion and pressure change. It helps a shark register nearby animals, flow and obstacles without direct contact.

Electroreception. The ability to detect electric fields generated by living tissue or movement through electromagnetic fields. It is most firmly established as a short-range sense, not distant prey radar.

Regional endothermy. Retention of metabolic heat in selected tissues through counter-current blood vessels. White sharks, makos and relatives can warm swimming muscles or organs without heating the whole body equally.

Oviparity. Reproduction by laying eggs. In sharks, embryos usually develop inside tough cases with yolk, exchanging water through openings while attached to or resting on the seabed.

Viviparity. Live bearing after embryos develop within the mother. Shark viviparity includes several nutrient systems and evolved repeatedly, so it is a category rather than one reproductive mechanism.

Histotrophy. Maternal nourishment of retained embryos through uterine secretions, sometimes called uterine milk. It supplements or replaces yolk in several live-bearing shark lineages, including white sharks.

Oophagy. Consumption of unfertilised eggs by embryos inside the uterus. It is a maternal provisioning system in some sharks and should not be confused automatically with embryos eating siblings.

Clasper. One of a male shark's paired pelvic-fin organs used to transfer sperm during internal fertilisation. Their presence helps identify sex even in species with little external colour difference.

Nursery area. Habitat used by young sharks more heavily or repeatedly than surrounding areas and contributing to recruitment. A nursery may need

protection while remaining connected to adult routes.

Philopatry. Repeated return to a home, breeding or nursery region. It can create stable local patterns, but also exposes aggregations to concentrated fishing or disturbance at predictable times.

Trophic level. A position in a food chain based on energy transfer from producers through consumers. One shark species may shift trophic level with age, habitat and available prey.

Bycatch. An animal caught while fishers target something else. Bycatch can still be retained and sold, and mortality includes animals that die during capture or after release.

Finning. Removing a shark's fins and discarding the carcass at sea. It is distinct from landing a whole shark and later selling its fins, meat and other products.

Fins naturally attached. A rule requiring sharks to be landed with fins still joined to the body. It deters finning and improves identification without automatically limiting total catch.

Catch per unit effort. Catch divided by a measure such as hooks, net length or fishing time. It can index abundance only after changes in gear, location and fisher behaviour are considered.

Stock assessment. A quantitative estimate of population status and fishing pressure using catch, surveys, life history and models. Its conclusions are specific to the defined stock and assumptions.

CITES Appendix II. An international trade listing requiring legal acquisition, permits and a finding that export will not harm species survival. It regulates cross-border trade rather than banning all fishing.

Go Deeper

For the living diversity. David A. Ebert, Marc Dando and Sarah Fowler, *Sharks of the World: A Complete Guide* (Princeton University Press, 2021). Start here when the word shark still produces one outline. The book covers 536 species with illustrations, range maps, identification features and compact natural histories. It is a reference rather than a continuous argument, which is the virtue: opening it at random repeatedly destroys the great-white average. Taxonomy keeps moving, so individual names may change after publication, but the scale and variety remain the corrective this subject needs. Use the family introductions to see which differences mark ancestry and which reflect similar ecological work.

For the working animal. A. Peter Klimley, *The Biology of Sharks and Rays* (University of Chicago Press, 2013). This is the bridge from general fascination to serious mechanism. It explains skeleton, skin, movement, senses, feeding, reproduction and behaviour across cartilaginous fishes, using experiments and anatomy rather than a sequence of spectacular encounters. The prose is accessible, though denser than a popular natural history and willing to stay with physiological detail. Read it when you want to understand why a trait works and what evidence supports the explanation. Keep a species guide nearby, since comparative anatomy becomes easier when the animals can be seen.

For the human relationship. Juliet Eilperin, *Demon Fish: Travels Through the Hidden World of Sharks* (Pantheon, 2011). Eilperin follows sharks through fisheries, markets, tourism, research and culture in several countries. Its strongest contribution is to show that there is no single human-shark relationship either: fear, food, status, livelihood and conservation occupy the same trade routes. Some statistics and policy details predate major assessments used in this book, so treat it as reporting from its period rather than a current status report. The people and incentives remain instructive. It is especially strong on the distance between a conservation message designed abroad and a fishery lived locally.

For conservation without easy slogans. David Shiffman, *Why Sharks Matter: A Deep Dive with the World's Most Misunderstood Predator* (Johns Hopkins University Press, 2022). Shiffman is a marine conservation biologist who separates emotionally satisfying campaigns from measures likely to reduce mortality. The book is inviting, opinionated and unusually clear about the difference between finning, fishing, trade restrictions, sustainable use and species protection. Its focus is conservation rather than the whole biology, and readers may disagree with particular policy judgements. That is useful: it makes the choices and evidence visible enough to argue with. Pair its recommendations with the newer 2024 mortality analysis where current global outcomes matter.

Notes and Sources

The notes follow the manuscript in order. Taxonomy, population status and regulation change, so current material was checked on 4 September 2026. Numerical claims retain the population, period and denominator used by the source rather than being combined into a single global shark statistic.

The Whole Thing in One Page and Why You Should Care

Living diversity. Ebert, Dando and Fowler described 536 living species in their 2021 guide. The number changes as species are described, synonymised and rearranged, so the body uses more than 500 rather than presenting 536 as permanent. Shark refers here to the living selachimorph branch unless a broader source explicitly covers sharks, rays and chimaeras.

The sensory experiment. Kalmijn's 1971 experiments established electroreception by controlling visual, chemical and mechanical cues and presenting biologically comparable electric fields. The body keeps the inference at close-range prey localisation. Wider claims about geomagnetic orientation draw on later experiments and remain bounded because the sensory route and its importance differ among species.

Bite figures and terminology. The Florida Museum's International Shark Attack File reviewed 105 alleged human-shark incidents from 2025, confirmed 65 unprovoked bites and recorded nine unprovoked fatalities. Those are reported and investigated cases, not an exposure-adjusted probability. Unprovoked describes the recorded human action before contact; it does not establish the shark's motive. Neff and Hueter explain why encounter terminology changes the public model and policy discussion.

Threat and abundance measures. Dulvy and colleagues assessed 1,199 chondrichthyan species and placed 391, or 32.6 per cent, in threatened categories; their modelling raised the estimated proportion to 37.5 per cent after accounting for Data Deficient species. Pacoureau and colleagues built a separate Living Planet Index from 57 abundance time series for 18 oceanic shark and ray species covering 1970 to 2018 and estimated a 71 per cent decline. The first result is a global extinction-risk assessment across sharks, rays and chimaeras. The second is a relative-abundance indicator for an oceanic subset. The manuscript keeps them separate.

Fishing mortality. Worm and colleagues combined fisheries, trade and regulatory evidence to estimate that fishing mortality rose from at least 76 million sharks in 2012 to 80 million in 2019, with about 25 million threatened-species deaths in 2019. The totals are model estimates and lower bounds, not complete observed counts. The paper distinguishes declining finning from rising total mortality and supports the manuscript's central policy correction.

The Core Ideas

Classification and habitats. Ebert, Dando and Fowler supply the species-level diversity, order and family distinctions, body sizes and distributions used throughout. Carrier, Simpfendorfer, Heithaus and Yopak provide the wider comparative framework for anatomy, ecology, behaviour and fisheries. No single habitat, ventilation method, feeding position or life-history speed is attributed to the whole group.

Cartilage and reinforcement. Dean and Summers describe mineralised

cartilage and tesserae in chondrichthyan skeletons. Seidel and colleagues review the multiscale architecture and the relationship between mineralised tiles, fibres and the unmineralised core. These sources support the correction that a cartilaginous skeleton is organised, locally reinforced tissue rather than soft, undifferentiated gristle. They do not justify calling cartilage universally lighter or mechanically superior to bone.

Buoyancy and locomotion. Gleiss, Potvin and Goldbogen compared buoyancy strategies across sharks and found physical trade-offs ranging from relatively buoyant, large-livered deep-water species to denser, smaller-livered forms associated with faster acceleration. Their comparative associations are not a rule for every species or individual. Klimley and the chapters in *Biology of Sharks and Their Relatives* support the integrated treatment of liver oil, body density, fins, tail, swimming and ventilation.

Denticles. Oeffner and Lauder measured real skin and biomimetic surfaces under controlled dynamic conditions. Flexible shark-skin membranes performed differently after denticles were removed, while a commercial fabric did not reproduce one universal effect. The body therefore treats drag, abrasion and fouling as context-dependent functions and rejects a fixed drag-reduction percentage for shark skin as a whole.

Smell. Meredith and Kajiura reviewed olfactory morphology and physiology and found no simple correspondence between olfactory-organ size and sensitivity. Experimental thresholds depend on species, chemical and method. The phrase parts per billion describes the order reached in some amino-acid tests, not a universal blood threshold. Current, turbulence and search behaviour remain necessary parts of any long-range chemical account.

Electroreception and multisensory search. Kalmijn is the primary evidence for prey-generated electric-field detection. Klimley and the comparative chapters in Carrier and colleagues place electroreception beside vision, hearing, the lateral line and olfaction. The manuscript treats the senses as overlapping channels whose useful ranges change with water, light, noise, current and distance. It does not rank one sense as a

master system.

Filter feeding. Motta and colleagues measured feeding anatomy, filtration and diet in whale sharks feeding at the surface off the Yucatan Peninsula and described cross-flow filtration as a supported mechanism. Their setting is a seasonal aggregation and does not represent all whale-shark feeding. The body presents the mechanism as a model rather than the only possible account, and does not turn a measured local feeding rate into a species-wide daily ration.

Specialised predation. Oliver and colleagues documented common thresher sharks using tail slaps against schooling sardines at one Philippine site. Carlisle and colleagues combined isotopes, fatty acids, environmental DNA and stomach evidence to show that cookiecutter diets include smaller prey as well as the conspicuous plugs taken from large animals. Both are setting-specific demonstrations used to widen the feeding model, not universal descriptions of their families.

Ecological roles. Dedman and colleagues review sharks as predators, competitors, facilitators, nutrient transporters and food, and warn that large ecosystem effects are not ubiquitous. The influential tiger-shark work from Shark Bay demonstrates behavioural and indirect effects in a particular seagrass system. The manuscript retains that example while refusing to convert it into a global trophic-cascade law.

Reproductive modes. Katona and colleagues reconstructed repeated changes among egg laying, live bearing and maternal provisioning across sharks and rays. Their ancestral-state model has subsequently attracted methodological comment, so the retained claim is limited to repeated evolutionary transitions and diversity of modes. Sato and colleagues documented lipid-rich uterine fluid as a major early source of embryonic nutrition before oophagy begins in white sharks. Tomita and colleagues later examined the uterus of a female with early embryos and identified lipid-rich histotroph produced by holocrine secretion. These findings establish stages and mechanisms in white sharks, not a universal shark pregnancy sequence.

Greenland-shark age. Nielsen and colleagues radiocarbon-dated eye-lens nuclei from 28 female Greenland sharks. Their model placed minimum lifespan at 272 years and estimated the largest animal near 392 years, with a 95.4 per cent probability interval of 272 to 512 years. Sexual maturity was estimated near 156 years. The body rounds the maturity estimate and keeps the uncertainty beside the memorable number.

Fossil assembly and preservation. Coates and colleagues redescribed *Gladbachus adentatus* and used its mosaic of features to examine how the shark body plan was assembled. Schnetz and colleagues quantified the poor and uneven skeletal completeness of Palaeozoic chondrichthyans. Together they support the distinction between early chondrichthyans, shark-like forms and the living shark branch, and explain why teeth, denticles and spines dominate the archive.

Functional history. Cooper and Pimiento reconstructed shark functional diversity through the past 66 million years from dental traits and estimated body size. Their result indicates broad Cenozoic expansion followed by decline, especially over roughly the past ten million years. Because teeth and size cannot recover every ecological function, the body describes the result as a trait-space reconstruction rather than a complete census of ancient roles.

Megalodon timing and extinction. Pimiento and Clements reanalysed fossil occurrences and placed the extinction of *Otodus megalodon* at about 3.6 million years ago, with later records treated as unreliable. The body uses roughly 3.5 million years and presents cooling, prey change, nursery habitat and competition as proposed pressures rather than one settled cause.

Megalodon and white sharks. McCormack and colleagues used zinc isotopes to infer comparably high trophic positions for megatooth and great white sharks in some settings, supporting possible competition where their ranges and prey overlapped. Ehret and colleagues described *Carcharodon hubbelli* and argued for a white-shark lineage linked to broad-toothed mako-like forms. The exact branching pattern remains open to new fossils, but direct descent of great whites from megalodon is unsupported.

Global extinction risk. Dulvy and colleagues identify overfishing as the threat affecting all 391 species placed in threatened categories, with other pressures adding risk in some places. The figures cover Chondrichthyes, not sharks alone. Geography, depth and life history are unevenly represented, so the manuscript describes disproportionate coastal and tropical danger without assigning one rate to every region.

Finning, landings and mortality. Worm and colleagues distinguish fin removal and carcass discard from total fishing mortality. Their analysis found that anti-finning rules could reduce finning while whole-shark retention, meat markets, coastal fishing and bycatch sustained or increased mortality. The paper supports stronger protection and fisheries regulation in many settings, but not a claim that every shark catch is biologically unsustainable.

Trade control. CITES Appendix II regulates international trade rather than prohibiting all capture or sale. Export requires evidence of legal acquisition and a finding that trade will not be detrimental to the species' survival. Domestic fishing remains under national and regional fisheries rules. The CITES shark and ray programme and Appendix descriptions were checked on 4 September 2026.

Sandbar sharks. NOAA Fisheries reports that the United States Atlantic sandbar stock was overfished and subject to overfishing in the 2006 assessment. A research fishery was created in 2008 and other federal commercial and recreational landings were prohibited. The 2018 assessment found the stock overfished but no longer subject to overfishing. The example is jurisdiction-specific and illustrates the difference between ending excessive current mortality and completing a rebuild.

How It Actually Works

Early sharks and the Palaeozoic. Coates and colleagues, Schnetz and colleagues, and the palaeobiological chapters in Carrier and colleagues support the branching account. Hybodonts and many Palaeozoic chondrichthyans are not treated as modern sharks. Tooth abundance is interpreted through repeated replacement, preservation and deposition rather than read as a direct census.

The Mesozoic and Cenozoic. Ebert, Dando and Fowler supply the living orders and their characteristic forms. Cooper and Pimiento provide the changing functional background, while Pimiento and Clements, Ehret and colleagues, and McCormack and colleagues support the megalodon and white-shark account. Dates are rounded because first and last appearances depend on fossil sampling and taxonomic judgement.

Human uses. Eilperin synthesises local fisheries, trade, food, status, tourism and conservation across several countries. Klimley and historical material in Carrier and colleagues support uses of meat, oil, skin and teeth. The examples are presented as varied practices rather than one universal pre-industrial relationship.

Tongue stones. Nicolas Steno's comparison of a large shark's teeth with glossopetrae in the seventeenth century helped establish their organic origin and contributed to the developing interpretation of fossils. The manuscript uses the episode for the narrow claim that shark teeth helped connect stone objects in rock with former organisms, not as a sole invention of palaeontology.

Jaws. Benchley's 1974 novel and Spielberg's 1975 film establish the dates and the cultural great-white template. The film's reach is clear; its causal contribution to later fishing mortality cannot be isolated from sport fishing, commercial fleets, markets and prior fear. The body therefore claims cultural compression and influence, not that one film caused global depletion.

Tracking and population science. Carrier and colleagues provide the operating distinctions among conventional, acoustic and satellite tags,

photo-identification, genetics, video surveys and environmental DNA. Each method samples different animals, places and periods. Detection, movement and population size are kept separate.

The industrial fishery. Pacoureau and colleagues establish the oceanic abundance indicator. Worm and colleagues provide the 2012 and 2019 mortality estimates and analysis of regulation. Dulvy and colleagues supply the global extinction-risk assessment. FAO's International Plan of Action for the Conservation and Management of Sharks, adopted in 1999 after development in the late 1990s, supplies a voluntary framework whose policy definition includes sharks, rays, skates and chimaeras.

How we know. The evidence limitations are drawn from the methods of the cited research: a cartilage-poor fossil record, taxonomic revision, gear-biased biological samples, incomplete tag coverage, detection without direct abundance, report-dependent bite files, and modelled catch totals. No single method is treated as a complete census.

What People Get Wrong and Use It

The seven corrections. Diversity rests on Ebert, Dando and Fowler. Deep-time change rests on Coates and colleagues, Schnetz and colleagues, and Cooper and Pimiento. Cartilage rests on Dean and Summers and Seidel and colleagues. Smell rests on Meredith and Kajiura. Bite interpretation rests on Ryan and colleagues, the International Shark Attack File and Neff and Hueter. Megalodon relationships rest on Ehret and colleagues and McCormack and colleagues. Finning and total mortality rest on Worm and colleagues.

Hazard and exposure. The Use It distinction is a standard risk model applied to bite reports. Global annual counts cannot supply a local probability without exposure, species occurrence and reporting conditions. The manuscript offers no location-specific safety rule and does not use low worldwide totals to minimise severe injuries.

Replacement and stock status. Life-history interpretation follows the demographic logic used in shark stock assessments and extinction-risk

work: maturity, reproductive interval, litter size, survival and movement set the capacity to replace removals. NOAA's sandbar-shark material supplies the concrete distinction between overfishing, a rate, and overfished, a stock condition.

Limits of ecological inference. Dedman and colleagues are the main authority for keeping shark roles diverse and context-dependent. The body retains strong local evidence while marking gaps for small-bodied, deep-water and polar sharks. No technically defensible case study is allowed to imply one inevitable ocean-wide response.

Bibliography

Original research and major reviews

Carlisle, Aaron B., Elizabeth Andruszkiewicz Allan, Sora L. Kim, Lauren Meyer, Jesse Port, Stephen Scherrer, and John O'Sullivan. "Integrating Multiple Chemical Tracers to Elucidate the Diet and Habitat of Cookiecutter Sharks." *Scientific Reports* 11 (2021): 11809. DOI: 10.1038/s41598-021-89903-z.

Coates, Michael I., John A. Finarelli, Ivan J. Sansom, Plamen S. Andreev, Katharine E. Criswell, Kristen Tietjen, Mark L. Rivers, and Patrick J. La Riviere. "An Early Chondrichthyan and the Evolutionary Assembly of a Shark Body Plan." *Proceedings of the Royal Society B* 285, no. 1870 (2018): 20172418. DOI: 10.1098/rspb.2017.2418.

Cooper, Jack A., and Catalina Pimiento. "The Rise and Fall of Shark Functional Diversity over the Last 66 Million Years." *Global Ecology and Biogeography* 33, no. 9 (2024): e13881. DOI: 10.1111/geb.13881.

Dean, Mason N., and Adam P. Summers. "Mineralized Cartilage in the Skeleton of Chondrichthyan Fishes." *Zoology* 109, no. 2 (2006): 164-168. DOI: 10.1016/j.zool.2006.03.002.

Dedman, Simon, Jerry H. Moxley, Yannis P. Papastamatiou, Matias Braccini, Jennifer E. Caselle, Demian D. Chapman, Joshua E. Cinner, et al.

"Ecological Roles and Importance of Sharks in the Anthropocene Ocean." *Science* 385, no. 6708 (2024): eadl2362. DOI: 10.1126/science.adl2362.

Dulvy, Nicholas K., Nathan Pacoureau, Cassandra L. Rigby, Riley A. Pollom, Rima W. Jabado, David A. Ebert, Brittany Finucci, et al. "Overfishing Drives over One-third of All Sharks and Rays toward a Global Extinction Crisis." *Current Biology* 31, no. 21 (2021): 4773-4787.e8. DOI: 10.1016/j.cub.2021.08.062.

Ehret, Dana J., Bruce J. MacFadden, Douglas S. Jones, Thomas J. DeVries, David A. Foster, and Rodolfo Salas-Gismondi. "Origin of the White Shark *Carcharodon* (Lamniformes: Lamnidae) Based on Recalibration of the Upper Neogene Pisco Formation of Peru." *Palaeontology* 55, no. 6 (2012): 1139-1153. DOI: 10.1111/j.1475-4983.2012.01201.x.

Gleiss, Adrian C., Jean Potvin, and Jeremy A. Goldbogen. "Physical Trade-offs Shape the Evolution of Buoyancy Control in Sharks." *Proceedings of the Royal Society B* 284, no. 1866 (2017): 20171345. DOI: 10.1098/rspb.2017.1345.

Kalmijn, Ad J. "The Electric Sense of Sharks and Rays." *Journal of Experimental Biology* 55, no. 2 (1971): 371-383. DOI: 10.1242/jeb.55.2.371.

Katona, Gergely, Flora Szabo, Zsolt Vegvari, Tamas Szekely Jr, Andras Liker, Robert P. Freckleton, Balazs Vagi, and Tamas Szekely. "Evolution of Reproductive Modes in Sharks and Rays." *Journal of Evolutionary Biology* 36, no. 11 (2023): 1630-1640. DOI: 10.1111/jeb.14231.

McCormack, Jeremy, Michael L. Griffiths, Sora L. Kim, Kenshu Shimada, Molly Karnes, Harry Maisch, Sarah Pederzani, et al. "Trophic Position of *Otodus megalodon* and Great White Sharks through Time Revealed by Zinc Isotopes." *Nature Communications* 13 (2022): 2980. DOI: 10.1038/s41467-022-30528-9.

Meredith, Tricia L., and Stephen M. Kajiura. "Olfactory Morphology and Physiology of Elasmobranchs." *Journal of Experimental Biology* 213, no. 20 (2010): 3449-3456. DOI: 10.1242/jeb.045849.

Motta, Philip J., Michael Maslanka, Robert E. Hueter, Ray L. Davis, Rafael de la Parra, Samantha L. Mulvany, Maria Laura Habegger, et al. "Feeding Anatomy, Filter-feeding Rate, and Diet of Whale Sharks *Rhincodon typus* during Surface Ram Filter Feeding off the Yucatan Peninsula, Mexico." *Zoology* 113, no. 4 (2010): 199-212. DOI: 10.1016/j.zool.2009.12.001.

Neff, Christopher, and Robert Hueter. "Science, Policy, and the Public Discourse of Shark 'Attack': A Proposal for Reclassifying Human-Shark Interactions." *Journal of Environmental Studies and Sciences* 3, no. 1 (2013): 65-73. DOI: 10.1007/s13412-013-0107-2.

Nielsen, Julius, Rasmus B. Hedeholm, Jan Heinemeier, Peter G. Bushnell, Jorgen S. Christiansen, Jesper Olsen, Christopher Bronk Ramsey, et al. "Eye Lens Radiocarbon Reveals Centuries of Longevity in the Greenland Shark (*Somniosus microcephalus*)." *Science* 353, no. 6300 (2016): 702-704. DOI: 10.1126/science.aaf1703.

Oeffner, Johannes, and George V. Lauder. "The Hydrodynamic Function of Shark Skin and Two Biomimetic Applications." *Journal of Experimental Biology* 215, no. 5 (2012): 785-795. DOI: 10.1242/jeb.063040.

Oliver, Simon P., John R. Turner, Ken Gann, Medel Silvosa, and Timothy D'Urban Jackson. "Thresher Sharks Use Tail-slaps as a Hunting Strategy." *PLoS ONE* 8, no. 7 (2013): e67380. DOI: 10.1371/journal.pone.0067380.

Pacoureau, Nathan, Cassandra L. Rigby, Peter M. Kyne, Richard B. Sherley, Henning Winker, John K. Carlson, Sonja V. Fordham, et al. "Half a Century of Global Decline in Oceanic Sharks and Rays." *Nature* 589, no. 7843 (2021): 567-571. DOI: 10.1038/s41586-020-03173-9.

Pimiento, Catalina, and Christopher F. Clements. "When Did *Carcharocles megalodon* Become Extinct? A New Analysis of the Fossil Record." *PLoS ONE* 9, no. 10 (2014): e111086. DOI: 10.1371/journal.pone.0111086.

Ryan, Laura A., David J. Slip, Daniel J. Hart, Kylie A. McDonald, Olivia M. O'Neill, Nathan P. McGregor, and Nathan S. Hart. "A Shark's Eye View: Testing the 'Mistaken Identity Theory' behind Shark Bites on Humans."

Journal of the Royal Society Interface 18, no. 183 (2021): 20210533. DOI: 10.1098/rsif.2021.0533.

Sato, Keiichi, Masaru Nakamura, Taketeru Tomita, Minoru Toda, Kei Miyamoto, and Ryo Nozu. "How Great White Sharks Nourish Their Embryos to a Large Size: Evidence of Lipid Histotrophy in Lamnoid Shark Reproduction." *Biology Open* 5, no. 9 (2016): 1211-1215. DOI: 10.1242/bio.017939.

Schnetz, Lisa, Emma M. Dunne, Iris Feichtinger, Michael I. Coates, Richard J. Butler, and Ivan J. Sansom. "The Skeletal Completeness of the Palaeozoic Chondrichthyan Fossil Record." *Royal Society Open Science* 11, no. 1 (2024): 231451. DOI: 10.1098/rsos.231451.

Seidel, Ronald, Aravind K. Jayasankar, and Mason N. Dean. "The Multiscale Architecture of Tessellated Cartilage and Its Relation to Function." *Journal of Fish Biology* 98, no. 4 (2021): 942-955. DOI: 10.1111/jfb.14444.

Tomita, Taketeru, Masaru Nakamura, Ryo Nozu, Nobuhiro Ogawa, Minoru Toda, and Keiichi Sato. "Mode of Uterine Milk Secretion in the White Shark." *The Anatomical Record* 305, no. 7 (2022): 1724-1731. DOI: 10.1002/ar.24860.

Worm, Boris, Sara Orofino, Echelle S. Burns, Nidhi G. D'Costa, Leonardo Manir Feitosa, Maria L. D. Palomares, Laurene Schiller, and Darcy Bradley. "Global Shark Fishing Mortality Still Rising despite Widespread Regulatory Change." *Science* 383, no. 6679 (2024): 225-230. DOI: 10.1126/science.adf8984.

Books and syntheses

Carrier, Jeffrey C., Colin A. Simpfendorfer, Michael R. Heithaus, and Kara E. Yopak, eds. *Biology of Sharks and Their Relatives*. 3rd ed. Boca Raton: CRC Press, 2022.

Ebert, David A., Marc Dando, and Sarah Fowler. *Sharks of the World: A Complete Guide*. Princeton: Princeton University Press, 2021.

Eilperin, Juliet. *Demon Fish: Travels Through the Hidden World of Sharks*. New York: Pantheon, 2011.

Klimley, A. Peter. *The Biology of Sharks and Rays*. Illustrations by Steven Oerding. Chicago: University of Chicago Press, 2013. DOI: 10.7208/chicago/9780226923086.001.0001.

Shiffman, David. *Why Sharks Matter: A Deep Dive with the World's Most Misunderstood Predator*. Baltimore: Johns Hopkins University Press, 2022. DOI: 10.56021/9781421443652.

Official data and policy

Convention on International Trade in Endangered Species of Wild Fauna and Flora. "The CITES Appendices" and "Sharks and Rays." Current programme and implementation pages. Accessed 4 September 2026.

Food and Agriculture Organization of the United Nations. *International Plan of Action for the Conservation and Management of Sharks*. Rome: FAO, 1999.

Florida Museum of Natural History. International Shark Attack File. "Yearly Worldwide Shark Attack Summary: 2025." Published 2026. Accessed 4 September 2026.

NOAA Fisheries. "Sandbar Shark" and "Sandbar Shark: Management." Updated 29 June 2026. Accessed 4 September 2026.

Cultural works

Benchley, Peter. *Jaws*. Garden City, NY: Doubleday, 1974.

Spielberg, Steven, dir. *Jaws*. Universal Pictures, 1975.

Notes

Fresh-audit verification

- 1 Movement and navigation: Bryan A. Keller and colleagues, "Map-like use of Earth's magnetic field in sharks", *Current Biology* 31 (2021), doi:10.1016/j.cub.2021.03.103.
- 1 Abundance and extinction risk: Nathan Pacoureau and colleagues, "Half a century of global decline in oceanic sharks and rays", *Nature* 589 (2021), doi:10.1038/s41586-020-03173-9; Nicholas K. Dulvy and colleagues, "Overfishing drives over one-third of all sharks and rays toward a global extinction crisis", *Current Biology* 31 (2021), doi:10.1016/j.cub.2021.08.062.
- 1 Fishing mortality and policy: Boris Worm and colleagues, "Global shark fishing mortality still rising despite widespread regulatory change", *Science* 383 (2024), doi:10.1126/science.adf8984; CITES, *Appendices I, II and III*, version in force on the verification date.