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Review article

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Status, trends and conservation of global sea turtle populations

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Sections

Abstract

Sea turtles experienced myriad human impacts during the twentieth century that caused extreme mortality across all seven species. Extensive conservation efforts have been undertaken to protect sea turtles and reverse the major declines seen in many of their populations. In this Review we assess the status and trends of global sea turtle populations and identify conservation interventions that have been linked to population recoveries. Some threats, such as the direct harvest of turtles, have abated, but threats posed by climate change and loss of nesting habitat continue to escalate. Both the International Union for the Conservation of Nature (IUCN) Red List assessments and an analysis of sea turtle abundance time series have revealed that, in general, sea turtle populations are rebounding worldwide, with nest numbers increasing at many nesting sites. However, certain populations are still declining dramatically, such as leatherback turtle populations in the Pacific Ocean and Caribbean Sea. Key unresolved questions include whether sea turtles can adapt to climate change, the magnitude of climate warming's impact on adult sex ratios, and the effect of growing threats such as increasing plastic pollution. Despite some conservation successes, cautious optimism is advised when considering the future of sea turtles in a rapidly changing world.

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Introduction

Sea turtles are among the marine taxa that have suffered the most severe declines in abundance as a result of the effects of climate change, habitat loss and overharvesting. Historical reports from the Caribbean in the fifteenth century described sea turtles as being so numerous that sailors were kept awake at night by turtles bumping into the hulls of their ships. The estimated 16–33 million adult green turtles (*Chelonia mydas*) in the Caribbean at that time[1] dwindled to less than 2 million in the year 2000, a decline of 95%[2]. Similarly, leatherback turtles (*Dermochelys coriacea*) nesting in peninsular Malaysia declined from around 10,000 annual nests in 1953 to only one or two annual nests by 2003, and by 2024 leatherback nesting was almost non-existent in that region[3]. Kemp's ridley turtles (*Lepidochelys kempii*), which nest mainly on one beach in Mexico, declined by 99% from 1947 to 1985 (121,517 to 702 nests per season, respectively)[4], before recovering since the 1990s.

Set against this backdrop of decimation, initiatives are under way to protect the world's oceans and rebuild ocean biodiversity[5]. For example, in December 2022, 190 nations agreed on the Kunming–Montreal Global Biodiversity Framework during the COP15 United Nations Biodiversity Conference, which sets out to protect and restore 30% of the world's land and seas globally by 2030 (refs. 6,7). In addition to these ongoing global efforts to safeguard more of our planet's oceans, numerous sea turtle conservation measures have been implemented around the world. In some regions, catastrophic sea turtle declines led to regional and/or local bans on direct harvest; now that some of these bans are decades old, successes have been seen in terms of rebounding turtle abundance. Given that many conservation efforts started as early as the 1950s and the hopes for increased future protection of ocean areas as part of the Kunming–Montreal Global Biodiversity Framework, it is timely to assess the status of ongoing sea turtle conservation and identify where the tide of historical declines has been reversed.

In this Review, we first introduce the different species of sea turtles, their habitats and distributions, and the threats they face. Threats to sea turtle populations are only briefly outlined, as they have been extensively reviewed elsewhere[8]. We discuss how trends in sea turtle abundance are assessed and highlight important data deficiencies. We then review the status of global sea turtle populations, bringing together the assessments made both through the IUCN Red Listing process as well as the compilation of published abundance time series from individual nesting beaches. We identify the conservation interventions that have been successful in this group and that could continue to help to prevent local and regional extinctions and promote population recoveries across species and regions.

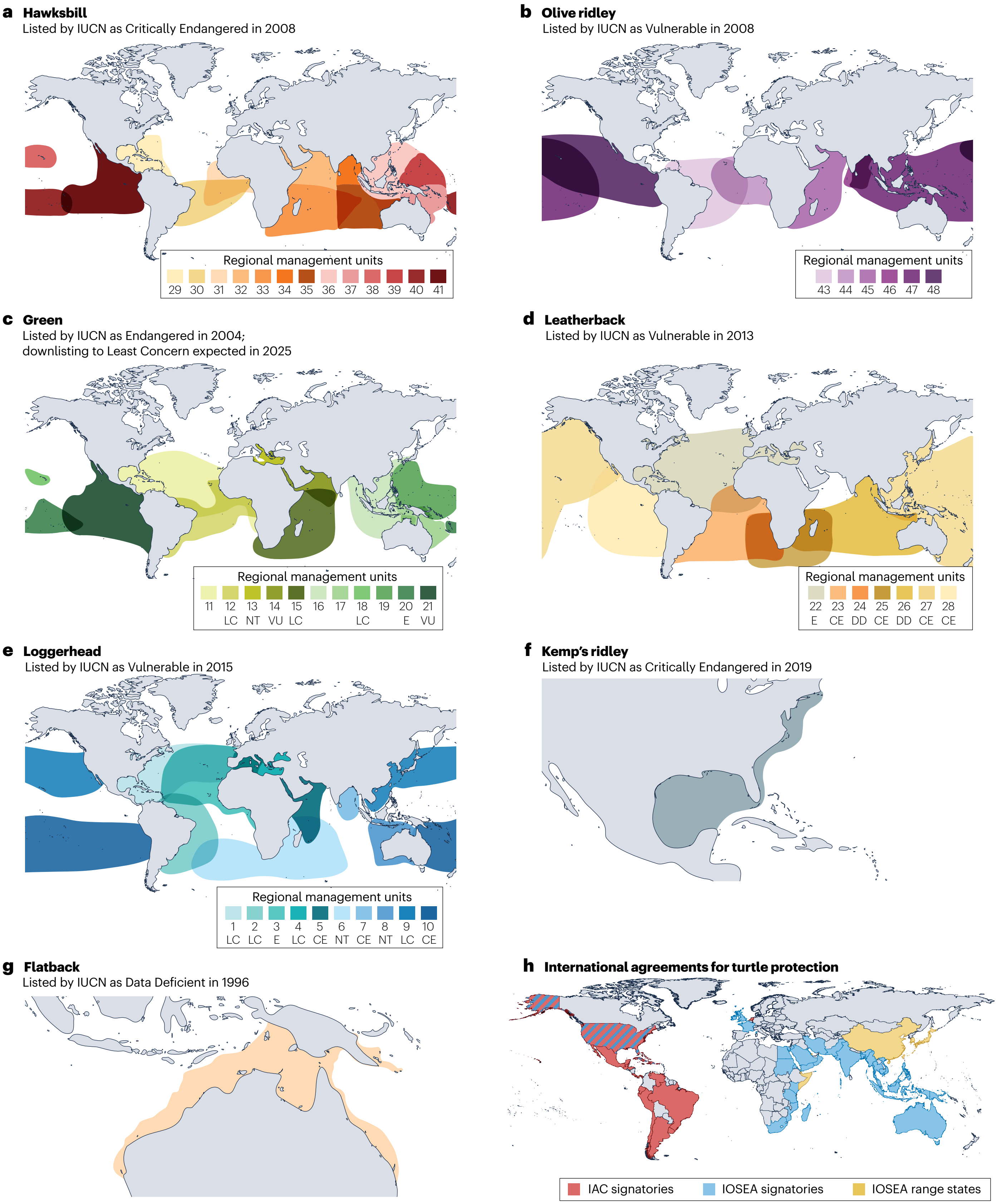
Distributions and habitat requirements

There are seven extant species of sea turtles (Fig. 1): the leatherback turtle (*D. coriacea*), Kemp's ridley turtle (*L. kempii*), olive ridley turtle (*Lepidochelys olivacea*), green turtle (*C. mydas*), loggerhead turtle (*Caretta caretta*), flatback turtle (*Natator depressus*) and hawksbill turtle (*Eretmochelys imbricata*). Two of the species have restricted regional distributions (Fig. 1): flatback turtles nest only in Australasia and Kemp's ridley turtles nest on only a handful of beaches in the western Gulf of Mexico. Five of the species (leatherbacks, olive ridleys, green turtles, hawksbills and loggerheads) have circumglobal distributions, nesting on continental and insular beaches generally between the latitudes of 34° S and 38° N (Fig. 1). The global populations of the widespread species are subdivided into regional management units (RMUs)[9], which are defined by a combination of genetic data (turtles nesting in different RMUs are genetically distinct), satellite tracking data and data from mark–recapture studies. RMUs represent a unit of protection above the level of nesting populations and below the level of species[9]. For widespread species, the designation of RMUs is important because their threats and population status vary regionally.

All species share the life-history feature of nesting on sandy beaches with no parental investment after eggs are deposited in a nest. Post-hatchling individuals disperse widely, recruit to coastal foraging areas or, in some cases (such as with leatherback turtles), remain in the high seas as juveniles. As adults, sea turtles move between foraging and breeding areas, with the extent of fidelity to foraging and breeding sites varying among species. For example, loggerhead, hawksbill, green, flatback and Kemp's ridley turtles have been shown to have tight fidelity to foraging sites[10,11] whereas leatherbacks tend to forage broadly across ocean basins (although in the Pacific they show fidelity to large regional feeding areas)[12,13]. Despite high fidelity at the individual level, foraging sites used by individuals within a nesting population can be separated by thousands of kilometres; for example, individual green turtles nesting in the Chagos Archipelago (Indian Ocean) forage at sites in the Seychelles, mainland Africa, Madagascar and the Maldives[14]. Similar to foraging ground fidelity, nesting females typically return to the same nesting area from which they hatched, a behaviour termed natal philopatry. This natal philopatry means that sea turtles rarely colonize new nesting areas[10]. However, a breakdown of nesting area fidelity has been recorded in some individuals and is presumably the process by which new nesting sites are colonized. For example, an individual green turtle in the Indian Ocean nested on beaches 2,250 km apart[15], and green turtles attempted to nest on an isolated Atlantic Island 1,100 km distant from the nearest nesting beaches, despite the fact that the rocky coastline and lack of sandy beaches preclude successful nest excavation and egg laying[16]. A breakdown in nesting beach fidelity has been implicated in increased nesting by loggerheads in the western Mediterranean[10]. However, the extent of breakdowns in nesting beach fidelity, differences between species and the potential for new nesting sites to be colonized in this way all remain poorly understood[10].

Species differ in diet and foraging habitat preference. For example, green turtles tend to feed near the base of the food chain on seagrass and macroalgae[17], hawksbill turtles often – but not always[18] – feed on sponges or other invertebrate prey[19,20], whereas leatherbacks feed almost exclusively on gelatinous zooplankton, including scyphozoan jellyfish, urochordates and pyrosomes[21]. With respect to foraging

Fig. 1 | Regional management units and conservation status of sea turtles. **a**–**g**, Regional management units (RMUs) and International Union for Conservation of Nature (IUCN) Red List statuses are shown for the seven sea turtle species: hawksbill (**a**); olive ridley (**b**); green (**c**); leatherback (**d**); loggerhead (**e**); Kemp's ridley (**f**); and flatback (**g**). IUCN global assessments have been conducted for all species (for example, refs. 89,90,98,117,118), but are long overdue in the case of flatback and olive ridley turtles. For green turtles (**c**), leatherback turtles (**d**) and loggerhead turtles (**e**), RMU-scale IUCN assessments are available. The status of these RMUs is shown below the RMU colour scale: LC, Least Concern; NT, Near Threatened; VU, Vulnerable; E, Endangered; CE, Critically Endangered; and DD, Data Deficient. **h**, Geographical areas are coloured by their involvement in two international agreements: the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC) and the Indian Ocean–South-East Asian (IOSEA) Marine Turtle Memorandum of Understanding. Parts **a** to **f** are adapted from ref. 9, CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).


a Hawksbill
Listed by IUCN as Critically Endangered in 2008
Regional management units
29 30 31 32 33 34 35 36 37 38 39 40 41
b Olive ridley
Listed by IUCN as Vulnerable in 2008
Regional management units
43 44 45 46 47 48
c Green
Listed by IUCN as Endangered in 2004;
downlisting to Least Concern expected in 2025
Regional management units
11 12 13 14 15 16 17 18 19 20 21
LC NT VU LC LC E VU
d Leatherback
Listed by IUCN as Vulnerable in 2013
Regional management units
22 23 24 25 26 27 28
E CE DD CE DD CE CE
e Loggerhead
Listed by IUCN as Vulnerable in 2015
Regional management units
1 2 3 4 5 6 7 8 9 10
LC LC E LC CE NT CE NT LC CE
f Kemp's ridley
Listed by IUCN as Critically Endangered in 2019
g Flatback
Listed by IUCN as Data Deficient in 1996
h International agreements for turtle protection
IAC signatories
IOSEA signatories
IOSEA range states

habitat, whereas green turtles, hawksbills and flatbacks tend to prefer shallow nearshore foraging habitats as adults, leatherbacks search for prey in the high seas. Loggerheads, Kemp's ridleys and olive ridleys use both coastal and high seas foraging zones, with individual foraging strategy strongly linked to region and/or life history phase[22–24].

Predominant threats

Turtle mortality occurs naturally via predation. For example, crabs and other natural predators can consume over 50% of eggs laid on some beaches[25,26] and hatchlings are eaten by fish and seabirds. Even large adult turtles are predated by sharks[8,27] and occasionally by orcas[28]. Beyond this natural mortality, multiple other threats can negatively affect sea turtle populations (Fig. 2a); we now discuss the predominant anthropogenic threats and evidence of their effects on populations.

Direct take

Direct take refers to the removal of either eggs or adults — including nesting females and turtles in foraging areas — for human consumption or use in products such as traditional medicines or curios[29,30]. For example, hawksbill turtle shell plates are harvested for the manufacture of and global trade in tortoiseshell jewellery and adornments[29,30]. Between 1990 and 2020 an estimated 1.1 million marine turtles were taken despite existing laws prohibiting their use in 65 countries or territories, with the harvest of green and hawksbill turtles accounting for the majority of take[29]. Although reported exploitation decreased by 28% from the 2000s to the 2010s[29], this rate of harvest is unsustainable for already depleted populations. Indeed, the harvest of leatherback eggs has been implicated in population declines in Indonesia[31], Costa Rica[32] and Mexico[33], as well as the local extinction of the nesting population in peninsular Malaysia[3].

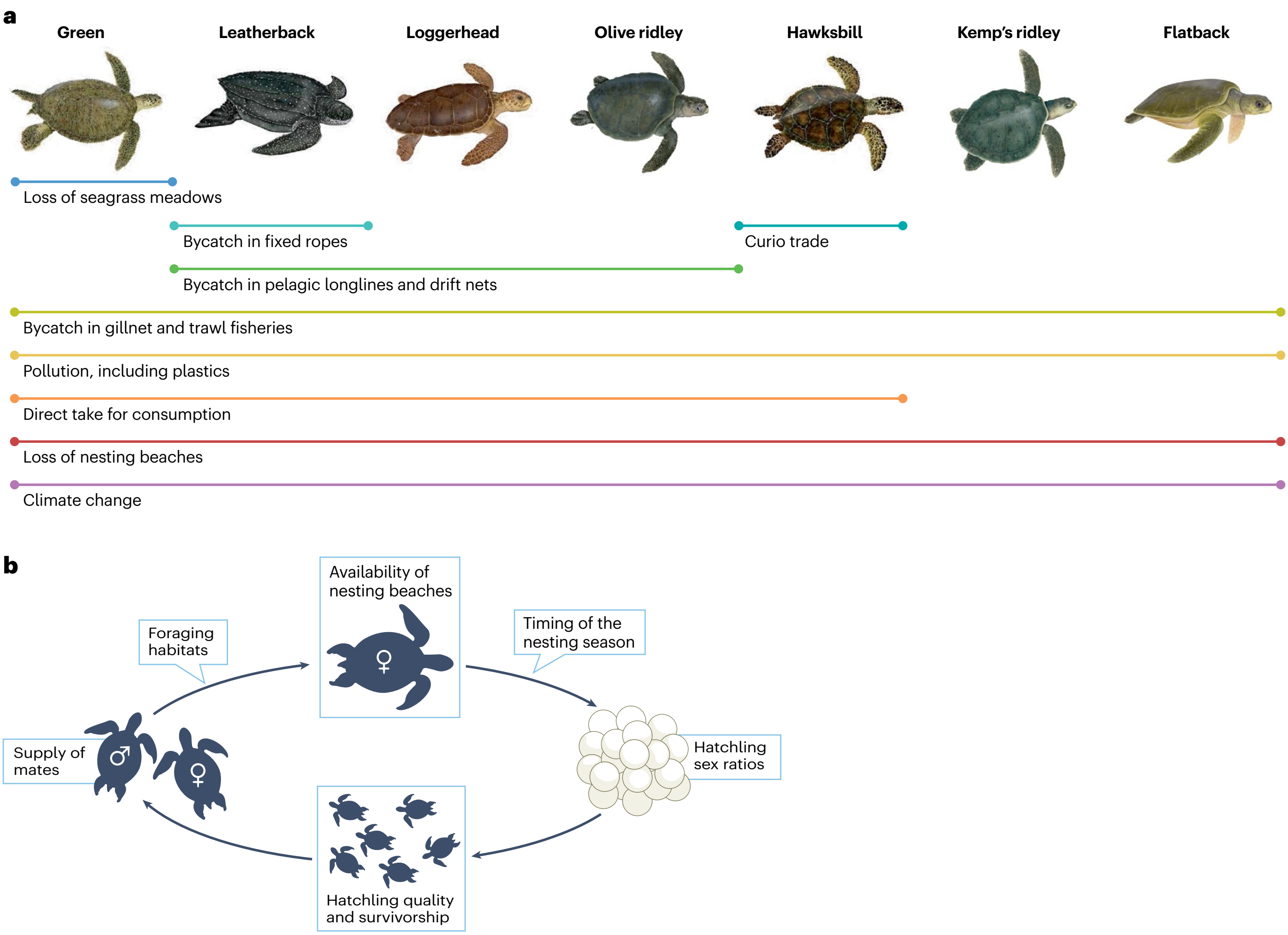


Fig. 2 | Threats to sea turtles. a, Some threats affect all seven species, whereas others are species-specific owing to unique habitat use (for example, with green turtles) or exposure to different types of fishing gear. **b**, Climate change is a multi-dimensional threat that affects sea turtles at multiple life-history stages. Sand temperature during incubation of eggs affects the sex ratio of hatchlings, their survival in the nest and their fitness upon emerging. Future warming is predicted to raise incubation temperatures; fewer male hatchlings will be produced and embryonic mortality will increase. Lower production of male hatchlings might subsequently limit the supply of breeding males. Climate change can negatively affect foraging habitats, such as seagrass meadows. Rising sea levels under climate change can decrease the availability of nesting beaches. Climate warming can affect the timing (phenology) of nesting, causing the nesting season to shift to earlier or later in the year. Turtle images in part **a** reprinted with permission from NOAA.

Direct take happens both legally and illegally. In 2014, 42 countries reported legal turtle take[34]; since then, new laws outlawing turtle take have been enacted[35]. Importantly, the existence of bans does not eliminate direct take. International trade in hawksbill turtles was prohibited by the Convention on International Trade in Endangered Species of Wild Fauna and Flora starting in 1981, and Japan ended its exception to this convention in 1992. Yet despite this closure of the global tortoiseshell trade[36], the killing of hawksbills for their shells continues in some regions, largely owing to economic need and a lack of wildlife law enforcement[37].

Bycatch

Bycatch in global fisheries is a threat for all sea turtle species, but vulnerability to bycatch from different fishing methods – longline, driftnet, trawl, anchored gillnet or pots – varies among species. Compared to the other turtle species, leatherbacks are at risk of bycatch in most fishing methods because they forage widely in diverse habitats[13,38,39] (Fig. 2a). Bycatch in global longline fisheries is thought to be a major driver of leatherback mortality and population declines, although specific numbers about leatherback bycatch globally are lacking. Off the coasts of Massachusetts (USA) and Nova Scotia (Canada) leatherbacks are often found entangled in fixed fishing gear, including nets and ropes associated with pot fisheries[40,41]. Bycatch in the artisanal coastal gillnet fisheries near nesting beaches in Trinidad (the Caribbean) has been estimated at 1,000–3,000 leatherbacks per year[42]. Loggerheads are vulnerable to bycatch in longline and driftnet fisheries because they are found in productive fishing areas and will take baits and so ingest hooks[43]. Annually, hundreds of thousands of loggerheads are taken as bycatch in oceanic longline fisheries[43]. For example, in 2000 it was estimated that 300,000 loggerheads were taken as bycatch in the Mediterranean, the Atlantic and the Pacific, and fishing intensity has probably increased since then[43]. Although the magnitude of mortality from bycatch is highest in leatherbacks and loggerheads, all other species have been documented as bycatch in coastal and/or pelagic fisheries[8].

Plastics and other pollutants

Plastic pollution is now an omnipresent threat to all turtle species[44]. Lethal and sub-lethal effects of plastic pollution include drowning, starvation, gastrointestinal tract damage, malnutrition, physical injury and reduced mobility[45]. These effects can result from either entanglement (for example, in 'ghost' fishing nets) or ingestion. A 30-year time series revealed increases in the ingestion of debris by turtles, consistent with increasing levels of plastics in the ocean[44]. Beyond plastics, other pollutants can cause immunosuppression and an increased incidence of disease in sea turtles, although these links are poorly resolved[8,46].

Climate change

Climate change, specifically warming, negatively affects turtles in multiple direct and indirect ways[47,48]. First, the life cycle of sea turtles is sensitive to temperature[49] (Fig. 2b). Sea turtle sex determination is temperature-dependent, with more females produced at high embryonic incubation temperatures[50]; under forecasted climate change scenarios, sea turtle populations are expected to become increasingly female-biased[51]. Indeed, a 2024 global assessment showed that most sea turtle nesting beaches currently produce highly female-biased primary sex ratios[52]. Importantly, although these temperature-driven shifts in sex ratios are assumed to affect populations negatively, female-skewed hatchling sex ratios could lead to an increased number of breeding females and thereby greater egg production, provided that sufficient males remain[53]; whether or not these climate-driven changes in sex ratios will positively or negatively affect turtle populations requires further study.

Second, excessively high incubation temperatures increase embryonic mortality and reduce hatchling fitness and survival[54,55], meaning that hatchling production is likely to decrease as temperatures increase[56]. For example, at the green turtle rookery on Raine Island, a decrease in hatchling survival has been linked to a worsening of incubation conditions due to rising sea levels and temperatures[57]. Some of these threats could be mitigated, at least partially, by phenological shifts in nesting (Box 1).

Indirect effects of climate change include impairments to the habitats on which turtles rely. Nesting habitats are likely to disappear as sea levels rise and beach erosion increases[58]. Foraging grounds and availability of food resources can be disrupted by increased exposure to extreme storm events and marine heatwaves, reducing turtle reproductive output[59–61]. As sea temperatures warm and oceanic currents change, the distribution of turtles in the oceans might be affected[62]. For example, the ongoing northward nesting range expansion of green turtles in North America has been attributed to warming ocean temperatures[63].

Other threats

In addition to the major threats already discussed, turtles also face anthropogenic threats from vessel strikes, feral (invasive) predators, coastal development and light pollution[8]. Turtles can be killed or severely injured by collision with marine vessels[64]; for example, between 1986 and 2014 over 10,000 sea turtles in Florida (USA) were stranded owing to injuries from vessel strikes[65]. Vessel strikes are a growing concern owing to increases in boat traffic globally[66]. Another form of impact that is escalating in coastal environments is light pollution, which can disorient nesting females and hatchlings, resulting in high hatchling mortality[67]. Sea turtle mortality has been attributed to introductions of invasive mammals since as early as 1700, when the green turtle nesting population on the island of Trindade nearly went extinct owing to egg predation by introduced pigs[68]. Feral pigs continue to cause substantial reductions in hatching rates for olive ridley and flatback turtles in Australia[69] and leatherbacks in Indonesia[70]. Finally, a threat unique to green turtles is the loss or degradation of the seagrass meadows that they use as foraging grounds[71]. Triaging these various threats remains an important challenge.

Assessment of sea turtle populations

The accurate estimation of species abundance is critical for conservation, but is particularly challenging in sea turtles owing to their life cycle, which entails geographic separation of breeding and foraging grounds. Because the number of nests (also referred to as clutches) is easier to count than the number of adults or juveniles, nest count has been the standard index of overall sea turtle population abundance for many decades[53]. In some cases, the numbers of nests are converted to the number of nesting females, but this conversion is potentially problematic because of poor information on the number of clutches laid by individual females[72]. Furthermore, the numbers of juveniles and males provide useful information, but represent an important data gap owing to sampling difficulties. Here we discuss current practices and ongoing improvements in how turtle abundances are measured and describe how they are used in official population assessments.

Box 1 | Turtle resilience to warming

Multiple aspects of sea turtle biology might help them to withstand the threat of climate change. Owing to the lower energetic costs of reproduction for males[157], the interval between breeding seasons (termed the remigration interval) is generally shorter for males than for females; for example, satellite tracking of loggerheads in Zakynthos (Greece) showed that 76.5% of males and 0% of females bred in successive years[157]. This shorter remigration interval — alongside the fact that a single male can mate with multiple females in a nesting season — could offset the effect of female-biased hatchling sex ratios and lead to more balanced operational sex ratios. However, a scarcity of adult males might ultimately lead to infertility of eggs. It remains unclear how skewed sex ratios among hatchlings and adults will influence population dynamics under continued warming across multiple generations.

A phenological shift in nesting (in other words, nesting at a different time of year) could reduce the consequences of warming incubation temperatures. For example, if the nesting season temperature warms by 1.5 °C on average, nesting earlier in the season could reduce the amount of warming 'experienced' by nests (Box 1 figure, panel **a**). However, the percentage (indicated by the numbers in the coloured circles in Box 1 figure panel b) of future expected warming that could be mitigated by a phenological shift of 27 days (a best-case scenario) was calculated to be an average of 55% (standard deviation 34%) across 58 nesting beaches[158,159] (Box 1 figure panel b). Therefore, nest temperatures are expected to increase and hatchling sex ratios are expected to become increasingly more female-biased under climate warming.

In addition to potential shifts in breeding timing, sea turtles might colonize new nesting sites in cooler locations. Colonization of new nesting sites can occur when turtles find new sites after existing beaches are destroyed by storms, or because of occasional breakdowns in natal homing. If newly colonized sites are in cooler locations than previous sites, the population could be buffered against future warming. Limited evidence suggests that loggerhead turtles in the Mediterranean Sea have expanded their nesting range into cooler areas[160,161], but the pace of colonization of new, cooler nesting areas is unlikely to be sufficient to mitigate expected climate warming and feminization across species.

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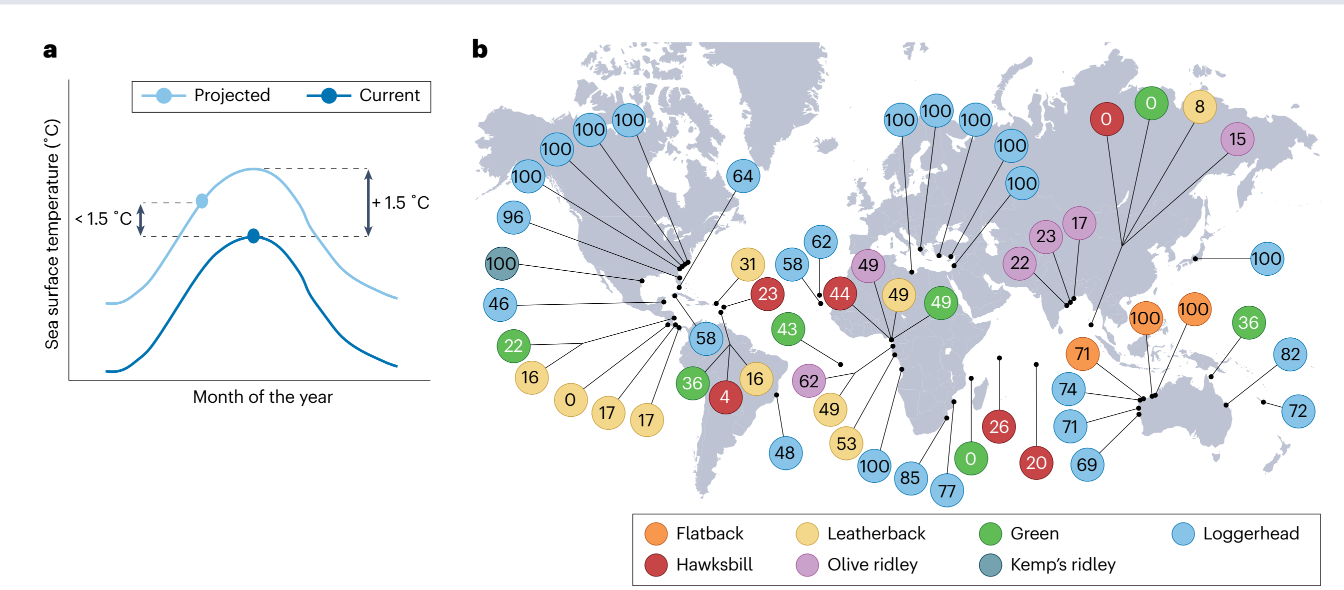


Accounting for uncertainty

Nest numbers are now recognized to be highly variable among years, in part because individual females typically do not nest every year[73]. Flipper tagging can reveal the interval between breeding seasons (termed the remigration interval) for individual females, but often only a fraction of individuals in any given population are sighted and tagged. In some years a high proportion of the population might attain sufficient body condition to breed, whereas in other years fewer individuals do so[74]. In extreme cases, nest numbers vary by more than an order of magnitude between successive years[73]. In recognition of this variability, abundance assessments often average abundance over several years or base trends on long time series in which variability is less influential[53,75]. However, researchers are increasingly aware of the need to move away from reliance on nest counts or the number of nesting females as the sole measure of population size and towards improved estimates of the number of males, and of juveniles.

Counting females, males and juveniles

Determining the annual number of nesting females directly is not straightforward; this variable is a composite of multiple other variables, including crawl tracks, the number of nests and nesting success rate (Fig. 3). Specifically, nest counts can reflect the number of total nesting females only when the number of nests per female is known; this information can be obtained by genotyping material within egg shells to attribute a clutch to an individual female[76], by saturation tagging (sighting the turtle every time there is a nest), or by fine-scale global positioning system (GPS) telemetry[72]. Rather than assessing total nesting females, often the total number of nests is used as an index of population abundance. The number of nests can be derived from track counts if the nesting success rate is known (Fig. 3). Tracks are routinely counted in beach monitoring programmes, yet not all tracks lead to a nest. Instead, sometimes turtles abort their nest excavation. The proportion of tracks leading to a nest is termed the nesting success rate.

Because adult males rarely come ashore, males are more difficult to count than females; as a result, long time series of male abundance do not yet exist (Fig. 3). Male abundance and the operational sex ratio (the ratio of males to females in the breeding population) are increasingly important to monitor because the female-biased hatchling sex ratios resulting from rising temperatures could make populations more vulnerable to collapse owing to insufficient numbers of males for egg fertilization. Fortunately, boat and drone surveys of adult males are becoming more common[77–79] and, if repeated, offer the promise of estimating time series of operational sex ratio and male abundance (Fig. 3). Genetic data on multiple paternity (the identity of fathers of a clutch determined from taking a blood or tissue sample from hatchlings) across years could provide a way to assess the relative abundance of adult males[80].

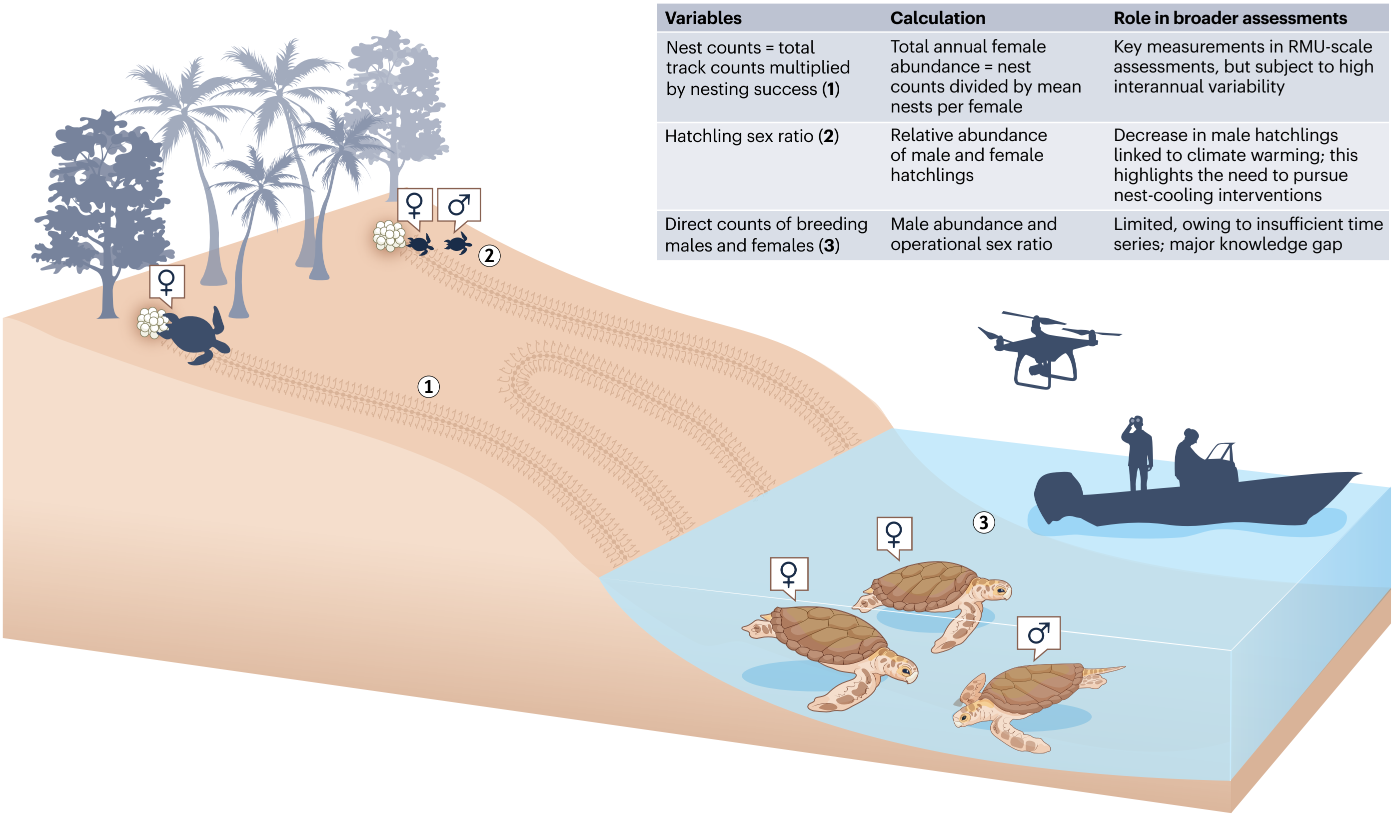
The abundance of juveniles is also difficult to measure because, like males, juveniles do not come ashore and so few time series are available. The best available time series are obtained from mark–recapture studies (for example, from captures by hand or net), extending over many decades[81]. Emerging approaches include counting juveniles at focal sites through drone surveys[82,83] and use of citizen science diver photographic surveys[84,85]. Heat-sensing drones to survey nesting beaches at night[86] and camera traps for remote monitoring of nesting activity are technological advances that also reduce the logistical problems of surveying large, remote or inaccessible beaches to find nesting females.

Official assessment frameworks

Trends in sea turtle numbers have been presented in published reports and papers[53,75], national species status reviews[87,88] and IUCN conservation assessments[89,90]. Here we compare these assessment frameworks and provide a summary of sea turtle status based on results from the most recent assessment efforts.

Trend assessments for sea turtles typically evaluate nesting time series data across many seasons (often decades) to account for the longevity of turtles and the aforementioned interannual variability in the proportion of females that nest. These long-term trends can be evaluated alongside data on environmental variables, direct take and/or bycatch to explore the drivers of population trends and to identify conservation priorities[91–94].

In contrast to assessments based on time series, an IUCN Red List assessment compares species abundance, typically the annual number



Variables	Calculation	Role in broader assessments
Nest counts = total track counts multiplied by nesting success (**1**)	Total annual female abundance = nest counts divided by mean nests per female	Key measurements in RMU-scale assessments, but subject to high interannual variability
Hatchling sex ratio (**2**)	Relative abundance of male and female hatchlings	Decrease in male hatchlings linked to climate warming; this highlights the need to pursue nest-cooling interventions
Direct counts of breeding males and females (**3**)	Male abundance and operational sex ratio	Limited, owing to insufficient time series; major knowledge gap

Fig. 3 | Assessing trends in turtle numbers. (1) Tracks of nesting turtles are routinely counted in beach monitoring programmes; from these tracks, the nesting success (in other words, the fraction of tracks that lead to a nest) and, subsequently, nest count, can be calculated. Nest count data, in combination with data on mean nests per female, can be used to estimate total annual female abundance. (2) The sex ratio of hatchlings provides an indication of the threat of climate warming. (3) Immature turtles and adults can be counted at sea from boats or drones, with adult males being distinguished from adult females by their extended tails. The ratio of breeding males to females, termed the operational sex ratio, indicates where the threat of feminization of populations due to climate warming is most acute. A prediction of climate warming is that a point will be reached where there are so few males that they start to become limiting.

of nests or the number of nesting females, at two points in time ('past' and 'present'), separated by an interval of ten years or three generations, whichever is longer[95]. For sea turtles, each estimate is usually taken as the mean annual number of nests over a three-year period (or one remigration interval) to account for natural interannual variability. A species is listed as Critically Endangered if the 'present' estimate decreased by at least 80% relative to the 'past' estimate, whereas Endangered and Vulnerable categories are applied when declines reach 50% and 30%, respectively.

Historically a single IUCN 'global' listing was generated for each species, with updates to this listing occurring infrequently. This lack of spatial resolution for globally distributed species such as sea turtles, coupled with the rarity of data from the past three generations (around 100 years) as required for sea turtle IUCN assessments, resulted in substantial academic and conservation practitioner scepticism about the value of Red List assessments for this taxon[96,97]. However, the IUCN changed the assessment requirements to allow for regional-scale evaluations at the RMU level for loggerhead turtles in 2015 (ref. 90), for leatherbacks in 2013 (ref. 98) and for green turtles in 2019 and subsequently (ref. 99). Future Red List assessments are expected to contain both global and regional listings.

Trends in sea turtle numbers

In addition to the formal species-specific regional assessments, compilations of time series of the annual number of nests from published scientific literature have provided holistic views of the global state of sea turtles[53,75]. These global evaluations show a generally encouraging picture of stable or upward trends across species and subpopulations (Fig. 4). For example, of 299 annual abundance time series analysed in 2017, population increases were three times more common than decreases[53]. In an updated compilation of additional time series published in 2024, increases were six times more frequent than decreases[75]. However, trends among species and among regions vary considerably. An important issue is that not all turtle RMUs have sufficient data for the identification of trends across years because of the difficulties of beach monitoring at remote nesting sites.

Green turtle population trends are generally increasing or stable. Increasing trends were reported in four of the five RMUs that contained time-series of nest numbers[53] and in 19 of 19 individual time-series of abundance from nesting sites[75]. For example, the annual number of green turtle nests increased from around 4,000 to 16,000 between 1980 and 2018 at Aldabra (Seychelles, Indian Ocean)[100]. On Ascension Island (South Atlantic Ocean), annual nest numbers increased from around 3,500 between 1977 and 1982 up to around 24,000 between 2010 and 2013 (ref. 101). Owing to these positive nesting trends in many areas, the global population of green turtles is expected to be downlisted in 2025 to Least Concern from their prior IUCN listing as Endangered[89] (IUCN Marine Turtle Specialist Group). As of 2024, the encouraging trends in green turtle populations have also been reflected in IUCN regional assessments: Least Concern in Hawaii[102], the Southwest Indian Ocean[99] and the South Atlantic Ocean[103], and Near Threatened in the Mediterranean Sea[104]. However, some conservation concerns remain. For example, in 2023, alarming declines in nesting were described for a previously stable population of green turtles at Tortuguero, Costa Rica[105], a site considered to be among the largest nesting sites globally[106].

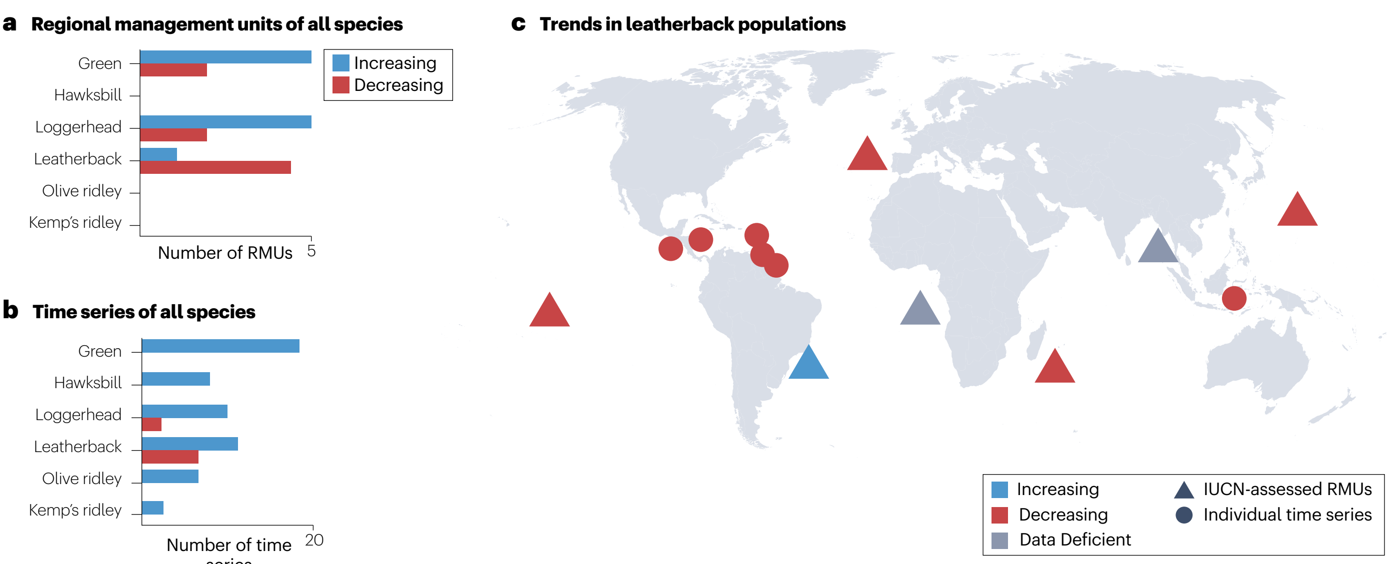


Fig. 4 | Trends in sea turtle abundance at focal sites and integrated across RMUs. a, The number of regional management units (RMUs) with increasing or decreasing population trends according to International Union for the Conservation of Nature (IUCN) regional or subpopulation assessments. **b**, The number of time series, typically from individual nesting beaches, with increasing or decreasing population trends from the published literature (data extracted from ref. 75). **c**, Regional variation in leatherback population trends; triangles represent all IUCN-assessed RMUs and circles represent individual time series where marked declines have been reported. The percentage changes in population size across RMUs are: a 97.4% decrease during the past 30 years in the East Pacific Ocean; a 7.9% decrease per year ongoing in the Northwest Atlantic Ocean; a 232% increase during the past 30 years (but this population is still very small and consequently listed by the IUCN as Critically Endangered) in the Southwest Atlantic Ocean; a 5.6% decrease over 30 years in the Southwest Indian Ocean; and a 83.0% decrease over 30 years in the West Pacific Ocean. Compilations of census data for leatherbacks, like other species, have identified conservation success stories as well as conservation concerns.

In loggerheads, 12 of 13 individual time series from nesting beaches[75] showed increases, some by nearly two orders of magnitude. For example, between 2008 and 2020 the annual number of nests increased from around 500 to 35,000 on Sal (Cape Verde, North Atlantic Ocean)[107]. However, the 13th time series showed a decline in the number of nests from around 30,000 to 10,000 between 2008 and 2016 at Masirah Island (Oman, Arabian Sea), which was formerly the world's largest loggerhead nesting aggregation[108]. In the global IUCN assessment, loggerheads were formerly Endangered in 1996 but downlisted to Vulnerable in 2015 (ref. 90). For this species, the development of RMU-specific IUCN assessments revealed variation in status across their range, with only 5 of 10 RMUs showing increasing trends[90]. In IUCN regional assessments conducted in 2015, loggerheads were listed as Least Concern in the Mediterranean Sea[109], the North Pacific Ocean[110], the Northwest[111] and the Southwest Atlantic Ocean[112], but Critically Endangered in the Northeast and Northwest Indian Ocean[113,114] and the South Pacific Ocean[115], and Endangered in the Northeast Atlantic Ocean[116].

Relative to loggerhead and green turtles, fewer time-series data are available for hawksbill, olive ridley, Kemp's ridley and flatback turtles and their IUCN assessments are more outdated. For hawksbills, increasing trends were found in all seven of the available nesting time series[75] (Fig. 4a,b). Only one of 13 RMUs has sufficient data; this RMU showed an increasing trend from 1987 to 2012 (ref. 53). Upon its most recent global IUCN assessment in 2008 the hawksbill population was listed as Critically Endangered. For olive ridleys, increasing trends occurred in all five individual time series[75], but RMU assessments have not yet been conducted for the species; this species was listed most recently as Vulnerable in 2008 (ref. 117). For both Kemp's ridleys and flatbacks, their limited distributions amount to only one single RMU for each. For Kemp's ridleys, an increasing trend occurred in the only individual time series available – at the main nesting beaches in Mexico – rising from around 2,000 in 1996 to around 17,000 in 2022 (ref. 75). However, in 2019 the Kemp's ridley was listed by the IUCN as Critically Endangered owing to its restricted nesting range[118], the smallest for any species. For flatbacks, a decreasing trend was reported in 2017 (ref. 53) and no additional data were available for a 2024 analysis[75]. The latest IUCN assessment was completed in 1996 and listed the flatback as Data Deficient; an updated assessment is expected in 2025.

Leatherbacks are the species with the most concerning population trends. Decreasing trends were reported in four of seven RMUs[98]. In a 2024 analysis of 61 annual abundance time series across all species, there were five downward trends reported, of which four were for leatherbacks, all at sites where nesting numbers have been high in the past[75] (Fig. 4c). At Las Baulas (on the Pacific coast of Costa Rica) the number of nesting females declined from around 1,500 to 15 between 1988 and 2018. In Suriname (Atlantic Ocean) the annual number of nests declined from around 10,000 to around 1,000 (ref. 75). Further major declines are seen in Indonesia (West Pacific Ocean) and the Caribbean coast of Costa Rica[75]. In the US Virgin Islands (St Croix, Caribbean Sea) and in French Guiana (West Atlantic Ocean), previously stable or increasing trends reversed to decreasing trends around 2009[75]. Current trends in leatherback numbers illustrate the issue of the long delays between IUCN Red List assessments. Leatherbacks were listed globally as Vulnerable in 2013 (ref. 98), but that assessment did not capture the major declines that were subsequently reported across many populations. Inaccurate Red List statuses owing to outdated assessments is a well known problem in conservation biology, but in the case of leatherbacks this delay highlights the value of other assessment efforts by conservation groups and academia that operate on shorter time intervals.

Key conservation interventions

Despite positive gains for many sea turtle populations, all species will require some level of conservation attention for the foreseeable future given the ongoing threats posed by direct take, bycatch mortality and climate change. This section provides an overview of the most influential international, regional and local-scale conservation initiatives (Fig. 5).

International instruments and policies

Because sea turtle movement between foraging and breeding grounds spans national borders, international agreements are essential for the sharing of technical expertise. International cooperation in enactment of legal frameworks is necessary to protect habitats and to curb illegal sea turtle use and trade. Two of the most influential international instruments to conserve sea turtles and their habitats are the Inter-American Convention (IAC) for the Protection and Conservation of Sea Turtles and the Indian Ocean-South-East Asian (IOSEA) Marine Turtle Memorandum of Understanding, part of the Convention on Migratory Species. The IAC, a legally binding inter-governmental conservation treaty enacted in 2001, currently has 16 signatory nations across North, Central and South America and the Caribbean. IAC delegates convene annually to share information, to identify emerging threats and to co-develop conservation action plans aimed at recovering sea turtles. These efforts focus on topics such as bycatch reduction, maintenance of suitable nesting habitat[119] and sustainable management practices in IAC nations in which egg harvest remains legal. The IOSEA is a non-binding inter-governmental agreement with 44 member countries (36 signatories and 8 range states), focused on protection and recovery of sea turtle populations throughout the Indian Ocean and Southeast Asia, also with annual meetings where the parties work together to pursue mutual conservation goals (Fig. 1h).

Despite their value in terms of advancing shared conservation goals across nations, the IAC and IOSEA – as with other international conservation efforts – do not always lead to effective implementation of policies, in part because some national governments lack awareness of the commitments[120]. Additional reasons for inadequate effectiveness include the inability to control local and/or regional illegal trade in turtle products and poaching; difficulty identifying incentives to comply with regulations; problems with translating international conventions into a format comprehensible to both local government officials and conservation practitioners; and a lack of incorporation of treaty policies into national laws even when a country is a signatory[120].

Protected area establishment

Data from satellite tracking and/or aerial surveys have been used to identify areas of high use by turtles, which, in some cases, have subsequently been protected through the establishment of new marine protected areas (MPAs) or fishery reserves. In 2016, a 8,848 km^2 marine reserve was established in an area used heavily by loggerheads in Baja California (off the Pacific coast of Mexico) to reduce turtle bycatch in gillnet fisheries[39,121]. Similarly, turtle bycatch has been reduced following the creation of large conservation zones since 2000 for green and hawksbill turtles off the Yucatan coast of Mexico, leatherbacks off the west coast of the USA, and leatherbacks and olive ridleys off Gabon[122]. Increases in nesting numbers of both green and hawksbill turtles are attributed to the creation of a large MPA in the Chagos Archipelago in 2010 (ref. 123).

Although the creation of MPAs can often be linked to an increase in the abundance of sea turtles, MPAs are not a panacea and do not always produce the intended benefits. For example, the reserve in Baja initially

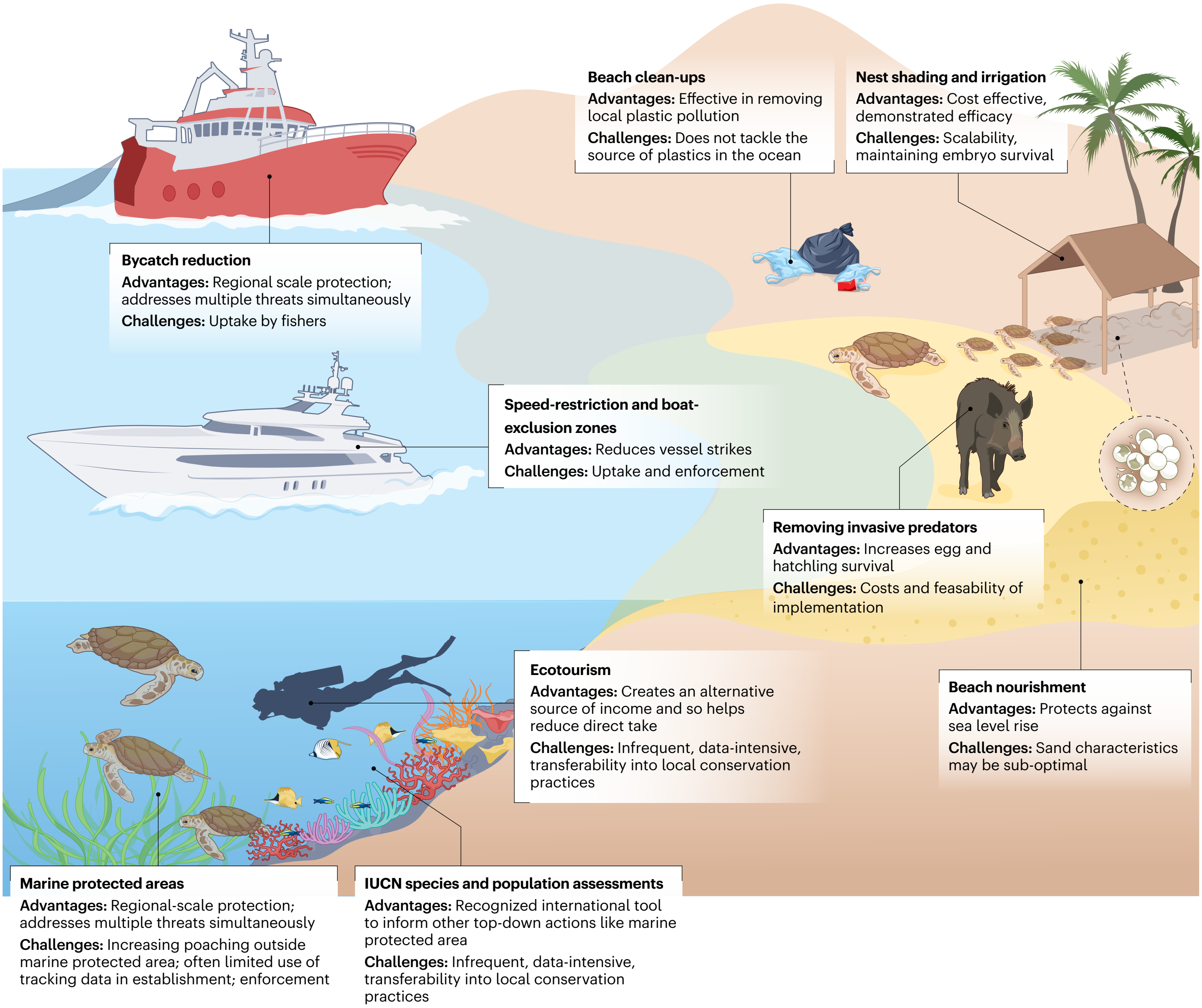


Fig. 5 | Conservation interventions to help populations to recover. Conservation interventions are thought to underpin observed increases in sea turtle abundance in many regions. Interventions vary in cost, uptake and scalability. Triaging threats and developing ways to mitigate threats are important challenges[8]. For example, there are no easy-to-implement solutions for how to reduce the fishery bycatch of leatherback turtles over large regions, which is thought to underpin ongoing population declines. IUCN, International Union for the Conservation of Nature.

reduced loggerhead bycatch by 90% over a three year time period, but poor governance and enforcement infrastructure has limited the reserve's long-term effectiveness[124]. Some MPAs offer protection only in name but not in function[125]. For example, enforcement and monitoring of illegal fishing can be quite difficult in very large MPAs[126]. Even well governed MPAs can fail to protect sea turtles when the turtles move beyond protected areas into locations with higher fishing pressure and risk of bycatch[127].

Reducing direct take

Beyond MPAs and national legislation, other conservation instruments (such as national bans on intentional turtle capture and demand-reduction initiatives) have had some success. In several locations, increases in turtle numbers have been attributed to reductions in direct take after policy change. For example, loggerhead nesting numbers rebounded in Cape Verde after the initiation of local conservation projects that reduced harvesting of nesting turtles[107]. Similarly, green turtle nesting populations showed rapid and sustained increases at Ascension Island following banning of its centuries-old turtle fishing industry in 1944 (ref. 101); in Aldabra following a ban on turtle capture (coupled with an effective nest monitoring programme to ensure compliance) in 1968 (ref. 100); and at Colola Beach (on the Pacific coast of Mexico) following a 1990 presidential decree outlawing harvest of turtles for meat and skins[128]. Although hunting of turtles still occurs in many regions, shifts in the social and economic value of sea turtle meat have led to increased dialogue among conservation practitioners and communities, resulting in more widespread community engagement and reduced take[129,130]. Bans are often reinforced, at a local level, by conservation biologists who patrol at night to deter the poaching of eggs and adult turtles, while collecting data on nest abundance and trends[131].

Demand-reduction campaigns are another conservation approach aimed at reducing harvest. For example, a conservation marketing campaign started in 2016 on the island of São Tomé (Central Africa) led to a decrease in sea turtle egg consumption and poaching of adult sea turtles[132]. The creation of alternative revenue schemes (for example through ecotourism or employing former poachers to protect nests) offer a financial avenue to reduce harvesting[133].

Bycatch reduction
Bycatch-reduction technologies such as turtle-excluder devices for trawl fisheries and circle hooks for longline fisheries have reduced bycatch in areas where these gear types are used. For example, driven by proposals from the US National Marine Fisheries Service, the mandating of turtle-excluder devices for the US shrimp fleet in the Gulf of Mexico in 1991 is widely believed to have driven the recovery of Kemp's ridleys, a species of sea turtle once on the brink of extinction[134]. Gear modifications to reduce bycatch in other fishery types are being developed[39,40,135] but are not yet in widespread use.

Rapid bycatch assessments are formal surveys of fishers across communities and regions undertaken by government, academia and non-governmental organization surveyors. These assessments help to define artisanal fishing methods and identify bycatch hotspots, thereby revealing where gear modifications are most needed[136]. These assessments can also foster partnerships with fishers that facilitate the development of bycatch-reduction measures. Early engagement with the fishing sector has strong benefits for widespread adoption of new gear types[137].

Protection of eggs and hatchlings
A practical approach for sea turtle population recovery is to focus local conservation efforts on eggs and hatchlings, the life stages with the lowest survivorship. Egg protection can be accomplished by relocation of egg clutches from unprotected beaches to secure egg hatcheries[138]. Such hatcheries have been widely adopted, and are now a fundamental conservation practice at nesting beaches throughout the world wherever egg harvest or depredation are present. On the other hand, headstarting, in which hatchlings are reared in captivity until they reach a size that makes them vulnerable to fewer predators, was once widely considered a viable approach[139] and responsible for repopulation of some nesting beaches[140] but today is rarely carried out (but see ref. 141). The viability of this approach has been questioned owing to its high cost, challenging husbandry needs, and low evidence of efficacy.

Beyond providing the direct benefit of egg protection, hatcheries also often enable managers to modify incubation conditions to mitigate the impacts of climate change[142]. On some beaches, nests have been cooled through irrigation or artificial shading (with shade cloth or palm fronds)[143]. However, whether these cooling approaches can be implemented over large areas without impairing hatching success remains unclear[47].

Beach nourishment or modification
Multiple types of beach modification can address the loss of sand habitat caused by sea level rise and erosion. Beach armouring (the use of physical structures to protect coastlines from erosion) is not ideal for turtle conservation because it impedes the access of nesting females to preferred locations. Beach nourishment entails artificially elevating nesting beaches by adding dredged material to eroded beaches. If done correctly and with a goal of protecting sea turtles and other natural resources, beach nourishment can be an effective tool for replacing lost turtle nesting habitat. For example, beach nourishment was successfully trialed on the green turtle nesting location of Raine Island (Australia)[57], where nourishment led to increased hatching success. However, beach nourishment can adversely affect sea turtles if the sand is too compacted for them to nest or if sand imported from another area has different characteristics from local sand[144]. These factors can alter patterns of nest-site selection, nest-excavation success, incubation temperature, and moisture and gas exchange within nests[145,146], which can have negative consequences for embryonic development.

Reducing vessel strikes
Although mortality from vessel strikes is a lower-magnitude threat than mortality from bycatch, interventions to reduce turtle mortality from these interactions are important. Reducing vessel strikes typically involves separating vessels and turtles with the use of exclusion zones and/or reducing vessel speed through 'go-slow' zones. Such interventions have been implemented successfully in some parts of the world[147], although further work is needed to assess the declines in turtle mortality caused by such go-slow zones. Key to successful mitigation of the threat of vessel strikes is to have good empirical data on the use of space by turtles, for example through high-resolution tracking[148] and support from boat operators, which can be improved through education programmes[64].

Community involvement and education
A fundamental part of sea turtle conservation is public outreach and education. Sea turtles are among the most charismatic and vulnerable species in marine ecosystems, yet their biology and their roles as habitat engineers, predators, prey and facilitators of nutrient cycling are poorly known by most people. Worldwide educational programmes at zoos, in classrooms, at nesting beach sites, and so on use sea turtles as 'ambassadors' to foster interest in science and to encourage a change in public perception of the importance of healthy ecosystems[149,150]. These endeavours can also teach the public to make better decisions about their own behaviours, such as not leaving litter on beaches. Community involvement in beach clean-ups has been an effective means of removing plastic waste that can harm sea turtles and other marine life.

Summary and future directions
There is widespread good news for sea turtles, with increases in abundance across several species and ocean basins resulting from the dedicated efforts of thousands of conservation biologists as well as implementation of national and international policies. However, these successes should not be met with complacency or a stalling of conservation efforts, because these positive trends can easily be reversed. Many leatherback populations[31,98,151] and one green turtle population[105] are in severe decline as of 2025. The most important present and future strategies for conserving sea turtles are: climate change adaptation and mitigation; reducing bycatch and deliberate harvesting; understanding and reducing the effects of pollution (including plastics); and mitigating the loss or degradation of foraging habitats such as seagrass meadows.

Addressing these challenges requires the best available science, yet there is considerable room for improvement in the collection and use of data in conservation decision-making. Many thousands of turtles have been tracked by satellite, but these tracking data are under-used[152]; only in a few isolated cases have tracking data been used to establish protected areas[122] or to implement dynamic ocean management to reduce bycatch[153]. Advances are also being made in the use of genetic techniques to define distinct regional management units for conservation, and uncrewed aerial drones to quantify operational sex ratios and to assess the abundance of immature and male turtles, which have represented major knowledge gaps (Fig. 3). These technological advances help to address some of the logistical challenges that hinder data collection, such as the need to survey remote or difficult-to-access beaches, the need to sample sites repeatedly to measure seasonal variation in nesting, and the need to discern between the tracks of different species.

The magnitude of threats to sea turtle populations is typically assessed by semi-quantitative or qualitative expert opinion[8] but more quantitative analysis is needed to assess the population-level impacts of threats, to triage threats in an informed way and to mitigate threats. Although it is well known that plastic pollution contributes to the deaths of individual turtles, a key unresolved question is the population-level impact of plastic ingestion and entanglement[45]. Mitigating this threat from plastics is also not straightforward, and large-scale solutions to reducing the sources of plastic waste are needed. A similarly challenging threat to address is climate change, because it has near-ubiquitous effects and the scale of effort necessary to combat the issue is immense.

Although some local-scale nest-cooling interventions (shading or irrigation) could buffer against embryonic sex ratio feminization, more research is needed to assess the efficacy and scalability of these methods. Beach nourishment could mitigate the loss of nesting beaches, but the potential negative effects of modified sediments on nesting success require further research before this approach can be considered effective in sea turtle conservation. Finally, the mass movement of thousands of eggs to new nesting beaches[154] could be considered as an emergency intervention for highly vulnerable populations, but requires a vast amount of effort that is not likely to be feasible in many regions.

The effective implementation of conservation action requires local community involvement, particularly the communication of conservation goals in focal communities[155]. Public comment periods can help conservation practitioners to identify both the greatest impediments to conservation and the greatest opportunities for success[156]. Bycatch reduction in particular requires willingness and genuine engagement by fishers, and conservation biologists must be open to learning from fishers about which turtle-friendly gear types fishers would be willing to adopt. A key priority is to develop gear types that fishers and communities will use when not monitored and not subsidized, which should provide a path to long-term sustainability in bycatch reduction. Fostering alternative livelihoods for fisher families could also reduce bycatch, because the additional household income can reduce the need for heavy fishing efforts and thus reduce sea turtle exposure to nets and hooks. In the coming decades, addressing the complex anthropogenic threats to sea turtles will require social science approaches alongside conventional conservation biology.

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