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Half a century of global decline in oceanic sharks and rays

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Summary: Overfishing is the primary cause of marine defaunation, yet individual species' declines and rising extinction risk are difficult to measure, particularly for the largest predators found in the high seas[1–3]. We calculate two well-established indicators to track progress towards Aichi Biodiversity Targets and Sustainable Development Goals[4,5]: the Living Planet Index (a measure of changes in abundance aggregating 57 abundance time-series for 18 oceanic shark and ray species), and the Red List Index (a measure of change in extinction risk calculated for all 31 oceanic species). We find that, since 1970, the global abundance of oceanic sharks and rays has declined by 71% due to an 18-fold increase in Relative Fishing Pressure. This depletion elevated global extinction risk to the point where three-quarters of this functionally important assemblage are threatened with extinction. Strict prohibitions and precautionary science-based catch limits are urgently needed to avert population collapse[6,7], avoid disruption of ecological function, and promote species recovery[8,9].

Over the United Nations 'Decade of Biodiversity' from 2011–2020, governments committed to improve human well-being and food security by safeguarding ecosystem services and halting biodiversity loss[10]. The Sustainable Development Goals, adopted by all United Nations Member States, and the 20 Aichi Biodiversity Targets of the Convention on Biological Diversity, provide a framework to track progress towards the 2020 deadline[4,5,10]. Seafood sustainability is an integral part of these commitments, and wild capture fisheries are essential nutritional and economic resources for millions of people globally[11,12]. Yet beneath the ocean surface, it is difficult to assess changes in the state of biodiversity and ecosystem structure, function, and services[13].

Elasmobranchs (sharks and rays, hereafter 'sharks') offer a unique window into the state of the oceans. Sharks are one of the most evolutionarily distinct and functionally diverse vertebrate radiations[14,15]. The first International Union for Conservation of Nature (IUCN) global assessment estimated that one-quarter of sharks were Threatened with extinction (classified as Critically Endangered, Endangered, or Vulnerable according to IUCN Red List criteria)[16], making sharks the most threatened vertebrate lineage after amphibians[16–18]. Long generation times and low intrinsic population growth rates of many sharks make them inherently susceptible to overexploitation[1,7,19]. Globally, sharks are landed for their meat, fins, gill plates, and liver oil[20,21] and catches rose to an estimated peak of 63–273 million individuals in the early 2000s before declining due to overfishing[6]. The first warnings of the dire status of sharks were based on boom and bust catch patterns and rising international trade in shark fins[22,23]. Subsequently, serious declines in many oceanic and coastal shark populations were documented, both in the Gulf of Mexico and Northwest Atlantic[24,25], and also in South Africa[26] and Australia[27]. Shark population assessments for many other regions have since become increasingly robust[8,28,29]. Until now, however, these have not yet been synthesised to provide a global perspective on shark population trends.

Here, we calculate for oceanic sharks two Biodiversity Indicators established by the Convention on Biological Diversity: the Living Planet Index (LPI)[5,30] on global population changes since 1970 and the Red List Index (RLI)[5,31], which tracks changes in the relative extinction risk of taxa. These indicators quantify progress toward Aichi Targets 6 (manage marine resources for sustainability) and 12 (prevent extinction), and UN Sustainable Development Goal 14 (conserve and sustainably use the oceans). First, we used a Bayesian state-space framework[32,33] to estimate trends in relative abundance of 18 species from 57 time-series compiled and reviewed at an expert workshop convened by the IUCN Species Survival Commission's Shark Specialist Group (IUCN SSC SSG). Using these trends, we calculated the global LPI for oceanic sharks from the reference year 1970 (which was set at 1) to 2018 — and then extrapolated each time-series to 2020 to encompass the Aichi Target assessment year — by hierarchically aggregating the annual rates of change from each time-series for a species by region, then globally (see Extended Data Figure [EDF] 1 and 2a). Second, we combined a retrospective Red List assessment (1980) with two recent assessments (~2005 and 2018) from the IUCN Red List of Threatened Species for all 31 species of oceanic sharks to build the RLI (see EDF 1). The RLI provides standardized assessments of species' extinction risk, comparable across taxa, that is particularly useful when robust trend data are missing. Comparing the RLI over time, among different taxa, reveals the common trends in extinction risk among groups, despite differences in habitat, life history, and threats. Such cross-taxon comparisons are useful to ensure appropriate allocation of global conservation resources across terrestrial, freshwater, and marine biomes.

Finally, we develop three lines of evidence to attribute decreasing abundance (shown by the LPI) and rising extinction risk (shown by the RLI) of oceanic sharks to overfishing: (i) increasing Relative Fishing Pressure over time (measured as changes in catch relative to the changes in the LPI), (ii) increasing proportion, over time, of oceanic sharks that are overfished below biomass or abundance levels that could produce Maximum Sustainable Yield (MSY, the equilibrium state of the exploited population sustaining the greatest yield [catch] over long time periods[34]), and (iii) the near-absence of significant threats other than fishing reported in each species' IUCN Red List assessment.

Declining abundance index

We find that, globally, abundance of oceanic sharks declined by 71.1% (95% credible interval [CI]: 63.2–78.4%; Fig. 1) from 1970 to 2018, at a steady rate averaging 18.2% per decade (see EDF 2c). Over the half-century from 1970–2020, the projected LPI estimates that abundance declined by 70.1% (CI: 62.8–77.2%, see EDF 2b). The declining trend of the LPI trajectory is robust to the exclusion of any individual species (EDF 3). There are three reasons why the true abundance trend index values are likely to be lower (and calculated percent declines worse) than estimated here (see Supplementary Discussion 1): (i) fishing levels were already unsustainable half a century ago, (ii) unreported catches (including discards) are not included in our time-series, and (iii) traditional stock assessments could underestimate fishing mortality.

The global trend index can be disaggregated into trajectories for each ocean and species, as well as for functional groups with similar ecological or life-history traits. In the Atlantic Ocean, following a long period of decline since 1970, abundance began to stabilize at low levels after 2000 (overall decline of 46.1%; CI: 30.7–61.1%; Fig. 2a). In the Pacific Ocean, abundance decreased steeply prior to 1990, and then declined at a slower rate (overall decline of 67.0%; CI: 53.6–79.4%; Fig. 2c). In the Indian Ocean, shark abundances have declined steeply since 1970 (overall decline of 84.7%; CI: 75.9–92.1%; Fig. 2b). Despite more resilient life histories, tropical sharks declined more steeply than temperate species (overall declines of 87.8%; CI: 79.8–94.3% versus 40.9%; CI: 30.4–50.5%, Fig. 2d). Overfishing of sharks followed a classic pattern of serial depletion, starting with the largest species, which dropped steeply prior to the 1980s, followed by declines of medium-sized species and eventually relatively small species (including some devil rays, *Mobula* spp.; Fig. 2e). Long lived, late-maturing species initially declined faster than those with shorter generation times, but two of these species (White Shark *Carcharodon carcharias* and Porbeagle *Lamna nasus*) have shown signs of population rebuilding since the early 2000s (Fig. 2f; EDF 7). All species, apart from the Smooth Hammerhead (*Sphyrna zygaena*), decreased in abundance over the last half-century (Fig. 2g). Devil ray abundance has declined by at least 85% in the past 15 years in the Southwest Indian Ocean (Fig. 2g). Although sparse, the available data for devil rays are representative of the repeated, rapid depletions and local extinctions suspected due to overfishing driven by target fisheries in many parts of their historical range (see Supplementary Discussion 2).

Rising extinction risk

For all 31 oceanic shark species, the risk of extinction, indicated by IUCN Red List category, has substantially worsened since 1980. The RLI declined from a retrospective estimate of 0.86 (range: 0.74–0.90) in 1980 to 0.56 in 2018, comparable to cycads (palm-like plants), the most threatened group of completely assessed species on Earth[35] (Fig. 3a). We estimate that in 1980, two-thirds (*n*=20) of oceanic shark species fell into the IUCN Red List category of Least Concern, and only nine were Threatened. The Basking Shark (*Cetorhinus maximus*) was the only species retrospectively classified as Endangered. More than three-quarters (*n*=24) of these species are Threatened now based on steep population reductions (IUCN Red List Criterion A). Some formerly abundant, wide-ranging sharks have declined so steeply that they are now classified in the two highest IUCN Red List categories: three are Critically Endangered (Oceanic Whitetip Shark *Carcharhinus longimanus*, Scalloped and Great Hammerhead *Sphyrna lewini* and *S. mokarran*), and four are Endangered (Pelagic Thresher *Alopias pelagicus*, Dusky Shark *Carcharhinus obscurus*, Shortfin and Longfin Mako *Isurus oxyrinchus* and *I. paucus*; Fig. 3b). In total, half (15 of 31) of oceanic shark species are now Critically Endangered (*n*=3; ≥80% population reduction over three generations) or Endangered (*n*=12; 50–79% population reduction).

Attributing declines and rising extinction risk to overfishing

We attribute oceanic shark population declines and elevated extinction risk to overfishing based on three lines of evidence. First, the last half-century has seen more than a two-fold increase in fishing with longlines and seine nets, the gears that catch the most oceanic sharks[36] (Fig. 4a; black lines; data corrected for technological creep, see Supplementary

Methods 1). Concomitantly, oceanic shark catch has risen three-fold since 1970 (Fig. 4a; grey line and polygons), resulting in an 18-fold increase in Relative Fishing Pressure (Fig 4b). This correlation suggests fishing drove declines in abundance with a striking breakpoint in 1990 that we hypothesize coincides with increasing retention of sharks to meet new market demands (specifically for fins)[37] (Fig. 4c). Second, the role of fisheries in driving declines is thoroughly addressed in the growing number of robust fisheries stock assessments (EDF 9b). The declining LPI is consistent with a rising proportion of populations and species assessed as overfished over time (21%; Fig. 4d); 6 of the 8 assessed species and over half of the populations (9 of 15) are below MSY (EDF 9c). Third, we compiled the causes of declines reported in Red List assessments, which are classified into 11 categories ranging from 'Human Intrusions and Disturbance', to 'Climate and Severe Weather'[38]. While there are numerous pressures acting on sharks, every Red List assessment for the 31 oceanic sharks concluded that the major threat was 'Biological Resource Use' and, more specifically, 'Fishing and Harvesting Aquatic Resources'. Other threats are reported for only two species (EDF 10).

Discussion

We document an alarming, ongoing, worldwide decline of oceanic shark populations across the world's largest ecosystem over the past half-century, resulting in an unprecedented increase in the risk of extinction of these species. The tremendous increase in Relative Fishing Pressure is mirrored by the general consistency in the rate and extent of declines across species of differing body sizes and generation times. The low reproductive output of these slow-growing species is clearly no match for the intense fishing pressure they currently encounter.

Overfishing of oceanic shark populations has far outpaced the implementation of fisheries management and trade regulations[39]. Despite great strides in conservation commitments in recent decades, relatively few countries impose catch limits specific to oceanic sharks, and fewer still can demonstrate population rebuilding or sustainable fisheries for these species. Obligations under international wildlife treaties (see [7]) to prohibit retention or restrict international trade of select species have not yet been effectively implemented[40]. The world's four major Regional Fishery Management Organizations focused on tunas (tRFMOs) have, to varying degrees, prohibited retention of inherently sensitive oceanic shark species that are also of relatively low value to the associated pelagic fisheries. However, tRFMOs' efforts to manage sharks using Ecosystem-Based Fisheries Management have been inadequate with respect to scientific advice and implementation[41,42] (see Supplementary Discussion 3).

There are some encouraging findings. We note that the White Shark historically declined by an estimated 70% worldwide over the last half-century, but is now recovering in several regions, aided by retention bans[43]. Hammerhead shark populations are rebuilding in the Northwest Atlantic, owing to strictly enforced quotas throughout their U.S. range. The Blue Shark has declined less than other species, despite being reported to be at significantly greater risk due to its high distributional overlap with heavily fished areas[44]. This is likely due to its relatively high reproductive rate (compared to other pelagic sharks), but nevertheless its management is warranted on a global scale as market interest and targeted fishing increase. It is possible to reverse shark population declines, even for slow-growing species, if precautionary, science-based management is implemented throughout a species' range [8,45] before depletion reaches a point of no return.

We can use IUCN Red List status and trends as a heuristic to guide the conservation priorities of countries with limited capacity to assess, manage, and conserve oceanic species. This guidance will be less relevant to nations with the capacity to undertake stock assessments and ensure compliance with management[8], reflecting that a species' global Red List Status and local status may differ. It has been previously recommended that sharks assessed globally as Near Threatened or even some assessed as Vulnerable may still be able to sustain modest levels of fishing, if managed immediately and carefully throughout their range[7,16]. Species classified as Critically Endangered or Endangered cannot support fisheries. In these cases, policy recommendations based on stock assessments or on global Red List Status will be congruent[46]; strict measures to prohibit landings and minimize bycatch mortality (by avoiding hotspots, modifying gear, and improving release practices) are urgently needed to halt declines and rebuild populations.

The ecosystem consequences of oceanic shark declines are uncertain because of the complexity and scale of marine food webs[47]. Nevertheless, profound effects of depleting predatory species are becoming apparent. For example, the decline of predatory sharks and tunas is associated with increases in mesopredators, including teleosts and smaller-bodied shark species[48], indicating fundamental functional changes to marine food webs[15]. Of further concern is the associated threat to food security and income in many poor and developing nations[7], many of which have fished sharks for generations[49]. Alternative livelihood and income options are needed to ease transitions to sustainability.

Conclusion

We demonstrate that — despite ranging farther from land than most species — oceanic sharks are exceptionally threatened by overexploitation. It is clear that the Sustainable Development Goals and specific Aichi targets (to reverse population declines and use marine resources sustainably) have not been met by 2020 for these species. Action is needed immediately to prevent shark population collapses and myriad negative consequences for associated economic and ecological systems. Specifically, there is a clear and urgent need for governments to adopt, implement, and enforce — at domestic and regional levels — science-based catch limits for oceanic sharks that are capable of supporting sustainable fisheries, and retention prohibitions, along with bycatch mitigation, for the others[7,8]. These steps are imperative for long-term sustainability, including potentially increased catch once populations are rebuilt[9,50], and a brighter future for some of the most iconic and functionally important animals in our oceans.

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Figure legend:

Figure 1. Global Living Planet Index (LPI) for 18 oceanic sharks estimated from 1970 to 2018. The global percentage (%) of decline was calculated from the posteriors of the LPI around the final assessment year relative to the posteriors for 1970. The black line denotes the mean, the white lines the 95% credible intervals and the grey lines each iteration.

Figure 2. Living Planet Index for 18 oceanic sharks from 1970 to 2018 disaggregated by Oceans (a, b, c), and the traits (d) geographical zone, (e) body size (maximum total length), (f) generation time (GT), and (g) species (species' time-series are in Extended Data Figure 4 to 8). Lines denote the mean and shaded regions the 95% credible intervals.

Figure 3. (a) Global Red List Index (RLI) for the 31 oceanic shark species (black line) estimated in 1980, 2005, and 2018, and for mammals, birds, amphibians, reef-forming corals, and cycads (in grey), and global chondrichthyans (sharks, rays, and chimaeras; point labelled

'Global sharks')[16]. The error bar denotes the uncertainty around the retrospective 1980 IUCN status (see Methods). A RLI value of 1.0 equates to all species qualifying as Least Concern (i.e., not expected to become Extinct in the near future), while a RLI value of 0 equates to all species having gone Extinct. (b) Change in Red List status of oceanic sharks from 1980 to 2018.

Figure 4. (a) Global catch data of 14 oceanic sharks and fishing effort of longline and seine gears. SAU: Sea Around Us project. FAO: Food and Agriculture Organization of the United Nations. Longline and Seine effort are effective corrected fishing effort[36]. (b) Fishing pressure (catch) encountered by oceanic sharks relative to the fishing pressure (catch) in 1970 and to their abundance from 1970 to 2014. The black line denotes the mean, the white lines the 95% credible intervals and the grey lines each iteration. (c) Living Planet Index (LPI) as a function of Relative Fishing Pressure (RFP, n=14 species) from 1970 (the initial state where LPI and RFP = 1) to 2014 for oceanic sharks (n=18 species). Light-grey, grey, and dark-grey polygons denote the 50%, 80%, and 95% 2D kernel density estimate of the iterations of LPI vs RFP for the last year (2014). (d) Proportion over time of oceanic sharks with stock assessments that are at a level of biomass or abundance equal or greater than that which would achieve Maximum Sustainable Yield.

Extended Data Figure legend:

Extended Data Figure 1. Hierarchical building of the global Living Planet Index and Red List Index.

Extended Data Figure 2. (a) Schematic example of constructing the observed (black) and projected (blue) Living Planet Index. First, year-to-year rates of change, abbreviated yyrc thereafter, (d_t) are averaged between species in the same region (e.g., in *Region 1*, species A

with d_{A_t} and species *B* with d_{B_t} averaged in d_{R1_t}). In a second step, yyrc are averaged between regions *Region 1, 2* and *3* to give the global yyrc. The observed LPI builds on yyrc calculated from the estimated abundance index from the state-space population model. The projected LPI builds on yyrc calculated from the estimated and projected abundance index from the state-space population model. Projections are from the last data point to 2020. (b) Global Living Planet Index for oceanic sharks and rays estimated from 1970 to 2018 in black and extrapolated to 2020 in blue. The black and the thick blue lines denote respectively the mean of the estimated and extrapolated LPI. The white and thin blues lines denote respectively, the 95% credible intervals of the estimated and extrapolated LPI and the grey lines each iteration of the estimated LPI. (c) The annual percentage change was calculated from the posteriors of the estimated LPI (in grey) and extrapolated LPI (in blue) around the final–assessment year relative to the posteriors for 1970. Vertical bars on the 1970–2018 period denote the median of the estimated and extrapolated LPI.

Extended Data Figure 3. Mean global Living Planet Index (LPI) for oceanic sharks and rays from 1970 to 2018 (black line). Faint gray lines show the effect of excluding all data for a single species at a time and recalculating the mean global LPI for all other species. No means from jackknife species trends fall outside the 95% credible Interval from the run with all the datasets included, suggesting our selection of species did not unduly influence the overall LPI result.

Extended Data Figure 4. Observed (black or empty points, and stars indicate different time-series) and modeled (black line) abundance index for (a) Silky Shark (*Carcharhinus falciformis*), (b) Oceanic Whitetip Shark (*Carcharhinus longimanus*), (c) Dusky Shark (*Carcharhinus obscurus*) and (d) Blue Shark (*Prionace glauca*) obtained from the state-space population model. The thick black line denotes the mean of the estimated abundance index and the shaded regions denote 95% credible intervals.

Extended Data Figure 5. Observed (black or empty points, and stars indicate different time-series) and modeled (black line) abundance index for (a) Scalloped Hammerhead (*Sphyrna lewini*), (b) Great Hammerhead (*Sphyrna mokarran*), and (c) Smooth Hammerhead (*Sphyrna zygaena*) obtained from the state-space population model. The thick black line denotes the mean of the estimated abundance index and the shaded regions denote 95% credible intervals.

Extended Data Figure 6. Observed (points) and modeled (black line) abundance index for (a) Pelagic Thresher (*Alopias pelagicus*), (b) Bigeye Thresher (*Alopias superciliosus*), and (c) Common Thresher (*Alopias vulpinus*) obtained from the state-space population model. The thick black line denotes the mean of the estimated abundance index and the shaded regions denote 95% credible intervals.

Extended Data Figure 7. Observed (black or empty points, and stars indicate different time-series) and modeled (black line) abundance index for (a) White Shark (*Carcharodon carcharias*), (b) Shortfin Mako (*Isurus oxyrinchus*), (c) Longfin Mako (*Isurus paucus*), and (d) Porbeagle (*Lamna nasus*) obtained from the state-space population model. The thick black line denotes the mean of the estimated abundance index and the shaded regions denote 95% credible intervals.

Extended Data Figure 8. Observed (points) and modeled (black line) abundance index for (a) Pelagic Stingray (*Pteroplatytrygon violacea*), (b) Reef Manta Ray (*Mobula alfredi*), (c) Giant Manta Ray (*Mobula birostris*), and (d) Shortfin Devilray (*Mobula kuhlii*) obtained from the state-space population model. The thick black line denotes the mean of the estimated abundance index and the shaded regions denote 95% credible intervals.

Extended Data Figure 9. (a) Oceanic shark stock status — over time — being at levels of biomass or abundance above Maximum Sustainable Yield (MSY) (green lines) or below MSY (red lines). Dotted lines indicate that a stock is above or below MSY following the last stock assessment value. (b) Number of published stock assessments for oceanic sharks and rays over time. (c) Presentation of 14 stocks of oceanic sharks (no available stock assessments for oceanic rays) status (biomass or abundance over value at MSY) versus pressure (F/F_{MSY}) in a *Kobe plot style*, for the last year with available data. Circles represent the species' unique values if only one stock exists and represent the mean of the values of the different stocks (diamonds) when the species has multiple stocks. The plot is divided into four panels: red panel (upper left) with 4 stocks and 3 species, corresponds to stocks that are being overfished and where overfishing is occurring; orange panel (upper right) with 1 stock and 1 species, corresponds to stocks that are not overfished but where overfishing is occurring; yellow panel (bottom left) with 4 stocks and 3 species, corresponds to stocks that are overfished but where overfishing is not occurring; and green panel (bottom right) with 5 stocks and 1 species, corresponds to stocks that are not overfished and where overfishing is not occurring.

Extended Data Figure 10. Percentage of reported threat categories in the 31 oceanic shark IUCN Red List assessments.

Materials and methods

Data collection and expert selection of oceanic shark time-series

Time-series data on relative abundance (*n*=57) for 18 species (see Supplementary Table S1) were gathered from peer-reviewed publications and the grey literature, including government reports. Relative abundance indices, and associated uncertainty estimates when available, included formal stock assessment outputs (trends in biomass), as well as standardized or nominal catch per unit effort (CPUE) or sightings per unit effort (SPUE) from scientific surveys, fisheries data, or bather protection nets (see Supplementary Table S1 and EDF 4 to 8). Entry of original time-series (in the database available at www.sharkipedia.org) was conducted by J.S.Y. and N.K.D. and subsequently independently checked by C.L.R. and N.P.

All datasets underwent extensive checks prior to analyses; their reliability was reviewed and assigned to ocean regions (North, South Atlantic Ocean; Indian Ocean; North, South Pacific Ocean) by experts during an IUCN SSC SSG workshop (Dallas, Texas, USA, 5–9 November 2018). Stock assessment outputs were preferred over standardized, then nominal CPUE or SPUE time-series when multiple data sets were available for the same species and region. Stock assessment models integrate the catch history, abundance trends and life-history information to infer population dynamics, whereas CPUE or SPUE represents the trend in relative abundance of the sampled fraction of the population. The details and rationale for the selection of datasets, where pertinent, are presented in the Population section of the relevant Red List assessment (www.iucnredlist.org). Two stock assessments were updated[25,51] after the workshop and are thus included in our analysis.

Data collation and calculation of ecological and life-history traits

Estimates of shark age and maximum size can vary regionally, as well as between studies and across regions. Where possible, estimates of generation time (GT) were based on observed rather than theoretical maximum age. Within regions, preference was given to studies that used: validated ages; the widest size range; and, age estimates that included repeat readers, measuring precision, and bias. The validated age estimates from the closest region were used in cases where there was not a published age and growth study for a region, or validated ages from a region[52–54]. Generation time is defined as the median age of parents in the current cohort[55]. Species- and regionally-specific GT (Supplementary Table S1) were calculated from female median age at maturity (A_{mat}) and maximum age (A_{max}) as $GT = \big((A_{max} - A_{mat}) * z\big) + A_{mat}$. The constant *z* depends on the mortality rate of adults and is typically around 0.3 for mammals[55,56]. We chose to assume a more conservative value of *z*=0.5 to account for the likelihood that age structure had already been truncated by overfishing by the time it was measured[26,27] and that ages of sharks have been systematically underestimated[54].

The details of GT were presented to the workshop for review and the final choices were used in the published IUCN Red List assessments and associated supplementary material for each species (see also Supplementary Methods 2).

Modeling population dynamics

To analyze oceanic shark trend data, we used a Bayesian population state-space model designed for IUCN Red List assessments (Just Another Red List Assessment, JARA[33,57]), which builds on the Bayesian state-space tool for averaging relative abundance indices by Winker et al.[32] and is available open-source on GitHub (www.github.com/henning-winker/JARA). Each relative abundance index (or time-series) was assumed to follow an exponential growth defined through the state process equation:

$$\mu_{t+1} = \mu_t + r_t$$

where μ_t is the logarithm of the expected abundance in year *t,* and r_t is the normally distributed annual rate of change with mean $\hat{r}$, the estimable mean rate of change for a time-series, and process variance σ^2. We linked the logarithm of the observed relative abundance indices to the logarithm of the true expected population trend using the observation equation:

$$\log(y_t) = \mu_t + \varepsilon_t$$

where y_t denotes the abundance value for year *t*, ε_t is observation residual for year *t*, which is assumed to be normally distributed on log-scale $\varepsilon_t \sim N(0,{\sigma_\varepsilon}^2)$ as a function of the observation variance ${\sigma_\varepsilon}^2$.

Multiple time-series for a species in a same region (North, South Atlantic Ocean; Indian Ocean; North, South Pacific Ocean) were analysed in a single run and treated as indices following [32]. We used vague normal prior for $\hat{r} \sim N(0{,}1000)$ and vague inverse-gamma prior for the process variance $\sigma^2 \sim IG(0.001{,}0.001)$.

For each time-series, we also projected model estimates from the last data point to 2020 to be able to estimate trajectories for the LPI up to the final year of assessment for progress towards the Aichi Targets. These projections were based on the posteriors of the estimated changes across all years in the observed time-series (see [57] for details):

$$\bar{r} = \frac{1}{n}\sum_{t=1}^{n} r_t$$

Three Monte Carlo Markov chains were run for each dataset with different initial values. Each Markov chain was initiated by assuming an initial population size in the first year drawn in log-space from a normal distribution with the mean equal to the log of the first available count (y_1) and a standard deviation of 1000. In each chain, the first 5,000 iterations were discarded ('burn-in'), and of the remaining 50,000 iterations, 10,000 were selected for posterior inference ('thinning rate' = 5). Thus, posterior distributions were estimated from 30,000 iterations. Convergence of each parameter was checked with the Gelman and Rubin diagnostics[58]. Every model comes with four diagnostic plots: the unscaled input data and uncertainty estimates around each observation in the form 95% Confidence Intervals, the observed and predicted abundance values for each time-series together with the 95% posterior predictive credibility intervals, individual fits on the log-scale, as well as the 95% Bayesian credible intervals derived from the observation variance, and residual plot (see [57] for detailed description and examples). We conducted posterior predictive checks (drawing simulated values from the joint posterior predictive distribution of replicated data and compare these samples to the observed data) by checking that the credible Interval of the fit of the models fall each time within the posterior predictive distribution limits and that Bayesian p-value were around 0.5 (using Pearson residuals)[59,60]. Analyses were performed using R Statistical Software v3.5.2[61] and via the interface from R ('R2jags' package v0.5-7;[62]) to JAGS ('Just Another Gibbs Sampler' v4.3.0;[63]). The Highest Posterior Density interval was used as the interval estimator of 95% credible intervals.

Calculation of Living Planet Index

The LPI for oceanic sharks is a quantitative mean index of year-to-year rate of change of all species that occur in a given region and finally aggregated to a global scale (see EDF 1). The annual rate of change d_t for each species in a region is the logarithm of the growth rate of the time-series in a given year (*t*):

$$d_t = \log_{10}\left(\frac{I_t}{I_{t-1}}\right)$$

where I_t denotes the posteriors of the estimated abundance trend in a given year (t) obtained from the Bayesian state-space model outputs.

To calculate the global LPI, the annual rates of change d_t for each species in a region were then aggregated to provide a single annual rate of change for each region (see EDF 1a for an example), and the same procedure was applied across regions in the same Ocean (if subdivided in south and north regions), and finally across the three Oceans to generate a global year-to-year rate of change. We also computed a global LPI for each species separately, by Oceans and by time-series with similar ecological lifestyle or life-history traits: geographical zone (temperate or tropical), body size (maximum total length), and generation time (following IUCN definition[55], see Supplementary Table S1). We back-transformed the log values to the linear scale to generate index values for the range of scales (global, by Ocean, by species or trait-groupings of time-series):

$$LPI_t = LPI_{t-1} \times 10^{\overline{d}_t}$$

where LPI_t is the Living Planet Index at a given year (t), with $LPI_{t=1} = 1$.

The global index started in 1970 and was modelled until 2018 using each year-to-year rate of change for the available time-series. In a second step, the global index was extrapolated through to 2020 using each year-to-year rate of change for the available time-series, and their projections after their last data point (see EDF 2a for an example).

Although the overall extent of change in the LPI is an indicator of status and trends in biodiversity, the trend may be driven by the data-rich species in our dataset. We evaluated the sensitivity of the LPI to the subset of species, using a jackknife procedure in which we sequentially dropped individual species and recalculated the index (see EDF 3).

Calculation of Relative Fishing Pressure

To investigate the underlying drivers of the abundance trend decline, we calculated the Relative Fishing Pressure, the changes in catch from 1970 to 2014 (end of the available data), relative to abundance (LPI) over the same time period, and scaled by the Relative Fishing Pressure in 1970. First, we extracted the total Sea Around Us Project reconstructed reported and unreported catch data[64] by species for 14 of our 18 focal species — catch data were not available for 4 of the species: *A. pelagicus*, Reef Manta Ray *M. alfredi*, Shortfin Devilray *M. kuhlii*, Pelagic Stingray *P. violacea*, and thus were not included in this analysis. To account for the disproportionately high catch of some species (e.g., Blue Shark) in the total catch that could affect the overall pattern, we scaled the catch data at the species level (*sp*) to the first catch value in each time-series before summing across species. The Relative Fishing Pressure (RFP) was then calculated as:

$$RFP_t = \frac{\frac{\sum_{sp} catch_t}{LPI_t}}{\frac{\sum_{sp} catch_{t=1970}}{LPI_{t=1970}}}$$

with LPI_t being the LPI of the 18 oceanic sharks in year *t*. We also calculated the RFP with the LPI_t of only the 14 species for which catch data were available and this was not credibly different from the RFP for all 18 species.

Calculation of Red List Index

We calculated the RLI based on the proportion of the 31 oceanic shark species in each IUCN Red List category in 1980, 2005, and 2018 (see Supplementary Table S2). The categories used in the assessments were Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC). No species of oceanic shark were assessed in the categories Extinct (EX), Extinct in the Wild (EW), or Not Evaluated (NE). The statuses in 2018 were assigned by the IUCN SSC SSG (Dallas, Texas, USA, 5–9

November 2018). For the RLI of 2005, we used the assessments published between 2000 and 2010. Red List assessments for ~2005 and 2018 are published on the IUCN Red List of Threatened Species website[65]. Following the recommended IUCN methodology, species previously assessed as Data Deficient (DD) were retrospectively assigned a data-sufficient category (see Table S2). No assessment was available in the 1980s and experts involved in the IUCN SSC SSG workshop (Dallas, Texas, USA, 5–9 November 2018) retrospectively determined Red List statuses for 1980, as well as missing statuses in ~2005, as per [31]. To account for uncertainty around a retrospective assessment, we used a bootstrap-like method to iteratively resample 10,000 times each species' status from its retrospective assigned status or one category better, or one category worse, denoted by the error bar (the range of bootstrap-like results) in Fig. 3a around the retrospective RLI in 1980 (black dot).

The RLI value of a particular year (*t*) is calculated by multiplying the number of species (*s*) in each Red List category by the category weight (*W*) (0 for LC, 1 for NT, 2 for VU, 3 for EN, 4 for CR, and 5 for EX), then summing the product and dividing by the maximum possible product (number of species (*N*) multiplied by the maximum weight 5), and subtracted from 1 to have an index between 0 (where all species are EX) and 1 (where all species are LC)[31]:

$$RLI_t = 1 - \frac{\sum_s W_{c(t,s)}}{W_{EX} * N}$$

To make the RLI in 2018 spatially explicit, we calculated 100,000 km^2 hexagonal cells in the world's oceans[66] using the IUCN Red List status of species that are distributed in each unique cell (based on IUCN distribution maps for each species, see Red List assessments). We analyse the difference of RLI between 1980 and 2018 in the same way, assuming the distribution of species did not change in between those years. All spatial data described were processed using ESRI ArcGIS v10.7[67] and R Statistical Software v3.5.2[61] in Eckert IV equal-area Projection.

The stand-alone point labelled 'Global sharks' in Figure 3a indicates the starting point for the global chondrichthyan (sharks, rays, and chimaeras) Red List Index calculated from the Red List status as reported in 2006 (the median date of available Red List assessments at this time)[16].

Sustainability of stocks of oceanic sharks

In order to represent the status of stocks (populations) of oceanic sharks, we compiled total biomass or abundance, relative to Maximum Sustainable Yield (MSY), provided by authors or extracted from the latest available stock assessment reports (the reference of the source and the trajectory used are in Supplementary Table S3). A stock assessment is the process of employing statistical models to quantify the population dynamics of a fished stock in response to fishing based on the best available catch, abundance, and life-history information. No stock assessment exists for any of the oceanic rays and one of the Blue Shark stock assessments could not be included because no estimates of MSY-related quantities were available[68]. We thus used the eight species (Oceanic Whitetip Shark, Dusky Shark, Shortfin Mako, Porbeagle, Scalloped Hammerhead, Great Hammerhead, Smooth Hammerhead, and Blue Shark) with published biomass or abundance trajectories relative to MSY (15 stocks in total) to produce the global proportion — over time — that these species were at levels above the biomass or abundance achieving the MSY (i.e., $p(B>B_{MSY})$), and thus not overfished (Figure 4d). Each stock's biomass or abundance relative to MSY was transformed into a binary variable, indicating if the stock was above (1) or below (0) MSY. To represent the status of species with several stocks, we calculated the proportion — over time — of stocks above or below MSY. We then calculated the global proportion — over time — that these species were at levels above the biomass or abundance achieving the MSY by averaging species' status proportion that were above MSY for each year.

In a stock assessment, scientists attempt to estimate the amount of fishing mortality (F) over time, and the fishing mortality that will achieve MSY (F_{MSY}). Using available stock assessments, we compiled the latest value of fishing mortality relative to the fishing mortality at MSY (F/F_{MSY}) and plotted them against the latest value of biomass or abundance trajectories relative to the MSY, in the ‘four quadrant, red-yellow-green’ Kobe plot style (EDF 9c).

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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Data and materials availability: Data are available on www.sharkipedia.org and at https://zenodo.org/badge/latestdoi/307472870.

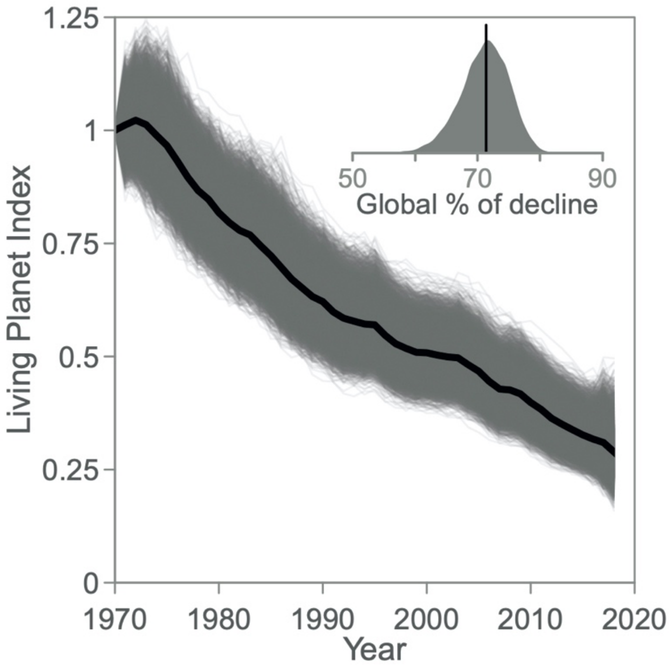

Figure 1. Global Living Planet Index (LPI) for 18 oceanic sharks estimated from 1970 to 2018. The global percentage (%) of decline was calculated from the posteriors of the LPI around the final assessment year relative to the posteriors for 1970. The black line denotes the mean, the white lines the 95% credible intervals and the grey lines each iteration.

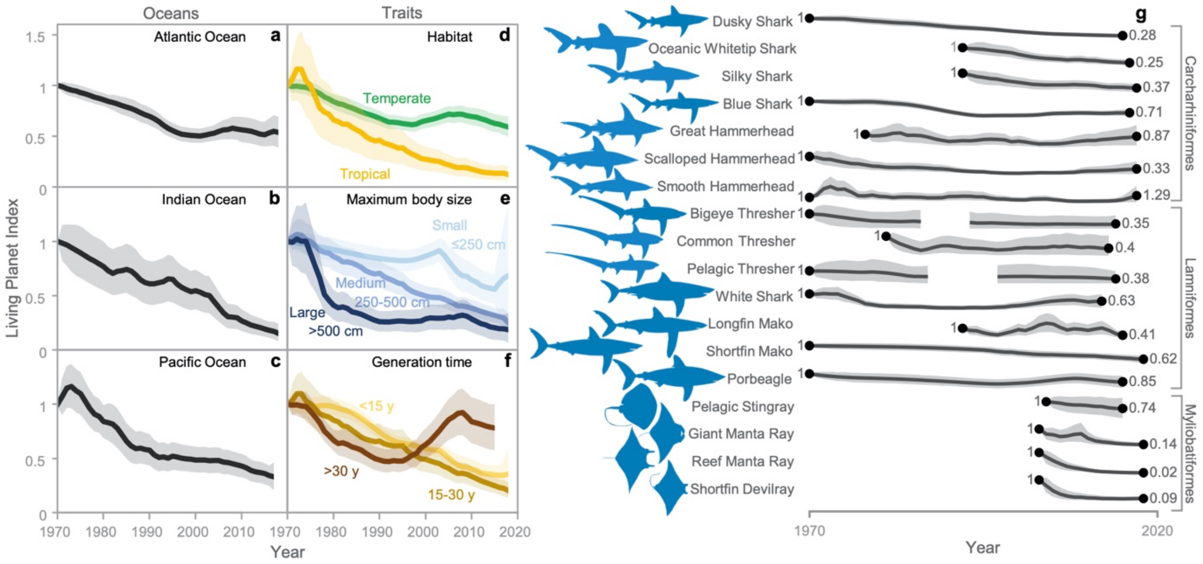

Figure 2. Living Planet Index for 18 oceanic sharks from 1970 to 2018 disaggregated by Oceans (a, b, c), and the traits (d) geographical zone, (e) body size (maximum total length), (f) generation time (GT), and (g) species (species' time-series are in Extended Data Figure 4 to 8). Lines denote the mean and shaded regions the 95% credible intervals.

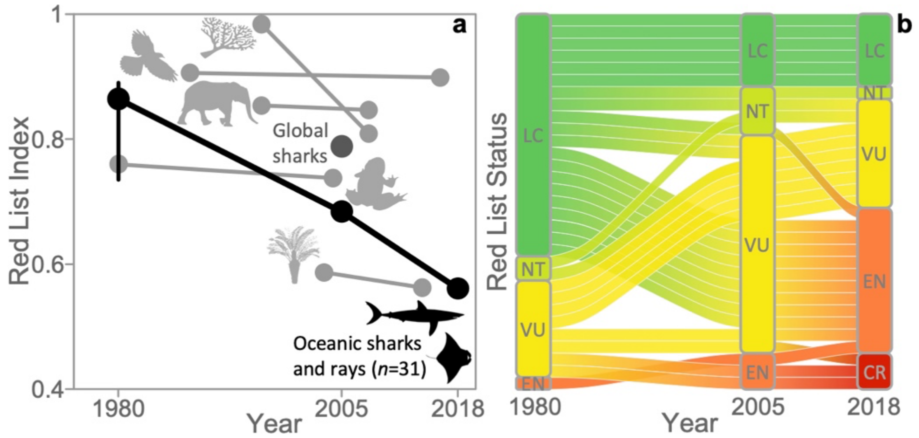

Figure 3. (a) Global Red List Index (RLI) for the 31 oceanic shark species (black line) estimated in 1980, 2005, and 2018, and for mammals, birds, amphibians, reef-forming corals, and cycads (in grey), and global chondrichthyans (sharks, rays, and chimaeras; point labelled 'Global sharks')[16]. The error bar denotes the uncertainty around the retrospective 1980 IUCN status (see Methods). A RLI value of 1.0 equates to all species qualifying as Least Concern (i.e., not expected to become Extinct in the near future), while a RLI value of 0 equates to all species having gone Extinct. (b) Change in Red List status of oceanic sharks from 1980 to 2018.

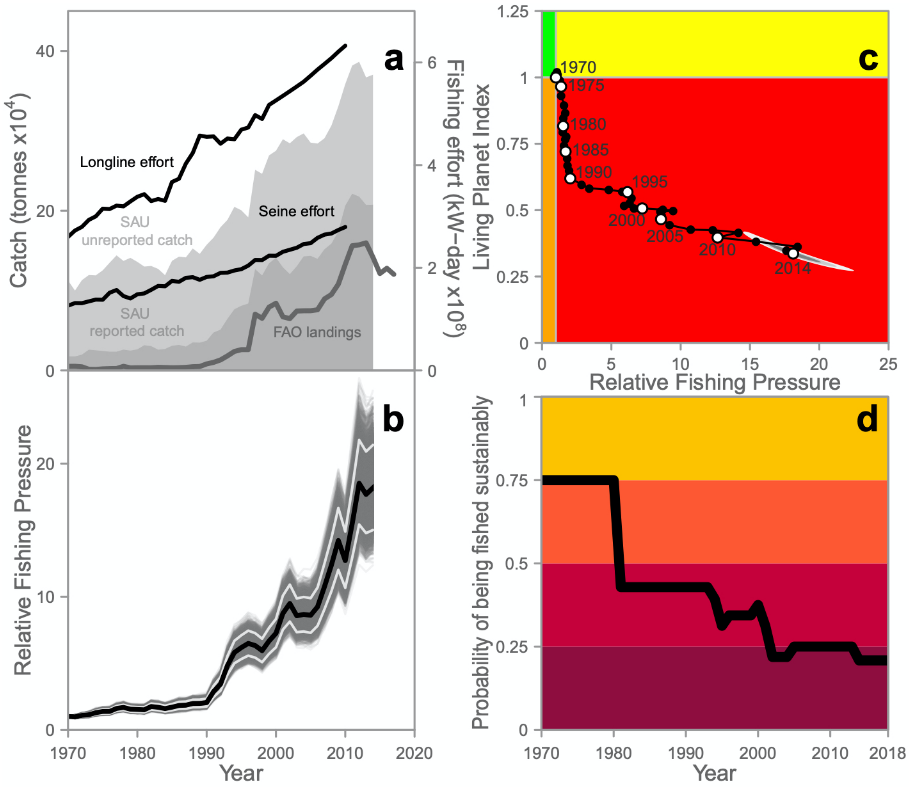

Figure 4. (a) Global catch data of 14 oceanic sharks and fishing effort of longline and seine gears. SAU: Sea Around Us project. FAO: Food and Agriculture Organization of the United Nations. Longline and Seine effort are effective corrected fishing effort[36]. (b) Fishing pressure (catch) encountered by oceanic sharks relative to the fishing pressure (catch) in 1970 and to their abundance from 1970 to 2014. The black line denotes the mean, the white lines the 95% credible intervals and the grey lines each iteration. (c) Living Planet Index (LPI) as a function of Relative Fishing Pressure (RFP, n=14 species) from 1970 (the initial state where LPI and RFP = 1) to 2014 for oceanic sharks (n=18 species). Light-grey, grey, and dark-grey polygons denote the 50%, 80%, and 95% 2D kernel density estimate of the iterations of LPI vs RFP for the last year (2014). (d)

Proportion over time of oceanic sharks with stock assessments that are at a level of biomass or abundance equal or greater than that which would achieve Maximum Sustainable Yield.