nature sustainability

ANALYSIS

https://doi.org/10.1038/s41893-020-0506-9

Check for updates

Comprehensive bycatch assessment in US fisheries for prioritizing management

Matthew S. Savoca[1,4] ✉, Stephanie Brodie[1,2], Heather Welch[1,2], Aimee Hoover[3], Lee R. Benaka[3], Steven J. Bograd[1,2] and Elliott L. Hazen[1,2]

Wild-capture fisheries help provide food security to billions of people, yet bycatch of non-target species threatens ecosystem health and fishery sustainability. Appropriate monitoring and fisheries management can mitigate bycatch but require standardized bycatch data to be robustly recorded and effectively disseminated. Here we integrated and analysed 30,473 species-specific bycatch records from 95 US fisheries in 2010–2015. We examined patterns in fish and invertebrate, marine mammal, seabird and sea turtle bycatch and developed a standardized scoring system, the relative bycatch index, to assess bycatch performance of each fishery. The estimated amount of fish and invertebrate discards totalled 1.93 million tonnes (4.26 billion pounds) over the 6-year period. We found that the national discard rate is 10.5%, considerably lower than past estimates. Results from our relative bycatch index analysis can be used to facilitate management intervention strategies for particular fisheries or gear types, such as shrimp and otter trawls and several pelagic longline and gillnet fisheries, which had the poorest bycatch performance. These findings underscore the need for continued, high-quality, easily accessible bycatch information to better support fisheries management in the United States and globally.

Marine fisheries account for 17% of worldwide protein intake[1], yet bycatch is an obstacle to sustainable fisheries due to mortality associated with bycatch and perceived waste of fisheries resources. Bycatch is defined here as fish and invertebrate discards as well as deleterious interactions with marine mammals, seabirds and sea turtles, plus unobserved mortality due to a direct encounter with fishing gear (see Supplementary Information for more details)[2]. Estimated global discard rates have improved in the past decade, decreasing from 40.4% of global fisheries catch in 2000–2003[3] to 10.8% in 2010–2014[4]. Mitigation strategies can be implemented to help reduce bycatch, but such strategies require the identification of where bycatch is most problematic, which can vary substantially by taxa, fishery, gear type or region[5–7]. Compounding this challenge, bycatch data are rarely recorded or disseminated efficiently with the level of detail required (for example, species-specific data at high spatiotemporal resolution) to craft and implement timely and effective mitigation strategies[5]. When available, high-resolution bycatch datasets can enhance our understanding of species' risk, which fisheries and gear types pose the greatest threats and which management strategies are most effective[8,9].

Fisheries have used numerous science-informed approaches to mitigate commercial fishery bycatch[5,6]. Improved understanding of species distribution has facilitated time–area closures to protect threatened wildlife and non-target catch[10–12]. Modifications of baits and bait setting, including altering colour, timing, depth, sinking rates and odours have reduced bycatch in a variety of taxa[6,13–15]. In addition, gear modifications, including turtle excluder devices, circle hooks, acoustic pingers and bird-scaring lines have been implemented with success in numerous fisheries worldwide, reducing bycatch rates by 20–92%[6,16–20]. An emerging approach is dynamic ocean management, in which eco-informatic tools are used to predict the spatiotemporal distribution of target and non-target species, ranging from near real-time to seasonal forecasts[21–23]. Despite these advances, high levels of bycatch persist in fisheries worldwide[24–26].

To monitor and reduce bycatch in US fisheries, the Magnuson–Stevens Fishery Conservation and Management Act (MSA) requires all fishery management plans to establish a standardized reporting methodology to assess the amount and type of bycatch occurring in a fishery and to minimize bycatch to the extent practicable, yet also to adhere to the requirements of the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA/NMFS) administers observer programmes in all of its management regions (Alaska, West Coast, Pacific Islands, Northeast (currently the 'Greater Atlantic') and Southeast). Information collected by fisheries observers is used to monitor total allowable catch levels, develop annual catch limits, monitor levels of fishery-related serious injury and mortalities of marine mammals, administer bycatch avoidance programmes and report 'take' (for example, harassing, harming, pursuing, hunting or collecting or to attempt to engage in any such conduct) of species listed under the ESA. The National Bycatch Report (NBR) is the only national-level report that compiles fish and invertebrate discards, in addition to marine mammal, sea turtle and seabird bycatch estimates from observer data across all major US federally managed fisheries[2]. However, in its current form, accessing NBR data in a unified format is challenging and limits comprehensive analyses.

Here we present the first holistic assessment of bycatch in US fisheries using NBR data and develop a publicly accessible, comprehensive, searchable database of federally managed fisheries in all NMFS regions ($n=5$ regions, $n=95$ fisheries; Fig. 1 and Supplementary Fig. 1). We use this database to describe recent (2010–2015) bycatch patterns in US waters by region, gear type and fishery. In order to facilitate inter-fishery comparisons, we developed a relative bycatch index (RBI) that accounts for not only

[1]NOAA Southwest Fisheries Science Center, Environmental Research Division, Monterey, CA, USA. [2]University of California Santa Cruz, Institute of Marine Science, Monterey, CA, USA. [3]NOAA Office of Science and Technology, National Observer Program, Silver Spring, MD, USA. [4]Present address: Stanford University, Hopkins Marine Station, Pacific Grove, CA, USA. ✉e-mail: msavoca13@gmail.com

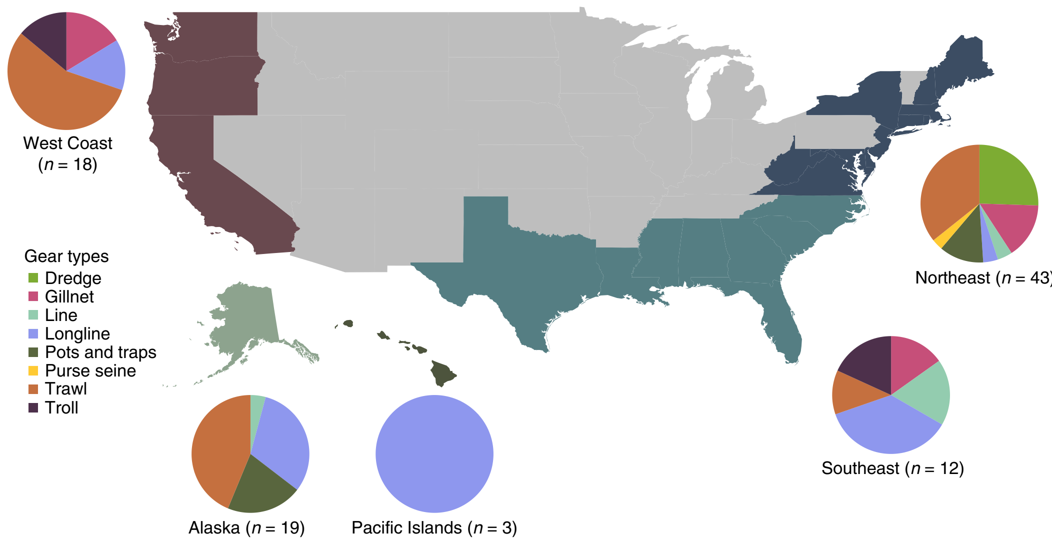

Fig. 1 | Proportion of US federally managed fisheries appearing in the NBR sorted by gear type in five NMFS reporting regions. The size of each slice represents the numerical proportion of NBR fisheries utilizing that gear type in the region and does not reflect the magnitude of respective fishery gear types being used in each region. The map was generated with R package 'fiftystater'[56] and modified.

bycatch numbers and discard rate, but also conservation status of target stocks and bycaught species (Box 1). To achieve this, data collected from disparate sources were normalized and combined, thus providing a single value for each fishery year that elucidates bycatch trends on a national scale (Box 1; see Methods for more details on RBI). This national synthesis highlights gear types and fisheries of particular concern and thus can expedite bycatch mitigation strategies to support healthy US fisheries.

Results and discussion

A summary of bycatch in US fisheries. Our dataset comprised 30,473 bycatch events in 95 fisheries in 2010–2015. The total amount of fish and invertebrate discards was 1.93 million tonnes (4.26 billion pounds) for those fisheries that listed their discards by weight ($n=86$ fisheries). By comparison, these fisheries landed 16.47 million tonnes (36.31 billion pounds) of target catch. The resulting overall discard rate of all fishery years in the dataset was 10.5%. This represents a halving of a 2002 estimate of 22.3% across US fisheries[3,27] and a reduction from a 2005 estimate of 17% using data from the first NBR[28], suggesting that gear modifications and fisheries management have been effective in curbing fish and invertebrate bycatch in US fisheries.

The top fish species bycaught across all fisheries in 2010–2015 were Atlantic croaker (*Micropogonias undulatus*; 165,282 tonnes bycaught), arrowtooth flounder (*Atheresthes stomias*; 57,811 tonnes bycaught) and spiny dogfish (*Squalus acanthias*; 49,995 tonnes bycaught). The latter species is also listed as vulnerable by the IUCN, but for the populations of spiny dogfish managed by the US for which the status is known, spiny dogfish are neither overfished nor subject to overfishing[29]. Roughly 20% of the world's Chondrichthyans (sharks, rays and chimaeras) are threatened with extinction[30] and many Chondrichthyans are bycaught in large numbers in US fisheries. Our dataset included 496 tonnes of Myliobatiform ray bycatch, 321,593 tonnes of Rajid skate bycatch and 5,892 tonnes of Lamniform shark bycatch. Nineteen of these shark species bycaught are also IUCN-listed species. In addition, several ESA-listed species were recorded across all fisheries in 2010–2015: the scalloped hammerhead (*Sphyrna lewini*; 139 tonnes bycaught; first ESA-listed in 2014), as well as Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*; 54 tonnes bycaught) and green sturgeon (*A. medirostris*; 11 tonnes bycaught).

There was substantial heterogeneity in fish discard rates among fishery gear types. Bottom longline, troll, purse seine and pot and trap fisheries consistently had fish discard rates <0.05, whereas otter and bottom trawls had the highest discard rates; fisheries using these gear types regularly reported discard rates >0.3 (Fig. 2a). Of all fisheries analysed, the California halibut trawl had the highest average discard rate at 0.77 from 2010–2015; however, this is a small state-permitted fishery with a total annual catch of 395.98 tonnes and thus, the total amount of fish and invertebrate bycatch in this fishery was relatively small (306.24 tonnes per year).

When discussing discard rates for gear types, it is important to note that NBR discard rates only apply to fish and invertebrate estimates. For marine mammals, gear types with lower fish and invertebrate discard rates, such as pots and traps, have caused entanglements resulting in serious injury or death, including for humpback and grey whales along the US West Coast and North Atlantic right whales on the East Coast[31]. However, because these entanglements may not be documented by observer programmes, they are not reflected in the NBR.

Longline fisheries were responsible for the majority of sea turtle bycatch reported in the NBR (Fig. 2b), which is similar to previous findings[9,32]. Longline fisheries along the East Coast of the United States reported the most sea turtle bycatch. In particular, the Atlantic and Gulf of Mexico highly migratory species (HMS) pelagic longline fishery caught an estimated 708 sea turtles annually (4,246.8 estimated total) in 2010–2015; bycatch of ESA-listed loggerhead ($n=378$ annually) and leatherback ($n=326$ annually) turtles remains a concern for that fishery. Fisheries regulations implemented in the Atlantic longline fisheries since 2004 have resulted in a 40% decrease in leatherback and 61% decrease in loggerhead bycatch per unit effort[33]. Such trends indicate the utility of appropriate regulation and compliance for reducing bycatch, yet highlight fisheries to explore additional bycatch reduction techniques.

Shrimp trawls were comparable with longlines in having high rates of sea turtle bycatch. Data from 2002, 2009, 2014 and 2015 found high levels of sea turtle bycatch in both the Gulf of Mexico shrimp trawl (709 sea turtles annually) and the Southeastern Atlantic shrimp trawl (147 sea turtles annually; see Supplementary Information for more details). This suggests that if sea turtle numbers from these trawls were reported for 2010–2013, it would put

Box 1 | Delineation and description of 12 criteria that make up the RBI

RBI is a weighted average of 12 normalized criteria, where higher values indicate fisheries with poorer bycatch sustainability. In the final index, only the MMPA category is weighted twice due its relative lower representation in the RBI.

(1) **Number of individual seabirds and sea turtles bycaught** (individuals).
(2) **Quantity of fish and invertebrate discarded** (pounds or individuals).
(3) **Discard rate**: the ratio of fish and invertebrate discards to total catch (discarded catch plus target catch), in fisheries where fish and invertebrate bycatch is given in pounds (86 of 95, 91% of fisheries in the dataset).
(4) **Number of ESA-listed species bycaught (value)**: the ESA of 1973 protects listed species from 'take' (harassing, harming, pursuing, hunting or collecting) to recover their populations.
(5) **Quantity of ESA-listed fish and invertebrates discarded** (pounds or individuals).
(6) **Number of individual ESA-listed seabirds and sea turtles bycaught** (individuals).
(7) **Number of International Union for Conservation of Nature (IUCN)-listed species bycaught** (value).
(8) **Quantity of IUCN-listed fish and invertebrates discarded** (pounds or individuals).
(9) **Number of individual IUCN-listed seabirds and sea turtles bycaught** (individuals).
(10) **MMPA category**: Category I, frequent interactions with marine mammals; Category II, occasional interactions with marine mammals; and Category III, remote likelihood/no known interactions with marine mammals.
(11) **Average coefficient of variation** (metric).
(12) **Fishery tier classification:** (category) 0, no bycatch data collection programmes; 1, bycatch estimates based on outdated or unreliable information and no observer data; 2, bycatch estimates included, but observer programmes inadequate; 3, bycatch estimates based on reliable observer data or recent logbook data but limited observer coverage and varied sampling designs; and 4, bycatch estimates based on reliable observer programme data collected on an annual basis for at least the past 5 years and negligible programme design deficiencies.

shrimp trawl fisheries on par with longline fisheries in terms of their numbers of sea turtle interactions. Furthermore, trawls consistently catch adult turtles with higher individual reproductive values than those turtles caught in other gear types, such as gillnets and longlines[34,35]. Mortality or injury at sensitive life history stages may provide disproportionately greater impact on populations than raw counts alone. Mitigating risk to the most sensitive life history stages may offer a greater conservation success than across-the-board bycatch reduction alone[36].

Seabird bycatch is reported on a regular basis in the Pacific Islands, Alaska and West Coast regions from fisheries with potential interactions with short-tailed albatross (*Phoebastria albatrus*), the only ESA-listed seabird species that is encountered in US fisheries. The majority of seabird bycatch reported in the NBR occurred in the Alaska region. In particular, the Bering Sea/Aleutian Islands Pacific cod longline fleet was responsible for an estimated 23,838 bycaught seabirds in 2010–2015, more than all other fisheries in our dataset combined. Historical efforts to mitigate seabird bycatch in this region have resulted in a 77–90% reduction in seabird bycatch rates from the period 1995–2005[37].

Nearly half of fisheries analysed (30 of 62), not including the Northeast region fisheries that aggregate seabird and sea turtle bycatch by fishery groups[2], reported no bycatch of seabirds and sea turtles on an annual basis (Fig. 2b). This is due to sea turtle bycatch being rare events or non-existent in particular regions (in Alaska) or challenging to estimate on an annual basis (Southeast shrimp trawl fisheries). Seabird estimation in fisheries from regions without short-tailed albatross is sporadic due to limited agency resources and a lower level of conservation concern.

To assess the impact of a fishery on marine mammals, we incorporated each fishery's MMPA category ranking, which indicates the relative frequency of marine mammal interactions within each fishery year from high (Category I) to low (Category III; Methods). Marine mammals are most commonly bycaught in gillnets compared with other gear types (Fig. 2c). Of particular concern are Northeast region gillnet fisheries, which all received a Category I MMPA ranking during our 6-year time series. In addition to gillnet fisheries, the Atlantic and Gulf of Mexico HMS pelagic longline and the Hawaii-based deep-set pelagic longline fishery for tuna also received a Category I ranking in 2010–2015. The California drift gillnet fishery was notable in our analysis because its MMPA ranking changed from Category III in 2011, to Category II in 2012 and Category I in 2013, where it remained through the end of 2015. Globally, bycatch rates of marine mammals dramatically decreased from 1990 to 1999 due to the implementation of time–area closures, acoustic pingers and concurrent reductions in fishery effort[38]. Management responses to MMPA rankings, in the form of take reduction plans, have had varied success in reducing mortality, with success more likely when regulations are simple and compliance is high[39]. Although these management strategies have typically been effective in reducing human-caused mortality, unprecedented environmental change has exposed some whale species to increased mortality rates, for example North Atlantic right whales and humpback whales on the US West Coast[40,41]. Although fisheries management has strategies to respond quickly to anomalous bycatch events[37,42], data limitations and regulatory requirements can increase the time lag in implementation. Continued focus on provision of timely observer bycatch data to fishery managers is important to ensure rapid communication of observed bycatch events.

Relative bycatch index. The RBI developed here provides a multivariate composite metric for each US fishery and with NBR bycatch estimates, allows bycatch trends to be compared across region, gear type and fishery. The RBI integrates bycatch information across 12 criteria, including absolute bycatch, bycatch of listed species and quality of bycatch monitoring (see Methods and Supplementary Information for more details). The distribution of RBIs is heavily right-skewed, indicating that the majority of fisheries have similar bycatch trends (Fig. 3) with a median of 0.136. The RBI for each gear type indicates a clear hierarchy among gear types, with highest RBI scores associated with gillnet gear (median = 0.246 ± 0.015 s.e.m.) and lowest with dredge (0.082 ± 0.008) and purse seine fisheries (0.053 ± 0.017) (Fig. 3b). Trawl and longline gear types generally had average scores (0.110 ± 0.008 and 0.118 ± 0.011, respectively) and only certain varieties of this gear type (for example, otter trawls, 0.224 ± 0.010; and surface and deep-set longlines, 0.370 ± 0.023) had consistently high scores.

An examination of fisheries' scores across regions illustrates that, in general, fisheries in the Alaska (median = 0.072 ± 0.005 s.e.m.) and West Coast (0.089 ± 0.007 s.e.m.) regions have the lowest RBI scores in our dataset (Fig. 3c). This is largely due to limited interaction with ESA and IUCN-listed species. In our dataset, all three fisheries with NBR bycatch estimates in the Pacific Islands region used longline gear (Fig. 1), which is a gear type that exhibits high rates of sea turtle, seabird, fish and invertebrate bycatch (Figs. 2 and 3c). The predominance of the longline gear type in the Pacific

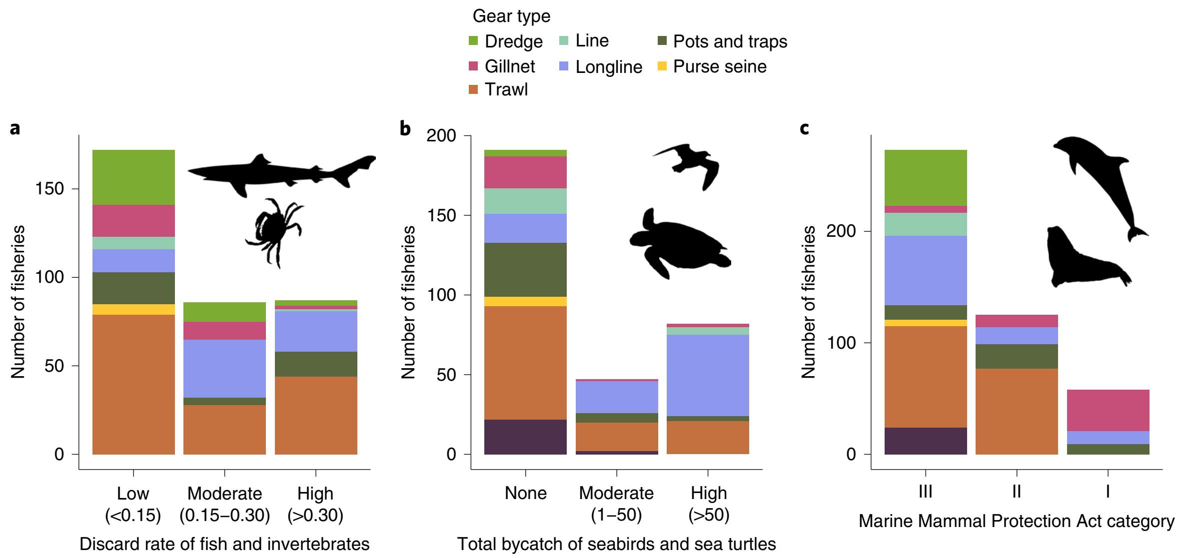

Fig. 2 | Bycatch patterns in all fisheries. a,**b**, Break points were made from histograms of raw data, setting the cutoffs at the 50% and 75% quantiles. This illustrates that those fisheries with the highest proportion of fish and invertebrate bycatch are trawl and longline fisheries (**a**). Longline fisheries are also disproportionately responsible for the majority of interactions with sea turtles and seabirds (**b**). **c**, Marine mammals are most heavily impacted by gillnets, as shown in the MMPA Category I chart.

Islands NBR fisheries led to the Pacific Islands having the highest bycatch index of any region (0.207 ± 0.025 s.e.m.), even though the Pacific Islands estimated total bycatch numbers were not as high as numbers in fisheries in other regions. The differences in RBI scores between regions highlights the complexity of bycatch management, as management strategies must be region- and gear-specific.

Our analysis also identified patterns in RBI through time, with higher scores more frequent in 2014–2015 (Fig. 3d). This shift is most pronounced in the Northeast region (2010–2013, 0.143 ± 0.008 s.e.m.; 2014–2015, 0.218 ± 0.010 s.e.m.), where bycatch estimates were conducted in a more expansive manner for 2014–2015 compared with 2010–2013. Specifically, the 2014–2015 report included approximately ten additional fisheries, and approximately 115 additional species. This change in methodology resulted in an increase in the magnitude of estimated bycatch for these fisheries for the latter time frame. Although it is conceivable that Northeast fisheries had more discards for a variety of reasons in 2014–2015 (for example, new size limits leading to increased regulatory discards, climate-driven target species migrations), the inclusion of so many more species with bycatch estimates had an effect on this pronounced shift for Northeast fisheries. This temporal change in RBI highlights the importance of standardized and accurate reporting of bycatch data.

In our dataset, there were 61 fisheries with data across all 6 years (Fig. 4), allowing us to analyse RBI through time and compare the relative performance of fisheries with respect to bycatch. Of all fisheries with 6-year records, the Hawaii-based deep-set pelagic longline fishery for tuna received the highest average RBI (0.399 ± 0.012 s.e.m.), followed in order by the Atlantic and Gulf of Mexico HMS pelagic longline (0.375 ± 0.016 s.e.m.), Gulf of Mexico shrimp trawl (0.374 ± 0.024 s.e.m.), Gulf of Mexico reef fish vertical line (0.324 ± 0.026 s.e.m.) and the Mid-Atlantic small-mesh gillnet (0.311 ± 0.033 s.e.m.). These fisheries have the highest RBIs because of their relatively high interaction rates with marine mammals and ESA-listed sea turtles. In addition, trawl fisheries with high RBI scores also had elevated levels of fish and invertebrate discards (discard rates >0.5) relative to other fisheries. A number of these fisheries have bycatch mitigation strategies in place, but they remain priorities for additional management intervention.

Examining the distribution of RBI values across all fisheries also highlights gear types and fisheries that could be a focus for fisheries management and conservation (Figs. 3 and 4). Although these examples highlight the potential to further reduce bycatch in US fisheries, piece-meal approaches to bycatch management can have unintended consequences, such as shifting bycatch pressure from one threatened taxon to another[6]. To resolve this, an integrated bycatch assessment and coordinated management structures have been suggested[6]. Such a synthetic approach would need to rely on a comprehensive, readily available, regularly updated and easily accessible bycatch database supported by a robust observer programme. The NBR used for this analysis requires process improvements to most effectively serve bycatch reduction management programmes. For example, the lag of several years between the data analysed in NBR updates and the publication date has resulted in the NBR being of limited utility to NMFS managers and regional fishery management councils.

There are other fisheries with fewer than 6 years of NBR data that show concerning bycatch patterns (Supplementary Fig. 1). The Southeastern Atlantic shrimp trawl caught an estimated 366 sea turtles annually in 2014 and 2015 and had an RBI of 0.353 ± 0.013 and the Mid-Atlantic lobster pots fishery was only included in the 2014 and 2015 NBR, but its Category I MMPA ranking led to an RBI of 0.297 ± 0.024. In contrast, several fisheries with 6 years of data consistently outperformed other fisheries in relation to bycatch. The Gulf of Alaska rockfish trawl (0.019 ± 0.013), West Coast limited-entry fixed-gear bottom trawl (0.021 ± 0.007), the Gulf of Alaska non-pelagic trawl (0.031 ± 0.007), the Gulf of Alaska pollock trawl (0.032 ± 0.012) and the Gulf of Alaska pot (0.036 ± 0.008) had the lowest RBIs. In addition, the Bering Sea/Aleutian Islands pollock trawl, the fishery with the most landings in our dataset and one of the world's largest fisheries, received a relatively low RBI (0.096 ± 0.014). Alaskan fisheries have low relative bycatch, while landing more target catch than all other regions combined because they target a highly productive, yet less biodiverse assemblage. Further, Alaskan fisheries have taken the initiative of contracting researchers to pool bycatch data and release it to fishermen at regular intervals, thus allowing timely responses to bycatch events[43,44].

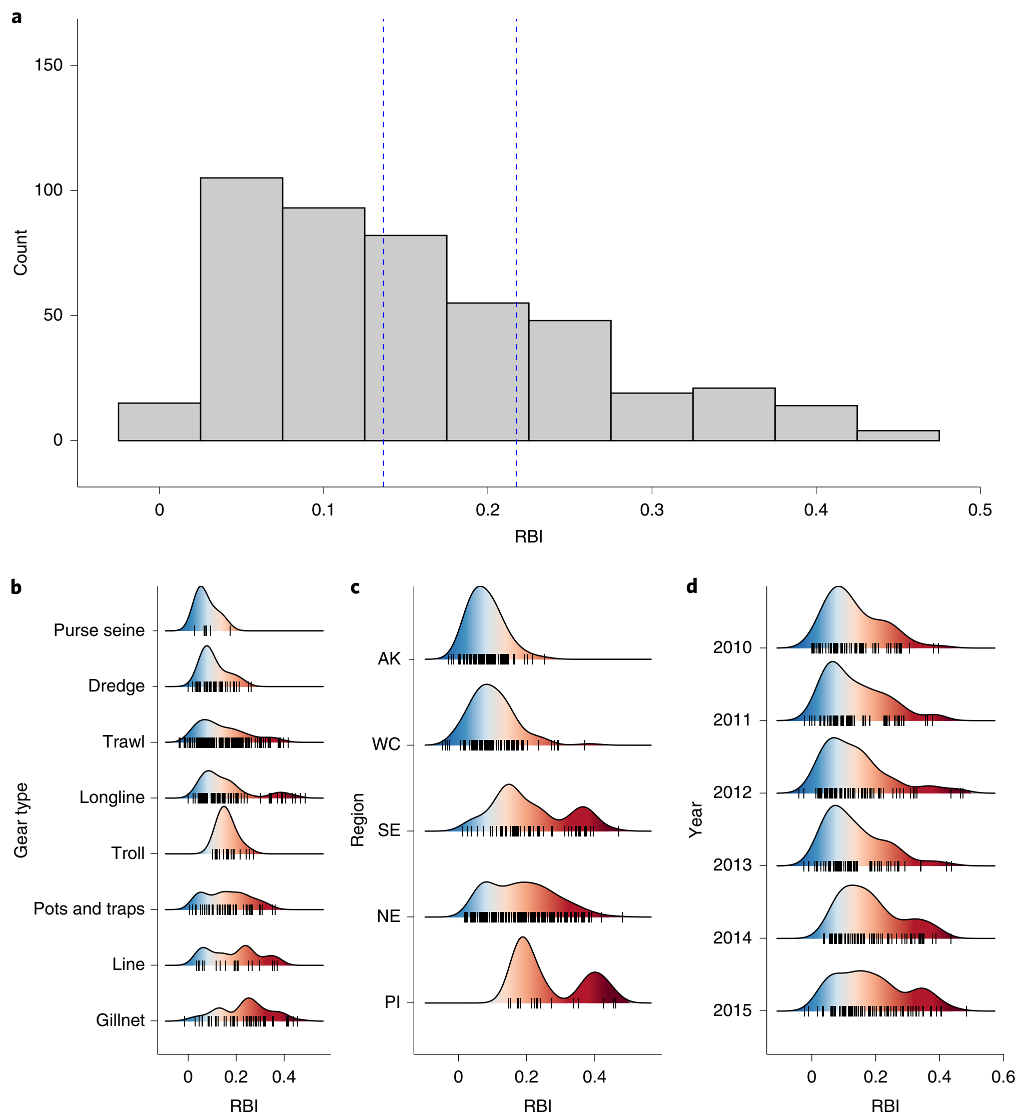

Fig. 3 | Distribution of relative bycatch index (RBI) scores. a–d, Distribution of RBI scores for each fishery in each year ($n = 457$ fishery years in total). Vertical dashed lines indicate 50% and 75% quantiles. Segregation of data from **a** by gear type (**b**), region (**c**) and year (**d**). Cool colours indicate low RBIs, while warm hues are indicative of higher RBIs. AK, Alaska; NE, Northeast; PI, Pacific Islands; SE, Southeast; WC, West Coast.

Global context. Bycatch is a complicated issue internationally for a multitude of reasons, including that species discarded in US fisheries are landed in other nations' fisheries. A global review of 2,000 fisheries reported 9.1 million metric tons of discards annually in 2010–2014[4], whereas fisheries in our dataset reported 0.32 million metric tons of fish and invertebrate discards annually over the same period, suggesting that US fisheries are responsible for ~3.5% of discards worldwide. Fish and invertebrate discards internationally has been estimated at up to 40.4% of global marine catch[3], which is well above previous US estimates of 20.2% (ref. [3]) and 17% (ref. [28]). Our estimate of 10.5% was nearly identical to the most recent global estimate of 10.8% (ref. [4]). Recent reliable and comprehensive estimates of global marine mammal, seabird and sea turtle bycatch are lacking, making comparisons difficult. However, the US seafood import regulation, which requires that all imported seafood comply with the MMPA, has resulted in increased pressure on international fisheries to report and reduce marine mammal bycatch[45]. Another example of the global nature of bycatch was seen in strict management for sea turtle interactions in the Hawaii-based shallow-set longline fleet, which has led to increased swordfish imports from international fisheries and, in turn, more sea turtle interactions overall than an entirely domestic fishery would have had[46].

Recent global analyses on fisheries discards[4,47] and ours also found contrasting discard rates among gear types. In the United States, trawl fisheries have lower discard rates (13% versus ~40% globally[4]) than the global average for this gear type, despite accounting for 72% of US fisheries discards by weight. In contrast, US longlines have a threefold higher gear-specific discard rate (22% versus 7% globally) and proportion of total discards (14% versus 4% globally[4]). Because the NBR includes bycatch estimates for most, but not all, major US fisheries, bycatch data presented here reflect an underestimate of US fisheries discards. Similarly, global discard estimates probably underestimate total discard levels due to data limitations[4]. Out of all the fisheries we explored, only ~14% (13 of 95) were experiencing overfishing or were overfished. While this suggests that bycatch may be limiting a high proportion of US fisheries, exploring the ratio of bycatch to target catch would provide further insight[48,49]. This could be difficult, however, as the majority of US fisheries target multiple stocks.

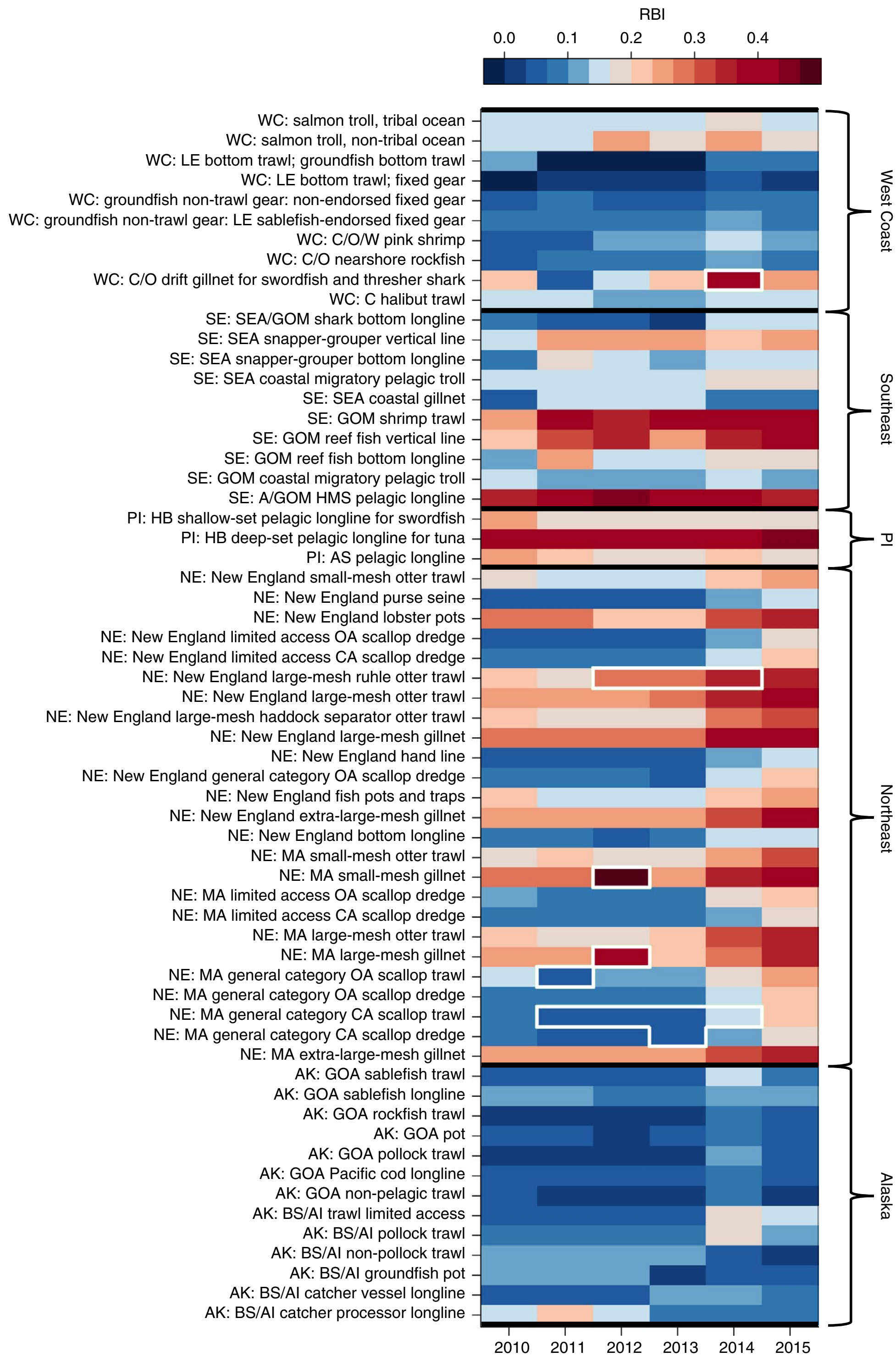

Fig. 4 | The annual relative bycatch index (RBI) score for 61 fisheries that have 6 years of data (2010–2015). Fisheries are grouped into regions. Acronyms used in fishery names are: MA, Mid-Atlantic; GOA, Gulf of Alaska; BS, Bering Sea; AI, Aleutian Islands; AS, American Samoa; HB, Hawaii-Based; A, Atlantic; GOM, Gulf of Mexico; SEA, Southeastern Atlantic; C, California; O, Oregon; W, Washington; CA, closed area; OA, open area; HMS, highly mobile species; LE, limited entry. Cells outlined in white denote RBI scores computed on fewer than seven criteria.

Management implications. The US NBR details bycatch performance at unprecedented spatial, temporal and taxonomic resolutions. We present the most comprehensive synthesis of bycatch in US fisheries to date to facilitate management priorities. Overall, we find that US fisheries show substantial heterogeneity among regions, gear types and target species in relation to bycatch (Figs. 2–4). Bycatch risk is driven by species and gear type (for example, for fisheries with regular bycatch NBR estimates, longlines and gillnets are most hazardous for sea turtles, marine mammals and seabirds[8]) even though these fisheries have implemented bycatch mitigation approaches. As a whole, US fisheries have reduced their bycatch rates since earlier comprehensive assessments in 2000–2003[27] and

2005[28]. Even in light of these successes, the RBI remains high in several fisheries, particularly for longlines, gillnets and otter trawls.

US fisheries' discards have declined absolutely and relatively over the past three decades[47], due to reduced industrial fishing pressure, less waste (for example, more selective gear and/or more marketable fish for aquaculture fishmeal) and enhanced management. In addition, research has shown that fisheries can respond quickly as new bycatch mitigation strategies are implemented[32,42,49]. Gear modifications have been successful in numerous fisheries worldwide[6], yet eliminating the last 10% of discards may be difficult to achieve; research and implementation of these gear modifications should continue along with more novel eco-informatic tools. For example, these dynamic management tools allow for quantification of tradeoffs between maximizing sustainable target catch and simultaneously reducing bycatch[23,50]. However, to evaluate the efficacy of these varied approaches we need continued, high-quality, easily accessible bycatch information disseminated rapidly to support management. Our dataset and associated web-based application provides a blueprint for how use of these data can be maximized by managers, scientists and the general public. The continued use of and investment in this dataset will provide insights on where to selectively target management intervention in US fisheries and provide a roadmap on assessing the impacts of bycatch on fisheries globally.

Methods

Data acquisition, description and summation. We developed a national bycatch database by obtaining, cleaning and aggregating NBR data and augmenting it with relevant ancillary data. Bycatch is defined in the NBR as the "discarded catch of any living marine resource plus unobserved mortality due to a direct encounter with fishing gear"[2]. This definition is more expansive than the MSA definition of bycatch because the purpose of the NBR is to provide estimates not only of fish discards but also fishery interactions with marine mammals and seabirds[2]. The first NBR was published in 2005, with the most recent NBR updates covering 2010 to 2015[2]. We acquired and integrated catch and bycatch data, along with relevant metadata for all federal fisheries into one data repository. NBR catch and bycatch data are publicly available on the NMFS website (https://www.fisheries.noaa.gov/resource/document/national-bycatch-report) and sourced through the NBR Database System (https://www.st.nmfs.noaa.gov/apex/f?p=243:101:11522042444195), which provides data via a series of downloadable Excel reports nested by bycatch type (fish, mammal, turtle and seabird); year (2010–2015); region (Alaska, Northeast, Pacific Islands, Southeast and West Coast). This nested format resulted in hundreds (>200) of individual bycatch reports being downloaded. The NBR is designed as a common approach to collating all available observer data from NOAA's National Observer Program making it an invaluable resource for fisheries comparisons. Species- or stock-specific population estimates to inform management decisions are best obtained from stock assessments and biological opinions that incorporate multiple sources of data. Additional details on the database and the NBR are available in the Supplementary Information.

We cleaned downloaded reports into a Tidy data format using the Tidyverse package (R Core Team). Data tidying is the process of structuring datasets to facilitate analysis and utilizes standard data cleaning concepts[51] with data arranged such that rows (observations) were species-specific bycatch events in a given fishery in a given year and columns were variables (for example, region and number of turtles caught). We accounted for changes to fishery names across years to ensure inconsistencies in reporting were fixed. The data included fishery-specific data on total bycatch (all species pooled), landings, total catch (discards and landings) and discard rate (discarded catch/total catch) when discards were listed in pounds from the five regions. For the Pacific Islands region, total and dead discards were listed separately, but we used the 'Bycatch (live and dead)' column, assuming that stress when released alive, known as capture myopathy, results in negative fitness for the individual. When available, we also sourced percentage observer coverage in each fishery from annual reports published by the NMFS National Observer Program (https://www.st.nmfs.noaa.gov/observer-home/reports/nopannualreports/). Due to differences in legal mandates, our analyses resulted in two final datasets: fish and invertebrate discards and fishery metadata ($n=29,415$ rows) and marine mammal, turtle and seabird bycatch events ($n=1,058$ rows). These data are available for exploration and download (https://ceg.ucsc.edu/projects/nbrexplorer).

Following data aggregation, additional relevant information on the fishery from other sources was added. Every year NMFS categorizes fisheries based on their frequency of interactions with marine mammals through the authority of the MMPA. The MMPA is federal legislation that prohibits the 'take' of marine mammals in US waters, with 'take' being defined as the act of hunting, killing, capture, and/or harassment of any marine mammal. The MMPA fishery categories are: (1) frequent incidental mortality or serious injury of marine mammals; (2) occasional incidental mortality or serious injury of marine mammals; and (3) remote likelihood/no known incidental mortality or serious injury of marine mammals. We included these MMPA category rankings in our database as the primary way to analyse the impact a fishery has on marine mammals in a given year because marine mammal bycatch estimates included in the NBR are derived from the NMFS Marine Mammal Stock Assessment reports (https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessments), which estimate bycatch using a 5-year mean approach. Therefore, the annual MMPA categories gave us annual resolution on marine mammal interactions in federally monitored fisheries.

We also included two conservation classifications for all bycaught species. First, we incorporated the status of each species according to the ESA. This was critical to include because bycatch of ESA-listed species (for example, sea turtles and salmon) can be subject to hard caps in US fisheries[50]. We also included the IUCN Red List status for each species (http://www.iucnredlist.org/) because the vast majority of marine fish and invertebrate species in US waters are not listed under the ESA. Furthermore, many nations do not have legislation analogous to the ESA, so using the IUCN status of each bycaught species increases the transferability of our analyses to other fisheries internationally, recognizing that the IUCN status may be an overly conservative metric. We considered any species with an IUCN ranking of 'near threatened' or rarer to be of conservation concern. Hereafter we call these species 'IUCN-listed'.

We included uncertainty for estimated bycatch by using the coefficient of variance reported in the NBR database system. Bycatch estimate coefficient of variance measure precision based on the ratio of the square root of the variance of the bycatch estimate (the s.e.m.) to the estimate itself and are provided in the NBR based on available regional estimation resources and priorities[52]. A categorical metric of reporting bycatch monitoring quality is also included as Fishery Tier Classification System[53] categories as follows: (0) no implemented bycatch data collection programmes; (1) bycatch estimates typically based on outdated or unreliable information and observer data are unavailable; (2) bycatch estimates include current or recent bycatch data, but observer programmes generally were inadequate due to factors such as limited coverage and inconsistent sampling; (3) bycatch estimates based on reliable observer programme data or recent logbook data with robust analytical approaches but limited observer coverage and varied sampling designs; and (4) bycatch estimates based on reliable observer programme data collected on an annual basis for at least the past 5 years, with negligible or non-existent programme design deficiencies.

Bycatch analysis. In order to facilitate analyses of bycatch data and make comparisons across regions and fisheries, we developed the RBI. We first summarized the compiled bycatch data for each fishery ($n=95$) and year ($n=6$). This process included summing the number of seabirds and sea turtles caught, as well as all fish and invertebrate discards (in pounds or individuals); summing the total numbers of ESA- and IUCN-listed species caught (fish and invertebrates, in pounds or individuals; seabirds and sea turtles, by individuals); averaging the coefficient of variation and appending bycatch ratio, MMPA category ranking and Fishery Tier Classification for each fishery year ($n=457$ fishery years). Twelve criteria were then used to develop the RBI metric for each fishery in each year (Box 1).

After examining the distributions of the raw data for each of the 12 criteria (Supplementary Fig. 2), we normalized each criteria data across all fisheries between 0 and 1 to allow for inter-fishery comparison. Fish and invertebrate discards vary between being reported in pounds or individuals and were combined after normalization. MMPA category rankings were inverted for analysis, so that 1 indicates a fishery with remote likelihood of bycatch and 3 indicates a fishery with frequent bycatch interactions. Fishery tier classifications were also inverted in the normalization, so that 1 indicates a fishery with good observer coverages and 4 indicates a fishery with poor observer coverage. This was conducted to ensure that across all criteria, low values indicate a good score and high values indicate a poor score. RBI for each fishery year (f) was calculated as the weighted average across criteria:

$$\mathrm{RBI}_f = \frac{\sum_{i=1}^{n} C_i W_i}{\sum_{i=1}^{n} W_i}$$

where C is the normalized data for each criteria (i) and W refers to the weights of each criteria. Weights were equal to one for all criteria except the MMPA, which was doubled to have greater representation of marine mammal bycatch in the analysis relative to the other criteria. We provide an adjustable slider for this criterion on the web-based application to visualize how changing the weightings influences the final RBI for each fishery in a given year. The 25% and 75% quantiles for fishery RBIs were calculated and fishery years exceeding these quantiles were chosen as representative examples in the discussion. The weighted variance of RBI for each fishery year $\left(\hat{\sigma}_f^2\right)$ was also calculated using the wt.sd function in the SDMTools package[54] in R (v.3.6):

$$\hat{\sigma}_f^2 = \frac{\sum_{i=1}^{n} W_i}{\left(\sum_{i=1}^{n} W_i\right)^2 - \sum_{i=1}^{n} \left(W_i^2\right)} \sum_{i=1}^{n} W_i (C_i - C')^2$$

where C' is the sample mean across criteria. The weighted variance highlights the variability in criteria values used to estimate the RBI for each fishery and year, where high values indicate more spread among criteria for a given fishery (Supplementary Fig. 3).

Finally, a sensitivity analysis was conducted to determine the relative effect of each criteria on the final RBI (Supplementary Fig. 4). This sensitivity analysis used Monte Carlo simulations ($n = 1,000$ iterations) to select unique criteria values for each fishery year, where criteria (C) values were randomly varied $\pm 10\%$. The random criteria values were then standardized and used in a multiple linear regression to express fishery score as a function of the 12 criteria. The resulting parameter coefficients represent the relative importance of parameters in the RBI[55].

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

All the raw NBR data can be explored, queried, visualized and downloaded at: https://ceg.ucsc.edu/projects/nbrexplorer.

Code availability

All code used to analyse data and generate plots found in the paper is at: https://github.com/mssavoca/NOP_NBR_bycatch_analysis.

Received: 4 October 2019; Accepted: 2 March 2020;
Published online: 30 March 2020

References

1. Food and Agriculture Organization. *The State of World Fisheries and Aquaculture 2018 – Meeting the Sustainable Development Goals* (FAO, 2018).
2. Benaka, L. R., Bullock, D., Hoover, A. L. & Olsen, N. A. (eds) *US National Bycatch Report First Edition Update 3* (US Department of Commerce, NOAA, 2019).
3. Davies, R. W. D., Cripps, S. J., Nickson, A. & Porter, G. Defining and estimating global marine fisheries bycatch. *Mar. Policy* **33**, 661–672 (2009).
4. Pérez-Roda, M. et al. *A Third Assessment of Global Marine Fisheries Discards* No. 633 (FAO, 2019).
5. Gilman, E. L. Bycatch governance and best practice mitigation technology in global tuna fisheries. *Mar. Policy* **35**, 590–609 (2011).
6. Gilman, E. et al. Robbing Peter to pay Paul: replacing unintended cross-taxa conflicts with intentional tradeoffs by moving from piecemeal to integrated fisheries bycatch management. *Rev. Fish. Biol. Fish.* **29**, 93–123 (2019).
7. Wilcox, C. & Donlon, C. D. Compensatory mitigation as a solution to fisheries bycatch–biodiversity conservation conflicts. *Front. Ecol. Environ.* **5**, 325–331 (2007).
8. Lewison, R. L., Crowder, L. B., Read, A. J. & Freeman, S. A. Understanding impacts of fisheries bycatch on marine megafauna. *Trends Ecol. Evol.* **19**, 598–604 (2004).
9. Lewison, R. L. et al. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. *Proc. Natl Acad. Sci. USA* **111**, 5271–5276 (2014).
10. Little, A. S., Needle, C. L., Hilborn, R., Holland, D. S. & Marshall, C. T. Real-time spatial management approaches to reduce bycatch and discards: experiences from Europe and the United States. *Fish. Fish.* **16**, 576–602 (2015).
11. Senko, J., White, E. R., Heppell, S. S. & Gerber, L. R. Comparing bycatch mitigation strategies for vulnerable marine megafauna. *Anim. Conserv.* **17**, 5–18 (2014).
12. Eguchi, T., Benson, S. R., Foley, D. G. & Forney, K. A. Predicting overlap between drift gillnet fishing and leatherback turtle habitat in the California current ecosystem. *Fish. Oceanogr.* **26**, 17–33 (2017).
13. Swimmer, Y. et al. Food color and marine turtle feeding behavior: can blue bait reduce turtle bycatch in commercial fisheries? *Mar. Ecol. Prog. Ser.* **295**, 273–278 (2005).
14. Shiode, D., Hu, F., Shiga, M., Yokota, K. & Tokai, T. Midwater float system for standardizing hook depths on tuna longlines to reduce sea turtle by-catch. *Fish. Sci.* **71**, 1182–1184 (2005).
15. Pierre, J. P. & Norden, W. S. Reducing seabird bycatch in longline fisheries using a natural olfactory deterrent. *Biol. Conserv.* **130**, 406–415 (2006).
16. Swimmer, Y. et al. Sea turtle bycatch mitigation in US longline fisheries. *Front. Mar. Sci.* **4**, 260 (2017).
17. Melvin, E. F., Guy, T. J. & Read, L. B. Best practice seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species. *Fish. Res.* **149**, 5–18 (2014).
18. Alessandro, L. & Antonello, S. An overview of loggerhead sea turtle (*Caretta caretta*) bycatch and technical mitigation measures in the Mediterranean Sea. *Rev. Fish. Biol. Fish.* **20**, 141–161 (2010).
19. Barlow, J. & Cameron, G. A. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Mar. Mammal. Sci.* **19**, 265–283 (2003).
20. Carretta, J. V., Barlow, J. & Enriquez, L. Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. *Mar. Mammal. Sci.* **24**, 956–961 (2008).
21. Hobday, A. J., Hartog, J. R., Spillman, C. M. & Alves, O. Seasonal forecasting of tuna habitat for dynamic spatial management. *Can. J. Fish. Aquat. Sci.* **68**, 898–911 (2011).
22. Turner, S. M. et al. Cooperative research to evaluate an incidental catch distribution forecast. *Front. Mar. Sci.* **4**, 116 (2017).
23. Hazen, E. L. et al. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. *Sci. Adv.* **4**, eaar3001 (2018).
24. Gilman, E., Passfield, K. & Nakamura, K. Performance of regional fisheries management organizations: ecosystem-based governance of bycatch and discards. *Fish. Fish.* **15**, 327–351 (2014).
25. Halpern, B. S. et al. Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat. Commun.* **6**, 7615 (2015).
26. Di Minin, E. et al. Identifying global centers of unsustainable commercial harvesting of species. *Sci. Adv.* **5**, eaau2879 (2019).
27. Harrington, J. M., Myers, R. A. & Rosenberg, A. A. *Wasted Resources: Bycatch and discards in US Fisheries* (Oceana, 2005).
28. Brooke, S. G., Desfosse, L. L. & Karp, W. A. Estimating overall fish bycatch in US commercial fisheries. *Mar. Fish. Rev.* **74**, 1–5 (2012).
29. NOAA/NMFS. Fishery stock status updates. *NOAA Fisheries* https://go.nature.com/38ZtTIl (2019).
30. Dulvy, N. K. et al. Extinction risk and conservation of the world's sharks and rays. *eLife* **3**, e00590 (2014).
31. Cassoff, R. M. et al. Lethal entanglement in baleen whales. *Dis. Aquat. Organ* **96**, 175–185 (2011).
32. Wallace, B. P. et al. Global patterns of marine turtle bycatch. *Conserv. Lett.* **3**, 131–142 (2010).
33. *Stock Assessment and Fishery Evaluation (SAFE) Report for Atlantic Highly Migratory Species* (NOAA/NMFS, 2019).
34. Wallace, B. P., Heppell, S. S., Lewison, R. L., Kelez, S. & Crowder, L. B. Impacts of fisheries bycatch on loggerhead turtles worldwide inferred from reproductive value analyses. *J. Appl. Ecol.* **45**, 1076–1085 (2008).
35. Bolten, A. B. et al. Quantifying multiple threats to endangered species: an example from loggerhead sea turtles. *Front. Ecol. Environ.* **9**, 295–301 (2011).
36. Casale, P. & Heppell, S. S. How much sea turtle bycatch is too much? A stationary age distribution model for simulating population abundance and potential biological removal in the Mediterranean. *Endanger. Species Res.* **29**, 239–254 (2016).
37. Melvin, E. F., Dietrich, K. S., Suryan, R. M. & Fitzgerald, S. M. Lessons from seabird conservation in Alaskan longline fisheries. *Conserv. Biol.* **33**, 842–852 (2019).
38. Read, A. J., Drinker, P. & Northridge, S. Bycatch of marine mammals in US and global fisheries. *Conserv. Biol.* **20**, 163–169 (2006).
39. McDonald, S. L., Lewison, R. L. & Read, A. J. Evaluating the efficacy of environmental legislation: a case study from the US marine mammal take reduction planning process. *Glob. Ecol. Conserv.* **5**, 1–11 (2016).
40. Hayes, S. A., Gardner, S., Garrison, L., Henry, A. & Leandro, L. *North Atlantic Right Whales – Evaluating Their Recovery Challenges in 2018* (NOAA, 2018).
41. Lebon, K. M. & Kelly, R. P. Evaluating alternatives to reduce whale entanglements in commercial Dungeness crab fishing gear. *Glob. Ecol. Conserv.* **18**, e00608 (2019).
42. Costello, C. et al. Global fishery prospects under contrasting management regimes. *Proc. Natl Acad. Sci. USA* **113**, 5125–5129 (2016).
43. North Pacific Fishery Management Council *Pollock Conservation Cooperative and High Seas Catchers' Cooperative Joint Annual Report 2018* (NPFMC, 2019).
44. Lewison, R. et al. Dynamic ocean management: identifying the critical ingredients of dynamic approaches to ocean resource management. *Bioscience* **65**, 486–498 (2015).
45. National Oceanic and Atmospheric Administration. Fish and fish product import provisions of the Marine Mammal Protection Act. *Fed. Register* **81**, 1–31 (2016).
46. Rausser, G., Hamilton, S., Kovach, M. & Stifter, R. Unintended consequences: the spillover effects of common property regulations. *Mar. Policy* **33**, 24–39 (2009).
47. Zeller, D., Cashion, T., Palomares, M. & Pauly, D. Global marine fisheries discards: a synthesis of reconstructed data. *Fish. Fish.* **19**, 30–39 (2018).
48. Burgess, M. G., Polasky, S. & Tilman, D. Predicting overfishing and extinction threats in multispecies fisheries. *Proc. Natl Acad. Sci. USA* **110**, 15943–15948 (2013).
49. Burgess, M. G. et al. Protecting marine mammals, turtles, and birds by rebuilding global fisheries. *Science* **359**, 1255–1258 (2018).
50. Howell, E. A., Kobayashi, D. R., Parker, D. M., Balazs, G. H. & Polovina, J. J. TurtleWatch: a tool to aid in the bycatch reduction of loggerhead turtles *Caretta caretta* in the Hawaii-based pelagic longline fishery. *Endanger. Species Res.* **5**, 267–278 (2008).
51. Wickham, H. Tidy data. *J. Stat. Softw.* **59**, 1–23 (2014).

52. *Evaluating Bycatch: A National Approach to Standardized Bycatch Monitoring Programs* (NOAA/NMFS, 2004).
53. Desfosse, L. L., Karp, W. A. & Brooke, S. G. Evaluating the quality of bycatch data and bycatch estimates among disparate fisheries. *Mar. Fish. Rev.* **74**, 6–13 (2012).
54. Vanderwal, J., Falconi, L., Januchowski, S., Shoo, L. & Storlie, C. *SDMTools. Species distribution modelling tools: tools for processing data associated with species distribution modelling exercises* (CRAN, 2014); http://www.rforge.net/SDMTools/
55. Brodie, S. et al. Improving consumption rate estimates by incorporating wild activity into a bioenergetics model. *Ecol. Evol.* **6**, 2262–2274 (2016).
56. Murphy, W. & Rowlingson, B. *Fiftystater: map data to visualize the fifty US states with Alaska and Hawaii insets* (CRAN, 2016); https://github.com/wmurphyrd/fiftystater

Acknowledgements

We thank the fisheries observers who collected bycatch data that informed this work. Further, we thank the team at the National Observer Program (NOAA/NMFS) for drafting the NBRs, which provided the raw data used in this study. In addition, we appreciate data management assistance by C. Donegan and an internal review by S. Mesnick and J. Carretta (NOAA Southwest Fisheries Science Center). This work was made possible by a California Sea Grant Fellowship to M.S.S. and funding through the Fisheries Information Systems NOAA/NMFS.

Author contributions

M.S.S., L.R.B., S.J.B. and E.L.H. conceived and designed the study. M.S.S., S.B., H.W. and A.H. analysed the data. H.W. created the web application with input from all authors. M.S.S. wrote the manuscript with input and edits from all authors.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41893-020-0506-9.

Correspondence and requests for materials should be addressed to M.S.S.

nature research

Corresponding author(s): Matthew Savoca

Last updated by author(s): Feb 18, 2020

Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see Authors & Referees and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☒	☐	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☒	☐	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	All data were collected and collated Microsoft Excel 2016 and in R version 3.6.
Data analysis	All data were analyzed and visualized in R version 3.6. The code for this paper's results, figures, and web-based application can be found on our GitHub repository: https://github.com/mssavoca/NOP_NBR_bycatch_analysis

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

Data we used for analyses are available on our GitHub repository: https://github.com/mssavoca/NOP_NBR_bycatch_analysis
All raw bycatch data and associated metadata is available for download at: https://ceg.ucsc.edu/projects/nbrexplorer

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	We synthesized information from NOAA's National Bycatch Reports. The purpose of our study was to examine overall patterns and trends in recent bycatch (2010-2015) in US Fisheries, create a metric to compare fisheries' to one another, and develop a web-based application to make the data easily accessible to the public.
Research sample	The National Bycatch Reports (NBR) from which our data was obtained can be viewed here: https://www.fisheries.noaa.gov/resource/document/national-bycatch-report. The raw data are available to view by clicking "guest login": https://www.st.nmfs.noaa.gov/apex/f?p=243:101:11522042444195 We augmented the NBR with species-specific conservation statuses from the Endangered Species Act (https://www.fws.gov/endangered/), the IUCN Redlist (https://www.iucnredlist.org/), and the Marine Mammal Protection Act List of Fisheries (https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act-list-fisheries). The raw data we compiled will be released in our web-based application in a format that is conducive for analysis and visualization. A draft of the app can be viewed here: https://ceg.ucsc.edu/projects/nbrexplorer
Sampling strategy	See most recent National Bycatch Report for how the bycatch information was collected and aggregated.
Data collection	We downloaded all raw data
Timing and spatial scale	The data were collected from the recent annual National Bycatch Reports that are available here: https://www.fisheries.noaa.gov/resource/document/national-bycatch-report
Data exclusions	No data were excluded from the analysis
Reproducibility	All of our results can be replicated using the R code made available on the github repository: https://github.com/mssavoca/NOP_NBR_bycatch_analysis
Randomization	This was a synthesis and meta-analysis of bycatch information in US fisheries. All data was used, therefore randomization was not necessary.
Blinding	This was a synthesis and meta-analysis of bycatch information in US fisheries. All data was used, therefore blinding was not necessary.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology
☒	☐	Animals and other organisms
☒	☐	Human research participants
☒	☐	Clinical data

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging