Understanding impacts of fisheries bycatch on marine megafauna

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Hunting by humans played a major role in extirpating terrestrial megafauna on several continents and megafaunal loss continues today in both terrestrial and marine ecosystems. Recent declines of large marine vertebrates that are of little or no commercial value, such as sea turtles, seabirds and marine mammals, have focused attention on the ecological impacts of incidental take, or bycatch, in global fisheries. In spite of the recognition of the problem of bycatch, few comprehensive assessments of its effects have been conducted. Many vulnerable species live in pelagic habitats, making surveys logistically complex and expensive. Bycatch data are sparse and our understanding of the demography of the affected populations is often rudimentary. These factors, combined with the large spatial scales that pelagic vertebrates and fishing fleets cover, make accurate and timely bycatch assessments difficult. Here, we review the current research that addresses these challenging questions in the face of uncertainty, analytical limitations and mounting conservation crises.

About 15 000 years ago, intense hunting pressure, combined with habitat loss, led to the rapid extinction of ≥35 genera of large mammals in North America [1] and similar patterns of megafaunal loss occurred in New Zealand, Madagascar and Hawaii [2–5]. In each case, large-bodied organisms were extirpated over a relatively short period of time (i.e. 100–1000 years). It is likely that paleohistoric megafauna had life-history strategies that were similar to those of extant megafauna: low (and uncertain) recruitment rates over a long lifetime, and low mortality rates of older individuals. Such strategies, although an ideal buffer against annual environmental and demographic stochasticity, resulted in populations that were vulnerable to extinction in the face of intense hunting pressure on older individuals.

A similar pattern is now occurring in the oceans, but the megafauna being depleted are often not the intended targets of the hunt. Large marine vertebrates, such as sea turtles, marine mammals and seabirds, have little or no commercial value, but become entangled or hooked accidentally by fishing gear that is intended for valuable target species, such as swordfish *Xiphias gladius* or tuna *Thunnus* spp.[6]. This incidental take, or BYCATCH (see Glossary), occurs in all fishing fleets [7]. Populations

that are subject to bycatch can decline over short timescales (i.e. decades), often without detection [8]. If the target species of the fishery can sustain intense fishing effort and if bycatch is proportional to that effort, bycatch mortality levels will increase as fishing effort intensifies, irrespective of the amount of the target caught [9]. Fisheries bycatch has been implicated as an important factor in many population declines, including Pacific loggerhead *Caretta caretta* and leatherback *Dermochelys coriacea* sea turtles, North Atlantic harbor porpoises *Phocoena phocoena*, vaquita *Phocoena sinus* in the Sea of Cortez, Mediterranean striped dolphins *Stenella coeruleoalba*, the wandering albatross *Diomedea exulans* and white-chinned petrel *Procellaria aequinoctialis* of the Southern Ocean. Consequently, research attention has focused on the impact of fisheries bycatch on large marine vertebrates (Box 1).

Glossary

Artisanal: fisheries that are small scale and subsistence in nature, in contrast to industrial. Artisanal fishing effort is often unmonitored by regional fishery commissions.

Bycatch: the incidental take of undesirable size or age classes of the target species (e.g. juveniles or large females), or to the incidental take of other non-target species. Individuals caught as bycatch can be unharmed, released with injuries, or killed.

Demersal: a habitat or fishing range on or near the bottom of the ocean. Demersal fisheries target bottom-dwelling fish, such as halibut *Hippoglos* spp. and cod *Gadus* spp.

Elasticity: the proportional contribution of each demographic parameter to total population growth. Because elasticities sum to 1, they can be compared among parameters, and can be used to identify which parameters contribute the most to changes in population growth rate.

Gillnets: mesh nets of various sizes used to target many species of fish. Gillnets can range in sizes from meters to kilometers. Gillnets can be fixed (set) or free floating (**Driftnets**), and are a non-selective fishing method. Driftnets in international waters were banned by a 1992 UN resolution, but can still be used in sovereign waters. They are still used in international waters by illegal fishing vessels.

Iteroparous: a reproductive strategy that involves producing offspring at multiple reproductive events over a long lifespan.

Longline: a selective fishing gear comprised of a mainline (that can extend to 50 km) of evenly spaced branching lines, each fitted with a hook. Longline fisheries can target either pelagic or demersal habitat.

Observer program: data collection plans in which observers (independent of the fishery) collect data aboard fishing vessels on catch of commercial and bycatch species.

Pelagic: a habitat or fishing range in the water column, anywhere between 50 and 1500 meters. Pelagic fisheries target tuna *Thunnus* spp. and billfish (e.g. *Xiphias gladius*).

Purse seines: long walls of surrounding nets that are pulled closed underneath a fish school by cinching the bottom of the nets. Purse seines are used to catch tuna and other species.

Trawl: a towed net with a conical body that tapers to a point and is held open by wing-like structures. Trawl nets can target pelagic or demersal habitats.

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Box 1. Marine megafauna at risk

Sea turtles
Sea turtles are caught primarily by trawl, pelagic longline and coastal gillnet fisheries. Six of the seven extant sea turtle populations worldwide are listed in the IUCN Red List of Threatened Species (http://www.redlist.org) (Figure Ia, loggerhead turtle *Caretta caretta*; reproduced with permission from A.F. Rees/ARCHELON).

Seabirds
Albatrosses and petrels are caught by DEMERSAL and pelagic longline fisheries and have one of the highest proportions of species listed in the IUCN Red List of Threatened Species of any bird family [65] (Figure Ib, black-browed albatross *Diomedea melanophris*; reproduced with permission from D. Hyrenbach).

Sharks
Sharks are caught by pelagic longlines and gillnets. Many shark populations have shown evidence of decline, based on indirect measures. However, shark declines cannot be attributed solely to fisheries bycatch. Depending on the fishery, sharks can be caught as unwanted bycatch (Northwest Atlantic pelagic longline fishery), as commercially valuable non-target catch (Northeast Atlantic pelagic longline fishery), or as target catch (Pacific gillnet fishery). The practice of finning (cutting off the fins and throwing the remainder of the shark overboard) has probably contributed to observed declines. Finning increased during the 1980s and 1990s because of the high market value of shark fins in Asian countries, and the practice continues in spite of finning being banned by several countries (Figure Ic, blue shark *Prionace glauca*; reproduced with permission from C. Fritz-Cope, Pelagic Shark Research Foundation http://www.pelagic.org/).

Marine mammals
Many of the recommended projects in the IUCN Action Plan for Cetaceans (http://www.iucn.org/themes/ssc/actionplans/cetaceans/cetaceans.pdf) pertain to bycatch. Fixed and drift gillnets cause the greatest bycatch of small marine mammals, although small cetaceans and pinnipeds also can be caught in purse seines and mid-water trawl nets. Pelagic driftnets were banned in international waters by a UN resolution adopted in 1992, but individual nations can still use driftnets <2.5 km in length and illegal high-seas driftnet boats continue to be found by law-enforcement vessels (Figure Id, Atlantic spotted dolphin *Stenella frontalis*; reproduced with permission from K. Urian).
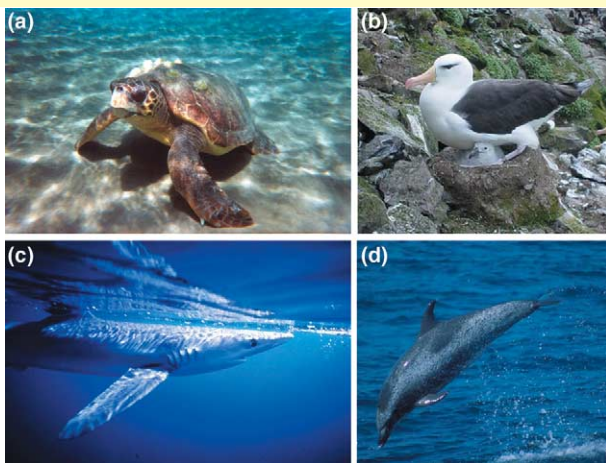

Figure I.

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Demographic profiles of at-risk species
Many species of marine megafauna are particularly vulnerable to overexploitation, as illustrated by the collapse of the Southern Ocean whale populations during the past century [10]. The link between large size and vulnerability to exploitation lies within life-history characteristics [11]. Although marine megafauna exhibit a range of life-history strategies, they typically have a long lifespan, mature late in life, have low reproductive output and rely on a strongly ITEROPAROUS reproductive strategy. To offset their low fecundity, these large-bodied species require high rates of sub-adult and adult survival. Whereas low and variable survival of eggs or juveniles might be the norm for many megafauna (e.g. survival rates for sea turtle eggs can be as low as 20%), intense predation by humans on adults or sub-adults is likely to have devastating effects [10].

Life-history theory and demographic analyses are important tools in helping us to understand the vulnerability of species to fisheries bycatch [12]. Unfortunately, many vulnerable megafauna, including large sharks, deep-sea fish, sea turtles and cetaceans have poorly known life histories as a result of the logistical challenges of studying PELAGIC organisms. In the absence of species-specific information, general life-history characteristics (e.g. age at sexual maturity, annual reproductive capacity and lifespan) as well as demographic techniques (e.g. life table analysis) can help to predict how populations will respond to bycatch perturbations. One such technique, ELASTICITY analysis, estimates the proportional contribution of each demographic parameter (i.e. age-specific fecundity and survivorship) to total population growth and has been used to quantify the vulnerability of particular species to chronic mortality sources that affect different age classes [13] As predicted by life-history theory, elasticity analyses have shown that many megafauna species are sensitive to changes in survival probabilities for sub-adult and adult life stages [14]. Across taxa, bycatch of even a few individuals from sensitive age classes can have large population-level effects [15–19].

Challenges to understanding the problem
The crucial proximate questions when considering the effects of fisheries bycatch are: (i) how many individuals are being removed from a population; and (ii) what are the demographic effects of these removals? To answer these questions, two key points must be addressed: data limitations and spatial scale.

Data limitations
In contrast to statistics collected for target species once fish are brought to shore, bycatch data are based on fishers' logbooks or independent OBSERVER PROGRAMS. Voluntary logbook records report catches of target (and other commercial) species and fishers can also record bycatch events. However, these data cannot be independently verified and most research suggests that logbooks significantly underreport the magnitude of bycatch [20]. Several nations employ independent observers to record bycatch, but observer effort is low relative to the total fishing effort (Box 2) and, although observer programs provide the highest quality bycatch data, they are costly and require well trained observers (Box 2, Table I). Logbook and observer programs vary by nation,

Box 2. Data limitations: how much bycatch data are there?

Observer programs provide the highest quality bycatch data, but are costly and require observers who are independent of the fishing industry and are well trained. There have been few attempts to synthesize these data into integrated analyses (but see [27]). Even for the pelagic longline fishery, which has the largest number of observer programs (15 programs for 40 major fishing nations), a global analysis of sea turtle bycatch found that there was observer data for <25% of the pelagic longline gear deployed during 2000 [27] (Table I).

Table I. Available observer data based on information from individual nations and international fishing commissions (ICCAT, IATTC, IOTC, and SPC)[a]

Fishery implicated in population declines	Total no. of fishing nations	No. of nations with observer programs[c]
Gillnet and driftnet[b]	37	5
Trawl	14	4
Pelagic longlines	40	15
Purse seine	62	10

[a]Abbreviations: IATTC, Inter-American Tropical Tuna Commission, http://www.iattc.org; ICCAT, International Commission for the Conservation of Atlantic Tunas, http://www.iccat.es; IOTC, Indian Ocean Tuna Commission, http://www.iotc.org; SPC, Secretariat of the Pacific Community, http://www.spc.org.nc
[b]Does not include the widespread artisanal or subsistence fisheries along coastal zones. A small proportion of the fishing effort from these small vessels is monitored by fishing management organizations.
[c]Not all data from programs have been published or made publicly available.

fishery and area (e.g. within national jurisdiction or international waters).

A substantial portion of global fishing effort is either under reported or entirely unreported. ARTISANAL and subsistence fisheries often receive little attention from domestic or international authorities and, as a result, both fishing effort and bycatch from these fisheries are largely unknown. Even large-scale industrial fisheries are subject to substantial illegal, unregulated, or unreported (IUU) fishing effort that contributes to overall bycatch. Populations caught as bycatch can also be subject to mortality from other anthropogenic factors (e.g. egg harvest, introduced predators, contaminants, debris ingestion and entanglement). These factors affect different age classes in different ways and, therefore, a comprehensive assessment of the relative effects of fishery bycatch requires considerable demographic data as well as information about other mortality sources.

The main consequence of these data limitations is the introduction of uncertainty, both in the data available and with unknown or missing data. The existence of uncertainty can impede progress in conservation efforts, because management actions needed to protect a species can be delayed until conclusive evidence is available. Therefore, finding ways to address data uncertainty explicitly is one of the primary challenges to bycatch research. Another important consideration is the inherent uncertainty (also described as limited knowability) in marine ecosystems [21]. Although data limitations contribute to uncertainty in bycatch research, some level of uncertainty is likely to exist even in the best-studied dynamic systems, given their dynamic nature and complex behavior. Although more data on bycatch events and trends will always be warranted, bycatch research must be based on available data and must make use of strategies that address these sources of uncertainty [22].

Spatial scale

Many marine species taken as bycatch have ocean-wide distributions - sea turtles travel across oceans to reach nesting and foraging areas [23,24], seabirds can travel hundreds of kilometers in days [25], and the same is true for many marine mammals and sharks [26]. Fishing effort is also globally distributed: some areas are subject to fishing pressure from multiple fisheries, but there are few (if any) ocean regions that remain entirely unfished [27]. Given the wide distributions of marine megafauna and the multinational fishing fleets with which they interact, a large-scale perspective is required to characterize accurately the magnitude and extent of bycatch effects. National bycatch assessments can address important local conservation concerns, but, for many marine species, these analyses are not indicative of the conservation status of the population or species as a whole. To further the state of bycatch research and to prevent future marine megafaunal extirpations, it is essential that researchers begin considering the effects of bycatch from multinational fleets across fisheries.

Ecological consequences

Fisheries bycatch can have direct effects on a single species that is incidentally caught by a particular type of gear, but can also lead to changes at the community or ecosystem level, often called higher-order effects.

Species-specific effects

The most obvious consequences of fisheries bycatch are population declines. Once a decline has been detected, the most immediate task is to identify the demographic effect that a given fishery could be having. However, evaluating the impact of fisheries on pelagic organisms can be problematic because of: (i) the time required to detect population changes of long-lived organisms; (ii) the existence of sublethal effects; and (iii) the challenges associated with surveys of pelagic organisms. Time lags, a result of a long generation time, can delay the response of a population to a disturbance by many years, particularly as generation times range from 10 to 30 years for many bycatch species [14,28]. Fisheries bycatch can result in direct mortality, but can also lead to delayed mortality or sublethal injuries, both of which are challenging to measure [29]. Pelagic populations are fundamentally difficult to monitor. Even for species with a terrestrial component to their life cycle (e.g. sea turtles, seabirds and seals that nest or breed on land), it is hard to detect changes in the total population through the filter of a single age class, because breeding adults represent only a small proportion of the total population [14,28].

In spite of these confounding factors, we now understand that many species of marine megafauna are at risk of extinction from fisheries bycatch. Research has linked declines in albatross populations to LONGLINE fishing effort, and TRAWL-fishing to the number of dead sea turtles that wash up on beaches [30–33]. Threats to populations of small cetaceans have been linked to GILLNET, DRIFTNET, PURSE SEINE and trawl fisheries [34,35]. Although certain fisheries have received the lion's share of recent research attention (e.g. driftnet, trawl and pelagic longline fisheries),

most fisheries can incidentally catch marine megafauna. Given the demographic vulnerability of megafauna, even a selective, or 'clean', fishery that catches only a few individuals incidentally can have serious population-level effects.

Higher order effects

Fisheries bycatch might also cause higher order effects, but these are more difficult to detect. Research focused on the impact of target species harvest and, in particular, the exploitation of apex species (i.e. those at the top of a food chain), has pointed to widespread community and eco-system effects of intense harvest of species at high trophic levels [36–39]. As apex species, large marine vertebrates play an important role in food-web structure and ecosystem function [37,38] and the incidental removal of such megafauna could lead to cascading ecological changes [40].

Solutions

Although understanding the impacts of fisheries bycatch is a daunting research challenge, scientists have recently laid the groundwork by developing methods that can identify bycatch effects and can quantify the magnitude of those effects.

Quantifying the effects of bycatch

Several approaches have been developed to quantify taxa-specific effects of fisheries bycatch. Given the importance and the ubiquity of uncertainty, all current approaches use some type of uncertainty analysis. To consider the impact of northern right whale dolphin *Lissodelphis borealis* bycatch in the now-defunct high seas driftnet fishery in the Pacific, Mangel [15] accounted for uncertainty by comparing different methods of calculating bycatch levels and alternative models of assessing the population-level effects. The author presented model results across a range of values for the demographic parameters with the highest level of uncertainty (i.e. mortality and population size) and found that, even across the range of values, the level of depletion of this population was likely to be severe. Caswell *et al.* [17] used Monte Carlo uncertainty analyses to evaluate the effect of gillnet bycatch on harbor porpoises *Phocoena phocoena* in the North Atlantic. After calculating uncertainty distri-butions for key parameters (e.g. age at first reproduction and age-specific survival), the authors used these para-meter distributions in a projection matrix and calculated the population-level effects of bycatch levels, determined from a bootstrap sample of known data, and found that gillnet bycatch posed a serious threat to harbor porpoise populations. A similar approach was used to assess dusky dolphin *Lagenorhynchus obscurus* bycatch in trawl fish-eries off Patagonia, Argentina suggesting that trawl bycatch is probably exceeding a population threshold of ½R, where R represents the upper limit of mortality that a population can sustain before declining. [35].

To consider population-level effects of shark bycatch in the Northwest Atlantic pelagic longline fishery, Baum *et al.* [41] used bycatch records from logbook data, which cover many more years than do observer data for this fishery. To address probable bias and uncertainty in the

fisheries-dependent logbook data, the authors developed a method that only included records of positive (non-zero) bycatch, assuming that, if a positive bycatch value was recorded, it was a correct approximation of the bycatch observed. From this analysis, these authors show evidence of rapid and substantial declines in large coastal and oceanic shark populations as a result of bycatch in this ocean region.

For many fisheries, some observer data are available, but have not been collected (or made available) for all fleets. To address this limitation while quantifying albatross bycatch in the central North Pacific pelagic longline fishery, Lewison and Crowder [19] accounted for missing fleet bycatch data by using a scenario analysis, an approach developed by economic forecasters to combine known parameters with realistic uncertainty [42,43]. The authors created probable bycatch scenarios based on known data, generated a range of bycatch estimates based on these scenarios, and estimated the population-level effects across this range of estimates. They found that even the lowest bycatch levels, if unmitigated, resulted in population declines over two to three gener-ations [19]. To evaluate the impact of bycatch for threatened sea turtles that interact with global fishing fleets, Lewison *et al.* [27] synthesized all existing and available observer data sets, and used empirical and extrapolation techniques to estimate a probable range of bycatch per ocean region, accounting for spatial and temporal variability in bycatch. To put this bycatch into a population-level context, the authors calculated the probability of capture for an individual turtle in the vul-nerable age-class. Even with deviations from demographic assumptions, the annual probability of a vulnerable turtle getting hooked or entangled was substantial (≥ 0.50).

The central theme of these studies is the need to address and incorporate uncertainty. By necessity, bycatch research makes demographic and analytical assumptions; for example, that positive logbook data records accurately characterize bycatch, or that bycatch rates from one fleet can be used to describe accurately bycatch from another fleet. The challenge is to present explicitly the caveats and limitations of these analyses and show how robust results are in response to deviations from assumptions.

Managing bycatch

As reports of declining marine vertebrate populations have increased, reducing or eliminating bycatch of endangered or threatened species has emerged as a management imperative. Although no management strat-egy has yet eliminated a bycatch problem, there are clear signs of progress (Table 1). Alliances between the fishing industry, scientists and conservation groups have gene-rated effective devices and gear changes to mitigate bycatch in several ocean regions [44–49]. The best-known bycatch reduction case study, the Eastern Tropical Pacific dolphin–tuna conflict, highlights both the suc-cesses and hurdles in bycatch reduction (Box 3).

Fisheries management policies (e.g. time and area closures or moratoria on fisheries) have also been implemented to reduce bycatch. Although these policies

Table 1. Gear innovations that reduce bycatch[a]

Technological fix	How it works	Fishery	Refs
Turtle excluder devices	A large metal grid in the neck of a trawl net that physically excludes turtles from base of trawl nets while allowing shrimp to be caught effectively	Trawl	[47]
Tori (bird scaring) lines	Keep seabirds from baited hooks	Pelagic longline	[44–46,58–60]
Weighted lines	Sink hooks faster out of reach of seabirds		
Side-setting	Reduces the scavenging area by half		
Line-setting devices	Place baited hooks immediately underwater		
Circle hooks	Reduce frequency of deeply ingested hooks and limits gut perforation	Pelagic longline	[48,49]
Pingers	Acoustic devices that alert marine mammals to the presence of gillnets to prevent entanglement	Gillnet	[61–63]
Medina panels	Fine-mesh net aprons that reduce the probability of dolphin entanglement during net retrieval	Purse seines	[64]

[a]Although these methods are effective in reducing bycatch for some fleets, none has yet eliminated the problem of bycatch. There is still a need for additional gear development, testing, and implementation across ocean areas and fisheries.

provide an immediate solution to reducing bycatch by temporarily reducing or displacing fishing effort, closures can also introduce additional problems, including the reallocation of fishing effort, which can lead to higher bycatch of other vulnerable species [41]. Recent research has identified links between oceanographic features and marine vertebrate distributions that might prove to be valuable management tools. For example, research on sea turtle movements has pointed to an association between turtles and temperature gradients that are associated with oceanic fronts [50,51]. If such relationships are consistent, fisheries managers could use spatially explicit bycatch reduction policies that utilize oceanographic features to protect marine megafauna.

International agreements also have helped address bycatch issues. Although most agreements are non-binding, they establish a common expectation and understanding among fishing nations and can provide momentum for subsequent multilateral treaties; for example, the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC, http://www.seaturtle.org/iac/). Several bycatch agreements have emerged in the past few years, including the of Conduct for Responsible Fisheries, (http://www.fao.org/fi/agreem/codecond/codecon.asp), the International Plan to Reduce Seabird Bycatch and the International Plan to Reduce Shark Bycatch (http://www.fao.org/fi/site.asp) of the United Nations Food and Agriculture Organization. Given that most of these agreements have been implemented only within the past few years, it is premature to assess their efficacy. However, these agreements are one of the only venues solely designed to facilitate international dialogue, cooperation, and coordination of bycatch mitigation technology and practices.

Conclusions and future directions

Research is fundamental to our understanding of the effects and consequences of fisheries bycatch. Although the scientific community has made recent progress in estimating the impact of fisheries on non-target species, we are still in the nascent stage of understanding population-level and ecosystem effects of bycatch. Although marine megafauna are particularly susceptible to bycatch, many other less charismatic species are also affected, and this is thought to have serious ecological consequences. Deep-sea corals and sponges are being destroyed in large numbers by bottom-trawling fisheries worldwide, [52–55] of the order of one million pounds of corals and sponges between 1997 and 1999 in Alaskan waters alone [56]. This highlights the fact that fisheries bycatch is a complex, ecosystem-wide issue. To promote both fisheries management and marine species conservation, future bycatch research must continue to address crucial data limitations (e.g. vulnerability of specific age classes, spatial and seasonal hotspots of bycatch, and bycatch differences among multinational fleets) and develop novel approaches to addressing uncertainty.

However, research is only one piece of a much larger puzzle; reducing bycatch to sustainable levels will also require collaborative efforts among scientists, conservation organizations, resource managers and industry, for example, the Cetacean Bycatch Resource Center (http://www.cetaceanbycatch.org). This integration must include an economic perspective and account for fisher behavior and decision making [57]. Consumers also play an important role by influencing market value and demand (Box 4).

Box 3. Purse seines and dolphins: a success story?

The Eastern Pacific tuna fishery targets yellowfin *Thunnus albacares*, bigeye *Thunnus obesus* and skipjack *Katsuwonus pelamis* tuna using a netting technique called purse seining. Purse seines are long walls of surrounding nets that are pulled closed underneath a fish school by cinching the bottom of the nets. For several decades in the Eastern Tropical Pacific, schools of dolphins have been used to locate mature yellowfin tuna, which often travel below the dolphins. After a prolonged chase, the purse seine is set around the dolphin school and tuna (such catches are termed 'dolphin sets'). As the net surrounds the area, both the tuna and dolphins are captured, which resulted in the deaths of hundreds of thousands of pelagic dolphins during the 1960s and 1970s.

Public concern over this mortality led, in part, to passage of the US Marine Mammal Protection Act in 1972. Since then, environmental groups have sought further protection for pelagic dolphins by imposing trade restrictions that prohibit the sale of tuna captured in dolphin sets in the US. In turn, the tuna fishery responded by developing several innovations that reduced the mortality of dolphins; in most sets, all dolphins are now released alive. Nevertheless, dolphin populations have not recovered, perhaps as a result of chronic, sub-lethal effects of prolonged chase and frequent capture. In addition, bycatch of immature tuna and other species (turtles and sharks) has increased as a result of the new fishing practices that use floating objects (such as logs or artificial devices) to attract large, mixed schools of tuna and associated species. This example highlights some of the difficulties of bycatch reduction, particularly the potential for sublethal effects, and also the limitations of a single-species approach to bycatch management.

Box 4. Outstanding questions

• Will a better understanding of the habitats and movement patterns of marine megafauna help minimize bycatch effects via time-area closures or pelagic marine reserves?
• How will the international fishing community implement effective and timely action to minimize bycatch in the open sea (64% of all ocean habitat), before marine megafanua are extirpated?
• How can we translate lessons learned in developed countries regarding assessment and bycatch reduction to fisheries of the developing world?
• Who will pay for monitoring programs and bycatch reduction technology in the fisheries of developing nations (e.g. India, China and the Philippines)?
• How will consumer choice and product labels (e.g. Marine Stewardship Council) influence the evolution of ecologically sustainable fisheries?

Although bycatch mitigation can begin at the national level, fisheries bycatch is a global problem. Effective bycatch mitigation will require coordinated actions by international stakeholders to develop a combination of technological gear fixes, changes in fishing practices, modification of fishing effort and international agreements that, together, can monitor and mitigate bycatch (Box 4).

More data on megafaunal (and non-megafaunal) bycatch is warranted. However, uncertainty in both existing data and in the dynamics of natural systems should not be used as an excuse to prevent research or management action. Uncertainty will always be a factor in research on pelagic organisms and their environment. Empirical data point to dramatic declines and changes in marine systems, and ongoing research continues to provide techniques to incorporate and contend with uncertainty. The challenge is to produce timely and scientifically defensible research based on available data to address this conservation crisis now.

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