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LETTER

Extinction risk and bottlenecks in the conservation of charismatic marine species

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Abstract

The oceans face a biodiversity crisis, but the degree and scale of extinction risk remains poorly characterized. Charismatic species are most likely to garner greatest support for conservation and thus provide a best-case scenario of the status of marine biodiversity. We summarize extinction risk and diagnose impediments to successful conservation for 1,568 species in 16 families of marine animals in the movie *Finding Nemo*. Sixteen percent (12–34%) of those that have been evaluated are threatened, ranging from 9% (7–28%) of bony fishes to 100% (83–100%) of marine turtles. A lack of scientific knowledge impedes analysis of threat status for invertebrates, which have 1,000 times fewer conservation papers than do turtles. Legal protection is severely deficient for sharks and rays; only 8% of threatened species in our analysis are protected. Extinction risk among wide-ranging taxa is higher than most terrestrial groups, suggesting a different conservation focus is required in the sea.

Introduction

The oceans are inhabited by all but one of the 31 described phyla and hence encompass the majority of the Earth's unique evolutionary history (May 1994). The threat status of terrestrial species is becoming increasingly clear (Butchart *et al*.2004; Stuart *et al*. 2004), but a high degree of uncertainty exists regarding extinction risk in the oceans. Systematic Red List assessments (Carpenter *et al*. 2008; Polidoro *et al*. 2010; Collette *et al*. 2011; Short *et al*. 2011), indices of biodiversity loss (e.g., Butchart *et al*. 2010), and debates over fishing impacts (e.g., Pauly *et al.* 1998; Branch *et al*. 2011) are unveiling an emerging marine biodiversity crisis. However, most assessments of marine species' status have focused on a few well-studied taxonomic groups and commercially exploited fish, which represent a small and biased fraction of marine biodiversity (Table 1).

One informative approach to assessing biodiversity loss and extinction risk in the ocean is to evaluate the status of charismatic species. One would hope that charismatic species would be least likely to disappear because they are more frequently studied by scientists (Clark & May 2002), receive disproportionate attention and funding relative to their conservation need (Tisdell & Nantha 2007), and garner greater attention from the media and the public (Duarte *et al*. 2008). Thus, the threat status of publically recognized species may provide an indication of the lower boundary of the likelihood of extinction in the sea.

Here we address two questions: (1) what is the threat status of some of the most charismatic species in the

Table 1 Evaluations of the threat status of marine species and ecosystems by geographic scale and taxonomic scope

Geographic scale	Taxonomic scope	Number of marine species	Reference
Global	Oceanic pelagic sharks	21	Dulvy *et al*. 2008
North Sea	Demersal fishes	23	Dulvy *et al*. 2006
Global	Tunas and billfishes	61	Collette *et al*. 2011
Circumtropical	Mangroves	70	Polidoro *et al*. 2010
Global	Seagrasses	72	Short *et al*. 2011
Global	Mammals	121	Schipper *et al*. 2008
Global	Commercially exploited fishes	124	Branch *et al*. 2011
Global	Birds	133	Butchart *et al*. 2004
Global	Commercially exploited fishes & invertebrates	220	Pauly *et al*. 1998
Global	Vertebrates	254	Hoffmann *et al*. 2010
Circumtropical	Reef-building corals	845	Carpenter *et al*. 2008
Global	Charismatic species	1,568	This study

Table 2 Groups of marine animals represented in *Finding Nemo* included in our analysis

Species group	Family	Number of marine species	Species in "Finding Nemo"
Turtles	Cheloniidae	6	Green turtle (Crush, Squirt)
Birds	Pelecanidae	8	Brown pelican (Nigel)
Elasmobranchs	Sphyrnidae	8	Hammerhead shark (Anchor)
	Lamnidae	5	Great white, mako sharks (Bruce, Chum)
	Myliobatidae	40	Spotted eagle ray (Mr. Ray)
Bony fishes	Acanthuridae	81	Blue & yellow tang (Dory, Bubbles)
	Grammatidae	13	Royal gramma (Gurgle)
	Monodactylidae	6	Moonfish (school)
	Pomacentridae	372	Clown anemonefish, four-striped damselfish (Nemo, Marlin, Coral, Deb)
	Zanclidae	1	Moorish idol (Gill)
	Chaetodontidae	128	Longnose butterfly fish (Tad)
	Syngnathidae	238	Seahorse (Sheldon)
	Tetraodontidae	126	Pufferfish (Bloat)
Invertebrates	Hippolytidae	329	Pacific cleaner shrimp (Jacques)
	Asteriidae	167	Sea star (Peach)
	Opisthoteuthidae	40	Flapjack octopus (Pearl)

ocean? and (2) what are the impediments to their successful conservation? First, we summarize the extinction risk of 1,568 species within 16 families of well-known marine animals represented in the 2003 Academy Award-winning movie, *Finding Nemo*. Second, we diagnose impediments, or bottlenecks, in the path toward their conservation by evaluating the availability of scientific knowledge leading to the completion of status assessments and the translation of threatened status to legal protection across taxonomic groups.

Methods

Species included in this analysis are those that appear in the animated film, *Finding Nemo*. We began with all major characters, as defined by those with credited speaking parts, and included all species within their taxonomic families, allowing for a comparison of differences among groups. Species lists were generated from the World Register of Marine Species (www.marinespecies.org), Fishbase (www.fishbase.org), the Tree of Life (www.tolweb.org), and occasional consultations with systematists. When families included both marine and nonmarine species (e.g., Syngnathidae), we excluded inland freshwater species, resulting in 1,568 marine and estuarine species for analysis (Table 2).

We evaluated extinction risk by determining the proportion of species at risk using International Union for the Conservation of Nature (IUCN) Red List Assessments. The IUCN categories of risk are Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD). We considered those that were listed as CR, EN, VU as "threatened," and assumed that DD species were threatened in the same proportion as data-sufficient species (*sensu* Hoffmann *et al*. 2010). We assumed that DD evaluations represented uncertainty around the true threat level and thus calculated a lower bound (by assuming no DD species were threatened) and an upper bound (assuming all DD species were threatened). We compiled a full list of "first-order threats" for each family, as defined by the IUCN threat typology (Salafsky *et al*. 2008). We then grouped these into major threat categories (exploitation, pollution, climate change, habitat loss, and invasive species) and ranked these by the number of species affected by each.

We evaluated impediments to the understanding of threat status across taxonomic groups by comparing the availability of scientific knowledge and the completion of IUCN Red List status assessments as of March 2011. We evaluated knowledge by family as (1) the total number of scientific papers included in the Web of Science database

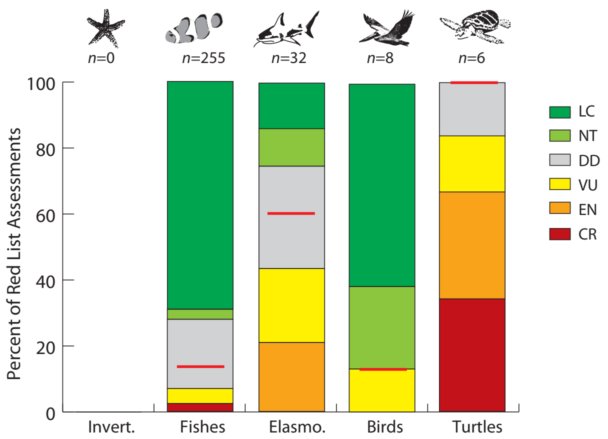

Figure 1 The proportion of species in different IUCN Red List categories. LC, Least Concern; NT, Near Threatened; DD, Data Deficient; VU, Vulnerable; EN, Endangered; CR, Critically Endangered. Red lines indicate the percentage of species considered threatened (VU, EN, & CR) if Data Deficient species are threatened in the same proportion as data-sufficient species.

(www.isiknowledge.com) and (2) the number of papers categorized by the subjects (not the narrower keywords) "biodiversity and conservation" or "environmental science." We standardized the results by the differing number of species in each family and determined the percentage of species that had at least one peer-reviewed conservation science paper.

We evaluated the translation of threatened status to legal protection by determining the percentage of threatened species within each family listed on Appendices of the Convention on the International Trade in Endangered Species (CITES 2008). CITES is the most comprehensive multilateral species-protection agreement for species threatened by international trade, and many marine taxa, including those in *Finding Nemo,* are subject to international trade in shells, fins, live reef fish, and for aquaria (e.g., Sadovy *et al*. 2003; Clarke *et al*. 2007). We augmented this CITES analysis with a qualitative review of additional conservation measures, including national legislation and regional action plans included in the IUCN Red List database for threatened species.

Table 3 The percent of threatened (Critically Endangered, Endangered, Vulnerable), Data Deficient and CITES-listed species within the families portrayed in *Finding Nemo*. The range of potential risk is shown in parentheses. Families are listed from most threatened to least threatened

Family	Threatened (%)	Data Deficient (%)	CITES-listed (% of threatened)
Cheloniidae (marine turtles)	100 (83–100)	17	100, Appendix I
Lamnidae (mackerel sharks)	80	0	25, Appendix I
Sphyrnidae (hammerhead sharks)	57 (50–63)	13	0
Myliobatidae (eagle rays)	50 (26–74)	47	0
Pomacentridae (damselfishes)	18 (17–20)	2	0
Syngnathidae (seahorses)	43 (15–80)	66	89, Appendix II
Pelecanidae (pelicans)	13	0	100, Appendix I
Tetraodontidae (pufferfishes)	13 (10–35)	25	0
Acanthuridae (surgeonfishes)	0 (0–25)	25	none threatened
Chaetodontidae (butterflyfishes)	0 (0–5)	6	none threatened
Grammatidae (basslets)	0	0	none threatened

Results

Extinction risk of charismatic species in the sea

Of our 1,568 species, 16% (12–34%) of those that have been evaluated are threatened, ranging from 9% (7–28%) of bony fishes to 100% (83–100%) of turtles (Cheloniidae) (Figure 1, Table 3). Aggregating data by major taxonomic groups masks higher than average risk within certain families, such as seahorses (Syngnathidae): 43% (15–80%) threatened, and mackerel sharks (Lamnidae): 80% threatened. High levels of data deficiency contribute to elevated levels of uncertainty among some groups, including seahorses (66% DD) and eagle rays (Myliobatidae) (47% DD) (Table 3). Elasmobranchs are the most data deficient of the major taxonomic groups, with 31% of the species in our subset lacking data for assessment.

Exploitation presents the greatest threat to survival of the marine species in our *Finding Nemo* sample, followed by climate change, then habitat loss and degradation (Figure 2A). The number of first-order threats varies among groups (Figure 2B). Sharks and rays are affected only by biological resource use, in the form of directed fisheries and bycatch in industrial and subsistence fisheries. Near-shore and reef-associated fish face threats originating from land, including pollution and development. Transboundary migratory species with marine and terrestrial phases to their life cycle (turtles and birds) are affected by the greatest diversity of threats including terrestrial habitat alteration in addition to threats more typical of the ocean environment.

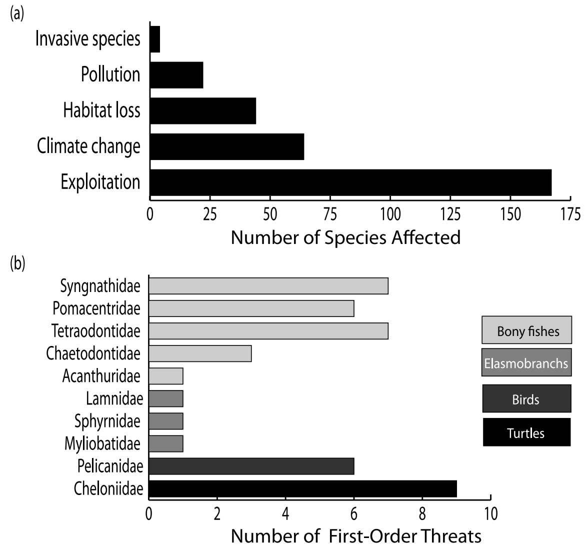

Figure 2 (A) Major threats and the number of species affected across all taxonomic groups. (B) The number of first-order threats faced by species in each family. First-order threats include biological resource use, climate change and severe weather, residential and commercial development, pollution, agriculture and aquaculture, human intrusions and disturbance, natural system modification, invasive and other problematic species and genes, transportation and service corridors, and energy production and mining (Salafsky *et al.* 2008).

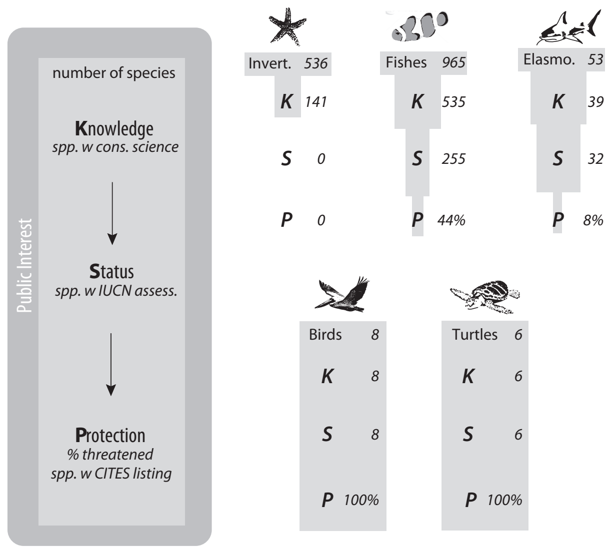

Figure 3 Conservation bottlenecks can exist at any stage of conservation, including acquisition of scientific knowledge, completion of conservation status assessments, and achievement of legal protection for threatened species. Here, *K* is the number of species in each group that have at least one conservation-related scientific paper; *S* is the number of species with IUCN Red List Assessments; and *P* is the percentage of threatened species (IUCN Red List categories: Critically Endangered, Endangered, or Vulnerable) that are CITES listed. For example, status assessments were completed for 32 species of elasmobranchs, but only 8% of those evaluated as threatened (1 out of 13) are listed by CITES.

Conservation knowledge

Forty-six percent of species are the subject of at least one conservation-relevant science paper, but there is a clear decline across taxonomic groups, from charismatic megafauna to invertebrates; all marine turtles and birds, 74% of elasmobranchs, 55% of bony fishes, and 26% of invertebrates are the subject of conservation science (Figure 3). Marine turtles are the knowledge-rich exception, with a total of 5,950 scientific papers and 1,164 conservation-relevant papers, or 194 per species. By comparison, sharks and rays have <10 conservation-related papers per species, bony fishes have an average of 2, and invertebrates are at the lowest end of the knowledge spectrum with an average of 0.1 conservation-relevant paper per species (Figure 4). Charismatic megafauna (>100 kg) are the subject of significantly more scientific research, with an average of 60 papers per species, compared with fewer than four papers per species for smaller-bodied charismatic marine animals ($t_{14} = 2.3$, $P < 0.05$).

Knowledge through IUCN Red List assessments

The percentage of species evaluated by the IUCN follows a similar pattern. Overall, 19% of our 1,568 species have been assessed, with 64% of megafauna assessed, compared with 17% of species in small-bodied families ($t_{14} = 3.2$, $P < 0.01$). All marine turtles (Cheloniidae, $n = 6$), pelicans (Pelecanidae, $n = 8$), mackerel sharks (Lamnidae, $n = 5$), and hammerhead sharks (Sphyrnidae, $n = 8$) have IUCN Red List assessments. Butterflyfishes (Chaetodontidae, $n = 128$) are also fully evaluated due to recent efforts to expand the number of assessments of reef fishes. Fewer than 30% of the bony fishes and none of the 536 marine invertebrate species in this sample are assessed (Figures 3 and 4). While peer-reviewed conservation-relevant scientific knowledge is lacking, monographs on species biology and geographic distribution, as typified by FAO species catalogs and taxonomic guides, have proven invaluable for threat assessments for sharks and reef fishes (e.g., Lieske & Myers 2001).

Level of legal protection

IUCN Red Listing does not confer legal protection and elevated risk of extinction has been translated into protection from international trade more effectively for some taxonomic groups than for others (Figure 3, Table 3). All threatened species of marine turtles and birds are listed

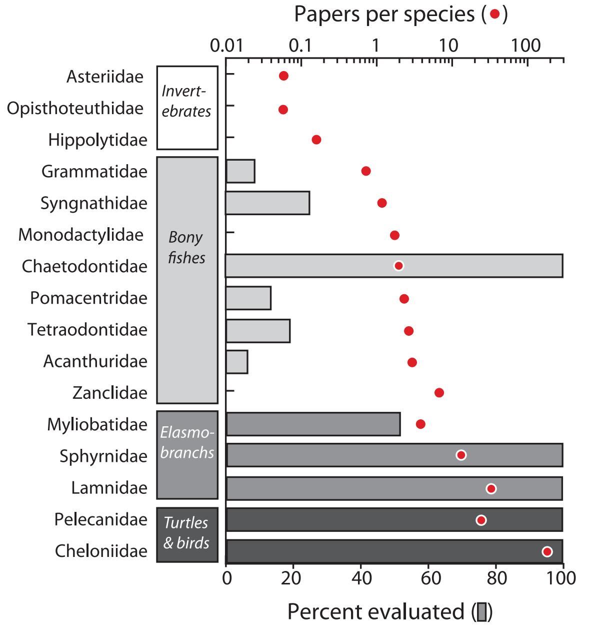

Figure 4 Number of scientific papers for each family, standardized for number of species, and percent of species in each family assessed by the IUCN. Shading represents broader taxonomic groupings (invertebrates, bony fishes, elasmobranchs, turtles, and birds).

on CITES Appendix I, the most restrictive listing prohibiting all international trade. Despite high levels of data deficiency, all species in the genus *Hippocampus* are listed on CITES Appendix II, which requires the use of import and export permits to monitor trade. As a result 44% of threatened bony fishes in our sample are listed by CITES. In contrast, sharks and rays conspicuously lack international legal protection despite greater than average conservation need. Fifty-nine percent of the elasmobranchs considered here face an elevated risk of extinction, but only one, the Vulnerable white shark (*Carcharodon carcharias*), is listed on CITES Appendix II, representing 8% of threatened elasmobranchs in our sample (Figure 3).

Additional conservation measures exist for some threatened marine species, but most are limited in scope, not legally binding, or nonenforceable. The Convention on the Conservation of Migratory Species of Wild Animals (CMS) provides protection for the largest number of species in our analysis either by prohibiting take (Appendix I), or requiring nations to cooperate on international management (Appendix II). Eighty three percent of turtles, 80% of mackerel sharks, and 25% of pelicans in our analysis are listed by CMS. Sharks are the subjects of more comprehensive FAO national plans of action, but these are voluntary and have only been completed by a handful of countries (Techera & Klein 2011). Bony fishes are similarly underprotected. No further conservation actions exist for any threatened fish species in our analysis with the exception of select species of seahorses, which have protection under watershed management plans or in marine protected areas in countries including Australia, Panama, and South Africa. Legal protection of marine turtles is more extensive. In addition to protection under CMS, all six species of turtles are listed on the U.S. Endangered Species Act.

Discussion

Our analysis of the status of the world's oceans is viewed through the lens of charismatic species portrayed in *Finding Nemo*. While our approach may appear whimsical, these charismatic species and their relatives are most likely to engender conservation concern and, one would hope, be least likely to suffer extinction. Our findings are a stark indictment of the shortfall in ocean managemen. We show that fewer than half of these 1,568 species have been the subject of conservation science and to date <20% have been assessed by the IUCN. One in every six assessed species is threatened, with exploitation affecting more species than any other threat, demonstrating the need to limit catch and trade with national regulation and international treaties. Despite this overwhelming need, only 39% of the subset of threatened species are listed by CITES. While our species represent <1% of the approximately 250,000 described marine species (Groombridge & Jenkins 2002) and do not include other charismatic groups such as marine mammals, they provide a sample of species that is more diverse than those typically considered in global assessments of marine health, which frequently rely solely upon trends in certain taxonomic groups, such as habitat building species and exploited fishes.

Extinction risk: differences between land and sea

Comparison to assessments of extinction risk on land underscores the high degree of threat in the sea. The most severely threatened terrestrial taxon, amphibians, has 41% of its species in danger of extinction (Hoffmann *et al*. 2010). Several marine families in our analysis have a higher percentage of species at risk, including marine turtles (100% threatened), mackerel sharks (80% threatened), hammerhead sharks (57% threatened), eagle rays (50% threatened), and seahorses (43% threatened). These charismatic marine species also lag behind terrestrial species in the number of assessments completed; 50% of vertebrates have been assessed by the IUCN globally (Hoffmann *et al*. 2010), but only 29% of the marine vertebrates in our analysis had completed assessments. Further, high levels of data deficiency among marine species inhibit successful conservation. On average 14% of global vertebrate species lack data for assessments (Hoffmann *et al*. 2010), but 22% of the marine vertebrates in this study are DD, and as many as 31% of elasmobranchs and 66% of seahorses lack sufficient data for assessment (Table 3).

The high degree of risk among wide-ranging taxa combined with widespread lack of knowledge suggests a fundamentally different conservation scale and focus is required for the seas. Many terrestrial species with high extinction risk are endemic to islands, mountains, and peninsulas and thus have small ranges that often fall within the borders of one nation (Mace *et al*. 2005). By comparison, the most threatened marine species, turtles and sharks, have vast geographic ranges, underscoring the fundamental need for binding multilateral treaties in the conservation of marine species. Further, the paucity of knowledge means that species-by-species protection will inevitably lag behind conservation need. The marine invertebrates analyzed here, for example, were the subject of few scientific papers and no IUCN Red List Assessments. Terrestrial invertebrates are similarly understudied (Clark & May 2002), but at least their conservation is supported by dedicated journals, newsletters, and societies (e.g., *Insect Conservation and Diversity*). Further, data deficiency in the sea is not limited to invertebrates. Regional and national assessments of risk for sawfishes, arguably the most threatened group of marine fishes globally, are hindered by a lack of information on current distribution, impacts, and trends in abundance (Simpfendorfer 2005). Together with the large scale of the most prevalent threatening processes, exploitation and climate change, this lack of data suggest that precautionary measures, including protection of representative habitats and restriction of trade under CITES Appendix II's "look alike" clause, are essential for marine conservation. Such restrictions currently exist for stony corals (Scleractinia) and seahorses in the genus *Hippocampus* for which data are difficult to collect on a species-by-species basis. Similar CITES protection could be used to streamline customs enforcement and regulate trade in shark fins, fish swim bladders, manta gillrakers, and other difficult-to-identify body parts subject to international trade.

The paradox of conserving exploited species

Many marine species are targeted for trade in high-value markets, including the $800 million live reef fish and the $400 million shark fin industries (Sadovy *et al.* 2003; Clarke *et al.* 2007), suggesting a need to recognize, monitor, and regulate international trade. However, marine species represent <10% of the 34,000 species protected under CITES (CITES 2008; Doukakis *et al*. 2008). Here we show that compared to all other taxonomic groups, sharks and rays are severely underprotected relative to their threat status. Attempts to CITES-list threatened exploited elasmobranchs, with few notable exceptions, have largely failed (Dulvy *et al*. 2008; Lack & Sant 2011), demonstrating the challenge of conserving exploited species. Exploited species often have more information relative to unexploited taxa, but experience more resistance to conservation initiatives (Sky 2010). An underlisting bias resulting from short-term economic interest has been shown at the national level: the Committee on the Status of Endangered Wildlife in Canada listed 93% of at-risk marine fish and mammals that were non-harvested, but only 17% of those that were subject to exploitation (Mooers *et al*. 2007). Our results provide a parallel international example and underscore the imperative to increase efforts to list commercially valuable species, and to engage with regional fishery management in the monitoring and protection of marine species threatened by commercial exploitation (e.g., Collette *et al*. 2011).

Translating charisma to conservation

Spikes in clownfish sales following the release of *Finding Nemo* caution that public awareness and conservation do not always go hand-in-hand (Osterhoudt 2004). However, charisma provides an opportunity for conservation and several prominent examples of consumer advocacy for charismatic marine species illustrate public interest in an increasing diversity of marine species. In 1988, a widely circulated video of endangered dolphins killed in fishing gear sparked a consumer boycott of tuna, which forced dolphin-safe practices in international tuna fisheries (Baird & Quastel 2011). A call in 2011 for new boycotts to protest the number of sharks, billfish, turtles, and seabirds caught as bycatch in the tuna fishery (Bittman 2011) suggests concern for a more diverse suite of ocean vertebrates. So too do shark fin sale bans that have come on the heels of media campaigns, which effectively used images of bloody shark carcasses to spotlight the impacts of fishing on global shark populations. The rapid rebranding of sharks as vulnerable and charismatic has also promoted research and the growth of professional societies dedicated to the science, conservation, and management of elasmobranchs (Simpfendorfer *et al*. 2011). Additional efforts to expand the taxonomic diversity of species that garner public concern include IUCN Red Listing, which has refocused public attention on less well-known species (Stuart *et al*. 2010) and the Census of Marine Life, which has spotlighted unique marine invertebrates (www.coml.org/image-gallery) and can only stimulate public interest in a broader diversity of marine life.

Charisma alone may not be enough to reverse declines, but sea turtle conservation provides optimism, even for species that face a diversity of threats across vast geographic areas and life history stages. Our results highlight the ongoing endangered status of marine turtles—all species that have sufficient data for assessment are threatened. Despite this poor prognosis, substantial progress has been made. Early efforts to reduce direct exploitation on land have led to increases in local populations (Troëng & Rankin 2005), and recent evidence from U.S. fisheries suggests that significant reductions in mortality also can be made at sea (Finkbeiner *et al*. 2011). Sea turtles may be exceptional among marine life as 10 times more scientific papers were published on marine turtles than any other charismatic taxonomic group, all species are assessed by the IUCN, and all threatened species are protected internationally. However, the successful results of these targeted conservation efforts demonstrate the efficacy of coordinated and multifaceted initiatives to protect marine species.

Marine species are highly threatened due to widespread and diffuse threats driven by a globalized market that incentivizes "roving bandits" in a manner largely unprecedented on land (Berkes *et al*. 2006). Our analysis of extinction risk for charismatic marine animals and bottlenecks in the conservation process underscores the tremendous need to address global threats to marine biodiversity on an appropriately large scale. The growing public interest in the ocean suggests that there may be room to take a broader and more comprehensive view of species conservation in the sea for a greater diversity of marine species. Directing this public attention toward the need for binding legal protection of at-risk species may help to counterbalance the economic interests that currently inhibit effective conservation in the sea.

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