Ann. N.Y. Acad. Sci. ISSN 0077-8923

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Issue: *The Year in Ecology and Conservation Biology*

The Marine Mammal Protection Act at 40: status, recovery, and future of U.S. marine mammals

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Passed in 1972, the Marine Mammal Protection Act has two fundamental objectives: to maintain U.S. marine mammal stocks at their optimum sustainable populations and to uphold their ecological role in the ocean. The current status of many marine mammal populations is considerably better than in 1972. Take reduction plans have been largely successful in reducing direct fisheries bycatch, although they have not been prepared for all at-risk stocks, and fisheries continue to place marine mammals as risk. Information on population trends is unknown for most (71%) stocks; more stocks with known trends are improving than declining: 19% increasing, 5% stable, and 5% decreasing. Challenges remain, however, and the act has generally been ineffective in treating indirect impacts, such as noise, disease, and prey depletion. Existing conservation measures have not protected large whales from fisheries interactions or ship strikes in the northwestern Atlantic. Despite these limitations, marine mammals within the U.S. Exclusive Economic Zone appear to be faring better than those outside, with fewer species in at-risk categories and more of least concern.

Keywords: Endangered Species Act; marine mammals; Marine Mammal Protection Act; status and trends; stock assessment reports

Introduction

Legislation protecting whales dates back to 1934, when right whale hunting was banned by an international treaty. In the early 1970s, further attempts to protect the great whales in the United States were met with resistance by the U.S. Department of Defense, which was concerned about the supply of sperm whale oil for use as a lubricant in submarines and other military engines. After a synthetic oil was produced, the Marine Mammal Protection Act (MMPA) was passed in October 1972. The MMPA went beyond protection for commercial reasons and attempted to restore the ecological role of all marine mammals. It was a critical step toward the passage of the Endangered Species Act (ESA) the following year.[1]

The fundamental objectives of the MMPA are (1) to maintain stocks of marine mammals at their optimum sustainable populations (OSP) and (2) to maintain marine mammal stocks as functioning elements of their ecosystems. The act does not define OSP, but the National Marine Fisheries Service (NMFS) has interpreted OSP to be a population level that falls between Maximum Net Productivity Level (MNPL) and carrying capacity (K). In operational terms, therefore, OSP is defined as a population size that falls between $0.5K$ and K. In addition, there is a clear mandate to protect individual marine mammals from harm, referred to as *take*.

In this review, we assess the success of the MMPA in protecting marine mammals, discuss its failures, and provide suggestions on ways to improve the act and marine mammal conservation in the United States and internationally.

By the numbers

U.S. marine mammal stocks 1995–2011

In the United States, two federal agencies direct the management and protection of marine mammals:

doi: 10.1111/nyas.12040

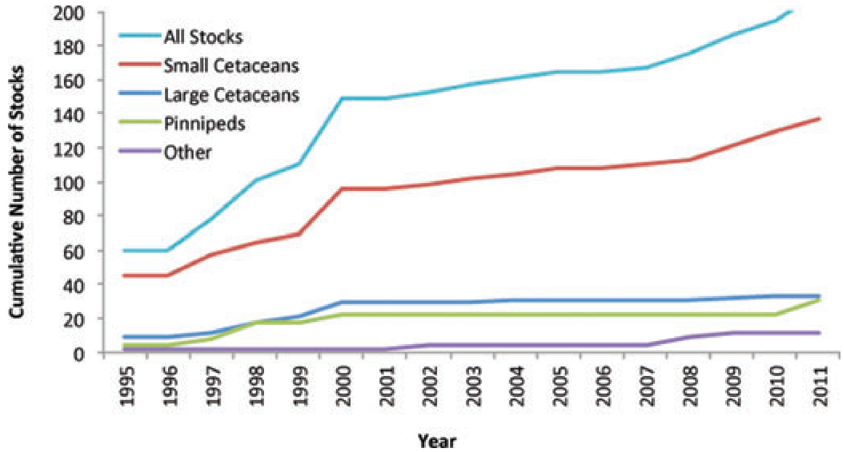

Figure 1. Cumulative number of stocks recognized under the Marine Mammal Protection Act since stock assessment reports began in 1995.

NMFS is responsible for managing most marine mammal stocks, including cetaceans, sea lions, and seals; the U.S. Fish and Wildlife Service (USFWS) has authority over a smaller number of stocks that include polar bears, sea otters, manatees, and walruses. Under the MMPA, a marine mammal stock is defined as a group of individuals "of the same species or smaller taxa in a common spatial arrangement that interbreed when mature." Stock assessment reports (SARs) for all marine mammals that occur in U.S. waters were first required when the act was amended in 1994. Since that time, all stocks have been reviewed at least every three years or as new information becomes available. Stocks that are designated as *strategic* are reviewed annually. Each draft SAR is peer-reviewed by one of three regional Scientific Review Groups (SRGs) and revised and published after a public comment period. These reports are extremely valuable for the information they provide and their transparency: documents are posted online (www.nmfs.noaa.gov/pr/sars/). During the 17 years that the agencies have conducted SARs, many new stocks have been recognized (Fig. 1), and information about the demography and distribution of existing populations has led to many cases of stock reclassification. In some cases, reclassified stocks leave older stocks obsolete; for example, if a single, large stock is recognized to be composed of multiple, small, and discrete breeding populations. In other cases, a remnant of the original stock may still be considered, even while a subset of the population is designated as an independent stock.

We examined the history of marine mammal stock classification over time (1995–2011), taking into account newly recognized stocks and the dissolution of older stocks. A cumulative frequency analysis shows that the number of recognized stocks for all groups of marine mammals increased rapidly in the early years of assessment, with most stocks designated between 1995 and 2000 (Fig. 1). After 2000, few additional stocks were identified for species of large cetaceans. The number of pinniped stocks increased as a result of the reclassification of Alaska harbor seal stocks from 3 to 12 distinct stocks in 2011. Similarly, USFWS stocks exhibited a slight increase in the number of recognized stocks in recent years owing mainly to the classification of sea otter. In contrast to the relatively small changes in stock classification of these groups since 2000, the number of small cetacean stocks exhibited a large increase. Since 2000, the annual rate of increase in the number of newly identified small cetacean stocks has been more than four times that of other groups (small cetaceans = 3.7; large cetaceans = 0.4; USFWS species = 0.8; pinnipeds = 0.8 newly designated stocks per year), suggesting that either information on the population structure of small cetaceans is increasing faster than for other taxa or that odontocetes have finer population structure than other marine mammals.

In 2011, a total of 212 stocks of marine mammals were designated under the management authority of NMFS and USFWS, of which most (65%) were small cetaceans. Large cetaceans represent the second largest group, accounting for nearly 16% of all stocks. Pinnipeds account for 15% of all current stocks, with the remainder being species managed by USFWS.

Population trends

For all currently recognized marine mammal stocks, we reviewed the earliest and most recent stock assessments to investigate trends in abundance. For many stocks, information on abundance is limited and even less is known about trends. It should be noted, however, that identifying trends in marine mammals is known to be difficult. Taylor *et al.*, for example, found that even precipitous declines would not be noticed for 72% of large whale stocks, 78% of dolphins and porpoises, and all pinnipeds counted on ice with current levels of survey effort.[2] Declines in land-based pinnipeds were much easier to detect. Whereas the MMPA does not require information on trends, stock assessment reports can describe a variety of available information on abundance trends, including information from the literature, unpublished data, and expert insight. Pulling all this information into a single document is useful and important, but obtaining a formal assessment of trends over time is often restricted by inconsistencies in the methods of multiple independent studies and limited understanding of patterns across the whole spatial range of the stock. Despite these limitations, it is important to analyze the evidence available on marine mammal trends since this is an essential metric for assessing the health of these populations.

For this work, we examined descriptions in the earliest and latest SARs and classified the presence and direction of the most recent trends identified for a stock. We noted if the trend was definitively stated in the SAR or if the description indicated a possible trend. We summarized trends with respect to the following categories: decreasing, increasing (including cases where the stock is classified as "stable or increasing"), stable, and unknown.

Information on population trends is currently unknown for the majority (71%) of U.S. marine mammal stocks. Ten percent of stocks currently exhibit increasing abundance trends with the percentage increasing to 19% when possible cases of increases are included. Two percent of stocks currently exhibit stable trends, which increases to 5% when stocks with possible stable trends are included. Three percent of stocks exhibit decline, which increases to 5% if possible declining trends are included (see Supporting Information).

Overall, the pattern is consistent with trends from the earliest years in which stocks were assessed. In the first year that each stock was assessed, 68% of the stocks had unknown trends; 7% showed evidence of increase, increasing to 21% when possible trends are included; 2% were stable, increasing to 5% when possible trends are included; and 4% were found to be decreasing, increasing to 6% when possible trends are included (see Supporting Information).

For stocks that exhibited a definitive trend in the earliest year in which they were assessed, we examined whether the population continued to show a similar trend in the most recent SAR. The majority of stocks in this group exhibit no change in the direction of the trend between the earliest and latest SAR. A total of seven stocks were found to exhibit stable or increasing trends in the earliest and latest years in which they have been assessed. Two stocks were described as declining in the earliest and latest SAR. Two other stocks demonstrated reversal of trends in the earliest and latest SARs. The Oregon–Washington coastal harbor seal was described as decreasing in the earliest SAR, then stable or increasing in abundance in the most recent report. In contrast, the Eastern Pacific northern fur seal was identified as stable in the earliest SAR and decreasing in the most recent report.

Status and trends: endangered species

We examined the status under the ESA for all current stocks of marine mammals using information from the latest SAR and additional sources of information (www.nmfs.noaa.gov/pr/species/esa/other.htm). Of the 212 current stocks, 38 (18%) are listed as endangered or threatened (Supporting Information Appendix 1). Although small cetaceans have the greatest number of stocks in U.S. waters, only two of them are listed under the ESA: the Southern resident eastern North Pacific killer whale and the recently listed Hawaiian insular false killer whale. In contrast, 25 stocks of large cetaceans (representing 76% of this group) are currently listed as threatened or endangered (Fig. 2A). Of the two other groups, four pinniped stocks (13%) and seven USFWS managed stocks (64%) are listed under the ESA.

The highest number and proportion of threatened or endangered stocks are found in the Pacific region, where 21 of the 81 stocks are listed (26%).

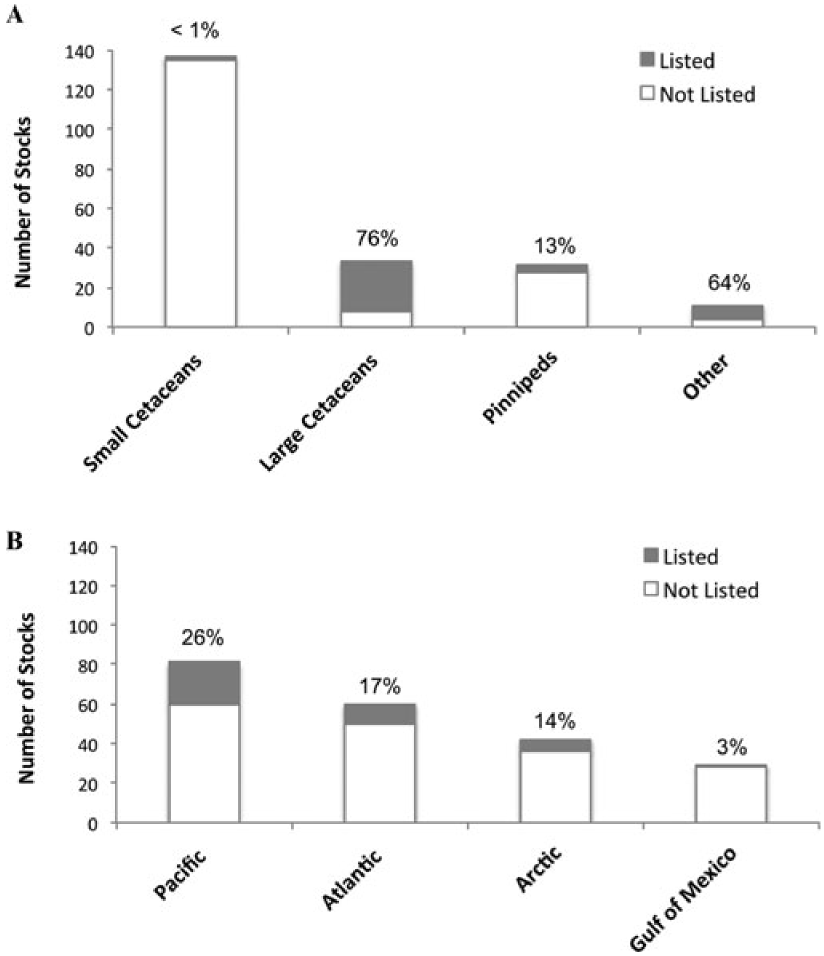

Figure 2. Number of marine mammal stocks protected by the Endangered Species Act, (A) by taxonomic group, (B) by geographical region. The percentage of ESA-protected stocks for each group is presented above the bars.

In the Atlantic region, 10 of 60 stocks are ESA listed, representing 17% of stocks found in this region. In the Arctic region six of 42 stocks (14%) are ESA listed. In the Gulf of Mexico, only the Northern Gulf of Mexico sperm whale is listed under the ESA (Fig. 2B).

To determine how the ESA status of marine mammals changed over time, we compared information from the earliest and most recent year each stock was assessed. The majority of the 38 stocks currently listed under the ESA were also listed at the time of their first assessment. Three stocks, however, became listed only in the most recent years in which they were assessed: the Alaska Chukchi/Bering Seas polar bear stock (which was designated as a stock in 2002 and became listed as threatened in 2008), the eastern North Pacific Southern resident false killer whale (designated as a stock in 1999, listed as endangered in 2005), and the Hawaiian insular false killer whale, which was classified as endangered in 2012. Endangered species listing is pending for three stocks. Recent petitions include the Alaskan Pacific walrus (2009), two distinct population segments of bearded seals associated with the Alaska stock (2010), and four subspecies of ringed seal associated with the Alaska stock (2010).

We did not identify any case in which a stock was listed as threatened or endangered in the earliest stock assessment and then delisted in the most recent assessment, but the Eastern stock of Steller sea lion was proposed for delisting in 2012 because the stock is thought to have recovered and the Gulf of Maine–Bay of Fundy harbor porpoise was proposed as a threatened species in 1995 and removed as a candidate by 2011. One marine mammal stock recovered before its first assessment—the eastern North Pacific gray whale, which was delisted in 1994. In addition, the Caribbean monk seal was delisted because the species was formally recognized as extinct. Efforts to investigate unconfirmed sightings of Caribbean monk seals since the species was first listed under the Endangered Species Protection Act in 1967 (and relisted under the ESA in 1979) revealed only extralimital northern seals. Last seen in 1952, the Caribbean monk seal was almost certainly extinct at the time of passage of the MMPA and ESA. Officially delisted in 2008,[3] it is the only known case of a recent extinction for a U.S. marine mammal.

Status and trends: strategic stocks that exceed potential biological removal

Potential biological removal (PBR) is the critical threshold defined under the MMPA as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to recover to or be maintained within its OSP. PBR is defined as the product of the minimum population estimate (N_{min}), half the maximum net productivity rate (R_{max}), and a recovery factor (F_{r}), which ranges from 0.1 to 1.0.[4] We examined stocks for which human-associated mortality exceeded PBR (or was very likely to exceed PBR) in either the earliest or the most recent year in which PBR was determined in a SAR. Occasionally information necessary to determine PBR was not available in the earliest or most recent SAR; in such cases, we examined all relevant SARs to find the earliest and latest years in which PBR was reported. For stocks that exceed PBR, we obtained the best available estimates of human-related mortality provided in the SAR and listed the primary sources of mortality.

We found nine improved stocks, for which mortality exceeded PBR in the original assessment but was less than PBR in the most recent SAR (Table 1A). Sixteen stocks are currently exceeding PBR based on the most recent information available (Table 1B–D). Of these, 9 (56%) show no change in status with respect to PBR. The most common sources of mortality for these stocks are fishing interactions and ship strikes (Table 1B). Four stocks have degraded, exceeding PBR in the most recent assessment but not the earliest for which information was available. The primary mortality sources for this group are also fisheries interactions (gillnets) and ship strikes (Table 1C). The remaining two stocks exceeding PBR are recently designated and have only been assessed once (Table 1D). Finally, there are three stocks in which mortality exceeded PBR in the earliest SAR, but no designation was made in the latest assessment because of insufficient mortality information (Table 1E).

Strategic stocks

Stocks that are listed under ESA and those where human-related mortality exceeds PBR are automatically considered *strategic* by NMFS and USFWS. In addition, a stock may be considered strategic if there is evidence that the population is declining and likely to be listed under the ESA in the foreseeable future.

A total of 76 stocks (i.e., 36% of all recognized stocks) are currently identified as strategic, including cases where stocks are identified as *probably strategic,* as with the false killer whale stock in American Samoa. Human mortality exceeds PBR for 15 of these stocks, based on the most recent information available (Table 1B–D). Thirty-five strategic stocks are considered depleted under MMPA, even though anthropogenic mortality is not currently known to exceed PBR. This category predominantly includes small cetaceans, such as bottlenose dolphins, and pinnipeds, such as Alaskan harbor seals, many of which are recently designated stocks for which there may be limited information to determine PBR and mortality. In these cases, strategic designation provides an added layer of protection when definitive data on population metrics do not exist. The remaining 26 strategic stocks are not considered depleted, nor are they known to experience human-related mortality exceeding PBR. For these cases, limited information and small population size may warrant classifying the stock as strategic until clear evidence can be gathered that it is not at risk. Some stocks with limited data and unknown population size, however, are not classified as strategic if it appears that abundance is high and human-related mortality is low.

Status of U.S. marine mammals species: a global perspective

To assess the relative success of marine mammal protection in the United States under the MMPA and ESA, we compared the status of marine mammal species found within the U.S. Exclusive Economic

Table 1. **U.S. marine mammal stocks for which human-influenced mortality exceeds (or is very likely to exceed) potential biological removal (PBR), either in the latest or earliest year in which information is available from the stock assessment report (SAR). Stocks that demonstrate improvement over time, where human-influenced mortality exceeded PBR in the earliest but not the most recent SAR are shown in group A. Group B includes stocks that exhibit no change with respect to exceeding PBR in the earliest and latest SAR. Stocks that exceed PBR only in the most recent SAR but not in the earliest SAR are shown in C. Recently designated stocks (with only a single assessment) for which mortality exceeds PBR are shown in D. Group E represents stocks for which PBR is exceeded in the earliest year and no designation can be made with respect to exceeding PBR in the most recent year. Values for PBR and mortality from relevant SARs are presented. Primary sources of mortality are also listed when this information is provided in the SAR.**

Group	Region	Species	Stock	Earliest year of SAR w/PBR	Earliest PBR/ mortality	Latest year of SAR w/PBR	Latest PBR/ mortality	Primary mortality sources
A								
	Atlantic	Common dolphin, short-beaked	Western North Atlantic	1995	32/449	2011	1,000/164	Fishing interactions (gillnet),[e] ship strikes,[e] whaling historic[e]
		Spotted dolphin, Pantropical	Western North Atlantic	1995	UNK/31	2007	30/7	Fishing interactions (gillnet),[e] ship strikes[e]
		Pilot whale, short-finned	Western North Atlantic	1995	3.7/UNK	2011	93/UNK	Fishing interactions (gillnet),[e] strandings[e]
	Pacific	Humpback whale[*d]	California–Oregon–Washington	1999	0.8/2	2010	11.3/3.6	
		Sperm whale[*d]	California–Oregon–Washington	1999	2/3	2010	1.5/0.4	Fishing interactions (gillnet)[e]
		Harbor porpoise	Monterey Bay	2002	11/80	2009	10/UNK	Fishing interactions (gillnet)[e]
		Pilot whale, short-finned	California–Oregon–Washington	1999	6.9/13	2010	4.6/0	Subsistence fishing[e]
		Steller sea lion[*d]	Western	1998	350/444	2011	253/227.1	Fishing interactions (gillnet, squid)[e]
	Arctic	Beluga whale	Cook Inlet	1998	14/72	2005	2/0	Fishing interactions (gillnet, trawl),[e] subsistence fishing[e]
B								
	Atlantic	Right whale, North Atlantic[*d]	Western Stock	1995	0.4/2.6	2011	0.8/2.4	Fishing interactions (gillnet),[e] ship strikes,[l] fishing interactions (unidentified)[l]
		Sei whale[*d]	Nova Scotia	2007	0.3/0.4	2011	0.4/1.2	Fishing interactions (gillnet, unidentified)[e,l]

Continued

Table 1. *Continued*

Group	Region	Species	Stock	Earliest year of SAR w/PBR	Earliest PBR/ mortality	Latest year of SAR w/PBR	Latest PBR/ mortality	Primary mortality sources
		Harbor porpoise[$]	Gulf of Maine-Bay of Fundy	1995	403/1,876	2011	701/927	Pollution,[e] fishing interactions (gillnet),[e,l] strandings,[e,l] fishing interactions (trawl, mackerel)[l]
		White-sided dolphin, Atlantic	Western North Atlantic	1995	125/127	2011	190/245	Fishing interactions (gillnet, longline, unidentified)[e,l]
		West Indian manatee[*d]	Antillean	1995	0/5	2009	0.144/8.2	Fishing interactions (longline),[e,l] boat strikes[l]
		West Indian manatee[*d]	Florida	1995	0/40.1	2009	11.8/86.6	Fishing interactions (longline),[e,l] boat strikes[l]
	Pacific	False killer whale	Pacific Islands Region Stock Complex - Hawaii	2000	0.8/9	2007	2.4/4.9	Fishing interactions (unidentified),[e,l] ship strikes[e,l]
		False killer whale	Pacific Islands Region Stock Complex - Hawaii Pelagic	2008	2.2/5.7	2011	2.4/10.8	Ship strikes[e,l]
	Arctic	Pacific walrus[¥]	Alaska	2009	2,580/5,460	2010	2,580/ 5,457	Fishing interactions (trawl, unidentified),[e,l] habitat/oil/gas[e,l]
C								
	Atlantic	Humpback whale[*d]	Gulf of Maine	1995	9.7/1	2011	1.1/5.2	Ship strikes[l]
	Gulf of Mexico	Bryde's whale	Northern Gulf of Mexico	1995	0.2/UNK	2011	0.1/1	Fishing interactions (gillnet),[e,l] ship strikes,[e,l] toxins from harmful algal blooms[e,l]
	Pacific	False killer whale[*]	Pacific Islands Region Stock Complex - Hawaii Insular	2008	0.8/0	2011	0.2/0.6	Fishing interactions (gillnet)[l]
		Killer whale[*d]	Eastern North Pacific Southern Resident	1999	0.9/0	2011	0.17/0.2	None reported[l]

Continued

Table 1. ***Continued***

Group	Region	Species	Stock	Earliest year of SAR w/PBR	Earliest PBR/ mortality	Latest year of SAR w/PBR	Latest PBR/ mortality	Primary mortality sources
D								
	Atlantic	West Indian manatee[*d]	Puerto Rico	2009	0.144/8.2	na	na	Fishing interactions (gillnet, squid, mackerel),[e] fishing interactions (longline, trawl, groundfish)[l]
	Pacific	False killer whale	American Samoa	2010	7.5/7.8	na	na	Fishing interactions (gillnet),[e] ship strikes[e]
E								
	Atlantic	Bottlenose dolphin	W.N. Atlantic Offshore	1995	92/128	2008	566/UNK	Fishing interactions (gillnet, trawl)[e]
		Bottlenose dolphin[d]	W.N. Atlantic Northern Migratory Coastal	2002	23/30	2010	71/UNK	
		Pilot whale, long-finned	Western North Atlantic	1995	28/UNK	2011	93/UNK	Pollution,[e] Fishing interactions (gillnet),[e,l] strandings,[e,l] fishing interactions (trawl)[l]

Notes: We followed designations within the SAR for exceeding potential biological removal (PBR) and indicated cases when mortality or PBR is unknown (UNK). For these cases, information from previous assessments is sometimes used to suggest whether PBR is likely exceeded. In addition, there are cases where small population size (and thus presumably small PBR) warrants a designation of PBR exceeded. Symbols after species names indicate that the stock is currently listed under ESA (*); petitioned for listing under the ESA (¥); recently removed as a candidate for ESA listing ($); and currently depleted under the MMPA (d). Letters after primary sources of mortality indicate (e) the mortality source was relevant in the earliest SAR and (l) the mortality source was relevant in the latest SAR.

Zone (EEZ) to those outside of the U.S. EEZ, using the most recent designations (1996–2012) provided by the International Union for Conservation of Nature (IUCN). The total number of marine mammal species associated with the two groups was nearly equal (number of U.S. marine mammal species = 65, non-U.S. species = 67) and results indicate that U.S. species generally fare better than non-U.S. species in all categories (Fig. 3). Specifically, fewer U.S. species are found in high-risk categories (vulnerable, critically endangered, near threatened, extinct) and more U.S. species are considered of least concern. In such an uncontrolled comparison, it is impossible to draw definitive conclusions regarding the factors responsible for this difference; nevertheless, the patterns suggest fundamental prohibitions against the taking of marine mammals in the MMPA, along with the ESA, likely contribute to this difference. We conclude that marine mammals found in the United States do appear to be doing as well and in many cases better than species found outside of U.S. waters, suggesting that current management actions are having a positive influence on marine mammal populations.

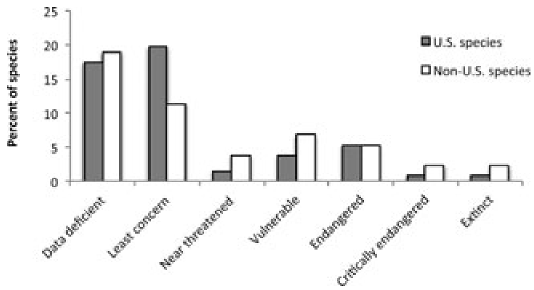

Figure 3. Status of marine mammal species found within and outside of the U.S. Exclusive Economic Zone, using the most recent designations (1996–2012) according to the International Union for Conservation of Nature (IUCN).

Successes

The MMPA was passed in response to concern over the conservation status of several species of marine mammals due to unregulated harvest or incidental mortality. Section 2 of the act notes that "certain species and population stocks of marine mammals are, or may be, in danger of extinction or depletion as a result of man's activities." The MMPA, buttressed by additional protection from the ESA, has successfully prevented the extirpation of any marine mammal population in the United States in the 40 years since it was enacted. Countless tens of thousands of individual cetaceans, pinnipeds, and sirenians have been protected from harm since 1972, exactly as intended by those who crafted the legislation. As a consequence, many marine mammal populations, particularly seals and sea lions, have recovered to or near their carrying capacity. The recovery of these stocks has been so successful that fisheries representatives have occasionally advocated for culls. Yet several recent studies have shown that whales, seals, and dolphins are not a threat to human fisheries and even a complete eradication of marine mammals would show little to no benefit and come at an ecological cost.[5,6] The remarkable recovery of harbor and gray seals in New England and California sea lions, harbor seals, and elephant seals on the Pacific Coast highlights the value of the act and serves as a striking reminder of the magnitude of the persecution of these species before 1972.

The provisions in Section 117 of the MMPA, which require NMFS and the USFWS to prepare assessments for each stock of marine mammals living in waters under the jurisdiction of the United States, have spurred an enormous amount of research by federal agencies, greatly increasing our understanding of marine mammal biology. As a result, we have an unparalleled grasp of the distribution, population structure, and status of marine mammals within the U.S. EEZ. The SARs, mandated under Section 117, are a treasure trove of information on the status of marine mammals in the United States, tracing the history and reviewing new information at least once every three years for every stock. As noted above, each SAR contains an estimate of PBR, the number of marine mammals that can be removed from a stock while allowing it to reach or maintain its OSP. This allows for a rapid quantitative assessment of the status of each stock. No other country has attempted such an audacious scientific undertaking.

Over time, we have seen an increase in the number of stocks, as a result of increased knowledge of the population structure of many species, especially small cetaceans (Fig. 1). Advances in research tools such as molecular genetics, photo-identification, and satellite telemetry, have increased our understanding of population structure, improving management of delineated stocks, and discrete population segments that were not originally recognized. Essential in helping to move these studies forward, the Marine Mammal Commission, established by the framers of the MMPA, has been effective in keeping attention on critical issues and funding compelling new research. An enhanced knowledge of stock structure, often through the efforts of academic researchers and nonprofit organizations, is likely to result in the designation of more stocks. In Hawaii, for example, there is evidence of multiple populations of rough-toothed dolphins and other species previously thought to exist as larger stock aggregates.[7,8]

One of the primary exceptions to the moratorium on take is the provision that allows the subsistence harvest of marine mammals by Alaska Natives. Under this provision, an aboriginal harvest is obtained from some stocks, such as Alaskan bowhead whale (*Baleana mysticetus*). The International Whaling Commission establishes the quota for the bowhead hunt with input from NMFS and the Alaska Eskimo Whaling Commission (AEWC). The AEWC then allocates the quota among Alaskan Eskimo communities. Under this carefully controlled harvest, the bowhead population is recovering at a rate of 3.2% per year,[9] and the cultural and subsistence needs of native Alaskans are being met. Not all aboriginal harvests are as well managed, however, and poorly controlled hunts can add significantly to the risks to local populations, such as the beluga whale stock of Cook Inlet, Alaska.[10] There are also concerns about the largely unregulated harvest of sea otters and walruses in Alaska.[11]

Another important exemption to the prohibition on taking allows incidental mortality of marine mammals in commercial fisheries. The mortality of pelagic dolphins in the yellowfin tuna purse seine fishery in the Eastern Tropical Pacific was one of the factors that lead to passage of the MMPA in 1972. Management of this bycatch has been addressed by other legislation in recent years, and this fishing threat was further reduced as the U.S. purse seine fleet dwindled in size. Amendments to the act in 1994, managed under Section 118, were intended to reduce marine mammal bycatch in direct fisheries interactions. The section requires the drafting of take reduction plans (TRPs) for all stocks in which incidental mortality and serious injury exceed PBR. These plans are prepared through a process of negotiated rulemaking by take reduction teams (TRTs) comprising stakeholders, including fishermen, representatives of environmental groups, fisheries managers, scientists, and others.[12] Several TRTs have been successful in reducing mortality to below PBR. The Pacific Offshore Take Reduction Team, for example, was formed in 1996 to address bycatch of beaked whales and other cetaceans in the drift-gillnet fishery. Since its implementation, beaked whale bycatch has been eliminated entirely.[13]

In these and many other instances, the Act has performed well. The status of many marine mammal populations is considerably better today than it was in 1972. The abundance of some pinnipeds, including California sea lions and harbor and gray seals, and some mysticetes, like humpback, blue, and gray whales, have greatly increased in the past 40 years. Since reports began, the status of at least twice as many stocks (8) have improved with respect to their status regarding PBR as have declined (4), an indication that TRTs are working. The act has also been effective in providing protection to marine mammal populations from direct threats, including those posed by unregulated harvest, persecution, and bycatch. In contrast to Canada, where there have been recent government proposals to cull transboundary stocks of harbor and gray seals in the northwest Atlantic, there have been relatively few serious calls for culls of marine mammals in the United States since passage of the act. Perhaps most tellingly, marine mammals in U.S. waters appear be to be doing better than those outside the U.S. EEZ (Fig. 3). The large percentage of species of least concern in the United States is especially encouraging, considering that its coastlines are highly affected by shipping, pollution, and fishing activities.[14] Along with federal regulation, the work of academic researchers and nonprofit groups has been an essential asset to protecting species.

Challenges

The MMPA is a well-intentioned and well-crafted piece of legislation that was improved by amendments in the 1990s. Despite the successes mentioned above, it has not yet succeeded in restoring many marine mammal stocks to OSP levels. In cases like the North Pacific right whale, populations were too small to rescue at the time of the passage of the act. Even under ideal circumstances, 40 years may not be enough time to restore populations of long-lived species with slow rates of potential population growth. In other cases, failures appear to be associated with a lack of enforcement or funding, political pressure, or a disregard for precautionary principles. The recent failure of the harbor porpoise Take Reduction Plan to keep bycatch of this species below PBR, for example, resulted from a lack of compliance with and enforcement of the measures contained in the TRP.[15]

Although no species or stock of marine mammals has been extirpated in U.S. waters since passage of the MMPA, 19% are listed as threatened or endangered and 7% are reported to be declining. Perhaps the biggest concern is that we lack sufficient information to ensure that many other stocks are not in significant decline: trends are unknown for 71% of marine mammal stocks. The PBR scheme was designed to address this issue, but its focus is on direct human-caused mortalities, providing little information on natural mortality or indirect effects. As a result some declines that do not result from direct kills may go unnoticed.[2]

The Government Accountability Office has noted that NMFS has failed to create TRTs for 16 of the 30 marine mammal stocks that meet the MMPA's requirements; additionally five TRTs have failed to meet statutory deadlines.[16] NMFS replied that teams were not established because (1) data on the stocks were outdated or incomplete and the agency lacked funds to obtain better information and (2) causes other than fishery-related incidental takes could contribute to marine mammal injury or death, so changes to fishing practices would not solve the problem.[16] Even when TRTs have been in place, they have not always been successful.[17] The factors underlying the success or failure of specific teams are unclear, but bycatch in gillnets remains a serious concern for marine mammal conservation: 84% of marine mammal bycatch between 1994 and 2006 in U.S. waters was caused by gillnets.[17]

Section 118 stipulates a goal of reducing the incidental mortality and serious injury of marine mammals to insignificant levels approaching zero (known as the Zero Mortality Rate Goal, or ZMRG), which has been interpreted by the agencies as equivalent to 10% of PBR. Unfortunately, many stocks continue to experience mortality rates considerably greater than ZMRG, and there is little serious effort to meet this mandate.

The MMPA on its own does not afford enough protection for many populations or from many stressors, and the protection of the ESA is still a critical last resort when populations are in decline. In several cases, the MMPA has not proven capable of protecting individual stocks. The Alaskan AT-1 killer whale, affected by the *Exxon Valdez* spill and other factors, has fewer than 10 individuals, has never been protected by the ESA, and is likely unsavable.[18] In general, the ESA can act as valuable safety net for the stocks most in need of protection, provided sufficient evidence is available on trends and the cause of decline to support the establishment of a distinct population segment. The absence of such data is an impediment to assessing the need for protection for many species and is a serious shortcoming to effective management under the act. Several species, such as the Southern resident killer whale and the Hawaiian insular false killer whale, have been listed under the ESA; others such as the Pacific northeastern offshore stock of the pantropical spotted dolphin and the AT-1 killer whale have been designated as depleted under MMPA. Of course, protection under the MMPA and ESA does not guarantee recovery: the Hawaiian monk seal has declined in the Northwestern Hawaiian Islands because of low juvenile survivorship, even though that area is fully protected as a National Monument and the species is protected by both the ESA and MMPA.[19] The North Pacific right whale (*Eubalaena japonicus*), which once numbered in the tens of thousands, now exists only as a few hundred individuals throughout the ocean.[20] The primary feeding and breeding grounds, if they still exist, remain largely unknown, though a recent match of an individual spotted off Hawaii with a sighting in the southeastern Bering Sea provides evidence that these areas, both within U.S. waters, may have been important for this species.[21] Even though this species has been protected by international treaties since the 1930s, and by both the MMPA and ESA, the population in the eastern North Pacific probably numbers fewer than 50 individuals and may be the smallest whale population on Earth.[22]

Collisions with ships and fisheries entanglements are significant causes of mortality among marine mammals, and several recent review articles provide ample evidence that great whales in particular remain at risk.[23] Van der Hoop *et al.*, for example, estimated that 67% of known mortalities of large whales in the North Atlantic resulted from human interactions, mostly from entanglement with fishing gear.[24] Humpback whales exceeded PBR by 579% and right whales by 650%. Efforts to reduce large whale mortality have become more extensive since 2003, and policies continue to evolve.[24] The shipping channel into Boston Harbor was rerouted to reduce collisions with humpback and right whales (Fig. 4).[25] The movement of this channel required long-term data on whale distribution that is unavailable for many areas. Speed-reduction measures and passive acoustic monitoring can help protect large whales and other marine mammals in areas that are less-well studied.[26]

Failure of implementation and enforcement

One of the most significant sources of failure in implementing the MMPA has been political interference. The U.S. Coast Guard and NMFS have not consistently pursued enforcement of violations related to domestic and foreign bycatch from fisheries, illegal shootings, oil and gas operations, and whale watching.[11,30] The failure of the harbor porpoise TRP, for example, is the result of a lack of compliance with conservation measures; few, if any, violations of the plan have been enforced.[27] In a

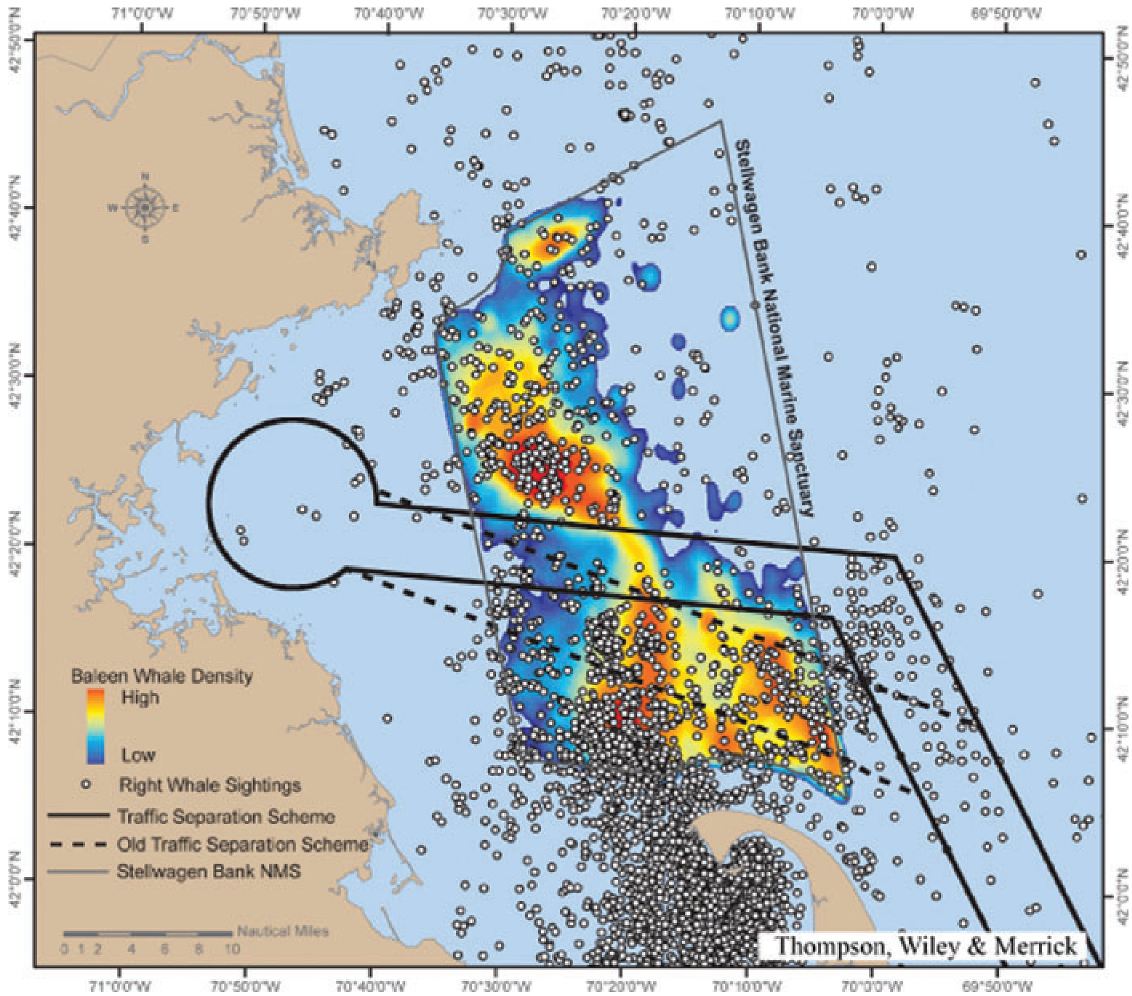

Figure 4. The distribution and density of baleen whales relative to the old (dotted line) and revised traffic separation scheme in the approach to Boston, Massachusetts. The new shipping lanes were estimated to reduce risk of ship strikes on right whales in the area by 58% and on other large whales by 81%. Courtesy of the NOAA.

critical conservation failure, NMFS has failed to deal effectively with the bycatch of North Atlantic right whales. On the east coast of the United States and Canada, right and humpback whales become entangled in fixed fishing gear, which is designed to maximize strength and durability. Such entanglements result in long, painful deaths: lines can become embedded in baleen plates and wrap around flippers, flukes, and blowholes; gear can flense large sections of blubber; and impaired feeding and infections are common.[28] Knowlton *et al.* found that 519 of 626 photo-identified right whales (82.9%) had been entangled at least once and 306 of the 519 (59.0%) had been entangled multiple times.[23] These authors conclude that the efforts made since 1997 to reduce entanglements and fatalities from fishing gear have not succeeded.

The continued mortality of Florida manatees from boat strikes represents another failure of the MMPA and the ESA to protect individual marine mammals from harm. Speed-limited zones and restrictions have been aggressively challenged in court and in Congress, although the total area of regulated boat speeds is only a small fraction of available waterways in Florida.[29] In both of these cases, powerful political interests (the commercial fishing and recreational boating industries) have managed to delay or prevent implementation of conservation measures that could improve the status of endangered marine mammals.

As a result of these limitations, increased protection often depends on evidence collected outside of the federal government. The authors of the ESA were prescient in including an innovative citizen initiative that allows individuals to petition the government to list unprotected species and challenge USFWS and NMFS decisions. Recent analyses have shown that species that are petitioned by such initiatives, on land and in freshwater, are overall more biologically threatened than those selected by the government.[30] Although, to our knowledge, no such analysis has been conducted for marine mammals, it is clear that these initiatives are essential in providing enhanced legal protection under the ESA. The insular stock of false killer whales appears to have declined significantly around the main Hawaiian Islands.[31] A petition to list them as endangered under the ESA was submitted in 2009 and confirmed in 2012. Other species that have been listed or are under consideration because of citizen petitions include the polar bear (listed as threatened in 2008); Southern resident killer whales of Washington State and British Columbia; and the ringed, bearded, and spotted seals, which are all dependent on sea ice.

Failure to monitor trends

Another failure in implementing the MMPA is inadequate resources to survey each marine mammal stock on a regular basis. For most species (71%), population trends remain unknown. This makes efforts to protect species by NMFS and engaged citizens especially challenging. It should be noted that the monitoring of more than 200 stocks in the U.S. EEZ is a huge undertaking, especially because many species, like ice seals and pelagic small cetaceans, are difficult to survey. Given the challenge in reliably assessing population numbers or biological removals, Robards *et al.* have recommended that managers base decisions on ecological needs and observed ecological changes.[32] NMFS has recognized the shortfall in a recent proposal to revise the guidelines for assessing marine mammal stocks, acknowledging that for many populations, data are so sparse that it is not possible to produce a minimum population size ($N_{\min}$) or estimate PBR. In the absence of such an estimate, species like the North Atlantic bottlenose whale (considered endangered in Canada) and Bryde's whale in the Northern Gulf of Mexico, may be at greater risk than is acknowledged in stock assessment reports. Yet even in instances when mortality appears to be kept below PBR, as with sea otters and killer whales in the North Pacific, populations can decline.

Failure to manage particular anthropogenic stressors and impacts

Contaminants. Marine mammals have ecological and physiological characteristics that make them highly susceptible to the negative effects of anthropogenically derived contaminants. Typically occupying high trophic levels, they are subject to contaminants that bioaccumulate within food webs. Moreover, the blubber tissue found in many marine mammal species is concentrated with lipids, which readily store some types of toxins. Contaminants like persistent organic pollutants (POPs) are known to compromise immune activity in laboratory animals and appear to cause similar effects in marine mammals based on both field-based and experimental studies.[33–38] Finally, maternal transfer of contaminants in marine mammals can be very high. Compared to adults, juveniles may be at even greater risk from the damaging effects of these pollutants given their high rates of development.[39]

A number of recent studies demonstrate high concentrations of contaminants in tissues of U.S. marine mammal populations. Contaminants in tissues of bottlenose dolphins from Charleston, South Carolina, and Indian River Lagoon, Florida were compared to threshold concentrations established through experimental dose–response studies focused on immunological and reproductive effects. Of the 139 individuals sampled in the wild, 88% of males exhibited levels of polychlorinated biphenyls (PCB) five times the established PCB threshold (the level at which an adverse effect is expected to become evident), with many individuals exhibiting PCB levels 15 times the threshold.[40] A suite of other organic contaminants found in blubber tissue from the two populations was also found to be at or above levels known to adversely affect humans, wildlife, and laboratory animals. Endangered killer whales that are summer residents of the Northeastern Pacific also exhibit contaminant levels that exceed thresholds for health effects in marine mammals.[39]

In the United States, successful efforts to restrict and in some cases ban the use of some toxic substances (e.g., DDT) have benefited wildlife populations. Although little is known about the long-term trends regarding contaminant levels in many marine mammal populations, some studies do exist. For example, DDT levels recently measured in California sea lion populations were found to be 10 times lower than values reported from 1970.[41] However, organic contaminants still persist in this population and may make individuals more susceptible to some types of disease. Specifically, California sea lions that likely died from metastatic carcinoma exhibited higher tissue burdens of PCBs than animals that died from other causes.[42]

Some examples above indicate a high risk for marine mammals populations to be affected by contaminants. However, understanding the population level consequences of contaminants requires broad sampling across all the demographic groups present. Knowledge of the relationship between body condition and contamination is also critical, since metabolic pathways that can change with food availability or other factors can influence the release of fat- or lipid-associated contaminants. Finally, a better understanding of contaminant patterns over long time scales is necessary to assess whether the potential threat is currently changing. Two U.S. programs provide useful resources in this context. First, the U.S. National Biomonitoring Specimen Bank includes well-preserved and documented tissue specimens associated with nine marine mammal species that are regularly analyzed for chlorinated hydrocarbons and trace elements.[43] These tissues can serve as a baseline to compare to recent samples. Second, the U.S. Navy directs a unique marine mammal program in which a large number of bottlenose dolphins are maintained in netted open water enclosures. These animals could serve as sentinels to assess contaminants and disease in a relatively controlled environment.[44]

Trophic impacts and declines in prey species. Fisheries can affect marine mammals through incidental capture in fishing gear or indirectly by reducing their prey base or competitors.[12,45,50,51] When resources are limited, competition can occur between marine mammals and commercial fisheries, with negative effects for both fisheries and marine mammal populations. The recovery of sea otters (*Enhydra lutris*) along the coast of California, for example, caused direct competition with, and the demise of, some shellfisheries, as invertebrate prey populations were reduced by the otters.[46] Likewise, commercial fisheries have caused the depletion of marine mammal prey, resulting in a negative indirect effect on populations: according to one recent study, a reduction in prey populations results in a 60–70% decline in predators.[47] Thus, a 50% prey reduction would result in a predator reduction of roughly 30–35%. Although the MMPA accounts for the direct effects of fisheries on marine mammals using PBR as a reference point, it typically fails to account for such indirect effects.

The depletion of world fish stocks has been well documented,[48–50] but the relationship between exploited fish species and marine mammals is complex. Competition with fisheries resulting in nutritional stress may be a causal factor in the failure of the western Steller sea lion population to recover, but the connections are far from clear.[52] In some cases, when fisheries reduce competitors to marine mammals, they can have an indirect positive effect on populations by reducing competition for prey resources.[51] On the eastern Scotian Shelf ecosystem off Nova Scotia, overfishing caused a cod collapse in the mid-1980s and early 1990s. Gray seals (*Halichoerus grypus*) may have benefited from this collapse, which released benthic fish prey species, resulting in a subsequent increase in seal abundance.[53]

When negative indirect effects of fisheries on marine mammal populations do occur, overexploited fisheries can prevent the MMPA from meeting its objectives by reducing the carrying capacity. Moore recently proposed a novel mechanism to modify the PBR reference point to account for the demographic effects of prey depletion on marine mammals.[47] A reduction in forage fish in the northeastern United States, for example, could be considered equivalent to a human-caused mortality of 3.2 fin and 4.6 humpback whales per year, a level that is above PBR for humpbacks.[47] Despite the strength of this theoretical framework, the modification of PBR is likely to be difficult and controversial, both because of data deficiencies and conflicts with current fishery management plans.

Cumulative sublethal effects from noise and disturbance. Since the early 1990s, undersea noise has emerged as a major topic of research, regulation, and public advocacy. Marine mammal research has seen an explosion of investment in the issue, often driven by litigation, public pressure, and regulatory requirements[54,55] and fed by user groups such as the U.S. Navy and the oil and gas industry, which annually fund more than $25 million in related research. For NMFS, most take authorizations issued each year under the MMPA are for the impacts of noise and disturbance, caused by military training, geophysical surveys, offshore construction, and aircraft overflights.[56] Several of these matters have had high public profiles, centered on what has been described as *focalizing events* such as mass strandings.[57]

It has long been recognized that the ocean is an acoustic world, and that marine mammals (and many other species) depend on sound for foraging, breeding, predator avoidance, navigation, maintaining social bonds, and environmental awareness.[58] Impacts associated with anthropogenic noise include dramatic, acute effects such as atypical mass strandings and mortalities of whales,[59,60] but also sublethal effects such as habitat displacement, silencing, and masking of biologically important sounds.[61–64] Anthropogenic noise can disrupt mother–calf bonds, resulting in increased call duration, with possible fitness consequences.[65] The cumulative effects of disturbance are extremely difficult to study in the wild, but in some discrete cases they have been causally linked to population decline.[66] But for many species, these effects occur at large temporal and spatial scales that challenge our capacity to monitor.[67,68]

Through the 1990s and 2000s, the MMPA's regulatory scheme was increasingly applied to major producers of ocean noise. For example, most naval activities within the U.S. territorial sea and EEZ are now the subject of programmatic rulemakings; in the oil and gas sector, operators regularly apply for MMPA incidental harassment authorizations as a condition of their geophysical exploration permits in the Arctic. Regulation remains spotty, however. Large sectors of some industries, like geophysical exploration in the Gulf of Mexico, the most heavily prospected body of water in the world, remain unregulated under the MMPA, and some industries, such as commercial shipping and whale watching, stand as yet outside the act's authorization process. Even for regulated activities, NMFS has not addressed the emergent problem of cumulative impacts from noise and disturbance, and, in general, relevant management tools in the MMPA have not been applied.

The PBR framework, as we have discussed, tends to cover only lethal take, with a focus on bycatch and entanglement, with little attention paid to nonlethal stressors such as noise. The MMPA's small numbers standard, which sets a ceiling for take authorizations, has not been systematically defined; nor has NMFS developed a methodology by which its crucial negligible impact standard, another ceiling, might apply to sublethal effects. Indeed, the small number and negligible impact standards are sometimes conflated.[69] As a result, NMFS commonly quantifies take, or risk of take, down to fractions of animals, then fails to evaluate what those takes mean biologically.[55]

To further confound matters, NMFS interprets the MMPA's authorization provision to give action proponents full discretion in deciding the scope of their application. Not only has this precluded programmatic evaluation of similar activities affecting the same populations in the same geographic area, such as oil and gas airgun surveys in the Arctic, but also it has allowed for segmentation of individual projects, such as the Apache Corporation's three- to five-year airgun survey in Cook Inlet, Alaska, which is being approved under successive, year-long authorizations.[70]

As Hatch and Fristrup have observed, the service's lack of capacity to assess large-scale cumulative impacts even from individual activities requires it to mitigate those impacts conservatively in the absence of population-level data.[71] Unfortunately, management efforts to date have focused primarily on reducing risk of exposure to lethal or directly injurious levels of noise, not on minimizing sublethal effects that occur on a much larger spatial scale.[72,73] Although more can be done to minimize large-scale impacts on an activity-by-activity basis, for example at the level of an individual seismic survey or sonar exercise, the agency has a wider range of management options when user groups bundle their activities into a single application and come in for programmatic MMPA review.

Various entities are attempting to develop means to evaluate cumulative impacts from noise and disturbance. Perhaps the most ambitious is the Population Consequences of Disturbance effort, led by the Office of Naval Research, which is attempting to quantify cumulative impacts in a small number of data-rich species by applying a series of transfer functions, running from short-term disturbance to impacts on biologically important activities and ultimately to effects on vital rates in individuals and populations.[74] An alternative approach is to develop proxies for significance and negligible impact based on multifactorial analyses, with at least one such effort applied successfully on the state level for a seismic survey off California.[75] Still others have proposed modifying the MMPA to incorporate concepts from marine spatial planning and ecosystem management.[71] In one of the most important developments, NMFS has produced cumulative noise and cetacean distribution maps covering, in varying degrees of resolution, the entire U.S. EEZ.[76] These maps could well become a transformative tool for cetacean management, and NMFS should invest in their further development and implementation.

Finally, many stakeholders inside and outside the government are focused pragmatically on developing effective mitigation: new technologies that can reduce the environmental footprint of large commercial ships and airgun surveys; new models that can define important habitat for protection; and a variety of measures that can reduce the amount of disruptive activity taking place seasonally or annually in a given area.[72,73,77,78] For these measures to succeed, NMFS must take concerted and proactive steps to use available methodologies to reduce impacts.

Disease. Disease reports in marine mammals, as with a variety of other ocean taxa, have increased over the past three decades.[38,79,80] The worrisome trend appears to reflect a real phenomenon rather than an artifact of increases in scientific publishing of marine mammal studies,[81] although new detection techniques using molecular genetics have also played a role in identifying and characterizing disease agents in marine environments.[80] A variety of large-scale factors (and their interactions) are likely influencing the distribution and prevalence of these diseases, including shifts in host/pathogen distribution, increased global temperatures, habitat loss and alteration, and changes in immunological response of individuals.[38]

Since the 1980s, a number of morbilliviruses have been the cause of marine mammal mass mortalities around the globe.[82–84] This group of viruses is also of serious concern in the United States where at least two mass mortality events of bottlenose dolphins are linked to morbillivirus outbreaks. One event took place off the U.S. east coast in 1987–1988, with mortality estimated at more than 50% of the population.[84,85] Morbillivirus is also implicated in the mass mortality of this species that occurred in 1993–1994 in the Gulf of Mexico.[84] A recent examination of the distribution and prevalence of morbillivirus antibodies in bottlenose dolphins from the eastern United States indicates that the viruses did not persist in coastal stocks after outbreaks in the 1980s, but appear to be circulating in more southerly regions.[86] Importantly, a number of U.S. resident estuarine populations of bottlenose dolphins have been identified in which antigens are largely absent. These populations would likely experience high initial mortality if contact with the pathogen emerges.[86] Studies like the one cited, which identify marine mammal populations at high risk from disease, could be used by management agencies to identify additional measures of protection for particular stocks.

Disease resulting from biotoxins has emerged as another serious threat: marine mammal mortalities associated with these toxins have exhibited an increase in frequency along the east and west coast of the United States since the mid 1990s.[80] Over the same period, the frequency of harmful algal blooms (HABs) has also increased, suggesting a direct link between the two.[89] Biotoxins are known to be inhaled by marine mammals,[87] and recent findings demonstrate that these toxins can also accumulate in fish tissues and spread through marine food webs.[88] It is likely that this newly identified vector mechanism was responsible for die-offs of endangered Florida manatees in 2002 and bottlenose dolphins in the Florida Panhandle in 2004.[88] Domoic acid, produced by marine diatoms, has caused the death and reproductive failure of California sea lions.[90]

A better understanding of the interactions between disease and a long list of anthropogenic factors is critically needed.[91] Some expected changes are likely to favor disease, including range shifts, compromised immunity as a result of stressors, and increased host density; others, such as population decreases or pathogens being more sensitive to environmental factors than their hosts, may result in their reduction.[92] Arctic stocks of marine mammals may be particularly at risk from interacting factors because environmental and ecological dynamics occurring from climate change are magnified there.[93] Relevant factors include loss of sea-ice habitat, which could lead to higher density of hosts and favor density-dependent disease; decreases in food availability leading to impacts on body condition and immune system function; and increases in human activity throughout the region leading to increased likelihood of pathogen introduction. Finally, increased susceptibility to disease has recently been linked to decreased genetic variability in populations of California sea lions,[94] underscoring the heightened threat to endangered populations. Anthropogenically exacerbated diseases in pinnipeds, cetaceans, and sea otters, from harmful algal blooms to pathogen pollution from pets and livestock, demonstrate that the protection of marine mammals also requires protection of the adjacent terrestrial environment.

The way forward

The MMPA has been very successful in protecting many marine mammals from harm and largely successful in restoring and protecting individual marine mammals stocks. One of the reasons for this success has been the development of the PBR approach by NMFS, designed expressly for management under the act. This current focus on species and individual animals is appropriate not only from a welfare perspective but also, given the lack of data and the need for precaution, from a demographic standpoint.

There have been few, if any, attempts to address the second fundamental objective: maintaining marine mammals as functional elements of their ecosystem. Many species lack historic baselines, and the understanding of the ecological role of marine mammals was limited when the act was passed. It is increasingly clear, however, that upper trophic level predators, such as marine mammals, play critical roles in structuring their ecosystems.[95–97] Humpback and fin whales in the Gulf of Maine increase productivity by pumping nutrients to the surface.[6] The benthic plowing of gray whales alters the microtopography of the seafloor and enhances benthic-pelagic coupling.[98] Estes *et al.* have even suggested that productive and dense kelp forests can be used as a sensitive and cost-effective measure of sea otter recovery, an approach that has broad potential in establishing recovery criteria for other reduced populations with clearly measurable ecosystem impacts.[99]

To restore the ecological role of marine mammals, there is a need for an ecoregional approach to conservation, with an increased understanding of predator–prey interactions and the cumulative effects of human impacts. A precautionary generalization of PBR that combines the direct and indirect effects of fisheries, including predator–prey relationships and ecological interactions, as well as cumulative impacts from other stressors, could form a central part of such policy. Such an effort would balance the apparently competing management goals of optimum fishery yield and sustainable marine mammal populations. This would, of course, require a fundamental rethinking of how we manage fisheries and other extractive and nonextractive ocean uses.

Our increased understanding of the stock structure of marine mammal populations has clearly aided in our ability to manage them. The number of U.S. stocks has more than tripled since SARs were first compiled, largely because of a better comprehension of odontocete population structure (Fig. 1). Assessing the status of marine ecoregions together with the dynamics of these individual stocks would represent a significant step forward in ocean conservation. Such a comprehensive management framework would move the species-based approach to one that can effectively restore the ecological function of marine mammals. Whales and other long-lived species can dampen the frequency and amplitude of oscillations from perturbations in climate, predation, and primary productivity.[97] The removal of these species from much of the world has left many marine communities dominated by *r*-selected species. Without whales, marine ecosystems have longer return time after perturbations.

The MMPA, along with the Endangered Species Act, has helped put several great whale species, including the Pacific gray whale, Pacific blue whale, and humpbacks in the Atlantic and Pacific, on the road to recovery, a process that was aided by the moratorium on commercial whaling by the great majority of nations. The restoration of whales and other marine mammals has been a great benefit to coastal communities in the United States, bringing more than $956 million a year in the form of whale watching,[100] increasing the diversity of jobs in areas suffering from fisheries decline, such as Gloucester and Provincetown, Massachusetts, and enhancing environmental tourism. The increase in whale watching has come at a cost, including collisions between whale-watching boats and whales and reduced reproductive fitness.[101,102] Other threats have also emerged or been acknowledged in the 40 years since the act was passed, including the rise of disease, ship collisions, declines in prey species, and noise and disturbance. Research and new technologies are clearly needed to protect marine mammals from noise-related impacts, including the study of behavioral responses to impulsive and continuous noise.[65]

The MMPA has focused on addressing direct effects, but it should be kept in mind that there are indirect consequences of restoration: you cannot have healthy marine mammal populations without a healthy marine ecosystem. In this way, a fully enforced MMPA could serve as a de facto marine conservation act, much as the ESA has become a habitat protection act, at least in terrestrial ecosystems. The restoration of marine mammals may go well beyond such legislative boundaries: as active members in the marine food web, they can help restore coastal and pelagic ecosystems simply by becoming functional members of marine communities.

Acknowledgments

We thank Brad Sewell for prompting a study of the status of U.S. marine mammals, and Rick Ostfeld and Bill Schlesinger, of the Cary Institute for Ecosystem Studies, for inviting us to prepare this review. Research was supported by the Natural Resources Defense Council's Endangered Oceans Project.

Supporting Information

Additional Supporting Information may be found in the online version of this article.
Appendix 1: Status and trends of U.S. marine mammal stocks

Conflicts of interest

The authors declare no conflicts of interest.

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