











CONTRIBUTED PAPERS

Red-list status and extinction risk of the world's whales, dolphins, and porpoises

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Article impact statement: One in 4 whale, dolphin, and porpoise species is threatened with extinction. River and coastal species, especially in Asia, are most threatened.

Abstract

To understand the scope and scale of the loss of biodiversity, tools are required that can be applied in a standardized manner to all species globally, spanning realms from land to the open ocean. We used data from the International Union for the Conservation of Nature Red List to provide a synthesis of the conservation status and extinction risk of cetaceans. One in 4 cetacean species (26% of 92 species) was threatened with extinction (i.e., critically endangered, endangered, or vulnerable) and 11% were near threatened. Ten percent of cetacean species were data deficient, and we predicted that 2–3 of these species may also be threatened. The proportion of threatened cetaceans has increased: 15% in 1991, 19% in 2008, and 26% in 2021. The assessed conservation status of 20% of species has worsened from 2008 to 2021, and only 3 moved into categories of lesser threat. Cetacean species with small geographic ranges were more likely to be listed as threatened than those with large ranges, and those that occur in freshwater (100% of species) and coastal (60% of species) habitats were under the greatest threat. Analysis of odontocete species distributions revealed a global hotspot of threatened small cetaceans in Southeast Asia, in an area encompassing the Coral Triangle and extending through nearshore waters of the Bay of Bengal, northern Australia, and Papua New Guinea and into the coastal waters of China. Improved management of fisheries to limit overfishing and reduce bycatch is urgently needed to avoid extinctions or further declines, especially in coastal areas of Asia, Africa, and South America.

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KEYWORDS

bycatch, Cetacea, marine biodiversity, marine conservation, marine ecosystems, marine mammals, threatened species

Estado en la lista roja y riesgo de extinción de las ballenas, delfines y marsopas del mundo
Resumen: Para comprender el alcance y la escala de la pérdida de biodiversidad, se necesitan herramientas que puedan aplicarse de forma estandarizada a todas las especies a nivel mundial y que abarquen todos los ámbitos desde la tierra hasta el océano. Utilizamos datos de la Lista Roja de la Unión Internacional para la Conservación de la Naturaleza para proporcionar una síntesis del estado de conservación y el riesgo de extinción de los cetáceos. Una de cada 4 especies de cetáceos (26% de 92 especies) se encuentra amenazada (es decir, en peligro crítico, en peligro o vulnerable) y el 11% de las especies está clasificado como casi amenazada. El 10% de las especies de cetáceos carecía de datos, por lo que predijimos que 2–3 de estas especies también podrían estar amenazadas. La proporción de cetáceos amenazados ha aumentado: 15% en 1991, 19% en 2008 y 26% en 2021. El estado de conservación evaluado del 20% de las especies ha empeorado de 2008 a 2021, pues sólo 3 pasaron a categorías de menor amenaza. Las especies de cetáceos con áreas de distribución geográficas pequeñas tenían más probabilidades de ser catalogadas como amenazadas que aquellas con áreas de distribución extensas, y aquellas que ocurren en hábitats de agua dulce (100% de las especies) y costeros (60% de las especies) eran las que se encontraban bajo mayor amenaza. La superposición de los mapas de distribución de las especies reveló la existencia de puntos calientes de pequeños cetáceos amenazados en el sudeste asiático y en una zona que abarca el Triángulo de Coral y se extiende por las aguas cercanas a la costa de la Bahía de Bengala, el norte de Australia, Papúa Nueva Guinea y las aguas costeras de China. Urge mejorar la gestión de las pesquerías para limitar la sobrepesca y reducir la captura accesoria con el fin de evitar extinciones o mayores descensos, especialmente en las zonas costeras de Asia, África y Sudamérica.

PALABRAS CLAVE

biodiversidad marina, captura accesoria, Cetacea, conservación marina, ecosistemas marinos, especies amenazadas, mamíferos marinos

全球鲸类、海豚和鼠海豚的红色名录濒危等级及灭绝风险

【摘要】要了解生物多样性丧失的范围和规模,需开发能够以标准化方式应用于全球从陆地到海洋的所有物种的工具。我们利用《世界自然保护联盟红色名录》数据,对鲸类物种的濒危等级及灭绝风险进行了综合分析。我们发现,四分之一的鲸类物种(92个物种中的26%)面临灭绝威胁(极危、濒危及易危),还有11%的物种近危。10%的鲸类物种缺乏数据,我们预测其中有2-3个物种可能也面临威胁。受威胁的鲸类物种比例在过去有所增加:1991年为15%,2008年为19%,而2021年为26%。从2008年到2021年,20%的物种濒危等级升高,同时只有3个物种濒危等级降低。地理分布窄的鲸类物种比广布物种更有可能被列为受威胁物种,而那些生活在淡水(100%的物种)和沿海(60%的物种)栖息地的物种受到的威胁最大。叠加物种分布范围后,我们发现全球受威胁小型鲸类的分布热点地区在东南亚和从珊瑚三角区延伸到孟加拉湾近岸水域、澳大利亚北部、巴布亚新几内亚和中国沿海水域的地区。我们提出目前急需加强渔业管理来限制过度捕捞并减少兼捕,以避免鲸类物种的灭绝或进一步减少,特别是在亚洲、非洲和南美洲的沿海地区。【翻译:胡怡思;审校:聂永刚】

关键词: 鲸类, 海洋保护, 海洋生物多样性, 海洋生态系统, 受威胁物种, 海洋哺乳动物, 兼捕

INTRODUCTION

There are fewer and fewer wild places left on the planet and a steady erosion of biodiversity in all realms from land to the open ocean (Eldredge, 2000). The sixth extinction is characterized by

a high rate of biodiversity loss, brought about almost entirely through human activities (Ceballos et al., 2010). To understand the scope and scale of the loss, the most widely used and globally recognized tool is the International Union for the Conservation

of Nature (IUCN) Red List of Threatened Species. Initiated in the 1960s, the red list is a science-based, standardized approach applied to all species globally and is designed to act as a “barometer of life” (IUCN, 2022). The red list itself has no regulatory power or standing; its role is to provide summarized information on the conservation-status, trends, and threats to species in the expectation that it will inform and motivate actions for biodiversity conservation and environmental safeguarding mechanisms (Betts et al., 2020).

In general, marine realms are less well understood and less well protected, but just as threatened as their terrestrial counterparts (Schipper et al., 2008). In particular, areas beyond national jurisdiction, which comprise 40% of the surface area of the planet, are extremely challenging to protect using currently available strategies (Elferink, 2021). Cetaceans (whales, dolphins, and porpoises; order Artiodactyla, infraorder Cetacea) are air-breathing, mammalian top predators that live exclusively in water, reproduce slowly, mature late, and range at relatively low densities over wide areas. These characteristics make cetaceans difficult to study, vulnerable to human impacts, and hard to protect. However, cetaceans are often ambassadors for functioning, clean oceans or rivers, inspiring people to venture out to sea for live encounters, encouraging a passion for marine biology, and acting as catalysts or flagships for ocean protection (Notarbartolo di Sciara & Würsig, 2022).

Cetaceans comprise 2 very different groups. Mysticetes, or baleen whales, consist of 15 generally large species that feed by filtering small food organisms through baleen plates (Jefferson et al., 2015). Odontocetes, or toothed whales, comprise 77 generally small species of dolphins and porpoises that typically feed on a variety of fish, squid, or, in the case of some killer whales (*Orcinus orca*), other mammals (Jefferson et al., 2015). Most baleen whales and some toothed whales were relentlessly hunted by commercial whaling over several centuries. Following the global moratorium on whaling in 1986 (IWC, 1983), presently only 3 nations allow baleen whales to be hunted commercially.

Collation of information on extinction risk based on the IUCN Red List can provide an informative overview of the status of groups of species that allows for comparison with other taxa, shows changes in extinction risk over time, and provides broad insights on endangerment that can aid in communication of important issues to decision makers and the public. Landmark papers summarizing red-list status and extinction risk have been published for various species groups (e.g., sharks [Dulvy et al., 2014], amphibians [Ficetola et al., 2015], terrestrial and marine mammals [Schipper et al., 2008]) and have successfully

shone a light on the high level of threat these groups face, but such an assessment has not been conducted for cetaceans since a brief review by Reeves et al. (2003). Thus, we conducted a new and up-to-date synthesis of the global status and extinction risk of cetaceans and explored changes in conservation status over time. We examined differences in range and habitat characteristics that render some species and families more vulnerable to extinction than others and sought to identify geographic locations and countries with the greatest number of cetacean species of conservation concern. We also summarised ways that the

IUCN Red List can be used to support cetacean conservation efforts.

METHODS

Red-list assessment process

The Cetacean Specialist Group (CSG) of the IUCN Species Survival Commission is responsible for conducting red-list assessments of all cetacean species. From 2017 to 2021, we (the CSG) reassessed nearly all (90 of 92) recognized species of cetaceans for the red list (hereafter the ‘2021 reassessment’). The IUCN publishes updates to the list each year, and all the data provided here are from the 2022-1 version of the red list. Since the 2021 update, 1 additional cetacean species, Ramari’s beaked whale (*Mesoplodon euen*), has been recognized and is awaiting assessment. The assessments of Hector’s dolphin (*Cephalorhynchus hectori*) and sperm whale (*Physeter macrocephalus*) have not been updated and date from 2008. A subset of subspecies (10) and subpopulations (30) have been assessed specifically to catalyze conservation actions; therefore, these do not provide unbiased insights into patterns of extinction risk for those infraspecies.

Each cetacean red-list assessment includes a concise summary of published information on systematics, distribution, abundance, trends, habitat, ecology, threats, and conservation measures. We evaluated this information relative to the IUCN Categories and Criteria 3.1 (IUCN, 2012), which serves as a framework for the classification of species as critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), data deficient (DD), or extinct (EX). The criteria relate to reduction in population size (criterion A), small geographic range (B), small population size and decline (C), very small or range-restricted population (D), and quantitative analysis of extinction probability (E). Included in each red-list assessment is a conclusion regarding population trajectory: increasing, decreasing, stable, or unknown. Assessors produce a digital map of the geographic range for each species based on areas of known or assumed occurrence and assign countries where the species is known or suspected to occur in the Exclusive Economic Zone. The maps rely heavily on those presented in *Marine Mammals of the World* (Jefferson et al., 2015) and have been verified and updated where necessary. Each assessment was entered into the IUCN Species Information Service entry module and checked by IUCN staff prior to publication.

Some assessments (e.g., of *Sousa*) were conducted at expert workshops, but the majority were drafted through correspondence among species experts and then reviewed by red-list-trained members of the CSG for quality and consistency across taxa. A total of 80 individual experts from 6 continents served as authors of the 2021 reassessments.

The taxonomic authority for cetaceans is the Committee on Taxonomy of the Society for Marine Mammalogy (Committee on Taxonomy, 2022). The agreed-on cetacean taxonomic list is updated by that committee at least annually, and the CSG

assesses each new species as quickly as possible after it has been accepted.

Red-list assessments for data-poor ziphiid species

Prior to the 2021 red-list update, almost half of all cetacean species ($n = 45$) were assessed as DD. This number included almost all of the 23 recognized species of beaked whales (or ziphiids, meaning species in the family Ziphiidae). Many of these species occur in multiple oceans and in offshore waters that have not been well surveyed. Assessment for the red list of such cryptic species with limited data is particularly challenging, and the vast gaps in knowledge led assessors to conclude that extinction risk could not be determined because of the insufficiency of data. A 2019 update to the IUCN Red List Guidelines refined the definition of *DD* so that a species must be so DD that it could plausibly belong in any category along the spectrum from CR to LC (IUCN Standards and Petitions Committee, 2022). Because CR and LC were not equally plausible for most ziphiids, a set of rules was developed by the CSG to lay out the reasoning used to arrive at a category that was based on rarity, range size, and proportion of range affected by well-documented threats (in the case of ziphiids, mainly anthropogenic noise and bycatch in fisheries) (Appendix S1). This rationale provided a transparent and logical framework to assign these extremely data-poor species to a category other than DD.

A certain proportion of the DD species were likely to be threatened. A variety of methods have been used for other species groups to predict the number of threatened DD species (Dulvy et al., 2014; Jetz & Freckleton, 2015). We used Fisher's exact test to compare the proportion of species in each red-list category for all data-sufficient species (Table 1) with the 36 species that were previously DD and assigned to another category in 2021. Based on those results, we then predicted the proportion of the remaining DD species that were likely to be threatened.

Change in extinction risk over time

The IUCN Red List was initiated in the 1960s, and for many years only threatened species were listed and there was no equivalent to the current LC or DD category (IUCN Operations Intelligence Centre, 1964). By 1991, a more extensive assessment of all cetacean species had been conducted that included the categories insufficiently known, rare, and indeterminate, as well as most of the categories still in use (Klinowska & Cooke, 1991). We tabulated the number of species assessed and the total listed under threatened categories (CR, EN, VU) in all red lists from the 1960s until the present to show changes in the proportion of threatened species listed over time.

All recognized cetacean species were assessed for the red list at a 2007 workshop, and the published assessments were dated 2008. All species were then reassessed from 2017 to 2021 (i.e., 10–14 years later). We tabulated change in red-list status between the 2 assessment periods. Species that retained the

same category were listed as no change; species that moved from a lower level of threat to a higher level of threat were considered uplisted; and those that moved from a higher level of threat to a lower level of threat were considered downlisted. We also tabulated the 36 species that had moved out of DD according to whether they had been reassigned to a threatened category or to one of the non-threatened categories (LC, NT).

Extinction risk of cetaceans and distribution

Eighty-five of the 92 cetacean red-list species assessments have range maps, whereas for 7 species (all ziphiids) there is insufficient knowledge of their occurrence and no range map. We downloaded the species range shapefiles from the red-list website and imported them into QGIS 3.10 (QGIS.org, 2022). The range area for each species was calculated using QGIS Geometry Tools. The polygons for IUCN marine species range maps are buffered resulting in extrapolation to a small extent beyond known ranges; therefore, absolute range size is likely to be an overestimate. However, the relative size of each range is expected to be comparable (Dulvy et al., 2014). A relationship between range size and extinction risk was explored using linear regression in which red-list category was the explanatory variable and range size was the predictor variable.

Extinction risk of cetaceans and habitat

At a global level, the zoogeography of cetacean species is determined primarily by depth and sea surface temperature, with most species' range influenced by 1 or both of these drivers (Martin & Reeves, 2002). To explore the relationship between habitat and extinction risk, we assigned each cetacean species to 1 of 4 broad habitat categories based on the descriptions of Martin and Reeves (2002) and Jefferson et al. (2015) as follows: primary habitat: rivers and lakes, coastal waters, continental shelf waters, or open ocean. Where species occurred in more than 1 habitat type, the one encompassing the largest proportion of the total range was selected. A chi-squared test was used to explore whether threatened cetacean species were equally distributed among the 4 habitat categories.

Geographic locations of species of high conservation concern

To identify the broad geographic locations where the greatest number of cetacean species of conservation concern are found, species range shapefiles were converted to the EPSG:3410 EASE equal earth projection, which is an equal area world coordinate reference system in QGIS. A 100 × 100 km global hexagonal grid was created and clipped so that it covered only the oceans, resulting in 44,387 cells, each 10,000 km² in size (or less where they intersected land). The individual species range shape files were merged with the global grid with the spatial join feature so that each grid cell included the presence or absence

TABLE 1 The International Union for the Conservation of Nature Red List status of cetaceans in 2021 by family (based on data in the 2022-1 Red List version).

Group	Taxon	Number of species ^a	Number of threatened species ^b	Species threatened (%)	Category						
					CR	EN	VU	NT	LC	DD	
Mysticete (baleen whales)	Balaenidae (right whales)	4	2	50	1	1	—	—	—	2	—
	Neobalaenidae (pygmy right whale)	1	0	0	—	—	—	—	—	1	—
	Eschrichtiidae (gray whale)	1	0	0	—	—	—	—	—	1	—
	Balaenopteridae (rorquals)	9	4	44	1	2	1	1	1	3	1
	All	15	6	40	2	3	1	1	1	7	1
Odontocete (toothed whales)	Physeteridae (sperm whale)	1	1	100	—	—	1	—	—	—	—
	Kogiidae (pygmy/dwarf sperm whale)	2	0	0	—	—	—	—	—	2	—
	Ziphiidae (beaked whales)	23	1	4	—	1	—	—	3	12	7
	Platanistidae (South Asian river dolphins)	2	2	100	—	2	—	—	—	—	—
	Iniidae (Amazon river dolphin)	1	1	100	—	1	—	—	—	—	—
	Lipotidae (Yangtze river dolphin)	1	1	100	1	—	—	—	—	—	—
Pinnipedia (seals, sea lions, walrus)	Pontoporiidae (Franciscana)	1	1	100	—	—	1	—	—	—	—
	Monodontidae (beluga/narwhal)	2	0	0	—	—	—	—	—	2	—
	Delphinidae (dolphins)	37	8	22	1	4	3	5	23	1	—
	Phocoenidae (porpoises)	7	3	43	1	1	1	1	3	—	—
	All	77	18	23	3	9	6	9	42	8	—
Total	92	24	26	5	12	7	10	49	9	—	

Abbreviations: CR, critically endangered; DD, data deficient; EN, endangered; LC, least concern; NT, near threatened; VU, vulnerable.

^a Following the current List of Marine Mammal Species and Subspecies as recognized by the Committee on Taxonomy of the Society for Marine Mammalogy (<https://marinemammalscience.org/science-and-publications/list-marine-mammal-species-subspecies/>).

^b Threatened species are those assessed as CR, EN, or VU.

of each species. Color maps were made to show the area of occurrence and range of threatened odontocete species. The maps covered marine habitat specifically, and the ranges of cetaceans in rivers were not included because they were very narrow and hard to visualize, and, because most rivers are inhabited by only 1 or 2 species, the information they would provide is limited. No maps were made of mysticete ranges. Although most mysticetes are only seasonally present in many areas, they migrate over long distances, and, as such, for most of those species the red-list range maps encompass most of the world's oceans. Range maps for these species likely obscure large areas of absence and therefore can be misleading (Williams et al., 2014).

RESULTS

Red-list status of cetacean species

In the 2022-1 version of the IUCN Red List, 1 in every 4 (26%, $n = 24$) cetacean species was classified in a threatened category and was therefore assessed as being at risk of extinction. Just over half (53%, $n = 49$) were classified as LC and 11% ($n = 10$) as NT. For 10% ($n = 9$) of the species, the available information was insufficient to support a meaningful assessment of conservation status, and they were classified as DD. Of the 15 mysticete species, 40% (6 out of 15) were assigned to a threatened category, compared with 23% (18 of 77) of odontocete species (Table 1; Appendix S2).

Five cetacean species, all from different families, were classified as CR: the Yangtze River dolphin or baiji (*Lipotes vexillifer*), which was classified as CR possibly extinct, and is regarded as actually extinct (EX) (Turvey et al., 2007); the vaquita (*Phocoena sinus*), endemic to the upper Gulf of California in Mexico (thought to number around 10 individuals [Rojas-Bracho et al., 2022]); the poorly known Atlantic humpback dolphin (*Sousa teuszii*), found only in nearshore waters of the Atlantic coast of Africa (Weir & Collins, 2015); the North Atlantic right whale (*Eubalaena glacialis*), limited to a remnant of its historical range in the western North Atlantic (Meyer-Gutbrod & Greene, 2017); and the recently described Rice's whale (*Balaenoptera ricei*), endemic to the Gulf of Mexico (Rosel et al., 2021).

The cetacean species and families that were listed as LC included 7 of 15 (46.7%) mysticetes and 45 of 77 (58.4%) odontocetes, most of them in the family Delphinidae or Ziphiidae. Many of the species classified as LC have very large ranges and occur in offshore waters, where threats tend to be less concentrated than in coastal habitats. However, it was often the case that even though the species overall did not qualify for a threatened category, 1 or more discrete populations units were, or could have been, listed as threatened (see IUCN Standards and Petitions Committee [2022] for details of IUCN's definition of *population* and *subpopulation*). For example, the Cook Inlet subpopulation of belugas (*Delphinapterus leucas*), the Chile-Peru subpopulation of southern right whales (*Eubalaena australis*), and the Baltic Sea subpopulation of harbor porpoises (*Phocoena phocoena*) were all assessed as CR subpopulations of LC species.

DD species

Based on the framework for assigning ziphiids to a category other than DD (see "Red-list assessments for data-poor ziphiid species" and Appendix S1) and the reassessment of the non-ziphiid species, of 45 species listed as DD in 2008, 36 were reassigned in the 2021 update. Approximately two thirds ($n = 25$, 69%) were moved to LC, about one fifth ($n = 8$, 22%) were NT, and the remainder were moved to a threatened category ($n = 3$, 8%). Only 9 cetacean species remained as DD; 7 of these were beaked whales (Ziphiidae) for which there were very limited data, and the other 2 were the Omura's whale (*Balaenoptera omurai*) and the killer whale. Omura's whale was only recently described and verified records were still limited. The killer whale, which is globally distributed, was assessed as DD due to taxonomic uncertainty. Several publications suggest that the killer whale is in fact a species complex that includes several well-documented ecotypes that may prove to be species or subspecies (Committee on Taxonomy, 2022).

There was no significant difference in the proportion of species in each red list category when comparing all data-sufficient species with species that were previously DD and assigned to another category in 2021 ($p = 0.989$). Therefore, we assumed that the same proportion of the DD species as the data-sufficient species were threatened (26%). It was therefore probable that at least 2 of the 9 DD species were in fact threatened, and we predicted that around 28% of all cetacean species would qualify for a threatened category.

Use of red-list criteria

Most cetaceans listed as threatened or near threatened (32 of 34) qualified based on criterion A, C, or both (these criteria refer to small population size and population decline). Criterion A was used for 74% ($n = 25$) and criterion C for 32% ($n = 11$) of those listed species. The most frequently applied subcriterion was A4 which was used as a basis for the listing of 17 odontocete species. (That subcriterion specifies a population decline [$VU \geq 30\%$, $EN \geq 50\%$, $CR \geq 80\%$] over 3 generations spanning the past and the future where the causes may not be understood or may be ongoing or may not be reversible.)

Change in extinction risk over time

Since the inception of the red list, the number of mysticetes listed as threatened declined slightly (7 in 1991 to 6 in 2021), whereas the number of odontocetes listed as threatened increased steadily (6 in 1991 to 18 in 2021). Approximately 4 new threatened species were added each decade (Table 2). In 2008, 19% of cetacean species were listed as threatened (17 of 87), whereas by 2021 26% (24 of 92) were threatened (Table 3). Just under half of the listed species (39 species, 42% of the total) remained in the same category they had been assigned in 2008. Three species (narwhal [*Monodon monoceros*], beluga, and fin whale [*Balaenoptera physalus*]) moved to a lesser threat category.

TABLE 2 Summary of cetacean species listed on the International Union for the Conservation of Nature Red List since the list's inception.

	1964 ^a	1986 ^b	1988 ^c	1991 ^d	1994 ^e	1996 ^f	2000 ^g	2008 ^h	2021 ^h
Mysticetes assessed	-	-	-	11	11	12	14	14	15
Odontocetes assessed	-	-	-	66	66	67	71	73	77
Total cetacean species assessed				77	77	79	85	87	92
Threatened mysticetes	7	5	6	7	7	5	6	5	6
Threatened odontocetes	-	4	6	6	6	9	9	12	18
Total threatened cetaceans species	7	9	21	13	13	14	15	17	24
Mysticetes threatened (%)	-	-	-	64	64	42	43	36	40
Odontocetes threatened (%)	-	-	-	9	9	13	13	16	23
Total threatened cetacean species (%)				17	17	18	18	19	26

^aIUCN Operations Intelligence Centre (1964).

^bIUCN Conservation Monitoring Centre (1986).

^cIUCN Conservation Monitoring Centre (1988).

^dKlinowska and Cooke (1991).

^eGroombridge et al. (1994).

^fIUCN (1996).

^gReeves et al. (2003).

^hIUCN (2022).

TABLE 3 Change in International Union for the Conservation of Nature Red List status of cetaceans between 2008 and 2021.

Change in status	Number of species	Species (%)
Same category	39	42.4
Uplisted (more threatened)	7	7.6
Downlisted (less threatened)	3	3.3
Moved out of DD to LC (because of change in category description or new information)	25	27.2
Moved out of DD to a threatened category (new information or increasing threat)	3	3.3
Moved out of DD to NT (new information or increasing threat)	8	8.7
New listing (new species or previously unlisted species)	5	5.4
Not assessed since 2008	2	2.2
Total	92	100

Note: New species added from 2008 to 2021: *Platanista minor*, *Sousa plumbea*, *Sousa sabulensis*, *Berardius minimus*, *Mesoplodon botaula*, and *Balaenoptera ricei*. Species removed: *Delphinus capensis*. Abbreviations: DD, data deficient; LC, least concern; NT, near threatened.

Overall, the conservation status of 7 species deteriorated from 2008 to 2021. These were 3 coastal cetaceans that occur in Asia, 1 in Australia, and 1 in Africa, plus the North Atlantic right whale (EN→CR) and Yangtze River dolphin (CR→CR possibly EX). Another 11 species moved out of DD into a threatened category.

Species population trajectory

For 71% ($n = 65$) of cetacean species, the global population trajectory was assessed as unknown. For species with sufficient information from which to draw conclusions regarding population trends ($n = 27$), 20 (74%) were decreasing, 1 was stable, and 6 (21%) were increasing in abundance. The species for which abundance was either stable or increasing were 6 mysticetes (bowhead [*Balaena mysticetus*], sei [*Balaenoptera bore-*

alis], blue [*Balaenoptera musculus*], fin, gray [*Eschrichtius robustus*], and humpback whales [*Megaptera novaeangliae*]) and 1 odontocete (the Indus River dolphin [*Platanista minor*]); all these species are believed to be recovering following the near cessation of commercial whaling or local hunting. Species suspected of declining in abundance were all coastal and freshwater dolphins and porpoises that occur near human populations in habitat that is fished intensively with gillnets and often degraded by other human activities.

Extinction risk of cetaceans and distribution

As might be expected for a taxon that includes species with extremely wide distributions in marine realms without physical barriers, one fifth of cetacean species ($n = 19$, 21% of the total) were confirmed to occur in the waters of more than

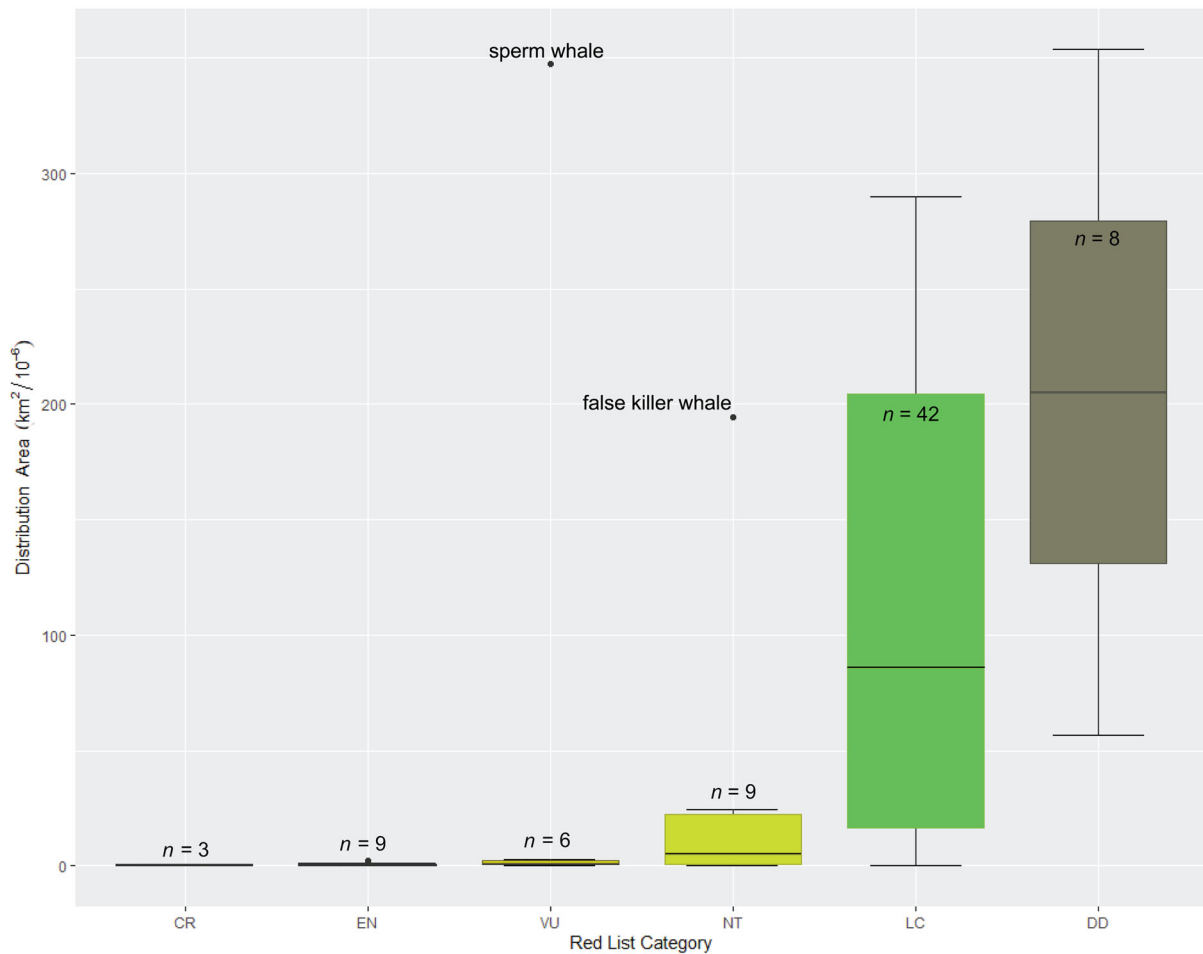


FIGURE 1 Area covered by the known range of odontocete cetacean species in each International Union for the Conservation of Nature Red List category (based on the 2022-1 red-list version) (horizontal lines, median; box limits, upper and lower quartiles; whiskers, 1.5 times the interquartile range; n , number of species). Sperm whale and false killer whale are outliers.

80 countries or territories and one quarter ($n = 24$) occur in more than 50 countries. Only 6 species (6.5%) were endemic to a single nation-state. There was a clear relationship between the number of range states in which a species occurred and the likelihood that it would be listed in a threatened category. Five of 6 (83%) nationally endemic cetacean species were threatened, as were 8 of 10 species (80%) that occur in only 1 or 2 countries. Of the 25 cetacean species that occur in 5 or fewer countries, almost half were listed as threatened, and close to 70% were either threatened or near threatened. In comparison only 3 species that occur in more than 50 countries were listed in a threatened category.

Cetacean species classified as LC and DD had, on average, larger range sizes than those assigned to any of the threatened categories (Figure 1). Species range size was an effective predictor of red-list category (Generalised Linear Model (GLM), $t = 2.54$, $p < 0.05$). Species with smaller ranges were more likely to be more seriously threatened than those with large ranges. Although mean and median range size decreased as extinction-risk category increased, there was a considerable amount of variability. For example, several species of baleen whales and the sperm whale were seriously depleted through centuries

of intense hunting, and they were listed as EN or VU even though they have large ranges spanning several ocean basins (see “Challenges of applying the red-list categories and criteria to cetaceans”). When only odontocetes were considered, the correlation between smaller range size and higher level of extinction risk was even more pronounced (GLM, $t = 3.63$, $p < .001$) (Figure 1).

Countries with the greatest number of cetacean species listed as threatened (Figure 2) tended to be those that have long coastlines, large territorial seas, and rivers inhabited by freshwater cetaceans (e.g., Brazil, China, and India). There was a relatively high number of threatened species in the United States, likely at least partially due to a large amount of cetacean research leading to several recent taxonomic splits (Committee on Taxonomy, 2022).

Extinction risk of cetaceans and habitat

Threatened cetacean species were not equally distributed among the 4 different habitat categories ($\chi^2 = 37.9$, $df = 1$, $p \leq 0.0001$, $n = 4$) (Figure 3). All dolphin species that occur predominantly

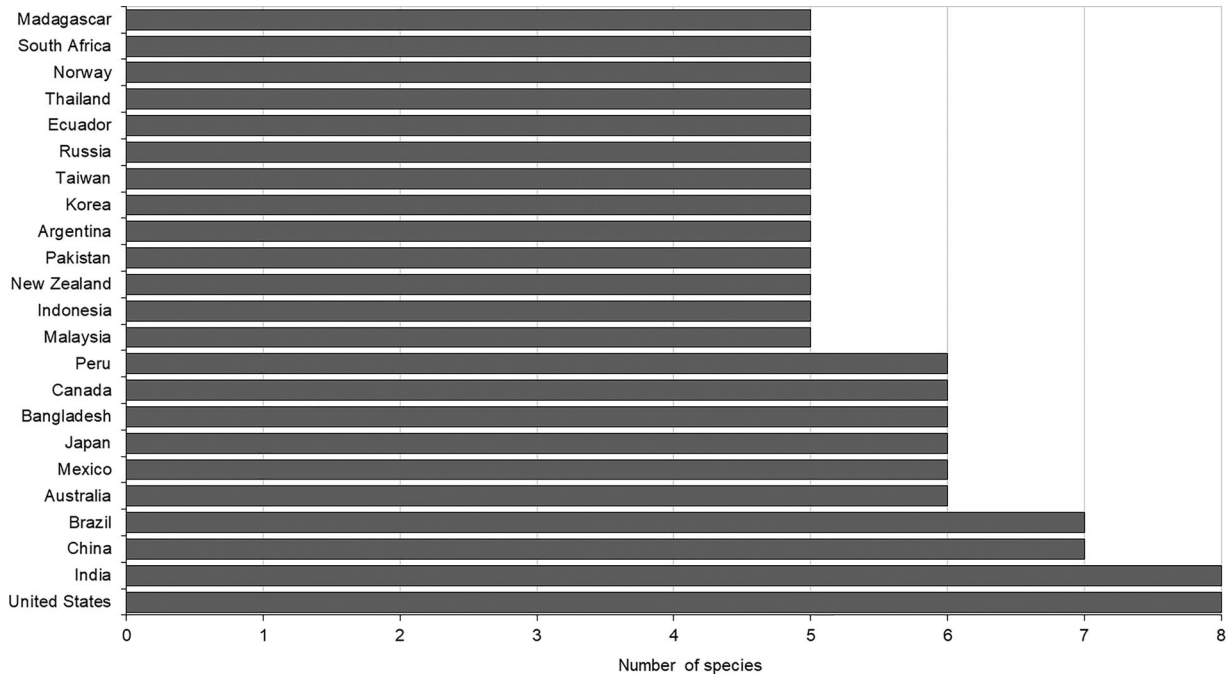


FIGURE 2 Countries or territories with the largest number of cetacean species assigned to a threatened category on the International Union for the Conservation of Nature Red List that are confirmed to occur in their waters.

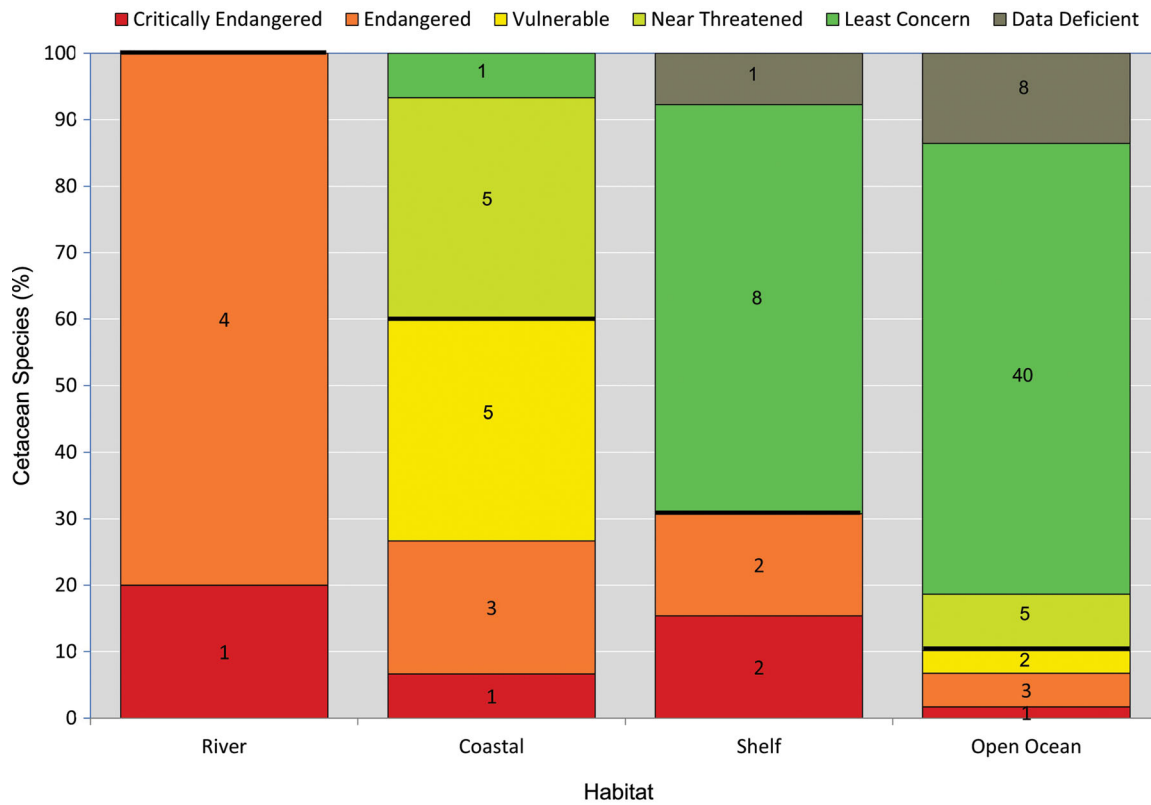


FIGURE 3 Percentage of cetacean species in each International Union for the Conservation of Nature Red List category according to their primary habitat (N, number of species).

in fresh water (5 of 5) were listed as threatened, whereas 60% (9 of 15) of those that occur in coastal habitats, 30% (4 of 13) of those that occur primarily on the shelf, and only 10% (6 of 59) of those that occur principally in the open ocean were so listed (Figure 3). Eight-two percent (40 of 49) of the species listed as LC were those with distributions primarily in the open ocean. All predominantly coastal and riverine cetaceans were assigned either to a threatened category or to NT, with 1 exception, Commerson's dolphin (*Cephalorhynchus commersonii*), which occurs in the coastal waters of Argentina and Chile and was classified as LC.

Geographic locations of species of high conservation concern

We identified a global hotspot of threatened odontocetes in coastal waters of Southeast Asia and the wider Indo-Pacific, an area encompassing the Coral Triangle and extending through nearshore waters of the Bay of Bengal, to northern Australia and Papua New Guinea, and further northward into the coastal waters of China and Taiwan. This hotspot included the overlapping ranges of 7 threatened coastal cetacean species (Figure 4).

DISCUSSION

Red-list status of cetaceans

We demonstrated a high level of threat to cetaceans (37% of species were either threatened or near threatened) and high levels of uncertainty, with trends in abundance unknown for 71% of assessed species. Odontocetes that occur in rivers and coastal habitats were by far the most threatened group, and extinction risk was correlated with range size, habitat, national endemism, and occurrence in 5 or fewer range states. The percentage of cetacean species that were threatened (26% observed, 28% estimated) was higher than that of many other vertebrate and invertebrate groups, including reptiles, birds, insects, and mammals as a whole (23%), but it was lower than the percentage of threatened sharks and rays (32%) and amphibians (36%) (Figure 5) (IUCN, 2022). Sharks and rays also have low population growth rates and are particularly threatened because they are subject to the same threats as cetaceans, but are also extensively targeted by commercial fisheries throughout the majority of the world's oceans (Dulvy et al., 2014).

One in 7 species of mammals (14%; 838 species) is listed as DD on the IUCN Red List (IUCN, 2022), whereas we found only 1 in 10 cetacean species was assessed as DD (9.8%; 9 species). Although the collection of data on cetaceans is challenging, other mammalian groups have perhaps even greater challenges: there are many more species to assess and similar problems with detectability (e.g., nocturnal small mammals, forest species, marine species that do not surface to breath), lack of information, identification, and taxonomic uncertainty.

Using the IUCN Red List to track overall changes in the status of all cetaceans over time was not straightforward because

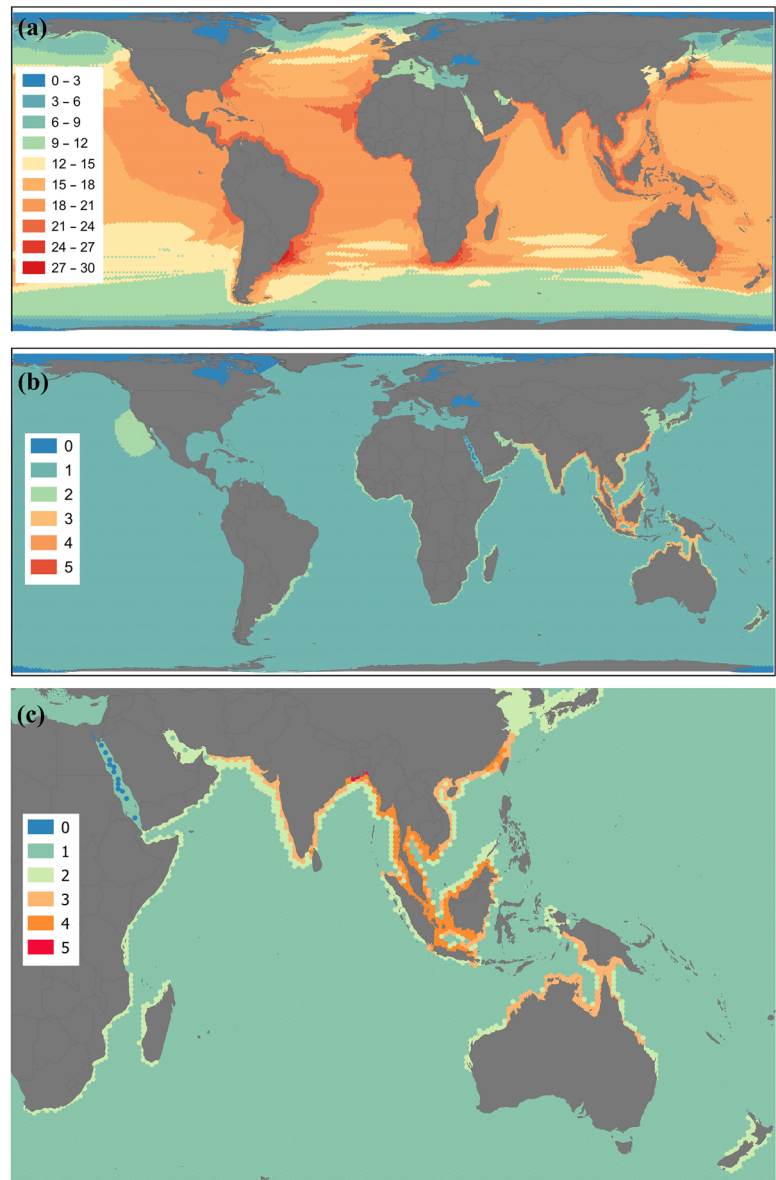
changes in the categories, changes in how the categories are interpreted and applied, changes in taxonomy (see below), increases in knowledge, and changes in the actual extinction risk of cetaceans all play a role in determining the proportion of cetaceans listed as threatened. However, since the IUCN red-listing process began in the 1960s, 2 trends are apparent: the number of odontocete species considered threatened has steadily risen, whereas the number and percentage of mysticete species that are threatened have declined slowly as they have recovered from the effects of industrial whaling.

All species, subspecies, and subpopulations of cetaceans that occur in freshwater ecosystems are threatened with extinction. The main known threats include accidental entanglement in fishing gear, impacts associated with river ship traffic, dredging, underwater noise, pollution, and habitat fragmentation by dams. In most cases, the threats are cumulative, synergistic, and challenging to address (Reeves & Martin, 2018). The extreme endangerment of freshwater cetaceans is emblematic of the declines in freshwater biodiversity globally, which exceed those in both terrestrial and marine ecosystems, especially for megafauna (He et al., 2017). Sharks and rays show the same pattern of extinction risk as cetaceans, where freshwater and euryhaline species have the highest extinction risk due to the combined effects of overexploitation and habitat degradation (Dulvy et al., 2014).

Factors affecting cetacean extinction risk

The near cessation of commercial whaling removed 1 of the major threats influencing extinction risk for baleen whales and the sperm whale (Parsons & Rose, 2022). Hunting of whales and small cetaceans still occurs in many countries, and although generally direct takes of cetaceans are at substantially lower levels than previously, many ongoing hunts of small cetaceans are likely to be unsustainable (Altherr & Hodgins, 2018). Primary factors that influence extinction risk of cetacean species are underwater noise, chemical pollution, vessel strikes, coastal development, climate change, disease, overfishing, and accidental entanglement in fishing gear (Simmonds, 2018; Thomas et al., 2016). The relative importance of these threats varies over space and time and by species and individual. However, intensification of fishing is the principal cause of marine biodiversity loss globally and the primary factor in the endangerment of threatened small cetaceans (Brownell et al., 2019). Small cetaceans are particularly vulnerable to bycatch; animals die entangled in cheap and efficient gillnets that are used by small-scale fisheries throughout the world (Read et al., 2006). Small ranges are linked to narrowly defined habitat requirements, smaller population sizes, and subsequently greater vulnerability to threats. The cetacean species with small ranges are frequently also those with obligatory habitat requirements in rivers and along coasts that are intensively used by humans. Coastal and riverine species are most at risk where their range is completely subsumed within the scope of fisheries. Meanwhile, for cetacean species with more expansive geographic ranges, not only are they likely to have larger population sizes and occur in multiple

FIGURE 4 Global patterns of marine odontocete diversity and extinction risk created by overlaying species range maps: (a) total species richness, (b) global distribution of those listed as threatened on the International Union for the Conservation of Nature Red List, and (c) close-up map of these patterns in the Indian Ocean and Southeast Asia (numbers, number of odontocete species whose range maps overlap each 10,000 km² cell). Range maps oversimplify spatial variability in animal distributions (Williams et al., 2014); thus, these maps should not be interpreted to mean each threatened species is threatened in each individual grid cell in which it is displayed, but that the species as a whole is threatened and its total range encompasses that area.



locations, which increases resilience, but the ranges frequently extend to open-ocean habitat, which tends to be less intensively affected by human activity.

The global hotspot of threatened odontocete species in the Indo-Pacific has also been identified as the area globally where cetaceans are at highest risk of bycatch in small-scale fisheries (Temple et al., 2021). The pressure from these fisheries is greater in shallow waters than in deeper areas because cetaceans cannot avoid fishing gear by moving vertically in the water column; thus, species restricted to shallow waters are more likely to encounter small-scale fisheries and have less refuge from them (Temple et al., 2021). This hotspot includes numerous islands, complex coastlines, and extensive shallow-water habitats that provide niches for a high diversity of coastal cetaceans (Figure 4). This, combined with high human population density, results in a region where many coastal cetacean species are exposed to degraded coastal habitats and high fishing intensity and are therefore threatened (e.g., Hines et al., 2020; Verutes

et al., 2021). We did not explore geographic patterns of extinction risk of mysticetes because global range maps do not reflect seasonal movements, and, as such, they obscure large areas of seasonal absence and do not capture important areas of seasonally high density (Williams et al., 2014). Geographic patterns of extinction risk in such widely distributed, migratory mysticetes are better captured by mapping migratory corridors and critical habitat (e.g., Johnson et al., 2022). In addition, our analyses could be extended in future studies through exploration of the relationships between extinction risk and threats on taxonomic, regional, or global levels.

Challenges of applying the red-list categories and criteria to cetaceans

Determination of a single red-list category for a widely distributed species with more than 1 subpopulation can be

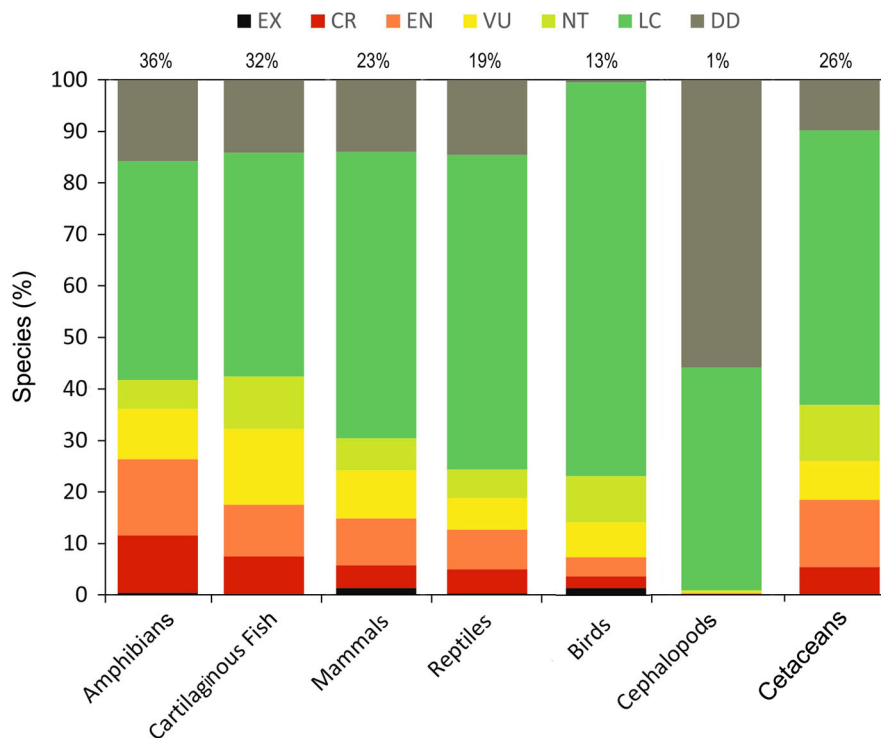


FIGURE 5 Comparison of the percentage of species listed under each International Union for the Conservation of Nature Red List category for a selection of vertebrate and invertebrate orders in comparison with cetaceans (percentages above bars, percent that are threatened); Abbreviations: CR, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern; DD, data deficient. (data from [iucnredlist.org](https://www.iucnredlist.org)).

challenging, for example, where trend data are available for only a portion of the species' geographic range. This is the case for the Amazon River dolphin (*Inia geoffrensis*), which occurs in 2 extensive river basins across 6 South American countries, but data on trends in abundance are available from a comparatively small area that is likely unrepresentative of the entire range (da Silva et al., 2018). There are also many situations where trends differ across the species' total range. For example, the humpback whale is a globally distributed species that, since the cessation of most commercial whaling, is increasing in abundance. However, subpopulations in the Arabian Sea and Oceania have not recovered and remain threatened (Cooke, 2018b). For some species, there is comprehensive information from some places, but no data from significant parts of the range. For example, the Ganges River dolphin occurs primarily in India and Bangladesh, and although there is extensive information on abundance from India, the network of rivers in Bangladesh is largely unsurveyed (Kelkar et al., 2022). The above examples are the norm rather than the exception for most cetacean species; thus, a single conservation status for widely distributed species frequently obscures significant conservation concerns that apply to specific locations or regions within the range. As a result, the CSG has implemented a process to select subspecies and subpopulations of cetaceans to assess for the red list (Appendix S3).

Collecting morphometric and genetic data on species with vast, remote, and generally inaccessible geographic ranges is challenging. As a result, there are significant gaps in knowl-

edge of cetacean systematics. Frequently, the description of new species involves the splitting of existing species into several new taxa, each of which has a smaller range and abundance than the previous taxonomic entity and hence a greater likelihood of being assigned to a threatened category (Mace, 2004). It is estimated that at least 40 of the more than 90 recognized cetacean species have additional unnamed taxa (Taylor et al., 2017). As knowledge grows and taxonomy is refined, the number of taxonomic units assessed as threatened also changes. For example, in 2008 the Indo-Pacific humpback dolphin was assessed as LC, and its large range, encompassing coastal waters from Australia to South Africa, was cited as one reason for not meeting any of the criteria for a threatened category. When *Sousa chinensis* was split into 3 species (*S. chinensis*, *Sousa sabulensis*, and *Sousa plumbea* [Jefferson & Rosenbaum, 2014]), all of them were assessed as threatened. Similarly, the South Asian River dolphin, previously a single EN species, was split into 2 EN species in 2021 (Braulik et al., 2021). Rice's whale was newly described as a species in 2021 (Rosel et al., 2021) and was assessed as CR, whereas it had previously been encompassed within the LC Bryde's whale assessment.

Some baleen whale species (e.g., blue, fin, and sei whales) were assessed as threatened on the basis of criterion A1, which relates to a population reduction ($\geq 90\%$ = CR, $\geq 70\%$ = EN, $\geq 50\%$ = VU) over 3 generations in the past where the cause of the reduction (commercial whaling) is clearly reversible, understood, and is now much less prevalent (e.g., Cooke, 2018a). Based on this criterion, it is possible for species that have

undergone substantial declines, but that are still relatively abundant and widespread, to qualify as threatened, and this can be controversial (Mace et al., 2008). For example, the span of 3 generations for the fin whale is approximately 78 years; therefore, in the most recent red-list assessment conducted in 2018, decline was measured from 1940 forward. Implementation of the global moratorium on commercial whaling only occurred in 1986; therefore, significant declines in fin whale abundance have occurred within the 3-generation window, and the species qualifies as VU based on an estimated 45% population decline, despite the fact that it is globally distributed with a mature population size estimated as about 100,000 (Cooke, 2018a). As a result, some species are listed as threatened on the basis of criterion A, but if they are still relatively numerous, some managers do not appreciate the logic in treating them as threatened (Betts et al., 2020). The red-list approach focuses on evaluating extinction risk, whereas the International Whaling Commission (IWC) evaluates the status of whale stocks relative to their pre-exploitation population size with an objective of ensuring that any proposed hunting be sustainable in the long term (IWC, 2018). Therefore, IUCN Red List and IWC assessments may have different ultimate aims, use different approaches, and can reach different conclusions regarding the status of species.

Uses and benefits of the red list for cetaceans

The role of the IUCN Red List is to provide authoritative species status assessments. Neither IUCN nor the red list has regulatory power to manage human behavior and therefore directly influence the status of species or populations. However, there are many ways in which the red list has indirectly influenced conservation action for cetaceans; some of these are summarized below.

By providing a high-level global overview, the red list can shine a light on the species most in need of conservation action, thereby acting as a catalyst. For example, recognition of the Taiwanese humpback dolphin (*Sousa chinensis taiwanensis*), found only in badly degraded coastal habitat along the west coast of Taiwan, as a CR subspecies led to substantial engagement in research and to calls for urgent conservation action (Taylor et al., 2019). The listing of Lahille's bottlenose dolphin (*Tursiops truncatus gephyreus*), found in coastal waters of Brazil, Argentina, and Uruguay, as an EN subspecies resulted in large increases in funding and research and an IWC Task Team was established to focus on its conservation (Fruet et al., 2020). Red listing of the Atlantic humpback dolphin as CR was a major factor in the launch of a species-specific conservation consortium and a Concerted Action under the Convention on the Conservation of Migratory Species of Wild Animals (CMS), initiatives that are leading to increased funding, research, and conservation initiatives in range countries (Minton et al., 2022).

The red list underpins the criteria used to identify important marine mammal areas (IMMAs) and key biodiversity areas (KBAs). Currently, 83% (144 of 173) of IMMAs satisfy a criterion explicitly requiring that the area provide important habitat for a marine mammal red-listed as threatened (Tetley et al.,

2022), and over 50 KBA sites qualify on the basis of supporting a significant proportion of the global population of a cetacean species facing a high extinction risk (IUCN, 2016).

Financial institutions (e.g., World Bank, Asian Development Bank) use red-list range maps and assessments to screen project sites for biodiversity risk when threat avoidance, such as alternative project siting, is still possible. The largest global development institution focused on developing countries is the International Finance Corporation, and under its Performance Standard 6, the presence of an EN or CR species qualifies an area as critical habitat, which triggers specific stipulations for minimizing impacts in order for financing to be approved (Betts et al., 2020).

The red list is used to inform decisions taken by several major biodiversity conventions. The CMS considers the inclusion of migratory species in its Appendix I if they have been assessed on the red list as EX in the wild, CR, or EN (CMS, 2017). Along with relevant national governments, CMS has developed concerted actions to implement priority conservation plans for certain Appendix 1 species, including the Ganges River dolphin (CR), Atlantic humpback dolphin (CR), and Arabian Sea humpback whale (EN). Most cetacean species that are red listed as threatened are also on Appendix 1 (trade prohibited) of the Convention on International Trade in Endangered Species, whereas all other cetacean species are on Appendix 2 (trade controlled). In 2021, the IWC launched the Species or Populations of Urgent or Emerging Concern Initiative, which leans heavily on the red list to identify populations for which urgent action is required.

Although the red list provides a high-level assessment of the conservation status of species and describes the threatening processes, the actions needed to address the threats are at a local or national level, involving numerous stakeholders, including communities, industry, and governments in tailored, location-specific interventions. The evaluation of extinction risk to cetaceans via the red list can provide a scientific basis and leverage for governments and conservation organizations to push for better management, conservation measures, policy frameworks, and enforcement of the law, all of which are urgently needed if cetaceans are to be adequately protected.

ACKNOWLEDGMENTS

We acknowledge the contribution of the 80 marine mammal scientists who contributed to producing the cetacean red-list assessments conducted from 2017 to 2021, on which this article is based. The members of the red-list authority in the CSG played an important role in many of the assessments. We greatly appreciate the pivotal role played by J. Cooke, who has led the process of cetacean red-list assessments over many decades. In addition, we thank R. Brownell Jr. for valuable contributions to many important assessments. We also acknowledge the support of F. Chiozza at the IUCN and L. Lowry for their help in submitting and checking assessments during submission.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Braulik, G. T., Taylor, B. L., Minton, G., Notarbartolo di Sciarra, G., Collins, T., Rojas-Bracho, L., Crespo, E. A., Ponnampalam, L. S., Double, M. C., & Reeves, R. R. (2023). Red-list status and extinction risk of the world's whales, dolphins, and porpoises. *Conservation Biology*, e14090. <https://doi.org/10.1111/cobi.14090>