XVII / ROGER REVELLE COMMEMORATIVE LECTURE PRESENTED BY THE OCEAN STUDIES BOARD

THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE

Managing Leviathan

Conservation Challenges for the Great Whales in a Post-Whaling World

FEATURED SPEAKER DR. PHILLIP CLAPHAM, NOAA'S MARINE MAMMAL LABORATORY

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Dear Lecture Participant:

On behalf of the Ocean Studies Board of the National Academies' National Research Council, we would like to welcome you to the Seventeenth Annual Roger Revelle Commemorative Lecture. This lecture was created by the Ocean Studies Board in honor of Dr. Roger Revelle to highlight the important links between the ocean sciences and public policy.

ROGER REVELLE

For almost half a century, Roger Revelle was a leader in the field of oceanography. Revelle trained as a geologist at Pomona College and the University of California, Berkeley. In 1936, he received his Ph.D. in oceanography from the University of California, Berkeley. As a young naval officer, he helped persuade the Navy to create the Office of Naval Research (ONR) to support basic research in oceanography and was the first head of ONR's geophysics branch. Revelle served for 12 years as the Director of Scripps (1950–1961, 1963–1964), where he built up a fleet of research ships and initiated a decade of expeditions to the deep Pacific that challenged existing geological theory.

Revelle's early work on the carbon cycle suggested that the sea could not absorb all the carbon dioxide released from burning fossil fuels. He organized the first continual measurement of atmospheric carbon dioxide, an effort led by Charles Keeling, resulting in a long-term record that has been essential to current research on global climate change. With Hans Suess, he published the seminal paper demonstrating the connection between increasing atmospheric carbon dioxide and burning of fossil fuels. Revelle kept the issue of increasing carbon dioxide levels before the public and spearheaded efforts to investigate the mechanisms and consequences of climate change. Revelle left Scripps for critical posts as Science Advisor to the Department of the Interior (1961–1963) and as the first Director of the Center for Population Studies at Harvard (1964–1976). Revelle applied his knowledge of geophysics, ocean resources, and population dynamics to the world's most vexing problems: poverty, malnutrition, security, and education.

In 1957, Revelle became a member of the National Academy of Sciences to which he devoted many hours of volunteer service. He served as a member of the Ocean Studies Board, the Board on Atmospheric Sciences and Climate, and many committees. He also chaired a number of influential Academy studies on subjects ranging from the environmental effects of radiation to understanding sea-level change.

SMITHSONIAN'S NATIONAL MUSEUM OF NATURAL HISTORY

The Ocean Studies Board is pleased to have the opportunity to present the Revelle Lecture in cooperation with the Smithsonian National Museum of Natural History through our partnership with the Smithsonian Science Education Center. The museum maintains and preserves the world's most extensive collection of natural history specimens and human artifacts and supports scientific research, educational programs, and exhibitions. The museum is part of the Smithsonian Institution, the world's largest museum and research complex. Dr. Kirk R. Johnson is the director.

The Smithsonian Science Education Center (SSEC) was founded in 1985 by the National Academy of Sciences and the Smithsonian Institution and continues today as a successful unit of the Smithsonian Institution. The mission of the SSEC is to develop STEM literate students from early childhood through the workplace. The SSEC does this through the implementation of a truly systemic approach that engages participants at every level, from students and classroom teachers up through the highest levels of district, state, national and international leadership.

TONIGHT'S LECTURE

Tonight's lecture, Managing Leviathan: Conservation Challenges for the Great Whales in a Post-Whaling World, will take you on a historical journey of whaling and its decline. In his lecture, Dr. Phillip Clapham from NOAA's Marine Mammal Laboratory will explain how certain whale populations have responded. He will also discuss the continuing challenges of managing whale populations, especially in light of anthropogenic threats, including fishing gear, shipping noise, and climate change. The lecture will be followed by a panel discussion with Dr. Douglas Wartzok, Provost Emeritus and Professor at Florida International University; Dr. Rebecca Lent, Executive Director of the Marine Mammal Commission; and Dr. James Mead, Curator Emeritus for the Smithsonian.

SPONSORSHIP

The Ocean Studies Board thanks the National Oceanic and Atmospheric Administration, the National Science Foundation, the National Aeronautics and Space Administration, the Office of Naval Research, the U.S. Geological Survey, and the Gordon and Betty Moore Foundation. This lecture series would not be possible without their generous support. The Board also extends gratitude to the Smithsonian Science Education Center and the Smithsonian Institution for their continued partnership.

We hope you enjoy tonight's event.

Larry A. Mayer,
CHAIR, OCEAN STUDIES BOARD

Susan Roberts,
DIRECTOR, OCEAN STUDIES BOARD

Phillip J. Clapham

Phil Clapham currently directs the Cetacean Assessment and Ecology Program at NOAA's Marine Mammal Laboratory in Seattle, where he supervises a staff of 25 scientists and oversees research projects on species ranging from harbor porpoises to blue whales.

After graduating from the University of London, he began his work with cetaceans in 1980 at the Center for Coastal Studies in Massachusetts, where he later served as the leader of the long-term study (now in its fifth decade) of individually identified humpback whales in the Gulf of Maine. Phil obtained his Ph.D. from the University of Aberdeen (Scotland), and subsequently conducted post-doctoral work in molecular genetics at Cambridge University and the University of Copenhagen. He remains affiliated with the Smithsonian Institution's National Museum of Natural History, where he worked for four years as a conservation biologist before accepting a position leading the Large Whale Biology Program at the Northeast Fisheries Science Center in Woods Hole, Massachusetts. In 2004 he moved to Seattle; there, his research group emphasizes multi–disciplinary studies that combine visual and acoustic surveys with oceanography, satellite telemetry, genetics and other innovative methods to better understand the population biology and conservation status of threatened cetaceans in Alaska and elsewhere. He has developed a wide network of national and international collaborators, and has worked on most large whale species in locations ranging from the Arctic to the South Pacific.

With his wife, Dr. Yulia Ivashchenko, Phil has played a major role in correcting the catch record relating to the former USSR's global campaign of illegal whaling, which ran for 30 years and involved almost 180,000 unreported whale catches. He and his wife also recently exposed similar illegal hunting of sperm whales by Japan in the 1960's.

Over the past thirty years, Phil has advised national governments and other bodies on whale research and conservation, including as scientific advisor to the Presidential Commission on Sanctuaries for the Dominican Republic. He is a former member of the Board of Governors of the Society for Marine Mammalogy, a founding member of the South Pacific Whale Research Consortium, and since 1997 has been on the U.S. delegation to the International Whaling Commission's Scientific Committee. To date, he has published five books and more than 150 refereed papers on large whales and other cetaceans. He has also served as Editor or Associate Editor for several prominent scientific journals, and is currently on the Editorial Board of the Royal Society of London.

“I see them in hundreds and thousands.”

Thus did the Norwegian whaler Carl Anton Larsen express his astonishment when, in 1903, he first encountered the vast numbers of whales at South Georgia in the South Atlantic. South Georgia, gateway to the Antarctic, was a principal feeding ground for large populations of blue, fin, humpback, and other whales, all of which were at that time virtually unexploited. Larsen established a shore whaling station on the island the following year, and it was not long before other whalers were flocking to the Southern Ocean to claim their share of the seemingly inexhaustible bounty to be found there.

But of course no resource is inexhaustible, and it did not take long for the populations concerned to be depleted by the efficient techniques of modern whaling. By the time of the Great War, the stock of humpback whales at South Georgia was essentially extirpated: more than 18,000 had been killed by 1915. The local exploitation of blue whales followed a similar pattern: more than 39,000 were killed at South Georgia in the years 1904-36, at the end of which the population had irretrievably crashed.

Worse was yet to come. Shore whaling stations gave way to large ocean-going whaling fleets, whose huge factory ships could process more whales in a single day than would be captured by a typical 19th century New England whaler during the course of a five-year voyage. Suddenly all whales were vulnerable, even those feeding in the most remote locations.

By the time Antarctic whaling had finally diminished to a relatively small-scale enterprise in the 1980's, great damage had been done. Most populations of the great whales, both there and elsewhere in the world, had been reduced to small fractions of their pristine levels.

With the emergence of the modern environmental movement, whales became a symbol of human misuse of resources and the environment. Today, although whaling continues at a modest level, many whale populations appear to be rebounding well. Here, I provide a brief overview of modern whaling, then examine the current status of whale populations and the threats they face in a largely post-whaling world. I emphasize the surprisingly important role that whales may play in the health of marine ecosystems, and their future in the warmer world so presciently predicted by Roger Revelle in his pioneering work on greenhouse gas and the oceans.

Modern Whaling: A Brief History

Whaling has a long history going back to at least Neolithic times. Basque whalers began commercial whaling in the 11th century and had taken the hunt to the New World by 1530. By the late 1700's a thriving whaling industry had developed in both Europe and the United States. In the 19th century, whaling ships from New England ranged across the world's oceans in their pursuit of whales, whose oil, burned in street lamps across the western world, lit cities, and lubricated the new machinery of the Industrial Revolution.

With the invention of the explosive harpoon and steam-powered catcher boats in the late 19th century, traditional sail-based whaling rapidly declined. The discovery of the vast untouched populations of whales in the Antarctic completed the modern picture, and thus began a slaughter that, in terms of sheer biomass, was probably unequaled in the history of human hunting.

Some of the 20th century catch totals are staggering, particularly for the Southern Hemisphere (Figure 1). The combined catch of blue and fin whales exceeded 300,000 animals during a single decade in the 1930's. Overall, between 1904 and the end of World War Two, more than 1,100,000 whales were killed worldwide (Rocha et al. 2014). Clearly, regulation was required if the industry was not going to whale itself out of business.

The Era of Excess

> "Fisheries management is endless debate about the status of stocks, until all doubt is removed."
>
> —JOHN GULLAND

In 1946, fifteen whaling nations signed the International Convention for the Regulation of Whaling, which created the International Whaling Commission (IWC) to oversee the management of the industry. The Convention was, in theory, designed to promote sustainable whaling.

However, this intention was immediately undermined by the desire for continued profit. Heavy capital investment in a finite resource provided a strong incentive to deny the existence of a problem when the resource declined, leading to a textbook case of mismanagement. Consequently, whale catches remained unreasonably high; the 1950's saw almost 614,000 whales killed, of which well over a quarter million were fin whales. Even more whales were taken in the following decade; from 1960 to 1969, global catches exceeded 700,000 animals, with almost half being sperm whales (Figure 2).

Ignoring mounting evidence of population declines, the whaling nations used uncertainty in abundance estimates to oppose more conservative catch quotas, and used procedural flaws in the Convention to obstruct the passage of rules for conservation or inspection measures.

In reality, an already bad situation was actually far worse than anyone knew; the Union of Soviet Socialist Republics (USSR) had been conducting a secret campaign of illegal whaling that

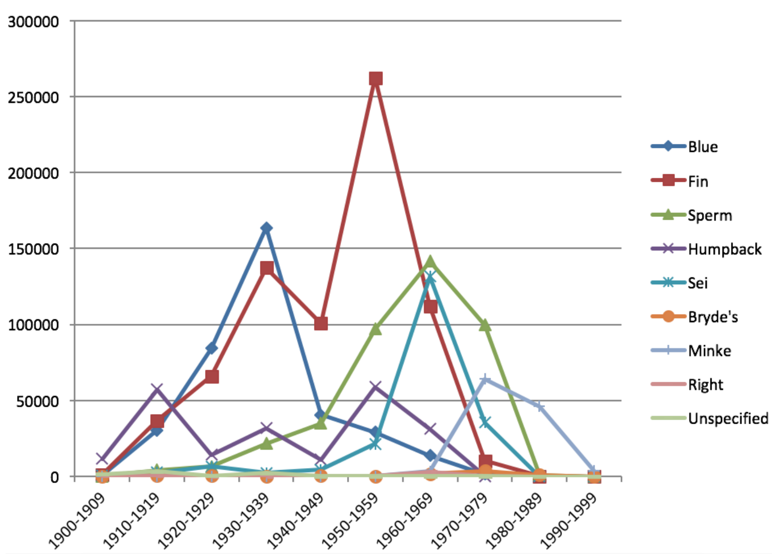


Figure 1 Southern Hemisphere industrial whaling totals, by decade, 1900-1999. Source: Rocha et al. (2014).

Figure 2 Sperm whales killed by a Soviet catcher boat await processing by the factory ship. Photo: MOSCOW Project.

had begun in 1948 (Yablokov 1994, Ivashchenko and Clapham 2014). Soviet factory fleets systematically ignored whaling regulations of all types, and submitted falsified catch data to the IWC to camouflage their actions.

Of an estimated 534,119 whales killed by the USSR between 1948 and 1979, 178,726 were not reported (Ivashchenko and Clapham 2014). Humpback whales in the Southern Hemisphere represented one of the most dramatic examples. The Soviets reported to the IWC that they had killed 2,710 when the true catch actually exceeded 48,000; remarkably, more than 25,000 of these were killed in just two Antarctic whaling seasons.

The impact of the USSR's illegal whaling on some populations was devastating, although it is important to recognize that the Soviets simply compounded the existing problem of excessive "legal" catches by other whaling nations. More recently, it has been shown that systematic illegal catches were also made by Japan (Kasuya 1999, Ivashchenko and Clapham, 2015). Also, recent molecular genetic analysis of whale meat samples in Japanese and Korean markets has revealed numerous cases in which products on sale are not from legitimate, documented sources (Baker et al. 2000, 2007).

Overall, the failure of the IWC to ensure sustainable catches, and the historical ability of whalers to violate whaling regulations on a large scale, has major policy implications for the management of any future whaling (and, by extension, of other liv-

ing marine resources). More than anything, the history of whaling underscores the need, in any fishery, for an independent, truly transparent system of inspection and enforcement - one that operates at every stage from the catch to the market.

The Decline of Whaling

With a shift in the 1970s towards more non-whaling nations gaining membership in the IWC, the pro-conservation bloc was sufficiently large to achieve the three-quarters majority vote required to impose a whaling moratorium, implemented in 1986. However, two loopholes in the Convention provided a means for the remaining whaling nations to circumvent the ban.

Today, Norway and Iceland hunt whales, because the Convention allows members to object to any IWC decision (such as the moratorium) and not be bound by it. Japan uses Article VIII of the Convention, which allows the killing of whales "for the purpose of scientific research" (so-called scientific whaling). Beginning in 1987, Japan developed a program of research in the Antarctic, which annually involved the killing of hundreds of whales (mostly Antarctic minke whales). A parallel program was subsequently implemented in the North Pacific, and both continue today.

The validity of the research conducted by Japan has been the subject of considerable debate. Japan has consistently claimed that such research is essential in order to gather the information required to manage whale stocks, and to understand the role that whales play in the ecosystem – in particular whether they compete with humans for fish (Morishita 2006). Opponents have argued that the information collected is either not required for management, or can be obtained as or more easily through widely used non-lethal methods (Clapham et al. 2006).

In 2014, the International Court of Justice (ICJ) ruled that the Japanese Antarctic whaling program was "not for the purpose of scientific research" as required under Article VIII, and ordered that the program be ended. The decision engendered much optimism regarding a possible end to Japanese whaling. However, Japan subsequently developed a new research program, stated that this complied with the spirit of the ICJ ruling, and resumed whaling a year later despite an IWC independent Expert Panel review, which concluded that lethal sampling had not been justified (Clapham 2014, Brierley and Clapham 2016). In a move with major policy implications for international fisheries disputes, Japan also announced that it no longer recognized the jurisdiction of the ICJ on matters pertaining to marine living resources.

Whale populations today: good news, bad news

Today, whales exist in a largely post-whaling world. Whaling has certainly not disappeared. In addition to the whaling by Norway, Iceland, and Japan, there remain also some small native subsistence hunts, which take large whales in various places. Despite these pockets of hunting, and while Japan in particular continues to campaign for a lifting of the IWC's moratorium, it is very unlikely that we will ever again see whaling that approaches the scale of the last century.

That said, there is no doubt that modern whaling had a devastating impact on the great whales. Between Larsen's establishment of a South Georgia whaling station in 1904 and the year 2000, some 2.9 million whales were killed worldwide (Rocha et al. 2014). The majority - more than two million - were taken in the Southern Hemisphere. The legacy of these huge catches is still evident today in many populations, some of which were reduced by 95-99% of their original numbers. Ideally, our conservation goal should be to help restore populations to their abundance before whaling, as legislated in the U.S. Marine Mammal Protection Act. This Act states that marine mammals should be restored to their "optimum sustainable population," and should not be permitted to decline below the level at which they "cease to be a significant functioning element" of their ecosystems.

All cetaceans are difficult to study because they live in remote environments that are inhospitable, and often dangerous, for human observers. As a consequence, our understanding of the status of many whale populations is still relatively limited. With that in mind—and with some major exceptions—it is reasonable to say that most populations of large whales are recovering to one degree or another from commercial whaling, although the great majority are probably not yet at pre-whaling abundance.

Success stories include eastern Pacific gray whales and humpbacks. Gray whales were removed from the Endangered Species List in 1994, and several humpback populations were recently proposed for delisting. Bowhead whales in the western Arctic are believed to number 17,000 animals despite a well-managed Alaskan Native hunt. California blue whales are also abundant, and at least some southern right whale stocks appear to be recovering strongly.

However, some whale populations have not rebounded. In a recent review of baleen whales, Thomas et al. (2015) listed 19 populations whose status they considered to be "of greatest concern." Of these, six are considered critically endangered: bowhead whales in the Sea of Okhotsk and off Svalbard, the Chile/Peru population of the southern right whale, eastern North Pacific right whales, western gray whales, and Arabian Sea humpbacks. North Pacific right whales are among the most endangered whales in the world, and the North Atlantic right whale is estimated to number only 500 individuals.

Why are some populations recovering well while others remain endangered? In some cases, the answer is fairly obvious. Illegal Soviet whaling likely removed the bulk of the already small eastern North Pacific right whale population (Ivashchenko and Clapham 2012), such that the remaining whales number in the tens. Here, as with the heavily-whaled Svalbard bowheads, the remnant population may be so small and scattered over such a huge geographic range that reproduction is compromised. In addition, the North Pacific right whale's male-biased sex ratio (Wade et al. 2011), low birth rate, and perhaps even inbreeding may be inhibiting recovery, despite the absence of known sources of mortality.

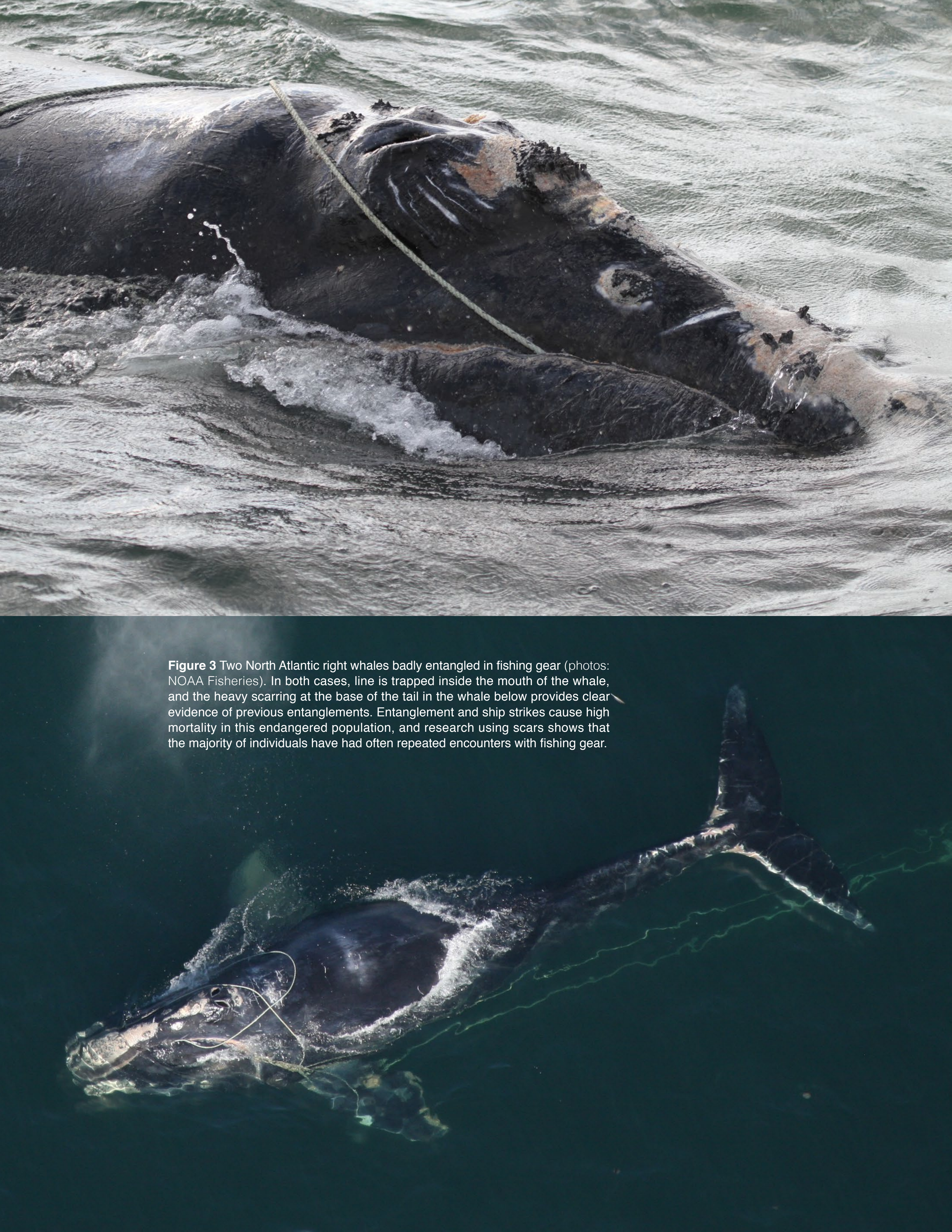


Figure 3 Two North Atlantic right whales badly entangled in fishing gear (photos: NOAA Fisheries). In both cases, line is trapped inside the mouth of the whale, and the heavy scarring at the base of the tail in the whale below provides clear evidence of previous entanglements. Entanglement and ship strikes cause high mortality in this endangered population, and research using scars shows that the majority of individuals have had often repeated encounters with fishing gear.

The same may be true for Antarctic blue whales. Although there are estimated to be perhaps 2,000 remaining, this is less than 1% of the pristine population (Branch 2007), and the survivors are scattered across the vast reaches of the Southern Ocean. We do not know how the huge disruptions that whaling introduced into the social ecology of some species have affected birth rates, distribution or recovery (Clapham and Zerbini 2015), but it is naïve to assume that they did not.

Other impacts from human activities may be preventing recovery in some whale populations. Unlike the recovered eastern stock, only about 150 gray whales remain in the population that feeds in summer in the Okhotsk Sea. These whales are at risk from oil and gas development off Sakhalin Island (Weller et al. 2013); furthermore, although the winter breeding ground of this population is unknown, it may lie in Chinese waters where coastal development could cause serious degradation of the whales' breeding habitats. Similarly, the humpback whale population in the Arabian Sea, which is estimated at just 80 animals (Minton et al. 2011), faces serious threats from entanglement, ship collisions, and pollution. High mortalities in this population may well be preventing its recovery. This is known to be the case with the North Atlantic right whale, which suffers documented high mortality from ship strikes and entanglement, although recent mitigation measures to modify fishing gear and slow down or re-route shipping appear to be having some success.

Unfortunately, we can only speculate on ecological factors that may be involved in the variable recovery rates observed among populations with no known anthropogenic impacts. Among baleen whales, there is no good evidence that food competition (where a dominant species consumes prey to the exclusion of another) is a significant factor in population dynamics (Clapham and Brownell 1996, Friedlaender et al. 2009). While major climatic events such as El Niños undoubtedly affect local prey abundance, whales have such large ranges that they can probably at least partially compensate for ecosystem disruptions by seeking resources elsewhere. The failure of Northern Hemisphere right whales to recover, in comparison to their southern counterpart, suggests that interactions with humans represent a dominant factor in population recovery despite the cessation of whaling.

Finally, it is remarkable that whaling was so intense that some populations were apparently extirpated (Clapham et al. 2008). Humpback and blue whales at South Georgia, where whalers killed many thousands of individuals, were not observed in the region as recently as 2008. In a hopeful sign, some humpbacks were seen at South Georgia in 2015, perhaps because the population elsewhere has now expanded to the point where whales are slowly rediscovering this key historical habitat.

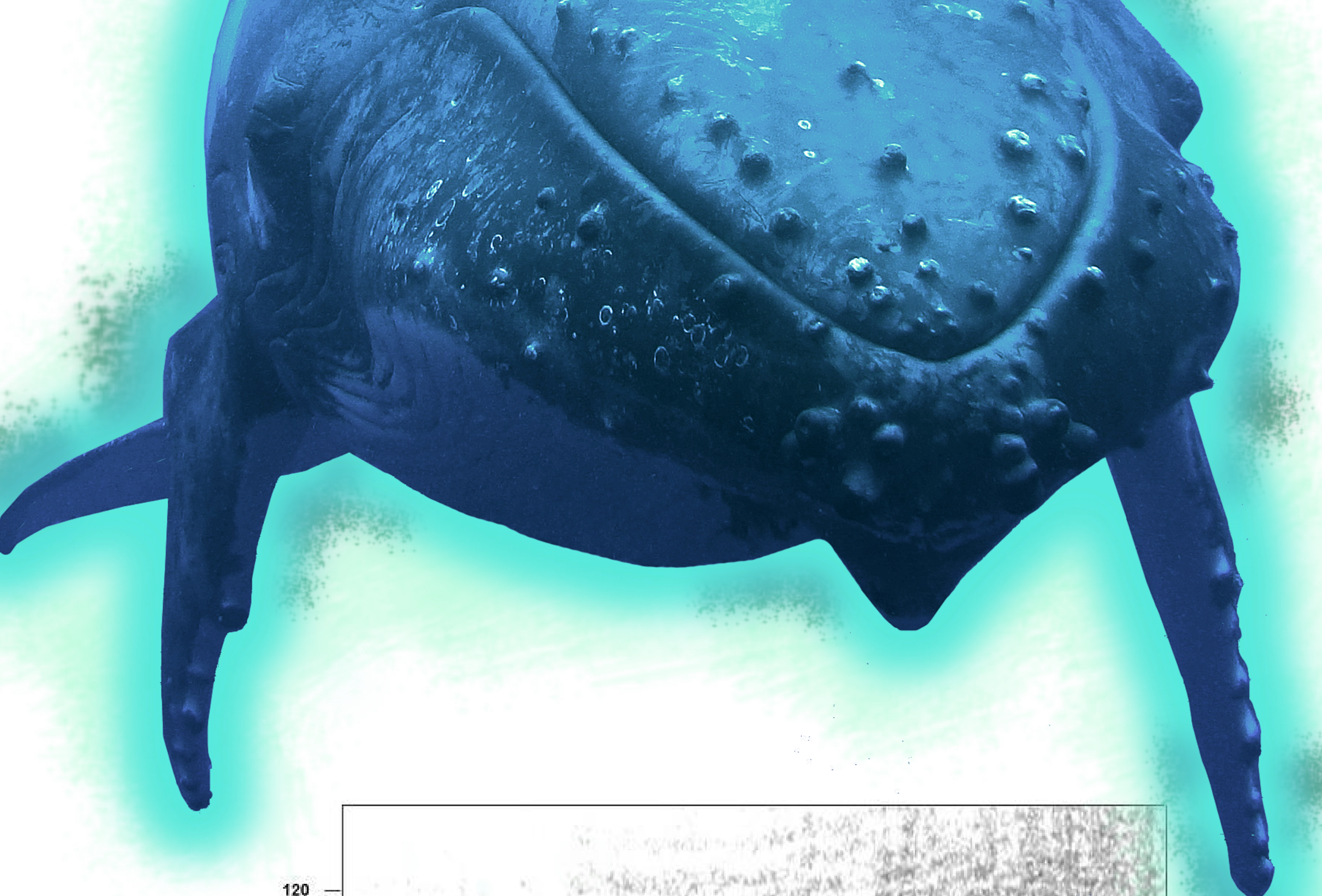
Elsewhere, North Atlantic right whales have yet to return to either the Bay of Biscay (where Basque whaling on this species began almost a thousand years ago), or other habitats in the eastern North Atlantic; and blue whales remain absent from Japanese waters after extirpation in about 1948.

In all these cases, it is quite possible that extirpation resulted in loss of the cultural memory of the existence of the habitats concerned—a remarkably grim legacy of whaling.

Conservation Challenges: Current and Future Threats

Although whaling has receded, many threats to cetacean populations continue, almost all of them human-caused. Some of these are well documented, while the effect of others is less tangible. Furthermore, we know virtually nothing about cumulative impacts on survival and reproduction.

Perhaps the most obvious threat to whales is entanglement in fishing gear. The introduction in the 1960's of synthetic fishing nets and lines precipitated a huge increase in the number



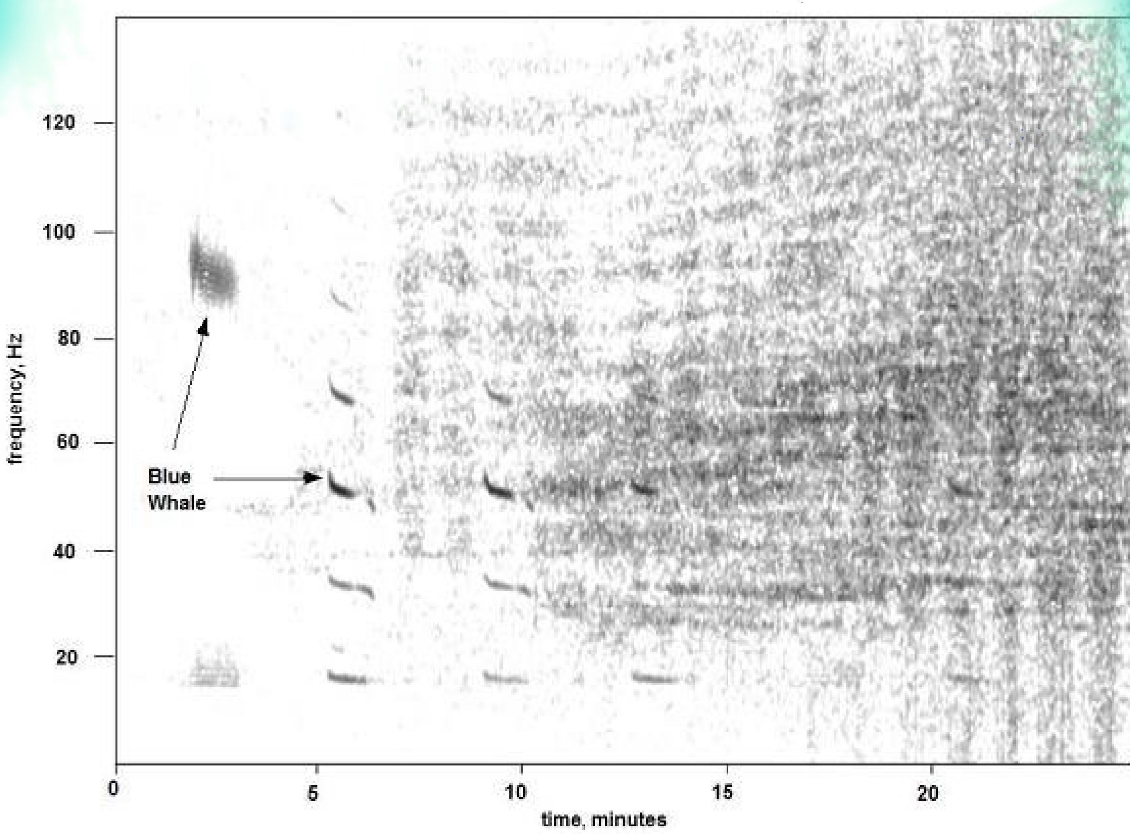


Figure 4 A blue whale's calling is overwhelmed by the noise from a distant vessel that was over the horizon at the time this was recorded. Source: Christoper W. Clark, Cornell University.

of cetaceans killed by entanglement. A recent study found that, in the past 20 years, at least 75% of odontocete species (toothed whales) and 64% of the baleen whales had been recorded entangled in one type of gear alone, the gill net (Reeves et al. 2013). In some populations the majority of individuals encounter fishing gear, often repeatedly (Figure 3). In some cases, entanglement is sufficiently prevalent to endanger entire populations: the Yangtse river dolphin (the baiji) was driven to extinction in part because of entanglement, and the vaquita in Mexico is now perilously close to extinction because of bycatch in the local tortuaba fishery.

The other known source of mortality among large whales is ship collisions. Together with entanglement, ship strike has particularly inhibited the recovery of North Atlantic right whales. Coastal habitats often overlap with shipping lanes, and mortalities can result. With the loss of sea ice in the Arctic, trans-polar shipping traffic will certainly increase, and with it the potential for noise, pollution, and collisions with whales, especially at choke points such as the Bering Strait.

Ocean noise is another major concern, but one whose impacts are difficult to quantify. Ever since 1819, when the steamship Savannah subjected a small space in the North Atlantic to the noise of an engine for the very first time, the oceans of the world have been filled with human-generated sound. Today, thousands of large ships regularly ply the sea routes of the world. At very low frequencies—those within the hearing range of some baleen whales—a supertanker or large bulk carrier can be heard tens of km away, and can overwhelm the acoustic calls of the animals (Figure 4). Seismic surveys for oil and gas exploration not only generate noise that can be heard literally halfway across an ocean basin, but do so with great frequency, so that some areas are subjected to a continuous barrage of industrial noise. Elsewhere, naval sonars have been shown to cause lethal mass strandings, especially among deep-diving beaked whales.

This is of concern, because marine mammals such as whales and dolphins live by sound, using calls and echolocation to communicate and navigate through the vast, dark, aquatic habitat. We know remarkably little about the short- or long-term effects of noise pollution, but it cannot be easy to exist and thrive in an environment in which the excess noise generated by humans overwhelms the sounds produced by animals.

Another intangible threat is pollution. Direct pollution, such as major oil spills, degrades habitat and can cause illness or death. Indirect pollution refers to dietary exposure to contaminants (often biomagnified); this probably affects most populations, since few places in the oceans are free of pesticides and other man-made toxins. These may affect immune function or reproduction, but impacts are very difficult to disentangle from the many other (often unquantifiable) variables involved.

Climate Change: The Big Unknown

As we look to the future of the great whales, there is of course one major issue that looms over everything: global climate change. Since Roger Revelle's visionary work on greenhouse gases (Revelle and Seuss 1957), there has been much debate about the impact of a warmer world on marine ecosystems. The IWC has held three workshops on the topic of climate change and cetaceans; however, none have reached firm conclusions, reflecting the huge uncertainty not only about the nature and scope of future ecosystem changes, but also how such changes would interact with the many factors affecting the survival and reproduction of individual whales, and the carrying capacity of key habitats. Responses to changes may include redistribution, adaptation, or (especially for critically endangered populations) extinction.

Vulnerability to climate-related changes will depend upon multiple biological and environmental factors (Laidre et al. 2008). The impacts may not all be negative. For example, Arctic surveys are recording humpback and fin whales expanding their ranges in polar waters as sea ice continues to retreat and new foraging habitat becomes accessible. Whether cetaceans closely associated with Arctic sea ice (such as bowheads) will gain or lose from diminished ice cover remains unknown.

Sorting all this out—i.e. attempting to predict the response of specific populations to highly uncertain future changes in everything from ocean currents to ecosystem dynamics to behavioral responses of whales—is, to say the least, a daunting task. Ecosystem models can be useful in exploring possible scenarios, but accurately measuring the multiplicity of variables involved—let alone understanding how they all interact—is exceedingly difficult.

The difficulty of the problem is illustrated by the lack of agreement on some key issues; for example, what will happen to krill populations as a result of climate change (Flores et al. 2012)? Southern Ocean baleen whales feed almost exclusively on krill, so major changes in the abundance of this prey source have potentially large implications for whale populations. Yet even without climate change, reliably estimating krill abundance is extremely difficult: some estimates of krill biomass differ by an order of magnitude (Nicol et al. 2000).

Also, a central topic of the current debate is whether krill do better with more or less sea ice. The underside of sea ice provides

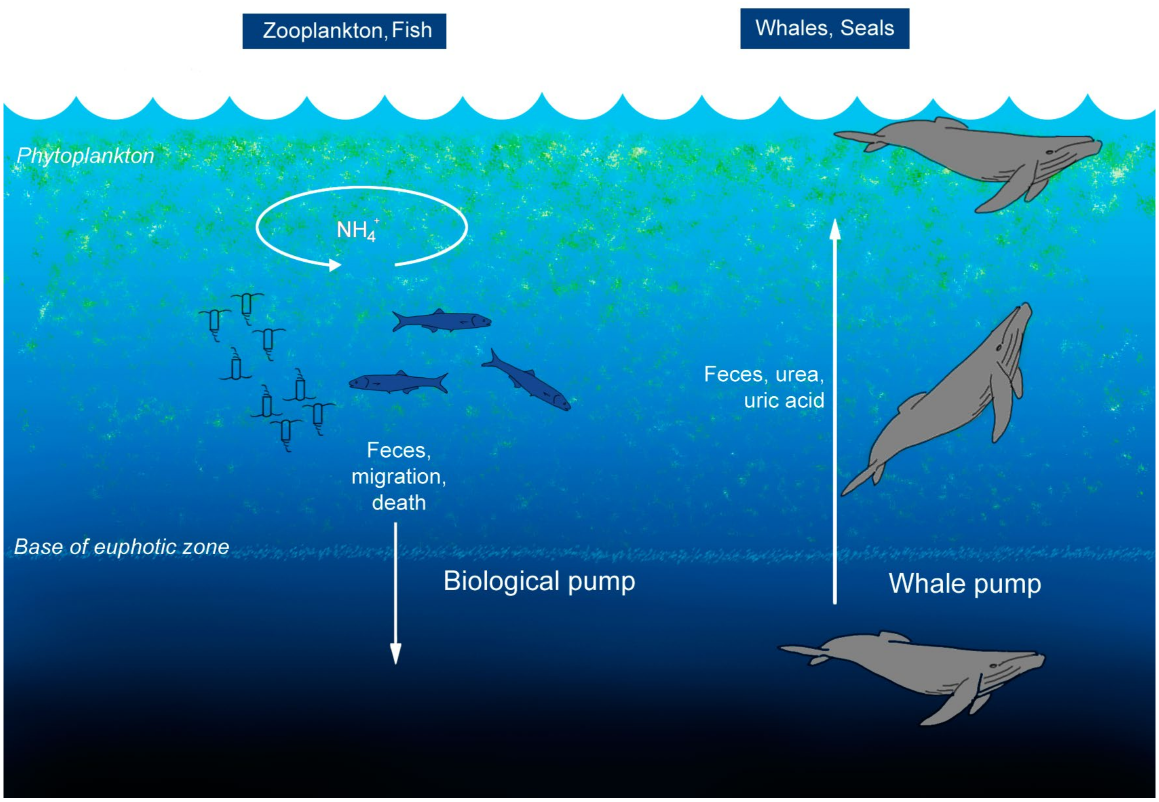


Figure 5 A conceptual model of what has been termed the "whale pump". In the common concept of the biological pump, zooplankton feed in the euphotic zone and export nutrients via sinking fecal pellets, and vertical migration. Fish typically release nutrients at the same depth at which they feed. By contrast, excretion for marine mammals, which must return to the surface to breathe, occurs at shallower depths than where they feed. Source: Roman and McCarthy (2010, Figure 1).

access to algae and protection from predators for overwintering adult and larval krill; extensive sea ice also displaces salps, which are krill competitors (Ballance et al. 2006). In this light, major loss of sea ice might have a negative impact on krill. However, an argument has been made that decreases in sea ice may enhance primary production, notably in areas affected by the upwelling of nutrient-rich deep water (Prezelin et al. 2000); krill might fare better in open water as a result (B. Meyer, in prep.).

In the Arctic, the loss of sea ice is already breaking down the separation of Arctic whale populations. Bowhead whales from Alaska, long separated from conspecifics in the Atlantic, are now mixing in Canadian waters. Even more dramatically, gray whales—which have been extinct in the North Atlantic since about 1800—are beginning to find their way into that ocean. Will we one day soon see gray whales reestablishing a viable Atlantic population for the first time in more than two centuries?

Looming large over all these issues are some potentially catastrophic scenarios such as the impact of ocean acidification (Caldeira and Wickett 2003, Royal Society 2005). In its most extreme manifestation, this potentially irreversible phenomenon could cause catastrophic changes to marine ecosystems through loss of calcifying organisms in the plankton. Should the worst-case scenarios come to pass, whales would likely be among innumerable marine species negatively affected—as would the commercial fisheries so important to human food security.

Whales: Competitors to Fisheries or Ecosystem Engineers?

> “The Southern Ocean is the site of a vast uncontrolled experiment that began when commercial sealing and whaling activities in the nineteenth and twentieth centuries brought some seal and whale populations near extinction.”
>
> R.M. LAWS (1977)

Whaling had an obvious and dramatic effect on the abundance of the great whales. But what was the effect on the marine ecosystem? Specifically, how did the removal of three million large predators impact productivity and the food chain?

One of the first scientists to address this question was Richard Laws, who suggested that, in the Antarctic, extensive whaling had created what he termed a “krill surplus,” which should now be available to benefit other predators (Laws 1962, 1977). Put simply: because in the Southern Ocean whales feed largely on krill, then with so many whales killed, there must be a massive excess of krill left uneaten.

The evidence for the effects of a krill surplus has been mixed. Some species, such as Antarctic fur seals, certainly experienced a major population boom after the peak of whaling (Weimerskirch et al. 2003). However, assessing the validity of the krill surplus hypothesis—and whether it is even still relevant so many years after whaling—depends upon reliable estimates of the abundance not only of krill (which, as noted above, is difficult) but of the many krill predators too.

In recent years, an intriguing alternative idea has emerged: that by recycling nutrients (notably iron and nitrogen) into the upper layers of the ocean through defecation, whales help stimulate the production of the planktonic organisms that underlie much of the marine food web (Figure 5; Roman and McCarthy 2010; Lavery et al. 2014; Ratnarajah et al. 2014). Thus, if (as some research has suggested) krill have actually not increased in abundance as whaling removed their major predator, this may be partly due to the reduction in nutrient recycling by whales, and a consequent reduction in plankton productivity.

From a policy perspective, this is a critical debate. Japan has predicated its scientific whaling programs upon the belief that whales compete with humans for fish and other marine resources, and therefore must be "managed" (i.e, culled; Morishita 2006). Yet this simplistic view ignores several key facts (Clapham et al. 2006). First and most obviously, human over-fishing (not whales) is the cause of the decline of commercial fish stocks worldwide. Also, the primary predators of fish are not whales, but other fish; and the removal of top predators such as cetaceans can cause major ecosystem perturbations, with negative consequences for fisheries. Finally, a key point is that the sizes of many whale populations today are at a small fraction of their levels in pre-whaling times when commercial fish populations were considerably larger and much healthier than today. Set within this historical context, the idea that whales have always served as "ecosystem engineers," fertilizing the oceans and promoting productivity and ecosystem health, becomes very plausible. Furthermore, as many whale populations continue to recover from whaling, they may help buffer marine ecosystems from destabilizing stresses (Roman et al. 2014).

Simply put, the oceans of the world probably need whales; and so, therefore, do we humans and our fisheries. We may also need whales in the battle against global warming; as suggested recently, whales likely play a significant role in sequestering carbon (Pershing et al. 2009, Lavery et al. 2010). This occurs directly, through storage in the living biomass of the whale, which sinks to the deep ocean when the whale dies. Additionally, iron defecated by whales stimulates phytoplankton blooms and results in increased export of carbon through the biological pump (Figure 5). Consequently, the ability of the oceans to act as a carbon sink may have been significantly diminished by industrial whaling, and restoration of populations to pre-whaling levels would potentially help mitigate global warming. Thus, the continued recovery of the world's great whales is a conservation goal that is not just noble and appropriate, but also very much in our self-interest.

Whales have been around for a great deal longer than we have. They have persisted over millions of years through major shifts in the climate and in marine ecosystems. They are also still here, rather improbably, despite centuries of whaling. Let us hope that they can now survive the large-scale changes that humankind has wrought upon this small blue planet that we all share.

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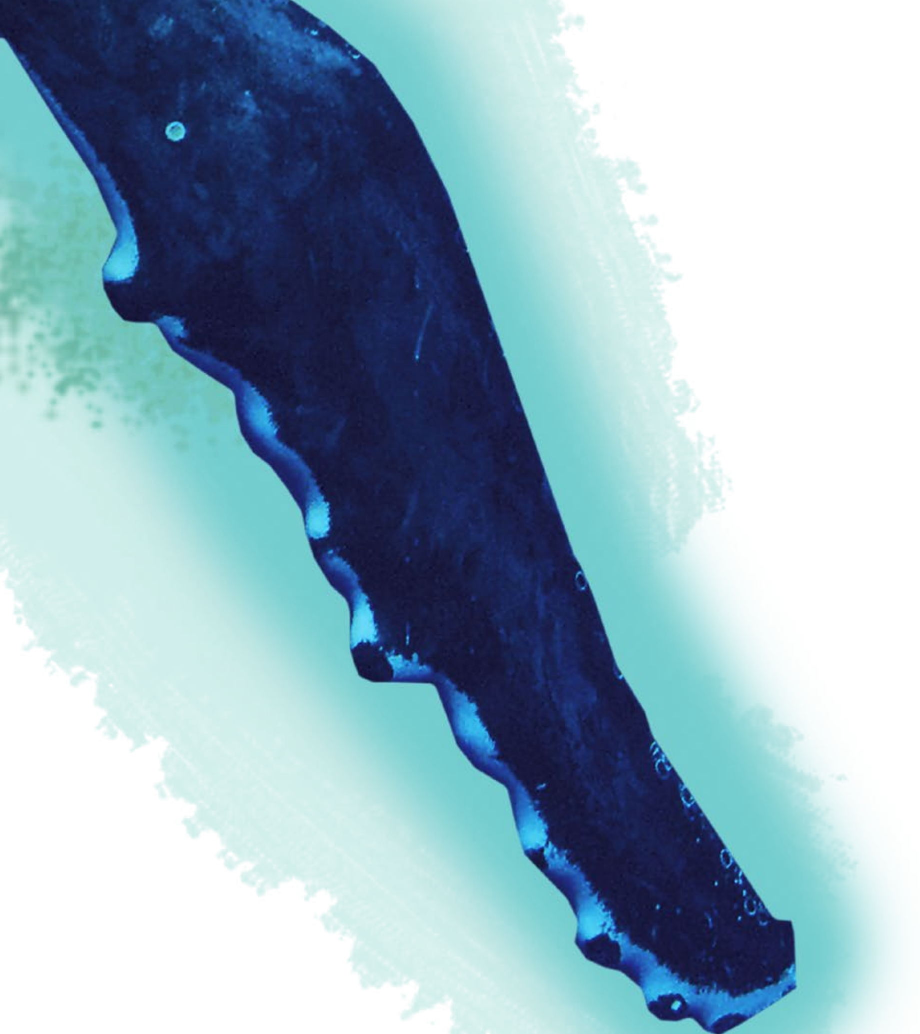
THIS YEAR'S PANELISTS

Douglas Wartzok is Provost Emeritus and Professor of Biology at Florida International University. He received his Ph.D. in biophysics (neurophysiology) from Johns Hopkins University. His research on marine mammals has taken him from the Arctic Ocean to Antarctica to study seals, whales, and walrus. He and his colleagues and graduate students have developed acoustic tracking systems for studying seals, and radio and satellite tracking systems for studying whales. His research focuses on marine mammal sensory systems. He is Editor Emeritus of Marine Mammal Science. He has served as Chairman of the Committee of Scientific Advisors, U.S. Marine Mammal Commission, he currently chairs the Society for Marine Mammalogy's Committee of Scientific Advisors, and he has chaired one and served on two other National Academy of Sciences committees dealing with noise and marine mammals.

Rebecca Lent is the Executive Director of the Marine Mammal Commission. A marine economist by training, she earned a Ph.D. in resource economics from Oregon State University in 1984. Her dissertation focused on modeling price determination in the global salmon market. After completing her dissertation, Dr. Lent received the Chateaubriand Fellowship from the Embassy of France in Washington, D.C., to conduct post-doctoral research at the Concarneau Laboratoire de Biologie Maritime on the ex-vessel market impacts of government minimum prices. She then moved to Canada to teach and conduct research in agricultural and resource economics at the Université du Québec à Rimouski (1984–86) and Université Laval (1986–1992). In 1992, Dr. Lent joined the Highly Migratory Species Division at National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service, where she served as economist and then Division Chief. She joined the Senior Executive Service in 2000, serving as the Regional Administrator of the Fisheries Southwest Region, the Deputy Assistant Administrator for Regulatory Programs, and the Director of the Office of International Affairs. Dr. Lent joined the Commission in 2013.

James Mead received his undergraduate degree in biology/geology at Yale in 1965, his masters in geology at the University of Texas and his doctorate in evolutionary biology in 1972 at the University of Chicago. During his time at the University of Chicago, from 1968-72, he worked as a biological technician for the Fisheries Research Board of Canada at a whaling station in Newfoundland. He was hired by the Smithsonian as Curator of Marine Mammals in 1972. He worked at that job until he retired in 2010 and became Curator Emeritus of Marine Mammals. He has mainly worked with the life history and systematics of the bottlenose dolphin and the beaked whales. In 2015, he received the Kenneth S. Norris Lifetime Achievement Award from the Society for Marine Mammalogy.



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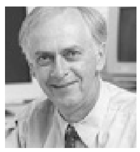
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