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LARGE-SCALE MARINE ECOSYSTEM CHANGE AND THE CONSERVATION OF MARINE MAMMALS

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Papers in this Special Feature stem from a symposium on large-scale ecosystem change and the conservation of marine mammals convened at the 86th Annual Meeting of the American Society of Mammalogists in June 2006. Major changes are occurring in multiple aspects of the marine environment at unprecedented rates, within the life spans of some individual marine mammals. Drivers of change include shifts in climate, acoustic pollution, disturbances to trophic structure, fisheries interactions, harmful algal blooms, and environmental contaminants. This Special Feature provides an in-depth examination of 3 issues that are particularly troublesome. The 1st article notes the huge spatial and temporal scales of change to which marine mammals are showing ecological responses, and how these species can function as sentinels of such change. The 2nd paper describes the serious problems arising from conflicts with fisheries, and the 3rd contribution reviews the growing issues associated with underwater noise.

Key words: cetaceans, climate change, fisheries, marine ecosystems, marine mammals, ocean noise, pinnipeds, sirenians, whales

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Based on a long tradition, bowhead whales (*Balaena mysticetus*) off the North Slope of Alaska are subjects of a well-regulated modern hunt by Alaska Natives. During the spring hunt of 1993, 2 stone harpoon points were recovered from the dorsal musculature of 1 of these whales. Supported by archaeological comparisons, these implements were judged to have been imbedded during unsuccessful strikes by hunters some 100–130 years earlier, substantiating maximum longevity estimates for bowhead whales obtained by a variety of other techniques (George et al. 1999). The population of North Atlantic right whales (*Eubalaena glacialis*) on the Atlantic coast of North America included 1 individual with unique markings well photographed as an adult in 1935 and then intermittently through 1995 (Kraus and Rolland 2007a). These examples show that some marine mammals can have remarkable life spans, a feature not likely to be unique to the 2 species noted above. In addition to the baleen whales, other groups of marine mammals are also known for high maximum longevities. Estimates of age for odontocete cetaceans include records exceeding 50 years in bottlenose dolphins (*Tursiops truncatus*—Hohn and Fernandez 1999) and 65–80 years in sperm whales (*Physeter catodon*—Evans and Hindell 2004). Sirenians have been documented to live 59–73 years (Marmontel et al. 1996; Marsh 1995). Pinnipeds live shorter lives, but nonetheless their longevity easily can span a quarter century (Cameron and Siniff 2004; Fay 1982).

Given these high longevities, one must consider the striking changes to marine ecosystems that some individual marine mammals likely still plying global waters today have experienced within their lifetimes. Some were alive during the factory whaling era, which ended (with few exceptions, including ongoing whaling by Japan) at the time of the 1982 International Whaling Commission moratorium; whaling has been characterized as 1 of the world's "most spatially extensive forms of exploitation of wild living resources" (Reeves and Smith 2006:82). Industrial whaling (including both legal and illegal factory ship whaling—Ivaschenko et al. 2007) removed huge segments of the world's whale populations, not only seriously reducing their population densities, but perhaps also sparking cascading effects on the trophic structure of marine ecosystems over grand scales (reviewed in depth in Estes et al. [2006]; see also Springer et al. [2003] and alternative analyses by Trites et al. [2007] and Wade et al. [2007]). In addition to past harvest of whales and its associated impacts, there are many new and growing drivers of change in marine ecosystems that can impact marine mammals. Expanding commerce and international trade have fostered tremendous growth in the traffic of large ships. This expanding ship traffic results in great

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amounts of underwater noise pollution or ‘‘acoustic smog’’ (Clark et al. 2007) from ship propulsion systems, as well as increased potential for mortality of marine mammals through direct strikes by hulls and propellers (Laist et al. 2001; Lightsey et al. 2006). Indeed the female northern right whale cited above as 1st photographed in 1935 was last observed in August 1995 with ‘‘a large propeller wound cutting deeply into the side of her head, undoubtedly the result of an unfortunate encounter with a ship’’ and has never been seen again (Kraus and Rolland 2007a:3). Along with increasing commerce, the human impact on marine fisheries resources has reached new dimensions with high world market demand and the increasing ability of fishing technology to penetrate previously unavailable or less used resources (Pauly et al. 1998). This has caused collapses in fisheries, impacting entire marine ecosystems and altering the prey base of some marine mammals (DeMaster et al. 2001; Jackson et al. 2001). Ecological effects of interactions between marine mammals and fisheries can be indirect or direct. The latter include injuries and mortality in fishing gear (Read 2008), whereas indirect effects can involve feeding-related interactions (such as indirect food web effects or direct competition for a target prey species) and habitat degradation through fishing activities (such as bottom trawling). Plagányi and Butterworth (2005) provide an in-depth review of indirect effects of fisheries on marine mammals and methods for assessment of their impact, particularly modeling approaches.

Additional changes to marine ecosystems with impacts on the conservation of marine mammals also have been documented. These include wide-ranging application of technology using sound for undersea research, oil and other resource exploitation, industrial activity, and military purposes (Hildebrand 2005; National Research Council 2000); alterations in ice cover and hydrologic and oceanographic conditions of the polar regions driven by climate change (Fischbach et al. 2007; Moore 2005); marine mammal die-offs and morbidity events from harmful algal blooms that seem to be increasing with runoff and other coastal ecosystem changes (Van Dolah 2005; Van Dolah et al. 2003); and an expanding list of chemical contaminants synthesized by humans. Indeed, a few of today’s surviving long-lived marine mammals may have been born in seas almost completely free of persistent organic pollutants, given that large-scale use of organochlorine pesticides such as DDT and industrial compounds such as polychlorinated biphenyls did not occur until the 1940s or later (O’Shea and Tanabe 2003). Today such compounds are likely to be found in every marine mammal on Earth, and are spread to arctic ecosystems from developed areas not only through marine food chains but by atmospheric transport on the winds (Simonich and Hites 1995).

The unprecedented scale of change that is taking place in marine ecosystems is likely to have grave consequences for the conservation of marine mammals. A recent volume (Reynolds et al. 2005) was devoted to many areas of concern regarding the future impact of large-scale marine ecosystem changes on marine mammals, and reviewed some of the research and management actions needed to address them. However, many mammalogists specializing in terrestrial species may not be familiar with the scope of these changes and their significance. Thus, in 2006 the American Society of Mammalogists sponsored a symposium at the 86th Annual Meeting in Amherst, Massachusetts, to focus on the topic of large-scale changes in marine ecosystems and the conservation of marine mammals. The papers in this Special Feature are an outgrowth of that symposium. They focus on 3 topics that are particularly critical, and indeed update some of the material covered by Reynolds et al. (2005). Moore (2008) reports on how marine mammals now may be ‘‘sentinels’’ of the magnitude and rapidity of this change, particularly in the Arctic, and that as sentinels their population health and other responses to marine ecosystem change take place over very large temporal and spatial scales. The extent and future implications of bycatch, unintended mortality, and unregulated harvest of marine mammals in fishing gear is treated by Read (2008), and Tyack (2008) reviews the growing problem of ocean noise and its effects on marine mammals. A final topic presented at the symposium dealt with the case history of the North Atlantic right whale as a species subject to intense ecosystem change from multiple causes. A thorough chronicle of this topic is now available elsewhere (Kraus and Rolland 2007b).

Findings summarized by the papers in this Special Feature are sobering. Moore (2008) points out that dramatic changes in polar ice cover have resulted in changes in body condition and reduced recruitment in ice-dependent species such as polar bears (*Ursus maritimus*) and ringed seals (*Pusa hispida*). Gray whales (*Eschrichtius robustus*) have made major shifts in the timing and geographic foci of their migrations in the North Pacific in response to ecosystem alterations that may span decades in time and thousands of kilometers in space. Some now overwinter in the Arctic with reduction in ice cover. Moore (2008) notes that it is specifically because some marine mammals integrate and reflect ecological variation across large geographic and long temporal scales that they are prime candidates as sentinels to marine ecosystem change; she cites examples where marine mammals may be useful sentinels for change in tropical and temperate reaches as well as at the high latitudes, and in both nearshore and open-water habitats. Marine mammals may tell us a great deal about ocean ‘‘health’’ through monitoring of their demography, pollutant burdens, disease, and other factors with direct implications for their conservation. On the positive side, she also suggests that because they are charismatic megafauna, marine mammals also can be used as captivating and compelling educational tools in attempts to inform public opinion on policy changes aimed at improving the condition of the marine environment.

The direct interactions between global fisheries and marine mammals present a conflict described by Read (2008) as a ‘‘looming crisis.’’ As a conservation threat, interaction with fisheries is of most immediate concern for small populations of cetaceans and sirenians, and is well illustrated by the 1st human-caused extinction of a cetacean in recorded history: the loss of the baiji (*Lipotes vexillifer*, a Yangtze River endemic) reported last year (Turvey et al. 2007). This also marks the 1st modern loss of a mammalian family (Lipotidae sensu Rice 1998; Nikaido et al. 2001; Yan et al. 2005; Yang et al. 2002).

Read (2008) notes that threats due to interactions with fisheries can take 3 forms: bycatches from small populations, a transition from bycatch to market hunting, and destruction of marine mammals that opportunistically depredate the fishery. The impact of fisheries on marine mammals globally has been estimated at more than 650,000 individuals killed annually, including both cetaceans and pinnipeds (Read et al. 2006). Read (2008) concludes that given their higher potential population growth rates, many (but not all) pinniped populations may be able to sustain such mortality, but that this is unlikely to be the case in smaller, more isolated populations of marine mammals. Of particular concern is the vaquita (*Phocoena sinus*) of the northern Gulf of California. The vaquita is perhaps as vulnerable to extinction as the baiji (Rojas-Bracho et al. 2006) and was the subject of a position letter from the President of the American Society of Mammalogists to the President of Mexico in 2004 commending conservation actions but expressing concern about the future of the species, primarily due to fisheries interactions (Patterson 2004). Read (2008) points out that direct fisheries interactions sometimes require difficult and unpopular management decisions for conservation of small populations of marine mammals because they are rare events in the eyes of the fishing industry. In some parts of the world the problems are not those of rarity, but of the shifting of fisheries from bycatch into the common taking of small cetaceans as human food in an unregulated and unsustained harvest, or of the intentional killing of marine mammals that have learned to take fish from nets or lines (Read 2008). Addressing conflicts between conservation of marine mammals and fisheries will take considerable effort in 3 areas outlined by Read (2008): developing rapid assessment tools for estimating bycatch, mitigating the impacts of gill nets, and transfer of technology to commercial and artisanal fisheries.

In the final paper, Tyack (2008) reviews the degree of change that is taking place in the underwater acoustic environment and the likely effects of such change on marine mammals. Many aquatic animals have evolved to use sound as their principal modality of communication rather than rely on the visual senses. This is because the laws of physics allow much further propagation of sound in water than in air, and over far greater distances in water than light can travel. The low-frequency sounds of baleen whales may propagate for hundreds of kilometers, perhaps even across ocean basins. Furthermore, odontocete cetaceans have, like the bats, evolved the use of sound of high frequency for echolocation of prey at distances of tens of meters, and some can perceive larger objects over distances of kilometers. However, seemingly quiet waters as seen from shore can be a riot of intense noise below the surface, hampering sound reception. Noise in the ocean is rapidly increasing. Sounds from shipping increase ambient noise by 1–2 orders of magnitude in the same low-frequency bands that baleen whales use for communication (Tyack 2008). Such calls are typically used by whales in mating advertisements and are critical for reproduction. Tyack (2008) reviews studies that document that shipping noise measured off California in the same 20-Hz range used for communication by baleen whales increased by 10 decibels (dB, which are measured on a logarithmic scale) from the 1960s to the 1990s. Noise then increased by another 10–12 dB from the 1990s to 2003–2004. He estimates that this change in noise would reduce the detection range of a whale call from 90 km in the 1960s to 32 km today. In addition to the problem of interference with communication, Tyack (2008) points out that the more intense sounds from air guns used for seismic exploration and sonar used for both military and commercial purposes can be viewed as comparable to an increased risk of predation. It is likely that underwater sound pollution may displace some marine mammals from otherwise suitable habitats, thereby limiting their populations and likely further altering other aspects of marine ecosystem function. The review by Tyack (2008) details a number of ways in which individual marine mammals can adapt to the problem of interference in communication by noise. However, underwater noise may be a chronic physiological stressor for some marine mammals with as yet poorly understood ramifications for conservation.

The likelihood that some marine mammals alive today have been present since a time when at least some of these large-scale changes to marine ecosystems were perhaps minor and incipient is testimony to the adaptability of these individuals in maintaining some degree of behavioral and physiological homeostasis. Can marine mammals adapt equally well at the level of population and genomic responses? Moore (2008) notes that the current pace of change may prove to be most challenging to marine mammal adaptation. Given the tidal waves of ecosystem change that have and will continue to sweep through the seas, this remains an open question. Major policy changes will be needed, and pathways to such policies have been suggested (e.g., Goodman 2005). In the United States, the Marine Mammal Protection Act of 1972 currently provides authority for this country to take actions that will protect marine mammal populations and the ecosystems of which they are part (the Marine Mammal Protection Act can be viewed as the 1st ecosystem-oriented legislation in the country's history). Numerous other nations have laws regarding the marine environment, and there are hundreds of international treaties and agreements for the protection of marine resources (United States Marine Mammal Commission 2000). However, as the papers in this Special Feature illustrate, these safeguards alone may not be strong enough to be effective for marine mammal conservation over time at the current scale and rate of change.

Resumen

Los artículos en esta edición especial surgen del simposio acerca del cambio a gran escala en los ecosistemas y la conservación de los mamíferos marinos llevada al cabo en la 86ava Reunión Anual de la Sociedad Americana de Mastozoología en junio del 2006. Grandes cambios están ocurriendo en varios aspectos del ambiente marino, a tasas sin precedentes y dentro del ciclo de vida de algunos mamíferos marinos. Algunos indicadores de estos cambios incluyen las variaciones en el clima, la contaminación acústica, alteraciones a la estructura trófica, la interacción con pesquerías, la explosión dañina de poblaciones de algas y los contaminantes ambientales. Esta edición especial brinda un estudio a fondo acerca de 3 temas que son particularmente problemáticos. El primer artículo hace notar las enormes escalas espacio-temporales de cambio a las que los mamíferos marinos están mostrando respuestas ecológicas y cómo estas especies pueden funcionar como centinelas ante estos cambios. El segundo artículo describe los serios problemas que surgen de los conflictos con las pesquerías; y el tercero aborda los temas crecientes asociados con el ruido submarino.

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