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Breaking down abundance to understand conservation for small populations: A case study of North Atlantic right whales

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Abstract

The world is currently facing a biodiversity crisis and for many species, this is exacerbated by historic exploitation. Monitoring programs provide an integral tool to understand changes in abundance and the impact of threats informing conservation actions. However, measures of absolute abundance for management can be misleading, particularly when there is a biased sex ratio. Here we recommend focusing on the rate-limiting cohort for management actions using the case of North Atlantic right whales. The North Atlantic right whale has a male-biased sex ratio, with reproductively active females making up less than a fifth of the species. We highlight the importance of understanding and incorporating reproductive potential into management actions to provide species with the best chance of recovery.

KEYWORDS

abundance, critically endangered, declining populations, management, marine mammals, reproduction, sex ratio

1 | INTRODUCTION

Biological extinctions are currently happening at an alarming rate, creating a biodiversity crisis. Over a million species are facing extinction (IPBES, 2019) and there has been an average decline of 69% in monitored vertebrate populations between 1970 and 2018 (WWF, 2022). Habitat destruction or modification, overexploitation, invasive species, pollution, and climate disruption are some of the key threats facing species globally (IPBES, 2019). The field of conservation biology has grown over recent decades with the goal of understanding the impacts of human activities on populations, species, communities, and ecosystems, as well as developing approaches to mitigate the extinction of species (Naiman et al., 2005). Monitoring programs for wildlife populations play an important role in understanding ecological systems and form the basis for management actions and decisions (Yoccoz et al., 2001). Long-term monitoring programs provide critical information on the status of many populations in the wild, helping to determine what changes in abundance are natural variability and what could be due to external pressures (Willis et al., 2007). With long-term monitoring being the only way to know if a population is declining, these programs are essential for conservation. However, many monitoring programs have "monitored populations to extinction" without guidelines on how or triggers on when to act when declines are first detected to conserve the species (Lindenmayer et al., 2013).

One affiliation of taxa that has significantly benefited from the shift from exploitation to conservation are marine mammals (Magera et al., 2013), which are a loose grouping of species including cetaceans (whales, dolphins, and porpoises), pinnipeds (true seals, fur seals, and sea lions), sirenians (manatees and dugongs) as well as marine otters, sea otters, and polar bears (Jefferson et al., 1994). Prized for their meat, oil, baleen, fur, and ivory, marine mammals were exploited by humans leading to the decline of many populations and species, and the global extinction of several species (Magera et al., 2013). In the twentieth century, these declines and extinctions led to the reduction or cessation of commercial exploitation and the implementation of conservation actions and policies (Magera et al., 2013). However, despite international and national level protection of marine mammals from commercial exploitation, numerous threats still impact many populations' ability to recover including vessel strikes, chemical and noise pollution, habitat modification, climate change, and fisheries interactions (bycatch and entanglements), reflecting the vulnerability of species that are slow-growing and long-lived (Read et al., 2006). Methods to account for the loss of individuals from a population or species as a result of human-caused mortalities have been developed, such as the potential biological removal (PBR) metric (Wade, 1998), the use of which is required as a management tool under the Marine Mammal Protection Act (MMPA) in the USA (Punt et al., 2018). The PBR is calculated for a "stock" or population of marine mammals, and estimates the number of individuals that can be removed or lost without a "stock" decreasing, or allowing it to increase to its optimum sustainable population level (Punt et al., 2018; Wade, 1998). The PBR formula uses the total abundance of a "stock." However, for iteroparous mammals, reproductive capacity is constrained by the number of reproductively active females rather than the total abundance of the "stock." Guidelines have been recommended for the adjustment of the PBR for age- or sex-bias to prevent declines resulting from the removal of females or reproductively mature individuals (Barlow et al., 1995). Despite this, known sex biases for many species have not been accounted for in PBR calculations. Nevertheless, it is recognized that the removal of particular classes may harm a population disproportionately to their numbers, and this should appropriately be factored into management plans (Barlow et al., 1995).

1.1 | Sex in managing conservation

In efforts to manage and conserve populations of endangered species vulnerable to anthropogenic pressures, demography and life history are critical. For small, endangered populations or species, a biased sex ratio increases the risk of extinction when the sex ratio deviates from 1:1 (Claus, 2012). Biased sex ratios can arise as a result of demographic stochasticity (low reproductive rates leading to an overproduction of one sex as a result of chance), through sex biased mortality or harvesting, or environmental conditions (Grayson et al., 2014). In mammals, female-biased sex ratios traditionally were of less concern for management. With relatively more females, a population's rate of reproduction may not be adversely affected, and the population's rate of decline will be less than if the sex ratio was equal. However, a male biased sex ratio leads to the opposite outcome with a relatively lower potential for the population growth rate and viability (Grayson et al., 2014).

Intraspecific differences between sexes due to variation in behavior, movement, and habitat use can also influence the risk of threats. Sexual segregation, or the differential use of space and resources by males and females has important implications for conservation and management, as differences in spatial dynamics can influence the overlap with area-specific human activities (i.e., fisheries, shipping lanes) (Wearmouth & Sims, 2008). In juvenile New Zealand sea lions (*Phocarctos hookeri*), females had double the overlap of foraging grounds with fisheries operations than males. This resulted in a higher risk of resource competition and bycatch and higher mortality of females (Leung et al., 2012). Sexual segregation has also been observed in migratory baleen whales, with a male bias observed for humpback whales (*Megaptera novaeangliae*) in winter breeding grounds and during migrations (Brown et al., 1995; Herman et al., 2011), while a female bias has been observed for some foraging areas along migratory corridors (Franklin et al., 2018). These differences in sexual segregation can be linked to differences in energetic demands, due to, for example, sexual dimorphism, or reproductive costs (i.e., lactation, post-weaning recovery). Threats and sex-biased mortality resulting from sexual segregation can be further exacerbated by sex ratio biases at the population level.

Effective management of wildlife populations requires detailed understanding of the distribution, habitat requirements, and threats faced by the population (Yoccoz et al., 2001). However, this information is often lacking for sexes within a population or species (Wearmouth & Sims, 2008). Despite the importance of sex ratios in conservation and management, they are rarely incorporated into plans for management or conservation. One example where this is an apparent case is the North Atlantic right whale (*Eubalaena glacialis*), listed as critically endangered under the IUCN Red List, and is

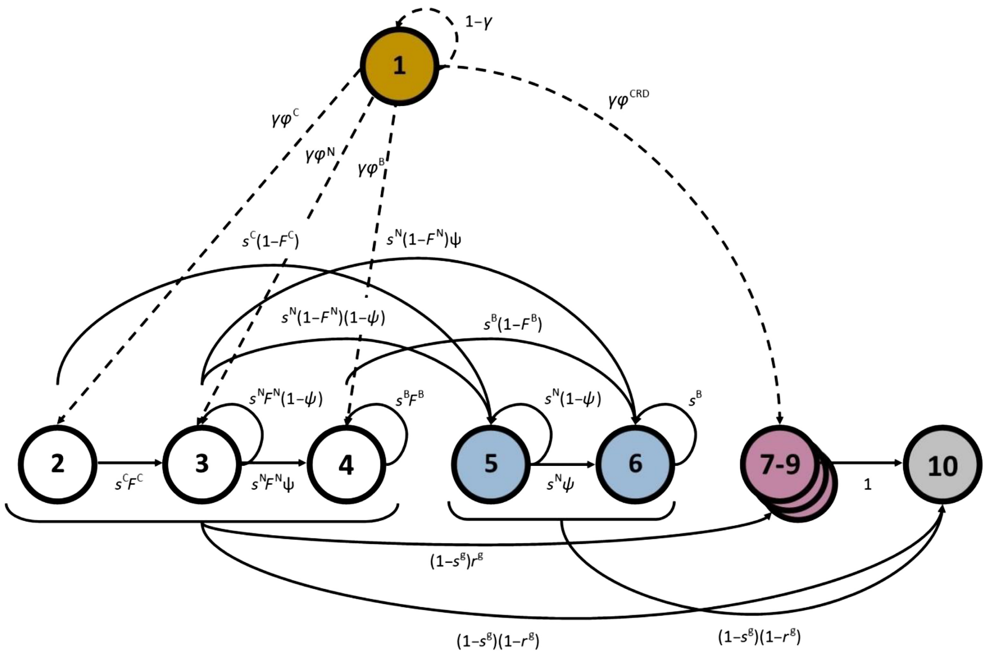

FIGURE 1 Life cycle diagram of female North Atlantic right whales used as the basis for the multi-event mark–recapture–recovery model in Reed et al. (2022). Each circle represents a different state. State 1 represents the initial state before an individual enters the population either through birth or being sighted for the first time. States 2–4 represent live states when an individual is within the study area (2: calf—an individual in their first year of life; 3: pre-breeder—an individual older than one who has yet to start breeding; 4: breeder—an individual who has bred at least once). The blue circles represent individuals who are alive but have permanently left the study area (5: pre-breeder; 6: breeder). The purple circles represent individuals who have been sighted dead (recovered) (7: recovered as a calf; 8: recovered as a pre-breeder; 9: recovered as a breeder), while the gray circle is the absorbing, dead state (10: dead). Superscripts refer to the stage class of the individual (C: calf; N: pre-breeder; B: breeder; CRD: calf recovered dead). Each year individuals can enter the population (γφ) or not (1−γ). Individuals who have entered the population and survive (s) can remain in the study area (F) or permanently leave the study area (1−F). Those individuals who are pre-breeders can remain pre-breeders (1−ψ) or transition into the breeding portion of the population (ψ). Those individuals who do not survive (1−s) can either be recovered (r) when their carcass is found or enter directly into the absorbing state (1−r) when their carcass is not discovered. Individuals whose carcass is discovered move directly into the absorbing state in the next time period.

one of the most endangered great whale species globally (Cooke, 2020). Within its range, the North Atlantic right whale is also listed as Endangered under both the Endangered Species Act in the U.S. and the Species at Risk Act in Canada. Both Acts have legal obligations for the management and protection of listed species. North Atlantic right whales are exposed to numerous threats including fisheries interactions resulting in entanglements, vessel strikes, and changes in prey availability (Knowlton et al., 2022; Reed et al., 2022).

1.2 | Case study: North Atlantic right whales

After the moratorium on commercial whaling, abundance of North Atlantic right whales increased until 2010–2011, peaked at under 500 individuals, and has been in decline ever since (Linden, 2023; Pace et al., 2017). Over time, the estimated sex ratio changed from 1.15 males per female in 1990 to 1.46 males per female in 2015 (Pace et al., 2017). Adult female North Atlantic right whales, particularly those who are reproductively active, have been shown to experience higher rates of mortality compared to males and non-breeding females, which is one of the drivers leading to this biased sex ratio (Runge et al., 2023).

The latest published estimate of the species' abundance is 356 individuals (95%CI: 346, 363) for 2022 (Linden, 2023). Estimates for female North Atlantic right whale abundance from Linden (2023) show a peak in mean abundance between 2011 and 2013 at ∼200 individuals, after which abundance declines until 2020. From 2020, abundance estimates by Linden (2023) show a flattening of the decline of males and females, with roughly 150 individual females alive in 2022. However, the number of breeding females has declined sharply since 2014 and was estimated to be 73 (95%CI: 67, 81) in 2018 (Reed et al., 2022).

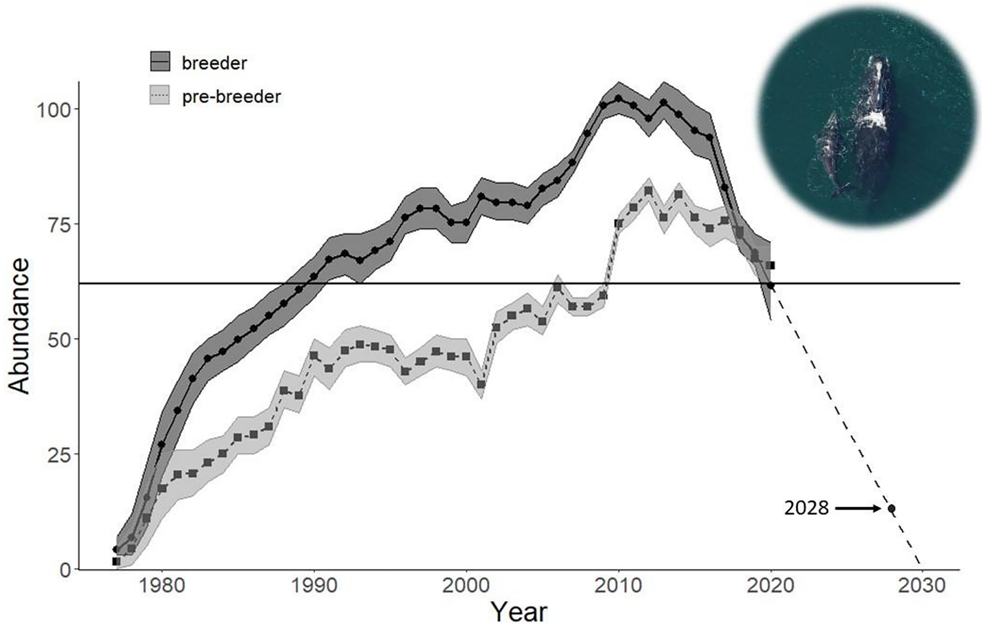

FIGURE 2 Abundance estimates for female North Atlantic right whales from 1977 to 2020. Abundance for female pre-breeders (light gray squares) and breeders (dark gray circles) with 95% credible intervals. Horizontal line indicates the mean number of breeders alive in 2020. Black dotted line indicates the projected decline of breeding females, based upon the current loss of 6–7 individuals annually without any measure of uncertainty. 2028 is indicated as the year when US managers have been mandated by US Congress to institute new measures to reduce fisheries impacts (Corkeron et al., 2023).

Using the multi-event Jolly–Seber model described in Reed et al. (2022), which analyzed data from 1977 to 2018, we reanalyzed the mark–recapture–recovery framework to include data on female North Atlantic right whales until 2020, updating estimates for the number of reproductive females left in this species. To do this, we used long-term sighting records (NORTH ATLANTIC RIGHT WHALE CONSORTIUM, 2022) to construct capture histories which were used to model the abundance of female North Atlantic right whales (Figure 1). A full description of the methods used can be found in the supplementary information.

Between 2018 and 2020, breeding females have further declined to a point estimate of ~64 (95%CI: 54,78, Figure 2). This is equal to their numbers at the beginning of the 1990s (Figure 2), so all conservation gains over the last 30 years have been lost for this vital cohort. To understand the magnitude of this decline in reproductive females, we calculated the average annual loss of breeding females using the point mean abundance estimates generated by the model. This sharp decline in reproductive females since 2014 resulted in the loss of 6–7 reproductive females on average from the species per year between 2014 and 2020.

The risk of quasi-extinction, the point where further declines would prohibit the continued survival of a species, has been set at a threshold of 50 reproductive females for North Atlantic right whales (Runge et al., 2023). Entanglements in fishing gear are a primary cause of mortality, morbidity, and reproductive failure in North Atlantic right whales (Corkeron et al., 2023; Moore, 2023; Runge et al., 2023). In the U.S., North Atlantic right whales are legally protected under the MMPA and Endangered Species Act (ESA). However, a rider in the last Congressional budget created legislative changes that postponed action to protect these whales until 2028. If this loss of 6–7 breeding females annually continues, the number of breeding North Atlantic right whales alive at the start of 2028 will be well below the threshold for quasi-extinction (Figure 2). With so few breeding females at that point, the management actions needed to prevent extinction will be draconian.

2 | CONCLUSION

For the past decade, calf production by North Atlantic right whales has been very poor, with a maximum of 18 calves born in the 2021 calving season (New England Aquarium, 2023). Our data (Figure 2) show where hope lies for North Atlantic right whales. Females that should be recruited to the breeding cohort are failing to do so, leading to a relatively higher proportion of non-breeders currently than in years past. Regardless of environmental conditions, by reducing entanglements, which are known to impact female right whales' calving capacity (van der Hoop et al., 2017) and ability to start breeding (Reed et al., 2024), these currently nonreproductive females could start breeding. The survival of female North Atlantic right whales is also disproportionately affected by entanglements, with females overall more likely to die from an entanglement event (Knowlton et al., 2022). This is particularly the case for minor entanglements, with females twice as likely to die than males with the same entanglement severity (Knowlton et al., 2022).

Marine mammals were the poster children for marine conservation, but the recovery of some species remains impacted by human activities (Thomas et al., 2016). Given the continuing loss of reproductive females and the failure of a substantial proportion of females to begin calving, there is little possibility of persistence of North Atlantic right whales unless drastic changes in fisheries impacts are made. Further steps must be taken quickly by managers in both the USA and Canada to reduce mortalities and impediments to reproductive recruitment by eliminating entanglements in fishing gear.

Absolute estimates of abundance can be misleading for small, declining populations, particularly when their sex ratios are biased (Claus, 2012). Our projection of less than 50 breeding females currently in the species is far more alarming than the species' current abundance of around 350 individuals in total. Even allowing for the possibility that the dramatic decline of breeding females in recent years did not continue in 2021/2022 (Linden, 2023), the new abundance estimates provide no information on the status of non-reproductive females and their likelihood of transitioning to calving. By considering only the total abundance of all individuals, we lose important insights into what is happening to the rate-limiting cohort. For most mammals, that is the reproductive females. We conclude that estimates of abundance for small, declining species of mammals must provide estimates on the rate-limiting cohort as part of stock assessments and population estimates to properly understand a species' reproductive potential and thus their status relative to continued persistence or extinction.

AUTHOR CONTRIBUTIONS

J. R. conducted the analysis and wrote the original draft. All authors contributed to the conceptualization, review, and editing of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

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DATA AVAILABILITY STATEMENT

Data used in this study is curated and managed by the North Atlantic Right Whale Consortium, where access can be requested via https://www.narwc.org/accessing-narwc-data.html.

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SUPPORTING INFORMATION

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

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