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# Marine Species Range Shifts Necessitate Advanced Policy Planning

## THE CASE OF THE NORTH ATLANTIC RIGHT WHALE

By Erin L. Meyer-Gutbrod, Charles H. Greene, and Kimberley T.A. Davies

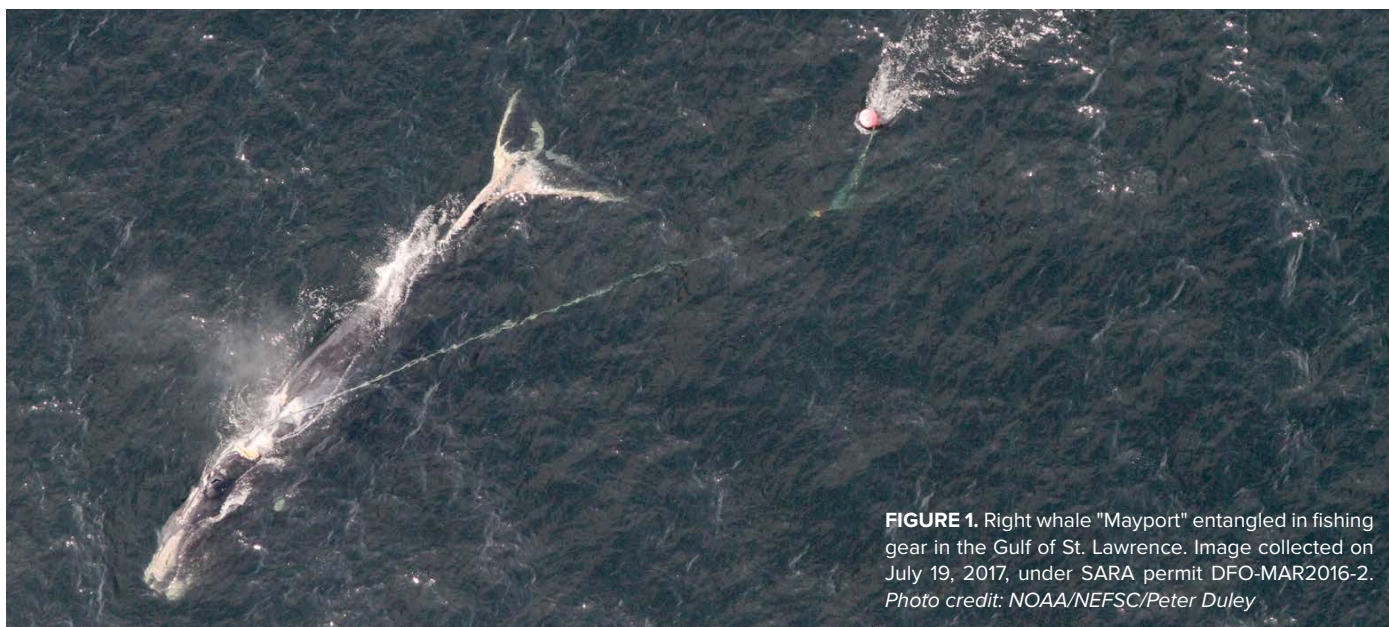
**ABSTRACT.** Rising global temperatures are causing a poleward shift in species distribution. Range shift velocities are higher in the marine environment, with observed rates of 30–130 km per decade. Both protected and exploited species will be at risk if marine species management policies are not structured to anticipate these range shifts. The 2017 mass mortality event of the North Atlantic right whale showcases the detrimental impact of unanticipated climate-mediated behavior in a species protected by geographically and seasonally fixed policies. Based on the results of a demographic capture-recapture model, right whales may face extinction in fewer than 30 years unless protective policies are expanded to cover their shifting distribution. Increased support of long-term monitoring programs paired with environmental modeling research is critical to developing more proactive conservation management strategies and preventing further ecological crises.

### RIGHT WHALES THREATENED BY HUMANS AND CLIMATE

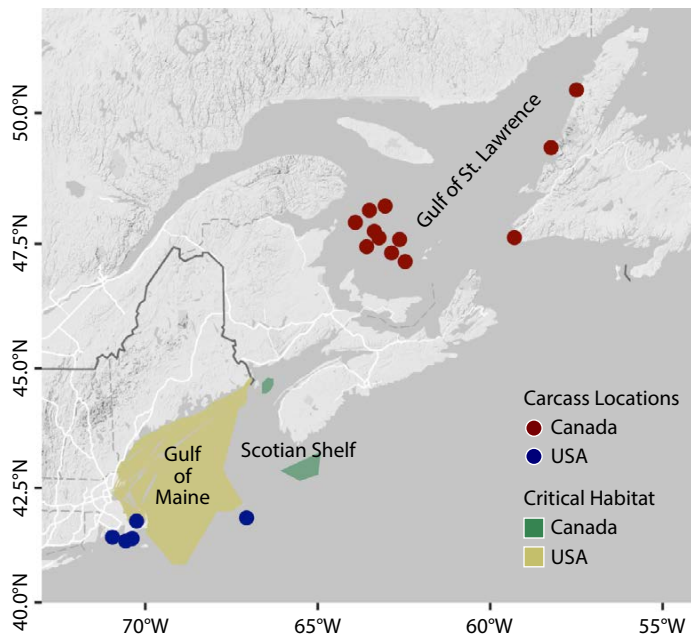
The North Atlantic right whale is one of the world's most endangered cetacean species, with estimates of fewer than

500 animals remaining in the population (Pace et al., 2017; Pettis et al., 2017). Evolving interactions with humans have greatly influenced the history of this species. Following centuries of intense

whaling pressure, population growth is now stifled by high mortality rates attributed to ship strikes and entanglement in fishing gear (Kraus et al., 2005, 2016; [Figure 1](#)). NOAA Fisheries and Fisheries and Oceans Canada have designated critical habitats throughout the right whale's traditional range, including portions of the Gulf of Maine and the Scotian Shelf where right whales typically forage for zooplankton (NMFS, 2016; Fisheries and Oceans Canada, 2014; [Figure 2](#)). These critical habitats guide the development of protective policies to reduce anthropogenic mortalities, such as vessel speed reductions, vessel rerouting zones, and fishery modifications.



**FIGURE 1.** Right whale "Mayport" entangled in fishing gear in the Gulf of St. Lawrence. Image collected on July 19, 2017, under SARA permit DFO-MAR2016-2. Photo credit: NOAA/NEFSC/Peter Duley



**FIGURE 2.** Map of NOAA Fisheries (yellow) and Fisheries and Oceans Canada (green) right whale northern critical habitat designations and locations of right whale carcasses found in US (blue) and Canadian (red) waters and beaches in 2017.

While scientists and managers have focused much of their effort on limiting mortalities in these feeding grounds, little consideration has been given to the effect of shifting prey distribution. In the 1990s, declines in the copepod species *Calanus finmarchicus*, the right whale's primary source of nutrition, were attributed to a regime shift in the Gulf of Maine ecosystem associated with climate forcing from the Arctic (Greene et al., 2013). These declines drove a shift in right whale habitat use among several important feeding grounds (Hamilton et al., 2007; Patrician and Kenney, 2010; Davies et al., 2015). Low prey abundances reduced calving rates, demonstrating the significant impact prey availability can have on right whale demography (Meyer-Gutbrod et al., 2015; Meyer-Gutbrod and Greene, 2018). Although previous observations of *C. finmarchicus* declines in the Gulf of Maine have been related to natural climate oscillations and variability in water mass advection (Pershing et al., 2010; Greene et al., 2013; Davies et al., 2014), anthropogenic warming will also play a role in right whale prey availability. Because the Gulf of Maine constitutes

the southern edge of suitable habitat for this subarctic copepod species, forecasts of future warming predict significant declines in *C. finmarchicus* in the Gulf of Maine within this century (Reygondeau and Beaugrand, 2011; Grieve et al., 2017).

Starting in 2012, right whale sightings in several traditional feeding habitats began to decline, causing speculation that a shift in right whale habitat usage was occurring (Pettis et al., 2017). Passive acoustic monitoring efforts indicated a decrease in summertime occupation of the northern Gulf of Maine, supporting this theory (Davis et al., 2017). With fewer animals sighted, scientists and managers were unable to distinguish between a decline in population size and a change in spatial distribution. Using knowledge of summer right whale feeding habitat history to guide

exploratory surveys of candidate habitats (e.g., Michaud and Taggart, 2011; Davies et al., 2014), a collaborative effort between the United States and Canada to search for the animals in 2015 revealed an aggregation in the southern Gulf of St. Lawrence (GoSL), well north of the known and protected critical feeding habitats. In 2017, the discovery of 17 right whale carcasses triggered the declaration of an unusual mortality event (Table 1; NOAA Fisheries, 2018). Twelve of these carcasses were located in the GoSL and five in the Gulf of Maine (Figure 2; Daoust et al., 2017). Necropsies of seven of the 12 GoSL carcasses found the causes of death to be blunt force trauma indicative of ship strike in four cases (57%), entanglement in snow crab gear in two cases (29%), and undetermined due to advanced decomposition in one case (14%; Daoust et al., 2017). In addition, five live right whales were seen entangled in snow crab gear in the GoSL (Daoust et al., 2017). When a portion of the right whale population shifted north, likely in search of better feeding grounds, the spatial and temporal mismatch between protective policies and habitat occupancy led to a confirmed loss of over 3% of the estimated population size.

## FORECASTING CHANGES TO THE POPULATION

The eventual fate of the North Atlantic right whale depends on both the timeliness and efficacy of new policies, which drive anthropogenic mortality rates, and the future prey environment, which drives reproduction. Prey-dependent demographic modeling studies spanning the period 1980 to 2012 demonstrate that the population has exhibited periods of growth and stasis, but no significant

**TABLE 1.** Annual counts of confirmed North Atlantic right whale mortalities. Counts are listed by the country where the carcasses were discovered, which is not necessarily the original location of the injury or death of the animal (Pettis and Hamilton, 2010, 2011; Pettis, 2012; NOAA Fisheries, 2018).

	2010	2011	2012	2013	2014	2015	2016	2017
<b>United States</b>	3	4	3	1	3	0	3	5
<b>Canada</b>	1	0	1	0	1	3	1	12

period of decline (Meyer-Gutbrod and Greene, 2018). However, models that include demographic data through 2015 indicate that the species has recently entered a period of decline (Pace et al., 2017). The discovery of 17 carcasses in 2017 constitutes a confirmed annual mortality count unprecedented since the cessation of whaling. Compared to the average of 3.1 confirmed mortalities per year from 1970 to 2009 (van der Hoop et al., 2013), 2017 represented more than a five-fold increase in confirmed mortalities.

Probability of species extinction and time to extinction can be derived from a 1980–2012 prey-dependent capture-recapture model (Meyer-Gutbrod and Greene, 2018) using the relative increase in mortality rates between that time period and 2017. For this analysis, the species is considered functionally extinct when fewer than 10 females remain. Given historical prey conditions, if the 500% relative increase in mortality rates observed in 2017 persists, the population will decline to extinction in just 34 years.

Additionally, if reduced *C. finmarchicus* abundance results in a decrease in reproduction similar to that observed in the late 1990s, which we hypothesize has occurred during the past five years, then extinction could take place in just 27 years (Figure 3). Even with a mortality rate increase of 200%–250%, extinction risk remains high. Under these more moderate increases in mortality, prey availability strongly influences the population's future (Figure 3).

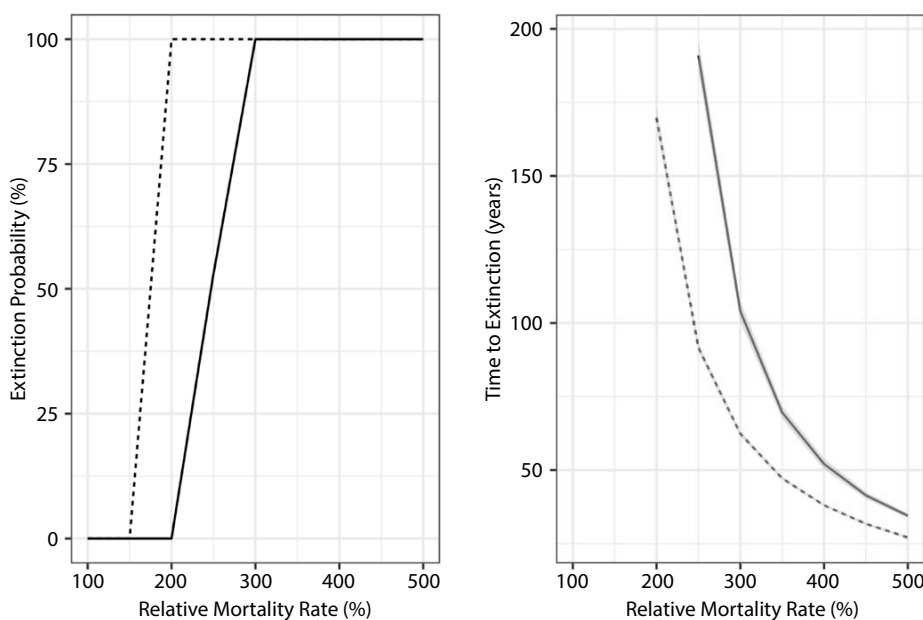
Unfortunately, there have been signals that the right whale prey environment is worsening. The reduced use of most traditional foraging grounds combined with the recent decline in calving rates indicate that the population has been facing prey limitation during the last few years (Pettis et al., 2017). *C. finmarchicus* abundance has been anomalously low in Gulf of Maine and Scotian Shelf waters since 2011 (Johnson et al., 2017). Concurrent declines in *Calanus* spp. in the Gulf of St. Lawrence suggest that the whales' northward range shift may not be

a successful adaptation to declines in Gulf of Maine prey (Devine et al., 2017). This decline in prey has been reflected in the low calving rates since 2012 (Pettis et al., 2017). Only five calves were born in 2017, and no newborn calves have been sighted thus far in 2018.

## EXPANDING PROTECTIVE POLICIES

These population projections demonstrate the extent of human involvement in the viability of the North Atlantic right whale population. Prior to the distributional shift, vessel speed reductions and rerouting zones in the United States and Canada resulted in a significant reduction in right whale deaths attributed to ship strikes (Vanderlaan and Taggart, 2009; Laist et al., 2014). Fishery modifications have been less successful in reducing mortalities, with increasing entanglement severity over the last three decades, potentially attributable to increasing rope strength (Knowlton et al., 2012, 2016). However, these government and industry efforts should inspire cautious optimism that conservation of this highly endangered species remains within our grasp. In an impressive display of rapid response during the GoSL mortality crisis, policy-makers and industry leaders were able to draw upon decades of research and experience to introduce emergency protection measures within weeks. These policies included a massive search for right whales using aerial, vessel, and autonomous vehicle platforms in the GoSL; a mandatory 10-knot speed limit for all large vessels; and snow crab fishery closures (Daoust et al., 2017).

The 2017 GoSL emergency management action was informed by the temporary, near-real-time right whale search effort, but these rapid-response measures were arduous and expensive. We are now challenged to develop a program that combines scientific effort and conservation policy that is sustainable and adaptive. It is essential that future management efforts continue to draw upon previous policy outcomes and scientific



**FIGURE 3.** Probability of right whale population extinction (left) and estimated time until extinction (right) derived from a capture-recapture model given a range of mortality rates and prey scenarios. Mortality rates are relative to those observed historically, where 100% indicates the rates observed from 1980 to 2012 (Meyer-Gutbrod and Greene, 2018) and 500% indicates a fivefold increase from those historical mortality rates. Modeled reproduction rates depend on *Calanus finmarchicus* anomalies resampled from annually averaged Continuous Plankton Recorder time series 1979–2011 (solid lines) or the lowest five annual anomalies observed in that same period (dashed lines).

Prey  
— Average  
--- Low



best practices while also considering the present and potential future distributional shifts in right whales.

The 2018 plan for protecting right whales in the Gulf of St. Lawrence announced by Fisheries and Oceans Canada includes a number of risk mitigation strategies, notably mandatory speed reductions for vessels >20 m, an early closure of the snow crab fishery, a large fixed closed area where no snow crab or lobster gear is permitted, and dynamic management areas (Fisheries and Oceans Canada, 2018). In addition to these efforts, we recommend the following strategies, some of which are under development:

1. Establish a robust and sustainable program for monitoring North Atlantic right whale occupation in the GoSL using a combination of vessel-based, aerial, and passive-acoustic monitoring methods. Monitoring efforts should be balanced to optimize the trade-off between monitoring known aggregation areas and searching for unknown habitats. These long-term data are essential for the creation and assessment of conservation policy.
2. Reinstitute the Continuous Plankton Recorder (CPR) program in the Gulf of Maine to monitor prey conditions in the traditional feeding grounds of right whales. Overseen by the Sir Alister Hardy Foundation for Ocean Science, this plankton monitoring program began in 1961 (Jossi and Kane, 2013), but due to funding limitations, samples have not been processed since 2011 and data collection ceased in spring 2017. Plankton data from the CPR survey are critical to predicting right whale reproductive potential and evaluating the likelihood of these feeding grounds being abandoned in any given year.
3. Conduct a robust study of the effectiveness of the mandatory dynamic management area strategies for fisheries and shipping implemented in the GoSL in 2018.

4. Continue to evaluate and enhance current efforts to minimize the spatial and temporal overlap between snow crab fishery gear and right whales through trap limits, quota limits, and changes to the seasonal timing of the fishery. Consider expanding these policies to other Canadian critical habitats according to observed habitat use.
5. Pilot test and implement appropriate fishing gear modifications to reduce risk of entanglements. Options currently under consideration include ropeless fishing and whale release ropes.
6. With the help of expanded routine and exploratory monitoring, establish and legislate new critical habitat(s) for right whales in the GoSL.

The GoSL crisis demonstrated that mismatches between localized policy implementation and habitat occupancy can rapidly and severely impact right whale recovery potential. A robust monitoring program forms the backbone of right whale science and policy development. Manned aerial and vessel-based surveys that collect photo-identification data will continue to be essential for population and health assessments. However, acoustic technologies on autonomous gliders and buoys can efficiently and inexpensively identify right whale presence over large areas in near-real time while operating in remote habitats or bad weather (Baumgartner et al., 2013). Extended support of environmental monitoring, including collection of oceanographic and climatic data and ecological monitoring programs such as the CPR survey, can help alert scientists to impending distributional shifts. It should be noted that while recent efforts to update right whale protections focus on the GoSL, continued survey support and progress in fishery modifications remain critical in US waters and other areas of Canada.

The need for expanded monitoring efforts and adaptive management strategies is not unique to right whale conservation. Evidence of impending

distributional shifts is mounting for marine top predators whose well-being relies on protective policies (Cheung et al., 2010; Hazen et al., 2013). Lagged policy responses pertaining to commercially exploited species threaten fishery sustainability and disproportionately impact the world's least developed nations (Allison et al., 2009; Pinsky and Fogarty, 2012). Because not all climate change interactions can be predicted, harvest control rules and conservation policies must be structured dynamically, allowing for rapid expansion following unexpected events. In the long term, effective policies should be expanded globally to encourage management that is proactive instead of just reactive. Under mounting pressure from increased anthropogenic stressors to marine ecosystems, the timely implementation and adaptation of conservation and management policies is critical to the health of the global ocean and its living inhabitants (Greene, 2016). As it has in the past, the future fate of iconic species such as the North Atlantic right whale, and the ecosystem that it depends upon and contributes to, will be determined by these policy decisions. 🌐

## REFERENCES

- Allison, E.H., A.L. Perry, M.C. Badjeck, W.N. Adger, K. Brown, D. Conway, A.S. Halls, G.M. Pilling, J.D. Reynolds, N.L. Andrew, and N.K. Dulvy. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries* 10(2):173–196, <https://doi.org/10.1111/j.1467-2979.2008.00310.x>.
- Baumgartner, M.F., D.M. Fratantoni, T.P. Hurst, M.W. Brown, T.V. Cole, S.M. Van Parijs, and M. Johnson. 2013. Real-time reporting of baleen whale passive acoustic detections from ocean gliders. *The Journal of the Acoustical Society of America* 134(3):1,814–1,823, <https://doi.org/10.1121/1.4816406>.
- Cheung, W.W., V.W. Lam, J.L. Sarmiento, K. Kearney, R.E.G. Watson, D. Zeller, and D. Pauly. 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology* 16(1):24–35, <https://doi.org/10.1111/j.1365-2486.2009.01995.x>.
- Daoust, P.-Y., E.L. Couture, T. Wimmer, and L. Bourque. 2017. *Incident Report: North Atlantic Right Whale Mortality Event in the Gulf of St. Lawrence, 2017*. Collaborative report produced by the Canadian Wildlife Health Cooperative, Marine Animal Response Society, and Fisheries and Oceans Canada, 256 pp.
- Davis, G.E., M.F. Baumgartner, J.M. Bonnelli, J. Bell, C. Berchok, J.B. Thornton, S. Brault, G. Buchanan, R.A. Charif, D. Cholewiak, and C.W. Clark. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right

- whales (*Eubalaena glacialis*) from 2004 to 2014. *Scientific Reports* 7(1):13460, <https://doi.org/10.1038/s41598-017-13359-3>.
- Davies, K.T.A., C.T. Taggart, and R.K. Smedbol. 2014. Water mass structure defines the diapausing copepod distribution in a right whale habitat on the Scotian Shelf. *Marine Ecology Progress Series* 497:69–85, <https://doi.org/10.3354/meps10584>.
- Davies, K.T.A., A.S.M. Vanderlaan, R.K. Smedbol, and C.T. Taggart. 2015. Oceanographic connectivity between right whale critical habitats and its influence on whale abundance indices during 1987–2009. *Journal of Marine Systems* 150:80–90, <https://doi.org/10.1016/j.jmarsys.2015.05.005>.
- Devine, L., M. Scarratt, S. Plourde, P.S. Galbraith, S. Michaud, and C. Lehoux. 2017. *Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence During 2015*. Canadian Science Advisory Secretariat, Research Document 2017/034, 53 pp., <http://waves-vagues.dfo-mpo.gc.ca/Library/40613537.pdf>.
- Fisheries and Oceans Canada. 2014. *Recovery Strategy for the North Atlantic Right Whale (Eubalaena glacialis) in Atlantic Canadian Waters*. Species at Risk Act Recovery Strategy Series, Fisheries and Oceans Canada, Ottawa, 75 pp.
- Fisheries and Oceans Canada. 2018. Government of Canada unveils its plan for protecting North Atlantic right whales in 2018. News release NR-HQ-18-13E, 1–3.
- Greene, C.H. 2016. North America's iconic marine species at risk due to unprecedented ocean warming. *Oceanography* 29(3):14–17, <https://doi.org/10.5670/oceanog.2016.67>.
- Greene, C.H., E. Meyer-Gutbrod, B.C. Monger, L.P. McGarry, A.J. Pershing, I.M. Belkin, P.S. Fratantoni, D.G. Mountain, R.S. Pickart, A. Proshutinsky, and others. 2013. Remote climate forcing of decadal-scale regime shifts in Northwest Atlantic shelf ecosystems. *Limnology and Oceanography* 58(3):803–816, <https://doi.org/10.4319/lo.2013.58.3.0803>.
- Grieve, B.D., J.A. Hare, and V.S. Saba. 2017. Projecting the effects of climate change on *Calanus finmarchicus* distribution within the US northeast continental shelf. *Scientific Reports* 7(1):6264, <https://doi.org/10.1038/s41598-017-06524-1>.
- Hamilton, P.K., A.R. Knowlton, and M.K. Marx. 2007. Right whales tell their own stories: The photo-identification catalog. Chapter 1 in *The Urban Whale: North Atlantic Right Whales at a Crossroads*. S.D. Kraus and R.M. Rolland, eds, Harvard University Press, Cambridge, MA.
- Hazen, E.L., S. Jorgensen, R.R. Rykaczewski, S.J. Bograd, D.G. Foley, I.D. Jonsen, S.A. Shaffer, J.P. Dunne, D.P. Costa, L.B. Crowder, and B.A. Block. 2013. Predicted habitat shifts of Pacific top predators in a changing climate. *Nature Climate Change* 3(3):234–238, <https://doi.org/10.1038/nclimate1686>.
- Johnson, C., E. Devred, B. Casault, E. Head, and J. Spry. 2017. *Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2015*. Fisheries and Oceans Canada, Science Advisory Secretariat, Research Document 2017/012, 53 pp., <http://waves-vagues.dfo-mpo.gc.ca/Library/350267.pdf>.
- Jossi, J.W., and J.M. Kane. 2013. *An Atlas of the Dominant Zooplankton Collected along a Continuous Plankton Recorder Transect between Massachusetts USA and Cape Sable NS, 1961–2008*. US Department of Commerce, Northeast Fisheries Science Center, Ref Doc. 13-12, 104 pp.
- Knowlton, A.R., P.K. Hamilton, M.K. Marx, H.M. Pettis, and S.D. Kraus. 2012. Monitoring North Atlantic right whale *Eubalaena glacialis* entanglement rates: A 30 yr retrospective. *Marine Ecology Progress Series* 466:293–302, <https://doi.org/10.3354/meps09923>.
- Knowlton, A.R., J. Robbins, S. Landry, H. McKenna, S.D. Kraus, and T.B. Werner. 2016. Effects of fishing gear strength on the severity of large whale entanglements. *Conservation Biology* 30:318–328, <https://doi.org/10.1111/cobi.12590>.
- Kraus, S.D., M.W. Brown, H. Caswell, C.W. Clark, M. Fujiwara, P.K. Hamilton, R.D. Kenney, A.R. Knowlton, S. Landry, C.A. Mayo, and W.A. McLellan. 2005. North Atlantic right whales in crisis. *Science* 309(5734):561–562, <https://doi.org/10.1126/science.1111200>.
- Kraus, S.D., R.D. Kenney, C.A. Mayo, W.A. McLellan, M.J. Moore, and D.P. Nowacek. 2016. Recent scientific publications cast doubt on North Atlantic right whale future. *Frontiers in Marine Science* 3:137, <https://doi.org/10.3389/fmars.2016.00137>.
- Laist, D.W., A.R. Knowlton, and D. Pendleton. 2014. Effectiveness of mandatory vessel speed limits for protecting North Atlantic right whales. *Endangered Species Research* 23(2):133–147, <https://doi.org/10.3354/esr00586>.
- Meyer-Gutbrod, E.L., C.H. Greene, P.J. Sullivan, and A.J. Pershing. 2015. Climate-associated changes in prey availability drive reproductive dynamics of the North Atlantic right whale population. *Marine Ecology Progress Series* 535:243–258, <https://doi.org/10.3354/meps11372>.
- Meyer-Gutbrod, E.L., and C.H. Greene. 2018. Uncertain recovery of the North Atlantic right whale in a changing ocean. *Global Change Biology* 24(1):455–464, <https://doi.org/10.1111/gcb.13929>.
- Michaud, J., and C.T. Taggart. 2011. Spatial variation in right whale food, *Calanus finmarchicus*, in the Bay of Fundy. *Endangered Species Research* 15:179–194, <https://doi.org/10.3354/esr00370>.
- NMFS (National Marine Fisheries Service). 2016. Endangered and threatened species; Critical habitat for endangered North Atlantic right whale. *Federal Register* 81(17):4,838–4,874, <https://www.greatatlantic.fisheries.noaa.gov/regs/2016/January/16narwhfinalrule.pdf>.
- NOAA Fisheries. 2018. 2017 North Atlantic Right Whale Unusual Mortality Event, <https://www.fisheries.noaa.gov/insight/frequent-questions-2017-north-atlantic-right-whale-unusual-mortality-event>.
- Pace, R.M. III, P.J. Corkeron, and S.D. Kraus. 2017. State–space mark–recapture estimates reveal a recent decline in abundance of North Atlantic right whales. *Ecology and Evolution* 7(21):8,730–8,741, <https://doi.org/10.1002/ece3.3406>.
- Patrician, M.R., and R.D. Kenney. 2010. Using the Continuous Plankton Recorder to investigate the absence of North Atlantic Right Whales (*Eubalaena glacialis*) from the Roseway Basin foraging ground. *Journal of Plankton Research* 32(12):1,685–1,695, <https://doi.org/10.1093/plankt/fbq073>.
- Pershing, A.J., E.H. Head, C.H. Greene, and J.W. Jossi. 2010. Pattern and scale of variability among Northwest Atlantic Shelf plankton communities. *Journal of Plankton Research* 32(12):1,661–1,674, <https://doi.org/10.1093/plankt/fbq058>.
- Pettis, H.M. 2012. North Atlantic Right Whale Consortium 2012 Annual Report Card. Report to the North Atlantic Right Whale Consortium, November 2012.
- Pettis, H.M., and P.K. Hamilton. 2010. North Atlantic Right Whale Consortium 2010 Annual Report Card. Report to the North Atlantic Right Whale Consortium, November 2010.
- Pettis, H.M., and P.K. Hamilton. 2011. North Atlantic Right Whale Consortium 2011 Annual Report Card. Report to the North Atlantic Right Whale Consortium, November 2011.
- Pettis, H.M., R.M. Pace III, R.S. Schick, and P.K. Hamilton. 2017. North Atlantic Right Whale Consortium Annual Report Card. Report to the North Atlantic Right Whale Consortium, October 2017.
- Pinsky, M.L., and M. Fogarty. 2012. Lagged social-ecological responses to climate and range shifts in fisheries. *Climatic Change* 115(3–4):883–891, <https://doi.org/10.1007/s10584-012-0599-x>.
- Reygondedeau, G., and G. Beaugrand. 2011. Future climate-driven shifts in distribution of *Calanus finmarchicus*. *Global Change Biology* 17(2):756–766, <https://doi.org/10.1111/j.1365-2486.2010.02310.x>.
- Vanderlaan, A.S., and C.T. Taggart. 2009. Efficacy of a voluntary area to be avoided to reduce risk of lethal vessel strikes to endangered whales. *Conservation Biology* 23(6):1,467–1,474, <https://doi.org/10.1111/j.1523-1739.2009.01329.x>.
- van der Hoop, J.M., M.J. Moore, S.G. Barco, T.V. Cole, P.Y. Daoust, A.G. Henry, D.F. McAlpine, W.A. McLellan, T. Wimmer, and A.R. Solow. 2013. Assessment of management to mitigate anthropogenic effects on large whales. *Conservation Biology* 27(1):121–133, <https://doi.org/10.1111/j.1523-1739.2012.01934.x>.

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