UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF COLUMBIA

CENTER FOR BIOLOGICAL DIVERSITY, *et al.*, *Plaintiffs*, v. GINA RAIMONDO, *et al.*, *Federal Defendants*, and MAINE LOBSTERMEN'S ASSOCIATION, INC., *et al.*, *Defendant-Intervenors*.	Civil Action No. 18-112 (JEB)

DECLARATION OF KRISTEN MONSELL

I, Kristen Monsell, declare as follows:

1. I am counsel for Plaintiffs in this case.

2. Exhibit 1 is a true and correct copy of excerpts of a page on the National Marine Fisheries Service's ("NMFS") website titled "North Atlantic Right Whale: Road to Recovery" last updated on August 9, 2022. I obtained a copy via the agency's website here: https://www.fisheries.noaa.gov/species/north-atlantic-right-whale#road-recovery.

3. Exhibit 2 is a true and correct copy of excerpts of the New England Aquarium's "North Atlantic Right Whale Consortium 2021 Annual Report Card." I obtained a copy here: https://www.narwc.org/uploads/1/1/6/6/116623219/2021report_cardfinal.pdf.

4. Exhibit 3 is a true and correct copy of excerpts of NMFS's 2021 Stock

Assessment Report for the North Atlantic Right Whale finalized in May 2022. I obtained a copy via the agency's website here: https://media.fisheries.noaa.gov/2022-08/N%20Atl%20Right%20Whale-West%20Atl%20Stock_SAR%202021.pdf.

5. Exhibit 4 is a true and correct copy of excerpts of a presentation NMFS gave to the Atlantic Large Whale Take Reduction Team during a Team meeting held on November 2, 2021. I obtained a copy via the agency's website here: https://media.fisheries.noaa.gov/2021-11/Nov%202%20presentation%20to%20ALWTRT.pdf.

1. Exhibit 5 is a true and correct copy of a NMFS memorandum to file on the "Endangered Species Act Consultation on the Continued Operation of the "Batched" Fisheries in the Greater Atlantic Region" dated October 28, 2020. The document is part of the administrative record in this case.

2. Exhibit 6 is a true and correct copy of excerpts of NMFS's 2019 Stock Assessment Report for the North Atlantic Right Whale dated April 2020. I obtained a copy via the agency's website here: https://media.fisheries.noaa.gov/dam-migration/2019_sars_atlantic_northatlanticrightwhale.pdf. The document is also part of the administrative record in this case.

3. Exhibit 7 is a true and correct copy of a scientific study published February 2021 titled "Cryptic mortality of North Atlantic right whales." I obtained a copy here: https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/csp2.346. The study is also part of the administrative record in this case.

4. Exhibit 8 is a true and correct copy of excerpts of Plaintiffs' March 2021 comment letter to NMFS on the proposed rule to amend the Atlantic Large Whale Take Reduction Plan. The document is part of the administrative record in this case.

5. Exhibit 9 is a true and correct copy of excerpts of the Marine Mammal Commission's March 2021 comments on the proposed rule to amend the Atlantic Large Whale Take Reduction Plan. The document is part of the administrative record in this case. The document is also available on the Commission's website here: https://www.mmc.gov/wp-content/uploads/21-03-01-Pentony-2021-NARW-TRP-Amendment-Rule.pdf.

6. Exhibit 10 is a true and correct copy of the Georgia Department of Natural Resources' February 2021 comments on NMFS's draft biological opinion. The document is part of the administrative record in this case.

7. Exhibit 11 is a true and correct copy of excerpts of the New England Aquarium's March 2021 comments on the proposed rule to amend the Atlantic Large Whale Take Reduction Plan. I obtained a copy via the Aquarium's website here: http://www.neaq.org/wp-content/uploads/2021/03/NEAq_NOAA-NMFS-2020-0031-0006_FINAL_0321.pdf.

8. Exhibit 12 is a true and correct copy of excerpts of the New England Aquarium's comments on NMFS's draft biological opinion. I obtained a copy via the Aquarium's website here: http://www.neaq.org/wp-content/uploads/2021/03/NEAq_Comment-on-Draft-Biological-Opinion_0221_FINAL.pdf.

9. Exhibit 13 is a true and correct copy of excerpts of a presentation NMFS gave to the Atlantic Large Whale Take Reduction Team during a Team meeting held on May 9, 2022. I obtained a copy via the agency's website here: https://media.fisheries.noaa.gov/202205/May92022Presentation_ALWTRT_GARFO.pdf

10. Exhibit 14 is a true and correct copy of a 2021 scientific paper titled "Decreasing body lengths in North Atlantic right whales" and published in Current Biology. I obtained a copy here: https://www.cell.com/current-biology/fulltext/S0960-9822(21)00614-X.

11. Exhibit 15 is a true and correct copy of a 2022 scientific paper titled "Larger females have more calves: influence of maternal body length on fecundity in North Atlantic right whales" and published in Marine Ecology Progress Series. I obtained a copy here: https://www.int-res.com/abstracts/meps/v689/p179-189/.

12. Exhibit 16 is a true and correct copy of a 2022 scientific paper titled "Vertical Line Requirements and North Atlantic Right Whale Entanglement Risk Reduction for the Gulf of Maine American Lobster Fishery" and published in Marine and Coastal Fisheries. I obtained a copy here: https://afspubs.onlinelibrary.wiley.com/doi/full/10.1002/mcf2.10203.

13. Exhibit 17 is a true and correct copy of excerpts from a NMFS report issued in July 2022 and titled "Draft Ropeless Roadmap A Strategy to Develop On-Demand Fishing." I obtained a copy via the agency's website here: https://media.fisheries.noaa.gov/2022-07/RopelessRoadmapDRAFT-NEFSC.pdf.

14. Exhibit 18 is a true and correct copy of a page on NMFS's website titled "North Atlantic Right Whale Calving Season 2022" last updated on June 26, 2022. I obtained a copy via the agency's website here: https://www.fisheries.noaa.gov/national/endangered-species-conservation/north-atlantic-right-whale-calving-season-2022.

15. Exhibit 19 is a true and correct copy of excerpts of a page on NMFS's website titled "10 Things You Should Know About North Atlantic Right Whales" and published on October 17, 2019. I obtained a copy via the agency's website here: https://www.fisheries.noaa.gov/feature-story/10-things-you-should-know-about-north-atlantic-right-whales.

Pursuant to the laws of the District of Columbia and of the United States of America, I declare under penalty of perjury that the foregoing is true and correct.

Executed on August 12, 2022, in Oakland, California.

/s/ *Kristen Monsell*
Kristen Monsell

EXHIBIT 1

NOAA FISHERIES

North Atlantic Right Whale

North Atlantic Right Whale

Eubalaena glacialis

Protected Status

ESA ENDANGERED
Throughout Its Range

CITES APPENDIX I
Throughout Its Range

MMPA PROTECTED
Throughout Its Range

MMPA DEPLETED
Throughout Its Range

Quick Facts

WEIGHT	Up to 140,000 pounds
LENGTH	Up to 52 feet
LIFESPAN	Up to 70 years
THREATS	Changes in distribution and availability of prey, Climate change, Entanglement in fishing gear, Habitat degradation, Ocean noise, Small population size, Vessel strikes

Stay 500 Yards Away

To protect right whales, NOAA Fisheries has regulations that prohibit approaching or remaining within 500 yards (1,500 feet) of a right whale—500 yards is the length of about five football fields. These regulations apply to vessels and aircrafts (including drones) and to people using other watercrafts, such as surfboards, kayaks, and jet skis. Any vessel within 500 yards of a right whale must depart immediately at a safe, slow speed.
Call the NOAA Fisheries Enforcement Hotline at **(800) 853-1964** to report a federal marine resource violation. This hotline is available 24 hours a day, 7 days a week for anyone in the United States.

Learn more about our marine life viewing guidelines ›

Report Marine Life in Distress

Report a sick, injured, entangled, stranded, or dead animal to make sure professional responders and scientists know about it and can take appropriate action Numerou organization around the country are trained and ready to respond. Never approach or try to save an injured or entangled animal yourself—it can be dangerous to both the animal and you.
Learn who you should contact when you encounter a stranded or injured marine animal ›

Be Informed and Get Involved

Stay updated on right whale take reduction and other conservation measures. For accurate information, check your ource or confirm them by reviewing our new and announcement Participate in public meetings and share your perspectives with Take Reduction Team members who represent your constituency.

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Last updated by NOAA Fisheries on 08/09/2022

Last updated by NOAA Fisheries on 08/09/2022

Road to Recovery

Endangered North Atlantic right whales are approaching extinction. The latest preliminary estimate indicates there are fewer than 350 individuals remaining and less than 100 breeding females. Primary threats to the species are entanglement in fishing gear and vessel strikes. Climate change is also affecting every aspect of their survival—changing their ocean habitat, their migratory patterns, the location and availability of their prey, and even their risk of becoming entangled in fishing gear or struck by vessels.

The *North Atlantic Right Whale Road to Recovery* describes NOAA Fisheries' efforts to halt the current population decline and recover the species. It is built on the foundation of the statutory requirements that we are charged with implementing under the Endangered Species Act and the Marine Mammal Protection Act. It shows how our collective actions, in collaboration with partners, fit together to save this iconic species. The strategy complements the North Atlantic right whale 2021–2025 Priority Action Plan by identifying our goals and related objectives, and by tracking and communicating progress on major activities and associated milestones, examples of which are given below. The *Road to Recovery* is a living information resource and will be updated regularly.

The Road to Recovery has two related goals: (1) Address Threats to the Species and (2) Monitor Recovery Progress. Under Address Threats to the Species, there are three objectives: (1.1) Address Vessel Strikes, (1.2) Address Fishing Gear Entanglements, and (1.3) Address Potential and Emerging Threats, including impacts from climate change, new and expanded ocean uses, and ocean noise. Under Monitor Recovery Progress, the three objectives are: (2.1) Monitor Population and Health, (2.2) Monitor Threats, and (2.3) Monitor Effectiveness of Conservation. Our stewardship responsibilities under the Endangered Species Act and Marine Mammal Protection Act form the foundation of the Road to Recovery.

The efforts that pave the way on the *Road to Recovery* are only possible with the support and collaboration of many partners, such as the Marine Mammal Commission and Canada (see the 2021-2025 Priority Action Plan and Recovery Plan).

Goal: Address Threats to the Species

For endangered North Atlantic right whales to recover, we must address existing and emerging threats to the species. To achieve this goal, the *Road to Recovery* focuses on three objectives: address vessel strikes, address fishing gear entanglements, and address potential and emerging threats, including impacts from climate change, new and expanded ocean uses, and ocean noise.

Vessel Strikes

EXHIBIT 2

North Atlantic Right Whale Consortium
2021 Annual Report Card

Pettis, H.M.[1], Pace, R.M. III[2], Hamilton, P.K.[1]

[1] *Anderson Cabot Center for Ocean Life at the New England Aquarium, Central Wharf, Boston, MA, USA 02110*
[2] *Grizzlywhaler Consulting Services, 137 W. Pelham Road, Shutesbury, MA 10702*

NORTH ATLANTIC RIGHT WHALE CONSORTIUM BACKGROUND

The North Atlantic right whale (*Eubalaena glacialis*) remains one of the most endangered large whales in the world. Over the past two decades, there has been increasing interest in addressing the problems hampering the recovery of North Atlantic right whales by using innovative research techniques, new technologies, analyses of existing databases, and enhanced conservation and education strategies. This increased interest demanded better coordination and collaboration among all stakeholders to ensure that there was improved access to data, research efforts were not duplicative, and that findings were shared with all interested parties. The North Atlantic Right Whale Consortium, initially formed in 1986 by five research institutions to share data among themselves, was expanded in 1997 to address these greater needs. Currently, the Consortium membership is comprised of representatives from more than 100 entities including: research, academic, and conservation organizations; shipping and fishing industries; whale watching companies; technical experts; United States (U.S.) and Canadian Government agencies; and state authorities.

The Consortium membership is committed to long-term research and management efforts, and to coordinating and integrating the wide variety of databases and research efforts related to right whales to provide the relevant management, academic, and conservation groups with the best scientific advice and recommendations on right whale conservation. The Consortium is also committed to sharing new and updated methods with its membership, providing up-to-date information on right whale biology and conservation to the public, and maintaining effective communication with U.S. and Canadian Government agencies, state authorities, the Canadian Right Whale Network, the U.S. Southeast and Northeast Right Whale Implementation Teams, the Atlantic Large Whale Take Reduction Team, the Atlantic Scientific Review Group, and members of the U.S. Congress. The Consortium membership supports the maintenance and long-term continuity of the separate research programs under its umbrella, and serves as executor for database archives that include right whale sightings and photo-identification data contributed by private institutions, government scientists and agencies, and individuals. Lastly, the Consortium is interested in maximizing the effectiveness of management measures to protect right whales, including using management models from other fields.

The Consortium is governed by an Executive Committee and Board members who are elected by the general Consortium Membership at the Annual Meeting.

North Atlantic Right Whale Consortium members agreed in 2004 that an annual "report card" on the status of right whales would be useful. This report card includes updates on the status of the cataloged population, mortalities and injury events, and a summary of management and research efforts that have occurred over the previous 12 months. The Board's goal is to make public a summary of current research and management activities, as well as provide detailed recommendations for future activities. The Board views this report as a valuable asset in assessing the effects of research and management over time.

ESSENTIAL SPECIES MONITORING AND PRIORITIES

In the 2009 Report Card to the International Whaling Commission (IWC), the Consortium Board identified key monitoring efforts that must be continued and maintained in order to identify trends in the species, as well as assess the factors behind any changes in these trends (Pettis, 2009). As right whale distributions change and emerging The key efforts are: (1) Photographic identification and cataloging of right whales in historically and emerging high-use habitats and migratory corridors, which currently includes, but is not limited to, the southeast United States, Cape Cod Bay, Gulf of St. Lawrence, Great South Channel, southern New England, Bay of Fundy, Scotian Shelf, and Jeffreys Ledge, (2) Monitoring of scarring and visual health assessment from photographic data, (3) Examination of all mortalities, and (4) Continue using photo-ID and genetic profiling to monitor species structure and how this changes over time.

The Pace et al. (2017) estimate for 2020 is **336 whales** (95% confidence range +/- 14) using data as of September 7, 2021. This estimate represents an 8% decline over the 2019 estimate. It should be noted that data from 2020 were still coming in when the data were exported for this analysis, so it is possible that the estimate will change once those data are complete. Any changes will be reflected in next year's report.

Figure 1. Assessments of the North Atlantic right whale population 1990-2020. Annual assessments are shown by a point "estimate" along with error bars which represent 95% of the posterior probability. The model estimates the number of whale alive *at the start* of each year plus any new whales estimated to enter during that year. The estimate for 2020 was 336 +/- 14. Data from the North Atlantic Right Whale Catalog as of September 7, 2021.

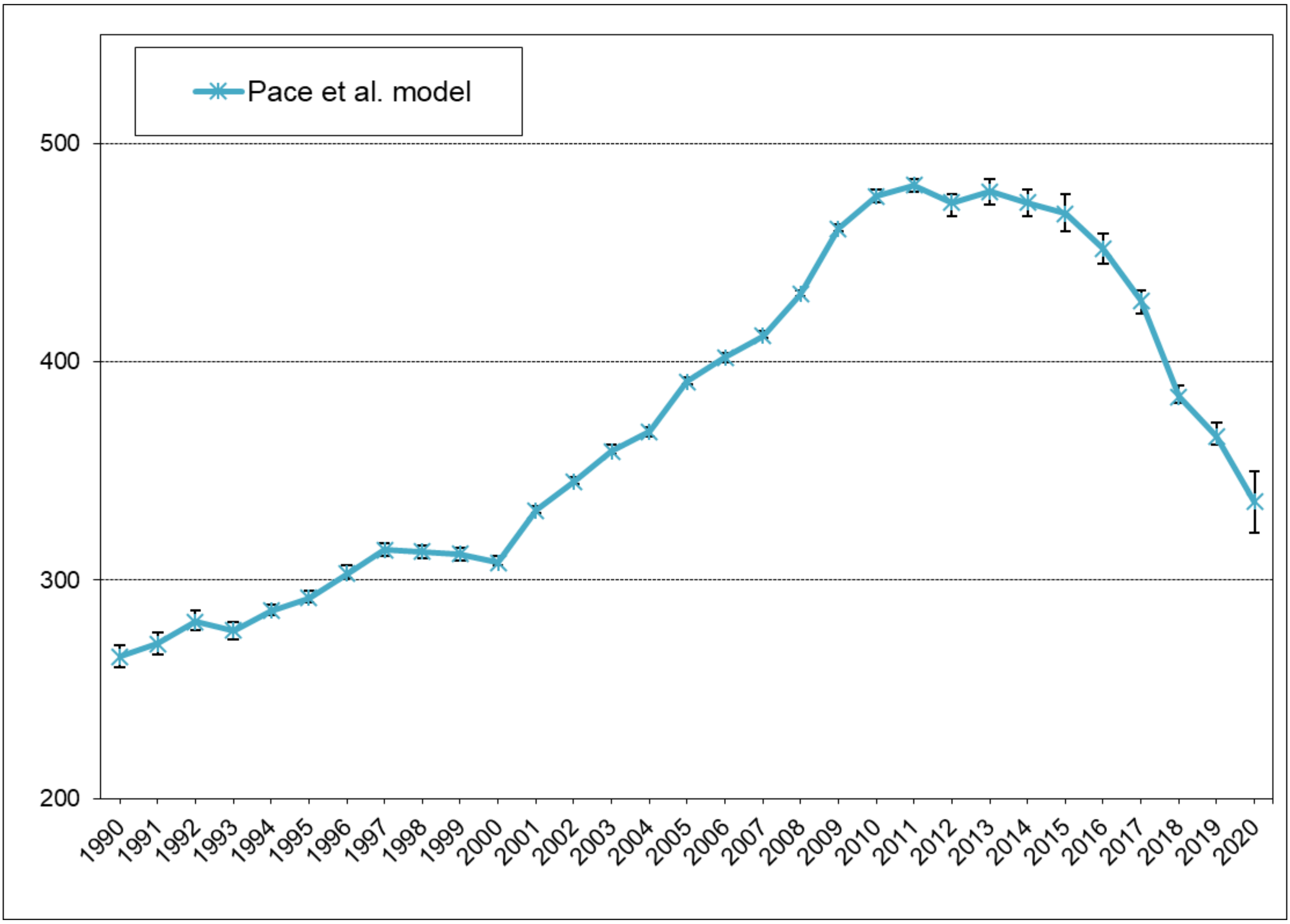


EXHIBIT 3

NORTH ATLANTIC RIGHT WHALE (*Eubalaena glacialis*): Western Atlantic Stock

STOCK DEFINITION AND GEOGRAPHIC RANGE

The western North Atlantic right whale population ranges primarily from calving grounds in coastal waters of the southeastern U.S. to feeding grounds in New England waters and the Canadian Bay of Fundy, Scotian Shelf, and Gulf of St. Lawrence (Figure 1). Mellinger *et al.* (2011) reported acoustic detections of right whales near the nineteenth-century whaling grounds east of southern Greenland, but the number of whales and their origin is unknown. Knowlton *et al.* (1992) reported several long-distance movements as far north as Newfoundland, the Labrador Basin, and southeast of Greenland. Resightings of photographically identified individuals have been made off Iceland, in the old Cape Farewell whaling ground east of Greenland (Hamilton *et al.* 2007), in northern Norway (Jacobsen *et al.* 2004), in the Azores (Silva *et al.* 2012), and off Brittany in northwestern France (New England Aquarium unpub. catalog record). These long-range matches indicate an extended range for at least some individuals. Records from the Gulf of Mexico (Moore and Clark 1963; Schmidly *et al.* 1972; Ward-Geiger *et al*. 2011) represent individuals beyond the primary calving and wintering ground in the waters of the southeastern U.S. East Coast. The location of much of the population is unknown during much of the year.

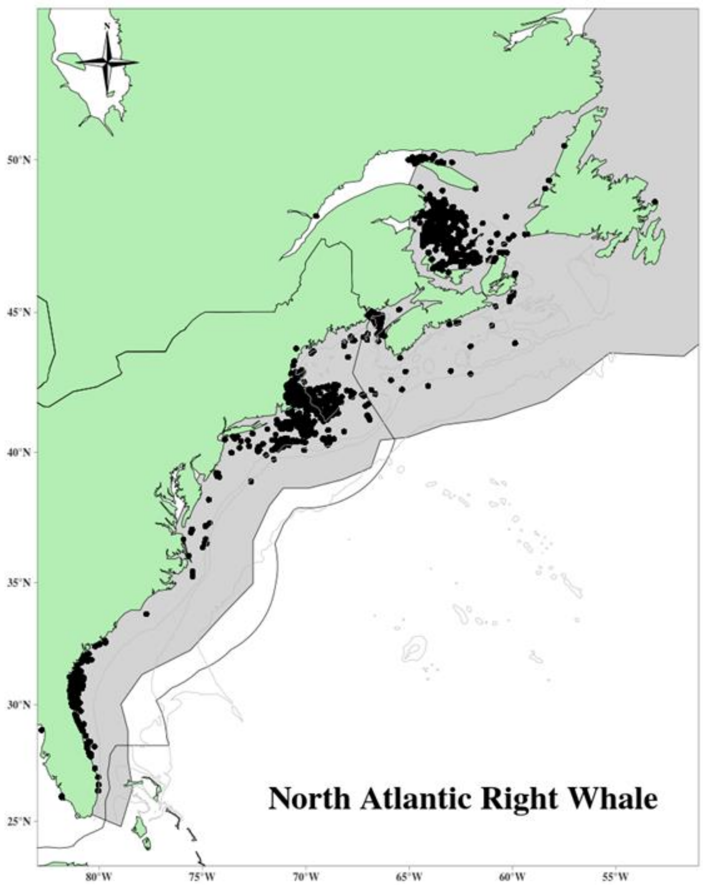


Figure 1. Approximate range (shaded area) and distribution of sightings (dots) of known North Atlantic right whales 2015–2019.

Passive acoustic studies of right whales have demonstrated their year-round presence in the Gulf of Maine (Morano *et al*. 2012; Bort *et al*. 2015), New Jersey (Whitt *et al*. 2013), and Virginia (Salisbury *et al*. 2016). Additionally, right whales were acoustically detected off Georgia and North Carolina in 7 of 11 months monitored (Hodge *et al*. 2015). Davis *et al*. (2017) recently pooled together detections from a large number of passive acoustic devices and documented broad-scale use of the U.S. eastern seaboard during much of the year. In Canada, Simard *et al*. (2019) documented the frequency of right whale contact calls in the Gulf of St. Lawrence from June 2010 to November 2018 using a year-round passive acoustic network. Acoustic detections indicated right whale presence every year. The earliest detections were at the end of April and the latest in mid-January, with peak occurrence between August and the end of October. Detections were focused in the southern Gulf, and daily detection rates quadrupled at listening stations off the Gaspé Peninsula beginning in 2015.

Individuals' movements within and between habitats across the range are extensive. In 2000, one whale was photographed in Florida waters on 12 January, then again 11 days later (23 January) in Cape Cod Bay, less than a

POTENTIAL BIOLOGICAL REMOVAL

Potential biological removal (PBR) is the product of minimum population size, one-half the maximum net productivity rate and a recovery factor for endangered, depleted, threatened stocks, or stocks of unknown status relative to Optimum Sustainable Population (OSP; MMPA Sec. 3. 16 U.S.C. 1362; Wade and Angliss 1997). The recovery factor for right whales is 0.1 because this species is listed as endangered under the Endangered Species Act (ESA). The minimum population size is 364. The maximum productivity rate is 0.04, the default value for cetaceans. PBR for the western North Atlantic stock of the North Atlantic right whale is 0.7 (Table 1).

ANNUAL HUMAN-CAUSED SERIOUS INJURY AND MORTALITY

For the period 2015 through 2019, the annual detected (i.e. observed) human-caused mortality and serious injury to right whales averaged 7.7 (Table 2). This is derived from two components: 1) incidental fishery entanglement records at 5.7 per year, and 2) vessel strike records averaging 2.0 per year.

Injury determinations are made based upon the best available information; these determinations may change with the availability of new information (Henry *et al.* 2022). Only records considered to be confirmed human-caused mortalities or serious injuries are reported in the observed mortality and serious injury (M/SI) rows of Table 2.

Annual rates calculated from detected mortalities are a negatively-biased accounting of human-caused mortality; they represent a definitive lower bound. Detections are irregular, incomplete, and not the result of a designed sampling scheme. Research on other cetaceans has shown the actual number of deaths can be several times higher than observed (Wells *et al.* 2015; Williams *et al*. 2011). The hierarchical Bayesian, state-space model used to estimate North Atlantic right whale abundance (Pace *et al.* 2017) can also be used to estimate total mortality. The estimated annual rate of total mortality using this modeling approach is 27.4 animals for the period 2014–2018 (Pace *et al.* 2021). This estimated total mortality accounts for detected mortality and serious injury (injuries likely to lead to death), as well as undetected (cryptic) mortality within the population. Figure 5 shows the estimates of total mortality for 1990–2018 from the state-space model. Using the methods of Pace *et al.* 2021, the detection rate of mortality and serious injury for the 5-year period 2014–2018 was 29.7% of the model's annual mortality estimates, which is 3.4 times larger than the 8.15 total detected mortalities and serious injuries during 2014–2018. The estimated mortality for 2019 is not yet available because it is derived from a comparison with the population estimate for 2020, which, in turn, is contingent on the processing of all photographs collected through 2020 for incorporation into the state-space model of the sighting histories of individual whales. An analysis of right whale mortalities between 2003 and 2018 found that of the examined non-calf carcasses for which cause of death could be determined, all mortality was human-caused (Sharpe *et al.* 2019). Based on these findings, 100% of the estimated mortality of 27.4 animals per year is assumed to be human-caused. This estimate of total annual human-caused mortality may be somewhat positively biased (i.e., a slight overestimate) given that some calf mortality is likely not human-caused.

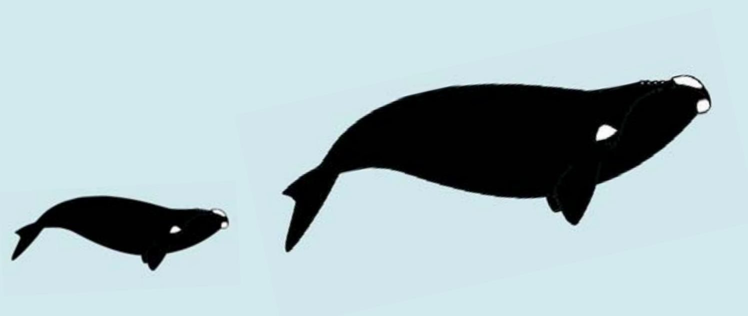
There is currently insufficient information to apportion the estimated total right whale mortality by country, e.g., occurring in U.S. versus Canadian waters. Apportioning the estimated total right whale mortality by cause, e.g., entanglement versus vessel collision, also remains uncertain at this time. Pace *et al.* (2021) suggest that entanglements account for more than twice the number of cryptic deaths compared to vessel collisions based on the preponderance of entanglement serious injuries; from 1990 to 2017, NMFS determined a total of 62 right whales were seriously injured, and of these 54 (87%) were due to entanglement. However, during the same period, of 41 right whale carcasses examined for cause of death, 21 (51%) were attributed to vessel collision and 20 (49%) to entanglement. Moore *et al.* (2004) and Sharpe *et al.* (2019) suggest that the underrepresentation of entanglement deaths in examined carcasses may be the result of weight loss in chronically entangled whales, who can become negatively buoyant and sink at the time of death, whereas whales killed instantly by vessel collision may remain available for detection for a longer period and are more likely to be recovered for examination. Both Pace *et al*. (2021) and Moore *et al*. (2020) recommend continued research into the potential mechanisms creating the disparity between apparent causes of serious injuries and necropsy results.

EXHIBIT 4

Informational Webinar: Update on Right Whale Population and Mortality Estimates

Atlantic Large Whale Take Reduction Team Webinar

November 2, 2021



Marisa Trego
Kara Shervanick
Jen Goebel
Crystal Franco
Chao Zou
Colleen Coogan

Atlantic Large Whale Take Reduction Plan Website

NOAA FISHERIES

Risk reduction calculations

Use the observed M/SI ratio to apportion the total mortality estimate produced by the Pace MRR model. Across three assumptions: 50%, 40%, or 30% US.

Country Apportionment	(a) PBR - draft 2021 SAR	(b) Annual average estimated mortality for 2015-2019	(c) Assumed US proportion	(d) US mortality based on country assumption (b*c)	(e) US mortality - 70% EN Observed M/SI for 2016-2020 (d* 0.70)	(f) % Reduction Needed for US to achieve PBR assuming 70% is EN ((e-a)/e)
50% US/ 50% CAN	0.7	31.4	0.50	15.7	11	**93.6%**
40% US/ 60% CAN			0.40	12.6	8.8	**92.0%**
30% US/ 70% CAN			0.30	9.4	6.6	**89.4%**

NOAA FISHERIES

Risk reduction calculations

Use the observed M/SI ratio to apportion the total mortality estimate produced by the Pace MRR model. Across three assumptions: 50%, 40%, or 30% US.

Country Apportionment	(a) PBR - draft 2021 SAR	(b) Annual average estimated mortality for 2015-2019	(c) Assumed US proportion	(d) US mortality based on country assumption (b*c)	(e) US mortality - 70% EN Observed M/SI for 2016-2020 (d* 0.70)	(f) % Reduction Needed for US to achieve PBR assuming 70% is EN ((e-a)/e)
50% US/ 50% CAN	0.7	31.4	0.50	15.7	11	93.6%
40% US/ 60% CAN			0.40	12.6	8.8	92.0%
30% US/ 70% CAN			0.30	9.4	6.6	89.4%

To be at PBR level, those 11 assumed US entanglements would need to be reduced by 10.3 or ~94%.

$$\frac{11 - 0.7}{11} = 93.6\%$$

NOAA FISHERIES

EXHIBIT 5

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
GREATER ATLANTIC REGIONAL FISHERIES OFFICE
55 Great Republic Drive
Gloucester, MA 01930

MEMORANDUM FOR: The File

FROM: Ellen Keane
Biologist
KEANE.ELLEN.P.1263827330 Digitally signed by KEANE.ELLEN.P.1263827330 Date: 2020.10.28 13:09:04 -04'00'

SUBJECT: Endangered Species Act Consultation on the Continued Operation of the "Batched" Fisheries in the Greater Atlantic Region

NOAA Fisheries' Protected Resources Division (PRD) is currently conducting an interagency Endangered Species Act section 7 consultation with the Sustainable Fisheries Division (SFD) on the continued operation of fisheries managed under eight federal and two interstate fishery management plans and the implementation of the New England Fisheries Management Council's Omnibus Essential Fish Habitat Amendment 2. The fisheries included in this consultation are the American lobster, Jonah crab, Atlantic bluefish, Atlantic deep-sea red crab, Atlantic mackerel/squid/butterfish, monkfish, Northeast multispecies, Northeast skate complex, spiny dogfish, and summer flounder/scup/black sea bass fisheries.

PRD has been working with SFD throughout this process to ensure that we are appropriately defining the proposed action. Given the declining status of the North Atlantic right whale, we recognize that these federal fisheries will need to continue to reduce their impact on the species over time to meet both Endangered Species Act and Marine Mammal Protection Act mandates.

With respect to how the fixed gear fisheries interact with North Atlantic right whales and the impacts of the fisheries on the species, we developed an option (referred to as the Conservation Framework) which would set targets for reducing serious injury and mortality of right whales in the federal fisheries and be considered as part of the proposed action. Consistent with common practice for developing information related to protected species interactions in fisheries, the draft Conservation Framework was developed by staff in PRD given their expertise. The draft was shared with SFD and multiple other staff for their input and to ensure it is accurate. During these discussions, we received the preliminary updated population estimate (366 individuals; 95% credible interval range of 353-377), which is considerably lower than previous estimates, from the Northeast Fisheries Science Center. We are currently reviewing this new information with respect to the ongoing consultation and will continue to work with the action agency on the appropriate targets and timelines to be considered.

EXHIBIT 6

NORTH ATLANTIC RIGHT WHALE (*Eubalaena glacialis*): Western Atlantic Stock

STOCK DEFINITION AND GEOGRAPHIC RANGE

The western North Atlantic right whale population ranges primarily from calving grounds in coastal waters of the southeastern U.S. to feeding grounds in New England waters and the Canadian Bay of Fundy, Scotian Shelf, and Gulf of St. Lawrence. Mellinger *et al.* (2011) reported acoustic detections of right whales near the nineteenth-century whaling grounds east of southern Greenland, but the number of whales and their origin is unknown. However, Knowlton *et al.* (1992) reported several long-distance movements as far north as Newfoundland, the Labrador Basin, and southeast of Greenland. In addition, resightings of photographically identified individuals have been made off Iceland, in the old Cape Farewell whaling ground east of Greenland (Hamilton *et al.* 2007), in northern Norway (Jacobsen *et al.* 2004), and in the Azores (Silva *et al.* 2012). The September 1999 Norwegian sighting represents one of only two published sightings in the 20th century of a right whale in Norwegian waters, and the first since 1926. Together, these long-range matches indicate an extended range for at least some individuals and perhaps the existence of important habitat areas not presently well described. A few published records from the Gulf of Mexico (Moore and Clark 1963; Schmidly *et al.* 1972; Ward-Geiger *et al*. 2011) likely represent occasional wanderings of individuals beyond the sole known calving and wintering ground in the waters of the southeastern U. S. The location of much of the population is unknown during the winter. Davis *et al.* (2017) recently pooled together detections from a large number of passive acoustic devices and documented broad-scale use of much more of the U.S. eastern seaboard than previously believed. Further, there has been an apparent shift in habitat use patterns (Davis *et al*. 2017). Surveys flown in an area from 31 to 160 km from the shoreline off northeastern Florida and southeastern Georgia since 1996 report the majority of right whale sightings occur within 90 km of the shoreline. One sighting occurred ~140 km offshore (NMFS unpub. data) and an offshore survey in March 2010 observed the birth of a right whale in waters 75 km off Jacksonville, Florida (Foley *et al.* 2011). Although habitat models predict that right whales are not likely to occur farther than 90 km from the shoreline (Gowan and Ortega-Ortiz 2015), the frequency with which right whales occur in offshore waters in the southeastern U.S. remains unclear.

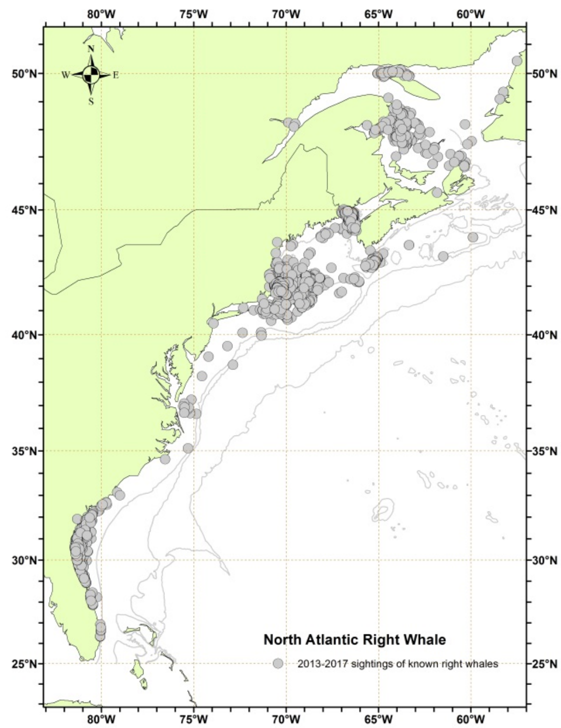


Figure 1. Distribution of sightings of known North Atlantic right whales, 2013-2017. Isobaths are the 100-m, 1000-m and 4000-m depth contours.

Visual and acoustic surveys have demonstrated the existence of seven areas where western North Atlantic right whales aggregate seasonally: the coastal waters of the southeastern U.S.; the Great South Channel; Jordan Basin; Georges Basin along the northeastern edge of Georges Bank; Cape Cod and Massachusetts Bays; the Bay of Fundy; and the Roseway Basin on the Scotian Shelf (Brown *et al*. 2001; Cole *et al.* 2013). Since 2013, increased detections and survey effort in the Gulf of St. Lawrence indicate right whale presence in late spring through early fall (Cole *et al.* 2016, Khan *et al.* 2016, 2018). Passive acoustic studies of right whales have demonstrated their year-round presence in the Gulf of Maine (Morano *et al.* 2012; Bort *et al.* 2015), New Jersey (Whitt *et al.* 2013), and Virginia (Salisbury *et al*. 2016). Additionally, right whales were acoustically detected off Georgia and North Carolina in 7 of 11 months whales correlated with satellite-derived sea-surface chlorophyll concentration (as a proxy for productivity), and calving rates correlated with chlorophyll concentration prior to gestation (Hlista *et al.* 2009). On a regional scale, observations of North Atlantic right whales correlate well with copepod concentrations (Pendleton *et al*. 2009). The available evidence suggests that at least some of the observed variability in the calving rates of North Atlantic right whales is related to variability in nutrition (Fortune *et al.* 2013) and possibly increased energy expenditures related to non-lethal entanglements (Rolland *et al.* 2016; Pettis *et al.* 2017; van der Hoop 2017).

An analysis of the age structure of this population suggests that it contains a smaller proportion of juvenile whales than expected (Hamilton *et al.* 1998; IWC 2001), which may reflect lowered recruitment and/or high juvenile mortality. Calf and perinatal mortality was estimated by Browning *et al.* (2010) to be between 17 and 45 animals during the period 1989 and 2003. In addition, it is possible that the apparently low reproductive rate is due in part to an unstable age structure or to reproductive dysfunction in some females. However, few data are available on either factor and senescence has not been documented for any baleen whale.

The maximum net productivity rate is unknown for this stock. For purposes of this assessment, the maximum net productivity rate was assumed to be the default value of 0.04. This value is based on theoretical modeling showing that cetacean populations may not grow at rates much greater than 4% given the constraints of their reproductive life history (Barlow *et al.* 1995). Single year production has exceeded 0.04 in this population several times, but those outputs are not likely sustainable given the 3-year minimum interval required between successful calving events and the small fraction of reproductively active females. This is likely related to synchronous calving that can occur in capital breeders under variable environmental conditions. Hence, uncertainty exists as to whether the default value is representative of maximum net productivity for this stock, but it is unlikely that it is much higher than the default.

POTENTIAL BIOLOGICAL REMOVAL

Potential biological removal (PBR) is the product of minimum population size, one-half the maximum net productivity rate and a recovery factor for endangered, depleted, threatened stocks, or stocks of unknown status relative to OSP (MMPA Sec. 3. 16 U.S.C. 1362; Wade and Angliss 1997). The recovery factor for right whales is 0.1 because this species is listed as endangered under the Endangered Species Act (ESA). The minimum population size is 418. The maximum productivity rate is 0.04, the default value for cetaceans. PBR for the Western Atlantic stock of the North Atlantic right whale is 0.8.

ANNUAL HUMAN-CAUSED SERIOUS INJURY AND MORTALITY

For the period 2013 through 2017, the minimum rate of annual human-caused mortality and serious injury to right whales averaged 6.85 per year. This is derived from two components: 1) incidental fishery entanglement records at 5.55 per year, and 2) vessel strike records at 1.3 per year. Early analyses of the effectiveness of the ship strike rule were reported by Silber and Bettridge (2012). Recently, van der Hoop *et al.* (2015) concluded that large whale mortalities due to vessel strikes decreased inside active seasonal management areas (SMAs) and increased outside inactive SMAs. Analysis by Laist *et al.* (2014) incorporated an adjustment for drift around areas regulated under the ship strike rule and produced weak evidence that the rule was effective inside the SMAs. When simple logistic regression models fit using maximum likelihood-based estimation procedures are applied to previously reported vessel strikes between 2000 and 2017 (Henry *et al.* 2020), there is no apparent trend (Fig 4). However, the odds of an entanglement event are now increasing by 6.3% per year.Although PBR analyses in this SAR reflect data collected through 2016, There were 17 right whale mortalities in 2017 (Daoust *et al.* 2017). This number exceeds the largest estimated mortality rate during the past 25 years. Further, despite high survey effort, only 5 and 0 calves were detected in 2017 and 2018, respectively. Therefore, the decline in the right whale population will continue for at least an additional 2 years.

EXHIBIT 7

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Cryptic mortality of North Atlantic right whales

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Abstract

Evaluations of the conservation status of the endangered North Atlantic right whale as well as many other wildlife species often rely extensively on counts and cause-of-death determinations of carcasses found accidentally or during dedicated surveys. Even when survey effort dedicated to a population is extensive, many deaths may go unseen. We used an abundance estimation model to derive estimates of cryptic mortality for North Atlantic right whales and found that observed carcasses accounted for only 36% of all estimated death during 1990–2017. We found strong evidence that total mortality varied over time, and that observed carcass counts were poor predictors of estimated annual numbers of whales dying. Importantly, there were substantial differences between fractions of deaths determined to be entanglement related during necropsy (49%) and the fraction of cryptic deaths suffering serious injuries related to entanglement (87%). Although we concluded that a single year's observations produced poor estimates of carcass detection rates due to the volatility of ratios of small counts, ratio estimates of data pooled over periods of consistent survey may offer better information on detection rates. Additionally, it appears unwise to consider cause of death determinations from detected carcasses as representative of cause-specific mortality rates in right whales given the large number of seriously injured whales from entanglement that are likely part of the unseen mortality.

KEYWORDS

carcass detection, cryptic mortality, detection bias, right whale, total mortality

1 | INTRODUCTION

The North Atlantic right whale, *Eubalaena glacialis*, is among the world's most endangered large whale populations (Reynolds, Marsh, & Ragen, 2009). The population at its recent peak numbered ∼500 individuals in 2010 (Pace, Corkeron, & Kraus, 2017) but has been declining since and at the start of 2018 numbers ∼400 (Pettis, Pace III, & Hamilton, 2020). The deaths of at least 17 individuals in 2017 (Davies & Brillant, 2019) and 10 more in 2019 has renewed concerns about recovery potential of this population (Kraus et al., 2016). Between 2003 and 2018, conclusions drawn from 38 of 44 (88%) necropsies conducted on right whales attributed death to human causes, namely collisions with vessels and entanglement in

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fishing gear (Moore, et al. 2004; Sharp, McLellan, Rotstein, et al., 2019).

The known deaths suggest that recovery of North Atlantic right whales is in serious jeopardy (Corkeron et al., 2018) unless substantial mitigation measures that reduce mortality and serious injury from human activities are instituted immediately (Kenney, 2018; Moore, 2014). But, these known deaths represent only a fraction of the true death toll, because counts of carcasses do not agree with the numbers of whales that disappear from long term sighting records. In the fisheries management literature, postrelease mortality of fish has been termed "cryptic mortality" (Coggins Jr, Catalano, Allen, Pine III, & Walters, 2007), and this term has been applied to human activities that kill marine mammals without resulting in an observed carcass. Several reference points have been developed that estimate the number of animals that can be removed from a marine mammal population each year while still achieving conservation objectives (e.g., Chilvers, 2008; Hammill & Stenson, 2007; Wade, 1998; Williams, Thomas, Ashe, Clark, & Hammond, 2016), but these all rely on unbiased calculations of mortality rates. For many smaller cetacean species, a bycatch mortality rate can be estimated from observers placed on a representative sample of fishing boats to document takes, which can then be scaled up to the fleet as a whole (Wade, 1998). The kinds of human activity resulting in major sources of mortality for many larger cetaceans do not lend themselves to estimation from dedicated observer coverage. Examples include bycatch in fixed gear and unattended fisheries, such as lobster or crab pots (Johnson et al., 2005), oil spills, or collisions with ships (Laist et al., 2001) Although these causes are readily detected in recovered carcasses, no sampling frameworks exist to infer their incidence rates.

Several factors interact to cause undercounting of human-caused mortalities of cetaceans. Generally speaking, in order for anthropogenic mortality to be detected, a whale carcass must float or strand, be detected by human observers before decomposition or scavenging occurs, be subject to an evaluation by a qualified veterinary pathologist to determine cause of death, and then have that result reported in the primary literature or in publicly accessible databases (Faerber & Baird, 2010). At any point along the time line from death to disintegration, information about the cause of mortality can be lost including even its occurrence. Herein, we distinguish between carcass "detection" (i.e., identifying an observed carcass to be a right whale and therefore a known death in the population regardless of whether it can be identified as a known individual), and carcass "recovery" (a term often used in studies of known individuals implying that the carcass has been identified to the list of known population members). Unless otherwise noted, we focus on carcass detection rates in this study.

Some studies have attempted to estimate carcass detection rates in a number of cetacean populations, and these studies reveal that the potential for underestimation of human-caused mortality is considerable. Two populations of resident, fish-eating killer whales (*Orcinus orca*) are found in the coastal waters of British Columbia (Canada) and Washington State (USA). The population is studied through an annual census. Between 1974 and 2008, only 3 and 20%, respectively, of the presumed deaths of northern and southern resident killer whales resulted in detected carcasses (Barbieri et al., 2013). In a relatively closed area, Wells et al. (2015) estimated dolphin carcass recovery rates as 33% in Sarasota Bay, FL. In a retrospective analysis inspired by the Deepwater Horizon oil spill, historic carcass detection rates in the northern Gulf of Mexico averaged 2% among 14 cetacean species (Williams, Gero, Bejder, et al., 2011). Some rare species had a carcass detection rate of 0%, and the sperm whale (*Physeter macrocephalus*, the largest whale in the study) had a detection rate of 3.4% (Williams et al., 2011).

A particularly data-rich study on a coastal population of bottlenose dolphins (*Tursiops truncatus*) revealed a carcass detection rate of 25% (95% CI = 20, 33%), and made the argument that observed (minimum) numbers of anthropogenic mortality of dolphins derived from strandings should be corrected to account for unobserved mortality (Carretta et al., 2016). This careful analysis led to a policy change for management of human activities affecting US Pacific coast dolphins. Now, US marine mammal stock assessment reports[1] for coastal bottlenose dolphins in California that report anthropogenic mortalities detected from beach-cast carcasses are multiplied by a factor of 4 to account explicitly for cryptic mortality.

A management focus merely on the number of detected carcasses will underestimate the severity of anthropogenic mortality, and consequently, the management response will fail to take into account the severity of the threats. Methods are needed to scale up the known mortality to estimate the total amount of human-caused mortality that must be mitigated to save endangered whales. An initial assessment of natural and human-caused mortality in North Atlantic right whales for the period 1980–1999 suggested a 17% carcass detection rate (Kraus, Brown, Caswell, et al., 2005), but increased search effort and stranding response funding in recent years would suggest a higher rate may apply now. Because the sighting rates of live right whales has varied over time (Pace et al., 2017), it stands to reason that carcass detection rate varies over time. Additionally, detectability of carcasses could be influenced by cause of death. For example, healthy whales struck by vessels likely float for longer periods and therefore may be detected at higher rates than chronically entangled animals that burn their fat stores for months as they slowly starve to death (Moore, Mitchell, Rowles, & Early, 2020). Additional analyses are needed to generate a robust multiplier that can be used in management (e.g., Carretta et al., 2016). Without a statistically robust multiplier, correction factors to account for imperfect carcass detection can result in estimates of mortality that exceed the size of the entire population (Parrish & Boersma, 1995).

Our study had three main objectives:

1. To estimate average carcass detection rates of North Atlantic right whales, and explore how this may have changed over time. Estimating this parameter will not affect our understanding of population dynamics, because detected and undetected mortality are already subsumed within the survival estimates (Pace et al., 2017). However, understanding the extent to which anthropogenic mortality is undercounted may alter our perspective of the potential scope for population recovery if precautionary mitigation measures were implemented broadly. We briefly explore two alternative estimators for detection rate over a specified time interval.
2. Explore the hypothesis that carcass detection may vary with cause of death. Evidence for differential carcass detection rates could change our understanding of the relative importance of the two main risk factors (i.e., collision with vessels and entanglement), and more accurate information could change the emphasis placed on various mitigation measures.
3. Our long-term objective is to stimulate a discussion at the science-policy interface on the need to improve the way that cryptic mortality is handled in management. Using the extremely data-rich case study of the North Atlantic right whale, we advocate developing multipliers to better account for cryptic mortality when assessing conservation status of marine mammal stocks (Carretta et al., 2016).

2 | METHODS

Three lines of inquiry were used to explore factors influencing carcass detection rates in North Atlantic right whales.

2.1 | The ratio of observed to estimated mortalities

Observed mortalities of right whales exist in two categories: (1) a discovered carcass that can be identified as a whale known to the North Atlantic Right Whale Catalog (Hamilton, Knowlton, & Marx, 2007) and (2) a discovered carcass that is not identifiable to individual either by photograph (position of carcass obscuring matching features or state of decomposition) or genetic fingerprint (no sample gathered or no match found).

Annual estimates of the total number of right whale deaths from 1990 to 2017 were generated from a previously published hierarchical state-space model of right whale abundance (Pace et al., 2017). The model to estimate abundance is parameterized to yield posterior distributions of N_t and B_t, which are respectively, the abundance and numbers of new entrants (Births) to the population in year t. For each of 20,000 realizations in the Markov chain Monte Carlo run after initial burn-in, we calculated the estimated number of deaths according to the following formula:

$$D_t = N_t - N_{t+1} + B_t$$

where D_t is the number of deaths occurring in the interval $[t, t+1]$. We assumed that the derived values represented a posterior distribution for each D_t and calculated 95% highly credible regions for each estimate. We further assume that the population is closed to permanent emigration, which seems well supported by the long study period and the lack of evidence of right whale being resident in other parts of the North Atlantic. We calculated an additional total mortality estimate from abundance estimates from the aforementioned model and detected calf counts according to:

$$D_{total} = N_{1990} - N_{2018} + C_{\Sigma(1990\ \ 2017)}$$

where $C_{\Sigma(1990–2017)} = 407$ was the total calf count during 1990–2017.

We fitted generalized linear models (GLMs) to examine whether or not the observed number of carcasses were predictive of estimated median number of deaths each year. Candidate models included: constant estimated death rate over time; a linear predictive relationship between annual carcass counts and annual estimated death count; a simple periodic variation in the estimated death count over three "eras" (1990–1991; 1992–2009; and 2010–2017); and a model with both era effect and observed carcass counts as predictors. The choice of eras was based on time frames of significant changes in search effort patterns and/or animal distributions, where the predictive value of carcass counts might vary with these changes. In particular, we believed that variable periods evident in the recapture rates of individuals was indicative of three eras that might have differing carcass detection rates. We estimated the relative effective detection effort as the mean adult female capture probability for the era.

2.2 | Cause of serious injuries and cause of death

Additionally, mortalities can be inferred for whales seen alive but declared seriously injured by the National Marine Fisheries Service (NMFS; Henry et al., 2017). These injured whales are often in poor health condition or suffering from complex entanglements that will interfere with foraging. Many are eventually presumed to have died as they commonly disappear from the sighting records within 1–2 years following their injury. We only counted whales as seriously injured the first year of their determined status and removed from the counts two whales that were determined to be seriously injured but appeared to recover. From first principles, it seems plausible that whales that become entangled and lose fat during the months it takes them to die may be less likely to be detected as carcasses if they sink soon after death, although Moore et al. (2020) show that carcasses that sink in shallower water are more likely to bloat and refloat. Conversely, healthy whales killed immediately by ship strikes would be more likely to float. It is impossible to test directly for differences in detection rate based on cause of death, precisely because one never sees the unobserved mortality. We explored the plausibility of this scenario using a subset of whales that were observed with serious injuries just prior to their disappearance (Henry et al., 2017; Knowlton, Hamilton, Marx, Pettis, & Kraus, 2012). Using data from New England Aquarium (NEAQ) and NMFS, we examined the fate of animals last seen with serious injuries arising from either fisheries gear entanglement or "other" (i.e., mostly consistent with blunt force trauma or fresh propeller wounds). We compared the frequency of occurrence of serious injuries from entanglement and other anthropogenic sources with sources of mortality determined from examined carcasses of noncalf animals. Causes of mortality for examined carcasses have been documented in Moore, Knowlton, Krauss, McLellan, and Bonde (2004) and Sharp et al. (2019). We note that a few animals may have been observed as serious injuries and later found dead but no link clearly establishing that it was the same individual. Because we are comparing the distributions of death causes, double counting in this instance would only act to reduce differences in distributions.

2.3 | Body condition and subsequent carcass recovery of known individuals

Each individual in the North Atlantic right whale catalog has a suite of health records over its sighting history, each of which includes a visual estimate of body fat stores (Pettis et al., 2004). For 159 whales that were known (28) or presumed (131) to have died and had an assessment of body condition within 6 months of its last sighting, we modeled the probability that a carcass would be recovered as a function of visual body condition. The rationale was that whales observed to be skinny just before death could act as a proxy for entangled whales that took several months to die (Pettis et al., 2017), whereas whales with healthy fat stores just before their death could act as a proxy for whales that were struck by a ship and died immediately with fat reserves intact (Moore et al., 2020).

We fitted a binomial GLM to the fate of each individual whale, whose carcass was either recovered (1) or not recovered (0), using body fat condition as a candidate covariate. Statistical support for including the covariate was estimated by comparing AIC of this model to an intercept-only model.

3 | RESULTS

3.1 | Magnitude of cryptic mortality

When compared with the derived estimates of total mortality from the abundance model (Pace et al., 2017) extended to produce estimates for 1990–2017, counts of carcasses seriously underrepresented total right whale mortality (Figure 1). During this period, the number of deaths derived from the abundance model was 2.8 times the carcass count.

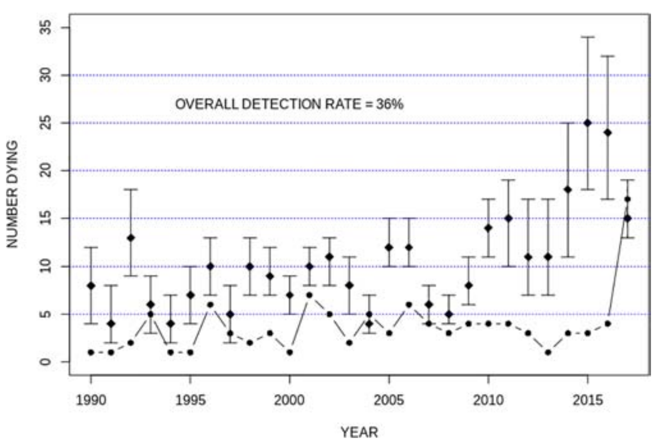

FIGURE 1 Counts (black dots) of right whale carcasses and total number of right whale deaths estimated from an abundance model (diamonds) together with their 95% credible intervals. Overall detection rate was the sum of carcass counts across the entire time frame divided by the sum of estimated deaths

TABLE 1 Information criteria generated from GLMs fit to estimated annual mortality of North Atlantic right whales

Model	Parameters count	AICc	Delta AICc	AICcWt
Era	3	151.0	0	0.79
Era + Carcass count	4	154.5	2.7	0.21
Carcass count	2	184.6	32.8	0
Constant	1	185.8	34.1	0

Note: Prior choice of models included (1) constant death count over time, (2) linear correspondence between observed carcasses estimates, (3) varying by different eras of survey effort or whale distribution a model, and (4) an additive model including 2 and 3. Models assumed data were Poisson and the three Eras were 1990 1991, 1992 2009, and 2010 2017.

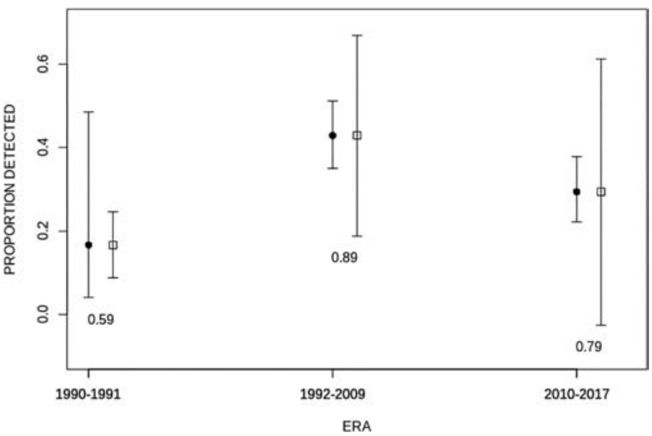

FIGURE 2 Variability in carcass detection rate in three periods that appear to correspond to changes in NARW distribution and search effort. Solid circles represent the retransformed predictions from the binomial GLM with Era as a categorical predictor accompanied by approximate 95% confidence bounds. Open squares are calculated as ratio estimates for each Era where Proportion detected Sum of observed/(Sum estimated total mortality for the period) mathematically equivalent to the GLM predicted values. Error bars are 1 standard error of each ratio estimates demonstrate the large variance among calculated annual detection ratios. Values below intervals are the Era specific means of estimated capture probability of adult females from the abundance model used to calculate total number of deaths

3.2 | The predictive ability of observed carcass counts

Comparison of four models used to evaluate the predictive value of annual carcass counts revealed that very little information about the number of right whales dying in a given year could be derived from carcass counts (Table 1). The model with the most support validated the higher undetected death tolls during 2010–2017 shown in Figure 1.

The overall estimate of carcass detection rate was 36%. Our GLM produced little support that annual counts of carcasses were predictive of annual mortality estimates (Table 1). However, when we pooled data from eras of more similar survey effort and whale distribution, a pattern of detection emerged that fit with our prior suspicions (Figure 2). When survey effort was lower for important whale use areas during 1990–1991, the ratio of detected carcasses was only 17% (2 s.e. = 5.5%). Detection increased significantly to 43% (2 s.e. = 0.6%) during a lengthy period of high whale recapture rate (1992–2009) and declined to 29% (2 s.e. = 2.8%) from 2010 to 2017 as whales changed their area use patterns and recapture rates declined.

TABLE 2 Likely cause of death distribution for noncalf North Atlantic right whales during 1990 2017 (excluding undetermined, *n* 3) from examined carcasses versus live animals declared as seriously injured by NMFS

Data source	Entanglement	Vessel collision
Carcass	20 (49%)	21 (51%)
Serious injury	54 (87%)	8 (13%)

Note: Chi sq. test for similar distributions between data sources X^2 16.1, *p* <.001.

3.3 | Cause of serious injuries and cause of death

From 1990 to 2017, a total of 62 North Atlantic right whales were reported by NMFS as having "serious injuries" that were defined as life-threatening, and subsequently disappeared. Entanglement accounted for the vast majority (54 of 62, or 87%) of serious injuries (Table 2). Because these whales were never seen again, one would also expect to see 87% of deaths to be caused by entanglement. Among 41 examined carcasses, only 49% of deaths were determined to be entanglement related. Assuming all of the "other" sources of serious injury or mortality of noncalf whales can be attributed to vessel collisions, there is a large disparity between the sets of observations ($X^2 = 16$, $p < .001$). This disparity suggests that it may be unreasonable to use the distribution of causes of death from examined carcasses to characterize the cryptic deaths.

3.4 | Body condition and subsequent carcass recovery of known individuals

The model with the highest information content based on AIC was one not relying on body condition to predict the probability of detection (AIC = 150.0). Using body fat condition at the time of the last sighting had little support from the data (AIC = 151.9; ΔAIC = 1.9 over an intercept-only model).

4 | DISCUSSION

Recent results from a hierarchical state-space model of North Atlantic right whale population dynamics (Pace et al., 2017) were integrated with data on animal health, encounters, necropsies, and serious injuries held by the North Atlantic Right Whale Consortium at the New England Aquarium (Hamilton et al., 2007; Pettis et al., 2004) or published literature (Moore et al., 2004; Sharp et al., 2019) with the serious injury and mortality database held by NMFS (Henry et al., 2017). Taken together, these data suggest that 36% of right whale deaths resulted in a carcass detection. Experts who have led the data collection efforts believe that changes in whale distribution and search effort by agencies on both sides of the Canada-US border may have changed carcass detection rates over time. By pooling data across relatively homogeneous periods of survey effort and whale distribution, we found modest deviations in carcass detection rates over time. The period of much lower effective searching (lower capture rates of live whales) produced a low estimated detection rate consistent with that reported by Kraus et al. (2005) using different methods to estimate total mortality. They estimated that the carcass detection rate was 17% based on data from 1980 to 1999 (Kraus et al., 2005). There appears to have been a large increase in detection rate to 43% during a period coincident with the highest estimated recapture rates of live whales reported by Pace et al. (2017), but the estimated value is still below half. In the most recent era, carcass detection rates have fallen off as whales spend less time in previously well surveyed areas.

Our analysis allows us to caution strongly against relying on a single year's count of carcasses to infer differing amounts of total mortality. These counts are usually small (<10) and hence widely varying relative to their mean. Despite our own cautionary note, we found it of interest that during 2017, a year of an unusually high carcass count coupled with a dramatic increase in Canadian survey effort to find carcasses, the number of dead found may have accounted for nearly every whale estimated to have died that year. This finding is clearly not indicative of the recent past, given that the overall detection rate during 2010–2017 was only 29%.

There is a striking mismatch between the causes of serious injuries observed in living whales and the causes of mortality revealed in necropsies of dead whales. Entanglement accounted for the vast majority (54 of 62, or 87%) of serious injuries, but only 20 of 41 (49%) of mortality in examined carcasses. Collisions with vessels and "other" causes represent 8 of 62 (13%) of serious injury cases, but represent 21 of 42 (51%) of mortalities in examined carcasses. We caution, however, that blunt force trauma incurred by whales that are seriously injured by a vessel collision may be difficult to detect from photographs of free swimming whale that may ultimately die as a result of the collision. Despite the possibility of missing some vessel collisions that produced serious injuries, the disparity in observed rates of serious injury by cause suggests that cryptic deaths due to entanglements significantly outnumbers cryptic deaths from vessel collisions or other causes. Although this dissonance could not be explained by a model of carcass detection as a function of visual body condition, the topic warrants continued research. If attempts are made to expand detected causes of mortality to total counts, detection rates should be calculated over a rolling time block to reduce the influence of any 1 year's values. Alternatively, estimated mortality values should be calculated over periods of homogeneous live right whale capture probabilities. Regardless, entanglement-related mortality is widely underestimated, which has important implications for management actions to promote recovery.

5 | CONCLUSION

The amount of cryptic mortality occurring over longer time intervals seem to vary with effective survey effort to finding live whales. The evidence surrounding whales not recovered following their likely deaths, suggests that cryptic deaths are more likely entanglement related than the record of examined carcasses indicates. As monitoring and managing the conservation status of North Atlantic right whales requires robust quantitative data, this study showed that total mortality was 2.8 times the number of detected carcasses during 1990–2017. Annual counts of right whale carcasses do a poor job of indicating the total mortality for that year, and carcass detection rates seem to vary with effective survey effort. The incidence rates among causes of mortality differs significantly between those examined carcasses from which a cause of death was determined, and those animals whose likely death followed a serious injury. The evidence surrounding whales not recovered following their likely deaths, suggests that cryptic deaths are almost twice as likely to be due to entanglements than the records from examined carcasses whales indicate.

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CONFLICT OF INTEREST

The authors have no conflicts of interests to declare.

AUTHOR CONTRIBUTIONS

Richard M. Pace and Rob Williams contributed equally to the analysis and writing of this paper and should be regarded as joint first authors. Scott D. Kraus helped focus the content, provided extensive edits, and access to data. Amy R. Knowlton and Heather M. Pettis compiled and extracted data and provided text and edits.

DATA AVAILABILITY STATEMENT

Data used to calculate total mortality and a table of known deaths by cause are available from RMP.

ETHICS STATEMENT

Data used in this manuscript were all collected using guidelines and permits provided by federal (US and Canadian) agencies which govern the ethical treatment of animals.

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ENDNOTE

[1] https://www.fisheries.noaa.gov/national/marine mammal protection/marine mammal stock assessment reports species stock

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EXHIBIT 8

• Center for Biological Diversity • Conservation Law Foundation •
• Defenders of Wildlife • Humane Society of the United States •
• Humane Society Legislative Fund •

Colleen Coogan
National Marine Fisheries Service
Northeast Regional Office
55 Great Republic Drive
Gloucester, MA 01930

March 1, 2021

via regulations.gov

Re: Proposed Rule to Amend Atlantic Large Whale Take Reduction Plan Regulations, 85 Fed. Reg. 86,878 (Dec. 31, 2020), and Draft Environmental Impact Statement NOAA-NMFS-2020-0031

Dear Ms. Coogan,

On behalf of the Center for Biological Diversity, Conservation Law Foundation, Defenders of Wildlife, the Humane Society of the United States, Humane Society Legislative Fund, and our millions of members and supporters, we submit these comments to the National Marine Fisheries Service (NMFS) on its proposed rule to amend the regulations implementing the Atlantic Large Whale Take Reduction Plan (Plan or ALWTRP) and associated Draft Environmental Impact Statement (DEIS).

As conservation members and alternates on the Atlantic Large Whale Take Reduction Team (Team), we have forcefully advocated for NMFS to fulfill its obligations under the Marine Mammal Protection Act[1] (MMPA) and Endangered Species Act[2] (ESA) to protect large whales covered by the Plan, especially the critically imperiled North Atlantic right whale. The history of the Plan is the history of NMFS's failure to meet these statutory mandates. The species and the fisheries now face the consequences of twenty-five years of agency denial and delay.

Since NMFS first promulgated the Plan in 1997, it has never complied with its MMPA obligation to bring mortalities and serious injuries (M/SI) in Category I and II fisheries to at or below the right whale's potential biological removal (PBR), to say nothing of the zero mortality rate goal (ZMRG). NMFS has been equally cavalier with its ESA obligations, tacitly allowing unlawful right whale take in both state and federal fisheries without consequences. On NMFS's watch, right whales don't die of old age.

Yet time and again NMFS has dragged its feet in amending and implementing the Plan. It has refused to finalize proposed regulations until compelled to do so by litigation. It has failed to

[1] 16 U.S.C. §§ 1361–1389.
[2] *Id.* §§ 1531–1544.

A. The Risk Reduction Targets are not based on the Best Scientific and Commercial Data Available

Nearly two years ago, NMFS provided the Atlantic Large Whale Take Reduction Team (TRT) with a 60-80% risk reduction goal based on 2016 population estimates and a PBR of 0.9. *Id.* at 3-47, 67. At the time, NMFS indicated that, if cryptic mortalities were included in its analysis, the average annual rate of serious injuries and mortalities from entanglement in U.S. fisheries was 4.3 and "would have to be reduced by about 80% in U.S. fisheries to get below the stock's PBR of 0.9." Since that time, NMFS has revised its population estimates and average annual rate of serious injuries and mortalities resulting from incidental entanglements in U.S. fishing gear. In its recently published draft BiOp , NMFS stated: "Using the methods in Pace et al. (2017), this year's preliminary estimate is 366 (95% credible interval range of 353-377) individuals as of January 2019."[6] Using 366 as the Nmin, PBR is now 0.7.[7] Table 57 of the draft BiOp estimates the annual average M/SI of right whales from U.S. fishery entanglements as 6.724.[8] Thus, **using NMFS's own methodology and updated data, the risk reduction target required to reduce M/SI in US fisheries is closer to 90%.**

The proposed rule needs to be revised to achieve M/SI below PBR (at minimum). That is especially true considering other new information, including an updated paper from Pace et al. (2021) that determined based on data from 2010 2017 that the observed mortality detection rate was only 29% of total mortality, leaving 71% of mortalities undetected,[9] and the estimate from the New England Aquarium that the number of right whales alive at the end of 2019 was only 356 individuals, as few as 70 of which were breeding females.[10]

B. The Gear Modifications Proposed to Reduce the Number of Vertical Lines Cannot Adequately Reduce Risk

The proposed rule describes 2 major gear modifications necessary to reduce the number of vertical lines in the Preferred Alternative: (1) increasing the number of traps on a trawl ("trawling up"); and (2) extending the maximum trawl length (distance between endlines) in LMA3. 85 Fed. Red. at 86,881. NMFS also analyzes capping line allocations at 50 percent of average monthly lines in federal waters in the DEIS for Alternative 3. *See* DEIS Vol. I at 1-7. We address each of these in turn.

1. <u>Trawling Up and Line Caps</u>

Every vertical line in the water increases entanglement risk for right whales. Trawling up is one method to reduce the number of vertical lines and could encourage efficiency. However, trawling up will only be guaranteed to reduce the number of vertical lines in the water (and thus risk) if it is combined with a line cap providing a concrete metric for reductions from the baseline. *See*

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[6] Draft BiOp.
[7] PBR = Nmin x 0.5 (Rmax) x Fr. In this case, 0.7 = 366 x 0.2 x 0.1.
[8] Draft BiOp.
[9] Pace, R. M. III et al. 2021. Cryptic mortality of North Atlantic right whales. Conservation Science and Practice. e346.
[10] New England Aquarium, Right Whale Consortium Releases 2020 Report Card Update, Nov. 9, 2020, https://www.andersoncabotcenterforoceanlife.org/blog/2020-narwc-report-card/.

EXHIBIT 9

MARINE MAMMAL COMMISSION

1 March 2021

Mr. Michael Pentony, Regional Administrator
Greater Atlantic Regional Fisheries Office
National Marine Fisheries Service
55 Great Republic Drive
Gloucester, MA 01930–2276

Subject: Comments on Proposed Amendments to the Atlantic Large Whale Take Reduction Plan

Dear Mr. Pentony:

On 31 December 2020, the National Marine Fisheries Service (NMFS) published a proposed rule and request for comments on an amendment to the Atlantic Large Whale Take Reduction Plan (the ALWTRP or Plan, herein) (85 Fed. Reg. 86879). At the same time, NMFS published a Draft Environmental Impact Statement (DEIS) and Regulatory Impact Review / Initial Regulatory Flexibility Analysis. The stated goal of the proposed amendment to the ALWTRP is to reduce the risk of 'human-caused mortality and serious injury' (MSI) of North Atlantic right whales (*Eubalaena glacialis*; right whales herein) and other large whales caused by the entanglement in Northeast Region lobster and Jonah crab trap/pot fisheries. The DEIS analyzes the potential environmental impacts of alternative potential amendments to the ALWTRP under the National Environmental Policy Act (42 U.S.C. § 4321 et seq.).

Section 118 of the Marine Mammal Protection Act (MMPA), added to the Act in 1994, governs the "Taking of Marine Mammals Incidental to Commercial Fishing Operations". Section 118(a)(1) establishes as the MMPA's "immediate goal" the reduction of MSI due to commercial fishing to "insignificant levels approaching zero within 7 years after the date of enactment," i.e., by 30 April 2001. This goal is carried forward in section 118(b), which mandates that commercial fisheries meet the goal by the specified date. Further, for strategic stocks taken by Category I or II fisheries,[1] section 118(f) requires NMFS to "develop and implement a take reduction plan designed to assist in the recovery or prevent the depletion of each [such] stock." In addition, section 118(f)(2) identifies two ALWTRP goals, the reduction of: (1) MSI due to fisheries interactions (fMSI) to a level less than the stock's potential biological removal level (PBR) within six months of plan implementation, and (2) fMSI to "insignificant levels approaching a zero mortality and serious injury rate" within five years, "taking into account the economics of the fishery, the availability of existing

[1] MMPA section 118(c)(1) requires NMFS to publish a list of fisheries that cause "(i) frequent incidental mortality and serious injury of marine mammals; (ii) occasional incidental mortality and serious injury of marine mammals; and (iii) a remote likelihood of or no known incidental mortality or serious injury of marine mammals." In implementing regulations (60 Fed. Reg. 45086, August 30 1995), NMFS defines fisheries as being Category I ("frequent" MSI): the fishery is "itself responsible for the annual removal of 50 percent or more of any stock's potential biological removal level"; or Category II ("occasional" MSI): "collectively with other fisheries, is responsible for the annual removal of more than 10 percent of any marine mammal stock's potential biological removal level and that is by itself responsible for the annual removal of between 1 and 50 percent, exclusive, of any stock's potential biological removal level".

Alternatives. The Commission believes it highly unlikely that the Preferred Alternative will be as effective as anticipated. Effectiveness in this context relies on measures that are to varying degrees untested or potentially unreliable. Rather than directly regulating the number of vertical lines that can be fished at any given time, the Preferred Alternative relies on an indirect method, trawling-up, to reduce the number of vertical lines, without any assurance that this approach would achieve the expected magnitude of line reduction. The Preferred Alternative also relies on weak-rope configurations that have not been tested. There is reasonably strong scientific support for requiring ropes to break at 1700 pounds or less, but it is unknown whether right whales will be able to break lines that have just one or two weak insertions, rather than lines with insertions every 40 feet or that are weak throughout, as recommended by scientists. Therefore, whether the proposed configurations will be effective is almost entirely speculative. Finally, the Preferred Alternative further relies heavily on fixed closures to continue providing protection for right whale hotspots, which is problematic in an era when marine environments are changing in response to ocean warming. This is in contrast to dynamic closures such as those being used in Canada, apparently with considerable success. The Commission therefore recommends that NMFS reject its Preferred Alternative as inadequate for the many reasons articulated above.

The Non-preferred Alternative will likely be more effective than the Preferred Alternative, but is likely still inadequate to achieve the goals of the MMPA. On the positive side, it relies on direct control of the number of vertical lines. This is an improvement on the trawling-up approach, but it is not without challenges. Although capping line numbers appears straightforward and could be achieved by permitting lines in addition to traps, Massachusetts is the only State where buoy or end lines currently are counted or regulated. Other states currently lack the data and regulatory mechanisms for implementing this approach. Implementing line caps will require a phase-in period during which regulatory agencies develop the necessary policies to regulate and monitor vertical line numbers, and collect baseline data on the number of lines being used. Another improvement offered by the Non-preferred Alternative would be the establishment of a larger closure south of Nantucket, which has become recognized as important winter habitat for right whales, and another closure north of Georges Bank. In addition, the Non-preferred Alternative would, for the most part, require fully weak rope. In contrast to these positive elements, however, the Non-preferred Alternative would not offer much improvement in the risk reduction in LMA3, and it also does not achieve the upper limit of the take-reduction target. NMFS and independent experts suspect that LMA3, where the offshore fishery operates, is responsible for a disproportionate number of entanglements, especially severe entanglements, that lead to fMSI. Because of the depths at which the gear is fished, the strong currents, and the large number of traps per trawl, that fishery uses very heavy (strong) lines, which almost certainly cannot be broken by adult right whales, let alone younger animals. Also, because of these factors it is difficult for the gear to incorporate weak insertions without compromising the ability of the fishermen to successfully retrieve their gear. As a result, under either alternative it is not likely that the offshore fishery will be able to achieve a risk reduction of more than 15 percent (Table 3.4 in the DEIS).

Considering the discussion and recommendations above, the Commission recommends that NMFS adopt the Non-preferred Alternative, with the following modifications—

1) Changes are made to the proposed mitigation measures to achieve an expected risk reduction sufficiently in excess of 80 percent to account for (i) performance uncertainty, (ii) double counting of the MRA 'credit', and (iii) the 64-percent cryptic mortality rate estimated by Pace et al. 2021, the best available science, which could be achieved by:

a. Increasing the sizes or durations of proposed closures, or establishing additional closures targeted at right whale hotspots with moderate to high entanglement risk;

b. Designing dynamic time-area closures similar to those implemented in Canada;

c. Capping vertical lines at much lower than present levels;[11] and

d. Establishing additional buoyless restricted areas in LMA3, or requiring the offshore fishery to adopt pop-up gear within three years.

2) Monitoring and adaptive modification of these measures and their proximate effects are mandated as an annual or biennial process to ensure that the actual performance of the proposed measures is matching expected performance.

Gear marking. One of the major sources of uncertainty in determining appropriate area-specific risk-reduction targets is the shortage of information on the types and sources of gear that entangles right whales. As described in the DEIS, the source (e.g., country, state, or fishery) could be identified in just 24 percent of the cases of whales found to be seriously injured or dead as a result of entanglement. Identifying the gear involved is critical to deriving accurate area-specific risk-reduction targets, and for improved understanding of the entanglement dynamics that lead to serious injuries and deaths. NMFS recognizes this imperative, as evidenced by the expanded gear-marking regulations included with the 2014 amendment to the ALWTRP, and by the improved marking schemes that are part of the proposed amendment's Preferred and Non-preferred Alternatives (see Table 3.3 in the DEIS). While the new regulations would allow, in some cases, retrieved gear to be linked to a state or management area (e.g., federal waters), the Commission believes that they fall well short of what is needed.

To improve understanding of entanglement dynamics and derive more accurate and site-specific risk-reduction targets, the proposed marking regulations need to be strengthened considerably. Among other things, gear-marking provisions should require more marks on lines and include unique marks for more fishing areas and marks that distinguish whether the rope was used as a buoy or end line or as a groundline. The Commission believes that this is the only way to provide the information needed to evaluate the effectiveness of current mitigation measures and to make informed decisions on any necessary further measures.

Therefore, at a minimum, <u>the Commission recommends</u> that NMFS revise the gear-marking measures in the proposed TRP amendment to include the following features:

1. Area-specific marking schemes are developed for jurisdictional areas (e.g., United States vs Canada, individual states, state vs federal waters) and areas of high entanglement risk (e.g., hot spots where there is a strong correlation or overlap between whale abundance and gear density);
2. All vertical end or buoy lines and groundlines are marked, including with an additional mark to distinguish vertical lines from groundlines;

[11] The Decision Support Tool (DST) should be used to determine the actual amount of vertical line reduction, in combination with other measures, necessary to account for serious injuries and total deaths in the population.

EXHIBIT 10

GEORGIA
DEPARTMENT OF NATURAL RESOURCES

WILDLIFE RESOURCES DIVISION

MARK WILLIAMS
COMMISSIONER

TED WILL
DIRECTOR

February 19, 2021

Mr. Michael Pentony, Regional Administrator
Greater Atlantic Regional Fisheries Office
National Marine Fisheries Service
55 Great Republic Drive
Gloucester, Massachusetts 01930

RE: Draft Biological Opinion for 10 Northeast U.S. Fisheries, Consultation No. GARFO-2017-00031

Dear Mr. Pentony:

On January 15, 2021 NMFS GARFO released a draft biological opinion (BiOp) that assesses the effects of 10 fisheries on ESA-listed species in Northeast U.S. federal waters. The draft BiOp concludes that the Northeast U.S. lobster fishery will not appreciably affect persistence of right whales or their potential for recovery. Attached are comments by Georgia Department of Natural Resouces, Wildlife Resources Division staff on the sections pertaining to the American lobster/Jonah crab fishery and North Atlantic right whales. We hope NMFS will address these concerns in the final opinion.

Thank you for the opportunity to review this draft biological opinion. We look forward to continued cooperation with NMFS on this and other matters. If you have further questions, please contact Clay George at 912-262-3336 or clay.george@dnr.ga.gov.

Sincerely,

Ted Will

Georgia DNR Wildlife Resources Division Comments on Draft Biological Opinion for 10 Northeast U.S. Fisheries, Consultation No. GARFO-2017-00031

- The jeopardy assessment accepts as fact that the pending Atlantic Large Whale Take Reduction Plan (ALWTRP) lobster buoy line rule will generate a 60% reduction in right whale mortality and serious injury (M/SI). Many modifications made to the ALWTRP since 1997 have failed to reduce entanglement-related M/SI to legally mandated levels (Hayes et al. 2018, Pace et al. 2015), and the proposed rule does not directly reduce the number of buoy lines by setting line caps or lowering lobster pot allocations.
- The draft BiOp assumes completion of federal actions that NMFS hopes to implement through the proposed right whale conservation framework over the next 10 years. It is impossible to know if these actions will be implemented in the future. As such, they should not be used to assess the effects that the lobster fishery is having on right whales at the current time.
- ALWTRP regulates fisheries in all state non-exempt waters, and the draft BiOp should consider effects in those locations.
- The draft BiOp does not account for sublethal effects, either quantitatively or qualitatively. Approximately one quarter of right whales become entangled each year (Knowlton et al. 2012). Nonlethal entanglements can have long-lasting sublethal effects and may be impacting reproductive rates and adult female survival at a species scale (Corkeron et al. 2018, Pettis et al. 2017, Robbins et al. 2015, Rolland et al. 2016, van der Hoop et al. 2017).
- The draft BiOp estimates the M/SI rate for right whales during 2010-2019 as 4.94/year. This is an underestimate; it should be 6.82 per year. This means an immediate 88% reduction in M/SI is needed in U.S. state and federal waters, not 60%[1].
- The assessment assumes low calving rates in the Southeast U.S. and high M/SI rates in Canada since 2010 will remain unchanged for the next 50 years. This assumption led to future population projections that are predictably pessimistic. Linden (2021) produced a variety of scenarios for the draft BiOp which recognize the considerable uncertainty inherent in future projections. NMFS should consider this uncertainty in their assessment.
- The final BiOp should recommend that NMFS implement vessel reporting and tracking requirements for federal lobster permits. The Atlantic States Fisheries Management Commission has already made similar recommendations. Data on fishing effort and gear configuration in federal waters will be needed to assess the effectiveness of this and future federal actions.
- North Atlantic right whales are declining rapidly because of a combination of high anthropogenic mortality and injury, low calving rates and climate-driven disruptions in food resources (Hayes et al. 2018, 2020). Although the risk of extinction appears increasingly real, right whales are long-lived animals—the species' trajectory can stabilize if vessel strikes and rope entanglement are reduced broadly and decisively (Corkeron et al. 2018, Meyer-Gutbrod et al. 2017, Linden 2021).

[1] Mortality rates should include all U.S. federal and state non-exempt waters and be calculated from statistically derived mortality estimates used in Pace et al. 2021 (not a combination of observed M/SI and estimated mortality waters) as follows: 201 (estimated mortality during 2010-2019, BiOp page 225) * 0.5 (proportion of entanglements assumed occurring in U.S. waters, BiOp page 224) * 0.73 (proportion of U.S. mortalities due to entanglement, BiOp page 227) * 0.93 (proportion of buoy lines fished by ALWTRP-regulated lobster fishery in the Northeast U.S., DEIS page 3-67) / 10 years = 6.82 estimated mortality/year. Risk reduction needed: 1 – (0.8 [current PBR, Hayes et al 2020] / 6.82 [estimated mortality/year]) = 0.88. See ALWTRP DEIS page 2-39 for risk reduction equation.

The draft BiOp concludes that reductions in lobster rope entanglement will not generate significant conservation benefit in the future because other factors have already placed right whales on a path toward functional extinction. It appears that NMFS came to this conclusion by (1) choosing the projection models that employed the most pessimistic combination of future management and demographic scenarios, (2) overestimating the conservation benefit of the proposed ALWTRP rule, and (3) underestimating the impact that lobster rope entanglement is having on the species.

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EXHIBIT 11

New England Aquarium

Protecting the blue planet

Mr. Ben Friedman
Deputy Under Secretary for Operations, performing the duties of Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator
National Oceanic and Atmospheric Administration

Re: Document ID NOAA-NMFS-2020-0031-0006 on the Proposed Rule *Taking of Marine Mammals Incidental to Commercial Fishing Operations; Atlantic Large Whale Take Reduction Plan Regulations; Atlantic Coastal Fisheries Cooperative Management Act Provisions; American Lobster Fishery*

March 1, 2021

Dear Mr. Friedman,

In response to the National Oceanic and Atmospheric Administration's (NOAA) Proposed Rule (Proposed Rule) to amend the regulations implementing the Atlantic Large Whale Take Reduction Plan to reduce the incidental mortality and serious injury to North Atlantic right whales (*Eubalaena glacialis*), fin whales (*Balaenoptera physalus*), and humpback whales (*Megaptera novaeangliae*) in northeast commercial lobster and crab trap/pot fisheries to meet the goals of the Marine Mammal Protection Act and the Endangered Species Act, the New England Aquarium (Aquarium) submits this comment to express our strong reservations that the measures outlined in the Proposed Rule and accompanying Draft Environmental Impact Statement (DEIS) are not nearly aggressive enough to change the fate of North Atlantic right whales (NARW) in U.S. waters. ***Based on our decades of NARW expertise, the Aquarium strongly urges NOAA to revise this Proposed Rule substantially before finalizing it***.

Founded in 1969, the Aquarium is a catalyst for global change through public engagement, commitment to marine animal conservation, leadership in education, innovative scientific research, and effective advocacy for a vital and vibrant ocean. For decades, the Aquarium has been working to protect marine and freshwater ecosystems from human impacts and conserve threatened and endangered animals and habitats. The Aquarium's scientists conduct cutting-edge research to understand, quantify, and reduce the consequences of human activities on the health of marine species and ecosystems by developing science-based solutions and advocating for policies that balance human use of the ocean with the need for a healthy, thriving ocean now and in the future.

Scientists at the Aquarium have been researching NARWs for more than 40 years with the express goal of preventing this species from going extinct. To that end, scientists from the Aquarium have served on the Atlantic Large Whale Take Reduction Team (ALWTRT) since it was formed in 1996. While we are pleased to see that published research by our scientists was used to inform aspects of the Proposed Rule, our primary concern with the Proposed Rule is that it fails to utilize more recent scientific results and, as a result, the proposed measures will fail to reduce the risks to NARWs and other whales from entanglements in fixed fishing gear resulting in serious injuries and mortalities.

The Aquarium's detailed comments regarding the Proposed Rule and DEIS follow together with specific, scientifically-informed recommendations on how to strengthen the regulations before they becomes final. We trust these comments will be viewed as a constructive contribution to the ongoing deliberations, and we are pleased to elaborate or clarify further as needed.

Percent Risk Reduction

RECOMMENDATION 1: In its Final Rule, NOAA should implement measures that reduce the risk of entanglements of NARWs and other cetaceans in fixed fishing gear by at least 80 percent.

North Atlantic right whales have been in decline for a decade after a slow documented recovery from the whaling era (Pace et al. 2017). In the absence of strong rules preventing entanglements and vessel strikes, the abundance of the species has declined at an unacceptable rate to the current number of 356 remaining animals[7]. Recognizing the time required to finalize regulations that result in action on the water, we expect the species' abundance will only continue to decline. The Proposed Rule was developed to reduce the risks of entanglements in fishing gear by a minimum of 60 percent, which may have been satisfactory when this process started in 2017, but is no longer sufficient now that that there are substantially fewer (16 percent) NARWs today than in 2017.

Because the Proposed Rule does not account for the most recent population number and the delays in finalizing regulations despite having this information available while the rule was being drafted (Pace et al. 2021), reducing the risk by at least 80 percent is now more appropriate. The Proposed Rule should be revised to reflect the best-available scientific data on the status of the population and to meet NOAA's legal requirements under the Marine Mammal Protection Act and the Endangered Species Act.

The Proposed Rule's accompanying DEIS states that "the immediate goal of a take reduction plan is to reduce the serious injury and mortality of strategic stocks being taken during U.S. commercial fishing operations to below PBR levels within six months of its implementation. The long-term goal of a take reduction plan is to reduce, within five years of its implementation, the incidental mortality and serious injury of strategic marine mammals taken in the course of commercial fishing operations to insignificant levels approaching a zero mortality and serious injury rate…" (p. 299); however, the Aquarium argues that reducing risk by 60 percent will not reduce mortalities and serious injuries to below the Potential Biological Removal (PBR) of 0.8 in a five-year timeframe.

The Aquarium would like to take this opportunity to address a common misinterpretation of the modeling results presented in Linden (2021) that suggested removing all mortality attributed to lobster fishing will not prevent the population from declining. This misinterpretation is used to argue that restrictions to the lobster fishery are not justified as they will not improve the conservation status of NARWs. This reasoning is fallacious. The matrix model used in Linden (2021) is the same one published in Corkeron et al. (2018), using the R code from that paper. What Linden (2021) does not provide is the estimates of annual survival and fecundity used to populate the model matrix. As Corkeron et al. (2018) demonstrate, using the upper estimates of survival that NARWs are capable of results in an annual population increase on the order of four percent. Corkeron et al. (2018) also demonstrate that the vast majority of NARW mortality is due to anthropogenic causes (including lobster fishing). Therefore, if all anthropogenic mortality were eliminated to allow NARWs to recover, their population should increase in abundance at about four percent per year. As entanglement in fishing gear accounts for a significant proportion of anthropogenic mortality and morbidity of NARWs (Sharp et al. 2019 and Pace et al. 2021), reducing the risks of mortality and serious injury from entanglements will have a conservation benefit.

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[7] https://www.narwc.org/report-cards.html

EXHIBIT 12

New England Aquarium

Protecting the blue planet

Michael Pentony
Regional Administrator
Greater Atlantic Regional Fisheries Office
55 Great Republic Drive
NOAA Fisheries Service
Gloucester, MA 01930

Re: **Draft Biological Opinion on 10 Fishery Management Plans in the Greater Atlantic Region and the New England Fishery Management Council's Omnibus Habitat Amendment 2**

In response to the *Draft Biological Opinion on 10 Fishery Management Plans*, the New England Aquarium (Aquarium) submits this comment strongly urging the National Oceanic and Atmospheric Administration (NOAA) to reconsider its finding of no jeopardy for North Atlantic right whales (NARW).

Founded in 1969, the Aquarium is a global leader in marine conservation and a catalyst for global change through public engagement, commitment to marine animal conservation, leadership in education, innovative scientific research, and effective advocacy for vital and vibrant oceans. For decades, the Aquarium has been working to protect marine and freshwater ecosystems from human impacts and conserve threatened and endangered animals and habitats. The Aquarium's scientists conduct cutting-edge research to understand, quantify, and reduce the consequences of human activities on the health of marine species and ecosystems by developing science-based solutions and advocating for policies that balance human use of the ocean with the need for a healthy, thriving ocean now and in the future.

Scientists at the Aquarium have been researching NARWs for more than 40 years with the goal of preventing this species from going extinct. In addition, representatives from the Aquarium have served on the Atlantic Large Whale Take Reduction Team since it was formed in 1996. The Aquarium is pleased to see that published research by our scientists was used to inform aspects of these measures.

Here we provide comments and recommendations on the Draft Biological Opinion (BiOp) and the Conservation Framework associated with it. This comment focuses on findings in the Draft BiOp pertaining to NARWs based on our long-standing scientific expertise and commitment to conserving this species. In addition, as the most endangered species reviewed in the Draft BiOp, it is critical to the conservation plan, pending rulemaking, and draft environmental impact statement that the findings in the Final BiOp are accurate and based on the best-available science.

First, we wish to compliment NOAA staff on aspects of this work. The review of the NARW in the Status of the Species section of the Draft BiOp is well written and cites the appropriate and best-available scientific literature. The modeling work conducted by Dr. Daniel Linden of Greater Atlantic Regional Fisheries Office (GARFO) presented in the document "*Population projections of North Atlantic right whales under varying human-caused mortality risk and future uncertainty*" (Appendix 3) is excellent, and we compliment his analysis. While it is possible to argue some of the detail of the models (as we do below), the work is of a very high standard. We see that the reviews of this work, conducted by expert reviewers for the Center for Independent Experts (CIE) were supportive, offering only a few suggestions for possible improvement to the science[1]. We also note that, although it is not part of the Draft BiOp or Conservation Framework, the recent paper led by Dr. Richard Pace of the Northeast Fisheries Science Center (NEFSC), which we cite several times below, is a very important contribution that informs our

[1] https://www.st nmfs.noaa.gov/science-quality-assurance/cie-peer-reviews/cie-review-2020

comments. Dr. Pace is to be complimented for his excellent analyses that have advanced our understanding of the current situation of NARWs.

Although we are impressed by these aspects of the work, we have significant concerns with other aspects of the Draft BiOp and Conservation Framework. While we concentrate our comment on the scientific content of the Draft BiOp, we also take this opportunity to raise one initial, yet critical, concern.

No Jeopardy Finding

The Draft BiOp finds no jeopardy based on the assumption that, in the first phase of the Conservation Framework, regulations still in draft form are sufficient enough to reduce fisheries-induced mortality and morbidity of NARWs to the extent that they will recover. As these regulations are still in draft form, there is no guarantee that they will be promulgated, implemented, and/or enforced. Whether or not they are sufficient is another question entirely, which the Aquarium will address in its response to the *Proposed Rule to Amend the Atlantic Large Whale Take Reduction Plan to Reduce Risk of Serious Injury and Mortality to North Atlantic Right Whales Caused by Entanglement in Northeast Crab and Lobster Trap/Pot Fisheries* and Draft Environmental Impact Statement.

Recommendation 1: In the absence of a final rule, the Aquarium does not think it is appropriate to make a "no jeopardy" finding.

Furthermore, as detailed below, the Aquarium has significant issues of concern with the Draft BiOp and Conservation Framework and strongly asserts that the science supports a jeopardy finding.

Risk reduction and the time required to implement changes

North Atlantic right whales have been in decline for a decade. In the absence of strong rules preventing entanglements and vessel strikes, we have come to expect the abundance of the species to continue to decline. Because it takes time to finalize regulations (and Biological Opinions) and even longer for those to result in action on the water, we understand that while these processes are ongoing, it is likely that the species' abundance will continue declining. The Draft BiOp does not account for this time delay, despite having a strong model that indicates the trajectory of the species' abundance while the BiOp and regulations were being drafted (see also Meyer-Gutbrod et al. 2018 on this topic in the Canadian management setting). This is not well thought through and should be.

It was clear after the Atlantic Large Whale Take Reduction Team (ALWTRT) meeting in 2017 that NARW Serious Injury and Mortality (SI/M) had exceeded the "jeopardy" threshold identified, thus initiating the need for a new BiOp. Despite this, it took almost four years for this Draft BiOp to be released, during which time the number of NARWs kept declining. The redrafted BiOp needs to account for this continuing decline and must account for the time in which it takes NOAA to implement changes on the water. Corkeron et al.'s (2018) matrix model [disclosure: Aquarium employees are authors of Corkeron et al. 2018], as applied by Linden 2021 and suitably corrected for uncertainty (see below), can be used to project what the abundance of NARWs is likely to be, and from that, appropriate measures reconsidered.

To give a concrete example, the Draft BiOp and Conservation Framework are predicated on the idea that a 60% reduction in anthropogenic mortality will be sufficient to take NARWs from jeopardy. While 60% risk reduction may have been satisfactory when this process started in 2017, in 2021 60% risk reduction is no longer sufficient as there are now substantially (16%) fewer NARWs than there were in 2017. An 80% risk reduction target initially is now more appropriate and should be used in the redrafted BiOp.

Recommendation 2: We recommend that the redrafted BiOp be based on an 80% risk reduction target.

Incorporating Uncertainty

There are several instances where the modeling that informs the Draft BiOp and Conservation Framework does not incorporate uncertainty in the data sufficiently, especially given the scale of the conservation challenges facing NARWs.

We note the significant paper on this topic by Dr. Barb Taylor and coauthors, "*Incorporating Uncertainty into Management Models for Marine Mammals,*" published in Conservation Biology in 2000 (Taylor et al. 2000). As Taylor et al. (2000) discuss in their paper, "The history of marine mammal management clearly demonstrates the need to incorporate uncertainty into management models" (p.1250); and "The simulations clearly show that accounting for uncertainty by using a lower percentile is precautionary, whereas the typical practice of the best estimate is not" (p.1248)—in this quote, the "best estimate" is generally considered the mean.

For example, the matrix modeling in Linden (2021) uses the mean estimates of posterior distributions of survival from the re-run mark-recapture model of Pace et al. 2017 as matrix model inputs. A more appropriate approach for conservation, following the findings of Taylor et al. (2000), would be to use the 80^{th} percentile of these posterior distributions to account for the substantial uncertainty in them. To be clear, this is not a criticism of the model used, but of how the model is applied *for conservation* to inform a Section 7 decision under the Endangered Species Act. We note parenthetically that better allowing for uncertainty was raised as a concern by Dr. New in her CIE review[2] of the Linden 2021 paper.

Likewise, the data used for the Decision Support Tool (DST, see, e.g., page 220 of the Draft BiOp) includes substantial uncertainties in both the models of whales' distribution and the data on fisheries. The DST should be re-run using appropriate percentiles rather than means or medians to estimate overlap of fisheries and the whales' distributions.

Recommendation 3: We recommend that the redrafted BiOp re-run the analyses using appropriate uncertainty parameters and that the conservation implications of the revised models be reassessed in the revised Section 7 assessment.

Cryptic mortality and its implications

A recent 2021 paper by Dr. Richard Pace and coauthors [disclosure: Aquarium employees are authors of this paper] estimates the unobserved ("cryptic") mortality of NARWs (Pace et al. 2021). In this paper, the authors show that for the period 2010-2017 (which is most relevant to the Draft BiOp), the probability of detecting a whale carcass was 29% (with two standard errors of 2.8%). In addition, during the 2019 North Atlantic Right Whale Consortium meeting, Dr. Pace gave a talk entitled, "*Estimating latent mortality of North Atlantic right whales*" that summarized the earlier stages of this analysis. Because the manuscript was submitted on July 2, 2020, we presume that it was reviewed and cleared by NOAA's NEFSC prior to submission based on Dr. Pace's affiliation with NEFSC. As these scientific results were available to

[2] https://www.st nmfs.noaa.gov/Assets/Quality-Assurance/documents/peer-review-reports/2020/2020_05%20New%20NARW%20Pop%20Model%20Review%20Report.pdf

EXHIBIT 13

NOAA FISHERIES

Atlantic Large Whale Take Reduction Team

Day 1: May 9, 2022

Risk reduction calculations

Use the most-recent 5 yr. observed M/SI ratio to apportion the total mortality estimate from Pace MRR model.
Across three country apportionment assumptions: 50%, 40%, or 30% US.

Country Apportionment	(a) PBR - draft 2021 SAR	(b) Annual average estimated mortality 2015-2019	(c) Assumed US proportion	(d) US mortality based on country assumption (columns b*c)	(e) US mortality - 70% EN Observed M/SI 2016-2020 (column d* 0.70)	(f) % Reduction Needed for US to achieve PBR assuming 70% EN ((e-a)/e)
50% US/ 50% CAN	0.7	31.2	0.50	15.7	11	93.6%
40% US/ 60% CAN			0.40	12.6	8.8	92.0%
30% US/ 70% CAN			0.30	9.4	6.6	89.4%

EXHIBIT 14

Current Biology

Report

Decreasing body lengths in North Atlantic right whales

Highlights

- Whales with severe entanglements in fishing gear are stunted
- Whales whose mothers were entangled while nursing are stunted
- Body lengths have been decreasing since 1981
- Cumulative impacts in addition to entanglements may contribute to stunted growth

Authors

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In brief

Stewart et al. examine trends in body lengths in endangered North Atlantic right whales using aerial photogrammetry. They show that whales that have experienced severe entanglements in fishing gear are shorter than whales with no documented entanglements, and that body lengths of right whales have been decreasing over the past four decades.

Stewart et al., 2021, Current Biology *31*, 3174–3179
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Report

Decreasing body lengths in North Atlantic right whales

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https://doi.org/10.1016/j.cub.2021.04.067

SUMMARY

Whales are now largely protected from direct harvest, leading to partial recoveries in many previously depleted species.[1] However, most populations remain far below their historical abundances and incidental human impacts, especially vessel strikes and entanglement in fishing gear, are increasingly recognized as key threats.[2] In addition, climate-driven changes to prey dynamics are impacting the seasonal foraging grounds of many baleen whales.[2] In many cases these impacts result directly in mortality. But it is less clear how widespread and increasing sub-lethal impacts are affecting life history, individual fitness, and population viability. We evaluated changes in body lengths of North Atlantic right whales (NARW) using aerial photogrammetry measurements collected from crewed aircraft and remotely operated drones over a 20-year period (Figure 1). NARW have been monitored consistently since the 1980s and have been declining in abundance since 2011 due primarily to deaths associated with entanglements in active fishing gear and vessel strikes.[3] High rates of sub-lethal injuries and individual-level information on age, size and observed entanglements make this an ideal population to evaluate the effects that these widespread stressors may have on individual fitness. We find that entanglements in fishing gear are associated with shorter whales, and that body lengths have been decreasing since 1981. Arrested growth may lead to reduced reproductive success[4,5] and increased probability of lethal gear entanglements.[6] These results show that sub-lethal stressors threaten the recoveries of vulnerable whale populations even in the absence of direct harvest.

RESULTS AND DISCUSSION

We combined age and length data collected from crewed aircraft in 2000–2002 and from remotely operated drones in 2016-2019 in a growth model mirroring a previous analysis of the 2000–2002 data.[7] We modified the 2-phase Gompertz growth equation to include model-estimated effects on asymptotic length for: (a) birth year, (b) duration of entanglements with attached fishing gear, (c) whether a whale's mother experienced a severe entanglement injury while nursing that whale, and (d) the number of lactation events a female whale experienced, which is known to be one of the most significant energetic expenditures for right whales.[8] We considered the cumulative effects of covariates from birth until age 10 (or until the time of measurement if it occurred prior to age 10), as the expected length at age 10 is more than 95% of the estimated asymptotic length and constraints to growth after that point would be unlikely to measurably affect whale lengths.

Across all years we collected 202 length measurements of 129 individual whales: 133 measurements from crewed aircraft and 69 from remotely operated drones. 76 whales were measured once, 36 twice (in separate years), 14 three times, and 3 four times. The ages of measured whales ranged from <1 to 37 years old, including whales born from 1981 to 2019. Eleven whales in our dataset were observed with attached gear; 8 of those whales were measured once, 2 were measured twice, and 1 was measured four times. Gear entanglement durations (midpoints) ranged from 65 to 334 days. Seven measured whales had known severe maternal entanglement injuries; 1 of those whales was measured twice. No whales in our dataset had both a maternal entanglement injury and an entanglement with attached gear. Nine measured whales had one lactation event, and 1 whale had two lactation events prior to age 10.

Birth year had the greatest effect on the estimated asymptotic length of NARW (99.8% of posterior distribution <0). The estimated

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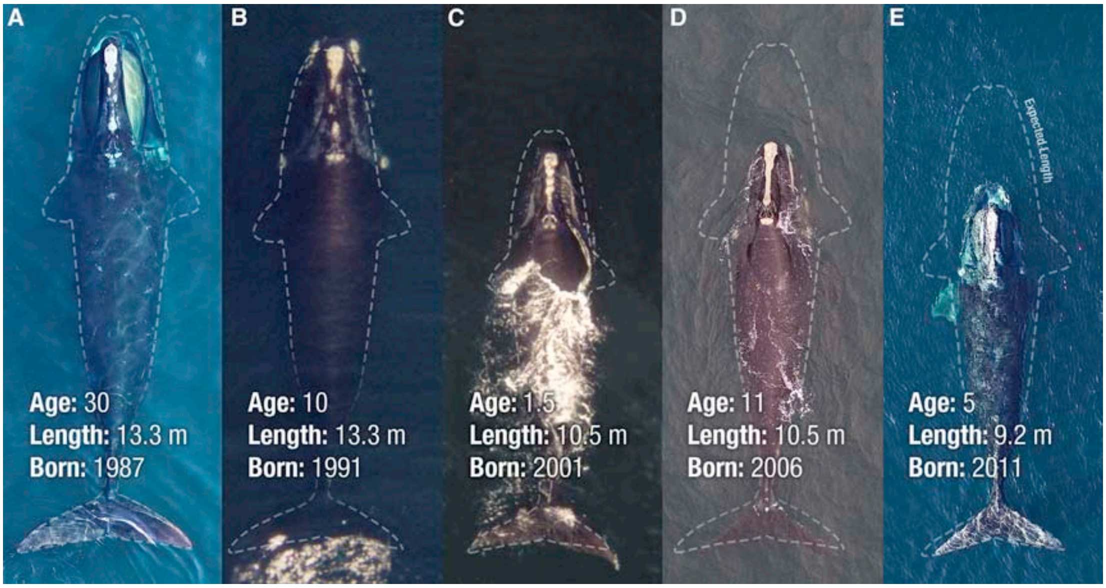

Figure 1. Stunted North Atlantic right whales

A scaled photo illustration comparing the body lengths of (A) Whale 1703, imaged in 2017 at age 30 using a remotely operated drone, (B) Whale 2145, imaged in 2001 at age 10 from a crewed aircraft, (C) Whale 3180, imaged in 2002 at age 1.5 from a crewed aircraft, (D) Whale 3617, imaged in 2017 at age 11 using a drone, and (E) Whale 4130, imaged in 2016 at age 5 using a drone. The dashed outline in each panel represents the median model estimated body length for a whale of the same age born in 1981 with no history of entanglements or maternal entanglements. Note the entanglement scarring around the caudal peduncle in (D). Figure design by Madeline Wukusick.

effect of birth year was an asymptotic length 0.025 m (95% credible intervals 0.01–0.04) shorter than the baseline asymptotic length per year born after 1981. With the maximum effect of birth year applied, a whale born in 2019 is expected to reach a maximum length approximately 1 m shorter than a whale born in 1981 (Figure 2). This corresponds to a 7.3% decline in maximum body length. Known entanglements of a whale with attached gear (97.4% of posterior distribution <0) and entanglements of its mother during nursing (99.7% of posterior distribution <0) also had negative effects on expected maximum length, of approximately 0.64 m (4.7% length reduction) and 0.69 m (5.0% length reduction), respectively. The effect of entanglement with attached gear was applied as a continuous effect, so a whale with an entanglement duration that is half the maximum duration is expected to experience half of that negative effect on asymptotic length, or an expected asymptotic length 0.32 m shorter than baseline. There was no significant effect of the number of lactation events (61.2% of posterior distribution >0) on expected maximum length of right whales (Figure 3). The estimates of error around the model-estimated mean length-at-age were different across altimeter types. GPS altimeter measurements had the highest error (median 0.63, 95% CI 0.26–1.01 m), followed by laser altimeter measurements (0.52, 0.19–0.77 m) and radar altimeter measurements (0.27, 0.01–0.48 m).

Our results demonstrate that NARW born in recent years have experienced stunted growth, and over the same period that we detected this effect they have experienced increasing rates of entanglement.[3] As a result, NARW appear to have less energy to devote to early growth. A portion of the estimated length reduction was directly attributable to entanglements, but the effect size of entanglements was smaller than the effect size of birth year. We posit that the birth year effects on asymptotic length represent the cumulative effects of dynamic and hard-to-observe impacts on individual NARW that may include unrecorded entanglements, shifting prey seascapes, vessel strikes, and foraging interference from vessel traffic (Figure 4). For example, entanglements of NARW are imperfectly observed, and many whales have evidence of entanglement injuries without direct observations of attached gear; in these scar-only cases it is impossible to determine the duration of those entanglements.[9] Even direct observations of attached gear events have only approximate entanglement durations (we considered the midpoint between minimum and maximum possible duration of each entanglement) and there is almost certainly a large amount of noise introduced into our analyses as a result of these imperfect observations. Consequently, while our analyses detected a negative effect of entanglements on whale length, we cannot rule out a larger true effect size than our estimate; for example, if entanglements that were not recorded in our dataset contributed to restricted growth that was instead reflected in birth year effects.

The abundance of *Calanus finmarchicus*, a primary copepod prey item for NARW, has fluctuated in the Gulf of Maine over the past 40 years (Figure 4), apparently driving reproductive output in the NARW population.[11] *C. finmarchicus* is a subarctic species, and its distribution is expected to shift poleward as the North Atlantic warms,[12] leading to projected abundance declines in the Gulf of Maine.[13] There has not been a steady decline in *C. finmarchicus* abundance coincident with the decreasing NARW body lengths reported here. However, in the past decade, sighting rates of NARW on their typical foraging grounds have declined, and the timing and geographic distribution of peak

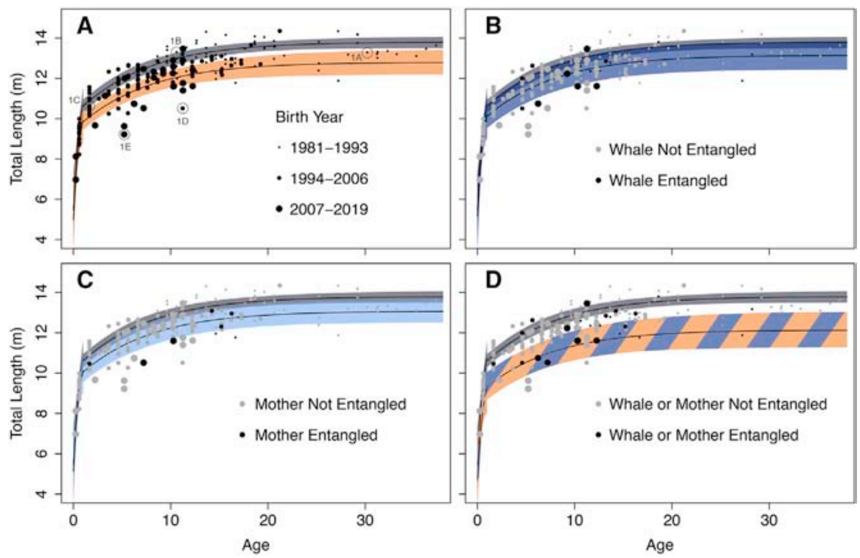

Figure 2. Growth curves for North Atlantic right whales

The gray curve in each panel represents the expected length at age for a typical NARW born in 1981 that experiences no entanglements and does not have an entangled mother while nursing. Solid lines represent median estimates and colored curves represent 95% Bayesian credible intervals for the mean length at age of whales with covariate effects applied.

(A) The expected length at age for a typical whale born in 2019 that experiences no entanglements and does not have an entangled mother while nursing (orange curve). Black points are observed lengths of known age whales, with point size indicating the birth year of the whale (in three ranges for clarity; all panels). The dashed circles and corresponding labels indicate the whales pictured in Figure 1 panels A E.

(B) The expected length at age for a typical whale born in 1981 that experiences a severe attached gear entanglement (maximum effect size of a 334 day entanglement duration applied; dark blue curve). Light gray points are whales with no observed attached gear entanglements; black points are whales with observed attached gear entanglements. Note that duration of entanglement is not indicated.

(C) The expected length at age for a typical whale born in 1981 whose mother is entangled while that whale is nursing (light blue curve). Black points are whales whose mothers were detected with a severe entanglement injury while the measured whale was a nursing calf.

(D) The expected length at age for a typical whale born in 2019 that experiences a severe entanglement (maximum effect size; orange and blue striped curve). In other words, the cumulative effects of birth year and entanglements. Black points are whales with observed attached gear entanglements or whales whose mother was known to have a severe entanglement injury while the measured whale was nursing, as these effect sizes were comparable. See model diagnostics in Figures S1 S3.

C. finmarchicus densities have been shifting.[14] These changes may indicate a deteriorating foraging environment in the Gulf of Maine. Given that NARW are dependent on hyper-dense patches of copepods to maximize foraging efficiency,[15] coarse regional indices of *C. finmarchicus* abundance (e.g., Figure 4) may not adequately represent foraging conditions that could affect growth rates. Other anthropogenic factors such as increasing vessel noise could also be interfering with foraging behavior and restricting NARW growth[16] (Figure 4).

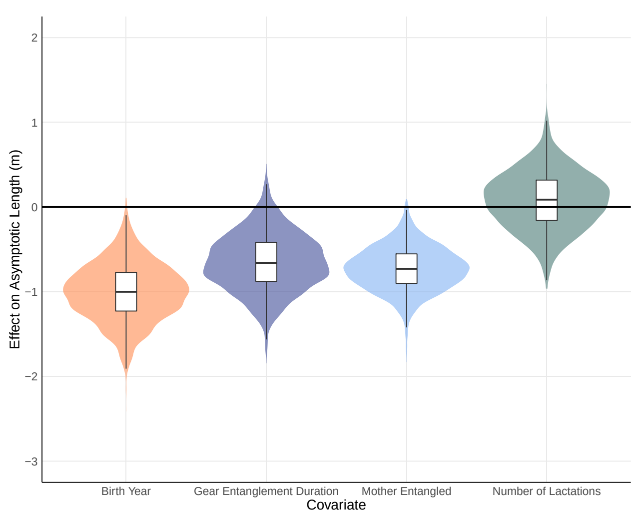

Figure 3. Covariate effects on asymptotic length of North Atlantic right whales

Violin plots represent the Bayesian posterior distributions of the estimated effect (in meters) of each covariate on the asymptotic length parameter in the 2 phase Gompertz growth equation. The interior boxplots represent the median effect size (horizontal black line), the 50% posterior density intervals (white box) and the 95% credible intervals (vertical black line). The effects of birth year, gear entanglement duration, maternal entanglement, and number of lactations are scaled to the maximum effect size as the minimum covariate values for each of these is zero. We considered an effect significant if >95% of posterior draws were below (or above) zero.

In baleen whales, larger maternal size and body condition are associated with faster calf growth rates and larger calves.[4,5] Decreasing body size may therefore be associated with smaller calves and lower calf survivorship, or potentially delayed first calving and lower reproductive success in females. NARW exhibit generally poor body condition compared to other populations of right whales,[17,18] which could contribute to synergistic negative effects where females in poor condition produce smaller calves that ultimately reach smaller maximum sizes, further contributing to reduced calf growth and declining calf condition. In addition, our results suggest that sub-lethal entanglements constrain overall body size in NARW, which may in turn make them less resilient to future entanglements by reducing their absolute energetic reserves and increasing the probability of a lethal entanglement.[6]

Mortality from vessel strikes and entanglements in fishing gear are thought to be a major driver of the current NARW population decline,[3] but the observed changes in body lengths also indicate a troubling trend that may have further negative effects on population viability in this critically endangered species, with chronic sub-lethal health effects slowing growth and potentially reducing reproductive success. Changes in body size can also be a leading indicator of population collapse,[19–21] further highlighting the ongoing and compounding threats to the NARW population. Implementing solutions to reduce entanglements and other anthropogenic impacts could give North Atlantic right whales increased

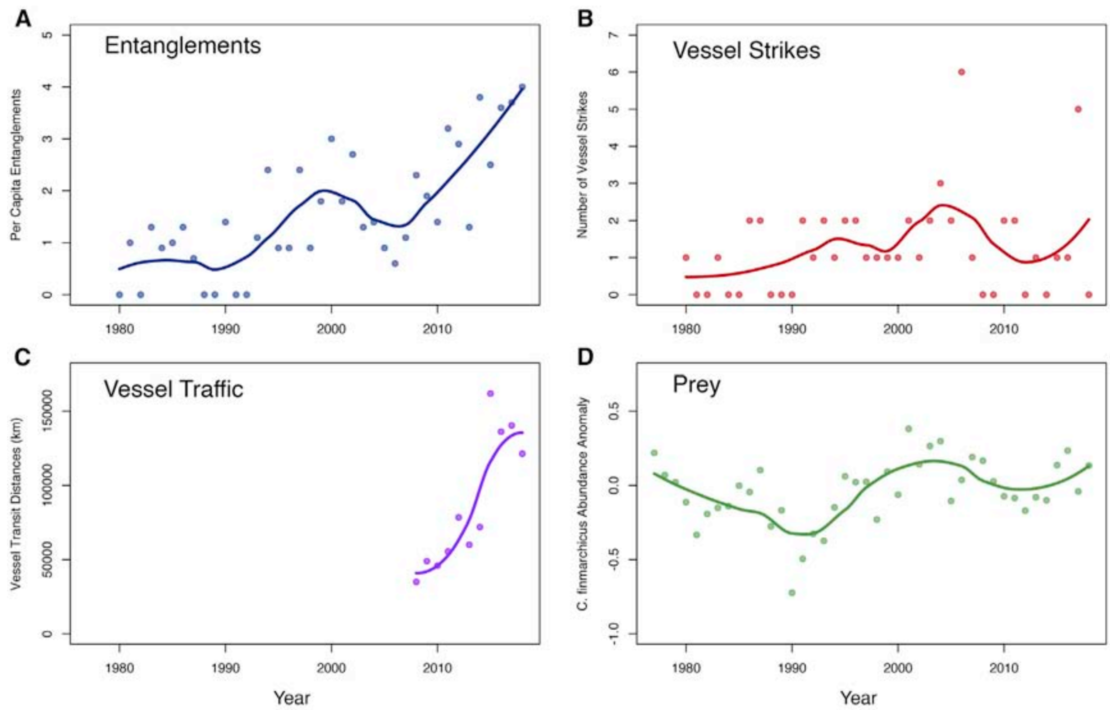

Figure 4. Possible cumulative impacts affecting right whale growth

Time series of potential stressors that could affect right whale energy budgets and foraging success.

(A) Number of new serious entanglements (attached gear or severe injuries) observed each year, standardized by the number of individual whales observed during field surveys; source ref.[9]

(B) Number of vessel strikes resulting in blunt trauma or deep lacerations observed each year. Note that vessel strikes are raw counts and not per capita rates; source ref.[10]

(C) Cumulative vessel transit distances (in kilometers) within three special management areas that are NARW foraging hotspots: Cape Cod Bay, Race Point, and Great South Channel; source NMFS Right Whale Vessel Speed Rule Assessment, June 2020.

(D) *Calanus finmarchicus* abundance anomalies for the Gulf of Maine; source NOAA Ecosystem Dynamics and Assessment Branch ecodata. The lines in each panel are a loess smooth to the annual data.

resilience to adapt to changing prey dynamics and other climate-related impacts while maintaining population viability.

Changes to life history traits, such as growth rates and age or size at maturity, are well documented in heavily exploited species (in particular fishes).[22] Body size changes in mammals (both positive and negative) are also expected under changing climate conditions.[23,24] Our results suggest that humans are impacting the demographic characteristics of endangered and protected marine mammals through indirect and incidental pressures on vulnerable populations. Entanglements in fishing gear are a growing problem for migratory baleen whale species and a wide variety of marine mammals.[25] Extensive survey effort for the NARW population allowed the sub-lethal effects of entanglements to be directly (if imperfectly) estimated, but it is likely that other marine mammal species that experience chronic entanglements are being similarly affected.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

- KEY RESOURCES TABLE
- RESOURCE AVAILABILITY
  - Lead Contact
  - Materials Availability
  - Data and Code Availability
- EXPERIMENTAL MODEL AND SUBJECT DETAILS
- METHOD DETAILS
- QUANTIFICATION AND STATISTICAL ANALYSIS

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.cub.2021.04.067.

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AUTHOR CONTRIBUTIONS

J.D.S., J.W.D., and M.J.M. conceived the analysis; J.W.D., M.J.M., and H.F. conceived the study; J.W.D., M.J.M., A.R.K., H.F., and W.L.P. obtained fund ing for data collection; J.W.D., M.S.L., M.J.M., H.F., J.B., A.R.K., C.A.M., and W.L.P. collected and processed data; J.D.S. analyzed data and drafted the manuscript; all authors edited and revised the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Software and algorithms		
R	The R Project for Statistical Computing	V4.0.0
Just Another Gibbs Sampler (JAGS)	Plummer 2013	V4.2.0
Other		
126mm Reconnaissance Camera	Chicago Aerial	KA 76A
Remotely Operated Hexacopter	Aerial Imaging Solutions	APH 22
Digital Camera System	Olympus	E PM2; 25mm Zuiko Lens

RESOURCE AVAILABILITY

Lead Contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Joshua Stewart (joshua.stewart@noaa.gov)

Materials Availability

This study did not generate new unique reagents

Data and Code Availability

All data and R code to replicate these analyses are available at http://github.com/stewart6/NARW-Growth.

EXPERIMENTAL MODEL AND SUBJECT DETAILS

Aerial photogrammetry measurements were collected from free-ranging North Atlantic Right Whales under NOAA National Marine Fisheries Service permits 21371, 17355 and 17355-01.

METHOD DETAILS

From 2000-2002, we used a fixed-winged, crewed airplane to collect aerial images of North Atlantic right whales (NARW) in the Bay of Fundy, Canada.[7] A 126mm format military reconnaissance camera captured images on film from approximately 250 m altitude. From 2016-2019 we flew a remotely controlled hexacopter drone at altitudes of approximately 50 m to collect images of NARW in Cape Cod Bay, U.S.A,[17] taking digital images using a 25mm lens mounted on an Olympus camera with micro 4/3 sensor.[26] Both methods achieved flat images that were undistorted across the entire frame. We collected altitude measurements using radar altimeters in 2000-2002,[7] drone GPS in 2016[17] and a laser altimeter[27] mounted on the vertical gimbal of the drone camera in 2017-2019. We established length estimates from image measurements by using altimetry data to convert image sensor distances to distances on the real scale.[7,26] We only selected images for use in length measurements when a whale was fully visible and appeared to be in flat orientation parallel to the water surface. In general, variability in repeated-measurements of total lengths of cetaceans is low, with average coefficients of variation typically ranging from approximately 1%–3%.[27–29] While altimeter inaccuracies can lead to both positive and negative length measurement errors, any movement or curvature of an animal will result in the animal appearing shorter from above than it actually is. To minimize this negative bias, and following previous studies using aerial photogrammetry to estimate cetacean lengths, we selected the longest measurement of each whale in cases of multiple measurements of an individual within a single sampling season[7,28,30]

We individually identified whales from aerial images based on their callosity patterns,[31] with known ages and birth years for individual whales provided by the Right Whale Consortium.[32] Directly observed entanglements with attached gear, as well as indirect evidence of entanglements (e.g., scarring) have been recorded for NARW since 1980.[9,32] Scarring patterns can provide approximate information about the severity of an entanglement injury (minor, moderate or severe),[33] but it is impossible to establish the duration of an entanglement based on scarring alone. Entanglements with attached gear provide quantitative—although still

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imperfect—information about entanglement duration. We estimated the minimum and maximum duration of entanglements with attached gear based on a whale's sighting records.[33] The minimum duration was calculated as the number of days between the date that a whale was first observed with gear attached and the date that a whale was last observed with gear attached. If a whale was first seen with attached gear on the same day that the gear was removed by a disentanglement team or shed by its next sighting, the minimum duration was recorded as one day. The maximum duration was calculated as the number of days between the most recent date that a whale was observed without attached gear prior to the first observation with attached gear, and the first observation without attached gear after the last observation with attached gear. For example, consider a whale that was seen on February 1st with no attached gear, March 10th with attached gear, May 1st with attached gear, and July 10th with no attached gear. The minimum entanglement duration would be March 10th – May 1st (52 days), and the maximum entanglement duration would be February 1st – July 10th (160 days). To account for the uncertainty in true entanglement duration, we used the midpoint between the minimum and maximum durations as our best estimate of entanglement duration. Growth rates in NARW slow considerably after age 10[7], so we used mid-point entanglement durations for any measured whale in our aerial photogrammetry dataset seen with attached gear during the first 10 years of life to represent a cumulative entanglement burden during early growth. If a length measurement was taken prior to age 10, we used the entanglement duration midpoint prior to that measurement. Entanglement duration was included as a continuous effect on asymptotic length (see model description below).

Maternal size and condition have been demonstrated to substantially impact calf growth rates in several populations of baleen whales, including southern hemisphere right whales.[4,5] This suggests that entanglements of a female with a dependent, nursing calf could affect calf growth if maternal energy stores are lost to excess drag from an entanglement.[34] In our dataset of aerial photogrammetry measurements, we had no records of measured whales whose mothers had an observed entanglement with attached gear while the measured whale was a nursing calf. However, there were three records of measured whales whose mothers were seen with attached gear that first appeared while the measured whale was < 1 year old and likely still nursing and eight records of measured whales whose mother was detected with attached gear or severe injuries that may have occurred when the calf was < 1 year old.[32] For measured whales whose mother had evidence of a severe entanglement injury or attached gear known to or likely to have occurred while the measured whale was nursing, we included a fixed effect of maternal entanglement on asymptotic length.

Lactation is an extremely costly life history event for right whales.[8] The energetic burden of supporting dependent calves could in theory reduce the amount of energy a female whale can devote to its own growth. We therefore considered the number of lactation events that a whale experienced[32] prior to age 10 as a continuous effect on the expected asymptotic length of that whale. If a whale was measured prior to age 10, we considered the number of lactation events experienced prior to measurement, similar to our handling of entanglement durations. For entanglement duration and number of lactation events, we scaled the covariate values associated with each measured whale to 1 by dividing the observed covariate by the maximum covariate value.

QUANTIFICATION AND STATISTICAL ANALYSIS

We based our growth model on the two-phase Gompertz growth function that was fit previously to age and length data for North Atlantic right whales collected between 2000 and 2002:[7]

$$S_t = Ae^{\ ce^{\ kt}}$$

where S is the expected length at age t, A is asymptotic length, c is the constant of integration, and k is the growth rate. This equation is fit separately in two phases to whales < 1 year old (Phase 1) and > 1 year old (Phase 2). We modified this equation to apply covariate effects to asymptotic length, such that:

$$S_{t,i} = A_i e^{\ ce^{\ kt}}$$

$$A_i = \widehat{A} + O_i$$

$$O_i = \sum_{j\ \ 1}^{n} Cov.Eff_{j,i}$$

$$Cov.Eff_{j,i} \sim N[Cov_{j,i} * \beta_j, \sigma_j]$$

where S is the expected length at age t for individual i, A is expected asymptotic length for individual i, $\widehat{A}$ is the asymptotic length shared across all whales before covariate effects are applied, and O is the asymptotic length offset for individual i. Cov is the covariate j (e.g., birth year, entanglement duration, etc.) experienced by whale i, and β is the model-estimated effect of covariate j. We introduce process error by allowing the estimated covariate effect $Cov.Eff$ to vary around the expected covariate effect with an independently estimated standard deviation σ for each covariate j. O is then calculated by summing the covariate effects $Cov.Eff$ for each individual *i.* We chose to apply covariate effects to asymptotic length because growth rate and asymptotic length are typically highly correlated in growth models, making it inappropriate to apply the same covariate to both parameters simultaneously. Whales are expected to have determinate growth due to the fusing of growth plates,[35,36] and we therefore applied covariate effects to asymptotic length rather than growth rate. This was based on the assumption that reduced early growth would lead to a truncated maximum attainable length for an individual, rather than slower growth that could eventually result in a similar maximum length to unaffected whales. In other words, we assume that the length a whale reaches by age 10-15 is likely to be close to the maximum size that whale can achieve. We applied the same model-estimated offset on asymptotic length to both growth phases. Our limited sample size of whales age < 1 (less than 10% of measured whales) contained no whales with attached gear or known maternal entanglements, and all but four measured calves were born in 2001, making the estimation of independent covariate effects for each growth phase impossible.

Previous analyses of NARW growth incorporated lengths from both aerial photogrammetry and necropsies from stranded whales. We excluded necropsied individuals from our analysis because we were investigating potentially small changes in body length as a result of covariate effects. Changes in body length are known to occur in stranded whales that have been towed to shore (stretching), and correction factors for these stretching effects are approximate.[7] As a result, our sample size of whales < 1 year old was smaller than in previous studies, so we applied an informative prior to $\widehat{A}$, *k,* and *c* for both Phase 1 & 2 based on the estimated parameters from the same Gompertz 2-phase growth equation fit using length data from both photogrammetry and necropsies:[7]

$$\widehat{A}_{\text{Phase1}} \sim N[11.93,\ 2.83]$$

$$\widehat{A}_{\text{Phase2}} \sim N[13.82, 0.28]$$

$$k_{Phase1} \sim N[2.325,\ 1.25]$$

$$k_{Phase2} \sim N[0.13,\ 0.03]$$

$$C_{Phase1} \sim N[1.017,\ 0.195]$$

$$\text{C}_{\text{Phase2}} \sim N[0.33,\ 0.02]$$

where each prior is normally distributed around a mean with standard deviation. This allowed parameter estimates to depart from the provided informative priors if there was sufficient information in the data to estimate a different value, but helped align baseline estimates of growth parameters with previous studies if there were insufficient data to produce a new estimate (see Figure S1 & Table S1).

To account for different aerial photogrammetry platforms that used different methods to calculate aircraft altitude (radar altimeter, GPS altimeter, and laser altimeter), we applied three separate model-estimated error terms to individual observations of length data, such that:

$$s_{t,i} \sim N[S_{t,i}, \sigma_{pt,i}]$$

where *s* is the measured length of individual *i* at age *t*, which is normally distributed around the expected length *S* of individual *i* based on its age *t* and applied covariate effects, with a unique standard deviation σ for each photogrammetry platform *p*, which is applied based on the platform used to measure individual *i* at time *t*.

We constructed and fit these models using the JAGS Bayesian modeling software[37] run via R.[38] We ran three chains, each of 100,000 iterations with a burn-in period of 50,000 iterations and a thinning interval of 50, for a total of 3,000 draws from the posterior distribution. Model convergence was determined based on visual inspection of chains and $\widehat{R}$ values < 1.05, which indicates that an infinite number of iterations would lead to potential reduction of posterior intervals by less than 5%.[39] We considered covariate effects to be significant if 95% of posterior draws for the estimated effect were < 0 for negative effects or > 0 for positive effects. To determine whether the model was specified appropriately, we performed posterior predictive checks on all 202 length measurements in our dataset. We applied the model-estimated covariate effects to the recorded covariates for each whale, and sampled from those mean values using the model-estimated observation error terms specific to the platforms used to image each whale. We then compared observed values to the 95% posterior prediction intervals (Figures S2 and S3).

EXHIBIT 15

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Larger females have more calves: influence of maternal body length on fecundity in North Atlantic right whales

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ABSTRACT: North Atlantic right whales (NARW) are critically endangered and have been declining in abundance since 2011. In the past decade, human-caused mortalities from vessel strikes and entanglements have been increasing, while birth rates in the population are at a 40 yr low. In addition to declining abundance, recent studies have shown that NARW length-at-age is decreasing due to the energetic impacts of sub-lethal entanglements, and that the body condition of the population is poorer than closely related southern right whales. We examined whether shorter body lengths are associated with reduced fecundity in female NARW. We compared age-corrected, modeled metrics of body length with 3 metrics of fecundity: age at first reproduction, average inter-birth interval, and the number of calves produced per potential reproductive year. We found that body length is significantly related to birth interval and calves produced per reproductive year, but not age at first reproduction. Larger whales had shorter inter-birth intervals and produced more calves per potential reproductive year. Larger whales also had higher lifetime calf production, but this was a result of larger whales having longer potential reproductive spans, as body lengths have generally been declining over the past 40 yr. Declining body sizes are a potential contributor to low birth rates over the past decade. Efforts to reduce entanglements and vessel strikes could help maintain population viability by increasing fecundity and improving resiliency of the population to other anthropogenic and climate impacts.

KEY WORDS: Photogrammetry · Cetacean · Reproduction · Anthropogenic impacts

1. INTRODUCTION

North Atlantic right whales *Eubalaena glacialis* (NARW) are listed under the Endangered Species Act in the USA (National Marine Fisheries Service 2008), the Species at Risk Act in Canada (COSEWIC 2013), and considered Critically Endangered by the International Union for Conservation of Nature (Cooke

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2020). Following a relatively slow but sustained 20 yr increase in abundance, the NARW population has been in decline since 2011, dropping from an estimated 481 whales in 2011 to an estimated 368 whales in 2019 (Pace 2021). Entanglements in fishing gear and vessel strikes are thought to be the leading sources of mortality in the NARW population (Moore et al. 2021). While a spike in mortalities in the past decade has contributed to the decline in abundance, birth rates in the NARW population have also been unusually low since 2012 (Pettis et al. 2021).

Previous studies have linked NARW fecundity to climate-associated fluctuations in *Calanus finmarchicus*, a key copepod prey species for NARW on their summer foraging grounds in the Gulf of Maine (Meyer-Gutbrod & Greene 2014, Meyer-Gutbrod et al. 2021). During periods of low *C. finmarchicus* abundance in the 1990s and early 2010s, birth rates dropped well below rates in the 1980s and the 2000s when *C. finmarchicus* abundance was higher, suggesting that prey availability is likely a major driver of fecundity in NARW (Meyer-Gutbrod et al. 2021).

Sub-lethal entanglements in fishing gear are energetically costly (van der Hoop et al. 2017) and an increasing rate of serious entanglements (i.e. those with attached gear or severe injuries; Knowlton et al. 2012) is likely to directly contribute to reduced birth rates by diverting energy away from reproduction and reducing fecundity or reproductive success. In addition, Stewart et al. (2021) showed that NARW body lengths have been decreasing since the 1980s, with entanglements explaining a portion of restricted growth rates. Maternal body size and condition in baleen whales are associated with calf growth rates and body sizes (Best & Rüther 1992, Christiansen et al. 2016, 2018), and Stewart et al. (2021) hypothesized that the shorter body lengths in NARW could also contribute to reduced fecundity by delaying first calving events and reducing reproductive success. Here, we build on the results of that study to investigate whether shorter body lengths in NARW are associated with reduced fecundity in females.

2. MATERIALS AND METHODS

Aerial photogrammetry measurements were collected from free-ranging NARW under NOAA National Marine Fisheries Service permits 21371, 17355, and 17355-01. From 2000 to 2002, we used a fixed-winged, crewed airplane to collect aerial images of NARW in the Bay of Fundy, Canada (Fortune et al. 2012). A 126 mm format military reconnaissance camera captured images on film from approximately 250 m altitude. Aircraft trim was monitored by scientists with bubble levels mounted at 2 sites in the back of the aircraft. During each pass over a whale, scientists communicated with the pilots to ensure the aircraft was in proper trim with the camera facing 90° downward off the vertical plane as the images were collected. A high precision paired transducer radar altimeter was used to collect altitude data during photo passes. Accuracy of the altimeter system was determined by photographing targets of known size and comparing altitudes calculated from measurements with those recorded from the altimeter (Perryman & Lynn 2002). From 2016 to 2019, we flew a remotely controlled hexacopter drone at altitudes of approximately 50 m to collect images of NARW in Cape Cod Bay, USA (Christiansen et al. 2020, Stewart et al. 2021), taking digital images using a 25 mm lens on an Olympus camera with micro 4/3 sensor (Durban et al. 2015), mounted in an electronic gimbal that maintained a 90° downward angle (Durban et al. 2022). We collected altitude measurements using drone GPS in 2016 (Christiansen et al. 2020) and a laser altimeter (Dawson et al. 2017) mounted on the vertical gimbal of the drone camera in 2017 to 2019 (Durban et al. 2021). The laser altimeter recorded altitude at a sampling rate of 16 measurements per second, and we selected the median altitude measurement from the same second that images were captured.

We calculated total lengths of whales using measured aircraft altitude, camera sensor/film size, and lens focal length to convert image sensor measurements to measurements on the real scale (Fortune et al. 2012, Durban et al. 2015). Images were filtered for those of measurement quality, such that the focus and clarity were sufficient to delineate the rostrum and tail for total length measurements. We only selected images for use in length measurements when a whale was fully visible and appeared to be in flat orientation parallel to the water surface. In general, variability in repeated measurements of total lengths of cetaceans is low, with average coefficients of variation typically <5% (Perryman & Lynn 1993, Miller et al. 2012, Durban et al. 2016) and in some cases approximately 1% (Dawson et al. 2017). While altimeter inaccuracies can lead to both positive and negative length measurement errors, any movement or curvature of an animal will result in the animal appearing shorter from above than it actually is. To minimize this negative bias, and following previous studies using aerial photogrammetry to estimate cetacean lengths, we selected the longest measurement of each whale in cases of multiple measurements of an individual within a single sampling season (Perryman & Lynn 1993, 2002, Fortune et al. 2012).

We developed a 2-phase Gompertz growth equation (modified from Fortune et al. 2012, 2021) with model-estimated covariate effects of birth year, fishing gear entanglements, and maternal entanglements applied to asymptotic length, as described by Stewart et al. (2021). Covariate values were summed across the first 10 yr of life, as growth rates slow considerably after age 10 (Fortune et al. 2021). The Gompertz growth model uses 2 main parameters to define individual growth trajectories: asymptotic length and growth rate. We chose to apply covariate effects to asymptotic length because growth rate and asymptotic length are typically highly correlated in growth models, making it inappropriate to apply the same covariate to both parameters simultaneously. Whales are expected to have determinate growth due to the fusing of growth plates (Kato 1988, Moran et al. 2015), which also supported our decision to apply covariate effects to asymptotic length rather than growth rate. This was based on the assumption that reduced early growth would lead to a truncated maximum attainable length for an individual, rather than slower growth that could eventually result in a similar maximum length to unaffected whales. In other words, we assume that the length a whale reaches by age 10 to 15 is likely to be close to the maximum size that whale can achieve (Fortune et al. 2021). In the growth model described by Stewart et al. (2021), we estimated separate observation error terms for measurements taken with the 3 different altimeter types (radar, GPS, and laser). Measurements taken using GPS altimeters had the highest estimated observation error (median 0.63 m, 95% CI 0.26–1.01 m), followed by laser altimeter measurements (0.52 m, 0.19–0.77 m) and radar altimeter measurements (0.27 m, 0.01–0.48 m). These observation errors were estimated within, and therefore explicitly included in, the growth model, propagating the resulting uncertainty into estimates of growth parameters, including in the estimates of asymptotic length used in the present study. Data collection, analysis, and model development and diagnostics are reported in further detail by Stewart et al. (2021).

For the analyses presented in this study, we examined a subset of the measured whales from Stewart et al. (2021). We only included female whales that were 6 yr or older at the time of measurement, which is the minimum reproductive age for the species (with one exception of parturition at 5 yr, see Hamilton et al. 1998). The reproductive histories of these whales were determined using the North Atlantic Right Whale Consortium identification database (North Atlantic Right Whale Consortium 2020). Measurements of individual whales were taken at different ages and across a 20 yr period. To standardize whale lengths on a common scale in order to evaluate relationships between size and fecundity, we used the asymptotic lengths of each whale estimated by the growth model of Stewart et al. (2021). The asymptotic lengths are the projected lengths that each whale would reach after infinite years, based on the model-estimated growth parameters and observed length-at-age of each whale (Fig. 1). This allows us to remove confounding effects of age on measured lengths, and produce a single relative size value that can be compared to lifetime metrics of fecundity. We considered the median of the Bayesian posterior distribution for model-estimated asymptotic length as our relative size metric for each whale, and included the uncertainty associated with the growth model estimates of asymptotic length in our analyses, as described below.

Reproduction in NARW is complex, with previous studies highlighting prey availability as a major driving factor of the timing of reproduction (Meyer-

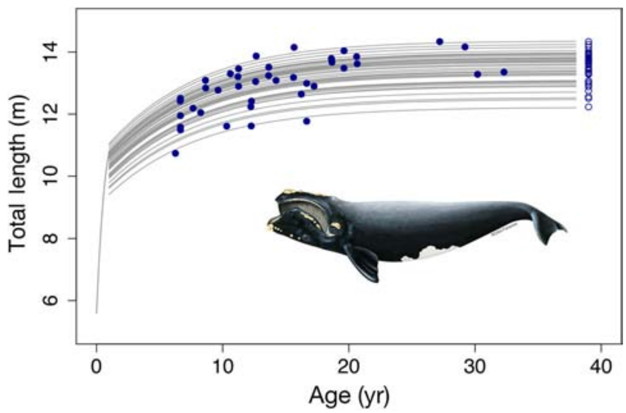

Fig. 1. Measured lengths and projected asymptotic lengths of North Atlantic right whale *Eubalaena glacialis* reproductive females. (●) Photogrammetry based measurements of total lengths of whales with known ages; gray curves: median of the Bayesian posterior distribution for the model estimated growth trajectory (from Stewart et al. 2021) for each of the 41 measured female whales in the present study, i.e. the most likely estimated growth trajectory associated with a length at age measurement after accounting for anthro pogenic impacts on growth using the 2 phase growth model specified by Stewart et al. (2021) (see Section 2). Note that measured total lengths are not expected to fall directly on the growth trajectories, as the lines are the median esti mates, and the growth model assumes observation error. In cases where a female was measured in more than 1 year, we show the length measurement associated with the oldest age. (○) Median model estimated asymptotic lengths, each corresponding to a measured whale

Gutbrod et al. 2021). Other factors such as female body condition are likely to affect reproductive timing and success (Miller et al. 2011, 2012, Christiansen et al. 2016, 2018). With this complexity in mind, our analyses are not intended to predict reproductive output in females. Instead, we use simple linear models to make inferences about the direction of the relationship (if any) between body lengths and metrics of fecundity, acknowledging the existence of many additional contributing factors.

We considered 4 metrics of fecundity to compare to estimated whale lengths. (1) Age at first reproduction, which we calculated as the number of years between the birth year of a whale and the year it was first observed with a dependent calf. We excluded females with zero births. (2) Average birth interval, which we calculated as the mean of the number of years between recorded births for an individual whale. For whales with only 2 recorded births, the average birth interval was the single recorded birth interval between the 2 births. We excluded females with zero or 1 recorded birth. (3) The total number of recorded births for each female whale, although this metric is severely confounded by maternal birth year (see next paragraph). (4) Births per reproductive year, which we calculated as the total number of recorded births divided by the potential reproductive span for each female whale. We calculated the potential reproductive span as the number of years between age 7 (the minimum age at first reproduction in our subset of female whales) and the year of the last recorded sighting of each whale.

While we accounted for the confounding effects of age at the time of measurement by using estimated asymptotic lengths rather than measured lengths, there are additional potentially confounding effects of age on some metrics of fecundity. Stewart et al. (2021) identified a declining linear trend in body length by birth year, where whales born in more recent years are stunted compared to older whales. Whales born more recently have, with few exceptions, the smallest estimated asymptotic lengths, and at the same time have had less time to reproduce than older whales, which could make it challenging to differentiate the effects of size versus potential reproductive span on fecundity (Fig. 2). For example, the maximum possible reproductive span for a whale declines linearly with its birth year (Fig. 2a). Similarly, the oldest observable age at first reproduction declines linearly with birth year (Fig. 2b). As the potential reproductive span of a whale increases, its total potential reproductive output predictably increases as well (Fig. 2c), meaning that older whales in general have produced more total offspring and are also generally the largest females. We addressed this by standardizing the total number of births by potential reproductive span to remove the correlation between birth year and reproductive output (Fig. 2d). In addition, average birth interval did not have a clear relationship with birth year, although no whales born after 2001 had enough births to calculate a birth interval (Fig. 2e).

To evaluate the relationships between fecundity and estimated whale length we used modified Bayesian linear regressions, fit using Markov chain Monte Carlo (MCMC) sampling implemented using JAGS (Plummer 2003) in R v4.1.2 (R Core Team 2021). In our analyses, the independent variable (estimated asymptotic length of a female) is derived from the growth model described by Stewart et al. (2021) with associated uncertainty (Fig. S1 in the Supplement at www.int-res.com/articles/suppl/m689p179 supp.pdf. To account for this uncertainty, we included an observation process in our regression models, such that:

$$\text{Est.}A_i \sim N(A_i, \sigma_i) \quad (1)$$

where Est.A is the estimated asymptotic length for individual i from the growth model, which is normally distributed around A, the latent or 'true' asymptotic length of individual i estimated by the regression model, with standard deviation σ, which is the standard deviation of the posterior distribution of the estimated asymptotic length for individual i from the growth model. We specified A with uninformative, uniform priors spanning 0 to 20. The regression model is then defined based on A, such that:

$$\mu_i = \beta_1 + \beta_2 \times A_i \quad (2)$$

where μ is the expected response for individual i, β_1 is the intercept for the regression, β_2 is the slope term, and A is the model-estimated true asymptotic length of individual i, as in Eq. (1). We specified both the slope and intercept terms using uninformative, normally distributed priors with mean 0 and standard deviation 10. For the analysis of total births, which are effectively count data, we modeled births as Poisson distributed around the mean linear relationship, such that:

$$\text{Obs}_i \sim \text{Poisson}(\mu_i) \quad (3)$$

where Obs is the observed fecundity metric (in this case total births) of individual i, which is Poisson

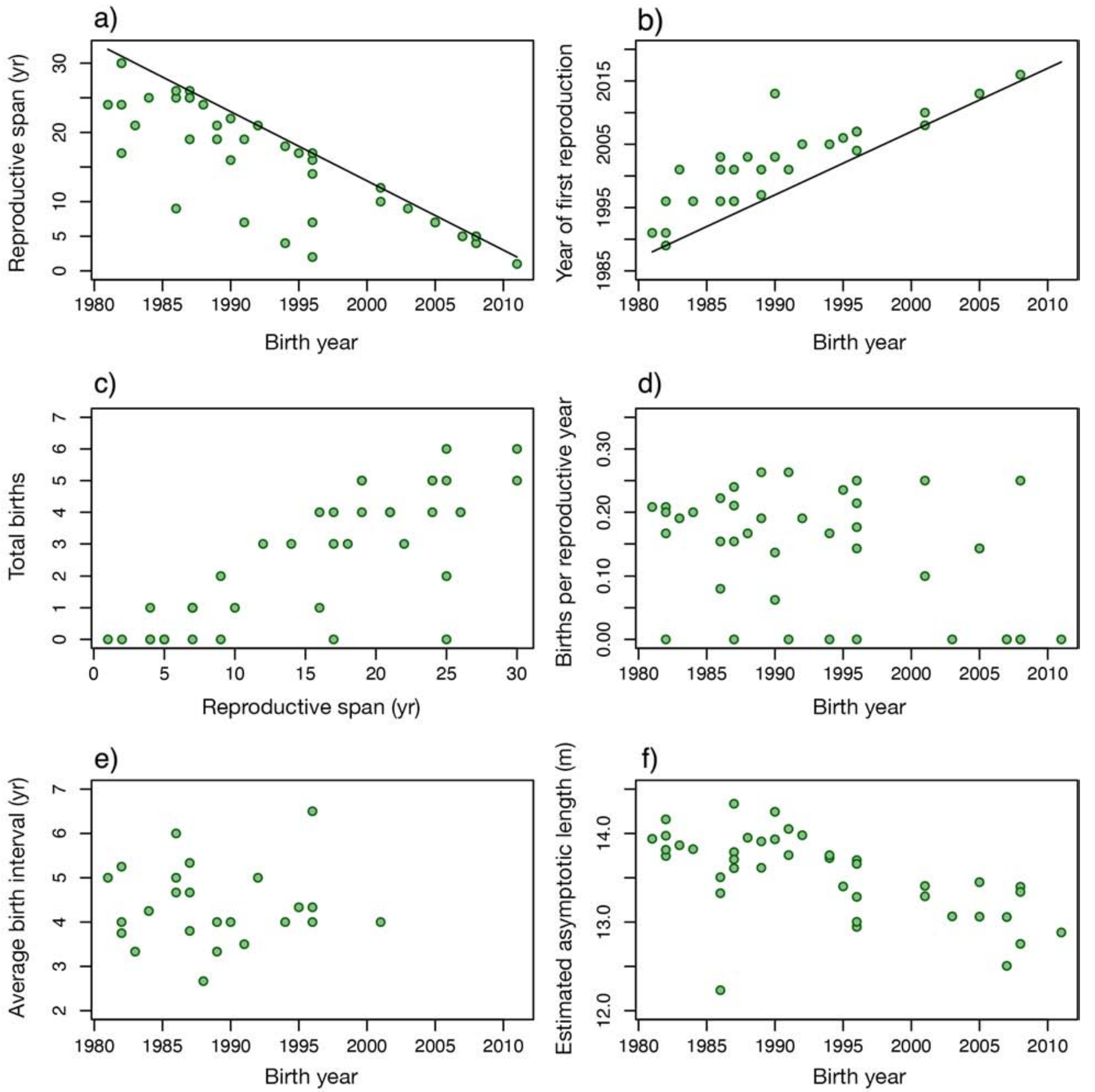

Fig. 2. Potentially confounding effects of birth year on metrics of fecundity in female North Atlantic right whales. (a) Potential reproductive span (defined here as the number of years between age 7 and the most recent sighting of an individual whale) of whales related to their birth year. Solid black line: maximum possible reproductive span for a whale based on its birth year. (b) Year of first observed reproduction related to birth year. Solid black line: earliest possible year of first reproduction for a whale born in a given year, using the minimum age at first reproduction of 7 in our subset of females. (c) Total recorded births for each female as related to their potential reproductive span. (d) Births per reproductive year (calculated as the number of recorded births for each female divided by their potential reproductive span for that female) by birth year. (e) Average birth interval for each whale by birth year. (f) Model estimated asymptotic length and birth year of each female

distributed with mean μ, the expected response for individual *i*. For average birth interval, age at first reproduction, and births per reproductive year, we modeled the response variables as normally distributed around the mean linear relationship, such that:

$$\text{Obs}_i \sim N(\mu_i, \sigma) \quad (4)$$

where Obs is the observed fecundity metric (in this case average birth interval, age at first reproduction, or births per reproductive year) of individual *i*, which is normally distributed with mean μ and standard deviation σ. We specified σ with uninformative, uniform priors spanning 0 to 5. For each model, we ran 3 chains of 200 000 iterations with a burn-in of 100 000 and a thinning interval of 200, resulting in 1500 draws from the posterior distribution. We evaluated convergence of the regression models based on visual inspection of chains and $\hat{R}$ values <1.01, which indicates that an infinite number of iterations would lead to potential reduction of posterior intervals by less than 1% (Gelman & Rubin 1992).

As noted above, birth year and estimated asymptotic length are highly correlated (correlation coefficient −0.63; or −0.79 if we exclude Whale 1608, born in 1986 with estimated asymptotic length 12.23, see Fig. 2f). This multicollinearity precluded us from using multivariate analyses with both estimated asymptotic length and birth year as explanatory variables for fecundity, as the estimated regression coefficients from multivariate regressions were similarly correlated.

3. RESULTS

Our subset of reproductive females included 41 whales, measured between 2000 and 2019 at ages ranging from 6 to 32 (Fig. 1). Of these, 21 whales were measured in only 1 year, 13 were measured in 2 years, 5 were measured in 3 years, and 2 were measured in 4 years. The ages of those whales at the time of their last sighting ranged from 8 to 37 yr old, and the time gap between the year of measurement and the year of last sighting in the photo-identification database ranged from 0 to 20 yr (median 8 yr). The median number of total calves born to each whale was 3 (range 0–6). A total of 11 whales (26.8%) did not reproduce, 6 whales (14.6%) reproduced only once, and 24 whales (58.5%) reproduced at least twice, allowing us to calculate reproductive intervals for this subset of females. To evaluate the statistical significance of linear regression slope coefficients, we calculated the proportion of the Bayesian posterior MCMC samples that were greater than (or less than) zero, which corresponds to the probability that the slope coefficient is positive or negative. If more than 95% of the posterior draws were greater than or less than zero, we considered the regression to be statistically significant. If more than 90% of posterior draws were greater than or less than zero, we considered the regression to be marginally significant. As expected, we found a significant positive relationship between length and total births (99.5% of posterior draws >0), which illustrates the correlation between maternal length, birth year, and reproductive span, and should not be interpreted as a biologically meaningful result. We found a significant positive relationship between length and births per reproductive year (97.8% of posterior draws >0); a marginally significant negative relationship between estimated asymptotic length and average birth interval (92.9% <0; Fig. 3); and a marginally significant positive relationship between length and age at first reproduction (92.0% >0). To evaluate the leverage of the smallest female in our dataset (Whale 1608) on the analyses, we ran the regression models both including and excluding this whale. With Whale 1608 excluded, the linear relationship between estimated asymptotic length and average birth interval was not significant (63.5% of posterior draws <0), the relationship between age at first reproduction and estimated asymptotic length was significant (96.9% >0), and the relationship between births per reproductive year and estimated asymptotic length remained significant (96.9% >0; see Fig. S2). In all of the linear regressions, >95% of the observations were within the 95% posterior prediction intervals of the regressions, indicating that the regressions were correctly specified to the distributions of the observed data (Fig. S3).

4. DISCUSSION

Our findings add to a growing body of evidence demonstrating that maternal size and nutritive condition in baleen whales influence fecundity through a variety of mechanisms. Larger and more robust females produce larger and more robust calves (Best & Rüther 1992, Perryman & Lynn 2002, Christiansen et al. 2016, 2018), which may influence calf survival rates. We show that smaller females produce fewer calves per reproductive year, possibly because the average interval between births is greater in shorter whales. Late gestation and lactation are costly energetic phases for female whales (Villegas-Amtmann et al. 2015, van der Hoop et al. 2017), with female body condition declining as calves increase in size prior to weaning (Miller et al. 2011, 2012, Christiansen et al. 2016, 2018). The degree to which the energetic reserves of females are depleted during lactation may govern the length of the resting period between successful pregnancies (Miller et al. 2011, Marón et al. 2015). The total energetic reserves of a female whale should be dependent on body volume, which is a combination of both body length and nutritive condition (Christiansen et al. 2018). Shorter whales would therefore be inherently limited in their

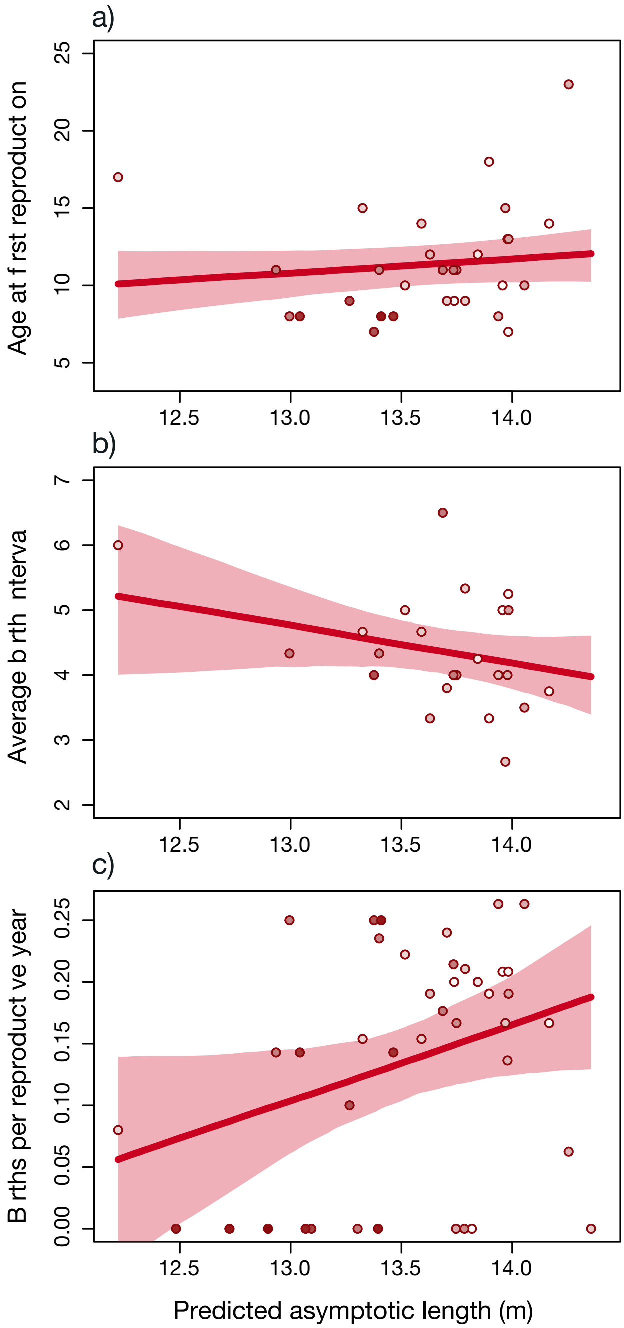

Fig. 3. Relationships between fecundity and the estimated asymptotic length of female North Atlantic right whales. Dark red line: median estimate of the Bayesian posterior dis tribution; light red polygon: 95% Bayesian credible interval for the linear regressions between: (a) estimated asymptotic lengths and the observed age at first reproduction; (b) esti mated asymptotic lengths and average birth intervals; and (c) estimated asymptotic lengths and the number of ob served births per reproductive year. In all panels, point colors represent the birth year of a given whale, with lighter colors representing whales born in earlier years and darker colors representing whales born in later years (range 1981 2011). Note Whale 1608 (born in 1986) had the smallest predicted asymptotic length of any whale in the dataset (leftmost point in all panels)

maximum energetic reserves compared to longer whales, even if they attain similar nutritive condition and blubber thickness, and may require a longer recovery period between births.

There are undoubtedly many other factors influencing reproduction and fecundity in NARW beyond female body lengths, including prey availability (Meyer-Gutbrod et al. 2021), maternal health (Rolland et al. 2016), and individual nutritive condition (Miller et al. 2011, 2012). Reduced prey availability in the 1990s and early 2010s was associated with a reduction in birth rates throughout the NARW population (Meyer-Gutbrod et al. 2021). Some of the shortest whales in our dataset were born in the early 2000s and would have reached sexual maturity during this recent period of reduced prey availability, which may be confounding the effects of maternal body length on fecundity. Indeed, 5 out of 10 females in our dataset born between 2001 and 2008 have not yet reproduced despite reaching ages ranging from 11 to 16, and it is challenging to determine how maternal length, prey availability, and the truncated observation windows due to the later birth years of these whales are each influencing the recorded reproductive output in this recent cohort of females. We note that the prediction intervals of our linear regressions, in particular the relationship between estimated asymptotic length and births per reproductive year, are wide (Fig. S3). This highlights that our analyses are most useful for inferring the direction of relationships between size and fecundity, and not for predicting the reproductive output of a female based solely on her estimated asymptotic length. A more complete accounting of the many potential drivers of reproductive output in NARW would help evaluate the relative contributions of these drivers to the depressed birth rates in recent years. For example, the multi-state model developed by Meyer-Gutbrod et al. (2021) could be extended to include maternal body length, health (e.g. Rolland et al. 2016), and nutritive condition in addition to prey availability, in order to explicitly account for these effects and their interactions. Nevertheless, while the effects of prey availability on fecundity almost certainly add noise to our analyses, our observations span periods of both high and low prey abundance, which should mitigate the confounding influence of prey availability on our inferences of the direction of the relationships between maternal body length and fecundity.

Maternal age at the time of reproduction may have important effects on calf fitness related to maternal body size and nutritive condition. For example, Whale 1608 had the shortest estimated asymptotic length (~12 m) of any female in our dataset and was a clear outlier among females born prior to 2000 (Fig. 2f). Her mother, Whale 1163, was entangled with attached gear while nursing 1608, which has a reported negative effect on calf growth (Stewart et al. 2021). In addition, the birth of Whale 1608 to Whale 1163 at age 5 is the youngest recorded age at first reproduction in the population (Hamilton et al. 1998). While maternal age was not explored as a potential effect on NARW growth rates by Stewart et al. (2021), it is likely that this reflects the pattern reported previously in several cetacean species of smaller female whales producing smaller calves (Best & Rüther 1992, Perryman & Lynn 2002, Christiansen et al. 2016). At 5 yr, Whale 1163 would be substantially smaller than most reproductive females and would likely be devoting considerable energy to her own continued growth, in addition to the added drag of attached gear, which may have contributed to the reduced growth of Whale 1608. In turn, Whale 1608 had one of the lower reproductive rates among females in our dataset (Fig. 3).

Almost all female whales with an estimated asymptotic length below 13 m in our dataset produced 0 or 1 calves within our study period, excluding them from our analyses of average birth interval. The 1 exception was Whale 1608, which, as noted above, was anomalously small for her cohort, most likely due to the age and entanglement status of her mother at her time of birth. When Whale 1608 is excluded from our analysis of average birth interval, the negative regression slope changes from moderately significant (92.5% of posterior draws <0) to not significant (63.5% <0). One possible explanation for this pattern is that average birth interval is not, in fact, related to the estimated asymptotic length of a female, and that the long birth interval recorded in Whale 1608 is an outlier. However, when Whale 1608 is excluded from the analysis of births per reproductive year, the positive regression slope remains significant (96.9% >0). Presumably, birth interval is the mechanism driving the number of calves a female produces per reproductive year, as a longer average birth interval would result in fewer calves produced within a given reproductive span. As such, our analysis of births per reproductive year is similar to our analysis of average birth interval, with the primary difference that we can include females that have produced 0 or 1 calves. Given that the regression analysis of births per reproductive year remains largely unchanged with or without the inclusion of Whale 1608, we posit that a more likely explanation is that our analysis of average birth interval is heavily impacted by our limited sample size, especially of younger females with shorter estimated asymptotic lengths. As these younger females extend their reproductive spans in coming years and produce more calves, it should be possible to determine whether the average birth interval of Whale 1608 is anomalous or indicative of the true influence of maternal length on birth intervals.

Interestingly, the relationship between female length and the age at first reproduction was opposite to the expectations of Stewart et al. (2021), who hypothesized that shorter females may need to delay first reproduction. Age at first reproduction was positively related to estimated asymptotic length, either at the marginal significance level (92% >0) or the full significance level (96.9% >0), depending on whether Whale 1608 was included or excluded in the analysis, respectively. The average age at first reproduction for female right whales is 9.6 (Hamilton et al. 1998), and almost half of the females in our dataset produced their first calf before age 10. This suggests that most female NARW produce their first calf before they have reached their expected maximum length (Fortune et al. 2021), and that the length of a female may not have a strong influence on when she first reproduces, as exemplified by Whale 1163, who had her first calving event at age 5. Instead, it is possible that the positive relationship between age at first reproduction and estimated asymptotic length we report here is indicative of the effect that delaying first reproduction can have on early growth in females. For example, females delaying first reproduction until after age 10 may devote the energy that would otherwise be used on parturition and lactation towards their own growth. However, we note that Stewart et al. (2021) explicitly included the number of calves produced before age 10 as an explanatory covariate for estimated asymptotic length, and found no significant effect. As such, we caution the overinterpretation of this result and emphasize that our sample sizes in the age at first reproduction analysis are constrained only to whales that have reproduced, which excludes many of the smallest whales in our dataset, similar to our average birth interval analysis.

In our analyses, we considered the number of calves produced by each female to be known. However, the NARW population is not fully censused each year, and between 1990 and 2018, 86 calves were born that were observed with their mothers but could not be photo-identified (Hamilton et al. 2022, P. K. Hamilton unpubl.). From 1991 to 2018, 105 whales with unknown birth years were added to the NARW photo identification database (P. K. Hamilton unpubl.). This implies that a minimum of 19 births were not recorded; more if some proportion of the 86 unidentified calves died and were not part of the 105 whales with unknown birth years. The reported reproductive histories of females in our dataset may therefore be incomplete in some cases, although we note that the minimum of 19 missing births would be applied to all reproductive females in the population, which is at least 4 times as large as our sample of 41 females analyzed here. If a calf were missing from the recorded reproductive history of a female, it would lead to an inflation of her average birth interval and an underestimate of fecundity (total births and births per reproductive year). If her first birth were missed, it could also affect the reported age at first reproduction. If every female in the dataset shares the same probability of having an unobserved calf, then we would expect these observation errors to produce a minimal effect on our analyses, especially at the scale of an expected approximately 5 missing calves from our dataset. However, if an observation bias exists, it is more likely that older females would have unobserved calving events, as survey effort for NARW at both their foraging grounds and calving grounds has increased over the past 40 yr. If the fecundity of older females is higher than reported here, we would expect the linear relationships between asymptotic length and fecundity to be even stronger than our results suggest, as older females are generally the largest individuals in our dataset. The one exception to this expectation is in the case of Whale 1608. If Whale 1608 had an unobserved calving event, then her average birth interval would likely be substantially lower, which would affect the significance of our birth interval analysis, as noted above.

Given the recently described declining trend in NARW body lengths by birth year (Stewart et al. 2021), the relationships we present here between body length and fecundity may be contributing to depressed birth rates in the population, and may be an early indicator of reduced birth rates for NARW in the future if the adult female size structure continues to decline. We did not examine the effects of body condition on birth rates as we typically have only 1 to 2 body condition measurements per female, and body condition fluctuates interannually depending on prey availability and individual energetic demands, making it impossible to compare annual body condition measurements with lifetime fecundity metrics. However, the overall body condition of the NARW population is poor compared to southern right whale populations (Miller et al. 2011, Christiansen et al. 2020). Body condition fluctuates substantially throughout the reproductive cycle of right whales, with the greatest blubber thickness observed in females shortly before the initiation of pregnancies, the thinnest blubber in lactating whales, and increasing blubber thickness post-weaning (Miller et al. 2011). The poor body condition observed in the NARW population may therefore be an indicator that females have insufficient energetic reserves to maintain a similar reproductive rate to southern right whales (1.98% population growth rate for NARW, 5.34–7.21% for southern right whales; Corkeron et al. 2018). The cumulative impacts of rapidly changing ocean conditions in the North Atlantic, repeated and worsening entanglements (Knowlton et al. 2012), and increasing vessel traffic and ship strikes may all be partially driving body length and condition declines in NARW (Corkeron et al. 2018, Christiansen et al. 2020, Stewart et al. 2021), which may have contributed to depressed birth rates in the past decade. Entanglements are energetically costly (van der Hoop et al. 2017), and there is a detectable negative effect of entanglements in fishing gear on whale lengths (Stewart et al. 2021). Reducing entanglements in fishing gear could help arrest the observed decline in body lengths in the NARW population as well as improve individual body condition, which may in turn help maintain population viability by increasing fecundity and improving resiliency to other anthropogenic and climate impacts.

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ARTICLE

Vertical Line Requirements and North Atlantic Right Whale Entanglement Risk Reduction for the Gulf of Maine American Lobster Fishery

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Abstract
In the U.S. western Atlantic Ocean, North Atlantic right whales *Eubalaena glacialis* are subject to gear entanglement in fixed-gear vertical line fisheries, with mortality risk increasing with line strength and spatial density. U.S. federal management agencies have mandated vertical line strength limits (235.033-kg-m [1,700-ft-lb] breaking strength) to curtail the injury and mortality risk that entanglement poses to right whales. Limiting the strength of vertical lines used in the trap fishery for American lobster *Homarus americanus*, however, could negatively impact the economic resilience of New England fishing communities if it forces the purchase of new equipment or increases the incidence of break-offs and lost gear. We provide a novel look at the spatially distinct vertical line strength requirements for the Maine American lobster trap fishery. The hauling load requirements of the fishery were modeled using measurements of strain put on vertical lines used in typical lobster trap operations to determine the minimum strength necessary to fish safely and avoid dangerous line breaks. New regulations on minimum trawl lengths (number of traps fished per vertical line) taking effect in 2022 will cause increases in lobster fishery vertical line loads across all fishing grounds, considerably increasing with depth and distance from shore. Our models indicated that inshore areas can be safely fished with vertical lines within the recommended whale-safe 235.033-kg-m (1,700-ft-lb) breaking strength specification, whereas the offshore lobster fishery will need a suite of measures beyond line strength reductions to reduce entanglement risk and mortality of right whales. We provide guidelines for the minimum line strength necessary for fishery operations, which can be used to inform management goals that balance the need for a sustainable lobster fishery and the conservation of right whales.

Fixed-gear fisheries support some of the most valuable crustacean landings in North America, occurring across the northeastern USA and Atlantic Canada (NMFS 2020). These fisheries also represent the greatest cause of human-induced injury and mortality to the critically endangered North Atlantic right whale (NARW)

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Eubalaena glacialis, with ship strikes being the second most frequent cause (Knowlton et al. 2012; Kraus et al. 2016; Pettis et al. 2021). Right whale entanglement has been linked with several novel, unusual mortality events in Canada resulting from a shifting right whale population distribution; these events killed between 7% and 17% of the total NARW population over a span of 3 years (Meyer-Gutbrod et al. 2021; Pace et al. 2021; Pettis et al. 2021). Right whale entanglement not resulting in mortality is expected to be a major contributor to reduced fitness, reduced size at age, and historically low calving rates (Pettis et al. 2021; Stewart et al. 2021). In 1990 2010, the NARW population experienced a window of recovery from historic lows, but since 2010 it has been in decline, with an estimated current population of 366 individuals (Pace et al. 2014, 2017; Pettis et al. 2021). Considering the current NARW population size and the potential for entanglement events to cause continued injury and mortality, entanglement mitigation efforts are a necessity.

Within the Gulf of Maine (GoM; Figure 1), vertical lines that pose entanglement risk are overwhelmingly represented by the trap fishery for American lobster *Homarus americanus*. The exact risk to NARWs from the variable vertical lines used by the American lobster fishery is understudied. Risk assessments generally try to capture the likelihood of spatial overlap between whales and traps as well as the effects of entanglement severity when they occur (NOAA 2020). Calculated risk assessments using vertical line strength, density, and spatial distribution along with spatial co-occurrence of vertical lines used in trap/pot fisheries and NARWs show a need to reduce entanglement risk by 60% to bring injury and mortality to acceptable levels (Johnson et al. 2005; Knowlton et al. 2016; NOAA 2020). Within the GoM, reductions in

FIGURE 1. Study area in the Gulf of Maine on the East Coast of the USA.

vertical line density and strength constitute a powerful method to reduce risk, as NARW densities are low and their transit paths through the GoM are unpredictable (Davis et al. 2017; Meyer-Gutbrod et al. 2021). The final federal rule to reduce the severity of NARW injuries and the frequency of mortalities that result from entanglement targets the breaking strength and spatial density of vertical lines used by the American lobster fishery (NMFS 2021); however, the line strength requirements for the fishery have not been comprehensively evaluated.

The entanglement problem remains unsolved, partially due to the lack of information on the spatial distribution of entanglement events. The distribution of NARWs is extremely variable, with high variance in seasonal occupancy across the GoM over time (Davis et al. 2017). The frequency of right whale migration is dependent on sex, age, and food availability (Gowan et al. 2019). Right whale distribution is shifting from historic ranges further north in pursuit of ideal prey calanoid copepods resulting in shorter residence times within the GoM (Meyer-Gutbrod et al. 2021). Sublethal entanglement events are common, with 82.9% of adult NARWs bearing entanglement scars, while gear is rarely retrieved from whales that are killed by entanglement (Johnson et al. 2005; Knowlton et al. 2012). This shortage of recovered gear makes it difficult to attribute entanglement events to a specific fishery area; attribution may be enhanced by the new gear marking rules, but it is unlikely that NARW mortalities will be discretely attributable in time for any immediate management action. The difficulty in attributing entanglement to a distinct fishery or spatial source has forced risk reduction proposals to take broad action across the range of this animal to reduce entanglement risk. It is difficult to propose effective risk reduction measures across the range of the NARW while fishing practices and gear requirements are not spatially uniform, especially within the diverse American lobster fishery found in the GoM (McCarron and Tetreault 2012).

The American lobster fishery represents the most valuable single-species fishery in the United States (NMFS 2020). Within the GoM, this fishery is uniquely composed of thousands of owner operator vessels fishing diverse gear configurations (McCarron and Tetreault 2012). Management measures regulating the allowed vertical line strength within this fishery could cost licensed fishers heavily, as new lines or weak links must be purchased to bring gear within specification. The proposed regulations have been the focus of a cost benefit analysis, with the cost of compliance and lost fishing revenue of US$9.8 19.2 million across affected fisheries (NMFS 2021). Fisher preferences regarding trawl lengths and total trap limits are highly variable, with the fisher response to these management measures being difficult to predict (Acheson 2001). Without spatially explicit knowledge of the gear requirements for fishing in the GoM, proposed regulations may (1) increase the risk of line breaks and make fishing more unsafe, (2) have unforeseen effects on fisher behavior, and (3) result in expensive gear loss in parts of the GoM. Gear lost to parted vertical lines can occasionally be recovered but often result in an expense to fishers and a risk to benthic organisms as "ghost" gear (Goodman et al. 2021). Knowledge about the gear configuration preferences of fishers across the GoM could influence management to consider alternative NARW risk reduction measures that minimize safety risks to fishers, as well as minimizing the economic impact of changes to gear configuration.

The modern fishery for American lobster has low social resilience to cope with extreme changes in landings or potentially strict management changes; extreme or unfeasible requests from management agencies may have outsize effects on this fishery (Henry and Johnson 2015). Modeling the relationship between lobster gear requirements and the oceanographic parameters of the local environment will provide a novel description of the fishing gear landscape in the GoM. This landscape can be used to validate currently untested assumptions about fishing gear and effort, guiding regulations that balance the needs of a sustainable lobster industry with risk reduction for the endangered NARW.

The American lobster fishery operates across large spatial scales, pursuing a shifting lobster distribution that changes seasonally and, more broadly, with climate change (Chen et al. 2005; Tanaka and Chen 2015). Likewise, the fishery operates at variable densities and with a variety of trawl lengths spatially and seasonally to pursue shifting lobster distributions (Kelly 1993; McCarron and Tetreault 2012). We propose that the most effective way to categorize the needs of the fishery is to account for the oceanographic and gear configuration variables that influence the vertical line strength needs of GoM fishers by modeling the load and line requirements for the fishery across the GoM.

Gear specifications are variable across fishers and areas and must be accounted for to accurately forecast industry needs and regulatory impacts. Federal right whale risk reduction rules use a 235.03-kg-m (1,700-ft-lb) breaking strength maximum for all or part of the vertical lines used in these fisheries to limit the potential for serious injury and mortality of NARWs in cases of entanglement (Knowlton et al. 2016; NOAA 2020). The feasibility of implementing these weak links across management zones is untested, and the current breaking strengths of lines used in the fishery are an unknown point of assumption, as identified by the Atlantic Large Whale Take Reduction Team (ALWTRT 2017).

In this study, we assess the typical loads to which modern lobster gear is subjected across the GoM as the gear is hauled. Using load cells, we captured the actual load as different gear configurations were fished across multiple fishing and geographic conditions. This method of quantifying local fishing practices can support regional gear modification regulations rather than blanket regulation. Using generalized additive models (GAMs), we predicted the minimum vertical line strength requirements spatially across the GoM. We also generated recommendations for (1) areas that can safely fish with vertical lines that are within the recommended breaking strength specifications and (2) areas that need a suite of measures beyond line strength reductions to reduce entanglement risk and mortality.

METHODS

This study used data collected by volunteer fishers across Maine, New Hampshire, Massachusetts, and Rhode Island (Figure 1). Volunteers were solicited by the University of Maine, FB Environmental, the Maine Department of Marine Resources (DMR), and local stakeholder organizations from 2018 to 2020. Volunteers were solicited by a mixture of local management meetings, cold calls, event outreach, and stakeholder group involvement, relying on local industry knowledge to direct our efforts. Outreach was directed to best represent the gear variety seen within the American lobster fishery in the GoM, fishing at variable depths with a variety of gear configurations. Volunteers were chosen opportunistically based on (1) availability to adapt their fishing methods to the use of a load cell and (2) willingness to participate. The final data set included 635 hauls worth of data from 16 different lobster fisher volunteers. This selection of fishers and representative hauls covered a wide range of trawl lengths, depths, and spatial areas (Supplementary Table 1 available separately online). Since the relationship between load and gear parameters is a physical correlation, encompassing the full variety of trap configurations across spatial scales is an important data consideration.

For effective model outputs, we required quantitative data on the actual load to which fixed gear is subjected while being fished in the GoM. This load data must be collated with appropriate environmental variables to quantify their effects on load. Volunteer fishermen were asked to complete a load cell characterization sheet and to provide data on vessel size, hauler size, sea state, the management zone in which they were operating, distance from shore, depth fished, average number of traps fished per trawl, groundline spacing between traps, weight of traps, anchor weight (if used), vertical line rope (diameter, type, and brand), and scope (the additional length of line beyond depth, used to account for tidal pull), as well as the presence of knots and splices in the vertical line. Distance from shore was binned into commonly used state-recognized management zone bins of 0–5.556 km (0 3 nautical miles [nm]), 5.556–22.22 km (3 12 nm), and 22.22 or more kilometers (12+ nm) from shore. These generalized bins were chosen rather than specific latitude longitude coordinates to reduce the burden of data recording on fishers and encourage participation in a fishery where fishing spots are well guarded (Acheson 2001). The line 11.11 km (6 nm) from shore was developed with the new federal regulations to provide additional specificity to trawl minimum areas. The 11.11-km (6-nm) line was not commonly used as a management tool during the period of data collection and was not used to bin data until the incorporation of the new trawl rules.

Load cells were fixed to the vessel at the point where the davit joins the hauling block. The davit acts as an arm and supports the hauling block over the water, where the load cell can accurately represent the downward pull of the line over the hauling block (pulley). The load cell continuously recorded the actual load as gear was hauled over the block, giving an output of the total force load on the line in foot-pounds at time intervals of approximately 3 readings/s over the course of the haul. Data were transmitted through a receiver onto an onboard laptop via software provided by the load cell manufacturer (Load Cell Central, Milan, Pennsylvania). Fishers were encouraged to run as many hauls as possible with the load cell; however, the increase in hauling block length resulting from the load cell restricted the efficiency of some hauling operations and reduced the volume of hauls possible for many fishers. When use of the load cell was completed, data were pulled from the computer and forwarded to the University of Maine for quality control and analysis.

Load cell data arrived as CSV (comma-separated values) files with time stamps. Individual CSV files were analyzed to ensure that no partial hauls or corrupted data were included. Load cell run time was then edited into discrete individual haul sessions. R programming language code developed by the Maine DMR was used to build plots of load across haul length. The position of the vertical line was identified as all lines between the surface buoy and the first trap to come aboard the fishing vessel. Trap positioning was identified on load plots as dips following spikes in the smoothed load rating. To ground-truth our data analysis process, observers from our research partner, FB Environmental, accompanied the load cell users and took notes on hauling methodology, trap timing, hang-up events, and snarl events, with precise spatial coordinates. These observer ground-truthing data were used to validate our methods. Time stamps indicating when the first trap came aboard found the dip-and-peak trap identification method to be effective for identifying the approximate end of the vertical line.

The point of maximum load on the vertical line varies with hauling factors like depth and the occurrence of hang-ups and snags on the seafloor. Load on the line was calculated by applying a conversion factor to the load cell output, allowing us to account for the multiplication of force as the line is hauled over the hauling block. Although the angle of the line over the block is variable depending on gear and vessel positioning and is influenced by wave and tidal action, we assumed an average of 90° when applying the conversion to these data. This angle conversion choice was validated by onboard observers as representative of typical hauling behavior. The conversion represented the physical formula (hauling stress/angle factor = true load). Conversion was performed with a multiplication factor of 0.7092, representing an angle factor of 1.41 that was taken from published block load multiplier engineering tables (Crosby Group 2013). Data were converted to metric units postanalysis.

Once identified, the maximum load experienced on the vertical line per haul was collated with other hauling information provided by the fishermen. These variables represent spatial identifiers (state, management area, and distance from shore), oceanographic parameters (weather, sea state, and depth), and fisher gear configuration data (vessel size, hauler size, traps per trawl, groundline spacing, scope, use of anchors, trap weight, rope diameter, presence of knots and splices, percent floating line, and additional room for individual comments). Due to the independent deployment of load cells with fishers, accuracy and fulfillment of these gear configuration data varied between fishers and between hauls. Additional quality control and follow-up with fisher volunteers to ensure the accuracy of these data were required, and some fields did not receive sufficient responses for meaningful analysis.

To supplement the spatial coverage of our load cell data and to account for variable fisher trawl length configurations across the GoM, observer data from the Maine DMR lobster survey program were sourced. These data represent the effort of Maine DMR observers sampling biological data across the fishery. For our modeling purposes, depth, trawl length, and latitude longitude positioning were taken from this data set. Incorporating this data set gave us the typical trawl lengths in Maine waters fished at a higher spatial resolution than the distance-from-shore bins used for the load cell data. We used a data subset that included the time frame of 2009 2019 to best represent modern fishing trends. Additional quality control was performed after data reception; trawl lengths over 40 traps, or long trawl lengths in atypically shallow water (e.g., 40 traps in 9.14 m [5 fathoms]), were assumed to be sampling error and removed as they did not match the known behavior of the fishery.

This study assumed that the relationship between gear and oceanographic parameters remains relatively constant over time and space. This is reasonable due to the relatively static nature of fixed-gear lobster fishery methods (Chen et al. 2005), as lobster traps have not functionally changed within the past two decades, and fishers set variable amounts of the same gear not different gear across spatial scales (McCarron and Tetreault 2012). For discussion purposes, this study also uses the Maine state and federally designated lobster management zones and distance-from-shore bins to make results more easily comparable to state and federal proposed rules.

Although data were collected with industry partners from coastal states across New England, we have limited the scale of this article to the Maine coastline. This decision was made to ensure that our assumptions would reflect the behavior of the fishing fleet. Data and products were routinely presented to lobster zone council meetings to solicit fisher feedback, which was incorporated into model decision making as much as possible. Zone council meetings are composed of fishers, management staff, nonfisher lobster industry members, and the public. These meetings exist to advise state management and settle issues within the fishery. Zone council members and meeting attendees were asked to describe whether they felt that the samples were representative of their fishing effort. Although we were restricted to the fishers that attended these meetings, those in attendance felt comfortable with the representation of our sampling distribution. This scientist fisher relationship was not as available for states other than Maine.

Due to differences in state fisheries, some of the assumptions made about gear configuration in trawl length modeling were inappropriate for areas outside of Maine waters. The relationship between inshore and offshore fishing effort for states like Massachusetts is influenced by productive but distant offshore grounds like Georges Bank (NOAA 2020). Although all states have inshore fisheries, the variability in total number of fishers, as well as the ratio of inshore to offshore fishers, varies widely across states and may have unique impacts on territoriality and fishing methodology that we were unable to quantify. Other New England states have large-scale seasonal closures driven by variable rates of NARW residency (NOAA 2021), and these closures influence fisher behavior. Results may be applied across the scale of the American lobster fishery if spatial fishery behavior changes are later proven to be inconsequential.

Maps of management zones were sourced from the Maine DMR. Bathymetric data for the GoM were sourced from the National Oceanic and Atmospheric Administration (NOAA) ETOPO1 Global Relief Model (NOAA National Geophysical Data Center 2009) to provide high-resolution depth data. Whale safety regulations were taken from the NOAA amendment to the take reduction plan published in 2021 (NMFS 2021).

Data were analyzed within R version 4.0.2. Multicollinearity tests were used to identify collinear variables. Variables were plotted into correlation matrices to show the level of collinearity between variables (Picard and Cook

1984). In this study, collinearity was found across a large proportion of variables (Supplementary Figure 1 available separately online). This is expected, as fishers tailor their gear type to the environment in which they fish. Fishers seemed to naturally settle into binned groups across variables, fishing unified tiers of trap weights, anchor weights, hauler sizes, traps per trawl, and groundline spacings depending on the spatial area they fished. Variance inflation factors show a corollary effect, and the vessel size, anchor size, anchor use, and groundline spacing variables were shown to have high collinearity with other variables. Anchor use and groundline spacing were excluded from the final model due to collinearity with other chosen variables as well as difficulty in modeling these data spatially at a meaningful scale.

Vessel and hauler sizes were highly correlated with depth. Larger vessels are better suited to fish offshore waters and long trawl lengths due to increased deck space and fuel capacity. It is intuitive that these vessels fishing long trawls would be subject to higher load requirements; due to the collinear nature of these variables, vessel size and hauler size were not used in the model so as to preserve depth as a highly explanatory variable. If there are significant changes to fishing methods, this assumption should be re-evaluated. Groundline spacing (i.e., the distance between traps on a trawl) and the use of anchors were so closely tied to depth and trawl length that these variables were also excluded from model training. The remaining variables were tested for outliers via histogram comparison and were groomed appropriately. Variables were tested for the reaction of residuals and fitted values to judge their contribution to model fit and model-specific Akaike's information criterion (AIC) and were eliminated by a backward approach (Figure 2; Supplementary Figure 2).

The mgcv package in R was used to run a series of models based on explanatory variables described by fishermen, with load being the response (Wood 2011). The mgcv package's default parameters were selected, and thin-plate splines were used for automatic smoothing of model terms (Wood 2011). Generalized additive models were applied due to their ability to incorporate nonlinear relationships (Guisan et al. 2002). Likewise, GAMs exhibit robustness to random effects (Guisan et al. 2002), which we may consider as differences between hauling speed and fishing methodology occurring on a small scale between individual fishers. Generalized additive mixed models were used to capture this difference, but the result was nonsignificant when tested with the study data.

Although lobster fishing effort is known to vary spatially with year and season, trawl length is poorly represented in many historical effort surveys. To best represent the modern distribution of gear configurations within the GoM, or the "as-is" case, sampling data from the annual Maine DMR observer lobster survey for the years 2009 2019 were used in a GAM to predict a continuous spatial grid of trawl length. Since the American lobster fishery is considered a pursuit fishery (Chen et al. 2005), the fishing behavior of the fleet is variable with lobster distribution and season. This 10-year period was chosen to best represent the recent actions of the fleet averaged annually. A GAM,

$$\text{Trawl length} \sim S(\text{Depth}) + S(\text{Latitude}) + S(\text{Longitude}),$$

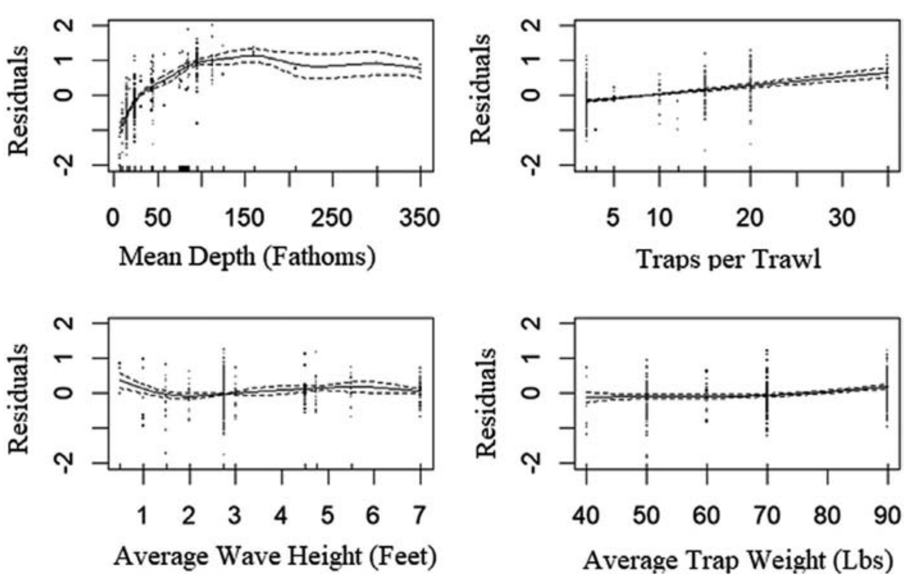

FIGURE 2. Residual distribution plots for smoother terms of the most explanatory covariates. The residuals for mean depth (fathoms), traps per trawl, average wave height (ft), and average trap weight (lb) are displayed.

was used to predict the number of trawls fished at a given location based on depth and spatial association using the Maine DMR survey data, applying a predicted trawl length for every depth point within the GoM study area based on smoothed input data. The predicted trawl lengths were capped at a 40-trap trawl maximum to give reasonable bounds to the predictions, which included some deep areas off the continental shelf that are poorly exploited by the fishery and may not hold to the previous assumptions of the fishery if heavy exploitation begins there.

A Tweedie family GAM was chosen to best describe the distribution of the response between the variables chosen and load when compared to Gaussian and Poisson distribution families. Shapiro Wilk and AIC testing were used to determine the normality and compare alternative variable GAM combinations. Model fitness was validated against the data by using root mean-square error (RMSE) to gauge the fit of the model to resampled test data. The spatial traps per trawl modeled output from the previous model was used as an input to describe fisher trawl length behavior in this overall predictive model using the following GAM:

$$\text{Vertical line load} \sim S(\text{Depth}) + S(\text{Traps per trawl}) + S(\text{Wave height}) + S(\text{Trap weight}),$$

and vertical line load according to these trawl length distribution data was predicted over space. Different outputs were produced for the baseline trawl length model output as well as the new NOAA rule-making trawl length minima.

To explore the results of implementing the new trawl length minima across the GoM management areas, we overlapped management area delineation spatial polygons on bathymetry maps, applying the NOAA trawl rules to their prescribed regions. The new rule differs from the proposed rule by having greater variation in trap minima across management areas. These rules enact a trawl length limit of 2 3 traps/trawl from the exemption line to within 5.556 km (3 nm) of shore, 5 10 traps/trawl from 5.556 to 11.11 km (3 to 6 nm) offshore, and 10 20 traps/trawl from 11.11 to 22.22 km (6 to 12 nm) offshore (NOAA 2020; NMFS 2021). The remainder of Lobster Management Area 1 (LMA1) occurring outside of Maine state waters (≥22.22 km [≥12 nm]) had the proposed 25-trap trawl minimum applied (Supplementary Figure 3). This analysis was contained to LMA1 to restrict our analysis to the location of most industry activity and likewise our highest fidelity data. These maps were created using the sp, tidyverse, and rgdal packages within the R programming language. Using the proposed trawl length rules, vertical line load was predicted with the best model. The predicted loads under the new trawl length scenario were compared to the "as-is" loads to demonstrate potential changes in fishing gear configuration and experienced loads within state management areas resulting from rule implementation.

Some of the variables could not be predicted as a continuous spatial grid. We were unable to effectively map the distribution of trap weights across the GoM with the data available; therefore, we used a fixed standard 31.75-kg (70-lb) trap weight across space. This represented the trap weight most commonly fished by our volunteers.

Industry volunteers reported hauling in sea heights from 0.3 to 2.13 m (1 to 7 ft), with 0.91–1.22 m (3 4 ft) being the most common. Given the difficulty in preparing models that were inclusive of all possible weather outcomes, we applied a standard 0.91-m (3-ft) wave height across space. Model testing showed an increase in load of approximately 5.5% across all load predictions with a wave height of 2.13 m (7 ft) relative to the 0.91-m (3-ft) average. We did not have any volunteers recording haul data in extreme weather conditions, thus restricting us from making assumptions about hauling loads in extreme weather.

RESULTS

Although lobster fishing effort varies spatially with year and season, trawl length is poorly represented in many historical effort surveys. The model responsible for predicting trawl lengths represents our best knowledge of current trap distribution trends as typically fished by the lobster industry over the past 12 years based on observer data (Figure 3). The relationship between trawl length, distance from shore, and depth is intuitive and was representative of industry behavior based on fisher feedback. The trawl length model predictions were useful for projecting the current load landscape across the GoM; when this information is combined with a high-resolution spatial image of trawl length from observer data (Figure 4), we can perform analysis on spatial gear requirements. There were no significant differences between loads across management areas outstanding from differences in oceanographic parameters. Depth fished, traps per trawl, wave height, and trap weight were determined as the most important variables for explaining the response variable (load on the vertical line). This subset of variables was confirmed by AIC comparison. This combination of variables produced a predictive model with the lowest comparative AIC while maintaining a variance inflation factor below 3 for all chosen variables. The RMSE for all models ranged from 800 to 900. Testing the models with training resampled data showed a minor change in RMSE, indicating that the model was neither underfit nor overfit but was constrained by the data. Shapiro Wilk normality testing of the residuals revealed a P-value of 1.168×10^{-5}, which is extremely low and suggests a nonnormal distribution. The vertical

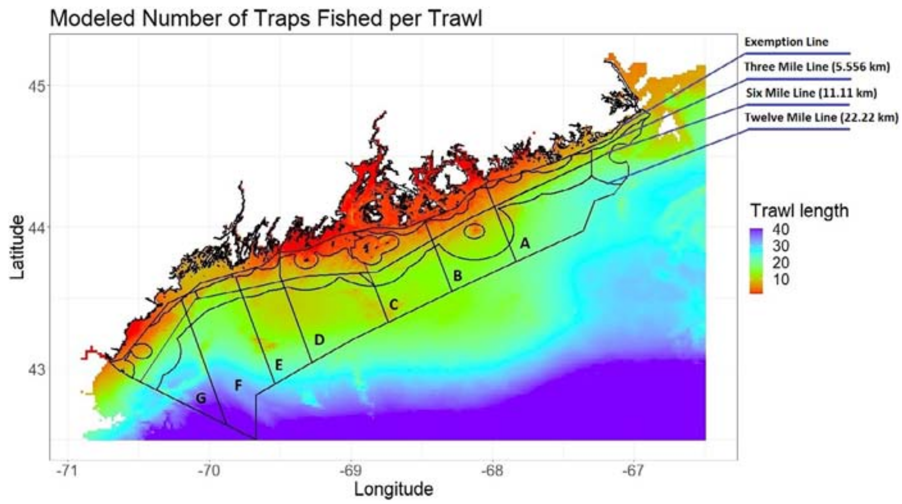

FIGURE 3. Distribution of trawl lengths (number of traps per vertical line) fished across the Gulf of Maine, predicted by a generalized additive model based on Maine Division of Marine Resources observer data. Lines represent management zones (lettered in black text) and distance from shore at the exemption line to 5.556 km (3 nm), 5.556 11.11 km (3 6 nm), and 11.11 22.22 km (6 12 nm) offshore (as labeled). The modeled result shows a highly variable trawl length distribution, with an increasing trend moving offshore.

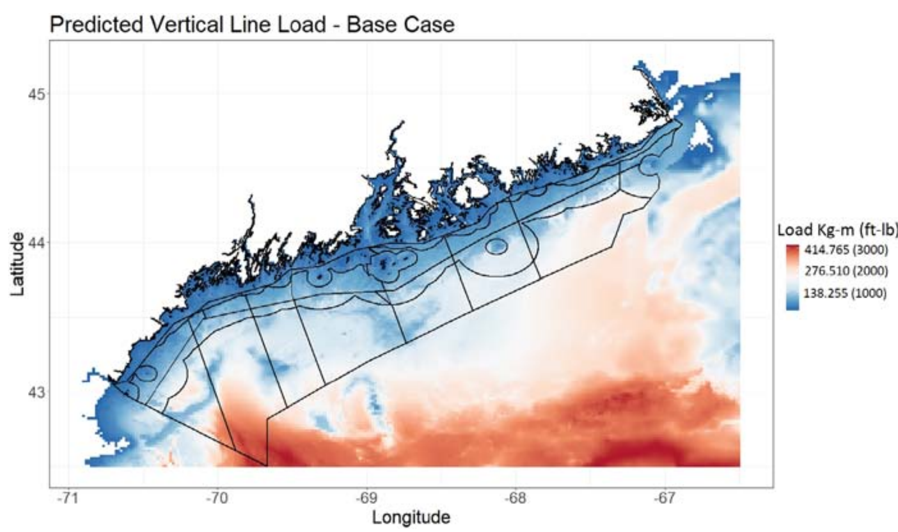

FIGURE 4. Predicted vertical line load (kg m and ft lb) for the base case trawl length scenario. Black lines represent the management zones depicted in Figure 3. The predicted loads follow the prescribed trawl lengths at depth. The color scale is based on the proposed 235.033 kg m (1,700 ft lb) line strength limit for reducing whale entanglement risk, with areas in shades of red exceeding 235.033 kg m (1,700 ft lb) during typical hauling behavior, increasing with color intensity.

line load GAM explained 95.2% of the variation in line load using trap count, depth fished, wave height, and trap weight (Table 1). This high level of deviance explained is reasonable given the physics-based nature of the model. This combination of variables presents the best relationship that offers precision while also making the model robust for predicting across different gear configurations and depth range.

We used generalized additive mixed models to test the variation between fishing styles/fishers as a meaningful contributor to load; however, these models failed to capture any individual variation across fishers. This suggests that the homogeneity of fisher hauling behavior is sufficient to avoid contributing significantly to load differences across fishers.

We used a model to predict vertical line load spatially by using the spatially explicit trawl lengths from Maine DMR

TABLE 1. Comparison of *P* values, CIs, R^2 values, and Akaike's information criterion (AIC) for the three tested predictive models of vertical line load. Model complexity beyond model A did not meaningfully improve AIC or R^2. Model A was chosen to best represent the contributors to load.

	Model A		Model B		Model C	
Predictor or statistic	Estimate	*P*	Estimate	*P*	Estimate	*P*
Intercept	512.01	<0.001	530.34	<0.001	486.49	<0.001
Depth		<0.001		<0.001		<0.001
Trawl length		<0.001		<0.001		<0.001
Wave height		<0.001		<0.001		
Trap weight		<0.001				
CI	503.4 520.77		521.32 539.51		478.270 494.86	
Observations	441		462		557	
R^2	0.952		0.944		0.916	
AIC	5,259.744		5,571.917		6,713.81	

observer data (Figure 3). Overall, we observed an increase in load with increasing trawl length (weight) across depths. Trawl lengths were highly variable by depth as well as management area, reflecting fisher conformity to oceanographic variables as well as fisher choice. Using the modeled trawl lengths from Figure 3, we predicted the vertical line load maxima spatially to produce the map in Figure 4. The color gradient accentuates the difference between areas fishing within the 235.03-kg-m (1,700-ft-lb) safety margin and areas where that load allowance is exceeded. Far below the 235.03-kg-m (1,700-ft-lb) threshold, the low loads inshore pose no serious problem from a shift to weaker lines. The shift from white to red area in Figure 4 occurred where hauling loads exceeded the widely accepted 235.03-kg-m (1,700-ft-lb) safety margin for whales. From the 11.11-km (6-nm) line to the extent of the LMA1 zone, loads commonly remained around the 235.03-kg-m (1,700-ft-lb) mark or went well over that weight threshold, and those areas will have trouble conforming to 235.03-kg-m (1,700-ft-lb) line regulations without compromises in trawl length from the base case.

Vertical line reduction plan trawl minima were applied to the modeled trawl lengths to present areas of load increase under the new management scheme (Supplementary Figure 3). A direct comparison of current and post-proposed rule implementation showed significant areas of load increase (Figure 5). To highlight the variation between rule implementation and the "as-is" case, the difference between these scenarios was isolated as well. The consistent increase in load from the 5.556-km (3-nm) line and further offshore suggested that these new trawl minima will require stronger lines. The management tactic of reducing the total volume of lines in the water will have the trade-off of fewer, albeit stronger, lines.

DISCUSSION

Given the high fit of this model, predictions about the load requirements for fishery operation in a variety of trawl length configurations across depth strata can be considered accurate to fishery behavior. This load study has been used to ground-truth some assumptions within the different NARW risk reduction plans of what loads are feasible for different areas.

Increasing the number of traps per trawl allows fishers to utilize the same number of traps with fewer vertical lines. While hauling the gear, the increasing load with increased trap count would suggest that there is an anchoring or drag effect from having more traps on a string. Previous dialogue with fishers had suggested that while hauling gear at the same depth, no matter the trawl length, there should be a relatively fixed number of traps suspended in the water column, supplying most of the resistance and driving the variation in line load. Although the number of traps suspended is fixed by depth and trawl length, traps on the ground provide resistance when dragged toward the hauling vessel. The presence of dragged gear was much more pronounced than anticipated and increased load significantly on longer trawls at any depth.

The presence of a substantial drag factor when hauling longer trawls creates the need for stronger vertical lines when considering "trawling up" to reduce the total amount of rope in the water. This presents some risk to NARWs, as regions with increased trawl minima will have fewer but stronger vertical lines. The subsequent increase in load and need for stronger lines must be considered when calculating the total risk reduction. Some alternative gear configurations have been proposed during Atlantic Large Whale Take Reduction Team meetings, such as increased lengths of groundline between the first and subsequent traps to reduce the dependency on strong vertical lines for increased trawl lengths (NOAA 2021). These increased groundline length proposals could become a critical component of reducing vertical line strength in offshore, high-trawl-length areas.

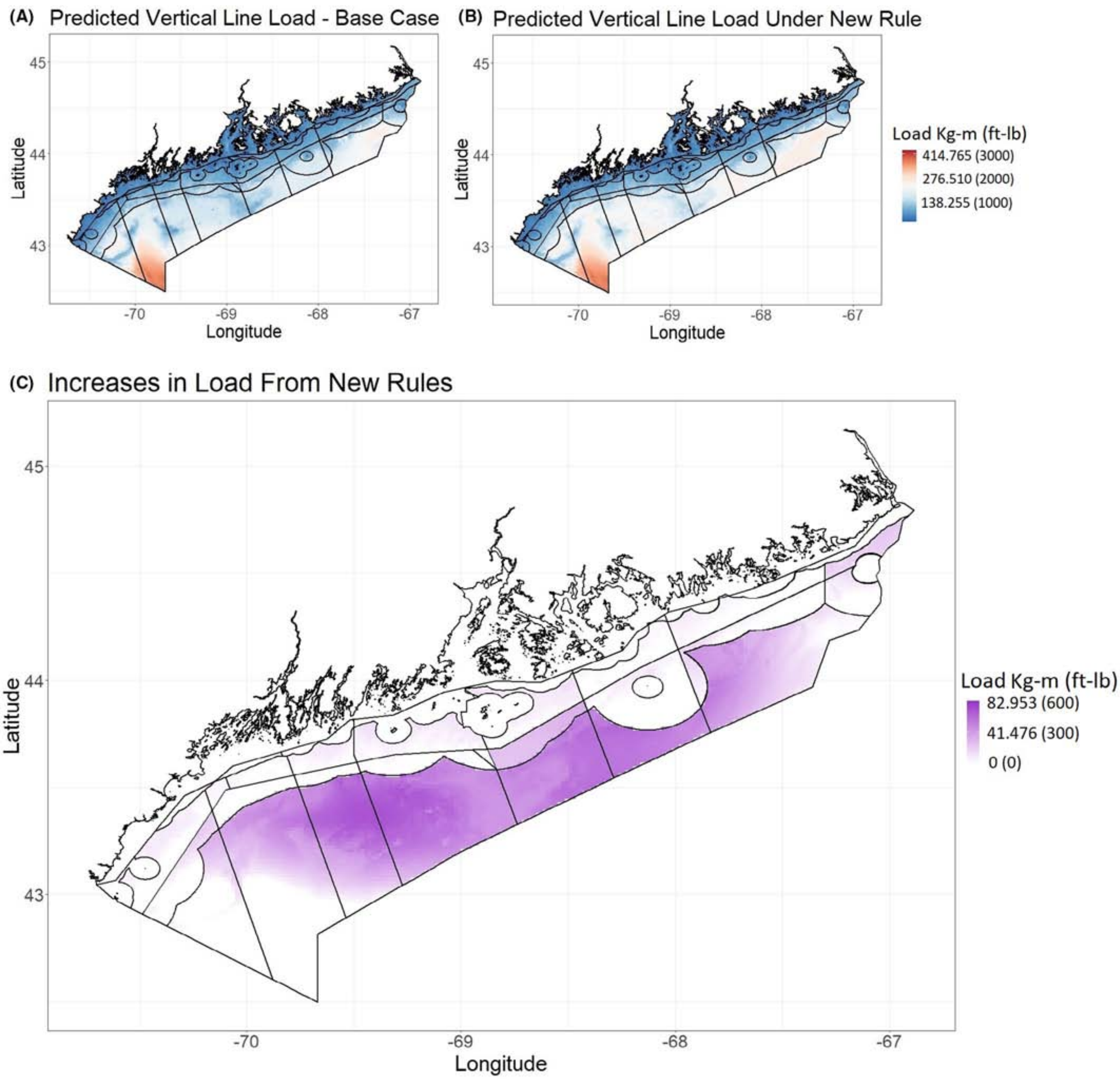

FIGURE 5. Predicted vertical line load (ft lb) under **(A)** an "as is" (base case) scenario and **(B)** proposed trawl length rule implementation of whale safe rules. The color scale is based on the proposed 235.033 kg m (1,700 ft lb) line strength limit for reducing whale entanglement risk, with areas in shades of red exceeding 235.033 kg m (1,700 ft lb) during typical hauling behavior. **(C)** The increase in load from the base case scenario is isolated to the new trawl minima; only the increase in load resulting from the new rule implementation is shown, increasing with color intensity. The black lines represent the lobster management delineations presented in Figure 3.

The area closest to shore in Maine is exempt from Atlantic Large Whale Take Reduction Plan regulations. When this exemption area was created, the National Marine Fisheries Service determined that NARWs were unlikely to utilize this rocky habitat close to the coastline. The Maine exemption area exists almost entirely inside of the state's statutory 5.556-km (3-nm) line and encompasses about 70% of those state waters. The areas outside of the exemption zone but within the 5.556-km (3-nm) line have new trawl minima; however, the minima do not exceed the trawl lengths already fished there. We do not expect any significant change in hauling loads for those areas. Hauling load largely stays below 138.26 kg-m (1,000 ft-lb) within the Maine exemption line and in the area between the exemption line and the 5.556-km (3-nm) demarcation.

Within the areas 5.556−11.11 km (3 6 nm) from shore (the 11.11-km [6-nm] line is defined within the Atlantic Large Whale Take Reduction Plan), loads started to approach the 235.033-kg-m (1,700-ft-lb) limit in deeper waters. These are the first areas that show pronounced increases in load under the new trawl minimum rule, with loads increasing by 13.83−41.48 kg-m (100 300 ft-lb) consistently from the base case. Hauling strain could approach or exceed the 235.033-kg-m (1,700-ft-lb) limit when the loads under new trawl minima combine with unusual circumstances, such as gear hang-ups, setovers with other fishing gear, or extreme weather conditions. This is most pronounced in the 5.556−11.11-km (3 6-nm) section of zone A (Figure 3) a direct result of the specialized higher trawl minimum in that area.

The 11.11−22.22-km (6 12-nm) fishery routinely experiences hauling loads over 235.033 kg-m (1,700 ft-lb) and likely would be unable to come within that specification given current fishing gear configurations and practices. Zone C (Figure 3) is likely to experience increased loads across the board, as the specialized rule for this area would involve a 20-trap minimum much higher than our modeled trawl length base case for this zone. Other than zone C and some areas of zones A and G, there will be little change from the base case to fishers operating in the 11.11−22.22-km (6 12-nm) area.

Offshore fishers (≥22.22 km [≥12 nm] offshore) within LMA1 would likely have to use a suite of measures to come within desired NOAA suggestions for risk reduction rather than just a switch to weaker rope. This offshore area will have the most pronounced increases in load unders the implementation of a blanket 25-trap minimum, with massively increased vertical line loads everywhere except the Wilkinson Basin. Although this may reduce risk to NARWs by reducing the total number of vertical lines in areas where the use of a weak, 235.033-kg-m (1,700-ft-lb) line is impossible, the increases in load there may exceed the breaking strength of the lines and gear currently in use by fishers in this area.

To reduce the break-off risk to fishers, the NOAA rule allows approximately half the trawl minimum per area to be fished if only using a singular vertical line. This provision may help fishers who cannot fish the new trawl minimums due to vessel size or gear strength constraints. The decreased trawl length should decrease loads and help reduce vertical line break-offs; however, without a secondary vertical line, break-offs will then have to be recovered by dragging for gear.

Recommendations must be considered in light of our model's gear homogeneity assumptions. Given the fixed values for wave height and trap weight, these load values should be considered a best-case scenario, as loads exceeding these values are likely in inclement weather. We noted an approximately 5.5% increase in predicted load force on the vertical line when fishing in 2.13-m (7-ft) seas from the original 0.91-m (3-ft) predictions. Dialogue with fishers suggested that weather-forced vessel rolling caused this increase. Vessel rolling, combined with additional difficulty in maintaining best-hauling practices (e.g., maintaining an even angle of approach to minimize dragging gear in heavy seas), was difficult to fully capture with fair-weather volunteer data. We recommend extra caution for safety when making line strength recommendations for zones that are close to the 235.033-kg-m (1,700-ft-lb) load limit, such as between the 11.11−22.22-km (6 12-nm) line and further offshore. An increase in load during an extreme weather event may cause line parting and mid-haul gear failure, carrying the potential for fisher injury. Fishers or management personnel examining these results must assume that larger loads will result from the use of heavier traps, foul weather, or changes in the relationship between anchor use and depth beyond the typical operational parameters used in the lobster fishery outlined above.

Hauling methodology was consistent across fishers, with vessels striving to maintain an even rate of haul while positioned vertically above the trawl. There was typically an even increase in load as the vertical line was brought aboard, although this was highly variable depending on gear hang-ups, fishing conditions, and trawl length. The NOAA rule includes provisions for either weak-link inserts or a 50% vertical line "topper" that increases in strength from surface to seafloor, which may capitalize on this relationship to provide some reduced risk to whales. This could be of particular benefit to risk reduction in inshore areas, where we have shown a low total load and little increase in load as a result of new trawl minimum implementation.

The more drastic changes resulting from longer trawl lengths at great depth may pose a challenge to fishers implementing these rules. Implementation of weak rope or weak links in these deep offshore areas is likely to pose a high break-off risk, as we predicted loads commonly exceeding 235.033 kg-m (1,700 ft-lb) in these areas. Implementation of these trawl minima may pose a break-off risk even to current gear since the increase is large when considered both as a flat rate and as a percentage of total previous load (Supplementary Figure 4).

Changes in the load landscape due to implemented trawl length minima were expected, and we saw variable changes across depth within management areas (Figure 5). The previous, somewhat smooth gradient of load change from areas of low load in shallow inshore waters to areas of higher load in deeper offshore waters was replaced with more abrupt cutoffs of increased loads along the distance-from-shore delineations as the new trawl minima were implemented. In practice, load decreases are unlikely to occur, as whale protective plans currently only implement changes to trawl length minima, while fishers may continue to fish trawl lengths greater than the minimum in areas where they already do so. To reflect this, trawl lengths were only changed where they were below the new minima, while areas where fishers currently fish above the minimum were unchanged (Supplemental Figure 3).

Results indicated that under the new rules, many fishers would experience increases in load across the GoM. These changes were particularly pronounced in areas of greater depth. Implementation of these trawl minima in offshore areas will increase the risk of breakaway fishing gear due to higher loads or will force adaptation costs for fishers buying stronger lines. If gear loss is common when fishing the new trawl minima in deep waters, these areas may no longer be cost effective for fishers to target, thereby effectively closing the area to fixed-gear lobster fishing. Fishers shift their effort distribution to seek the highest CPUE outside of closed areas (Hilborn 2018). It is possible that fishers will redistribute their fishing effort to avoid the costs of fishing new trawl minima attributed to historic fishing areas. Displaced effort may change the overall NARW entanglement risk depending on the likelihood of whale occurrence in the preferred fishing area. The potential for a shifting effort distribution ought to be considered as a point of further study when testing the outcomes of the new trawl minima.

Further research in this field should more acutely describe the overlap of fishing effort and NARW distribution in the GoM. The high variability in NARW seasonal and spatial residency and transit pathways through the GoM suggests that management will have to review risk reduction proposals on an annual basis until NARW migration patterns are consistently and accurately described (Wikgren et al. 2014; Meyer-Gutbrod et al. 2021). The American lobster fishery exhibits strong seasonal variation in effort scale and distribution, posing variable risk to NARWs as their temporal residency patterns change. We expect that a comparison of shifting NARW distributions with the load landscape described here could yield information on areas of high entanglement severity as well as areas where lobster fishing and NARWs fail to overlap.

Efforts to describe the overlap of fishing effort and NARWs could utilize the impending mandate for fishing vessel monitoring systems in federal waters to improve the spatial resolution of trawl areas fished. This potential data stream or a modern comprehensive study of gear distribution within the GoM may better inform management decision making on spatial risk for NARWs. With regard to Figure 4, it is important to note that fishing effort is not uniform across the GoM. The majority of the American lobster fishing fleet operates within 5.556 km (3 nm) of shore (McCarron and Tetreault 2012). When quantifying risk to NARWs, it is important to consider the relative high density of low-load lines inshore as well as the lower density but relatively high-load lines in the 5.556–22.22-km (3 12-nm) and offshore areas. The ability of the inshore fishery to comply with the new trawl minima generates a marked reduction in risk to NARWs and, thus, a potential benefit to fishers by avoiding an NARW mortality-induced fishery closure. Areas beyond the 22.22-km (12-nm) boundary overwhelmingly exceed 235.033 kg-m (1,700 ft-lb) under rule implementation, and break-off risk is high if fishers are forced to implement the weak, 235.033-kg-m (1,700-ft-lb) rope under the new trawl minima. Changes in fisher behavior, such as targeting more shallow, low-load-inducing environments, may be required if fishers want to avoid gear loss and maintain entanglement risk reduction goals.

Management decisions that are intended to reduce risk to NARWs by increasing minimum trawl lengths and reducing the overall number of vertical lines in the water must also consider the capacity of the fleet to operate within these new rules. Changes to trawl length minima may cause fishing effort displacement or shifts in fishing methodology, with unforeseen effects on overlap between whales and fishing gear. Inshore vessels fishing historically low-load environments are typically smaller vessels (McCarron and Tetreault 2012) and may not have the deck size to fish the newly mandated trawl length minima safely. Although some flexibility for small vessels is included in the provision allowing half trawl length for a single vertical line, the possibility of lost gear without a secondary vertical line may drive fishers to conform to the higher trawl minima. This study has occurred simultaneously with management proposals calling for sweeping changes to trawl lengths and fishery behavior in the GoM. As management continues to develop and refine risk reduction proposals, the outlined mechanisms between trawl length, depth, and drag force on load should be considered, with the entanglement severity implications of stronger lines balancing the benefit of reduced numbers of lines. Applying these lessons to other fixed-gear or high-bycatch fisheries, it appears prudent to maintain modern fishery gear distribution data so that management can react swiftly and with minimal detriment to fishing communities when crises like endangered species mortality occur.

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.

EXHIBIT 17

NOAA FISHERIES

Northeast Fisheries Science Center

Draft Ropeless Roadmap

A Strategy to Develop On-Demand Fishing

About This Document

This document describes the current state of on-demand, or "ropeless," fishing and outlines a path for increasing adoption of this technology in U.S. East Coast commercial fisheries. We discuss this developing technology and forecast its future path based on the status of gear development, ongoing regulatory changes, and the need to decrease whale entanglements and associated mortality under the Endangered Species Act and Marine Mammal Protection Act (Figure 1). The need for on-demand fishing is driven by the urgent conservation crisis facing the endangered North Atlantic right whale (*Eubalaena glacialis*), hereafter referred to as the right whale. The species has been in decline for over a decade and is approaching extinction due to human impacts, including entanglement in fishing lines (Figure 2).[1] As the need for larger and longer seasonal restricted areas increases to protect right whales, on-demand fishing represents the best solution to separate rope and right whales in areas of highest risk. The following sections explore the potential for on-demand fishing gear to provide substantial reductions in entanglement risk for fixed gear trap/pot fisheries in a rapidly changing Atlantic ecosystem.

This document is intended for a broad audience to serve as a roadmap for future research, engagement, and policy change to enable the continued development of on-demand fishing. Each of the components of this roadmap provide a broad overview of the steps forward. We recognize that there are many partners who are key to this process and strategy, particularly state fishery managers and fishery management councils and commissions. Our intent is to share this plan for input and move forward in close collaboration with our partners. We welcome continued feedback on this document via https://bit.ly/3GHOIdE to incorporate the perspectives of all stakeholders involved in these processes and to ensure that all voices are heard to help guide our next steps. We intend to revise this roadmap over time and would like it to serve as a living document to provide our vision for proceeding through this rapidly evolving landscape.

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[1] Pace, R. M., 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, 7:2045-7758.
Pettis, H.M., R.M. Pace, and P.K. Hamilton. 2022. North Atlantic Right Whale Consortium 2021 Annual Report Card. Report to the North Atlantic Right Whale Consortium.

where gear density is low enough to navigate with a GPS recording of where the trawl was deployed from the vessel (e.g., second scenario of Step 3 above). This could have multiple advantages:

- More fishermen would gain experience working with geolocation data;
- It moves us closer to an ALWTRP conservation goal of removing more lines without trap reductions and/or closures;
- It provides more time for on-demand technology, especially interoperable underwater acoustic communication, to evolve and for prices to decrease; and
- It provides time for current management actions to be evaluated, while gaining more data on areas most in need of risk reduction.

Regulatory actions should be developed that take advantage of the full potential of on-demand technology, including on-demand systems that are geopositioned by acoustic technology from passing vessels. The timeline and spatial extent of this action are not defined at this time, although it will take several years. Regardless, fishery management bodies should begin working toward these goals immediately.

Where is On-Demand Fishing Needed?

Given the continued critical decline in right whale populations caused in large part by entanglement in buoy lines, on-demand gear would be the most effective means of modifying gear to reduce risk of right whale entanglement (and mortality) in commercial fishing gear set in and around habitat used by right whales. To achieve necessary risk reduction goals, on-demand fishing gear will not need to be required everywhere in the future. Rather, it poses a solution to access areas where entanglement risk is currently highest. Comparing the relationship between fixed gear (trap/pot and gillnet fisheries, measured by buoy lines) and entanglement risk in federal vs. state waters on the U.S. east coast, 20% of fixed gear effort occurs in federal waters but are estimated to represent 70% of entanglement risk.[10] Conversely, 80% of the fixed gear operates in state waters but represents 30% of entanglement risk. This suggests that, in general, vessels operating in federal waters represent a disproportionate amount of entanglement risk and might be candidates for early adoption of on-demand gear in appropriate, high risk locations.

To identify how many buoy lines would need to be converted to on-demand gear to attain the maximum risk reduction benefit (given the higher cost of on-demand gear), we calculate which lines are most “risky.” This is largely driven by the overlap of lines in areas with high densities of right whales, but also by expected line strength, our current proxy for entanglement lethality.[11] Calculating cumulative risk and identifying the

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[10] This is calculated using NOAA Fisheries’ Decision Support Tool preliminary estimates of approximately 3.3 million “vertical line months” (one vertical line for one month) in state waters and 800,000 line months in federal waters; 4.1 million total

[11] This is assuming the risk maps as they were prior to Phase I ALWTRP management measures and does not account for the new closures and gear configuration modifications.

Use this QR code or https://bit.ly/3GHOIdE to submit feedback.

EXHIBIT 18

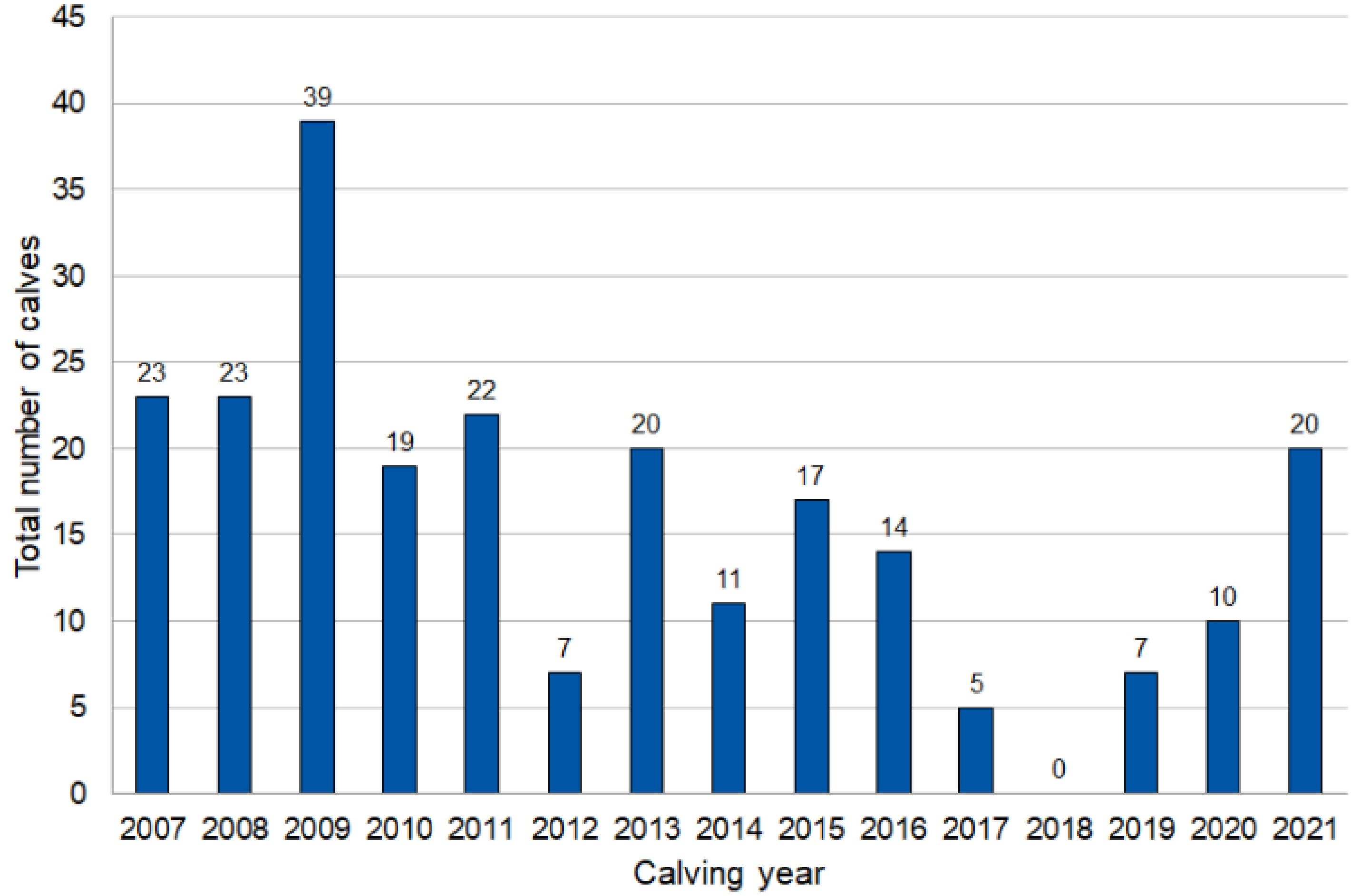
NOAA FISHERIES

North Atlantic Right Whale Calving Season 2022

North Atlantic right whales are approaching extinction with fewer than 350 remaining. With so few of these whales left, researchers closely monitor the southeastern United States for new offspring during the annual right whale calving season.

Every single female North Atlantic right whale and calf are vital to this species' recovery. So far, researchers have identified fifteen live calves this calving season. Check back here or follow NOAA Fisheries on Twitter for updates.

North Atlantic right whales are dying faster than they can reproduce, largely due to human causes. Since 2017, the whales have been experiencing an Unusual Mortality Event, which has resulted in more than 14 percent of the population either dead or seriously injured. The primary causes of the Unusual Mortality Event are entanglements in fishing gear and collisions with boats and ships. In addition, there are fewer breeding females producing fewer calves each year, which impacts the ability of the species to recover. Researchers estimate there are fewer than 70 reproductively active North Atlantic right whale females remaining.



The number of North Atlantic right whale births each "calving year" in past years. North Atlantic right whales typically calve between mid-November and mid-April. Credit: NOAA Fisheries

Meet the Mothers and Calves of the 2022 Season

Every identified North Atlantic right whale has an assigned four-digit number in the Right Whale Catalog. Researchers assign names to whales that have a unique physical feature or a strong story in connection to a community or habitat where they were seen.

While we are excited to see fifteen new mom-calf pairs so far this calving season, North Atlantic right whales are dying faster than they can reproduce. That's why every whale counts.

With the current number of females and the necessary resting time between births, 20 newborns in a calving season would be considered a relatively productive year. However, given the estimated rate of human-caused mortality and serious injury, we need approximately 50 or more calves per year for many years to stop the decline and allow for recovery. The only solution is to significantly reduce human-caused mortality and injuries, as well as stressors on reproduction.

#4180

Right Whale Catalog #4180 and her new calf were sighted 38 nautical miles southeast of the entrance of the Chesapeake Bay, off the coast of Corolla, North Carolina, on March 2, 2022. #4180 is at least 11 years old and this is her second calf. Her first calf was born just three years ago, in

EXHIBIT 19

NOAA FISHERIES

10 Things You Should Know About North Atlantic Right Whales

October 17, 2019

The endangered North Atlantic right whale population has been steadily declining for nearly the past decade. Today, researchers estimate that only about 400 right whales are left. Learn more about what we are doing and what you can do to help save right whales.

Editor's Note December 10, 2021: When this story was published in 2019, there were an estimated 400 North Atlantic right whales remaining. The latest preliminary estimate suggests there are now fewer than 350.

1. The North Atlantic right whale is one of the world's most endangered large whale species.

North Atlantic right whale. Credit: Georgia Department of Natural Resources. Image taken under NOAA Research Permit 15488.

Sadly, North Atlantic right whales got their name from being the "right" whales to hunt because they floated when they were killed. Their population has never recovered to pre-whaling numbers. These whales have been listed as endangered under the Endangered Species Act since 1970 and have been experiencing a steady population decline for nearly a decade.

2. Survival of this species depends on no more than one whale death per year. Since 2017, at least 31 right whales have died, and 10 more have been seriously injured.

North Atlantic right whale mother and calf. Credit: Florida Fish and Wildlife Commission. Image taken under NOAA Research Permit 665-1652.

The birth rate for right whales has been very low the past few years. Only 22 births have been observed in the four calving seasons since 2017. This is less than one-third the previous average annual birth rate for right whales. And deaths have been exceeding births, resulting in a further decline in the population.

3. Vessel strike and entanglement reduction efforts continue to be critical for reducing right whale deaths.

In 2016, a team coordinated by the International Fund for Animal Welfare (IFAW), conducted a necropsy on a right whale calf found off of Massachusetts. Researchers determined that the whale died from a vessel strike. Photo Credit: IFAW, collected under NOAA permit 18786.

We created speed reduction management areas in 2008 for vessels 65 feet or longer to protect right whales. Mariners must slow down in these areas during seasons when right whale distribution is expected to overlap with major shipping lanes. Since its inception, the rule has reduced right whale vessel strikes, but collisions are still a cause of injury and death for these whales. And we have put regulations in place to reduce entanglement risk to protect right whales. These are important efforts, but we need to do more.

4. North Atlantic right whales don't live long enough to die of old age because they are often killed by collisions with vessels and entanglement in fishing gear, two of the leading causes of right whale mortality.

Credit: Florida Fish and Wildlife Commission. Image taken under NOAA Research Permit 775-1600-10.

Female North Atlantic right whales only live to be around 45 and males only to around 65. This is in large part because of human impacts like entanglements in fishing gear and collisions with vessels. These average lifespans are much lower than the 80+ years documented in southern right whales, a similar species that occurs in the southern hemisphere.

5. Entanglement in fishing gear is a big issue for right whales.

More than 85 percent of right whales have been entangled in fishing gear at least once, and the majority (60 percent) have been entangled multiple times. Right whales mostly get caught in the lines that attach fishing gear, like lobster and crab pots or gillnets, to buoys on the surface. These lines can cut into a whale's body, cause serious injuries, and result in infections and mortality. Even if gear is shed or disentangled, the time spent entangled can severely stress a whale, which weakens it, prevents it from feeding, and saps the energy it needs to swim and feed. Right now, we are focused on addressing the risk of entanglement in vertical lines that connect traps and pots to the surface. This is among the leading threats to right whale survival.

6. Right whales have been dying in both U.S. and Canadian waters, so both countries are taking action.

Right whale mother and calf, sighted June 8, 2014, during survey.

NOAA Fisheries is actively collaborating with Canada through ongoing bilateral negotiations on the science and management gaps that are impeding the recovery of North Atlantic right whales in both Canadian and U.S. waters. We meet twice a year to share information on the state of the science for this species as well as management measures that foster healthy fisheries, reduce the risk of entanglements, and create whale-safe shipping practices.

7. We are continuing to expand our collaborative actions with partners to spur recovery for this species because we cannot do this alone.

Woods Hole Oceanographic Institution (WHOI) researchers deploy a floating buoy for right whale monitoring efforts. WHOI is a key NOAA partner in passive acoustic monitoring. Photo by Matthew Barton © Woods Hole Oceanographic Institution.

NOAA scientists and policy experts work with North Atlantic right whale recovery teams that include scientists, fishermen, conservationists, and natural resource managers from Florida to Canada. Together, we examine what we know and what we need to know about the biggest threats facing right whales and their health and population dynamics to save them from extinction. Learn more about right whale recovery.

8. NOAA Fisheries has authority to make regulations to protect whales under the Marine Mammal Protection Act and the Endangered Species Act.

North Atlantic right whales. Credit: NOAA Fisheries, Northeast Fisheries Science Center. Image taken under the authority of the MMPA

When we develop regulations to protect whales from the effects of commercial fisheries, we do so with input of the fishermen who will be affected by those regulations. We also incorporate input from scientists, conservationists, and federal and state resource managers through a process called “take reduction." These take reduction team members negotiate to develop measures for reducing entanglement risk that all stakeholders can support.

9. Right whales are now a part of the “Species in the Spotlight" initiative.

North Atlantic right whale during an aerial survey. Credit: NOAA Fisheries, Northeast Fisheries Science Center.

The NOAA Fisheries' Species in the Spotlight initiative brings greater attention and increased resources to save the species we consider among the most at risk of extinction in the near future. Since 2015, this "priority species" effort has been an effective way to focus federal and non-federal resources to safeguard these most endangered species. We hope that adding North Atlantic right whales to the Species in the Spotlight list will similarly help stabilize this declining population.

10. You can help right whales survive.

Credit: Georgia Department of Natural Resources. Image taken under NOAA Research Permit 15488.

Here are some actions you can take to help North Atlantic right whales recover:

- **Report right whale sightings.** Please report all right whale sightings from Virginia to Maine to (866) 755-6622, and from Florida to North Carolina at 877-WHALE-HELP ((877) 942-5343). Right whale sightings in any location may also be reported to the U.S. Coast Guard via channel 16 or through the WhaleAlert mobile app.

- **Contact Stranding and Enforcement Hotlines.** Report a sick, injured, entangled, stranded, or dead right whale to your regional or state professional responders so they can take appropriate action. Call the NOAA Fisheries Enforcement Hotline at (800) 853-1964 to report a federal marine resource violation.
- **Keep your distance if you see a right whale.** Boats, aircraft (including drones), people using other watercraft such as surfboards, paddleboards, kayaks, and jet-skis, and divers and snorkelers must stay at least 500 yards away.
- **Slow down around right whales**. There are several areas along the East Coast where vessels 65 feet or longer must slow to 10 knots or less during times of the year when right whales are likely to be in the areas in large numbers.
- **Stay updated on right whale take reduction and other conservation measures.** For accurate information, check your sources or confirm them by reviewing our news and announcements.
- **Participate in** public meetings and share your perspectives with Take Reduction Team members who represent your constituency.
- **To find out how you can help**, please contact your local stranding network partner.

Last updated by Office of Communications on December 10, 2021