Ocean Regime Shift is Driving Collapse of the North Atlantic Right Whale Population

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C. FINMARCHICUS ABUNDANCE

Figure S1 shows the time series of the annual *C. finmarchicus* Abundance Index for the Gulf of Maine. It should be noted that NOAA funding cuts resulted in the Gulf of Maine Continuous Plankton Recorder (CPR) survey being discontinued in 2017. In addition, the survey route was changed in 2009, shifting its departure port from Boston, Massachusetts, to Portland, Maine. Therefore, coverage of Massachusetts Bay was discontinued, and coverage of the western Gulf of Maine was markedly different after 2009. Coverages of the eastern Gulf of Maine and western Scotian Shelf remained comparable.

Results from a spatially and temporally resolved right whale reproduction model (Meyer-Gutbrod et al., 2015) demonstrated that when the summertime (third quarter–July, August, September) *C. finmarchicus* Abundance Index in the eastern Gulf of Maine falls below a certain threshold value, prenatal or neonatal calf mortality is triggered, presumably due to inadequate prey availability and poor maternal nutrition. This threshold value is shown in Figure S2, the time series of the summertime *C. finmarchicus* Abundance Index in the eastern Gulf of Maine. Due to the previously mentioned limitations in the availability of CPR survey data in the western Gulf of Maine during recent years, this threshold value could only be estimated, with the model using data through 2009. Because of this constraint, it was decided to show the threshold value in Figure S2 rather than in Figure 2c.

RIGHT WHALE SIGHTINGS

Right Whale Sightings per Unit Effort (SPUE) are used to estimate right whale relative abundance and correspond to the number of whale sightings made divided by the effort expended to collect those sightings. Effort is measured as the number of kilometers transited by a survey vessel or aircraft while making visual observations. In this study, SPUE are standardized by reporting the number of whales sighted per 100 km transited. It should be noted that survey effort is not collected consistently across space or time, and therefore SPUE data are biased with more effort exerted in areas where researchers expect right whales to occur.
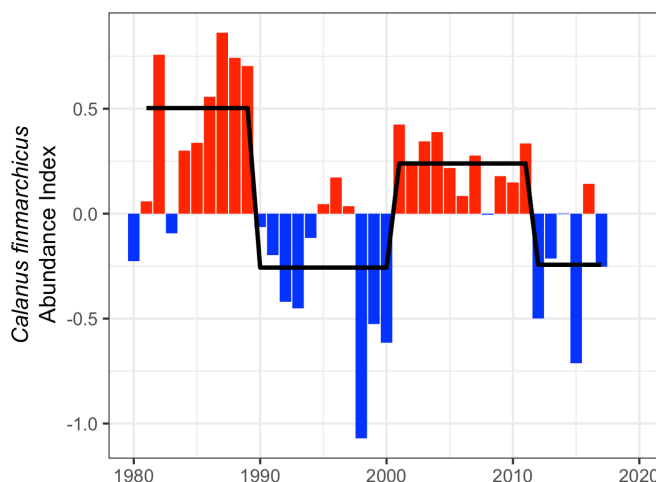

FIGURE S1. Time series of the annual *C. finmarchicus* Abundance Index for the Gulf of Maine. Positive index values are shown in red, negative values in blue. The black solid line indicates regime shifts in the time series detected using the Sequential t-test Analysis of Regime Shifts (STARS) algorithm (Rodionov, 2004).
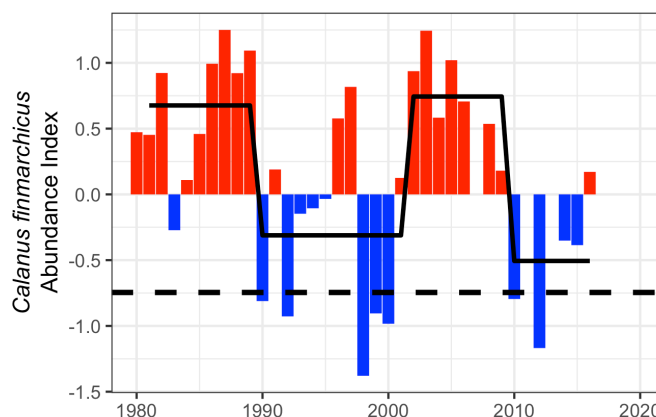

FIGURE S2. Time series of the third quarter *C. finmarchicus* Abundance Index for the eastern Gulf of Maine. Positive index values are shown in red, negative values in blue. The black solid line indicates regime shifts in the time series detected using the STARS algorithm (Rodionov, 2004). The black dashed line corresponds to a previously estimated threshold value in the index below which prenatal or neonatal calf mortality is triggered due to inadequate prey availability and poor maternal nutrition (Meyer-Gutbrod et al., 2015). Gaps in the time series during 2007, 2011, and 2013 are due to inadequate CPR survey sampling in the eastern Gulf of Maine during the third quarters of those years.

In **Figure S3**, the decadal mean SPUE for 2000–2009 and 2010–2019 are determined for each seasonal quarter (Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December) and each of the five key right whale foraging grounds: Cape Cod Bay, Great South Channel, Bay of Fundy, Roseway Basin, and southern Gulf of St. Lawrence. These are the data that underlie the whale icon representations shown in **Figure 3**. Sightings were aggregated from geographic polygons corresponding to each of the foraging grounds (**Figure S4**). Seasonal quarters and foraging grounds that had low survey efforts (<1,000 km) are clearly delineated in **Figure 3**. It should be noted that a consistent visual survey was not implemented in the Gulf of St. Lawrence until 2015, and no SPUE data for 2019 are available yet.

RIGHT WHALE POPULATION DOUBLING TIME AND TIME TO EXTINCTION

The right whale population doubling time and time to extinction were derived from a prey-dependent mark-recapture model fit to demographic data from 1980–2012 (**Figure 4**; Meyer-Gutbrod et al., 2015). The doubling time is based on constant mortality rates estimated from right whale demographic data from 1980–2012 and reproduction estimates based on prey resampled from the same time period. The time to extinction analysis utilizes the same mark-recapture model with adjustments made to account for the increased mortality and decreased reproduction observed in the most recent decade. The population projection was based on reproduction rates from the low-prey scenario, in which *C. finmarchicus* abundance anomalies were resampled from the decade of the 1990s. Extinction time was then calculated assuming that mortality rates increased to 250% and 400%, comparable to what was observed in 2019 and 2017, respectively. The right whale population was considered functionally extinct when fewer than 10 females remained. In the low-prey scenario, a 250% increase in mortality rate results in a projected extinction within 92 years; a 400% increase in mortality rate results in a projected extinction within 38 years.
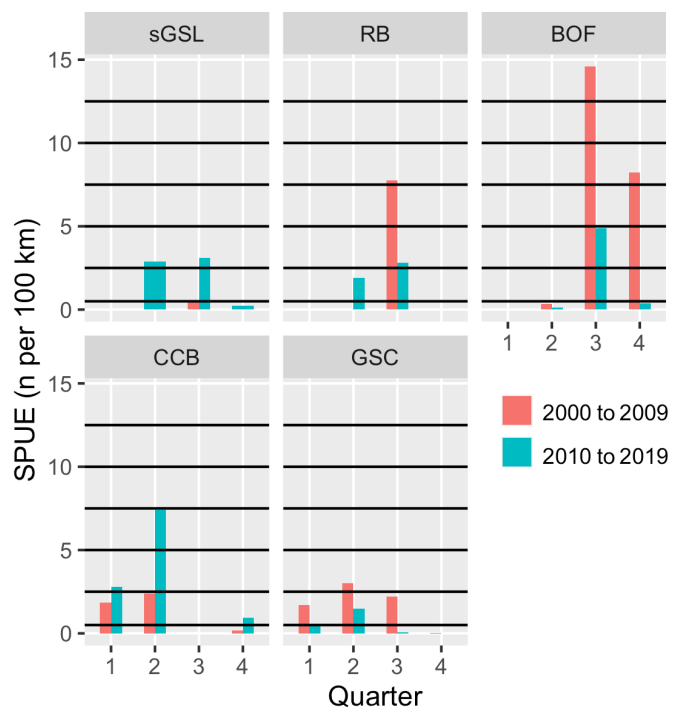

FIGURE S3. Decadal mean SPUE for the decades of 2000–2009 and 2010–2019 for each seasonal quarter (Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December) and each of the five key right whale foraging grounds: Cape Cod Bay (CCB), Great South Channel (GSC), Bay of Fundy (BOF), Roseway Basin (RB), and southern Gulf of St. Lawrence (sGSL). Black horizontal lines correspond to the SPUE bins established in Figure 3 (0.5, 2.5, 5.0, 7.5, 10.0, and 12.5 whales/km).
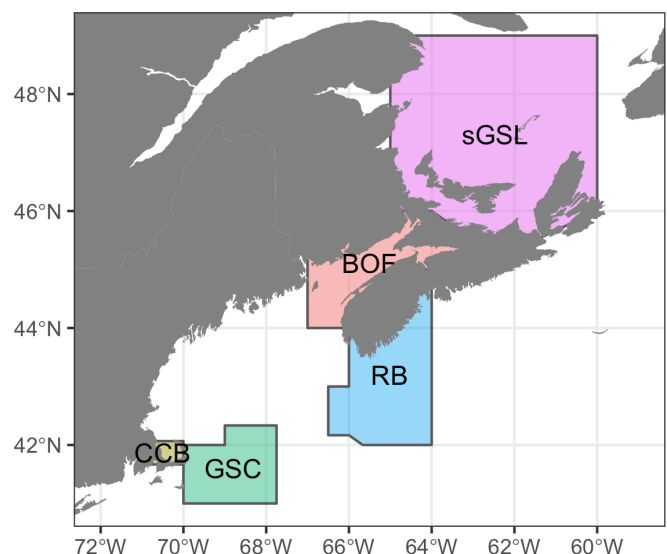

FIGURE S4. Geographic polygons from which SPUE data were aggregated to each of the five key right whale foraging grounds: Cape Cod Bay (CCB), Great South Channel (GSC), Bay of Fundy (BOF), Roseway Basin (RB), and southern Gulf of St. Lawrence (sGSL).