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.

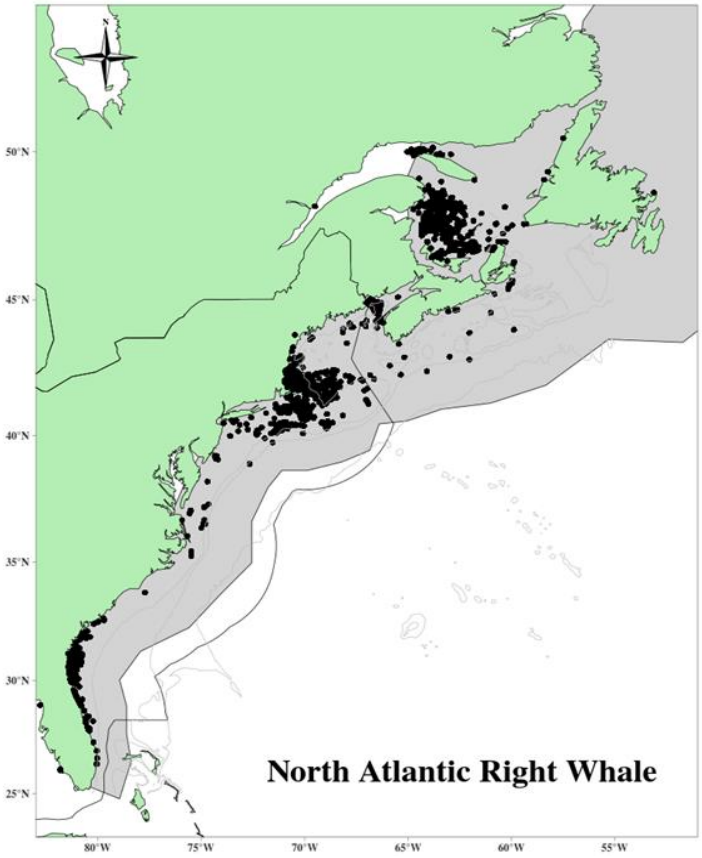

Figure 1. Approximate range (shaded area) and distribution of sightings (dots) of known North Atlantic right whales .

Although the location of much of the population is unknown during much of the year, 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) 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 month later off Georgia (16 February), and back in Cape Cod Bay on 23 March, effectively making the round-trip migration to the Southeast and back at least twice during the winter season (Brown and Marx 2000). Results from satellite-tagging studies clearly indicate that sightings separated by a few weeks in the same area should not necessarily be assumed to indicate a stationary or resident animal. Instead, telemetry data have shown lengthy excursions, including into deep water off the continental shelf over short timeframes (Mate *et al*. 1997; Baumgartner and Mate 2005). The majority of right whale sightings off northeastern Florida and southeastern Georgia were within 90 km of the shoreline, as was most of the survey effort, however, one sighting occurred ~140 km offshore (NMFS unpub. data).

Systematic visual surveys conducted off the coast of North Carolina during the winters of 2001 and 2002 sighted 8 calves, suggesting the calving grounds may extend as far north as Cape Fear (W.A. McLellan, Univ. of North Carolina Wilmington, pers. comm.). Four of those calves were not sighted by surveys conducted farther south. One of the females photographed was new to researchers, having effectively eluded identification over the period of its maturation. An offshore survey in March 2010 observed the birth of a right whale in waters 75 km off Jacksonville, Florida (Foley et al. 2011). In 2016, the Southeastern U.S. Calving Area Critical Habitat was expanded north to Cape Fear, North Carolina. There is also at least one case of a calf apparently being born in the Gulf of Maine (Patrician *et al*. 2009) and another calf was detected in Cape Cod Bay in 2012 (Center for Coastal Studies, Provincetown, MA USA, unpub. data).

New England and Canadian waters are important feeding habitats for right whales, where they feed primarily on copepods (largely of the genera *Calanus* and *Pseudocalanus*). Right whales must locate and exploit extremely dense patches of zooplankton to feed efficiently (Mayo and Marx 1990). These dense zooplankton patches are likely a primary characteristic of the spring, summer, and fall right whale habitats (Kenney *et al*. 1986, 1995). The characteristics of acceptable prey distribution in these areas are summarized in Baumgartner *et al*. (2003) and Baumgartner and Mate (2003). In 2016, the Northeastern U.S. Foraging Area Critical Habitat was expanded to include nearly all U.S. waters of the Gulf of Maine (81 FR 4837, 26 February 2016).

An important shift in habitat-use patterns in 2010 was highlighted in an analysis of right whale acoustic presence in the western North Atlantic from 2004 to 2014 (Davis *et al*. 2017). This shift was also reflected in visual survey data in the greater Gulf of Maine region. Between 2012 and 2016, visual surveys detected fewer individuals in the Great South Channel (NMFS unpublished data) and the Bay of Fundy (Davies *et al*. 2019), while the number of individuals using Cape Cod Bay in spring increased (Mayo *et al*. 2018; Ganley *et al*. 2019). In addition, right whales apparently abandoned the central Gulf of Maine in winter (see Cole *et al*. 2013), but have since been seen in large numbers, and both feeding and socializing observed, in a region south of Martha's Vineyard and Nantucket Islands (Leiter *et al*. 2017; Stone *et al*. 2017; Quintana-Rizzo *et al*. 2021), an area outside of the 2016 Northeastern U.S. Foraging Area Critical Habitat. Right whale presence in this area is nearly year round, including in summer months. The highest sighting rates are from winter through early spring; close to a quarter of the population may be present at any given time between December and May. The age and sex of the whales using this area did not vary significantly from that of the population (Quintana-Rizzo *et al.* 2021). Since 2015, increased acoustic detections and survey effort in the Gulf of St. Lawrence have documented right whale presence there from late spring through the fall (Cole *et al*. 2016; Simard *et al*. 2019; DFO 2020). Photographic captures of right whales in the Gulf of St. Lawrence during the summers of 2015–2019 documented 48, 50, 133, 132, and 135 unique individuals using the region, respectively, with a total of 187 unique individuals documented over the five summers (Crowe *et al*. 2021).

Genetic analyses based upon direct sequencing of mitochondrial DNA (mtDNA) have identified seven mtDNA haplotypes in the western North Atlantic right whale population, including heteroplasmy that led to the declaration of the seventh haplotype (Malik *et al*. 1999; McLeod and White 2010). Schaeff *et al*. (1997) compared the genetic variability of North Atlantic and southern right whales (*E. australis*), and found the former to be significantly less diverse, a finding broadly replicated by Malik *et al*. (2000). The low diversity in North Atlantic right whales might indicate inbreeding, but no definitive conclusion can be reached using current data. Modern and historic genetic population structures were compared using DNA extracted from museum and archaeological specimens of baleen and bone. This work suggested that the eastern and western North Atlantic populations were not genetically distinct (Rosenbaum *et al*. 1997, 2000). However, the virtual extirpation of the eastern stock and its lack of recovery in the last hundred years strongly suggest population subdivision over a protracted (but not evolutionary) timescale. Genetic studies concluded that the principal loss of genetic diversity occurred prior to the 18th century (Waldick *et al*. 2002). However, revised conclusions that nearly all the remains in the North American Basque whaling archaeological sites

were bowhead whales (*Balaena mysticetus*) and not right whales (Rastogi *et al*. 2004; McLeod *et al*. 2008) contradict the previously held belief that Basque whaling during the 16th and 17th centuries was principally responsible for the loss of genetic diversity.

High-resolution (*i.e.*, using 35 microsatellite loci) genetic profiling improved the understanding of genetic variability, the number of reproductively active individuals, reproductive fitness, parentage, and relatedness of individuals (Frasier *et al*. 2007, 2009). It has also helped fill gaps in our understanding of the species' age structure, calf development, calf survival, and weaning (Hamilton *et al*. 2022). Because the callosity patterns used to identify individual right whales take months to develop after a whale's birth, obtaining biopsy samples from calves on the calving grounds provides a means of genetically identifying calves later in life, or death. Between 1990 and 2010, only about 60% of all known calves were seen with their mothers in summering areas when their callosity patterns are stable enough to reliably make a photo-ID match later in life. The remaining 40% were not seen on a known summering ground. Because the calf's genetic profile is the most reliable way to establish parentage, if the calf is not sampled when associated with its mother early on, information such as age and familial relationships may be lost. From 1980 to 2001, there were 64 calves born that were not sighted later with their mothers and thus unavailable to provide age-specific mortality information (Frasier *et al*. 2007). Hamilton *et al*. (2022) reported that of the 470 calves observed between 1998 and 2018, 370 (78.7%) were biopsied, 293 as calves and 77 later in life, their identification linked by photographs. Of the 100 calves not biopsied during this period, 32 were sufficiently photographed to allow subsequent identification and aging, but 68 had yet to be identified other than as a unique calf.

Frasier (2007b) genetically examined the paternity of 87 calves born between 1980 and 2001. Although genetic profiles were available for 69% of all potential fathers in the population, paternity was assigned to only 51% of the calves, and all the sampled males were excluded as fathers of the remaining calves. The findings suggested that either the unsampled males were particularly successful, or that the population of males, and the population as a whole, was larger than suggested by the photo-identification data (Frasier 2007b). However, a study comparing photo-identification and pedigree genetic data for animals known or presumed to be alive during 1980–2016 found that the presumed alive estimate is similar to the actual abundance of this population, which indicates that the majority of the animals have been photo-identified (Fitzgerald 2018).

POPULATION SIZE

Estimation of the western North Atlantic right whale stock size is based on a published state-space model of the sighting histories of individual whales identified using photo-identification techniques (Pace *et al*. 2017; Pace 2021). Sightings histories were constructed from the photo-ID recapture database as it existed in December 2021, and included photographic information up through November 2020. Using a hierarchical, state-space Bayesian open population model of these histories produced a median abundance value (Nest) as of 30 November 2020 of 338 individuals (95%CI: 325-350; Table 1). As this model relies on individual animals being photographically identifiable from their callosity patterns to be recruited into the population, which are typically not stable until animals are greater than 1 year old, this estimate does not include recent calves. As with any statistically-based estimation process, uncertainties exist in the estimation of abundance because it is based on a probabilistic model that makes certain assumptions about the structure of the data. Because the statistically-based uncertainty is asymmetric about N, the credible interval is used to characterize that uncertainty (as opposed to a CV that may appear in other stock assessment reports).

Table 1. Best and minimum abundance estimates as of 30 November 2020 for non-calf western North Atlantic right whales (Eubalaena glacialis) with Maximum Productivity Rate (R_{max}), Recovery Factor (F_r) and PBR.

N_{est}	95% Credible Interval	60% Credible Interval	N_{min}	F_r	R_{max}	PBR
338	325–350	332–343	332	0.1	0.04	0.7

Historical Abundance

The total North Atlantic right whale population size pre-whaling is estimated between 9,075 and 21,328 based on extrapolation of spatially explicit models of carrying capacity in the North Pacific (Monserrat *et al.* 2015). Basque whalers were thought to have taken right whales during the 1500s in the Strait of Belle Isle region (Aguilar 1986), however, genetic analysis has shown that nearly all of the remains found in that area are, in fact, those of bowhead whales (Rastogi *et al.* 2004; Frasier *et al.* 2007). This stock of right whales may have already been substantially reduced by the time colonists in Massachusetts started whaling in the 1600s (Reeves *et al.* 2001, 2007). A modest but

persistent whaling effort along the coast of the eastern U.S. lasted three centuries, and the records include one report of 29 whales killed in Cape Cod Bay in a single day in January 1700. Reeves *et al*. (2007) calculated that a minimum of 5,500 right whales were taken in the western North Atlantic between 1634 and 1950, with nearly 80% taken in a 50-year period between 1680 and 1730. They concluded "there were at least a few thousand whales present in the mid-1600s." The authors cautioned, however, that the record of removals is incomplete, the results were preliminary, and refinements are required. Based on back calculations using the present population size and growth rate, the population may have numbered fewer than 100 individuals by 1935 when international protection for right whales came into effect (Hain 1975; Reeves *et al.* 1992; Kenney *et al.* 1995). However, little is known about the population dynamics of right whales in the intervening years.

Minimum Population Estimate

The minimum population estimate is the lower limit of the two-tailed 60% credible interval about the median of the posterior abundance estimates using the methods of Pace *et al*. (2017) and refinements of Pace (2021). This is roughly equivalent to the 20th percentile of the log-normal distribution as specified by Wade and Angliss (1997). The median estimate of abundance for adult and juvenile western North Atlantic right whales is 338 (computed November 30, 2021). The minimum population estimate as of 30 November 2020 is 332 (non-calf) individuals (Table 1).

Current Population Trend

The population growth rate reported for the period 1986–1992 by Knowlton *et al*. (1994) was 2.5% (CV=0.12), suggesting that the stock was recovering slowly, but that number may have been influenced by the discovery phenomenon as existing whales were recruited to the catalog. Work by Caswell *et al.* (1999) suggested that crude survival probability declined from about 0.99 in the early 1980s to about 0.94 in the late 1990s. The decline was statistically significant. Additional work conducted in 1999 was reviewed by an IWC workshop on status and trends in this population (IWC 2001); the workshop concluded based on several analytical approaches that survival had indeed declined in the 1990s. Although capture heterogeneity could negatively bias survival estimates, the workshop concluded that this factor could not account for the entire observed decline, which appeared to be particularly marked in adult females. Another workshop was convened by NMFS in September 2002, and it reached similar conclusions regarding the decline in the population (Clapham 2002). At the time, the early part of the recapture series had not been examined for excessive retrospective recaptures which had the potential to positively bias the earliest estimates of survival as the catalog was being developed.

Examination of the adult and juvenile abundance estimates for the years 1990–2011 (Figures 2a, 2b) suggests that abundance increased at about 2.8% per annum from posterior median point estimates of 270 individuals in 1990 to 481 in 2011, but that there was a 100% chance that abundance declined from 2011 to 2020 when the final estimate was 338 individuals. The overall abundance decline between 2011 and 2020 was 23.5% (CI=21.4% to 26.0%). There has been a considerable change in right whale habitat-use patterns in areas where most of the population had been observed in previous years (*e.g.*, Davies *et al*. 2017), exposing the population to new anthropogenic threats (Hayes *et al.* 2018). Pace (2021) found a significant decrease in mean survival rates since 2010, correlating with the observed change in area-use patterns (Figure 2c). This apparent change in habitat use also had the effect that, despite relatively constant effort to find whales in traditional areas, the chance of photographically capturing individuals decreased (Figure 3). However, the methods in Pace *et al.* (2017) and Pace (2021) account for changes in capture probability.

There were 17 right whale mortalities reported in 2017 (Daoust *et al.* 2017). This number exceeds the largest estimated annual mortality rate during the past 25 years. Further, despite high survey effort, only 5 and 0 calves were detected in 2017 and 2018, respectively. In 2019, 7 calves were identified, and in 2020 10 calves were documented (Pettis *et al.* 2021).

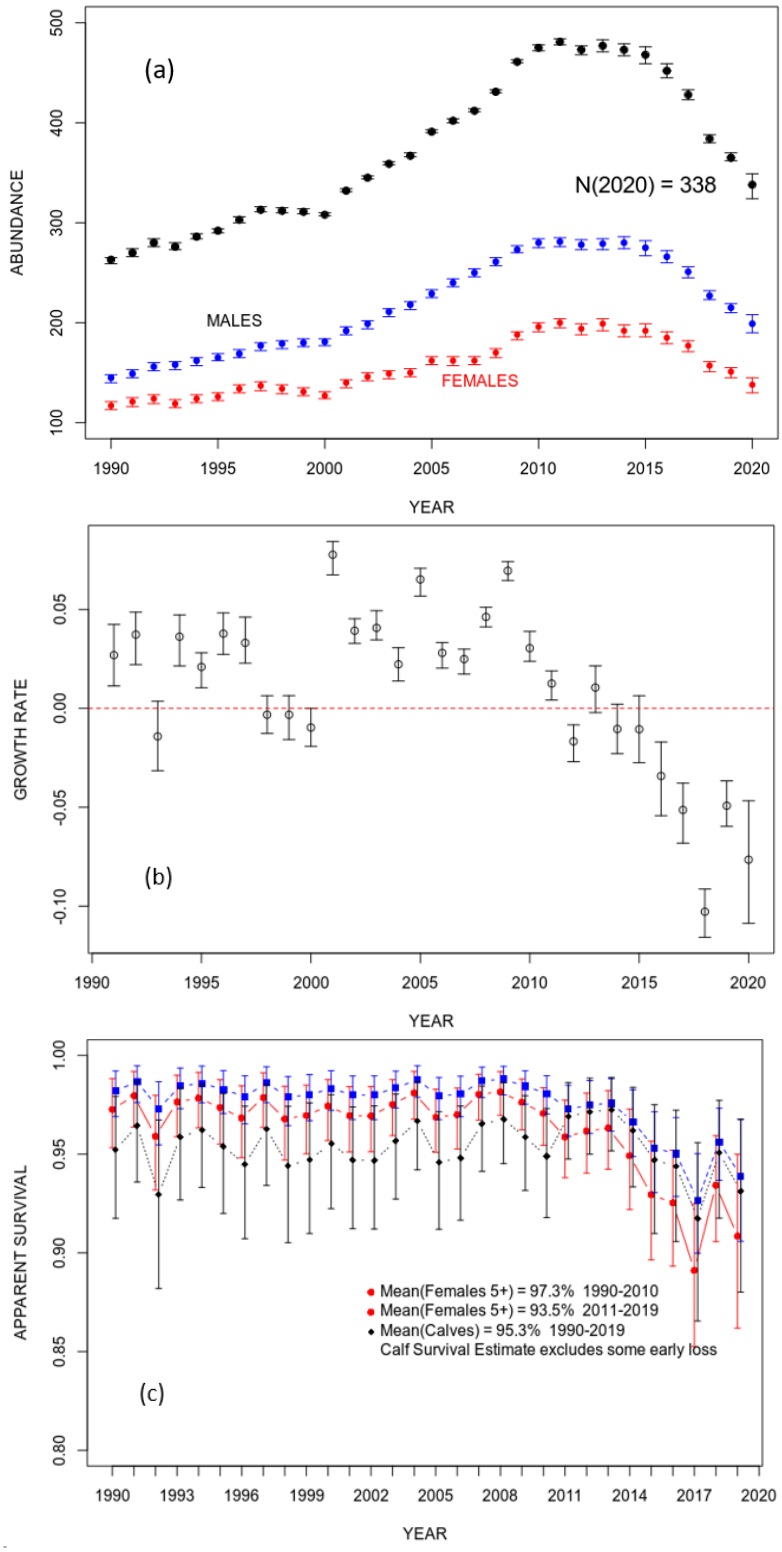

Figure 2. (a) Abundance estimates for adult and juvenile North Atlantic right whales. Estimates are the median values of a posterior distribution from modeled capture histories. Also shown are sex-specific abundance estimates. (b) Annual growth rates from the abundance values (c) Sex-specific survival rate estimates. All graphs show associated 95% credible intervals.

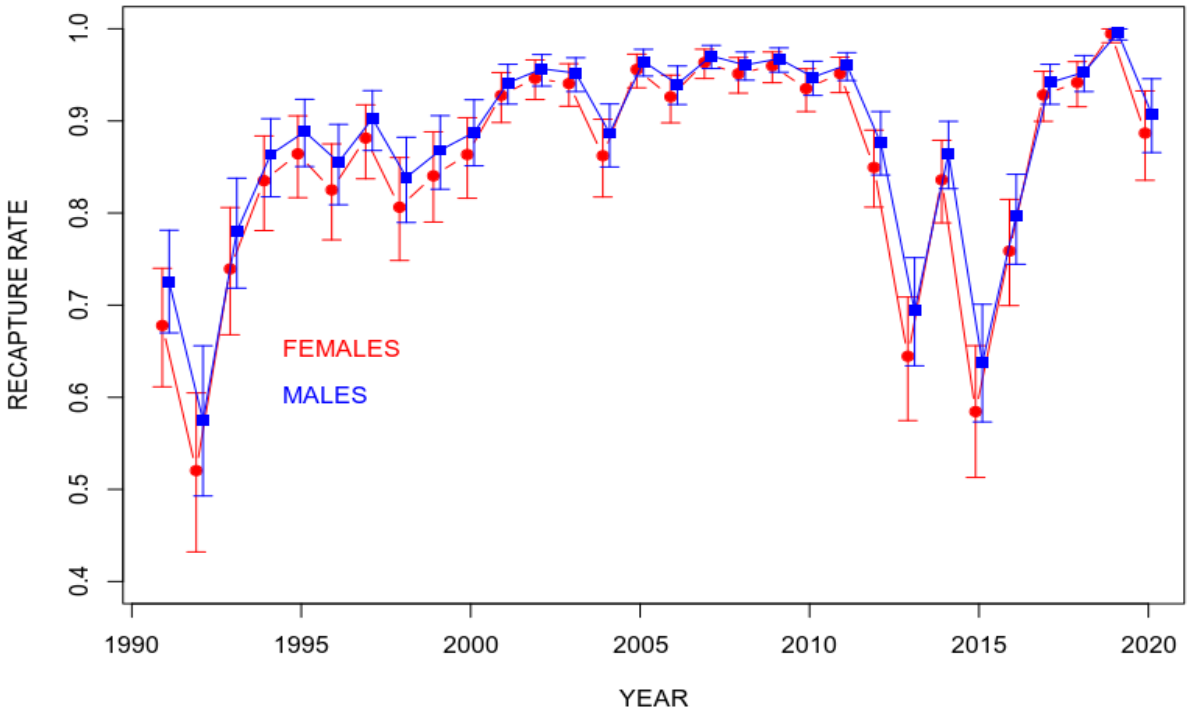

Figure 3. Estimated recapture probability and associated 95% credible intervals of North Atlantic right whales 1990–2018 based on a Bayesian mark-resight/recapture model allowing random fluctuation among years for survival rates, treating capture rates as fixed effects over time, and using both observed and known states as data (from Pace et al. 2017). Males are shown in blue with squares, females are shown in red with circles.

CURRENT AND MAXIMUM NET PRODUCTIVITY RATES

During 1980–1992, at least 145 calves were born to 65 identified females. The number of calves born annually ranged from 5 to 17, with a mean of 11.2 (SE=0.90). The reproductively active female pool was static at approximately 51 individuals during 1987–1992. Mean calving interval, based on 86 records, was 3.67 years. There was an indication that calving intervals may have been increasing over time, although the trend was not statistically significant (P=0.083) (Knowlton *et al.* 1994). Since 1993, calf production has been more variable than a simple stochastic model would predict.

During 1990–2020, at least 481 calves were born into the population. The number of calves born annually ranged from 0 to 39, and averaged 15 but was highly variable (SD=9.1). No calves were born in the winter of 2017–2018. The fluctuating abundance observed from 1990 to 2020 makes interpreting a count of calves by year less clear than measuring population productivity, which we index by dividing the number of detected calves by the estimated adult and juvenile abundance each year (Apparent Productivity Index or API). Productivity for this stock has been highly variable over time and has been characterized by periodic swings in per capita birth rates (Figure 4). Notwithstanding the high variability observed, as expected for a small population, productivity in North Atlantic right whales lacks a definitive trend. Corkeron *et al.* (2018) found that during 1990–2016, calf count rate increased at 1.98% per year with outlying years of very high and low calf production. This is approximately a third of that found for three different southern right whale (*Eubalaena australis)* populations during the same time period (5.3–7.2%). Based on the most recent population estimate, there are approximately 68 females known to have calved that are likely (>50% probability) still alive.

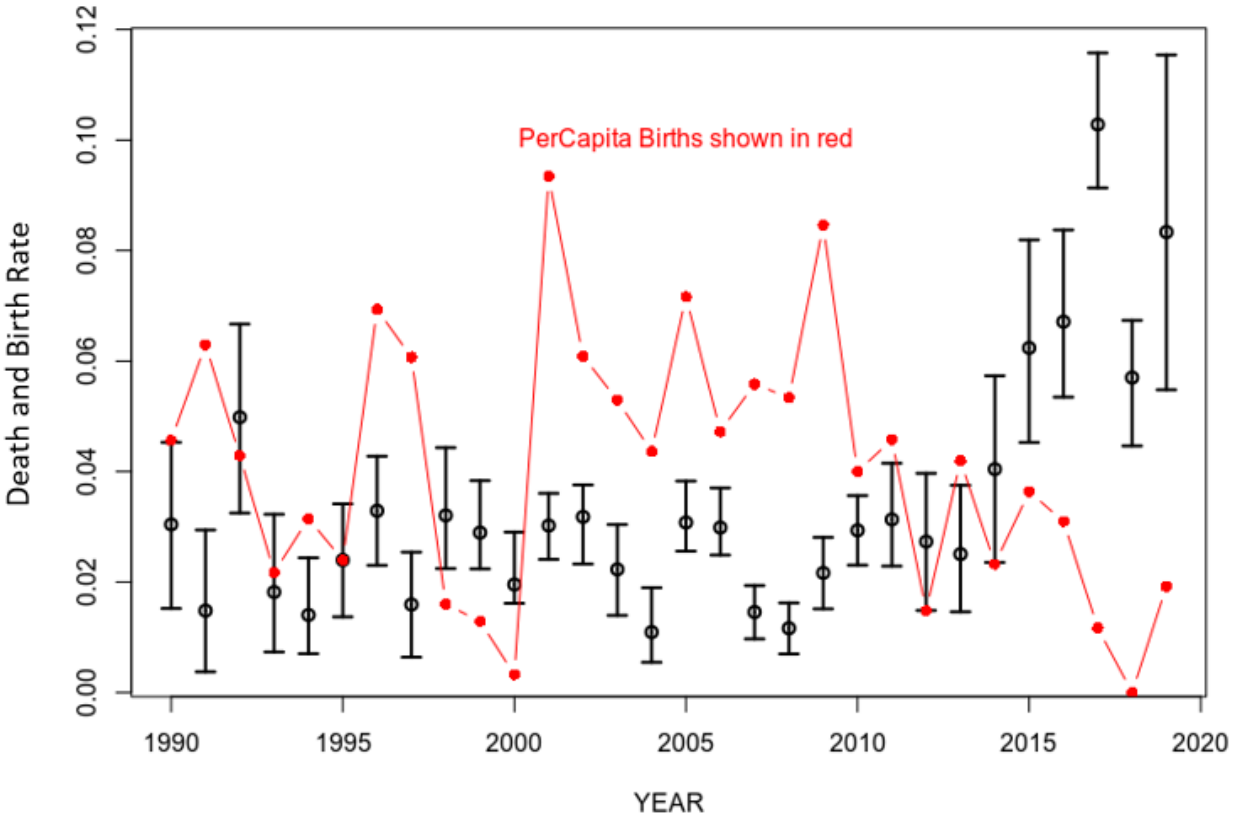

Figure 4. North Atlantic right whale per capita birth rate (red line, closed circles) and death rate with associated 95% credible intervals, 1990 – 2019.

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). There is also clear evidence that North Atlantic right whales are growing to shorter adult lengths than in earlier decades (Stewart *et al.* 2021) and are in poor body condition compared to southern right whales (Christiansen *et al.* 2020, Miller et al. 2011). All these changes may result from a combination of documented regime shifts in primary feeding habitats (Meyer-Gutbrod and Greeene 2014; Meyer-Gutbrod *et al.* 2021; Record *et al.* 2019), and increased energy expenditures related to non-lethal entanglements (Rolland *et al.* 2016; Pettis *et al.* 2017; van der Hoop 2017). Only non-lethal entanglements can be affected by management intervention, and despite recent management actions, overall entanglement rates (as measured by the rate at which scars are acquired by living North Atlantic right whales; Hamilton *et al.* 2020; Fig. 5 here) remain high. As such, entanglement will continue to impact calving rates, and the declining trend in abundance will likely continue.

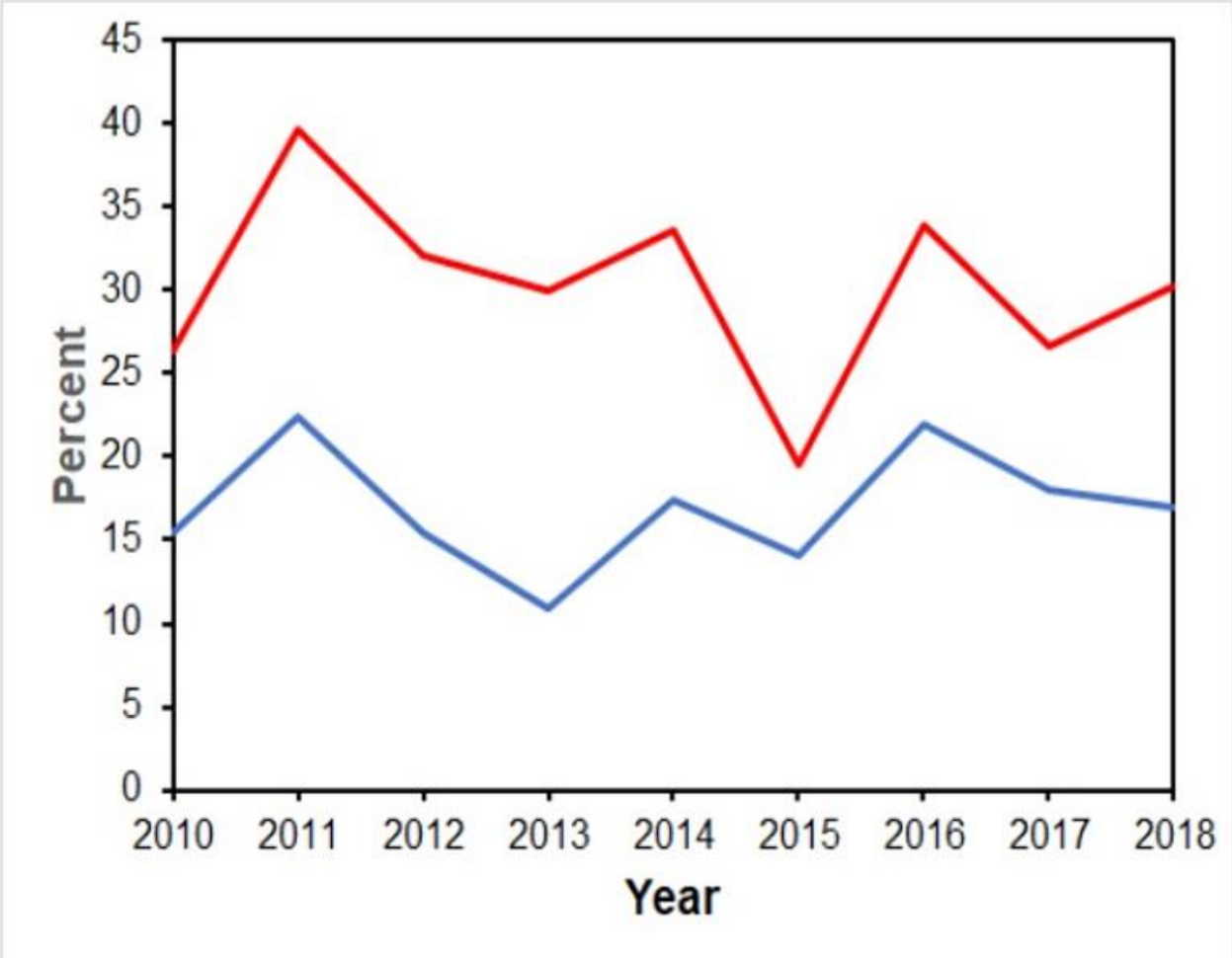

Figure 5. North Atlantic right whale entanglement rates estimated by monitoring scars on living whales. The crude entanglement rate (blue line) is the proportion of whales seen with newly discovered entanglement scars. The annual entanglement rate (red line) is the proportion of adequately photographed whales with new scars (data from Hamilton et al. 2020).

An analysis of the age structure of this population suggested that it contained 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). Projection models suggest that this rate could be 4% per year if female survival was the highest recorded over the time series from Pace *et al.* (2017). Reviewing the available literature, Corkeron *et al.* (2018) showed that female mortality is primarily anthropogenic, and concluded that anthropogenic mortality has limited the recovery of North Atlantic right whales. In a similar effort, Kenney (2018) back-projected a series of scenarios that varied entanglement mortality from observed to zero. Using a scenario with zero entanglement mortality, which included 15 'surviving' females, and a five-year calving interval, the projected population size including 26 additional calf births would have been 588 by 2016. 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 of adults and juveniles is 332. 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 2016 through 2020, the annual detected (*i.e.*, observed) human-caused mortality and serious injury to right whales averaged 8.1 individuals per year (Table 2). This is derived from two components: 1) incidental fishery entanglement records at 5.7 per year, and 2) vessel strike records averaging 2.4 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 for adults and juveniles. The estimated annual rate of total mortality using this modeling approach is 31.2 animals (non-calves) for the period 2015–2019 (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 6 shows the estimates of total mortality for 1990–2019 from the state-space model. The estimated mortality rate for the 5-year period 2015–2019 using the methods of Pace *et al*. (2021) is 4.1 times higher than the 7.7 detected mortality and serious injury value reported for the same period in the previous stock assessment report. The estimated mortality for 2020 is not yet available because it is derived from a comparison with the population estimate for 2021, which, in turn, is contingent on the processing of all photographs collected through 2021 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 (Sharp *et al.* 2019). Based on these findings, 100% of the estimated mortality of 31.2 animals (non-calves) per year is assumed to be human-caused. Sharp et al. (2019) found that 5 of 10 (50%) calf mortalities were from natural causes.

There is currently insufficient information to apportion the estimated total mortality of adults and juveniles occurring in U.S. waters. To apportion the estimated total mortality by cause, *e.g.*, entanglement versus vessel collision, we used the proportion of observed mortalities and serious injuries from entanglement compared to those from vessel collision for the period 2016–2020. During this period, 71% of the observed mortality and serious injury was the result of entanglement and 29% was from vessel collisions. Applying these proportions to the estimated total mortality of adults and juveniles provides an estimate of 111 total entanglement deaths and 45 total vessel collision deaths during 2016–2020 (Table 2). These estimates may be biased if there is significant bias in the detection of entanglement versus vessel collision 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 Sharp *et al.* (2019) theorized 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. However, floating carcasses of whales will only drift with wind and currents, and may not be carried into areas where detection is likely, whereas entangled whales may continue to swim for months and move into areas patrolled by survey teams. An initial review of the serious injury and mortality records maintained by NMFS between 2001–2020 found that 59% of all

right whale serious injuries were first documented by survey teams, but only 19% of right whale carcasses were first discovered by survey teams. The visibility of some entanglements can also add to the likelihood of detection, whereas blunt trauma from a vessel collision is not externally detectable. 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.

Table 2. Annual estimated and observed human-caused mortality and serious injury for the North Atlantic right whale (Eubalaena glacialis). Observed values are from confirmed interactions from 2016–2020. Estimated total mortality is derived from annual population estimates for adults and juveniles from 2015–2019 (Pace et al. 2017; Pace et al. 2021).

Years	Source	Total	Annual Average
2015–2019	Estimated total adult and juvenile mortality	156	31.2
	Estimated adult and juvenile incidental fishery-related mortality	110	22.0
	Estimated adult and juvenile vessel collision mortality	46	9.2
2016–2020	Observed total human-caused M/SI[a]	40.5	8.1
	Observed incidental fishery-related M/SI[a,b]	28.5	5.7
	Observed vessel collision M/SI1	12	2.4
	Fishery-related SI prevented[c]	6	1.2

a. Observed serious injury events with decimal values were counted as 1 for this comparison.
b. The observed incidental fishery interaction count does not include fishery-related serious injuries that were prevented by disentanglement.
c. Fishery-related serious injuries prevented are a result of successful disentanglement efforts.

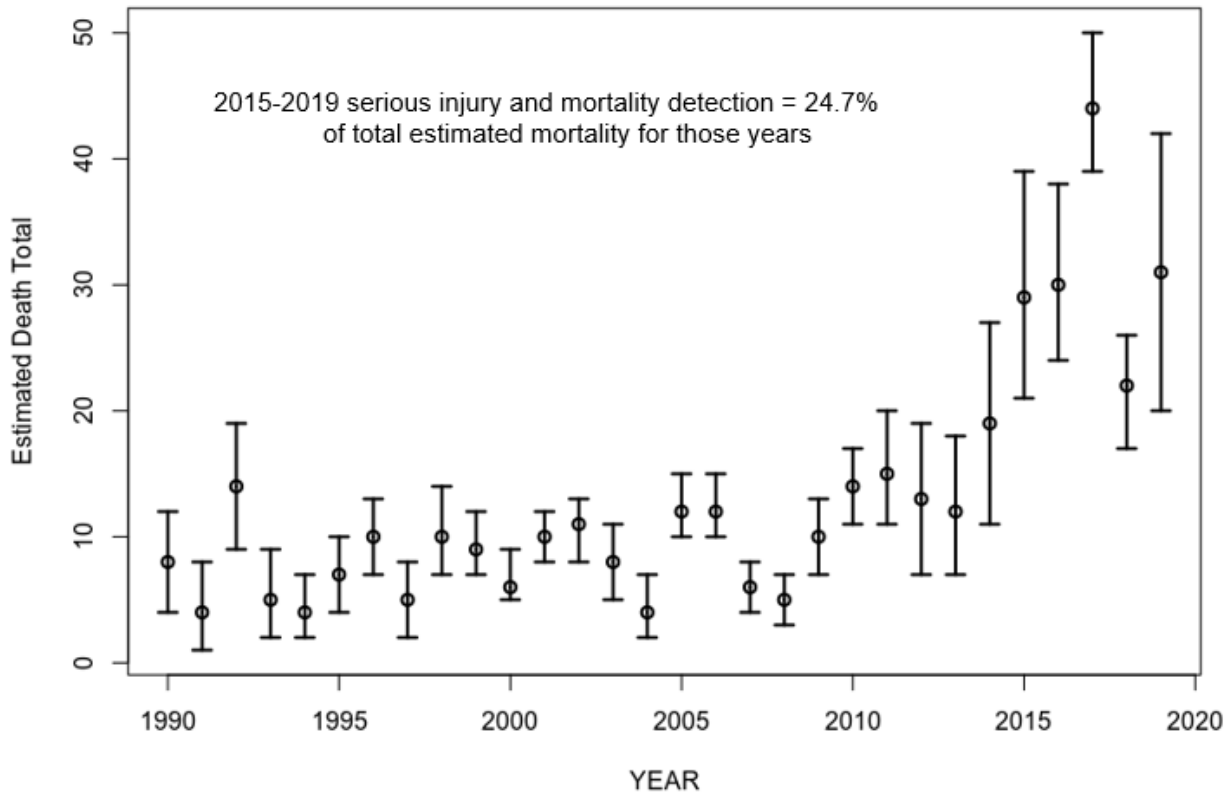

Figure 6. Time series of estimated total adult and juvenile right whale mortalities, 1990–2019.

The small population size and low annual reproductive rate of right whales suggest that human sources of mortality have a greater effect relative to population growth rates than for other whale species (Corkeron *et al.* 2018). The principal factors preventing growth and recovery of the population are entanglement and vessel strikes. Between 1970 and 2018, 124 right whale mortalities were recorded (Knowlton and Kraus 2001; Moore *et al.* 2005; Sharp *et al.* 2019). Of these, 18 (14.5%) were calves that were believed to have died from perinatal complications or other natural causes. Of the remainder, 26 (21.0%) resulted from vessel strikes, 26 (21.0%) were related to entanglement in fishing gear, and 54 (43.5%) were of unknown cause. At a minimum, therefore, 42% of the observed total for the period and 43% of the 102 non-calf deaths were attributable to human impacts (calves accounted for six deaths from vessel strikes and two from entanglements). However, when considering only those cases where cause of death could be determined, 100% of non-calf mortality was human-caused. Hayes *et al*. (2018) reported an increasing trend in entanglement mortality and serious injuries during 2000-2017, while vessel strikes had no specific trend despite several reported cases in 2017. Detected vessel strike mortalities were again relatively numerous in 2019, and in 2020 one calf was seriously injured and another killed by vessel strikes in US waters (Table 3).

The details of a particular mortality or serious injury record often require a degree of interpretation (Moore *et al.* 2005; Sharp *et al.* 2019). The cause of death is based on analysis of the available data; additional information may result in revisions. When reviewing Table 3 below, several factors should be considered: 1) a vessel strike or entanglement may have occurred at some distance from the location where the animal is detected/reported; 2) the mortality or injury may involve multiple factors; for example, whales that have been both vessel struck and entangled are not uncommon; 3) the actual vessel or gear type/source is often uncertain; and 4) entanglements may involve several types of gear. Beginning with the 2001 Stock Assessment Report, Canadian records have been incorporated into the mortality and serious injury rates to reflect the effective range of this stock. However, because whales have been known to carry gear for long periods of time and over great distances before being detected, and recovered gear is often not adequately marked, it can be difficult to assign some entanglements to the country of origin.

It should be noted that entanglement and vessel collisions may not seriously injure or kill an animal directly, but may weaken or otherwise affect a whale's reproductive success (van der Hoop *et al.* 2017; Corkeron *et al.* 2018; Christiansen *et al*. 2020; Stewart *et al*. 2021). The NMFS serious injury determinations for large whales commonly include animals carrying gear when these entanglements are constricting or are determined to interfere with foraging (Henry *et al*. 2022). Successful disentanglement and subsequent resightings of these individuals in apparent good health are criteria for downgrading an injury to non-serious. However, these and other non-serious injury determinations should be considered to fully understand anthropogenic impacts to the population, especially in cases where females' fecundity may be affected.

Fishery-Related Mortality and Serious Injury

Not all mortalities are detected, but reports of known mortality and serious injury relative to PBR, as well as total human impacts, are contained in the records maintained by the New England Aquarium and NMFS. Records were reviewed and those determined to be human-caused are detailed in Table 3. Information from an entanglement event often does not include the detail necessary to assign the entanglements to a particular fishery or location.

Although disentanglement is often unsuccessful or not possible for many cases, there are several documented cases of entanglements for which the intervention by disentanglement teams averted a likely serious-injury determination. See Table 2 for the annual average of serious injuries prevented by disentanglement.

Whales often free themselves of gear following an entanglement event, and as such scarring may be a better indicator of fisheries interaction rates than entanglement records. Scarring rates suggest that entanglements occur at about an order of magnitude more often than detected from observations of whales with gear on them. Knowlton et al. (2012) reviewed scarring on identified individual right whales over a period of 30 years (1980–2009), documenting 1,032 definite, unique entanglement events on the 626 individual whales. Most individual whales (83%) were entangled at least once, and over half of them (59%) were entangled more than once. About a quarter of the individuals identified in each year (26%) were entangled in that year. Juveniles and calves were entangled at higher rates than were adults. Moore *et al.* (2021) reported that between 1980 and 2017, 86.1% (642 of 746) individual whales identified had evidence of entanglement interactions. Analysis of whales carrying entangling gear also suggest that entanglement wounds have become more severe since 1990, possibly due to increased use of stronger lines in fixed fishing gear (Knowlton *et al*. 2016).

Knowlton *et al.* (2012) concluded from their analysis of entanglement scarring rates from 1980–2009 that efforts of the prior decade to reduce right whale entanglement had not worked. Using a completely different data source

(observed mortalities of eight large whale species, 1970–2009), van der Hoop *et al*. (2012) arrived at a similar conclusion. Similarly, Pace *et al*. (2015), analyzing entanglement rates and serious injuries due to entanglement during 1999–2009, found no support that mitigation measures implemented prior to 2009 had been effective at reducing takes due to commercial fishing. Since 2009, new entanglement mitigation measures (72 FR 193, 05 October 2007; 79 FR 124, 27 June 2014) have been implemented as part of the Atlantic Large Whale Take Reduction Plan, but their effectiveness has yet to be evaluated. One difficulty in assessing mitigation measures is the need for a statistically significant time series to determine effectiveness.

Other Mortality

Vessel strikes are a major cause of mortality and injury to right whales (Kraus 1990; Knowlton and Kraus 2001, van der Hoop *et al.* 2012). Records from 2016 through 2020 have been summarized in Table 3. Early analyses of the effectiveness of the vessel-strike rule were reported by Silber and Bettridge (2012). van der Hoop *et al.* (2015) concluded that large whale mortalities due to vessel strikes appeared to have decreased inside active seasonal management areas (SMAs) but increased outside inactive SMAs. They suggested increasing spatial coverage to improve the Rule's effectiveness. Analysis by Laist *et al.* (2014) incorporated an adjustment for drift around areas regulated under the vessel-strike rule and produced weak evidence that the rule was effective inside the SMAs. Hayes et al. (2018) found there was no apparent trend up or down in ship strike serious injury and mortality between 2000 and 2017 when simple logistic regression models fit using maximum likelihood-based estimation procedures were applied to reported vessel strikes. NMFS (2020) found that compliance to the vessel strike rule varied across the right whale's range in US waters. In 2018-2019, ten years after the rule's enactment, compliance in seasonal management areas from Delaware northward exceeded 85%. Morehead City also exceeded 85%, and the Southeast seasonal management area compliance was 84.6%. Lower compliance rates were noted for the Chesapeake (78%) and North Carolina to Georgia (69%) seasonal management areas. Compliance varied considerably by vessel type; fishing vessels showed the highest level of compliant transit (93%) while other cargo and pleasure vessels had low levels of compliance (44% and 31%, respectively). Using simple biophysical models, Kelley *et al*. (2020) determined that whales can be seriously injured or killed by vessels of all sizes, and that collision with a 50-ton fishing vessel transiting at 7 knots has a probability of lethality greater than 50%.

An Unusual Mortality Event was established for North Atlantic right whales in June 2017 due to elevated strandings along the Northwest Atlantic Ocean coast, especially in the Gulf of St. Lawrence region of Canada. There were 33 dead whales documented through December 2020, with 19 whales having evidence of vessel strike or entanglement as the preliminary cause of death. Additionally, 11 free-swimming whales were documented as being seriously injured due to entanglements during the time period. One additional free-swimming whale was seriously injured by vessel strike. Therefore, through December 2020, the number of whales included in the UME was 45, including 33 dead and 12 seriously injured free-swimming whales. UME updates are available at (https://www.fisheries.noaa.gov/national/marine-life-distress/2017-20210-north-atlantic-right-whale-unusual-mortality-event).

Table 3. Observed human-caused mortality and serious injury records of right whales: 2016–2020[a]

Date[b]	Fate	ID	Location[b]	Assigned Cause	Value against PBR[c]	Country[d]	Gear Type[e]	Description
01/29/2016	Serious Injury	1968	off Jupiter Inlet, FL	EN	1	XU	NP	No gear present, but evidence of recent entanglement of unknown configuration. Significant health decline: emaciated, heavy cyamid coverage, damaged baleen. Resighted in April 2017 still in poor cond.

05/19/2016	Serious Injury	3791	off Chatham, MA	EN	1	XU	NP	New entanglement injuries on peduncle. Left pectoral appears compromised. No gear seen. Significant health decline: emaciated with heavy cyamid coverage. No resights post Aug 2016.
05/03/2016	Mortality	4681	Morris Island, MA	VS	1	US	-	Fresh carcass with 9 deep ventral lacerations. Multiple shorn and/or fractured vertebral and skull bones. Destabilized thorax. Edema, blood clots, and hemorrhage associated with injuries. Proximate COD - sharp trauma. Ultimate COD - exsanguination.
07/26/2016	Serious Injury	1427	Gulf of St Lawrence, QC	EN	1	XC	NP	No gear present, but new entanglement injuries on peduncle and fluke insertions. No gear present. Resights show subsequent health decline: gray skin, rake marks, cyamids.
08/1/2016	Serious Injury	3323	Bay of Fundy, NS	EN	1	XC	NP	No gear present, but new, severe entanglement injuries on peduncle, fluke insertions, and leading edges of flukes. Significant health decline: emaciated, cyamids patches, peeling skin. No resights.
08/13/2016	Serious Injury	4057	Bay of Fundy, NS	EN	1	CN	PT	Free-swimming with extensive entanglement. Two heavy lines through mouth, multiple loose body wraps, multiple constricting wraps on both pectorals with lines across the chest, jumble of gear by left shoulder. Partially disentangled: left with line through mouth and loose wraps at right flipper that are expected to shed. Significant health decline: extensive cyamid coverage. Current entanglement appears to have exacerbated injuries from previous entanglement (see 16Feb2014 event). No resights.
08/16/2016	Prorated Injury	1152	off Baccaro, NS	EN	0.75	XC	NR	Free-swimming with line and buoy trailing from unknown attachment point(s). No resights.

08/28/2016	Serious Injury	2608	off Brier Island, NS	EN	1	XC	NR	Free-swimming with constricting wraps around rostrum and right pectoral. Line trails 50 ft aft of flukes. Significant health decline: heavy cyamid coverage and indication of fluke deformity. No resights.
08/31/2016	Mortality	4320	Sable Island, NS	EN	1	CN	PT	Decomposed carcass with multiple constricting wraps on pectoral with associated bone damage consistent with chronic entanglement.
09/23/2016	Mortality	3694	off Seguin Island, MA	EN	1	CN	PT	Fresh, floating carcass with extensive, constricting entanglement. Thin blubber layer and other findings consistent with prolonged stress due to chronic entanglement. Gear previously reported as unknown.
12/04/2016	Prorated Injury	3405	off Sandy Hook, NJ	EN	0.75	XU	NE	Lactating female. Free-swimming with netting crossing over blowholes and one line over back. Full configuration unknown. Calf not present, possibly already weaned. No resights. Gear type previously reported as NR.
04/13/2017	Mortality	4694	Cape Cod Bay, MA	VS	1	US	-	Carcass with deep hemorrhaging and muscle tearing consistent with blunt force trauma.
06/19/2017	Mortality	1402	Gulf of St Lawrence, QC	VS	1	CN	-	Carcass with acute internal hemorrhaging consistent with blunt force trauma.
06/21/2017	Mortality	3603	Gulf of St Lawrence, QC	EN	1	CN	PT	Fresh carcass found anchored in at least 2 sets of gear. Multiple lines through mouth and constricting wraps on left pectoral. Glucorticoid levels support acute entanglement as COD.
06/23/2017	Mortality	1207	Gulf of St Lawrence, QC	VS	1	CN	-	Carcass with acute internal hemorrhaging consistent with blunt force trauma.
07/04/2017	Serious Injury	3139	off Nantucket, MA	EN	1	XU	NP	No gear present, but evidence of recent extensive, constricting entanglement and health decline. No resights.

07/06/2017	Mortality	-	Gulf of St Lawrence, QC	VS	1	CN	-	Carcass with fractured skull and associated hemorrhaging. Glucorticoid levels support acute blunt force trauma as COD.
07/19/2017	Serious Injury	4094	Gulf of St Lawrence, QC	EN	1	CN	PT	Line exiting right mouth, crossing over back, ending at buoys aft of flukes. Non-constricting configuration, but evidence of significant health decline. No resights.
07/19/2017	Mortality	2140	Gulf of St Lawrence, QC	VS	1	CN	-	Fresh carcass with acute internal hemorrhaging. Glucorticoid levels support acute blunt force trauma as COD.
08/06/2017	Mortality	-	Martha's Vineyard, MA	EN	1	XU	NP	No gear present, but evidence of constricting wraps around both pectorals and flukes with associated tissue reaction. Histopathology results support entanglement as COD.
09/15/2017	Mortality	4504	Gulf of St Lawrence, QC	EN	1	CN	PT	Anchored in gear with extensive constricting wraps with associated hemorrhaging.
10/23/2017	Mortality	-	Nashawena Island, MA	EN	1	XU	NP	No gear present, but evidence of extensive ent involving pectorals, mouth, and body. Hemorrhaging associated with body and right pectoral injuries. Histo results support entanglement as COD.
01/22/2018	Mortality	3893	55 nm E of Virginia Beach, VA	EN	1	CN	PT	Extensive, severe constricting entanglement including partial amputation of right pectoral accompanied by severe proliferative bone growth. COD - chronic entanglement.
02/15/2018	Serious Injury	3296	33 nm E of Jekyll Island, GA	EN	1	XU	NP	No gear present, but extensive recent injuries consistent with constricting gear on right flipper, peduncle, and leading fluke edges. Large portion of right lip missing. Extremely poor condition - emaciated with heavy cyamid load. No resights.

07/13/2018	Prorated Injury	3312	25.6 nm E of Miscou Island, NB	EN	0.75	CN	NR	Free swimming with line through mouth and trailing both sides. Full configuration unknown - unable to confirm extent of flipper involvement. No resights.
07/30/2018	Prorated Injury	3843	13 nm E of Grand Manan, NB	EN	0.75	XC	GU	Free-swimming with buoy trailing 70 ft behind whale. Attachment point(s) unknown. Severe, deep, raw injuries on peduncle & head. Partial disentanglement. Resighted with line exiting left mouth and no trailing gear. Possible rostrum and left pectoral wraps, but unable to confirm. Improved health, but final configuration unclear. No additional resights.
08/25/2018	Mortality	4505	Martha's Vineyard, MA	EN	1	XU	NP	No gear present. Evidence of constricting pectoral wraps with associated hemorrhaging. COD - acute entanglement
10/14/2018	Mortality	3515	134 nm E of Nantucket, MA	EN	1	XU	NP	No gear present, but evidence of constricting wraps across ventral surface and at pectorals. COD - acute, severe entanglement.
12/20/2018	Prorated Injury	2310	Nantucket, MA	EN	0.75	XU	NR	Free-swimming with open bridle through mouth. Resight in Apr2019 shows configuration changed, but unable to determine full configuration. Health appears stable. No additional resights
12/1/2018	Serious Injury	3208	South of Nantucket, MA	EN	1	XU	NP	No gear present. Evidence of new, healed, constricting body wrap. Health decline evident - grey, lesions, thin. Previously reported as 24Dec2018
6/4/2019	Mortality	4023	46.4 nm ESE of Perce, QC	VS	1	CN	-	Abrasion, blubber hemorrhage, and muscle contusion caudal to blowholes consistent with pre-mortem vessel strike
6/20/2019	Mortality	1281	27.3 nm E of Magdalen Islands, QC	VS	1	CN	-	Sharp trauma penetrating body cavity consistent with vessel strike. Vessel >65 ft based on laceration dimensions.

6/25/2019	Mortality	1514	20.3 nm E of Miscou Island, QC	VS	1	CN	-	Fractured ear bones, skull hemorrhaging, and jaw contusion consistent with blunt trauma from vessel strike.
6/27/2019	Mortality	3450	37.4 nm E of Perce, QC	VS	1	CN	-	Hemothorax consistent with blunt force trauma.
7/4/2019	Serious Injury	3125	35.2 nm E of Perce, QC	EN	1	CN	PT	Free-swimming with extensive entanglement involving embedded head wraps, flipper wraps, and trailing gear. Baleen damaged and protruding from mouth. Partially disentangled: 200-300 ft of line removed. Embedded rostrum and blowhole wraps remain, but now able to open mouth. Significant health decline. No resights.
8/6/2019	Mortality	1226	36.4 nm NW of Iles de la Madeleine, NS	EN	1	CN	NR	Constricting rostrum wraps, in anchored or weighted gear. Carcass found with no gear present but evidence of extensive constricting entanglement involving rostrum, gape, both flippers. COD - probable acute entanglement
1/8/2020	Serious Injury	2020 Calf of 2360	7 nm E of Altamaha Sound, GA	VS	1	US	-	Dependent calf with deep lacerations to head and lips, exposing bone. No resights post 15Jan2020.
2/24/2020	Serious Injury	3180	38.2 nm SE of Nantucket, MA	EN	1	XU	NR	Free-swimming with bullet buoy lodged in right mouthline, far forward. Line seen exiting left gape. No trailing gear visible. Poor condition - emaciated with heavy cyamid load. No resights.
3/16/2020	Prorated Injury	-	Georges Bank	EN	0.75	XU	NR	Free-swimming with 2 polyballs trailing approximately 30 ft aft of flukes. Attachment point(s) and full configuration unknown. No resights
6/24/2020	Mortality	5060	0.5 nm off Elberon, NJ	VS	1	US	-	Dependent calf with deep lacerations along head and peduncle from 2 separate vessel strikes. Head lacerations were chronic and debilitating while the laceration to peduncle was acutely fatal. Proximate COD - sharp and blunt vessel trauma. Ultimate COD - hemorrhage and paralysis.

10/11/2020	Serious Injury	4680	2.7 nm E of Sea Bright, NJ	EN	1	XU	NR	Free-swimming with 2 lines embedded in rostrum, remaining configuration unknown. Extremely poor condition - emaciated with greying skin. Large, open lesion on left side of head. No resights.
10/19/2020	Mortality	3920	10.1 nm S of Nantucket, MA	EN	1	CN	PT	Free-swimming with deeply embedded rostrum wrap. Partial disentanglement - removed 100 ft of trailing line and attached telemetry. Health deteriorated over subsequent sightings - emaciation, increased cyamid load, sloughing skin. Carcass documented on 27Feb2021 off Florida. No necropsy conducted but COD from chronic entanglement most parsimonious.

Assigned Cause	**Observed five-year mean (US/CN/XU/XC)**
Vessel strike	2.4 (0.8/1.6/0/0)
Entanglement	5.7 (0/2.15/2.65/0.9)

a. For more details on events please see Henry *et al.* 2022.
b. The date sighted and location provided in the table are not necessarily when or where the serious injury or mortality occurred; rather, this information indicates when and where the whale was first reported beached, entangled, or injured.
c. Mortality events are counted as 1 against PBR. Serious injury events have been evaluated using NMFS guidelines (NOAA 2012).
d. CN=Canada, US=United States, XC=Unassigned 1st sight in CN, XU=Unassigned 1st sight in US.
e. H=hook, GN=gillnet, GU=gear unidentifiable, MF=monofilament, NP=none present, NR=none recovered/received, PT=pot/trap, WE=weir.

HABITAT ISSUES

Baumgartner *et al.* (2017) discussed that ongoing and future environmental and ecosystem changes may displace *C. finmarchicus*, or disrupt the mechanisms that create very dense copepod patches upon which right whales depend. One of the consequences of this may be a shift of right whales into different areas with additional anthropogenic impacts to the species. Record *et al.* (2019) described the effects of a changing oceanographic climatology in the Gulf of Maine on the distribution of right whales and their prey. The warming conditions in the Gulf have altered the availability of late stage *C. finmarchicus* to right whales, resulting in a sharp decline in sightings in the Bay of Fundy and Great South Channel over the last decade (Record *et al.* 2019; Davies *et al.* 2019; Meyer-Gutbrod *et al.* 2021), and an increase in sightings in Cape Cod Bay (Ganley *et al.* 2019). Gavrilchuk *et al.* (2021) suggested that ocean warming in the Gulf of St. Lawrence may eventually compromise the suitability of this foraging area for right whales, potentially displacing them further to the shelf waters east of Newfoundland and Labrador in search of dense *Calanus* patches.

In addition, construction noise and vessel traffic from extensive development of offshore wind along the east coast of the US could result in communication masking, behavioral disruption of foraging and socializing (leading to increased energetic expenditure), increased risk of vessel strike, or avoidance of wind energy areas. Operational noise may be above the behavioral harassment threshold identified by NOAA for continuous noise across entire wind energy areas (Stöber and Thomsen 2021). Offshore wind turbines could also influence the hydrodynamics of seasonal stratification and ocean mixing, which, in turn, could influence shelf-wide primary production and copepod distribution (Broström 2008; Paskyabi and Fer 2012; Paskyabi 2015, Carpenter *et al.* 2016, Afsharian *et al*. 2020). Floating wind turbines may introduce additional hazards for whales, including entanglement in fishing gear or other marine debris caught on turbine mooring lines (Maxwell et al. 2022).

STATUS OF STOCK

This is a strategic stock because the average annual human-related mortality and serious injury exceeds PBR, and also because the North Atlantic right whale is listed as an endangered species under the ESA. The size of this stock is considered to be extremely low relative to OSP in the U.S. Atlantic EEZ and has been declining since 2011 (see Pace *et al.* 2017). The North Atlantic right whale is considered one of the most critically endangered populations of large whales in the world (Clapham *et al.* 1999; NMFS 2017; IUCN 2020). The observed (and clearly biased low) human-caused mortality and serious injury was 8.1 right whales per year from 2016 through 2020. Using the refined methods of Pace *et al.* (2021), the estimated annual rate of total mortality of adults and juveniles for the period 2015–2019 was 31.2, which is 4.1 times larger than the 7.7 total derived from reported mortality and serious injury for the same period. Given that PBR has been calculated as 0.7, human-caused mortality or serious injury for this stock must be considered significant.

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