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 the winter.

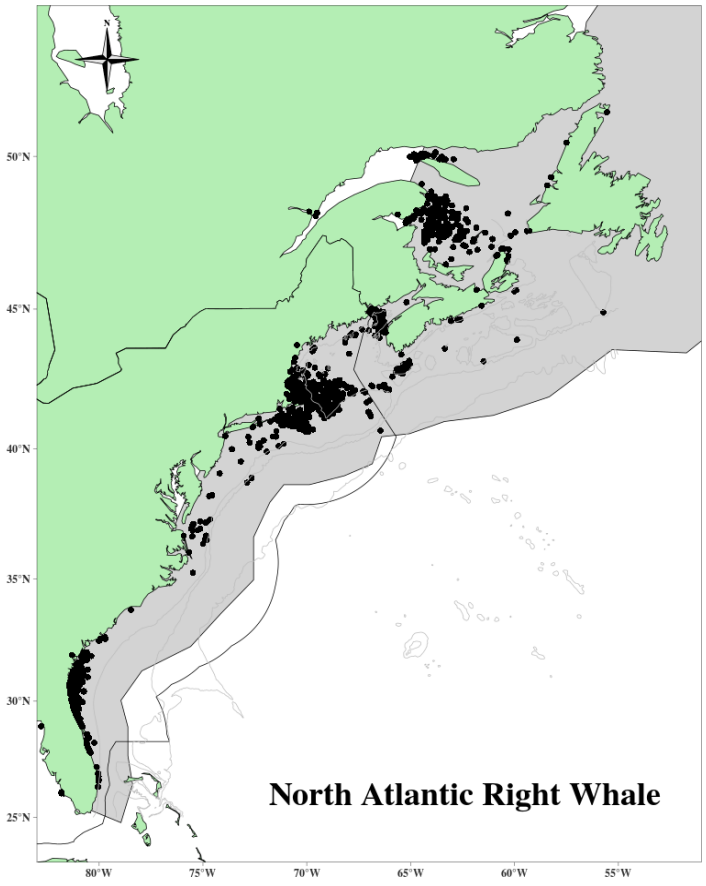

Figure 1. Approximate range (shaded area) and distribution of sightings (dots) of known North Atlantic right whales 2014–2018.

Davis *et al.* (2017) recently pooled together detections from a large number of passive acoustic devices and documented broad-scale use of U.S. eastern seaboard 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).

Movements within and between habitats are extensive, and the waters off the mid-Atlantic states are an important migratory corridor. 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 perhaps two weeks 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 (Mate *et al.* 1997, Baumgartner and Mate 2005).

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. 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 neonate was detected in Cape Cod Bay in 2012 (Center for Coastal Studies, Provincetown, MA USA, unpub. data).

New England 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). While feeding in the coastal waters off Massachusetts has been better studied than in other areas, right whale feeding has also been observed on the margins of Georges Bank, in the Great South Channel, in the Gulf of Maine, in the Bay of Fundy, and over the Scotian Shelf (Baumgartner *et al.* 2007). The characteristics of acceptable prey distribution in these areas are beginning to emerge (e.g., Baumgartner *et al.* 2003, Baumgartner and Mate 2003). The National Marine Fisheries Service (NMFS) and Center for Coastal Studies aerial surveys during the springs of 1999–2011 found right whales along the Northern Edge of Georges Bank, in the Great South Channel, in Georges Basin, and in various locations in the Gulf of Maine including Cashes Ledge, Platts Bank, and Wilkinson Basin. In 2016, the Northeastern U.S. Foraging Area Critical Habitat was expanded to include nearly all U.S. waters of the Gulf of Maine based on the presence of the physical and biological features required for right whale foraging (81 FR 4837, 26 February 2016).

Analysis of sightings data has shown that the right whales' utilization of these areas within the Gulf of Maine had a strong seasonal component (Pace and Merrick 2008). Although whales were consistently found in these locations, studies also highlight the high interannual variability in right whale use of some habitats (Pendleton *et al.* 2009, Ganley *et al.* 2019). An important shift in habitat use patterns in 2010 was highlighted in an analysis of right whale acoustic presence along the U.S. Eastern seaboard 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). In addition, right whales apparently abandoned the Jordan Basin in the central Gulf of Maine in winter (Cole *et al.* 2013), but have since been seen in large numbers in a region south of Martha's Vineyard and Nantucket Islands (Leiter *et al.* 2017), an area outside of the 2016 Northeastern U.S. Foraging Area Critical Habitat. 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). Aerial surveys of the Gulf of St. Lawrence during the summers of 2015, 2017, and 2018, documented at least 34, 105, and 131 unique individuals using the region, respectively (NMFS unpublished data).

Genetic analyses based upon direct sequencing of mitochondrial DNA (mtDNA) have identified 7 mtDNA haplotypes in the western North Atlantic right whale, 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 our understanding of genetic variability, the number of reproductively active individuals, reproductive fitness, parentage, and relatedness of individuals (Frasier *et al.* 2007a, 2009). One finding of the genetic studies is the importance of obtaining biopsy samples from calves on the calving grounds. 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 only reliable way to establish parentage, if the calf is not sampled when associated with its mother early on, then it is not possible to link it with a calving event or to its mother, and information such as age and familial relationships is 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.* 2007a). An additional interpretation of paternity analyses is that the population size may be larger than was previously thought. Fathers for only 45% of known calves have been genetically determined; yet, genetic profiles were available for 69% of all photo-identified males (Frasier 2005). The conclusion was that the majority of these calves must have different fathers that cannot be accounted for by the unsampled males, therefore the population of males must be larger (Frasier 2005, Frasier *et al.* 2007b). However, a recent 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

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). Sightings histories were constructed from the photo-ID recapture database as it existed in October 2019, which included photographic information up through January 2018. Using a hierarchical, state-space Bayesian open population model of these histories produced a median abundance value (Nest) of 412 individuals (95%CI: 403–424; Table 1). 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 (CI) 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 for the western North Atlantic right whale (Eubalaena glacialis) with Maximum Productivity Rate (R_{max}), Recovery Factor (Fr) and PBR.

N_{est}	95% Credible Interval	60% Credible Interval	N_{min}	Fr	R_{max}	PBR
412	403–424	408–416	408	0.1	0.04	0.8

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.* 2007a). 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). 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 western North Atlantic right whales is 412. The minimum population estimate as of January 2018 is 408 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 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 the 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 abundance estimates for the years 1990–2011 (Figure 2) 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 100.00% chance that abundance declined from 2011 to 2018 when the final estimate was 412 individuals. The overall abundance decline between 2011 and 2018 was 14.35% (CI=11.67%–16.60%). 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 additional anthropogenic threats (Hayes *et al.* 2018). This apparent change in habitat use has the effect that, despite relatively constant effort to find whales in traditional areas, the chance of photographically capturing individuals has decreased. However, the methods in Pace *et al.* (2017) account for changes in capture probability.

There were 17 right whale mortalities in 2017 (Daoust *et al.* 2018). 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.

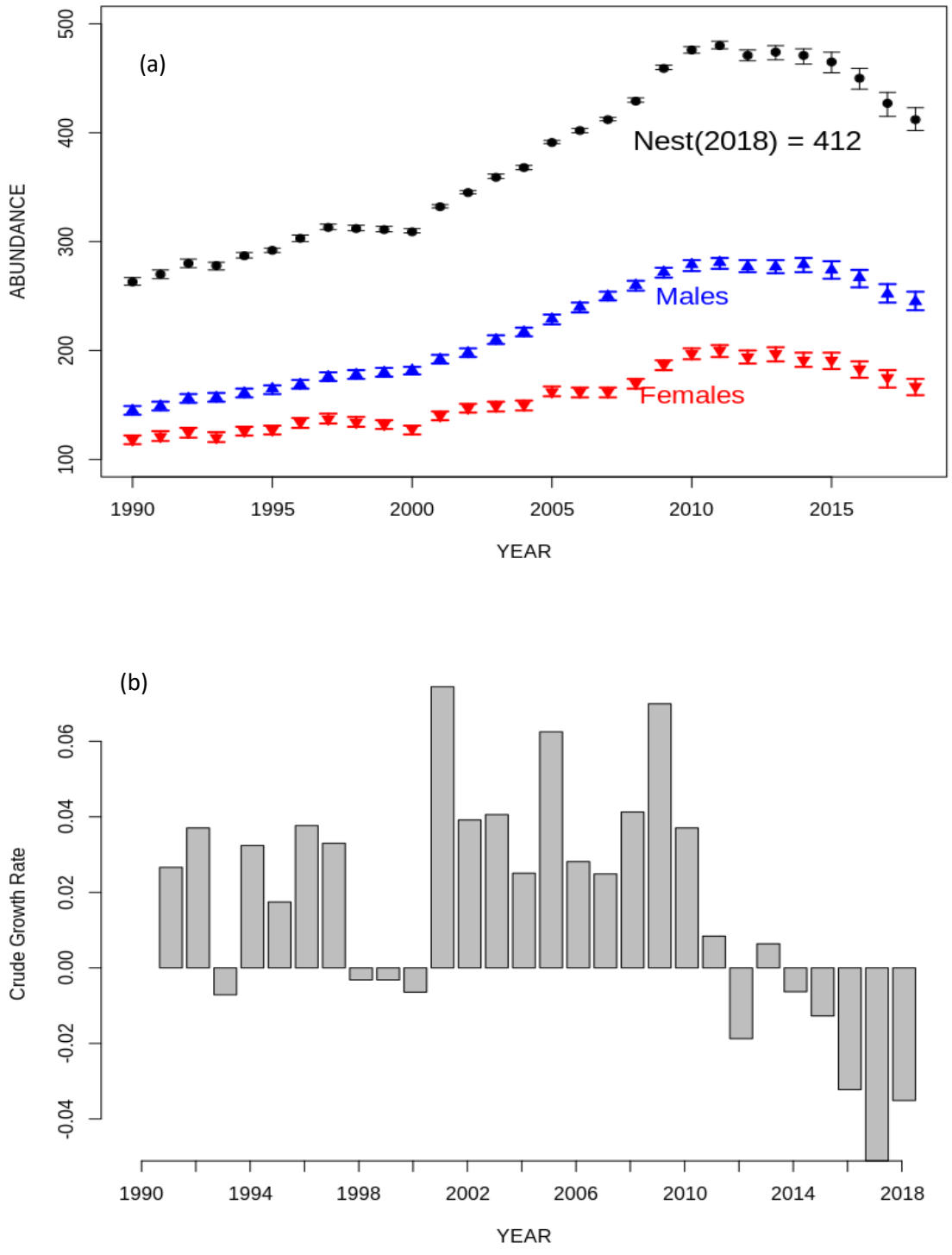

Figure 2. (a) Abundance estimates for North Atlantic right whales. Estimates are the median values of a posterior distribution from modeled capture histories. Also shown are sex-specific abundance estimates. Cataloged whales may include some but not all calves produced each year. (b) Crude annual growth rates from the abundance values.

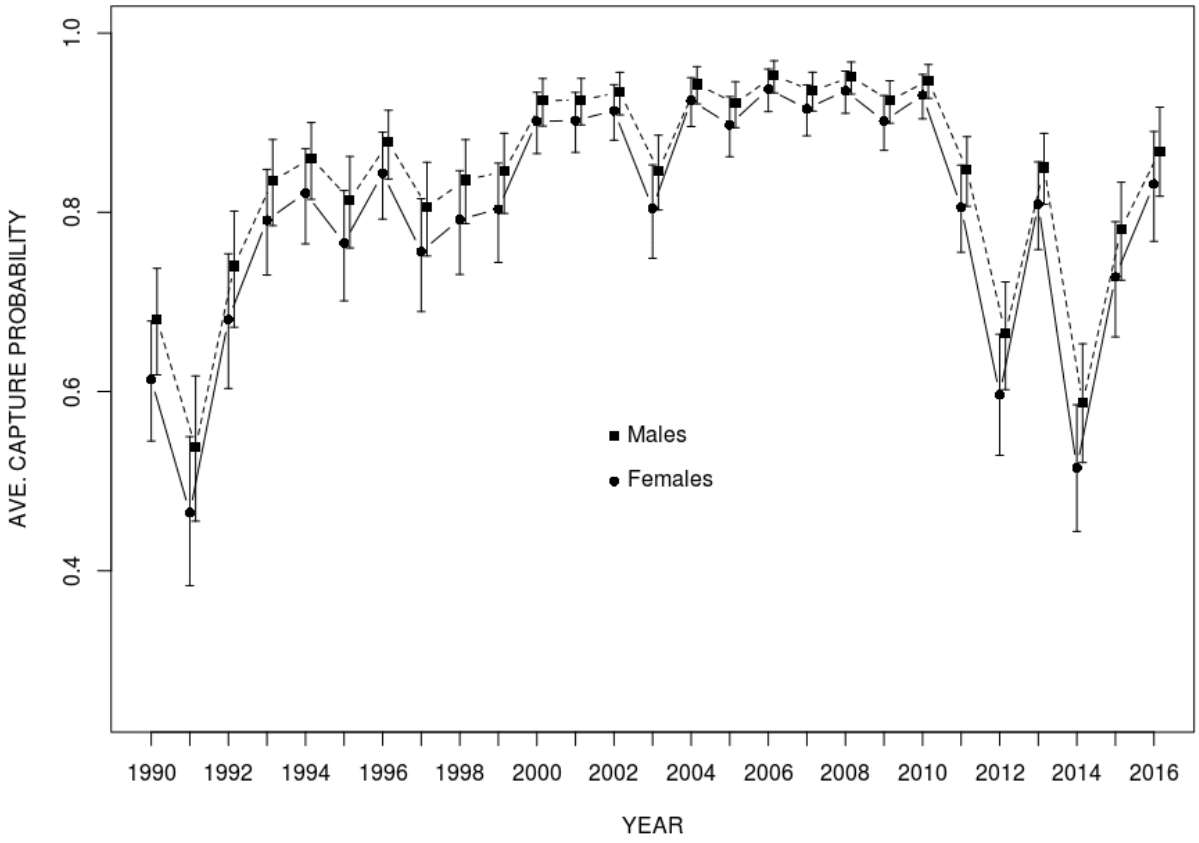

Figure 3. Estimated recapture probability and associated 95% credible intervals of North Atlantic right whales 1990–2016 based on a Bayesian MRR model allowing random fluctuation among years for survival rates, treating capture rates as fixed effects over time, and using both observed and known states as data (from Pace et al. 2017).

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 1990–2017, at least 447 calves were born into the population. The number of calves born annually ranged from 1 to 39, and averaged 16 but was highly variable (SD=8.9). No calves were born the winter of 2017–2018. The fluctuating abundance observed from 1990 to 2017 makes interpreting a count of calves by year less clear than measuring population productivity, which we index by the number of calves detected/estimated abundance (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 3). 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%).

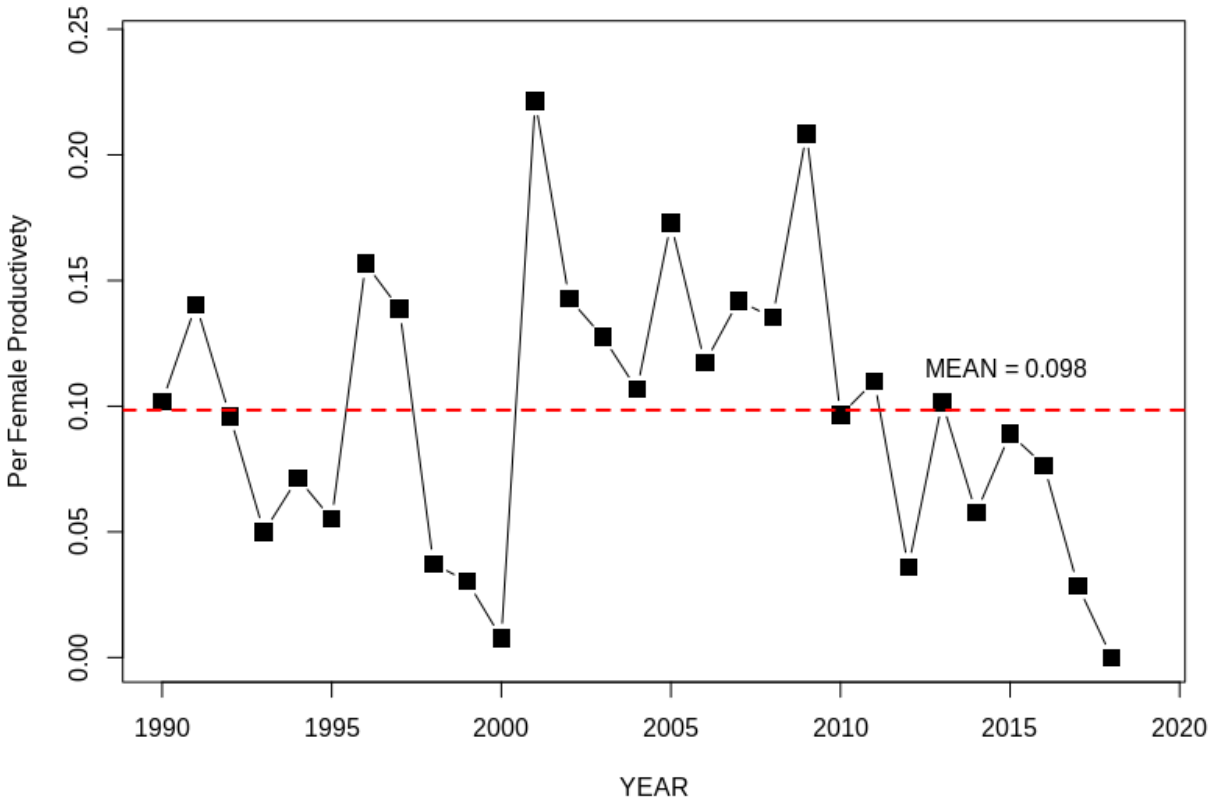

Figure 4. Productivity in the North Atlantic right whale population as characterized by calves detected/estimated number of females.

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, Christiansen *et al*. 2020).

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). 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 is 408. 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 0.8 (Table 1).

ANNUAL HUMAN-CAUSED SERIOUS INJURY AND MORTALITY

For the period 2014 through 2018, the average annual detected (i.e. observed) human-caused mortality and serious injury to right whales averaged 8.15 (Table 2). This is derived from two components: 1) incidental fishery entanglement records at 6.85 per year, and 2) vessel strike records averaging 1.3 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.* 2021). 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 should be considered 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 that 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 18.6 animals for the period 2013−2017 (Pace *et al.* 2021). This estimated total mortality accounts for detected mortality and serious injury, as well as undetected (cryptic) mortality within the population. Figure 5 compares the observed mortality and serious injury totals for the years 2000−2017 to the estimates of total mortality from the state-space model. The detection rate of mortality and serious injury for the 5-year period 2013−2017 was 51% of the model's annual mortality estimates (based on methods from Pace *et al*. 2021). The estimated mortality for 2018 is not yet available because it is derived from a comparison with the population estimate for 2019, which, in turn, is contingent on the processing of all photographs collected through 2019 for incorporation into the state-space model of the sighting histories of individual whales. At this time, we are unable to apportion estimated mortality by cause (fishery interaction vs. vessel strike) or by nationality (occurring in U.S vs. Canadian waters). However, 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 18.6 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.

Table 2. Average annual observed and estimated human-caused mortality and serious injury for the North Atlantic right whale (Eubalaena glacialis). Observed values are from confirmed interactions. Estimated total mortality is model-derived (Pace et al. 2017). Injuries prevented are a result of successful disentanglement efforts.

Years	Source	Annual Average
2014–2018	Observed incidental fishery interactions	6.85
2014–2018	Observed vessel collisions	1.30
2014–2018	Observed total human-caused M/SI	8.15
2013–2017	Estimated total mortality	18.6
2014–2018	SI prevented	1.2

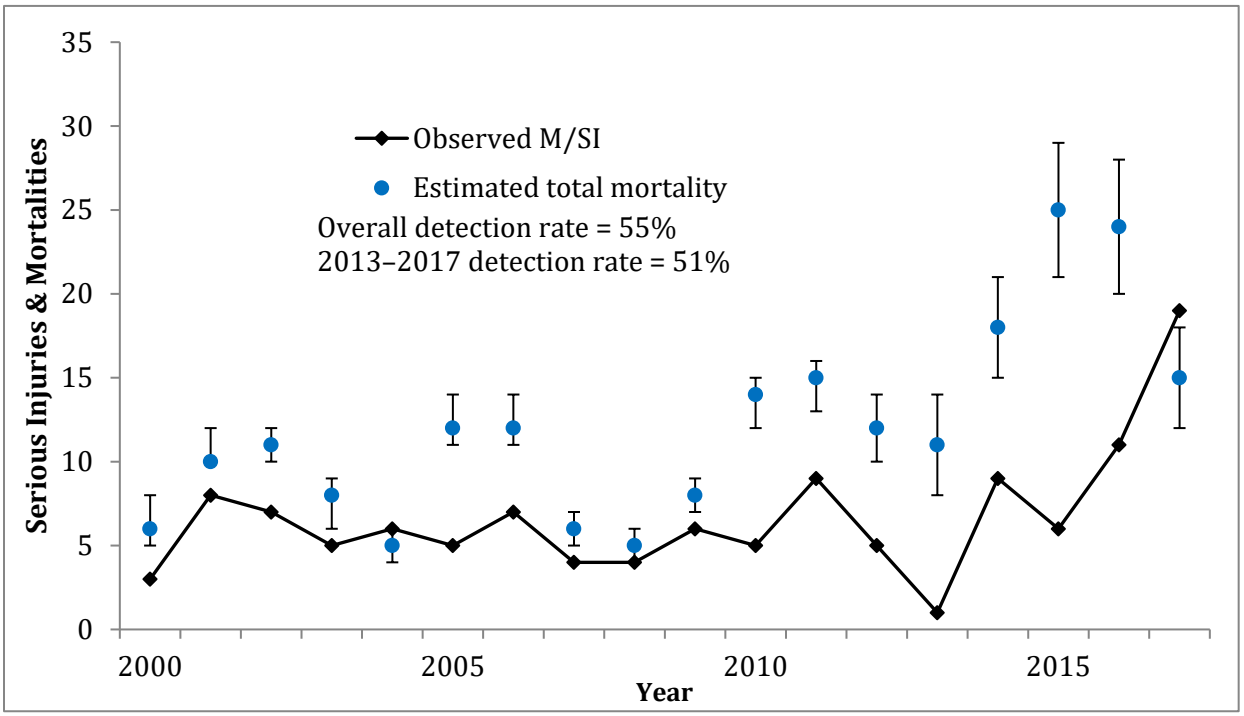

Figure 5. Time series of observed annual total mortality and serious injury (M/SI; black line) versus estimated total mortalities (blue points with associated error bars).

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 whales (Corkeron *et al.* 2018). The principal factor believed to be preventing growth and recovery of the population is entanglement with fishing gear (Kenny 2018). Between 1970 and 2018, a total of 124 right whale mortalities was recorded (Knowlton and Kraus 2001; Moore *et al.* 2005; Sharp *et al.* 2019). Of these, 18 (14.5%) were neonates 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. A recent analysis of human-caused serious injury and mortality during 2000–2017 shows that entanglement injuries have been increasing steadily over the past twenty years while injuries from vessel strikes have shown no specific trend despite several reported cases in 2017 (Hayes *et al.* 2018).

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 its reproductive success (van der Hoop *et al.* 2017, Corkeron *et al.* 2018). 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*. 2021). 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 the NMFS Greater Atlantic and Southeast Regional Offices. Records are 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 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 than entanglement records. A review of scars detected on identified individual right whales over a period of 30 years (1980–2009) documented 1,032 definite, unique entanglement events on the 626 individual whales identified (Knowlton *et al*. 2012). Most individual whales (83%) were entangled at least once, and over half of them (59%) were entangled more than once. Hamilton *et al* (2019) estimated that 30.25% of the population was entangled annually between 2010 and 2017. Juveniles and calves were entangled at higher rates than were adults. Scarring rates suggest that entanglements occur at about an order of magnitude more often than detected from observations of whales with gear on them. Analyses 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 2014 through 2018 have been summarized in Table 3. Early analyses of the effectiveness of the vessel-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 vessel-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 were applied to previously reported vessel strikes between 2000 and 2017 (Henry *et al.* 2021), there was no apparent trend (Hayes *et al.* 2018).

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 (https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2020-north-atlantic-right-whale-unusual-mortality-event). There were 20 dead whales documented through December 2018, with 12 whales having evidence of vessel strike or entanglement as the preliminary cause of death. Additionally, seven free-swimming whales were documented as being seriously injured due to entanglements during the time period. Therefore, through December 2018, the number of whales included in the UME was 27, including 20 dead and 7 seriously injured free-swimming whales.

Table 3. Confirmed human-caused mortality and serious injury records of right whales: 2014–2018[a]

Date[b]	Fate	ID	Location[b]	Assigned Cause	Value against PBR[c]	Country[d]	Gear Type[e]	Description
01/15/2014	Serious Injury	4394	off Ossabaw Island, GA	EN	1	XU	NP	No gear present but new ent. injuries indicating prior constricting gear on both pectorals and at fluke insertion. Injury to left ventral fluke. Evidence of health decline. No resights post Feb/2014.
04/01/2014	Serious Injury	1142	off Atlantic City, NJ	EN	1	XU	NR	Constricting rostrum wrap with line trailing to at least mid-body. Resighted in 2018. Health decline evident.
04/09/2014	Prorated Injury	-	Cape Cod Bay, MA	VS	0.52	US	-	Animal surfaced underneath a research vessel while it was underway (39 ft at 9 kts). Small amount of blood and some lacerations of unknown depth on lower left flank.
06/29/2014	Serious Injury	1131	off Cape Sable Island, NS	EN	1	XC	NR	At least 1, possibly 2, embedded rostrum wraps. Remaining configuration unclear but extensive. Animal in extremely poor condition: emaciated, heavy cyamid coverage, overall pale skin. No resights.
09/04/2014	Serious Injury	4001	off Grand Manan, NB	EN	1	XC	NR	Free-swimming with constricting rostrum wrap. Remaining configuration unknown. No resights post Oct/2014.
09/04/2014	Mortality	-	Far south of St. Pierre & Miquelon, off the south coast of NL	EN	1	XC	NR	Carcass with constricting line around rostrum and body. No necropsy conducted, but evidence of extensive, constricting entanglement supports entanglement as COD.
09/17/2014	Serious Injury	3279	off Grand Manan, NB	EN	1	XC	NR	Free-swimming with heavy, green line overhead cutting into nares. Remaining config. unk. In poor overall condition: heavy cyamids on head and blowholes. Left blowhole appears compromised. No resights.

Date[b]	Fate	ID	Location[b]	Assigned Cause	Value against PBR[c]	Country[d]	Gear Type[e]	Description
09/27/2014	Mortality	-	off Nantucket, MA	EN	1	US	NR	Fresh carcass with multiple lines wrapping around head, pectoral, and peduncle. Appeared to be anchored. No necropsy conducted, but extensive, constricting entanglement supports entanglement as COD.
12/18/2014	Serious Injury	3670	off Sapelo Sound, GA	EN	1	XU	NP	No gear present but new, healing entanglement injuries. Severe injuries to lip, peduncle and fluke edges. Poss. damage to right pectoral. Resights indicate health decline.
04/06/2015	Serious Injury	CT04CCB14	Cape Cod Bay, MA	EN	1	XU	NP	Encircling laceration at fluke insertion with potential to affect major artery. Source of injury likely constricting entanglement. No gear present. Evidence of health decline. No resights.
06/13/2015	Prorated Injury	-	off Westport, NS	EN	.75	XC	NR	Line through mouth, trailing 300-400m ending in 2 balloon-type buoys. Full entanglement configuration unknown. No resights.
09/28/2015	Prorated Injury	-	off Cape Elizabeth, ME	EN	.75	XU	NR	Unknown amount of line trailing from flukes. Attachment point(s) and configuration unknown. No resights.
11/29/2015	Serious Injury	3140	off Truro, MA	EN	1	XU	NR	New, significant ent. injuries indicating constricting wraps. No gear visible. In poor cond. with grey skin and heavy cyamid coverage. No resights.
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.
08/01/2016	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. No gear present. Significant health decline: emaciated, cyamids patches, peeling skin. No resights.

Date[b]	Fate	ID	Location[b]	Assigned Cause	Value against PBR[c]	Country[d]	Gear Type[e]	Description
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.

Date[b]	Fate	ID	Location[b]	Assigned Cause	Value against PBR[c]	Country[d]	Gear Type[e]	Description
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 70ft 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	-	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.

Date[b]	Fate	ID	Location[b]	Assigned Cause	Value against PBR[c]	Country[d]	Gear Type[e]	Description
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
12/24/2018	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.

Assigned Cause	Five-year Mean (US/CN/XU/XC)
Vessel strike	1.3 (0.50/0.80/0.00/0.00)
Entanglement	6.85 (0.20/1.55/3.25/1.85)

a. For more details on events, see Henry *et al.* 2021.
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) discuss 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), and an increase in sightings in Cape Cod Bay (Ganley *et al.* 2019).

In addition, construction noise and vessel traffic from planned development of offshore wind in southern New England and the mid-Atlantic could result in communication masking, increased risk of vessel strike or avoidance of wind energy areas. 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, Carpenter *et al.* 2016, Afsharian *et al*. 2020).

STATUS OF STOCK

The size of this stock is considered to be extremely low relative to OSP in the U.S. Atlantic EEZ. This species is listed as endangered under the ESA and has been declining since 2011 (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). The total level of human-caused mortality and serious injury is unknown, but the reported (and clearly biased low) human-caused mortality and serious injury was a minimum of 6.65 right whales per year from 2013 through 2017. Given that PBR has been calculated as 0.8, human-caused mortality or serious injury for this stock must be considered significant. 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 an endangered species. All ESA-listed species are classified as strategic by definition; therefore, any uncertainties discussed above will not affect the status of stock.

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