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

## STOCK DEFINITION AND GEOGRAPHIC RANGE

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

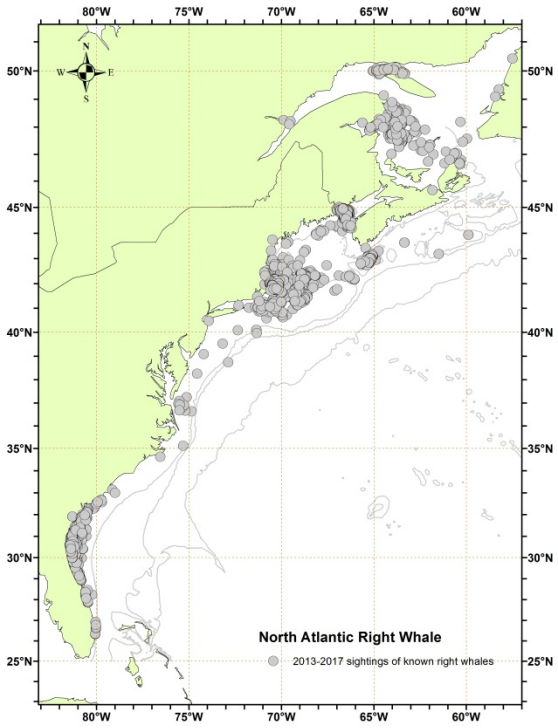


***Figure 1. Distribution of sightings of known North Atlantic right whales, 2013-2017. Isobaths are the 100-m, 1000-m and 4000-m depth contours.***

Visual and acoustic surveys have demonstrated the existence of seven areas where western North Atlantic right whales aggregate seasonally: the coastal waters of the southeastern U.S.; the Great South Channel; Jordan Basin; Georges Basin along the northeastern edge of Georges Bank; Cape Cod and Massachusetts Bays; the Bay of Fundy; and the Roseway Basin on the Scotian Shelf (Brown *et al*. 2001; Cole *et al.* 2013). Since 2013, increased detections and survey effort in the Gulf of St. Lawrence indicate right whale presence in late spring through early fall (Cole *et al.* 2016, Khan *et al.* 2016, 2018). Passive acoustic studies of right whales have demonstrated their year-round presence in the Gulf of Maine (Morano *et al.* 2012; Bort *et al.* 2015), New Jersey (Whitt *et al.* 2013), and Virginia (Salisbury *et al*. 2016). Additionally, right whales were acoustically detected off Georgia and North Carolina in 7 of 11 months

monitored (Hodge *et al*. 2015). All of this work further demonstrates the highly mobile nature of right whales. Movements within and between habitats are extensive, and the area off the mid-Atlantic states is 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 rather 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 newborn was detected in Cape Cod Bay in 2012 (Center for Coastal Studies, Provincetown, MA USA, unpub. data).

Right whale calls have been detected by autonomous passive acoustic sensors deployed between 2005 and 2010 at three sites (Massachusetts Bay, Stellwagen Bank, and Jeffreys Ledge) in the southern Gulf of Maine (Morano *et al*. 2012, Mussoline *et al*. 2012). Comparisons between detections from passive acoustic recorders and observations from aerial surveys in Cape Cod Bay between 2001 and 2005 demonstrated that aerial surveys found whales on approximately two-thirds of the days during which acoustic monitoring detected whales (Clark *et al*. 2010). These data suggest that the current understanding of the distribution and movements of right whales in the Gulf of Maine and surrounding waters is incomplete. Additionally, the aforementioned apparent shift in habitat use patterns since 2010, highlighted by Davis *et al.* (2017), includes increased use of Cape Cod Bay (Mayo *et al.* 2018) and decreased use of the Great South Channel.

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 (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. Analysis of the sightings data has shown that the utilization of these areas has a strong seasonal component (Pace and Merrick 2008). Although right whales are 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). 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 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 have detected fewer individuals in the Great South Channel and the Bay of Fundy. In addition, late winter use of a region south of Martha's Vineyard and Nantucket Islands was recently described (Leiter *et al.* 2017). A large increase in aerial surveys of the Gulf of St. Lawrence documented at least 34, 105, and 131 unique individuals using the region, respectively, during the summers of 2015, 2017, and 2018 (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 has been completed for >75% of all North Atlantic right whales identified through 2006. This work has improved our understanding of genetic variability, the number of reproductively active individuals, reproductive fitness, parentage, and relatedness of individuals (Frasier *et al.* 2007, 2009). One emerging result 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.* 2007). 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). However, a recent study compared photo-identification and pedigree genetic data for animals known or presumed to be alive during 1980-2016 and 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 2018. Using a hierarchical, state-space Bayesian open population model of these histories produced a median abundance value. The best abundance estimate available for the North Atlantic right whale stock is 428 individuals (95% credible intervals 406-447). 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 above to characterize that uncertainty (as opposed to a CV that may appear in other stock assessment reports).

### 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). 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 428. The minimum population estimate as of January 2017 is 418 and stands as Nmin. The 17 known mortalities from 2017 are not accounted for in this estimate.

**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 imilar 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 99.99% chance that abundance declined from 2011 to 2017 when the final estimate was 428 individuals. As noted above, there seems to have been a considerable change in right whale habitat use patterns in areas where most of the population has been observed in previous years 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, the chance of seeing an individual that is alive has decreased. However, the methods in Pace *et al.* (2017) account for changes in capture probability.

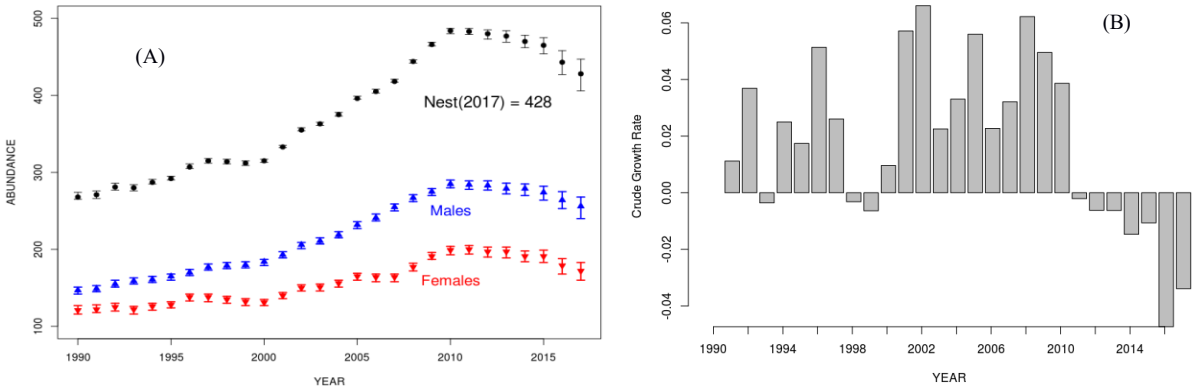


**Figure 2. (A) Abundance estimates for North Atlantic right whales. Estimates are the median values of a posterior distribution from modeled capture histories. Also shown are sex-specific abundance estimates. Cataloged whales may include some but not all calves produced each year. (B) Crude annual growth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

**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). 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, and 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%). Their 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, Kenny (2018) 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 be 588 by 2016.

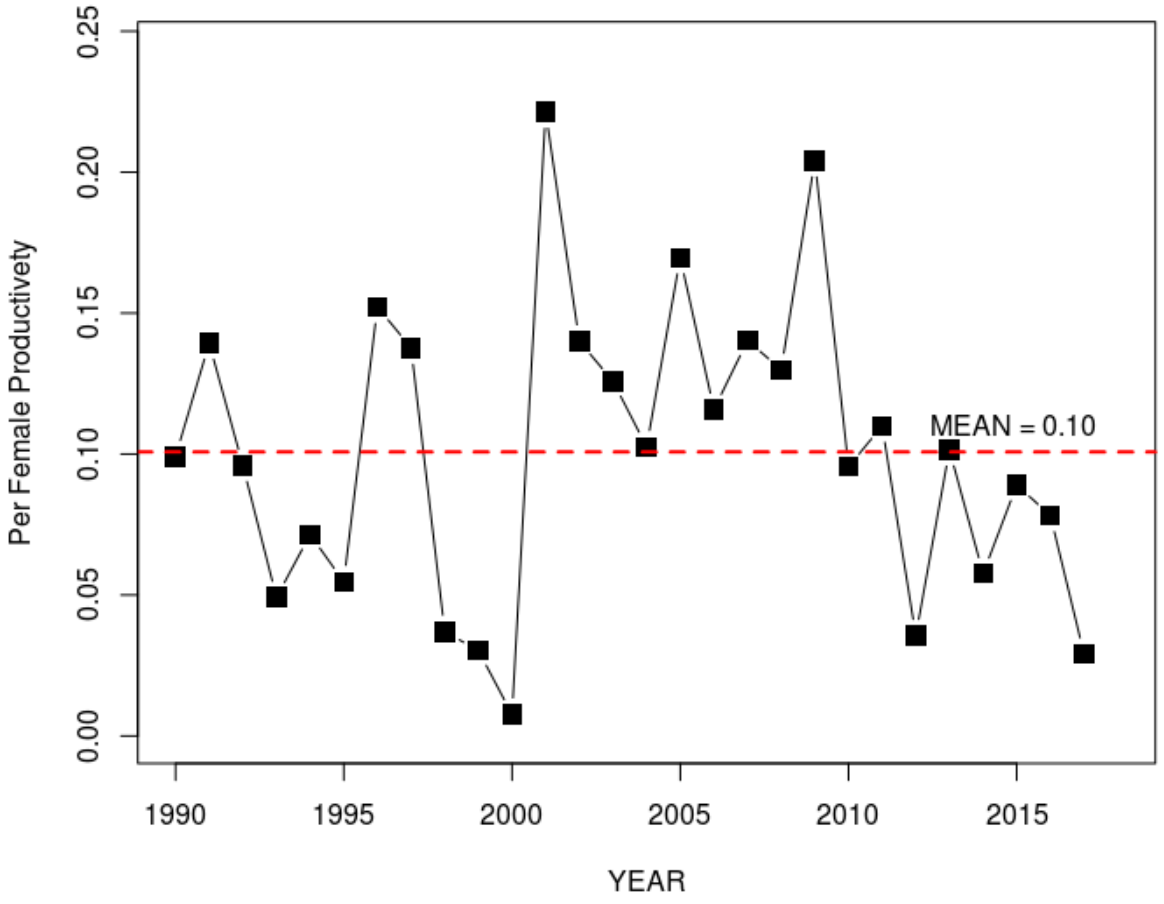


**Figure 3. Productivity in the North Atlantic right whale population as characterized by calves detected/(estimated number of females).**

North Atlantic right whales have thinner blubber than southern right whales off South Africa (Miller *et al.* 2011). Blubber thickness of male North Atlantic right whales (males were selected to avoid the effects of pregnancy and lactation) varied with *Calanus* abundance in the Gulf of Maine (Miller *et al.* 2011). Sightings of North Atlantic right

whales correlated with satellite-derived sea-surface chlorophyll concentration (as a proxy for productivity), and calving rates correlated with chlorophyll concentration prior to gestation (Hlista *et al.* 2009). On a regional scale, observations of North Atlantic right whales correlate well with copepod concentrations (Pendleton *et al*. 2009). The available evidence suggests that at least some of the observed variability in the calving rates of North Atlantic right whales is related to variability in nutrition (Fortune *et al.* 2013) and possibly increased energy expenditures related to non-lethal entanglements (Rolland *et al.* 2016; Pettis *et al.* 2017; van der Hoop 2017).

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

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

**POTENTIAL BIOLOGICAL REMOVAL**

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

**ANNUAL HUMAN-CAUSED SERIOUS INJURY AND MORTALITY**

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

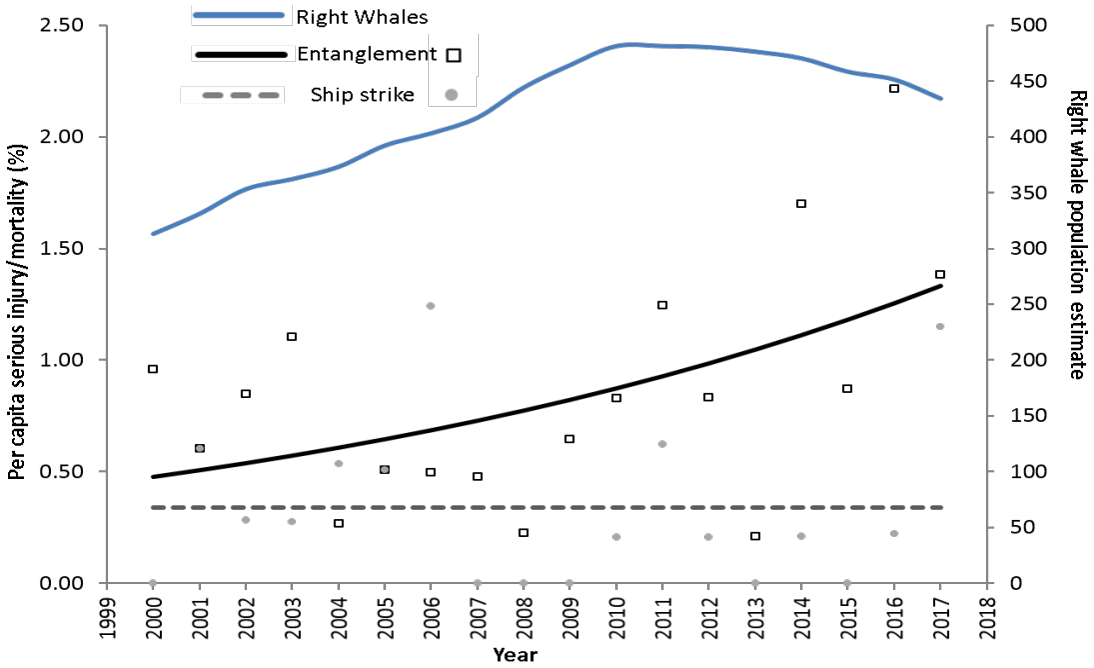


**Figure 4. North Atlantic right whale serious injury/mortality rates from known sources 2000-2017. The right whale population trend is overlaid and referenced to right y-axis**

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. It is important to stress that serious injury determinations are made based upon the best available information; these determinations may change with the availability of new information (Henry *et al.* 2020). For the purposes of this report, discussion is limited to those records considered confirmed human-caused mortalities or serious injuries. Annual rates calculated from detected mortalities should be considered a low-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. A key uncertainty is the fraction of the actual human-caused mortality represented by the detected serious injuries and mortalities. Research on small cetaceans has shown the actual number of deaths can be several times higher than that observed (Wells and Allen 2015; Williams *et al.* 2011). For North Atlantic right whales, estimates of the total mortality exceed or equal the number of detected serious injuries and mortalities (Figure 5) and currently 72% of mortalities since 2000 are estimated to have been observed. Because annual population estimates are now available (Pace *et al*. 2017), it is possible to estimate total annual mortality (and the number of undetected mortalities) by applying the basic population dynamic formula (Williams *et al.* 2002):

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

Where $N_t$ is the number of animals in a population in year *t*, $N_{t+1}$ is the number of animals in the population in year $t+1$, $B_t$ is the number of births in the population in year *t*, and $D_t$ is the number of deaths in the population in year *t*.

Solving for $D_t$ yields: $D_t = N_t + B_t - N_{t+1}$ which can then be used to estimate undetected mortality as: $D_t$- observed deaths= undetected deaths.

The total mortality estimated described above is based on the assumption that all animals that exit from the population in the model are actual deaths and that all entries into the population are births. If immigration were occurring, new mature animals would be documented and captured in the estimate of $B_t$. There is a lack of any evidence for permanent emigration from the population. Temporary emigration (*e.g.* the animal is not observed in the survey area for multiple years) only adds to individual capture heterogeneity, which is accommodated by the model given the longevity of the data sets. Importantly, these assumptions are not novel to the total mortality estimate, but a core part of the published Pace *et al*. (2017) population estimate. A method to assign cause to these undetected mortalities is currently under development; as such these additional mortalities are not counted towards PBR at this time. Another uncertainty is assigning many of the detected entanglements to country of origin. Gear recovered is

often not adequately marked and whales have been known to carry gear for long periods of time and over great distances before being detected.

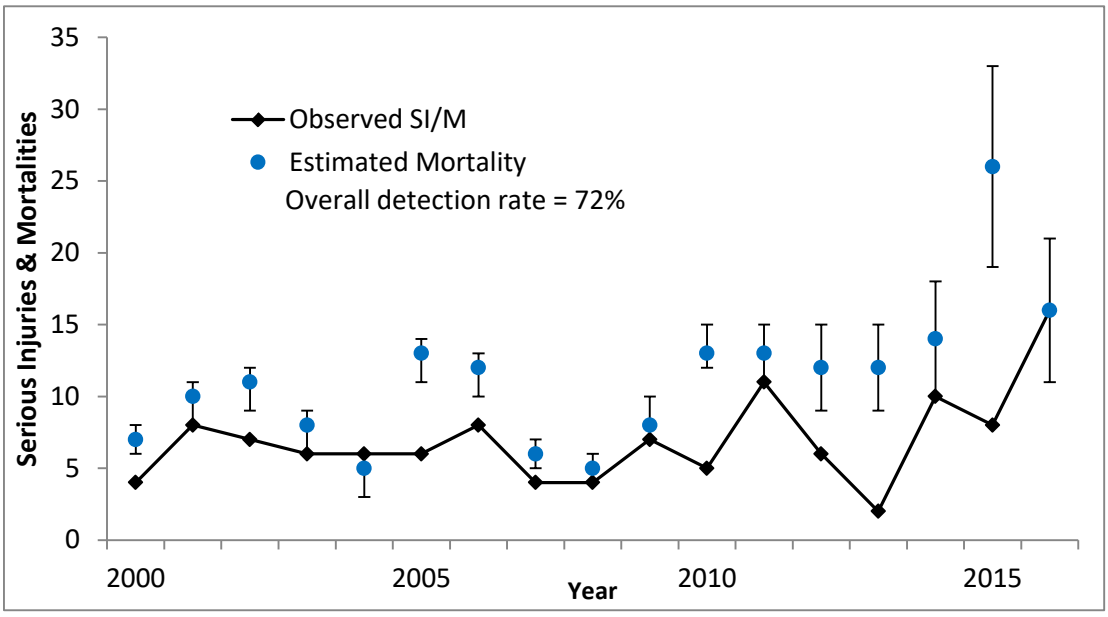


**Figure 5. Time series of observed annual total serious injuries and mortalities (SI/M; black line) versus estimated total mortalities (blue points with associated error bars).**

**Background**

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 assigned cause is based on the best judgment of the available data; additional information may result in revisions. When reviewing Table 1 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) in entanglements, several types of gear may be involved.

Further, 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 retarding 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 was attributable to human impacts (calves accounted for six deaths from ship strikes and two from entanglements). One should be cautious in applying these percentages as more than minimum rates as they only represent carcasses, and exclude serious injury which is highly skewed towards entanglement. A recent analysis of human-caused serious injury and mortality during 2000–2017 (Figure 4) 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).

Finally, entanglement or minor vessel collisions may not kill an animal directly, but may weaken or otherwise affect it so that it is more likely to become vulnerable to further injury. Serious injury determinations for large whales commonly include animals carrying gear when these entanglements are constricting or appear to interfere with foraging (Henry *et al*. 2020).

**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 (Table 1). From 2013 through 2017, 28 of those examined records of mortality or serious injury (including records from both U.S. and Canadian waters, prorated to 27.75 using serious injury guidelines) involved entanglement or fishery interactions. For this time frame, the average reported mortality and serious injury to right whales due to fishery entanglement was 5.55 whales per year. 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 of disentanglement teams averted a likely serious-injury determination. Seven serious injuries were prevented by intervention during 2013–2017 (Henry *et al.* 2020). Sometimes, even with disentanglement, an animal may die of injuries sustained from fishing gear. A female yearling right whale, #3107, was first sighted with gear wrapping its caudal peduncle on 6 July 2002 near Briar Island, Nova Scotia. Although the gear was removed on 1 September by the New England Aquarium disentanglement team, and the animal seen alive during an aerial survey on 1 October, its carcass washed ashore at Nantucket on 12 October 2002 with deep entanglement injuries on the caudal peduncle. Additionally, but infrequently, a whale listed as seriously injured becomes gear-free without a disentanglement effort and is seen later in reasonable health. Such was the case for whale #1980, listed as a serious injury in 2008 but seen gear-free and apparently healthy in 2011.

Incidents of entanglements in waters of Atlantic Canada and the U.S. east coast were summarized by Read (1994) and Johnson *et al.* (2005). Despite the long history of known fishing interactions, the only bycatch of a right whale observed by the Northeast Fisheries Observer Program was in the pelagic drift gillnet fishery in 1993. No mortalities or serious injuries have been documented by fisheries observers in any of the other fisheries monitored by NMFS.

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. 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. Scarring rates suggest that entanglements occur at about an order of magnitude more often than detected from observations of whales with gear on them. More recently, 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 over time that efforts made since 1997 to reduce right whale entanglement have not worked. Working from 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. Vessel strikes and entanglements were the two leading causes of death for known mortalities of right whales for which a cause of death could be determined. Across all 8 species of large whales, there was no detectable change in causes of anthropogenic mortality over time (van der Hoop *et al*. 2012). Pace *et al.* (2015) analyzed entanglement rates and serious injuries due to entanglement during 1999–2009 and 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. Assessment efforts are underway but rely on 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 2013 through 2017 have been summarized in Table 1. For this time frame, the average reported mortality and serious injury to right whales due to vessel strikes was 1.3 whales per year.

An Unusual Mortality Event was established for North Atlantic right whales in June 2017 due to elevated stranding along the Atlantic coast, especially in the Gulf of St. Lawrence region of Canada (https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2018-north-atlantic-right-whale-unusual-mortality-event).

***Table 1. Confirmed human-caused mortality and serious injury records of right whales: 2013–2017[a]***

| Date[b] | Fate | ID | Location[b] | Assigned Cause | Value against PBR[c] | Country[d] | Gear Type[e] | Description |
|---|---|---|---|---|---|---|---|---|
| 07/12/2013 | Prorated Injury | 3123 | off Virginia Beach, VA | EN | .75 | XU | NR | Constricting gear cutting into mouthline; Partially disentangled; final configuration unknown. No resights post Jul/2013 |
| 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 | .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. |
| 1/29/2016 | 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. |

| Date[b] | Fate | ID | Location[b] | Assigned Cause | Value against PBR[c] | Country[d] | Gear Type[e] | Description |
|---|---|---|---|---|---|---|---|---|
| 5/19/2016 | 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. |
| 5/03/2016 | 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. |
| 7/26/2016 | 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. |
| 8/1/2016 | 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. No gear present. Significant health decline: emaciated, cyamids patches, peeling skin. No resights. |
| 8/13/2016 | 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. |
| 8/16/2016 | 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. |

| Date[b] | Fate | ID | Location[b] | Assigned Cause | Value against PBR[c] | Country[d] | Gear Type[e] | Description |
|---|---|---|---|---|---|---|---|---|
| 8/28/2016 | 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. |
| 8/31/2016 | 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. |
| 9/23/2016 | Mortality | 3694 | off Seguin Island, MA | EN | 1 | XC | 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. |

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

| **Assigned Cause** | **Five-year mean (US/CN/XU/XC)** |
|---|---|
| Vessel strike | 01.3 (0.50/ 0.80/ 0.00/ 0.00) |
| Entanglement | 5.55 (0.20/ 1.20/ 2.45/ 1.70) |

a. For more details on events please see Henry *et al.* 2020.
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.

## 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 (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). 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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