SC/68A/ASI/07

Assessment of bias in population abundance estimates for North Atlantic fin whales (Balaenoptera physalus)

Elisabeth Slooten

INTERNATIONAL WHALING COMMISSION

Assessment of bias in population abundance estimates for North Atlantic fin whales (*Balaenoptera physalus*)

Elisabeth Slooten, Department of Zoology, University of Otago, Dunedin, New Zealand

ABSTRACT

An assessment of the accuracy of population abundance estimates for North Atlantic fin whales (*Balaenoptera physalus*) was performed based upon a review of North Atlantic Sightings Surveys (NASS) conducted since 2001 and peer reviewed scientific literature concerning the appropriate methodological components of line transect surveys for cetaceans. It is shown that fin whale abundance estimates derived through NASS are likely positively biased. This bias is attributable to observer measurement errors that collectively resulted in an underestimate of duplicate sightings, the effective strip width and the track line detection probability. Other factors relevant to the potential sustainability of fin whale quotas based upon these abundance estimates include the effect of regional fin whale population distribution shifts, genetic analysis of pre-whaling era fin whale population levels and the negative effect of the removal of large numbers of pregnant female fin whales.

KEY WORDS: ABUNDANCE ESTIMATE, SURVEY – VESSEL, TRENDS, *g*(0), DISTRIBUTION, MIGRATION, GENETICS

INTRODUCTION

When Iceland rejoined the International Whaling Commission (IWC) in 2002, it asserted that:

> *Under no circumstances will whaling for commercial purposes be authorised without a sound scientific basis and an effective management and enforcement scheme*.

However, the scientific basis of Iceland's commercial whaling program is potentially flawed. In the following sections, some of these deficiencies are highlighted – with a particular focus on methodological failings in North Atlantic fin whale surveys that undermine the reliability of abundance estimates based upon those surveys. Given the Icelandic government's recent announcement that stock assessments are a primary factor in making whaling permit decision (Júlíusson 2019), it is critical to ensure the accuracy of such assessments.

ICELAND RELIES UPON POTENTIALLTY BIASED NORTH ATLANTIC FIN WHALE ABUNDANCE ESTIMATES

Scientists from whaling nations rely upon whale population survey data to evaluate trends in abundance for each whale species to help determine if whaling is "sustainable".

The primary points of this paper may be summarized as follows:

- The surveys on which the abundance estimates are based suffer from uncorrected measurement errors that collectively result in a substantial positive bias in those estimates. In particular, errors in distance and angle measurements from the track lines of the survey vessels to the observed whales resulted in (1) a failure to adequately identify duplicate sightings; (2) a significant underestimate of the width of the strip that is being surveyed (inflating the calculation of whale population density); and (3) an underestimate of the probability of the survey vessel observer detecting an animal at zero distance from the track line (also resulting in inflated density estimate). This positive bias results in the mistaken conclusion that there has been a large increase in whale abundance. The lack of comparability between surveys further complicates any population trend analysis.

- The authors of the papers describing the surveys acknowledge that an increase in fin whale numbers in the survey areas may be attributable to regional distributional shifts in population rather than population growth.

- Even assuming the validity of the latest abundance estimates, some scientists have advanced an argument based upon genetic analysis suggesting that whale populations are far below the pre-whaling era number for North Atlantic fin whales. If so, this undermines the argument that North Atlantic fin whale populations are fully recovered from past exploitation caused by whaling.

- A narrow focus on total fin whale numbers fails to represent the skewed sex ratios in Iceland's whale catches, with a large number of pregnant females being targeted. This has important implications for the health of the North Atlantic fin whale population and does not appear to be adequately addressed by the way the RMP is being implemented in this case.

The potential problems with the surveys, outlined in this paper, mean that the abundance estimates are not sufficiently robust to ensure the catches are sustainable. Each of these issues is discussed in the following sections.

Line transect surveys of North Atlantic fin whale populations significantly overestimate abundance

Line-transect surveys from ships or aircraft are a standard survey method. However, in this case only a very small proportion of the surveyed areas have been covered frequently enough by line-transect surveys to allow an analysis of population trend (Kaschner 2012). Additionally, population density estimates are often "not directly comparable across studies . . . due to differences in survey methodology, data analyses and intra-annual and interannual temporal coverage" (Becker 2017).

In the North Atlantic, there have been six cetacean surveys (1987, 1989, 1995, 2001, 2007 and 2015) in the "North Atlantic Sightings Surveys" (NASS) series – in which fin whales were a target species. However, the "overall abundance over the entire survey area is not directly comparable between NASS as coverage has varied between surveys" (IWC 2016). In addition to such variance in geographic coverage, survey methodology (as discussed below) has also varied in ways that make an overall trend analysis of fin whale abundance for the surveyed areas difficult.

Errors in distance and angle measurements can result in biased abundance estimates

Visual line transect surveys involve an observer traversing a predefined line for a certain distance within the survey area. The survey area is usually divided into smaller "strata". The survey methodology is dependent upon a number of assumptions, including that the animals are randomly distributed in the survey area and that observer measurements are accurate (Nomani 2012).

Upon sighting an animal, the observer records the species and other data concerning the sighting (*e.g.* group size, behaviour) and measures the perpendicular distance (the distance at 90 degrees to the direction of travel) to the sighting from the observation platform (Barlow 2001). Statistical analysis of the distances of sightings to the trackline are used to estimate the width of the strip that is being surveyed – referred to as the "effective strip width" or "*esw*" (Barlow 2001). Effective strip width is a key parameter in estimating abundance from line transect surveys (Barlow 2001). However, errors in estimating the perpendicular distances that underlie *esw* calculations can significantly bias abundance estimates (Leaper 2010). Given that there is an inverse relationship between *esw* and the animal density in each surveyed strip, abundance estimates are inversely proportional to *esw*.[1] Accordingly, the narrower the strip width the higher the abundance estimate.

[1] To understand the basic mathematics behind this inverse relationship, consider the following density equation used in line transect surveys: $D = n \cdot f(0) / 2 \cdot L \cdot g(0)$, where L = the length of "on-effort" transect lines, $f(0)$ = the probability density of the detection function evaluated at zero perpendicular distance, $g(0)$ = the track line detection probability, and n = the number of sightings (Barlow 2015). This equation can be rewritten as: $D = n / 2 \cdot L \cdot esw \cdot g(0)$. From a conceptual standpoint, $2 \cdot L \cdot esw$ can be viewed as the area surveyed. Thus, density is simply the number of animals divided by the area. As discussed further in the main text, $g(0)$ is the proportion of animals present along the track line (zero distance) that were detected by the observer. Looking back at the rewritten equation with this concept in mind, it should be clear that if $g(0)$ equals 1, then $n/g(0)$ represents the actual number of animals that would have been seen with perfect observers.

Another critical component of the survey abundance estimate is the track line detection probability, or "*g*(0)" (Barlow 2015), the probability of an observer detecting whales at zero distance from the track line. Conceptually, *g*(0) is the proportion of whales present on the track line that were actually detected. In line transect surveys, *g*(0) has often been assumed to equal 1 – meaning that all whales are assumed to have been detected on the track line (Barlow 2015). Nevertheless, many conditions can affect *g*(0), potentially resulting in a biased abundance estimate. For example, observers may miss visible whales *e.g.* because of weather conditions – referred to as "perception bias" – or whales may be diving while the ship moves past them – known as "availability bias" (Barlow 2015). In an attempt to counter these potential biases, the survey may estimate *g*(0) at a number less than 1 – thereby offsetting the estimated availability and perception bias. Because *g*(0) is inversely proportional to whale density[2], if the *g*(0) estimate is biased low, it will artificially inflate abundance estimates.

Clearly, the estimation of *esw* and *g*(0) is critical to accurately estimating abundance. Observer error in estimating distances and angles to sightings can introduce significant biases into surveys and the resulting abundance estimates (Leaper 2010). With respect to distance, there is "evidence of a non-linear relationship between error in [estimated] distance and [the actual] distance, with over-estimation of close distances and under-estimation of far distances" (Leaper 2010). This nonlinear relationship is particularly problematic in surveys reliant upon naked eye estimates (*e.g.* compared to distance estimates using binoculars) – <u>with one study showing that there would have been a 29 percent bias in *esw* if the survey had relied on naked eye estimates</u> (Leaper 2010).[3] Bias in abundance estimates is inversely related to bias in distance estimates, with a negative bias in distance estimates leading to a positive bias in abundance estimates (Williams 2007). Random errors in distance estimation are usually assumed to have a relatively small impact on line transect surveys, unless the errors are systemic. However, more recent assessments have "challenged this relaxed assumption" (Williams 2007; Borchers 2010).

Errors in angle estimations also introduce bias into abundance calculations. Angle errors tend to positively bias the encounter rate (the number of individuals sighted) by failing to identify duplicate sightings <u>when the survey relies upon specific sighting angles as the means of identifying duplicates</u>. For example, the survey may classify sightings as non-duplicates where two sightings differ by more than a certain number of degrees (*e.g.* 10 degrees). On this point, Leaper *et al.* (2010) found root mean square errors (RMSEs) of 5 to 7 degrees in angle estimations in surveys similar (as discussed below) to the 2015 NASS (Leaper 2010).[4] This level of error introduces significant uncertainty into the identification of duplicate sightings.

To the extent the survey <u>fails to sufficiently detect duplicates due to angle estimation error</u>, the resulting positive bias in encounter rates will affect the abundance estimates. Further, given that *g*(0) is estimated from the proportion of whales known to be present that are seen by the different observers, the failure to identify one or more animals as duplicates will reduce *g*(0) – thereby also positively biasing the abundance estimate. This result follows from the incorrect conclusion that one or both observation platforms missed sighting a whale (or whales), thus artificially inflating the number of whales believed to be present versus the number observed (reducing the probability of observation to less than 1).[5]

The 2007 NASS acknowledged that naked eye distance estimates could result in substantially biased abundance estimates

In light of the critical importance of avoiding measurement errors, a survey should be designed in a manner that avoids sensitivity to such error in order to generate accurate abundance estimates. The team designing the 2007 NASS survey recognized the possibility of positive bias in abundance estimates from naked eye distance estimation.

---

[2] *See* discussion of density equation, *supra* note 3.

[3] The study further concluded that the demonstrated "lack of a significant correlation between the truncated naked eye estimates (over the distance range of 200-500m) and measured distances, highlight[ed] the difficulties of estimating distances by naked eye" (Leaper 2010).

[4] The RMSE may be viewed as a quantification of the spread of the measured values about the predicted y value. <u>Thus, if the predicted value were 10 degrees, then the observed values could range from 3 to 17 degrees if the RMSE is 5 to 7 degrees.</u>

[5] For example, if there are 10 whales on the track line, but the observers fail to identify one whale as a duplicate, this error creates the false perception that there are 11 whales, but only 10 were seen by both observers. As a result, *g*(0) will be estimated as less than 1 (10/11).

In that survey, ship board observations were conducted in the Buckland and Turnock (B-T) mode (Pike 2007). This survey methodology involves the use of two independent observation platforms, a primary and a tracking platform. The observers on the tracking platform search ahead of the vessel using mounted binoculars while the observers on the primary platform rely principally on naked eye observations (Pike 2007). The primary platform operates independently of the tracker platform but reports all sightings to a duplicate identifier on the tracker platform (Pike 2007).

In the 2007 NASS, separate abundance estimates were made on the basis of sightings from the primary platform and the combined primary and tracker platforms. Significantly, the survey report expressly acknowledged the possibility of positively biased abundance estimates due to measurement error from naked eye observations – stating that "an abundance estimate would be expected to be 34% too large if based only on primary [naked eye estimates] rather than only tracker data [reticle binocular estimates]" (Pike 2007). Similarly, in the summary of their findings submitted to the NAMMCO Working Group on Abundance Estimates, the authors of the 2007 NASS survey report highlighted the substantial negative bias in distance estimation (64 percent of the tracker platform estimates) by the primary platform (NAMMCO 2018). The Working Group devoted considerable discussion to this distance estimation bias, including the nonlinear relationship between distance and bias (with the degree of bias increasing or decreasing with distance) (NAMMCO 2018). Although it decided to accept the estimates without correction, the Working Group recommended that this issue be further explored in future studies.

The 2015 NASS fin whale abundance estimates are subject to significant positive bias due to a failure to minimize measurement errors

Despite consideration of negative distance estimate biases in the 2007 NASS, the team designing the 2015 NASS surprisingly failed to adequately guard against errors in estimation of distances (and angles). This calls into question the reliability of the resulting abundance estimates. Equally surprising, the 2015 survey rejected the B-T mode in favor of a fully independent double platform observer (IO) mode that relied substantially more on naked eye estimates than the B-T mode (Pike 2016). In particular, binoculars were only in "general" use on each platform versus the dedicated reticle binocular use by the tracker platform in B-T mode (Pike 2016). More specifically, in B-T mode, observers systematically scan with binoculars in order to detect whales at greater distances and then carefully track the animal. Accordingly, these observers are already looking through the reticle binoculars when they make the first sighting. By comparison, in IO mode, observers will generally only use the binoculars after first sighting a possible target with their naked eyes. This latter method is more prone to distance estimation errors. Nevertheless, in spite of this greater sensitivity to error (and express recognition of the risk of such error), no attempt was made to conduct distance estimation experiments to quantify the amount of error (Pike 2016).

An important consequence of this failure to minimize error in distance estimates is the resulting effect on calculation of estimated strip width. As previously discussed, the narrower the strip width, the higher the abundance estimate. Accordingly, it is noteworthy that the strip widths derived for the 2015 NASS were particularly narrow as compared with those calculated in the 2001 NASS, which employed the same vessels and observation platforms (Víkingsson 2009). Specifically, strip widths for the Icelandic vessels in 2001 were 2.1-2.3 km, whereas they were only 1.1-1.8 km in 2015 (Víkingsson 2009; Pike 2016). The 2001 NASS was conducted in B-T mode (with the dedicated use of reticle binoculars by the tracker platform) and, therefore, was less sensitive to distance estimation error than the 2015 NASS (Víkingsson 2013). Thus, there is a high likelihood that the substantially narrower strip widths from the 2015 NASS are attributable to distance estimation error. Further, the reliance on naked eye observations in the 2015 NASS is of particular concern, as narrow strip widths are associated with naked eye estimates even when paired with some binocular usage (Barlow 2011). The result here is a significant positive bias in abundance estimates.

In addition to exposure to greater error in distance estimation, the 2015 NASS was also susceptible to angle estimation error. Angles were estimated using either reticle binoculars or angle boards (Gunnlaugsson 2016). The angle estimates were employed as one of the primary means of detecting duplicate sightings, with fin whale sightings "generally classified as non-duplicates if they differed by 10° in angle to track when seen within a short interval" (Gunnlaugsson 2016). However, as noted previously, Leaper *et al.* (2010) found RMSEs of 5 to 7 degrees in angle estimations using similar measurement techniques (*e.g.* binoculars or naked eyes with angle boards). Given this similarity, a similar RMSE range in the 2015 NASS is anticipated. As a consequence, there is a strong likelihood that reliance on the "10 degree to track" criterion to detect duplicates resulted in a bias in duplicate identification, as angle estimation would vary between 5 and 7 degrees from 10 degrees. Of note, assuming an RMSE of 6 degrees, 24 percent of the sightings of the same animal would be expected to differ in bearing from the two platforms by greater than 10 degrees (and, thus, not be classified as duplicates). For an RMSE error of 5 degrees, the equivalent misclassification would be 16 percent. As a result, the collected data would underestimate duplicates – resulting in a positive bias in encounter rate and, thus, in the abundance estimate.[6]

This increased encounter rate would also positively bias the abundance estimate by, as discussed above, reducing *g*(0). In the 2015 NASS, to correct for alleged perception bias, *g*(0) was calculated to be 0.86 (Pike 2016). Although higher than the *g*(0) calculated in the 2007 NASS, the 2015 *g*(0) would be expected to be higher than 0.86 given that, in IO mode, "bias is estimated for the combined sightings by both platforms" (Pike 2016). In contrast, the 2007 NASS only estimated perception bias for the primary platform, which means that the derived *g*(0) only represented the probability of detection on the track line by a single observer team (Pike 2016). However, in 2015, *g*(0) was the probability of detection by either team – with each whale, therefore, having two chances of being detected. This enhanced probability of detection should translate into a higher *g*(0). Thus, the lower 2015 *g*(0) is most likely attributable to the failure to adequately identify duplicates.

While there was little discussion of duplicate identification methodology in the 2015 NASS, the authors expressly recognized the importance of such identification. As stated by Daniel Pike to the NAMMCO Abundance Estimate Working Group:

> The most important means of improving the accuracy and certainty of duplicate identification [is] to increase the precision of distance measurements and sighting times. Given that duplicate identification is probabilistic, uncertainty in duplicate identification should be incorporated in abundance estimates. (NAMMCO 2018)

Surprisingly, in view of this apparent understanding, the 2015 NASS failed to incorporate this uncertainty into its abundance estimate calculations. Rather, the authors only made passing reference to it in their admission that "duplicate identification may be more certain when B-T mode is successfully implemented" (Pike 2016). They then concluded their discussion of duplicates with the acknowledgment that "[m]ore accurate and precise measurement of sighting angles, distances and times would improve the certainty of duplicate identification" (Pike 2016). Accordingly, although recognizing the need for greater certainty and the contribution of the B-T mode to such certainty, the 2015 NASS team selected an observational mode more prone to estimation error, with correspondingly increased uncertainty in duplicate identification. The result of their failure to adequately address duplicates through survey design is a further positive bias in abundance estimates.

To summarize, in light of the acknowledged problems associated with estimation error in the 2007 NASS, it is surprising that no attempt was made to address this issue in 2015. Indeed, the methods used in 2015 were more sensitive to estimation error, which would affect *esw*, encounter rate and *g*(0). Estimation error likely explains the large differences in total abundance numbers between the 2015 NASS and the previous surveys. Thus, at a minimum, this issue warrants further investigation before Iceland issues further whaling permits based on the potentially biased 2015 NASS results.

The claimed increase in North Atlantic fin whale populations may be attributable to regional distributional shifts, not intrinsic population growth

A principal assumption underlying all NASS fin whale surveys is that the assumed increases in abundance are explained by population growth. However, even assuming that there have been such increases, the survey authors admit that the apparent increases may be attributable to regional distributional shifts. For example, on this point, the surveys include the following acknowledgements:

- **2001 NASS:** "The <u>possibility of immigration from other area cannot . . . be ruled out</u>, as recent estimates of abundance are not available for large areas of particularly the western Atlantic." (Víkingsson 2009)

- **2015 NASS:** "The abundance of fin whales around the Faroe Islands and to the south of Iceland . . . was also strikingly high compared to earlier surveys . . . <u>It is interesting to speculate that this might have been due to a northern incursion of fin whales into the area from the Spanish stock area</u>, where earlier surveys

[6] At a minimum, the potentially wide variability in angle estimation undermines confidence in duplicate identification.

found fin whales to be abundant. . . . While overall abundance over the entire survey area is not directly comparable between NASS as coverage has varied between surveys, the numbers seen here are the highest of any NASS in the Central North Atlantic. This suggests either an increase in abundance in northern areas or a distributional shift, or a combination of both of these. A distributional shift is not unlikely as Víkingsson et al. (2015) have demonstrated that fin whales have both increased in abundance and changed their distribution patterns within the NASS survey area between 1987and 2007." (Pike 2016)

These statements concerning the potential for fin whale regional distribution shifts raise serious doubts about the assumption that the apparent changes in population size are due to population growth. This uncertainty concerning fin whale population structure is attributable to the significant gaps in temporal and geographic cetacean survey coverage discussed above. The 2015 NASS survey designers further admit the existence of these informational gaps in observing that "abundance over the entire survey area is not directly comparable between NASS as coverage has varied between surveys" (ICW 2016).

In the face of such scientific uncertainty, Iceland must be guided by the precautionary principle, given the considerable uncertainty as to whether fin whale population numbers are actually increasing (as represented in the NASS).

Genetic analysis may demonstrate that the North Atlantic fin whale population is a fraction of its pre-whaling era size

Beginning in the 19th century, fin and blue whales "were most important species for the whaling industry in the North Atlantic and subsequently in other ocean areas" (Víkingsson 2009). As a consequence, their populations were heavily depleted. Estimation of pre-whaling population numbers is critical to an assessment of whether fin and other whale species have recovered from human exploitation. Based on whaling logbooks, the pre-whaling North Atlantic fin whale population was thought to be approximately 50,000 (Roman 2003). However, these anecdotal historic data sources, dating back to the mid-1880's, are potentially biased (e.g. due to intentional underreporting) making them an unreliable measure of historical population numbers (Roman 2003).

Since 2004, these historical population estimates based upon anecdotal records have been challenged by genetic analysis. The basic premise is that large populations have greater genetic diversity than smaller populations, as the latter is subject to a loss in diversity through inbreeding (Roman 2003; Palumbi 2007). Relying upon this genetic measure, it has been postulated that "the depletion of the great whales may be in the range of 90% or greater" (Roman 2014). If this alternative measure is accurate, this would be significant for a number of reasons, including the negative effect on the substantial ecosystem services provided by whales (Roman 2014). It has been shown, for example, that whales are responsible for enhancing primary productivity by transporting important nutrients to the surface (the so-called "whale pump"), mitigating climate change through carbon sequestration and supporting ecosystem stability (Roman 2014). These beneficial effects are especially noticeable at the local and regional levels (Roman 2014).

Using the genetic record, historical fin whale populations in the North Atlantic have been estimated at 360,000 (Roman 2003) – orders of magnitude greater than previous estimates and substantially greater than the 2015 NASS estimates (if those numbers are accurate). Accordingly, these considerably higher estimates of historical North Atlantic fin whale populations indicate they are a long way from even partial recovery from the impacts of the commercial whaling era. In addition, the ecosystem services benefit to Iceland of allowing more complete recovery is considerable. Furthermore, recovery is critical to the long- term health of North Atlantic fin whale populations in the face of growing environmental threats throughout their range from climate change, toxic pollutants and other anthropogenic stressors.

Potential adverse population effects from the removal of pregnant female fin whales in the Icelandic hunts

During the 2018 hunting season, Hvalur hf targeted and killed at least 21 pregnant fin whales.[7] Given the lack of any observer coverage for the hunts, it is possible that pregnant females constituted an even larger percentage of the catch. Reports of 21 well-developed (mid-fetal period) foetuses underscore the potential impacts of the population.

[7] Although 21 deaths of pregnant females were documented, additional pregnant females may have been struck and lost at sea. However, the lack of observer coverage prevents a full assessment of the true scale and nature of the whale slaughter.

The impact of targeting pregnant females and females with calves is well understood. For example, demographic research of the North Atlantic right whale has shown that increased mortality of pregnant females and females with calves can cause declines in population growth rate, life expectancy and the number of life-time reproductive events (Fujiwara 2001; Corkeron 2018). Additionally, studies of humpback harvests demonstrated that, "[i]f catches were female-biased, population declines could become more pronounced because reproductive rates are more dependent on the numbers of females than males" (Jackson 2016). Given these acknowledged risks, in considering whether to renew Hvalur's permits, the Icelandic government must also take into account the negative effects on North Atlantic fin whales from the likely continued loss of a large number of pregnant females in the hunts.

CONCLUSION

The effect of each individual bias, as outlined above, may not be large on its own. However, taken together the problems identified have the potential to significantly affect the conclusions from the NASS surveys and the sustainability of recent and proposed catches.

REFERENCES

Barlow, J. 2015. Inferring trackline detection probabilities, g(0), for cetaceans from apparent densities in different survey conditions. *Marine Mammal Science*, 31(3), 923-943. doi:10.1111/mms.12205.

Barlow, J., Ballance, L.T. & Forney, K.A. 2011. Effective strip widths for ship-based line-transect surveys of cetaceans. NOAA Technical Memorandum NMFS. NOAA-TM-NMFS-SWFSC-484 (2011).

Barlow, J., Gerrodette, T. & Forcada, J. 2001. Factors affecting perpendicular sighting distances on shipboard line-transect surveys for cetaceans. *J. Cet. Res. Manage*. 3:201–212.

Becker, E. A., Forney, K. A., Thayre, B. J., Debich, A. J., Campbell, G. S., Whitaker, K. & Hildebrand, J. A. 2017. Habitat-based density models for three cetacean species off Southern California illustrate pronounced seasonal differences. *Frontiers in Marine Science,* 4. doi:10.3389/fmars.2017.00121.

Borchers, D., Marques, T., Gunnlaugsson, T. & Jupp, P. 2010. Estimating distance sampling detection functions when distances are measured with errors. *Journal of Agricultural, Biological, and Environmental Statistics,* 15(3), 346-361. doi:10.1007/s13253-010-0021-y.

Corkeron, P., Hamilton, P., Bannister, J., Best, P., Charlton, C., Groch, K. R. & Pace, R. M. 2018. The recovery of North Atlantic right whales, Eubalaena glacialis, has been constrained by human-caused mortality. *Royal Society Open Science,* 5(11), 180892. doi:10.1098/rsos.18089.

Fujiwara, M. & Caswell, H. 2001. Demography of the endangered North Atlantic right whale. *Nature,* 414(6863), 537-541. doi:10.1038/35107054.

Gunnlaugsson, Th.,Víkingsson, G.A. & Mikkelsen, B. 2016. Cruise Report of the Icelandic NASS 2015 Cetacean census vessel survey. SC/66b/1A/18.

International Whaling Commission. 2016. Report of the Working Group on Abundance Estimate. SC/23/15.

Jackson, J. A., Carroll, E. L., Smith, T. D., Zerbini, A. N., Patenaude, N. J. & Baker, C. S. 2016. An integrated approach to historical population assessment of the great whales: Case of the New Zealand southern right whale. *Royal Society Open Science,* 3(3), 150669. doi:10.1098/rsos.150669.

Júlíusson, K.P. (Iceland Minister of Fisheries and Agriculture). 2019. Report on the impact of whales on marine life. January 29, 2019 speech before the Iceland Althingi, 149th congress - 58th session. [Available at https://www.althingi.is/altext/raeda/149/rad20190129T141313.html]

Kaschner, K., Quick, N. J., Jewell, R., Williams, R. & Harris, C. M. 2012. Global coverage of cetacean line-transect surveys: Status quo, data gaps and future challenges. *PLoS ONE*, 7(9). doi:10.1371/journal.pone.0044075.

Leaper, R., Burt, M. L., Gillespie, D. M. & Macleod, K. 2010. Comparisons of measured and estimated distances and angles from sightings surveys. *J. Cet. Res. Manage.* 11(3) 229-237.

Marques, T. A. 2004. Predicting and correcting bias caused by measurement error in line transect sampling using multiplicative error models. *Biometrics,* 60(3), 757-763. doi:10.1111/j.0006-341x.2004.00226.x.

NAMMCO-North Atlantic Marine Mammal Commission. 2018. Report of the NAMMCO Scientific Working Group on Abundance Estimates (2018) [Available at https://nammco.no/topics/sc-working-group-reports/]

Nomani, S. Z. 2012. Line transects by design: The influence of study design, spatial distribution and density of objects on estimates of abundance. *The Open Ecology Journal*, 5(1), 25-44. doi:10.2174/1874213001205010025.
Palumbi, S. R. & Roman, J. 2007. The History of Whales Read from DNA. pp. 102-115. In: Estes JA (ed) *Whales, whaling and ocean ecosystems.* University of California Press, Berkeley. i-xiv+418pp.

Pike, D.J., Gunnlaugsson, Th., Mikkelsen, B. & Vikingsson, G.A. 2016. Estimates of the abundance of fin whales (*Balaenoptera physalus*) from the NASS Icelandic and Faroese ship surveys conducted in 2015. SC/66b/RMP/01 Rev1.

Pike, D.J., Gunnlaugsson, Th.,Víkingsson, G.A. & Mikkelsen, B. 2007. Estimates of the abundance of fin whales (*Balaenoptera physalus*) from the T-NASS Icelandic and Faroese ship surveys conducted in 2007. IWCSC/60/PFI13-revised (2008).

Roman, J. 2003. Whales before whaling in the North Atlantic. *Science,* 301(5632), 508-510. doi:10.1126/science.1084524.

Roman, J., Estes, J. A., Morissette, L., Smith, C., Costa, D., Mccarthy, J. & Smetacek, V. 2014. Whales as marine ecosystem engineers. *Frontiers in Ecology and the Environment,* 12(7), 377-385. doi:10.1890/130220.

Víkingsson, G.A., Pike, D.G., Desportes, G., Øien, N., Gunnlaugsson, Th. & Bloch, D. 2009. Distribution and abundance of fin whales (Balaenoptera physalus) in the Northeast and Central Atlantic as inferred from the North Atlantic Sightings Surveys 1987-2001, NAMMCO Scientific Publications 7:49-72.

Williams, R., Leaper, R., Zerbini, A. N. & Hammond, P. S. 2007. Methods for investigating measurement error in cetacean line-transect surveys. *Journal of the Marine Biological Association of the United Kingdom,* 87(1), 313-320. doi:10.1017/s0025315407055154.