North Atlantic Right Whale (*Eubalaena glacialis*) 2017-2021

Bibliography

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Table of Contents

Background & Scope

The North Atlantic right whale is one of the world's most endangered large whale species, with less than 400 individuals remaining. This bibliography focuses on any relevant North Atlantic right whale literature (peer-reviewed, technical reports, memos, biological opinions, etc.) published from July 2017 to July 2021. It is intended as a reference resource for Endangered Species Act (ESA) recovery staff of the NOAA Fisheries' Office of Protected Resources when compiling and summarizing any relevant new information for this cetacean species. It is organized into five sections: Biology, Ecology, Population Abundance and Trends, Threats and Conservation, and General.

Section I – Biology

Section one is intended to provide an overview of new information since July 2017 on the biology of the North Atlantic right whale. The research in this area includes a compilation of literature on lifespan, metabolism, reproduction, genetics, and body size.

Section II – Ecology

Section two is intended to provide an overview of ecology for the North Atlantic right whale. The research in this area includes habitat, migration, feeding, acoustics, behavior, and social ecology.

Section III – Population Abundance

Section three is intended to provide an overview of the latest population estimates (since July 2017) for the North Atlantic right whale.

Section IV – Threats and Conservation

A threat is defined as any factor that could represent an impediment to a species' recovery. Thus, section four is intended to provide an overview of any new and/or existing threats to the North Atlantic right whale. This may include anthropogenic noise, entanglements, vessel strikes, and climate change. Current conservation efforts related to the North Atlantic right whale are also included in this section.

Section V – General

Section five contains literature that gives a generalized overview on North Atlantic right whales and factors surrounding their feeding, migration and general life history.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; Digital Science's Dimensions.ai; Lens.org; ProQuest's Science and Technology including Aquatic Science Fisheries Abstracts; Elsevier's Science Direct; JSTOR; EBSCO's Academic Search Complete and Environment Complete; NOAA's Institutional Repository; Elsevier's Science Direct; International Whaling Commission (IWC); IUCN Red List of Threatened Species; Science.gov; Right Whale News; and Google Scholar.

Section I: Biology

Ajo, A. A. F., Hunt, K. E., Uhart, M., Rowntree, V., Sironi, M., Maron, C. F., . . . Buck, C. L. (2018). Lifetime Glucocorticoid Profiles in Baleen of Right Whale Calves: Potential Relationships to Chronic Stress of Repeated Wounding by Kelp Gulls. *Conservation Physiology, 6*(1). https://doi.org/10.1093/conphys/coy045

Baleen tissue accumulates stress hormones (glucocorticoids, GC) as it grows, along with other adrenal, gonadal and thyroid hormones. The hormones are deposited in a linear fashion such that a single plate of baleen allows retrospective assessment and evaluation of long-term trends in the whales' physiological condition. In whale calves, a single piece of baleen contains hormones deposited across the lifespan of the animal, with the tip of the baleen representing prenatally grown baleen. This suggests that baleen recovered from stranded carcasses of whale calves could be used to examine lifetime patterns of stress physiology. Here we report lifetime profiles of cortisol and corticosterone in baleen of a North Atlantic right whale ('NARW'-*Eubalaena glacialis*) calf that died from a vessel strike, as well as four southern right whale ('SRW'-*Eubalaena australis*) calves that were found dead with varying severity of chronic wounding from Kelp Gull (*Lams dominicanus*) attacks. In all five calves, prenatally grown baleen exhibited a distinctive profile of elevated glucocorticoids that declined shortly before birth, similar to GC profiles reported from baleen of pregnant females. After birth, GC profiles in calf baleen corresponded with the degree of wounding. The NARW calf and two SRW calves with no or few gull wounds had relatively low and constant GC content throughout life, while two SRW calves with high numbers of gull wounds had pronounced elevations in baleen GC content in postnatal baleen followed by a precipitous decline shortly before death, a profile suggestive of prolonged chronic stress. Baleen samples may present a promising and valuable tool for defining the baseline physiology of whale calves and may prove useful for addressing conservation-relevant questions such as distinguishing acute from chronic stress and, potentially, determining cause of death.

Allwood, J. S., Scheible, M. K., & Faith, S. A. (2018). Demonstration of a Basic Mitochondrial Enrichment Method to Produce the Complete Mitochondrial Genome Sequence of the Endangered North Atlantic Right Whale (*Eubalaena glacialis*). *Conservation Genetics Resources, 10*(3), 483-486. https://doi.org/10.1007/s12686-017-0854-6

The North Atlantic right whale is one of only three species within the Eubalaena genus, a group heavily targeted by the whaling industry prior to the twentieth century. All three species (*Eubalaena australis*, *Eubalaena japonica* and *Eubalaena glacialis*) are CITES listed (Appendix I), with the latter two species listed as endangered (IUCN, v 2017-1). The mitochondrial genome of the first two species have been sequenced and are publicly available, while *E. glacialis* was unavailable. Here we present the complete mitochondrial genome sequence of *E. glacialis*, while also detailing a straight forward mitochondrial enrichment method that facilitates analysis using next generation sequencing. This method simultaneously allows for efficient sequencing of the mitochondrial genome, while demonstrating quality sequence coverage that is even across the genome. This enrichment illustrates a marked improvement in sequence depth compared to that achieved when performing whole genome sequencing using a standard DNA extraction.

Bisconti, M., Lambert, O., & Bosselaers, M. (2017). Revision of "Balaena" Belgica Reveals a New Right Whale Species, the Possible Ancestry of the Northern Right Whale, *Eubalaena glacialis*, and the Ages of Divergence for the Living Right Whale Species. *PeerJ, 5*, e3464. https://doi.org/10.7717/peerj.3464

In 1941, Abel established *Balaena belgica* based on a series of fused cervical vertebrae and citing other cranial fragments from the late Neogene of the Antwerp harbor (northern Belgium). Later, Plisnier-Ladame & Quinet (1969) added a neurocranium and other skeletal remains from the same area to this species. Recently, the neurocranium was re-assigned to the genus Eubalaena thanks to newer phylogenetic analyses. Here, a new description is provided of materials previously assigned to "Balaena" belgica together with taxonomic revisions. Our work suggests that the cervical complex originally designated as the type of "Balaena" belgica is too poorly preserved to be used as such and is assigned to Balaenidae gen. et sp. indet., thus making "Balaena" belgica a nomen dubium. In addition to the neurocranium, the other remains consist in a fragment of maxilla assigned to Balaenidae gen. et sp. indet. and in a humerus assigned to Eubalaena sp. Discovered in the Kruisschans Sands Member of the Lillo Formation (3.2-2.8 Ma, Piacenza, Late Pliocene), the neurocranium is designated as the holotype of the new species *Eubalaena ianitrix*. Our phylogenetic analysis supports a sister-group relationship of *Eubalaena ianitrix* and *Eubalaena glacialis*, and helps constraining the ages of origin for balaenid clades. Ecological and phylogenetic data suggest that *Eubalaena ianitrix* may represent the direct ancestor of *Eubalaena glacialis*, the latter having evolved through phyletic transformation including body size increase during the temperature decline of the Late Pliocene.

Browning, C. L., Wise, C. F., & Wise, J. P. (2017). Prolonged Particulate Chromate Exposure Does Not Inhibit Homologous Recombination Repair in North Atlantic Right Whale (*Eubalaena glacialis*) Lung Cells. *Toxicology and Applied Pharmacology, 331*, 18-23. https://doi.org/10.1016/j.taap.2017.04.006

Chromosome instability is a common feature of cancers that forms due to the misrepair of DNA double strand breaks. Homologous recombination (HR) repair is a high fidelity DNA repair pathway that utilizes a homologous DNA sequence to accurately repair such damage and protect the genome. Prolonged exposure (>72 h) to the human lung carcinogen, particulate hexavalent chromium (Cr(VI)), inhibits HR repair, resulting in increased chromosome instability in human cells. Comparative studies have shown acute Cr(VI) exposure induces less chromosome damage in whale cells than human cells, suggesting investigating the effect of this carcinogen in other species may inform efforts to prevent Cr(VI)-induced chromosome instability. Thus, the goal of this study was to determine the effect of prolonged Cr(VI) exposure on HR repair and clastogenesis in North Atlantic right whale (*Eubalaena glacialis*) lung cells. We show particulate Cr(VI) induces HR repair activity after both acute (24 h) and prolonged (120 h) exposure in North Atlantic right whale cells. Although the RAD51 response was lower following prolonged Cr(VI) exposure compared to acute exposure, the response was sufficient for HR repair to occur. In accordance with active HR repair, no increase in Cr(VI)-induced clastogenesis was observed with increased exposure time. These results suggest prolonged Cr(VI) exposure affects HR repair and genomic stability differently in whale and human lung cells. Future investigation of the differences in how human and whale cells respond to chemical carcinogens may provide valuable insight into mechanisms of preventing chemical carcinogenesis.

Burgess, E. A., Hunt, K. E., Kraus, S. D., & Rolland, R. M. (2017). Adrenal Responses of Large Whales: Integrating Fecal Aldosterone as a Complementary Biomarker to Glucocorticoids. *General and Comparative Endocrinology, 252*, 103-110. https://doi.org/10.1016/j.ygcen.2017.07.026

Until now, physiological stress assessment of large whales has predominantly focused on adrenal glucocorticoid (GC) measures. Elevated GC concentrations in feces (fGC) are known to reflect stressful disturbances, such as fishing gear entanglement and human-generated underwater noise, in North Atlantic right whales (*Eubalaena glacialis*). However, there can be considerable variation in GC production as a function of sex and life history stage, which may confound the interpretation of fGC levels. Additionally, GC antibodies used in immunoassays can cross-react with other fecal metabolites (i.e., non-target steroids), potentially influencing fGC data. Here, aldosterone concentrations (fALD; aldosterone and related metabolites) were measured in fecal samples from right whales (total n = 315 samples), including samples from identified individuals of known life history (n = 82 individual whales), to evaluate its utility as a complementary biomarker to fGC for identifying adrenal activation. Concentrations of fALD were positively correlated with fGCs in right whales ($r = 0.59$, $P < 0.001$), suggesting concurrent secretion of these hormones by the adrenal gland. However, fALD levels were less influenced by concentrations of reproductive steroids in feces, minimizing the potential confounder of assay cross-reactivity in samples with highly skewed hormone ratios. Across different life history states for right whales, fALD concentrations showed similar patterns to those reported for fGC, with higher levels in pregnant females (35.9 +/- 7.6 ng/g) followed by reproductively mature males (9.5 +/- 0.9 ng/g) ($P < 0.05$), providing further evidence of elevated adrenal activation in these groups of whales. The addition of fALD measurement as a biomarker of adrenal activation may help distinguish between intrinsic and external causes of stress hormone elevations in large whales, as well as other free-living wildlife species, providing a more comprehensive approach for associating adrenal activation with specific natural and anthropogenic stressors.

Burgess, E. A., Hunt, K. E., Kraus, S. D., & Rolland, R. M. (2018). Quantifying Hormones in Exhaled Breath for Physiological Assessment of Large Whales at Sea. *Scientific Reports, 8*(1), 10031. https://doi.org/10.1038/s41598-018-28200-8

Exhaled breath analysis is a non-invasive assessment tool that has shown promise in human diagnostics, and could greatly benefit research, management, and conservation of large whales. However, hormone assessment of whale respiratory vapor (blow) has been challenged by variable water content and unknown total volume of collected samples. To advance this technique, we investigated urea (a compound present in narrow range in circulation) as a normalizing factor to correct for blow sample concentration. Normalized progesterone, testosterone, and cortisol concentrations of 100 blow samples from 46 photo-identified North Atlantic right whales (*Eubalaena glacialis*) were more biologically relevant compared to absolute estimates, varying by sex, age class, or individual. Progesterone was elevated in adult females compared with other cohorts and highest in one independently confirmed pregnant female. For both sexes, testosterone was two-fold higher in reproductively mature whales but studied adult females showed the widest variation. Cortisol was present in relatively low concentrations in blow and demonstrated variation between individual whales, suggesting potential for studies of individual differences in adrenal activity. Incorporation of methodologies that normalize sample concentration are essential for blow hormone analysis of free-swimming whales, and measurement of urea could be used to optimize non-invasive physiological assessment of whales.

Christiansen, F., Dawson, S. M., Durban, J. W., Fearnbach, H., Miller, C. A., Bejder, L., . . . Moore, M. J. (2020). Population Comparison of Right Whale Body Condition Reveals Poor State of the North Atlantic Right Whale. *Marine Ecology Progress Series, 640*, 1-16. https://doi.org/10.3354/meps13299

The North Atlantic right whale *Eubalaena glacialis* (NARW), currently numbering <410 individuals, is on a trajectory to extinction. Although direct mortality from ship strikes and fishing gear entanglements remain the major threats to the population, reproductive failure, resulting from poor body condition and sublethal chronic entanglement stress, is believed to play a crucial role in the population decline. Using photogrammetry from unmanned aerial vehicles, we conducted the largest population assessment of right whale body condition to date, to determine if the condition of NARWs was poorer than 3 seemingly healthy (i.e. growing) populations of southern right whales E. australis (SRWs) in Argentina, Australia and New Zealand. We found that NARW juveniles, adults and lactating females all had lower body condition scores compared to the SRW populations. While some of the difference could be the result of genetic isolation and adaptations to local environmental conditions, the magnitude suggests that NARWs are in poor condition, which could be suppressing their growth, survival, age of sexual maturation and calving rates. NARW calves were found to be in good condition. Their body length, however, was strongly determined by the body condition of their mothers, suggesting that the poor condition of lactating NARW females may cause a reduction in calf growth rates. This could potentially lead to a reduction in calf survival or an increase in female calving intervals. Hence, the poor body condition of individuals within the NARW population is of major concern for its future viability.

Corkeron, P., Rolland, R. M., Hunt, K. E., & Kraus, S. D. (2017). A Right Whale Pootree: Classification Trees of Faecal Hormones Identify Reproductive States in North Atlantic Right Whales (*Eubalaena glacialis*). *Conservation physiology, 5*(1), cox006. https://doi.org/10.1093/conphys/cox006

Immunoassay of hormone metabolites extracted from faecal samples of free-ranging large whales can provide biologically relevant information on reproductive state and stress responses. North Atlantic right whales (*Eubalaena glacialis* Muller 1776) are an ideal model for testing the conservation value of faecal metabolites. Almost all North Atlantic right whales are individually identified, most of the population is sighted each year, and systematic survey effort extends back to 1986. North Atlantic right whales number <500 individuals and are subject to anthropogenic mortality, morbidity and other stressors, and scientific data to inform conservation planning are recognized as important. Here, we describe the use of classification trees as an alternative method of analysing multiple-hormone data sets, building on univariate models that have previously been used to describe hormone profiles of individual North Atlantic right whales of known reproductive state. Our tree correctly classified the age class, sex and reproductive state of 83% of 112 faecal samples from known individual whales. Pregnant females, lactating females and both mature and immature males were classified reliably using our model. Non-reproductive [i.e. 'resting' (not pregnant and not lactating) and immature] females proved the most unreliable to distinguish. There were three individual males that, given their age, would traditionally be considered immature but that our tree classed as mature males, possibly calling for a re-evaluation of their reproductive status. Our analysis reiterates the importance of considering the reproductive state of whales when assessing the relationship between cortisol concentrations and stress. Overall, these results confirm findings from previous univariate statistical analyses, but with a more robust multivariate approach that may prove useful for the multiple-analyte data sets that are increasingly used by conservation physiologists.

Fauquier, D., Long, K., Biedron, I., Wilkin, S., Rowles, T., Patterson, E., . . . Ziccardi, M. (2020). *Report of the Health Assessment Workshop for North Atlantic Right Whales (Eubalaena glacialis), June 24-26, 2019.* https://doi.org/10.25923/jygt-k217

Under the auspices of the Working Group on Marine Mammal Unusual Mortality Events, this workshop was held in response to the ongoing North Atlantic Right Whale (*Eubalaena glacialis*) Unusual Mortality Event and the endangered status of the species. The main goals of the workshop were to: (1) assess current health information data, including associated data gaps, and (2) identify appropriate available and needed tools and techniques for collecting standardized health data that can be used to understand health effects of environmental and human impacts (e.g., entanglement), and inform fecundity and survivorship models to ultimately guide population recovery of North Atlantic right whales.

Fortune, S. M. E., Moore, M. J., Perryman, W. L., & Trites, A. W. (2021). Body Growth of North Atlantic Right Whales (*Eubalaena glacialis*) Revisited. *Marine Mammal Science, 37*(2), 433-447. https://doi.org/10.1111/mms.12753

Knowing size-at-age is important for determining food requirements and making inferences about the nutritional status of individuals and their populations. Accurate growth curves are also needed to quantify drug dosages to treat wounded or entangled animals. However, body sizes are often based on small numbers of measured animals that must be improved as new data become available. We updated an existing body growth model for North Atlantic right whales (NARWs) using new data from dead animals and from older individuals. Our models indicate that NARWs attain mean lengths and weights of 4.3 m and 1.0 mt at birth, and 13.1 m and 31.7 mt when sexually mature. Calves more than double their length and attain nearly three-quarters of their asymptotic adult size during their first year of life. Overall, our length estimates agreed well with previous estimates, but our mass-at-age values were considerably higher. These differences revealed that necropsy data used alone in allometric models underestimate mass due possibly to several of the stranded animals in the database having been chronically entangled and in poor body condition. Augmenting the database with healthier individuals, such as harvested North Pacific right whales, yielded mass predictions that reflect both healthy and unhealthy individuals.

Graham, K. M., Burgess, E. A., & Rolland, R. M. (2021). Stress and Reproductive Events Detected in North Atlantic Right Whale Blubber Using a Simplified Hormone Extraction Protocol. *Conservation physiology, 9*(1), coaa133. https://doi.org/10.1093/conphys/coaa133

As studies quantifying steroid hormones in marine mammal blubber progress, methodological refinements may improve the utility and consistency of blubber hormone measurements. This study advances blubber extraction methodologies by testing a simplified extraction protocol that reduces time and complexity compared to a protocol widely used in cetacean blubber studies. Using blubber samples archived from remote biopsy (n = 21 live whales) and necropsy collection (n = 7 dead whales) of North Atlantic right whales (NARW; *Eubalaena glacialis*) of known life history states, we performed analytical and biological validations to assess the feasibility of measuring reproductive (testosterone, progesterone) and glucocorticoid (cortisol) hormones in blubber via enzyme immunoassay following the simplified extraction. Analytical validations (parallelism, accuracy, extraction efficiency, repeatability) showed the simplified extraction produced similar results to the extended protocol, offering a more efficient and consistent technique. In live, apparently healthy whales, blubber testosterone

concentrations (mean +/- SE) were significantly higher in males (2.02 +/- 0.36 ng/g) compared to females (0.81 +/- 0.15 ng/g). Blubber progesterone was highest in a confirmed pregnant female (60.3 ng/g), which was 12-fold greater than the mean concentration of non-pregnant females (4.56 +/- 0.88 ng/g). Blubber cortisol concentrations in whales that died from anthropogenic causes averaged 5.31 +/- 2.28 ng/g, whereas most live, healthy whales had cortisol values below 1 ng/g. Among living whales, a whale actively entangled in fishing gear had the highest blubber cortisol measurement (3.51 ng/g), exhibiting levels similar to whales that died from acute entanglement (2.88 +/- 0.42 ng/g). Overall, the highest blubber cortisol concentration (18.0 ng/g) was measured in a dead whale with a severe chronic entanglement, approximately 30-fold greater than mean blubber cortisol of apparently healthy whales (0.58 +/- 0.11 ng/g). The methodological approach presented here provides a reference for researchers interested in an alternative, streamlined technique for hormone extraction of cetacean blubber and contributes to the diverse tool set for stress and reproductive assessments of endangered NARWs.

Hunt, K. E., Lysiak, N. S., Matthews, C. J. D., Lowe, C., Ajo, A. F., Dillon, D., . . . Buck, C. L. (2018). Multi-Year Patterns in Testosterone, Cortisol and Corticosterone in Baleen from Adult Males of Three Whale Species. *Conservation physiology, 6*(1), coy049. https://doi.org/10.1093/conphys/coy049

Male baleen whales have long been suspected to have annual cycles in testosterone, but due to difficulty in collecting endocrine samples, little direct evidence exists to confirm this hypothesis. Potential influences of stress or adrenal stress hormones (cortisol, corticosterone) on male reproduction have also been difficult to study. Baleen has recently been shown to accumulate steroid hormones during growth, such that a single baleen plate contains a continuous, multi-year retrospective record of the whale's endocrine history. As a preliminary investigation into potential testosterone cyclicity in male whales and influences of stress, we determined patterns in immunoreactive testosterone, two glucocorticoids (cortisol and corticosterone), and stable-isotope (SI) ratios, across the full length of baleen plates from a bowhead whale (*Balaena mysticetus*), a North Atlantic right whale (*Eubalaena glacialis*) and a blue whale (*Balaenoptera musculus*), all adult males. Baleen was subsampled at 2 cm (bowhead, right) or 1 cm (blue) intervals and hormones were extracted from baleen powder with methanol, followed by quantification of all three hormones using enzyme immunoassays validated for baleen extract of these species. Baleen of all three males contained regularly spaced peaks in testosterone content, with number and spacing of testosterone peaks corresponding well to SI data and to species-specific estimates of annual baleen growth rate. Cortisol and corticosterone exhibited some peaks that co-occurred with testosterone peaks, while other glucocorticoid peaks occurred independent of testosterone peaks. The right whale had unusually high glucocorticoids during a period with a known entanglement in fishing gear and a possible disease episode; in the subsequent year, testosterone was unusually low. Further study of baleen testosterone patterns in male whales could help clarify conservation- and management-related questions such as age of sexual maturity, location and season of breeding, and the potential effect of anthropogenic and natural stressors on male testosterone cycles.

Hunt, K. E., Lysiak, N. S., Moore, M., & Rolland, R. M. (2017). Multi-Year Longitudinal Profiles of Cortisol and Corticosterone Recovered from Baleen of North Atlantic Right Whales (*Eubalaena glacialis*). *General and Comparative Endocrinology, 254*, 50-59. https://doi.org/10.1016/j.ygcen.2017.09.009

Research into stress physiology of mysticete whales has been hampered by difficulty in obtaining repeated physiological samples from individuals over time. We investigated whether multi-year

longitudinal records of glucocorticoids can be reconstructed from serial sampling along full-length baleen plates (representing similar to 10 years of baleen growth), using baleen recovered from two female North Atlantic right whales (*Eubalaena glacialis*) of known reproductive history. Cortisol and corticosterone were quantified with immunoassay of subsamples taken every 4 cm (representing similar to 60 d time intervals) along a full-length baleen plate from each female. In both whales, corticosterone was significantly elevated during known pregnancies (inferred from calf sightings and necropsy data) as compared to intercalving intervals; cortisol was significantly elevated during pregnancies in one female but not the other. Within inter calving intervals, corticosterone was significantly elevated during the first year (lactation year) and/or the second year (post-lactation year) as compared to later years of the intercalving interval, while cortisol showed more variable patterns. Cortisol occasionally showed brief high elevations ("spikes") not paralleled by corticosterone, suggesting that the two glucocorticoids might be differentially responsive to certain stressors. Generally, immunoreactive corticosterone was present in higher concentration in baleen than immunoreactive cortisol; corticosterone:cortisol ratio was usually >4 and was highly variable in both individuals. Further investigation of baleen cortisol and corticosterone profiles could prove fruitful for elucidating long-term, multi-year patterns in stress physiology of large whales, determined retrospectively from stranded or archived specimens.

Hunt, K. E., Lysiak, N. S., Robbins, J., Moore, M. J., Seton, R. E., Torres, L., & Buck, C. L. (2017). Multiple Steroid and Thyroid Hormones Detected in Baleen from Eight Whale Species. *Conservation physiology, 5*(1), cox061. https://doi.org/10.1093/conphys/cox061

Recent studies have demonstrated that some hormones are present in baleen powder from bowhead (Balaena mysticetus) and North Atlantic right (*Eubalaena glacialis*) whales. To test the potential generalizability of this technique for studies of stress and reproduction in large whales, we sought to determine whether all major classes of steroid and thyroid hormones are detectable in baleen, and whether these hormones are detectable in other mysticetes. Powdered baleen samples were recovered from single specimens of North Atlantic right, bowhead, blue (*Balaenoptera [B.] musculus*), sei (*B. borealis*), minke (*B. acutorostrata*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*) and gray (*Eschrichtius robustus*) whales. Hormones were extracted with a methanol vortex method, after which we tested all species with commercial enzyme immunoassays (EIAs, Arbor Assays) for progesterone, testosterone, 17 beta-estradiol, cortisol, corticosterone, aldosterone, thyroxine and triiodothyronine, representing a wide array of steroid and thyroid hormones of interest for whale physiology research. In total, 64 parallelism tests (8 species x 8 hormones) were evaluated to verify good binding affinity of the assay antibodies to hormones in baleen. We also tested assay accuracy, although available sample volume limited this test to progesterone, testosterone and cortisol. All tested hormones were detectable in baleen powder of all species, and all assays passed parallelism and accuracy tests. Although only single individuals were tested, the consistent detectability of all hormones in all species indicates that baleen hormone analysis is likely applicable to a broad range of mysticetes, and that the EIA kits tested here perform well with baleen extract. Quantification of hormones in baleen may be a suitable technique with which to explore questions that have historically been difficult to address in large whales, including pregnancy and inter-calving interval, age of sexual maturation, timing and duration of seasonal reproductive cycles, adrenal physiology and metabolic rate.

Ierardi, J. L., Veloso, A., & Mancia, A. (2021). Transcriptome Analysis of Cadmium Exposure in Kidney Fibroblast Cells of the North Atlantic Right Whale (*Eubalaena glacialis*). *Comparative Biochemistry and Physiology C-Toxicology & Pharmacology, 242*, 108946. https://doi.org/10.1016/j.cbpc.2020.108946

An 8X15 k oligonucleotide microarray was developed consisting of 2334 *Eubalaena glacialis* probes and 2166 *Tursiops truncatus* probes and used to measure the effects, at transcriptomic level, of cadmium exposure in right whale kidney fibroblast cells. Cells were exposed to three concentrations (1 mu M, 0.1 mu M, and 0.01 mu M) of cadmium chloride (CdCl2) for three exposure times (1, 4, and 24 h). Cells exposed to 1 mu M CdCl2 for 4 h and 24 h showed upregulated genes involved in protection from metal toxicity and oxidative stress, protein renaturation, apoptosis inhibition, as well as several regulators of cellular processes. Downregulated genes represented a suite of functions including cell proliferation, transcription regulation, actin polymerization, and stress fiber synthesis. The collection of differentially expressed genes in this study support proposed mechanisms of cadmium-induced apoptosis such as ubiquitin proteasome system disruption, Ca2+ homeostasis interference, mitochondrial membrane potential collapse, reactive oxygen species (ROS) production, and cell cycle arrest. The results also have confirmed the right whale microarray as a reproducible tool in measuring differentiated gene expression that could be a valuable asset for transcriptome analysis of other baleen whales and potential health assessment protocols.

Lanyon, J. M., & Burgess, E. A. (2019). Reproductive Science Methods for Wild, Fully-Marine Mammals: Current Approaches and Future Applications. In *Reproductive Sciences in Animal Conservation, 2nd Edition.* P. Comizzoli, J. L. Brown, & W. V. Holt (Eds.), (Vol. 1200, pp. 363-411) https://doi.org/10.1007/978-3-030-23633-5_13

Determining reproductive rates of marine mammal populations can give insight into their persistence and resilience in changing environments. As our marine environments continue to degrade along developed coastal fringes and as mankind's influences extend across even our widest oceans, there is a concern that the reproductive functioning of marine mammals may be affected adversely. Since many marine mammal species and populations are still in the recovery phase post-commercial harvest, and yet others are endangered or threatened by ongoing pressures, further environmental changes may represent direct or indirect threats to their reproductive potential. In this chapter, we review the current methods employed to investigate various aspects of reproductive science in fully-marine mammals, including direct observation of reproductive behavior and output, endocrinology to determine reproductive state, and assisted reproductive technologies to enhance reproductive outcomes. In particular, we focus on the most recent developments and innovations to reproductively sample marine mammals. Two case studies are presented to illustrate the challenges thrown up to researchers studying free-ranging marine mammals, and to highlight diversity in research approach. The North Atlantic right whale is on the brink of extinction through historic overharvest and presentday entanglement and ship strike. Environmental disruption to their migration routes and declining population health has resulted in reduced reproductive rates. In contrast, the main current threats to the reproductive success and survival of the vulnerable dugong are extreme weather events that affect availability of its seagrass diet. Climate disruption with increasingly severe coastal storms and flooding threaten the health of coastal seagrass beds, and consequently reproductive success and survival of this species. It is anticipated that climate change may have diverse and often serious effects on marine mammal reproduction in populations around the globe.

Lee, A. M. (2021). Molecular Aging of North Atlantic Right Whales (*Eubalaena glacialis*). In *Saint Mary's University*.

Knowing the age of individuals within a population provides a wealth of information that is important for understanding aspects of their biology, including many aspects that are important for conservation. Some of these include the relative rates of birth, survival, immigration, and emigration for each age class. This gives useful information for estimating trends over time and estimating extinction probabilities. Cetaceans (whales, dolphins, and porpoises) are challenging to study because they spend the vast majority of their lives below the surface of the water and their habitats are widespread across oceans. Current methods for estimating age in baleen whales are limited. Recent studies have found that methylation patterns associated with certain genes change consistently over time, and therefore provide a "molecular clock" that can be used to estimate the age of individuals. This study investigated whether the agerelated methylation patterns exist at CpG sites in the GRIA2, KLF14, and TET2 genes in North Atlantic right whales (*Eubalaena glacialis*). Specifically, methylation patterns were examined for 40 known-age individuals, representing males and females from throughout the spectrum of known ages, to understand the relationship between CpG methylation and age at these age-related CpG sites. The results showed that the levels of methylation at these sites correspond with the age of the individuals, but that methylation patterns were also influenced by how long the tissue samples were in storage. Therefore, this approach can be used to molecularly estimate age in North Atlantic right whales, but the age of the samples must also be taken into account. Future studies should investigate how methylation patterns degrade and what storage solutions are best to prevent degradation.

Martins, M. C. I., Miller, C., Hamilton, P., Robbins, J., Zitterbart, D. P., & Moore, M. (2020). Respiration Cycle Duration and Seawater Flux through Open Blowholes of Humpback (Megaptera Novaeangliae) and North Atlantic Right (*Eubalaena glacialis*) Whales. *Marine Mammal Science, 36*(4), 1160-1179. https://doi.org/10.1111/mms.12703

Little is known about the dynamics of baleen whale respiratory cycles, especially the mechanics and activity of the blowholes and their interaction with seawater. In this study, the duration of complete respiration cycles (expiration/inhalation events) were quantified for the first time in two species: North Atlantic right whale (NARW) and humpback whale (HW) using high resolution, detailed imagery from an unoccupied aerial system (UAS). The mean duration of complete respiration cycles (expiration/inhalation event) in the NARW and HW were 3.07 s (SD = 0.503, n = 15) and 2.85 s (SD = 0.581, n = 21), respectively. Furthermore, we saw no significant differences in respiration cycle duration between age and sex classes in the NARW, but significant differences were observed between age classes in the HW. The observation of seawater covering an open blowhole was also quantified, with NARW having 20% of all breaths with seawater presence versus 90% in HW. Seawater incursion has not been described previously and challenges the general consensus that water does not enter the respiratory tract in baleen whales. Prevalent seawater has implications for the analysis and interpretation of exhaled respiratory vapor/mucosa samples, as well as for the potential inhalation of oil in spills.

Moore, M. J., Rowles, T. K., Fauquier, D. A., Baker, J. D., Biedron, I., Durban, J. W., . . . Ziccardi, M. H. (2021). Assessing North Atlantic Right Whale Health: Threats, and Development of Tools Critical for Conservation of the Species. *Diseases of Aquatic Organisms, 143*, 205-226. https://doi.org/10.3354/dao03578

Whaling has decimated North Atlantic right whales *Eubalaena glacialis* (NARW) since the 11th century and southern right whales *E. australis* (SRW) since the 19th century. Today, NARWs are Critically Endangered and decreasing, whereas SRWs are recovering. We review NARW health assessment literature, NARW Consortium databases, and efforts and limitations to monitor individual and species health, survival, and fecundity. Photographs are used to track individual movement and external signs of health such as evidence of vessel and entanglement trauma. Post-mortem examinations establish cause of death and determine organ pathology. Photogrammetry is used to assess growth rates and body condition. Samples of blow, skin, blubber, baleen and feces quantify hormones that provide information on stress, reproduction, and nutrition, identify microbiome changes, and assess evidence of infection. We also discuss models of the population consequences of multiple stressors, including the connection between human activities (e.g. entanglement) and health. Lethal and sublethal vessel and entanglement trauma have been identified as major threats to the species. There is a clear and immediate need for expanding trauma reduction measures. Beyond these major concerns, further study is needed to evaluate the impact of other stressors, such as pathogens, microbiome changes, and algal and industrial toxins, on NARW reproductive success and health. Current and new health assessment tools should be developed and used to monitor the effectiveness of management measures and will help determine whether they are sufficient for a substantive species recovery.Y

Radvan, S. N. (2019). Effects of Inbreeding on Fitness in the North Atlantic Right Whale (*Eubalaena glacialis*). In *Saint Mary's University*.

Offspring that are a product of inbreeding often have reduced fitness, known as inbreeding depression. Though our understanding of the impacts of inbreeding depression in wild populations is in its infancy, it is thought that the effects of inbreeding depression are much stronger in the wild than previously suspected. This is due to the cost of inbreeding being higher in wild populations than in captive. The North Atlantic right whale (*Eubalaena glacialis*) is one of the most endangered large whale species and has shown little signs of recovery over the past 70 years. This lack of recovery is due, at least in part, to a reproductive rate that is three-times lower than their known potential. North Atlantic right whales also have extremely low levels of genetic diversity. This project was conducted to assess the degree to which inbreeding could explain the variation seen in the fitness of individuals of this species. Demographic and genetic data measured at 35 microsatellites, made available to us from the North Atlantic Right Whale Consortium, were used to calculate measures of both fitness and inbreeding for individual right whales from 1990-2016. Fitness was measured through the use of the de-lifing method, and the inbreeding coefficient quantified was the internal relatedness calculation. Measures of fitness in survival showed small amounts of variation between years with most individuals surviving. Mean values of fecundity each year showed greater amounts of variation and overall lower levels of fitness. Results from linear regression analyses showed that inbreeding explains little of the variation in both survival and fecundity for this species. This study has provided quantified measures of fitness for each right whale. Further studies should be completed using genomic data to continue examining the potential impacts of inbreeding on fitness in the North Atlantic right whale.

Rolland, R. M., McLellan, W. A., Moore, M. J., Harms, C. A., Burgess, E. A., & Hunt, K. E. (2017). Fecal Glucocorticoids and Anthropogenic Injury and Mortality in North Atlantic Right Whales *Eubalaena glacialis*. *Endangered Species Research, 34*, 417-429. https://doi.org/10.3354/esr00866

As human impacts on marine ecosystems escalate, there is increasing interest in quantifying sub-lethal physiological and pathological responses of marine mammals. Glucocorticoid hormones are commonly used to assess stress responses to anthropogenic factors in wildlife. While obtaining blood samples to measure circulating hormones is not currently feasible for free-swimming large whales, immunoassay of fecal glucocorticoid metabolites (fGCs) has been validated for North Atlantic right whales *Eubalaena glacialis* (NARW). Using a general linear model, we compared fGC concentrations in right whales chronically entangled in fishing gear (n = 6) or live-stranded (n = 1), with right whales quickly killed by vessels (n = 5) and healthy right whales (n = 113) to characterize fGC responses to acute vs. chronic stressors. fGCs in entangled whales (mean +/- SE: 1856.4 +/- 1644.9 ng g(-1)) and the stranded whale (5740.7 ng g(-1)) were significantly higher than in whales killed by vessels (46.2 +/- 19.2 ng g(-1)) and healthy whales (51.7 +/- 8.7 ng g(-1)). Paired feces and serum collected from the live-stranded right whale provided comparison of fGCs in 2 matrices in a chronically stressed whale. Serum cortisol and corticosterone in this whale (50.0 and 29.0 ng ml(-1), respectively) were much higher than values reported in other cetaceans, in concordance with extremely elevated fGCs. Meaningful patterns in fGC concentration related to acute vs. chronic impacts persisted despite potential for bacterial degradation of hormone meta bolites in dead whales. These results provide biological validation for using fGCs as a biomarker of chronic stress in NARWs.

Shinn, H., & Riley, T. (2018). *Health Assessments of North Atlantic Right Whales.* https://doi.org/10.25923/kvch-s167

A working group as part of the Office of Protected Resources within NOAA Fisheries is striving to improve its knowledge of North Atlantic right whale (NARW) health to advance species recovery. The NARW is an endangered species protected under the Endangered Species Act. To that end, this bibliography was developed to give a comprehensive overview of literature related to NARW health indicators and the types of health assessments being done with other marine mammals.

Springate, L. D. (2017). Gamete Compatibility and Reproductive Success in the North Atlantic Right Whale. In *Saint Mary's University*. Halifax, Nova Scotia. Retrieved from http://library2.smu.ca/handle/01/27153

The goal of this project was to assess the influence that genetic characteristics at gamete compatibility genes have on the reduced reproductive rates in the endangered North Atlantic right whale. To do this candidate genes were identified that play a role in fertilization, and primers were developed for the amplification of the putative functional sites of these genes. Mother-father-calf triads were sequenced to test for non-random mating patterns and non-Mendelian inheritance patterns, which would be indicative of mate choice and/or biased fertilization based on the characteristics of these genes. Overall there was low variability across individuals, but a slight bias in mate choice for mates with similar genotypes within loci, but differing across loci. One locus also showed signs of biased fertilization patterns, with successful fertilizations resulting when offspring inherit the same allele from both parents.

Stewart, J. D., Durban, J. W., Knowlton, A. R., Lynn, M. S., Fearnbach, H., Barbaro, J., . . . Moore, M. J. (2021). Decreasing Body Lengths in North Atlantic Right Whales. *Current Biology*. https://doi.org/10.1016/j.cub.2021.04.067

Whales are now largely protected from direct harvest, leading to partial recoveries in many previously depleted species. However, most populations remain far below their historical abundances and incidental human impacts, especially vessel strikes and entanglement in fishing gear, are increasingly recognized as key threats. In addition, climate-driven changes to prey dynamics are impacting the seasonal foraging grounds of many baleen whales. In many cases these impacts result directly in mortality. But it is less clear how widespread and increasing sub-lethal impacts are affecting life history, individual fitness, and population viability. We evaluated changes in body lengths of North Atlantic right whales (NARW) using aerial photogrammetry measurements collected from crewed aircraft and remotely operated drones over a 20-year period (Figure 1). NARW have been monitored consistently since the 1980s and have been declining in abundance since 2011 due primarily to deaths associated with entanglements in active fishing gear and vessel strikes. High rates of sub-lethal injuries and individual-level information on age, size and observed entanglements make this an ideal population to evaluate the effects that these widespread stressors may have on individual fitness. We find that entanglements in fishing gear are associated with shorter whales, and that body lengths have been decreasing since 1981. Arrested growth may lead to reduced reproductive success and increased probability of lethal gear entanglements. These results show that sub-lethal stressors threaten the recoveries of vulnerable whale populations even in the absence of direct harvest.

Werth, A. J., Blakeney, S. M., & Cothren, A. I. (2019). Oil Adsorption Does Not Structurally or Functionally Alter Whale Baleen. *Royal Society Open Science, 6*(5), 182194. https://doi.org/10.1098/rsos.182194

Mysticete whales filter small prey from seawater using baleen, a unique keratinous oral tissue that grows from the palate, from which it hangs in hundreds of serial plates. Laboratory experiments testing effects of oils on material strength and flexibility, particle capture and tissue architecture of baleen from four mysticete species (bowhead, *Balaena mysticetus*; North Atlantic right, *Eubalaena glacialis*; fin, *Balaenoptera physalus*; humpback, *Megaptera novaeangliae*) indicate that baleen is hydrophilic and oleophobic, shedding rather than adsorbing oil. Oils of different weights and viscosities were tested, including six petroleum-based oils and two fish or plankton oils of common whale prey. No notable differences were found by oil type or whale species. Baleen did not adsorb oil; oil was readily rinsed from baleen by flowing water, especially from moving fringes. Microscopic examination shows minimal wrinkling or peeling of baleen's cortical keratin layers, probably due to oil repelling infiltrated water. Combined results cast doubt on fears of baleen fouling by oil; filter porosity is not appreciably affected, but oil ingestion risks remain. Particle capture studies suggest potentially greater danger to mysticetes from plastic pollution than oil.

Section II: Ecology

Asaro, M. J. (2017). Managing the Impacts of Commercial Fisheries on the Endangered North Atlantic Right Whale: A Social-Ecological Systems Approach. In *Northeastern University*: Northeastern University. Retrieved from http://hdl.handle.net/2047/D20240477

This dissertation is a social-ecological systems analysis of the federal policy framework in place in the U.S. under the Marine Mammal Protection Act to reduce human-caused mortality of the endangered North Atlantic right whale (*Eubalaena glacialis*) resulting from entanglement in commercial fishing gear. Right whales are among the rarest large whales in the world, having first been hunted to near extinction and now facing a number of human-caused threats. This research consists of three complementary parts that aim to gain a systems-oriented understanding of the past, present, and future of right whale conservation and management under the Marine Mammal Protection Act. This dissertation utilizes a social-ecological systems theoretical framework and draws conclusions on both the theory and its practical application to right whale conservation.

Baumgartner, M. F., Bonnell, J., Corkeron, P. J., Van Parijs, S. M., Hotchkin, C., Hodges, B., . . . Bruner, S. M. (2020). Slocum Gliders Provide Accurate near Real-Time Estimates of Baleen Whale Presence from Human-Reviewed Passive Acoustic Detection Information. *Frontiers in Marine Science, 7*. https://doi.org/10.3389/fmars.2020.00100

Mitigating the effects of human activities on marine mammals often depends on monitoring animal occurrence over long time scales, large spatial scales, and in real time. Passive acoustics, particularly from autonomous vehicles, is a promising approach to meeting this need. We have previously developed the capability to record, detect, classify, and transmit to shore information about the tonal sounds of baleen whales in near real time from long-endurance ocean gliders. We have recently developed a protocol by which a human analyst reviews this information to determine the presence of marine mammals, and the results of this review are automatically posted to a publicly accessible website, sent directly to interested parties via email or text, and made available to stakeholders via a number of public and private digital applications. We evaluated the performance of this system during two 3.75-month Slocum glider deployments in the southwestern Gulf of Maine during the spring seasons of 2015 and 2016. Near real-time detections of humpback, fin, sei, and North Atlantic right whales were compared to detections of these species from simultaneously recorded audio. Data from another 2016 glider deployment in the same area were also used to compare results between three different analysts to determine repeatability of results both among and within analysts. False detection (occurrence) rates on daily time scales were 0% for all species. Daily missed detection rates ranged from 17 to 24%. Agreement between two trained novice analysts and an experienced analyst was greater than 95% for fin, sei, and right whales, while agreement was 83-89% for humpback whales owing to the more subjective process for detecting this species. Our results indicate that the presence of baleen whales can be accurately determined using information about tonal sounds transmitted in near real-time from Slocum gliders. The system is being used operationally to monitor baleen whales in United States, Canadian, and Chilean waters, and has been particularly useful for monitoring the critically endangered North Atlantic right whale throughout the northwestern Atlantic Ocean.

Baumgartner, M. F., Wenzel, F. W., Lysiak, N. S. J., & Patrician, M. R. (2017). North Atlantic Right Whale Foraging Ecology and Its Role in Human-Caused Mortality. *Marine Ecology Progress Series, 581*, 165-181. https://doi.org/10.3354/meps12315

Endangered North Atlantic right whales *Eubalaena glacialis* suffer from unacceptably high rates of ship strikes and fishing gear entanglements, but little is known of the role that diving and foraging behavior plays in mediating human-caused mortality. We conducted a study of right whale foraging ecology by attaching tags to whales for short periods of time (hours), tracking their movements during daytime, and repeatedly sampling oceanographic conditions and prey distribution along the whales' tracks. Right whales were tagged from late winter to late fall in 6 regions of the Gulf of Maine and southwestern Scotian Shelf from 2000 to 2010. The diving behavior of the tagged whales was governed by the vertical distribution of their primary prey, the copepod *Calanus finmarchicus*. On average, right whales tagged during spring spent 72% of their time in the upper 10 m (within the draft of most large commercial vessels), indicating the need for expanded ship speed restrictions in western Gulf of Maine springtime habitats. One out of every 4 whales dove to within 5 m of the sea floor during the short time they were tagged, spending as much as 45% of their total tagged time in this depth stratum. Right whales dove to the sea floor in each habitat studied except for one (where only 1 whale was tagged). This relatively high incidence of near-bottom diving raises serious concerns about the continued use of floating ground lines in pot and trap gear in coastal Maine and Canadian waters.

Brennan, C. E., Maps, F., Gentleman, W. C., Plourde, S., Lavoie, D., Chasse, J., . . . Johnson, C. L. (2019). How Transport Shapes Copepod Distributions in Relation to Whale Feeding Habitat: Demonstration of a New Modelling Framework. *Progress in Oceanography, 171*, 1-21. https://doi.org/10.1016/j.pocean.2018.12.005

Two copepod species, *Calanus finmarchicus* and *Colossus hyperboreus*, constitute the main prey of endangered North Atlantic right whales in eastern Canadian shelf waters. Estimating the spatial distribution of Calanus spp. and understanding how it changes in response to environmental variability are crucial information requirements for mitigating risks to the right whale population. Here we present a new coupled dynamic model that builds on observations from the Atlantic Zone Monitoring Program (AZMP) and statistical modelling of copepod spatial distributions using Generalized Additive Models (GAMs). The coupled model is initialized with the GAMs climatological abundance and explicitly represents transport of the two species *C. finmarchicus* and *C. hyperboreus* via particle tracking, considering Calanus vertical swimming behavior and along-track mortality and temperature-dependent development. Assessment of model performance and the role of advection in determining the modelled Calanus distributions is focused on the southern Gulf of St. Lawrence (sGSL), an area regularly visited by right whales, and where local Calanus abundance is likely dependent on the seasonal transport from deep upstream areas. The coupled model simulates high Colossus abundance in the sGSL in summer and fall, distinct from the spatial distribution estimated by GAMs, which do not consider the effect of transport in the region. The exercise of building and testing this model allows us to investigate the factors producing high concentrations of late stage Colossus, and in the cases of model-data mismatch, infer important processes that are not adequately represented in the model. The model constitutes an important step forward in the ongoing effort to improve estimates of Colossus availability in the region, guiding future modelling efforts (e.g., a population development model) and potentially informing North Atlantic right whale management.

Charif, R. A., Shiu, Y., Muirhead, C. A., Clark, C. W., Parks, S. E., & Rice, A. N. (2020). Phenological Changes in North Atlantic Right Whale Habitat Use in Massachusetts Bay. *Global Change Biology, 26*(2), 734-745. https://doi.org/10.1111/gcb.14867

The North Atlantic right whale (*Eubalaena glacialis*) is one of the world's most highly endangered baleen whales, with approximately 400-450 individuals remaining. Massachusetts Bay (MB) and Cape Cod Bay (CCB) together comprise one of seven areas in the Gulf of Maine where right whales seasonally congregate. Here, we report on acoustically detected presence of right whales in MB over a nearly 6 year period, July 2007-April 2013, a time of both rapid ocean warming throughout the Gulf of Maine and apparent changes in right whale migratory dynamics. We applied an automated detection algorithm to assess hourly presence of right whale "up-calls" in recordings from a 19-channel acoustic array covering approximately 4,000 km(2) in MB. Over the survey, up-calls were detected in 95% of 8 day periods. In each year, as expected, we observed a "peak season" of elevated up-call detections in late winter and early spring corresponding to the season when right whales congregate to feed in CCB. However, we also saw an increase in right whale occurrence during time periods thought to be part of the "off-season." With the exception of 2009-2010, when acoustic presence was unusually low, the mean percent of hours in which up-calls were detected increased every year, both during the peak season (from 38% in 2008 to 70% in 2012), and during the summer-fall season (from 2% in 2007 to 13% in 2012). Over the entire study, the peak season start date varied between 17 January and 26 February. Changes in right whale phenology in MB likely reflect broadscale changes in habitat use in other areas within the species range. This study demonstrates the value of continuous long-term survey datasets to detect and quantify shifts in cetacean habitat use as environmental conditions change and the long-term continued survival of right whales remains uncertain.

Cronin, T. W., Fasick, J. I., Schweikert, L. E., Johnsen, S., Kezmoh, L. J., & Baumgartner, M. F. (2017). Coping with Copepods: Do Right Whales (*Eubalaena glacialis*) Forage Visually in Dark Waters? *Philosophical Transactions of the Royal Society B-Biological Sciences, 372*(1717). https://doi.org/10.1098/rstb.2016.0067

North Atlantic right whales (*Eubalaena glacialis*) feed during the spring and early summer in marine waters off the northeast coast of North America. Their food primarily consists of planktonic copepods, *Calanus finmarchicus*, which they consume in large numbers by ram filter feeding. The coastal waters where these whales forage are turbid, but they successfully locate copepod swarms during the day at depths exceeding 100 m, where light is very dim and copepod patches may be difficult to see. Using models of *E. glacialis* visual sensitivity together with measurements of light in waters near Cape Cod where they feed and of light attenuation by living copepods in seawater, we evaluated the potential for visual foraging by these whales. Our results suggest that vision may be useful for finding copepod patches, particularly if *E. glacialis* searches overhead for silhouetted masses or layers of copepods. This should permit the whales to locate *C. finmarchicus* visually throughout most daylight hours at depths throughout their foraging range. Looking laterally, the whales might also be able to see copepod patches at short range near the surface. This article is part of the themed issue 'Vision in dim light'.

Cusano, D. A., Conger, L. A., Van Parijs, S. M., & Parks, S. E. (2019). Implementing Conservation Measures for the North Atlantic Right Whale: Considering the Behavioral Ontogeny of Mother-Calf Pairs. *Animal Conservation, 22*(3), 228-237. https://doi.org/10.1111/acv.12457

Understanding the behavioral ecology of a species is fundamental to effective conservation and management efforts. This study quantifies the behavioral ontogeny of North Atlantic right whale mother-calf pairs from birth to weaning spanning three critical habitat areas off the eastern coast of the United States and Canada. Data from 55 focal follows of 34 mother-calf pairs were collected from 2011 to 2015. Resting behaviors dominated the activity budgets for both mother and calf during the first 5 months, putting them at increased risk of vessel collisions. There was an increase in the proportion of active behaviors (travel, foraging, social activity) in both mother and calf as the calf matured. Importantly, the type of active behaviors, in particular surface skim feeding and surface active social behavior, meant that the risk of vessel collision to the pair did not decrease as the calf matured. Mother-calf right whale pairs showed very low calling rates on the calving grounds, suggesting that passive acoustic monitoring may not be an effective mitigation tool during the early months. However, calling rates increase once the pair leave the calving areas with both calf age and activity levels increasing, at which point passive acoustic monitoring becomes valuable. Protective measures need to take these rapid developmental changes throughout calf growth into account to improve the efficacy of protection measures for the endangered North Atlantic right whale and other species where behavioral ecology changes rapidly during maturation.

Davies, K. (2020). *Foraging Habitat Associations of North Atlantic Right Whales (Eubalaena glacialis) Measured Using Ocean Gliders.* Paper presented at the Ocean Sciences Meeting 2020.

North Atlantic right whales (*Eubalaena glacialis*) migrate seasonally into several temperate North Atlantic habitats to feed on dense aggregations of planktonic copepods. Recently a previously unknown foraging area was discovered within the Gulf of St. Lawrence (GSL), a body of water that lies several hundred kilometers north of the known right whale foraging range. Key feeding habitat characteristics, such as dominant prey species, water mass hydrography and tidal current amplitude, appear strikingly different in the GSL relative to other described habitats. This study is the first description of regional environmental associations of right whales in the newly discovered habitat. Between 2016 and 2018 profiling gliders were equipped with hydrophones and conductivity-temperature-depth sensors and deployed continuously between 2 and 6 months per year to measure physical habitat associations of right whales in the GSL. Binary multivariate regression models were applied to these data to explain right whale acoustic presenceabsence as a function of variables describing water mass characteristics. Preliminary models containing the main effects of temperature, salinity and stratification were selected over a null model containing only static explanatory variables such as bathymetric depth. This demonstrates that dynamic oceanographic processes are important for explaining regional right whale occurrence. The odds of acoustically detecting a right whale each day were twenty times higher in stratified summer conditions than well-mixed conditions typical of the windy autumn period, suggesting a preference for certain seasonally-varying physical processes that affect prey energy density and availability. After accounting for the seasonal effect, right whales were ten times less likely to be detected in warm, fresh water that signifies the regional coastal current, suggesting that right whales target offshore species of copepods such as Calanus spp., as opposed to coastal species, in this habitat. This study identifies key spatiotemporal constraints on right whale occurrence and demonstrates the use of gliders as tools to study whale-habitat associations.

Davies, K. T. A., Brown, M. W., Hamilton, P. K., Knowlton, A. R., Taggart, C. T., & Vanderlaan, A. S. M. (2019). Variation in North Atlantic Right Whale *Eubalaena glacialis* Occurrence in the Bay of Fundy, Canada, over Three Decades. *Endangered Species Research, 39*, 159-171. https://doi.org/10.3354/esr00951

North Atlantic right whales *Eubalaena glacialis* (hereafter right whales) have recently shifted their distribution away from some protected feeding habitats, which suggests large-scale changes in food supply have occurred. Quantifying the nature and extent of the apparent shift is key to exploring this hypothesis and planning or revising conservation strategies. This paper characterizes decadal right whale occurrence in the Bay of Fundy summer feeding habitat using data derived from 7522 h of survey effort collected over 30 yr (1987 to 2016) that yielded 11483 right whale sightings. Eight occurrence descriptors were derived to quantify temporal variation in right whale presence, encounter rates and time of arrival in the Bay. Time of arrival was modeled using linear and power function models fit to annual discovery curves. Principal component analysis showed 2 modes that explained 58 and 14 % of the variation in occurrence, respectively. The first mode captured a significant decline in summertime right whale occurrence beginning in 2010. The second mode captured a decadal-scale cycle in seasonal timing of occurrence, which highlighted a sharp change from early to late occupancy at the turn of the millennium. Annual occurrence during the 2010-2016 period was anomalously low in both the Grand Manan Basin critical habitat and the Bay of Fundy Traffic Separation Scheme (shipping lanes), whereas encounters in the region NW of the critical habitat containing Owen Basin and The Wolves islands may be increasing due to a distributional shift within the Bay. We discuss the consequences of these changes for both population dynamics and future conservation of the species.

Davis, G. E., Baumgartner, M. F., Bonnell, J. M., Bell, J., Berchok, C., Thornton, J. B., . . . Van Parijs, S. M. (2017). Long-Term Passive Acoustic Recordings Track the Changing Distribution of North Atlantic Right Whales (*Eubalaena glacialis*) from 2004 to 2014. *Scientific Reports, 7*(1), 13460. https://doi.org/10.1038/s41598-017-13359-3

Given new distribution patterns of the endangered North Atlantic right whale (NARW; *Eubalaena glacialis*) population in recent years, an improved understanding of spatio-temporal movements are imperative for the conservation of this species. While so far visual data have provided most information on NARW movements, passive acoustic monitoring (PAM) was used in this study in order to better capture year-round NARW presence. This project used PAM data from 2004 to 2014 collected by 19 organizations throughout the western North Atlantic Ocean. Overall, data from 324 recorders (35,600 days) were processed and analyzed using a classification and detection system. Results highlight almost year-round habitat use of the western North Atlantic Ocean, with a decrease in detections in waters off Cape Hatteras, North Carolina in summer and fall. Data collected post 2010 showed an increased NARW presence in the mid-Atlantic region and a simultaneous decrease in the northern Gulf of Maine. In addition, NARWs were widely distributed across most regions throughout winter months. This study demonstrates that a large-scale analysis of PAM data provides significant value to understanding and tracking shifts in large whale movements over long time scales.

Davis, G. E., Baumgartner, M. F., Corkeron, P. J., Bell, J., Berchok, C., Bonnell, J. M., . . . Van Parijs, S. M. (2020). Exploring Movement Patterns and Changing Distributions of Baleen Whales in the Western North Atlantic Using a Decade of Passive Acoustic Data. *Global Change Biology, 26*(9), 4812-4840. https://doi.org/10.1111/gcb.15191

Six baleen whale species are found in the temperate western North Atlantic Ocean, with limited information existing on the distribution and movement patterns for most. There is mounting evidence of distributional shifts in many species, including marine mammals, likely because of climate-driven changes in ocean temperature and circulation. Previous acoustic studies examined the occurrence of minke (*Balaenoptera acutorostrata*) and North Atlantic right whales (NARW;*Eubalaena glacialis*). This study assesses the acoustic presence of humpback (*Megaptera novaeangliae*), sei (*B. borealis*), fin (*B. physalus*), and blue whales (*B. musculus*) over a decade, based on daily detections of their vocalizations. Data collected from 2004 to 2014 on 281 bottom-mounted recorders, totaling 35,033 days, were processed using automated detection software and screened for each species' presence. A published study on NARW acoustics revealed significant changes in occurrence patterns between the periods of 2004-2010 and 2011-2014; therefore, these same time periods were examined here. All four species were present from the Southeast United States to Greenland; humpback whales were also present in the Caribbean. All species occurred throughout all regions in the winter, suggesting that baleen whales are widely distributed during these months. Each of the species showed significant changes in acoustic occurrence after 2010. Similar to NARWs, sei whales had higher acoustic occurrence in mid-Atlantic regions after 2010. Fin, blue, and sei whales were more frequently detected in the northern latitudes of the study area after 2010. Despite this general northward shift, all four species were detected less on the Scotian Shelf area after 2010, matching documented shifts in prey availability in this region. A decade of acoustic observations have shown important distributional changes over the range of baleen whales, mirroring known climatic shifts and identifying new habitats that will require further protection from anthropogenic threats like fixed fishing gear, shipping, and noise pollution.

Dombroski, J. R. G., Parks, S. E., & Nowacek, D. P. (2021). Dive Behavior of North Atlantic Right Whales on the Calving Ground in the Southeast USA: Implications for Conservation. *Endangered Species Research*. https://doi.org/10.3354/esr01141

The North Atlantic right whale *Eubalaena glacialis* is a critically endangered whale whose habitat overlaps with areas of high human use. On feeding grounds, aspects of this species' behavior increase the whales' vulnerability to anthropogenic threats such as entanglement in fishing gear and vessel strikes. On the calving ground, natural dive behavior and the implications for conservation efforts in this species remain to be evaluated. In this study, we used 102.17 h of tag data collected over 15 deployments of archival tags on 14 individuals to describe the dive behavior of right whales in the Southeast USA. Lactating females spent up to 80% of the time at depths ≤3.5 m, leading to increased risk of vessel strike compared to other whale groups that spent a maximum of 30% of the time at those depths in this habitat. Non-lactating whales had significantly deeper maximum dive depths (12.1 m) than lactating females (7.3 m) and spent more time in the bottom phase of dives, closer to the sea floor (45 vs. 37% of the dive duration, respectively). Time spent closer to the sea floor increases the probability of interaction with fishing gear. Therefore, these dive data are useful to justify seasonal closures of fishing activity on the calving ground to protect both lactating and non-lactating whales. Opportunistic comparisons revealed that diel period, calf presence and age affect dive behavior of right whales. In the face of the impacts of human-caused mortality on right whale populations, these results will aid vessel strike and entanglement risk assessment on the Southeast USA calving ground.

Durette-Morin, D. (2021). Measuring the Distribution of North Atlantic Right Whales (*Eubalaena glacialis*) across Multiple Scales from Their Vocalizations: Applications for Ecology and Management. In *Dalhousie University*. Retrieved from http://hdl.handle.net/10222/80343

The objective of this thesis was to assess the distribution of North Atlantic right whales, *Eubalaena glacialis* (NARW), in Canadian waters using passive acoustic monitoring (PAM) technology at daily to seasonal time-scales, and over sub-regional to continentalshelf spatial-scales, to help advance their conservation. Using a network of PAM platforms, I estimated the quasi-synoptic NARW distribution from the Bay of Fundy to the Labrador Sea, revealing that the current geographic distribution of the species may be constrained to temperate-subarctic latitudinal ranges. In a performance study, I identified the strengths and weaknesses of acoustic gliders equipped with a real-time PAM system as a tool to inform dynamic fishery management designed to minimize NARW entanglements in the Gulf of St Lawrence. Overall, my thesis provides critical information needed to implement PAM in decision-making to mitigate human caused risks to NARWs as well as improve Canada's ability to economically and sustainably monitor the species.

Durette-Morin, D., Davies, K. T. A., Johnson, H. D., Brown, M. W., Moors-Murphy, H., Martin, B., & Taggart, C. T. (2019). Passive Acoustic Monitoring Predicts Daily Variation in North Atlantic Right Whale Presence and Relative Abundance in Roseway Basin, Canada. *Marine Mammal Science, 35*(4), 1280-1303. https://doi.org/10.1111/mms.12602

North Atlantic right whale monitoring in Roseway Basin, Canada, is primarily based on short-term (<14 d) visual surveys conducted during August-September. Variability in survey effort has been the biggest limiting factor to studying changes in the population's occurrence and habitat use. Such efforts could be enhanced considerably using passive acoustic monitoring (PAM). We sought to determine if variation in whale presence, relative abundance, demography, and/or behavior (estimated through visual surveys) could be explained by variation in three right whale call types in this habitat. A generalized linear model was fit to 23 d of concurrent PAM and visual monitoring during four summers within the Roseway Basin Right Whale Critical Habitat boundaries. The model revealed significant positive relationships between relative abundance, call counts and presence of surface-active group behavior. PAM can refine daily right whale presence estimates. While visual observations (n = 23 d) implied a 40% decline in right whale presence during 2014-2015 relative to 2004-2005, PAM data (n = 211 d) showed right whales were present between 71%-85% of survey days throughout all years analyzed. We demonstrate that PAM is a useful tool to extend periods of right whale monitoring, especially in areas where visual monitoring efforts may be limited.

Esfahanian, M., Erdol, N., Gerstein, E., & Zhuang, H. Q. (2017). Two-Stage Detection of North Atlantic Right Whale Upcalls Using Local Binary Patterns and Machine Learning Algorithms. *Applied Acoustics, 120*, 158-166. https://doi.org/10.1016/j.apacoust.2017.01.025

In this paper, we investigate the effectiveness of two-stage classification strategies in detecting north Atlantic right whale upcalls. Time-frequency measurements of data from passive acoustic monitoring devices are evaluated as images. Vocalization spectrograms are preprocessed for noise reduction and tone removal. First stage of the algorithm eliminates non-upcalls by an energy detection algorithm. In the second stage, two sets of features are extracted from the remaining signals using contour-based.and texture based methods. The former is based on-extraction of time-frequency features from upcall

contours, and the latter employs a Local Binary Pattern operator to extract distinguishing texture features of the upcalls. Subsequently evaluation phase is carried out by using several classifiers to assess the effectiveness of both the contour-based and texture-based features for upcall detection. Comparing ROC curves of machine learning algorithms obtained from Cornell University's dataset reveals that LBP features improved performance accuracy up to 43% over time-frequency features. Classifiers such as the Linear Discriminant Analysis, Support Vector Machine, and TreeBagger achieve highest upcall detection rates with LBP features.(C) 2017 Elsevier Ltd. All rights reserved.

Fasick, J. I., Baumgartner, M. F., Cronin, T. W., Nickle, B., & Kezmoh, L. J. (2017). Visual Predation During Springtime Foraging of the North Atlantic Right Whale (*Eubalaena glacialis*). *Marine Mammal Science, 33*(4), 991-1013. https://doi.org/10.1111/mms.12417

To assess the role that vision plays in the ability of the North Atlantic right whale (*Eubalaena glacialis*) to detect its primary prey species, the calanoid copepod *Calanus finmarchicus*, we have compared the absorbance spectrum of the *E. glacialis* rod visual pigment, the transmittance spectra of *C. finmarchicus* carotenoid pigments, as well as the downwelling irradiance and horizontal radiance spectra collected during springtime at three locations in the western Gulf of Maine. The *E. glacialis* rod visual pigment absorbs light maximally at 493 nm, while microspectrophotometric measurements of the *C. finmarchicus* carotenoid pigments reveal transmission spectra with minima matching very well with the *E. glacialis* rod visual pigment absorbance spectra maximum. Springtime spectral downwelling irradiance and horizontal radiance values from the surface waters of Cape Cod Bay and at all depths in Great South Channel overlap the *E. glacialis* rod absorbance spectrum, allowing *C. finmarchicus* to appear as a high-contrast dark silhouette against a bright background spacelight, thus facilitating visually guided contrast foraging. In contrast, spectral downwelling irradiance and horizontal radiance at depth in Cape Cod Bay, and all depths in Wilkinson Basin, do not overlap the *E. glacialis* rod absorbance spectrum, providing little if any useful light for contrast vision.

Gavrilchuk, K., Lesage, V., Fortune, S., Trites, A. W., & Plourde, S. (2020). *A Mechanistic Approach to Predicting Suitable Foraging Habitat for Reproductively Mature North Atlantic Right Whales in the Gulf of St. Lawrence.* Fisheries and Oceans Canada Ottawa.

The North Atlantic right whale (*Eubalaena glacialis*, NARW) is an endangered cetacean which faces population decline from anthropogenic activities. Climate change may also be adding pressure on population recovery by shifting distribution of their preferred prey, Calanus copepods. The Gulf of St. Lawrence (GSL) in eastern Canada has been used as a foraging ground by a large proportion of the NARW population in recent years (at least from 2015 to present). Given the motivation to better understand NARW contemporary habitat use patterns and propose recovery measures for this population, we used a mechanistic modeling approach to predict areas that hold foraging potential in the GSL. We first assessed the overall annual energetic costs incurred by an adult female NARW in one of three reproductive states, and determined the theoretical prey densities required to sustain energy demand. We used a 12-year data set describing the abundance and three-dimensional distribution of late-stage Calanus copepods in the GSL coupled to a foraging bioenergetics model to identify potentially suitable foraging areas for NARW. Results show interannual variations in the spatial distribution and quantity of suitable habitat, with a decreasing amount of habitat available for resting, pregnant and lactating females, respectively. Suitable prey densities for foraging NARW were found in nearly all areas

of the GSL that were surveyed for copepods, in one year or another, with a greater frequency of suitable prey densities identified in the southern GSL.

Gavrilchuk, K., Lesage, V., Fortune, S. M. E., Trites, A. W., & Plourde, S. (2021). Foraging Habitat of North Atlantic Right Whales Has Declined in the Gulf of St. Lawrence, Canada, and May Be Insufficient for Successful Reproduction. *Endangered Species Research, 44*, 113-136. https://doi.org/10.3354/esr01097

Climate-induced changes in calanoid copepod (Calanus spp.) availability in traditional feeding areas might explain why a large proportion of the North Atlantic right whale *Eubalaena glacialis* population has fed in the Gulf of St. Lawrence (Canada) in recent years. However, little is known about the distribution of copepods in the gulf, and whether their abundance is sufficient to energetically sustain right whales. We used a mechanistic modelling approach to predict areas within the gulf that have foraging potential for adult female right whales, based on the annual energetic needs of resting, pregnant and lactating females, and their theoretical prey density requirements. We identified suitable foraging areas for right whales by coupling a foraging bioenergetics model with a 12 yr data set (2006-2017) describing the abundance and 3-dimensional distribution of late-stage Calanus spp. in the gulf. Prey densities in the southern gulf (from Shediac Valley to the Magdalen Islands) supported all 3 reproductive states in most (>= 6) years. However, foraging habitat became progressively sparse in the southern gulf over time, with noticeably less suitable habitat available after 2014. Few other potentially suitable foraging areas were identified elsewhere in the gulf. Overall, the availability of foraging habitat in the gulf varied considerably between years, and was higher for resting females than for pregnant and lactating females. Our findings are consistent with the recent low calving rates, and indicate that prey bio-mass in the Gulf of St. Lawrence may be insufficient in most years to support successful reproduction of North Atlantic right whales.

Gerstein, E. R., Trygonis, V., & Moir, J. (2017). Vocal Behavior and Ontogeny of Northern Right Whales in the Southeast Critical Habitat. *The Journal of the Acoustical Society of America, 141*(5), 4002-4002. https://doi.org/10.1121/1.4989179

North Atlantic right whales are one of the most endangered of the great whales. A remnant population of ~500 inhabits the eastern seaboard of North America. A small fraction (2%) travels south to their critical calving habitat along the Florida and Georgia coast. By late November and through the winter, right whales give birth and nurse their calves in these shallow waters before departing in early spring to their northern habitats. In the southeast critical habitat mother-calf pairs remain generally isolated from other whales, presenting a unique platform to study vocal development and learning in large whales. Using small boats, GPS-instrumented, free-drifting autonomous acoustic buoys were deployed in close proximity to 44 photo-identified mother-calf pairs over 7 calving seasons. Surface video and synchronized underwater recordings documented their social and vocal behavior. With the exception of some low-energy gunshot sounds, mothers, and their calves, remained predominantly silent during the first 4 weeks. This might be due to calf maturation, and or a strategy to avoid harassment by other whales or potential predators. Over 100 calls have been analyzed from 15 different calves. Some of these calves were resampled at different stages at <1 week up to 12 weeks of age. Evidence of individual and age-related variance and changes in call structure, complexity, power, rates, as well as vocal mimicry are presented.

Gervaise, C., Simard, Y., Aulanier, F., & Roy, N. (2021). Optimizing Passive Acoustic Systems for Marine Mammal Detection and Localization: Application to Real-Time Monitoring North Atlantic Right Whales in Gulf of St. Lawrence. *Applied Acoustics, 178*. https://doi.org/10.1016/j.apacoust.2021.107949

This study addresses the problem of determining optimal design of passive acoustic monitoring (PAM) systems for detecting and localizing whale calls in real-time in variable-noise environments. The performance of various PAM system is assessed using the detection theory and simulation modeling applied to the context of North Atlantic right whale (NARW) upcalls in feeding grounds and noisy shipping corridor of the Gulf of St. Lawrence. Realistic simulations are performed using an estimated NARW upcall source level (SL), the actual shipping traffic, measured local fleet ship SLs, and transmission loss (TL) from a regional 2.5-D propagation model accounting for the bathymetric and environmental structures. The comparisons consider single-hydrophone and hydrophone-array PAM systems, mounted on buoys, gliders, or cabled to shore and three families of NARW upcall detectors. The targeted performance is a low false-alarm rate of 1 per day and a detection probability > 0.5. The time-frequency-based detector offers the best trade-off between detection performance and robustness against NARW upcall variability. The effective detection ranges are similar to 15 times lower with single-hydrophone systems compared to hydrophone-arrays, whose beamforming enhances the signal in the upcall direction while damping interfering discrete noise from nearby transiting ships in other directions. Detecting and localizing NARWs in the large target areas (>10000-km(2) scale) is possible with a few well-located arrays of 10-20 hydrophones, which appears as the optimal cost/performance trade-off.

Gomez, C., Konrad, C. M., Vanderlaan, A., Moors-Murphy, H. B., Marotte, E., Lawson, J. W., . . . Buren, A. (2020). *Identifying Priority Areas to Enhance Monitoring of Cetaceans in the Northwest Atlantic Ocean.* Fisheries and Oceans Canada Ottawa. Retrieved from https://open.canada.ca/data/en/dataset/c094782e-0d6f-4cc0-b5a3-58908493a433

Species Distribution Models (SDM) were used to predict seasonal suitable habitat of cetaceans during spring (2 species), summer (10 species), and autumn (7 species) in eastern Canadian waters off Nova Scotia, and Newfoundland and Labrador. Available cetacean sightings data from 1975-2015 was compiled from the Department of Fisheries and Oceans Canada (DFO), the Ocean Biogeographic Information System (OBIS), the North Atlantic Right Whale Consortium (NARWC), the Whitehead Lab at Dalhousie University, and the Environment and Climate Change Canada (Canadian Wildlife Service) Eastern Canada Seabirds at Sea (ECSAS) program. As proxies for prey availability, we selected five predictor environmental variables for our SDM: ocean depth, compound topographic index, sea surface temperature, areas of persistently high chlorophyll-a concentration, and regional chlorophyll-a magnitude. Habitats with high suitability in this report are interpreted as areas where cetacean monitoring efforts may be prioritized, and results can help direct future survey efforts. While the SDM developed are informative, this report also illustrates that our results do not necessarily provide a fully accurate representation of the current distribution of cetaceans in the region and thus their use in marine spatial planning processes should be accompanied by complimentary approaches such as acoustic and visual validation of the SDM results as well as additional monitoring and modeling efforts. This study represents a significant initiative in eastern Canada to highlight key areas for cetacean monitoring efforts in waters off Nova Scotia, and Newfoundland and Labrador. Future efforts will focus on improving these models to facilitate the inclusion of cetaceans in marine spatial planning processes that are currently underway.

Gowan, T. A., Ortega-Ortiz, J. G., Hostetler, J. A., Hamilton, P. K., Knowlton, A. R., Jackson, K. A., . . . Naessig, P. J. (2019). Temporal and Demographic Variation in Partial Migration of the North Atlantic Right Whale. *Scientific Reports, 9*(1), 353. https://doi.org/10.1038/s41598-018-36723-3

Animal movement plays a fundamental role in the ecology of migratory species, and understanding migration patterns is required for effective management. To evaluate intrinsic and environmental factors associated with probabilities of endangered North Atlantic right whales *Eubalaena glacialis* migrating to a wintering ground off the southeastern United States (SEUS), we applied a multistate temporary emigration capture-recapture model to 22 years of photo-identification data. Migration probabilities for juveniles were generally higher yet more variable than those for adults, and non-calving adult females were the least likely group to migrate. The highest migration probabilities for juveniles and adult males coincided with years of relatively high calving rates, following years of higher prey availability in a fall feeding ground. Right whale migration to the SEUS can be classified as condition-dependent partial migration, which includes skipped breeding partial migration for reproductive females, and is likely influenced by tradeoffs among ecological factors such as reproductive costs and foraging opportunities that vary across individuals and time. The high variability in migration reported in this study provides insight into the ecological drivers of migration but presents challenges to right whale monitoring and conservation strategies.

Grieve, B. D., Hare, J. A., & Saba, V. S. (2017). Projecting the Effects of Climate Change on *Calanus finmarchicus* Distribution within the Us Northeast Continental Shelf. *Scientific Reports, 7*(1), 6264. https://doi.org/10.1038/s41598-017-06524-1

Calanus finmarchicus is vital to pelagic ecosystems in the North Atlantic Ocean. Previous studies suggest the species is vulnerable to the effects of global warming, particularly on the Northeast U.S. Shelf, which is in the southern portion of its range. In this study, we evaluate an ensemble of six different downscaled climate models and a high-resolution global climate model, and create a generalized additive model (GAM) to examine how future changes in temperature and salinity could affect the distribution and density of *C. finmarchicus*. By 2081-2100, we project average *C. finmarchicus* density will decrease by as much as 50% under a high greenhouse gas emissions scenario. These decreases are particularly pronounced in the spring and summer in the Gulf of Maine and Georges Bank. When compared to a high-resolution global climate model, the ensemble showed a more uniform change throughout the Northeast U.S. Shelf, while the high-resolution model showed larger decreases in the Northeast Channel, Shelf Break, and Central Gulf of Maine. *C. finmarchicus* is an important link between primary production and higher trophic levels, and the decrease projected here could be detrimental to the North Atlantic Right Whale and a host of important fishery species.

Ibrahim, A. K., Zhuang, H., Ch'erubin, L. M., Erdol, N., Corry-Crowe, G. O., & Ali, A. M. (2020). North Atlantic Right Whales up-Call Detection Using Multimodel Deep Learning. *arXiv*. Retrieved from https://arxiv.org/abs/2005.08356

A new method for North Atlantic Right Whales (NARW) up-call detection using Multimodel Deep Learning (MMDL) is presented in this paper. In this approach, signals from passive acoustic sensors are first converted to spectrogram and scalogram images, which are time-frequency representations of the signals. These images are in turn used to train an MMDL detec-tor, consisting of Convolutional Neural Networks (CNNs) and Stacked Auto Encoders (SAEs). Our experimental studies revealed that CNNs work

better with spectrograms and SAEs with sca-lograms. Therefore in our experimental design, the CNNs are trained by using spectrogram im-ages, and the SAEs are trained by using scalogram images. A fusion mechanism is used to fuse the results from individual neural networks. In this paper, the results obtained from the MMDL detector are compared with those obtained from conventional machine learning algorithms trained with handcraft features. It is shown that the performance of the MMDL detector is sig-nificantly better than those of the representative conventional machine learning methods in terms of up-call detection rate, non-up-call detection rate, and false alarm rate.

Ibrahim, A. K., Zhuang, H., Erdol, N., & Ali, A. M. (2018). *Detection of North Atlantic Right Whales with a Hybrid System of Cnn and Dictionary Learning.* Paper presented at the 2018 International Conference on Computational Science and Computational Intelligence (CSCI). https://doi.org/10.1109/csci46756.2018.00232

In this paper, a hybrid approach of using Convolutional Neural Network (CNN) and dictionary learning is proposed for the detection of North Atlantic Right Whale (NARW) up-calls. The CNN was applied to extract features from NARW up-calls after these sound signals are converted into spectrograms. The features were then used to train a dictionary with a dictionary learning algorithm. The hybrid system of CNN and dictionary learning was compared with other methods using empirical data. It is shown in the paper that the proposed hybrid system produces superior results for detecting NARW up-calls.

Ibrahim, A. K., Zhuang, H., Erdol, N., & Ali, A. M. (2018). *Feature Extraction Methods for the Detection of North Atlantic Right Whale up-Calls.* Paper presented at the 2018 International Conference on Computational Science and Computational Intelligence (CSCI). https://doi.org/10.1109/csci46756.2018.00042

In this paper, a feature extraction method for detecting North Atlantic Right Whale (NARW) upcalls is proposed. The core of the scheme is an integration of Mel Frequency Cepstral Coefficients (MFCC) or Gammatone Frequency Cepstral Coefficients (GFCC) with Discrete Wavelet Transforms (DWT) for the extraction of features of NARW up-calls. Several types of wavelets are tested in terms of detection accuracy. Once the up-call features are extracted, popular classifiers such as Support Vector Machines and K-Nearest Neighbors are applied to classify call types. Detection results show that the upcall detection rate by using Mel Frequency Cepstral Coefficients is 73.82%, and False alarm rate is 2.48%. However, the upcall detection rate and false alarm rate are improved to 92.27% and 1.48% when these are integrated with Discrete Wavelet Transforms for feature extraction. GFCC works better than MFCC as a feature extractor if it is used alone. When both are integrated with DWT, the advantage of the former disappears. Furthermore, it is shown through experimental studies that the proposed detection scheme is superior to those obtained using spectrogram-based techniques in terms of both detection accuracy and speed. Due to its effectiveness and efficiency, the proposed algorithm can potentially be implemented in auto-detection buoys.

Johnson, H. D., Baumgartner, M. F., & Taggart, C. T. (2020). Estimating North Atlantic Right Whale (*Eubalaena glacialis*) Location Uncertainty Following Visual or Acoustic Detection to Inform Dynamic Management. *Conservation Science and Practice, 2*(10). https://doi.org/10.1111/csp2.267

The United States and Canada employ dynamic management strategies to improve conservation outcomes for the endangered North Atlantic right whale (*Eubalaena glacialis*). These strategies rely on near real-time knowledge of whale distribution generated from visual surveys and opportunistic sightings. Near real-time passive acoustic monitoring (PAM) systems have been operational for many years but acoustic detections of right whales have yet to be incorporated in dynamic management because of concerns over uncertainty in the location of acoustically detected whales. This rationale does not consider whale movement or its contribution to location uncertainty following either visual or acoustic detection. The goal of this study was to estimate uncertainties in right whale location following acoustic and visual detection and identify the timescale at which the uncertainties become similar owing to post-detection whale movement. We simulated whale movement using an autocorrelated random walk model parameterized to approximate three common right whale behavioral states (traveling, feeding, and socializing). We then used a Monte Carlo approach to estimate whale location over a 96-hr period given the initial uncertainty from the acoustic and visual detection methods and the evolving uncertainties arising from whale movement. The results demonstrated that for both detection methods the uncertainty in whale location increases rapidly following the initial detection and can vary by an order of magnitude after 96 hr depending on the behavioral state of the whale. The uncertainties in whale location became equivalent between visual and acoustic detections within 24-48 hr depending on whale behavior and acoustic detection range parameterization. These results imply that using both visual and acoustic detections provides enhanced information for the dynamic management of this visually and acoustically cryptic and highly mobile species.

Kirsebom, O. S., Frazao, F., Simard, Y., Roy, N., Matwin, S., & Giard, S. (2020). Performance of a Deep Neural Network at Detecting North Atlantic Right Whale Upcallsa). *Journal of the Acoustical Society of America, 147*(4), 2636-2646. https://doi.org/10.1121/10.0001132

Passive acoustics provides a powerful tool for monitoring the endangered North Atlantic right whale (*Eubalaena glacialis*), but robust detection algorithms are needed to handle diverse and variable acoustic conditions and differences in recording techniques and equipment. This paper investigates the potential of deep neural networks (DNNs) for addressing this need. ResNet, an architecture commonly used for image recognition, was trained to recognize the time-frequency representation of the characteristic North Atlantic right whale upcall. The network was trained on several thousand examples recorded at various locations in the Gulf of St. Lawrence in 2018 and 2019, using different equipment and deployment techniques. Used as a detection algorithm on fifty 30-min recordings from the years 2015-2017 containing over one thousand upcalls, the network achieved recalls up to 80% while maintaining a precision of 90%. Importantly, the performance of the network improved as more variance was introduced into the training dataset, whereas the opposite trend was observed using a conventional linear discriminant analysis approach. This study demonstrates that DNNs can be trained to identify North Atlantic right whale upcalls under diverse and variable conditions with a performance that compares favorably to that of existing algorithms.

Kowarski, K. A., & Moors-Murphy, H. (2021). A Review of Big Data Analysis Methods for Baleen Whale Passive Acoustic Monitoring. *Marine Mammal Science, 37*(2), 652-673. https://doi.org/10.1111/mms.12758

Many organizations collect large passive acoustic monitoring (PAM) data sets that need to be efficiently and reliably analyzed. To determine appropriate methods for effective analysis of big PAM data sets, we undertook a literature review of baleen whale PAM analysis methods. Methodologies from 166 studies (published between 2000-2019) were summarized, and a detailed review was performed on the 94 studies that recorded more than 1,000 hr of acoustic data (big data). Analysis techniques for extracting baleen whale information from PAM data sets varied depending on the research observed. A spectrum of methodologies was used and ranged from manual analysis of all acoustic data by human experts to completely automated techniques with no manual validation. Based on this assessment, recommendations are provided to encourage robust research methods that are comparable across studies and sectors, achievable across research groups, and consistent with previous work. These include using automated techniques when possible to increase efficiency and repeatability, supplementing automation with manual review to calculate automated detector performance, and increasing consistency in terminology and presentation of results. This work can be used to facilitate discussion for minimum standards and best practices to be implemented in the field of marine mammal PAM.

Krumhansl, K. A., Head, E. J. H., Pepin, P., Plourde, S., Record, N. R., Runge, J. A., & Johnson, C. L. (2018). Environmental Drivers of Vertical Distribution in Diapausing Calanus Copepods in the Northwest Atlantic. *Progress in Oceanography, 162*, 202-222. https://doi.org/10.1016/j.pocean.2018.02.018

Copepods of the genus Calanus play a critical trophic role in the North Atlantic ecosystems, where they serve as an important source of energy-rich food for fish and marine mammals, including the endangered North Atlantic right whale. As a strategy for coping with unfavorable near-surface conditions, Calanus enter diapause and migrate to deep water in late summer and fall after feeding and accumulating lipid stores in spring and summer. In order to assess the most important physical drivers of vertical distribution of diapausing Calanus, we synthesized existing depth-stratified abundance data of *Calanus finmarchicus* and *Calanus hyperboreus* from the Northwest Atlantic continental shelf and slope regions, spanning Newfoundland in the northeast to the Gulf of Maine in the southwest. Bottom depth strongly constrained the depth and shape of vertical distributions, with distributions becoming deeper and less compact as bottom depth increased. Diapausing Calanus, observed across a broad range of temperature (T) and in-situ density (sigma) conditions (T = -1.0 to 14.4 degrees C, a = 25.3-28.1 kg m(-3)), tended to distribute at depths with the coldest temperatures locally available. Over the shelf, diapausing Calanus in the GOM and SS generally did not have access to temperatures considered optimal for diapause (< 5 degrees C), in many cases occurring at temperatures well above this threshold. Diapausing Calanus in both habitats were most commonly below the Cold Intermediate Layer (CIL), a feature formed through wind-driven mixing during the winter, but this effect was more obvious over the shelf than in slope waters. Our analysis highlights key differences in the vertical distributions of diapausing Calanus over the shelf vs. the slope, having regional implications for ecological dynamics and population persistence in the face of warming temperatures. In general, understanding factors that influence vertical distributions of diapausing Calanus will allow us to more accurately predict how the environmental conditions they encounter while overwintering may shift during climate change, which has implications for survival through diapause, and consequently, shelf-wide population dynamics.

Krzystan, A. M., Gowan, T. A., Kendall, W. L., Martin, J., Ortega-Ortiz, J. G., Jackson, K., . . . Taylor, C. R. (2018). Characterizing Residence Patterns of North Atlantic Right Whales in the Southeastern USA with a Multistate Open Robust Design Model. *Endangered Species Research, 36*, 279-295. https://doi.org/10.3354/esr00902

Effective conservation of endangered North Atlantic right whales *Eubalaena glacialis* requires information about their spatio-temporal distribution. Understanding temporal distribution is particularly important, because a portion of the population migrates between high-latitude summer feeding grounds off the northeastern US and Canadian Maritimes coasts and lower-latitude calving and wintering grounds off the southeastern US coast (SEUS). Here, we modeled SEUS residence patterns using photo-identification data from coastal South Carolina, Georgia, and Florida from 7 winter seasons (2004/2005-2010/2011). We used multistate open robust design models to evaluate effects of reproductive status, demographic group, and environmental conditions on SEUS residence. Model estimates accounted for temporal variation and imperfect detection and provided probabilities of entering the SEUS, staying in the SEUS, and being sighted in the SEUS. We also derived estimates for residence time and seasonal abundance. We observed staggered arrival and departure patterns and demographic differences in residence patterns that are characteristic of a differential migration strategy. Calving females arrived earliest and, in most seasons, had mean residence periods more than twice as long as other demographic groups. Conversely, adult males arrived the latest and had the shortest residence times. Within-season detection was positively influenced by survey effort, and overall seasonal mean (+/- SE) detection rate estimates ranged from 0.83 +/- 0.08 for non-calving adult females to 0.98 +/- 0.02 for calving females. Results provide insights into right whale behavior, biology, and temporal distribution in the SEUS and can be used to evaluate spatially and temporally dynamic management measures.

Lehoux, C., Plourde, S., & Lesage, V. (2020). *Significance of Dominant Zooplankton Species to the North Atlantic Right Whale Potential Foraging Habitats in the Gulf of St. Lawrence : A Bio-Energetic Approach.* Fisheries and Oceans Canada Ottawa.

The North Atlantic Right Whale (NARW) is an endangered species that feeds primarily on *Calanus finmarchicus* in their traditional feeding areas in the western North Atlantic. In recent years, the Gulf of St. Lawrence (GSL) was identified as an important feeding ground for this population. In this region, the large and lipid-rich *C. finmarchicus*, *C. hyperboreus* and *C. glacialis* are abundant species, but other small calanoids such as Pseudocalanus spp. and Temora spp. and krill are also numerically abundant. Since the diet of NARW is unknown in the GSL, the potential relative contribution of these prey to NARW in early and late summer between 2006 and 2017 was assessed using a bioenergetics model. The model used a 3D preyscape, which was predicted using the depth-integrated biomass of zooplankton and species-specific vertical distributions. The model assessed the energy gained according to prey density in each 10 m-depth bins, and the energy requirement of mature females that were resting, pregnant or lactating. A suitable habitat was defined as a positive difference between the energy gained and the energy required divided by the energy required.Alternate abstract:La baleine noire de l'Atlantique Nord (BNAN) est une espèce en voie de disparition qui se nourrit principalement de *Calanus finmarchicus* dans ses aires d'alimentation traditionnelles dans l'Atlantique Nord-Ouest. Dans les dernières années, le golfe du St-Laurent (GSL) a été identifié comme une aire d'alimentation importante pour cette population.Dans cette région, *Calanus finmarchicus*, *C. hyperboreus* qui est plus grand et riche en lipides, C. glacialis ainsi que d'autres petits calanoids tels que Pseudocalanus spp. et Temora spp. et le krill sont abondants. Étant donné que la diète des BNAN est inconnue dans le GSL, la contribution relative de ces

proies aux BNAN au début et à la fin de l'été entre 2006-2017 a été évaluée en utilisant un modèle bioénergétique. Le modèle a utilisé la distribution 3D des proies prédites en couplant la biomasse de zooplancton intégrée sur toute la colonne d'eau et les distributions verticales spécifiques à chaque espèce. Le modèle a évalué l'énergie acquise selon la densité de proies dans chaque couche de 10 m et l'énergie requise par des femelles matures qui sont au repos, enceintes ou qui allaitent. Un habitat propice se définit par une différence positive entre l'énergie acquise et l'énergie requise divisée par l'énergie requise.

Leiter, S. M., Stone, K. M., Thompson, J. L., Accardo, C. M., Wikgren, B. C., Zani, M. A., . . . Kraus, S. D. (2017). North Atlantic Right Whale *Eubalaena glacialis* Occurrence in Offshore Wind Energy Areas near Massachusetts and Rhode Island, USA. *Endangered Species Research, 34*, 45-59. https://doi.org/10.3354/esr00827

Recent surveys of wind energy areas offshore of Massachusetts and Rhode Island (USA) have demonstrated that they encompass habitat used by the Endangered North Atlantic right whale *Eubalaena glacialis*. Prior to 2011, little systematic survey effort had been conducted in the area. The Bureau of Ocean Energy Management and the state of Massachusetts supported 3.5 yr of twice-monthly aerial surveys by the Northeast Large Pelagic Survey Collaborative (NLPSC). Additional survey teams including the Northeast Fisheries Science Center and the Center for Coastal Studies have collected sightings data in the region. Data systematically collected by the NLPSC allowed analyses of monthly sightings rates, sightings per unit effort, and hot spots which provided information on current temporal and spatial use patterns. Abundance estimates for each season-year (i.e. a 3 mo period within a given survey year) were calculated. Behaviors observed included feeding and surface active groups. Photo-identification of whales since 2010 yielded a minimum count of 196 unique individuals (annual average = 35), or over one-third of the current population estimate. Analyses of demographics of these individuals revealed that 34 known calving females (30% of the total currently presumed alive) visited the study area. These results demonstrate consistent annual use of this area by a significant portion of the *E. glacialis* population, with a strong correlation between season and presence. These findings can inform management activities and development planning, and be used as a baseline dataset for assessing long-term impacts to the species.

Liu, X. (2020). An Empirical Analysis of Cross-Entropy Based and Metric-Based Methods on North Atlantic Right Whale Acoustic Data. In *Dalhousie University*: Dalhousie University. Retrieved from https://dalspace.library.dal.ca/handle/10222/79390

With increasing concern for marine species extinction, a massive effort has been made to conserve, prevent, and search for a sustainable solution. However, data labeling is a labor-heavy and time-consuming work, resulting in limited annotated acoustic data. What's more, a majority of labeled acoustic data are background noise. Both issues together raise interests in searching for solutions on how to effectively train a reliable classification model. We simulate different degrees of data compositions to study the impact of data scarcity and class imbalance on North Atlantic Right Whale (NARW) acoustic data. In the meantime, we explore two types of supervised deep learning approaches: metric-based classifiers and cross-entropy based classifiers. The empirical results show that our classifiers trained with fewer NARW acoustic data have comparable performance to the-state-of-art classifiers trained with a larger amount of acoustic data

Mayo, C. A., Ganley, L., Hudak, C. A., Brault, S., Marx, M. K., Burke, E., & Brown, M. W. (2018). Distribution, Demography, and Behavior of North Atlantic Right Whales (*Eubalaena glacialis*) in Cape Cod Bay, Massachusetts, 1998-2013. *Marine Mammal Science, 34*(4), 979-996. https://doi.org/10.1111/mms.12511

The occurrence of North Atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay was documented during aerial surveys between 1998 and 2013. The seasonal occurrence remained relatively unchanged during the study, spanning the January through mid-May timeframe. The number of individual whales visiting the Bay was positively correlated with the increasing Best Cataloged Estimate (BCE), the number of photographed whales alive, with a maximum in 2011 of 56.9% (n=277) of BCE. However, the rate of increase in number of individuals during the study was significantly greater than that of the BCE (difference in slope: 12.72; P< 0.01) suggesting that increased visitation to the Bay was due in part to a change in habitat preference. Although the demographic composition of whales observed during the study differed little from that of the cataloged whales, the proportion of calves born in the North Atlantic that were documented in the Bay increased significantly (P<0.01). Models of random visitation demonstrated an individual preference for or rejection of the Bay by the right whales of the North Atlantic population.

National Marine Fisheries Service. (2017). *Biological and Conference Opinion on the Issuance of Permit No. 20556 and Its Subsequent Modification (Permit No. 20556-01) to the Georgia Department of Natural Resources, Responsible Party Jonathan P. Ambrose, for Research on North Atlantic Right Whales.* https://doi.org/10.7289/V5F18WZT

The action agency for this consultation is NMFS, Office of Protected Resources, Permits and Conservation Division (hereafter the Permits Division). The Permits Division proposes to issue a scientific research permit (Permit No. 20556, Appendix A) and then modify this permit (to become Permit No. 20556-01) pursuant to section 10(a)(1)(A) of the ESA and section 104 of the Marine Mammal Protection Act of 1972, as amended (MMPA; 16 USC 1361 et seq.) to the Georgia Department of Natural Resources (GA DNR), Responsible party Jonathan P. Ambrose, 2070 U.S. Highway 278 SE, Social Circle, Georgia 30025-4711. The purpose of the proposed permit is to allow an exception to the moratoria and prohibition on takes established under the ESA and MMPA in order to allow the applicant to conduct scientific research on North Atlantic right whales (*Eubalaena glacialis*) in the Atlantic Ocean and Gulf of Mexico. The purpose of the proposed modification to the permit is to authorize the use of a new tag technology, fully-piercing tags, pending results of testing

National Marine Fisheries Service. (2017). *Biological Opinion on the Issuance of Permit No. 20951 to Ann Zoidis, Cetos Research Organization, for Research on Cetaceans in the Gulf of Maine.* https://doi.org/10.7289/V5MG7MRG

This document represents NMFS opinion on the effects of the proposed issuance of Permit No. 20951 on blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*), North Atlantic right whales (*Eubalaena glacialis*), sei whales (*Balaena borealis*), sperm whales (*Physeter macrocephalus*), green turtles (*Chelonia mydas*, North Atlantic Distinct Population Segment [DPS]), hawksbill turtles (*Eretmochelys imbricata*), Kemp's ridley turtles (*Lepidochelys kempii*), leatherback turtles (*Dermochelys coriacea*), and loggerhead turtles (*Caretta caretta*, Northwest Atlantic DPS). A complete record of this consultation is on file at NMFS Office of Protected Resources in Silver Spring, Maryland

Padovese, B., Frazao, F., Kirsebom, O. S., & Matwin, S. (2021). Data Augmentation for the Classification of North Atlantic Right Whales Upcalls. *Journal of the Acoustical Society of America, 149*(4), 2520. https://doi.org/10.1121/10.0004258

Passive acoustic monitoring (PAM) is a useful technique for monitoring marine mammals. However, the quantity of data collected through PAM systems makes automated algorithms for detecting and classifying sounds essential. Deep learning algorithms have shown great promise in recent years, but their performance is limited by the lack of sufficient amounts of annotated data for training the algorithms. This work investigates the benefit of augmenting training datasets with synthetically generated samples when training a deep neural network for the classification of North Atlantic right whale (*Eubalaena glacialis*) upcalls. We apply two recently proposed augmentation techniques, SpecAugment and Mixup, and show that they improve the performance of our model considerably. The precision is increased from 86% to 90%, while the recall is increased from 88% to 93%. Finally, we demonstrate that these two methods yield a significant improvement in performance in a scenario of data scarcity, where few training samples are available. This demonstrates that data augmentation can reduce the annotation effort required to achieve a desirable performance threshold.

Parks, S., Read, A. J., & Nowacek, D. P. (2017). Acoustic Environment of North Atlantic Right Whales in the Southeastern United States. *Journal of the Acoustical Society of America, 141*(5), 3942-3942. https://doi.org/10.1121/1.4988932

North Atlantic right whales are an endangered species of baleen whale that migrates along the east coast of the United States, with winter calving grounds located in the coastal waters off Florida and Georgia. This study investigated the acoustic environment experienced by individual right whales swimming through this habitat though the use of suction cup attached acoustic recording tags. Nineteen tag attachments were made between 2014 and 2016. These tags documented a range of sounds from the right whale acoustic environment, including calls produced by the tagged whale, sounds produced by conspecifics, as well as sounds from other biological (fish and dolphin) and anthropogenic sources. The call rates of individual whales were relatively low, with calls typically produced in short duration bouts. Sounds from other biological sources, particularly fish and dolphin, and anthropogenic sources, particularly vessels, were common. This project presents an initial step toward characterizing the acoustic environment experienced by individual whales to allow future comparisons to stationary acoustic recordings in the same habitat.

Parks, S. E., Cusano, D. A., Van Parijs, S. M., & Nowacek, D. P. (2019). Acoustic Crypsis in Communication by North Atlantic Right Whale Mother–Calf Pairs on the Calving Grounds. *Biology Letters, 15*(10), 20190485. https://doi.org/10.1098/rsbl.2019.0485

Mammals with dependent young often rely on cryptic behaviour to avoid detection by potential predators. In the mysticetes, large baleen whales, young calves are known to be vulnerable to direct predation from both shark and orca predators; therefore, it is possible that mother-calf pairs may show cryptic behaviours to avoid the attention of predators. Baleen whales primarily communicate through low-frequency acoustic signals, which can travel over long ranges. In this study, we explore the potential for acoustic crypsis, a form of cryptic behaviour to avoid predator detection, in North Atlantic right whale mother-calf pairs. We predicted that mother-calf pairs would either show reduced calling rates, reduced call amplitude or a combination of these behavioural modifications when compared with other

demographic groups in the same habitat. Our results show that right whale mother-calf pairs have a strong shift in repertoire usage, significantly reducing the number of higher amplitude, long-distance communication signals they produced when compared with juvenile and pregnant whales in the same habitat. These observations show that right whale mother-calf pairs rely upon acoustic crypsis, potentially to minimize the risk of acoustic eavesdropping by predators.

Parks, S. E., Cusano, D. A., Van Parijs, S. M., & Nowacek, D. P. (2019). North Atlantic Right Whale (*Eubalaena glacialis*) Acoustic Behavior on the Calving Grounds. *Journal of the Acoustical Society of America, 146*(1), EL15-EL21. https://doi.org/10.1121/1.5115332

Passive acoustic monitoring is a common method for detection of endangered North Atlantic right whales. This study reports on the acoustic behavior of right whales on the winter calving grounds to assess their acoustic detectability in this habitat. In addition to known call types, previously undescribed low amplitude short broadband signals were detected from lactating females with calves. The production of higher amplitude tonal calls occurred at lower rates for lactating females than from other age/sex classes suggesting that passive acoustic monitoring may be less effective in detecting mother-calf pairs in this critical habitat area.

Pershing, A. J., & Stamieszkin, K. (2020). The North Atlantic Ecosystem, from Plankton to Whales. In *Annual Review of Marine Science, Vol 12.* C. A. Carlson & S. J. Giovannoni (Eds.), (Vol. 12, pp. 339-359) https://doi.org/10.1146/annurev-marine-010419-010752

Compared with terrestrial ecosystems, marine ecosystems have a higher proportion of heterotrophic biomass. Building from this observation, we define the North Atlantic biome as the region where the large, lipid-rich copepod Calanus film/al-chic-us is the dominant mesozooplankton species. This species is superbly adapted to take advantage of the intense pulse of productivity associated with the North Atlantic spring bloom. Most of the characteristic North Atlantic species, including cod, herring, and right whales, rely on C. film/al-chic-us either directly or indirectly. The notion of a biome rests inherently on an assumption of stability, yet conditions in the North Atlantic are anything but stable. Humans have reduced the abundance of many fish and whales (though some recovery is underway). Humans are also introducing physical and chemical trends associated with global climate change. Thus, the future of the North Atlantic depends on the biome's newest species, *Homo sapiens*.

Plourde, S., Lehoux, C., Johnson, C. L., Perrin, G., & Lesage, V. (2019). North Atlantic Right Whale (*Eubalaena glacialis*) and Its Food: (I) a Spatial Climatology of Calanus Biomass and Potential Foraging Habitats in Canadian Waters. *Journal of Plankton Research, 41*(5), 667-685. https://doi.org/10.1093/plankt/fbz024

This study aimed at identifying potentially suitable foraging habitats for the North Atlantic right whale (NARW; *Eubalaena glacialis*) in the Gulf of St Lawrence (GSL), on the Scotian Shelf (SS) and in the Bay of Fundy (BoF), Canada, based on the distribution densities of their main prey, Calanus copepod species. More than 4800 historical Calanus spp. water column integrated samples as well as 221 vertically stratified sampling stations were used to create a 3D (latitude, longitude and vertical) climatology of Calanus spp. biomass densities for spring and summer-fall when NARW are feeding in Canadian waters. We then combined this 3D preyscape with bio-energetic considerations to highlight potentially suitable

NARW foraging habitats in the region. Our 3D climatological approach successfully identified the known feeding areas of Grand Manan (BoF) and Roseway Basin (western SS), confirming its validity. Expanding our analyses to the GSL and other parts of the SS, we identified in both regions areas previously unknown where Calanus spp. biomass densities exceeded minimum levels suitable for foraging NARW. Our results represent a key contribution to the identification of important foraging areas for NARW in Canadian waters, especially in the context of climate change and the documented shift in NARW distribution.

Quintana-Rizzo, E., Leiter, S., Cole, T. V. N., Hagbloom, M. N., Knowlton, A. R., Nagelkirk, P., . . . Kraus, S. D. (2021). Residency, Demographics, and Movement Patterns of North Atlantic Right Whales *Eubalaena glacialis* in an Offshore Wind Energy Development in Southern New England, USA. *Endangered Species Research*. https://doi.org/10.3354/esr01137

Offshore wind energy development is growing quickly around the world. In southern New England, USA, the largest commercial offshore wind energy farm will be established in the waters off Massachusetts and Rhode Island, an area used by the critically endangered North Atlantic right whale *Eubalaena glacialis*. Prior to 2011, little was known about right whales' use of this area. We examined aerial survey data collected between 2011–2015 and 2017–2019 to quantify right whale distribution, residency, demography, and movements in the region. Right whale occurrence increased during the study period. Since 2017, whales have been sighted in the area nearly every month, with peak sighting rates between late winter and spring. Model outputs suggest that 23% of the species' population is present from December through May, and the mean residence time has tripled to an average of 13 days during these months. Age and sex ratios of the individuals present in the area are similar to those of the species as a whole, with adult males the most common demographic group. Movement models showed that southern New England is an important destination for right whales, including conceptive and reproductive females, and qualitative observations included animals feeding and socializing. Implementing mitigation procedures in coordination with these findings will be crucial in mitigating the potential impacts on right whales from construction noise, increased vessel traffic, and habitat disruption in this region.

Reeves, R. R. (2020). Overview of Catch History, Historic Abundance and Distribution of Right Whales in the Western North Atlantic and in Cintra Bay, West Africa. *IWC Journal of Cetacean Research and Management*, 187-192. https://doi.org/10.47536/jcrm.vi.289

The catch history of the North Atlantic right whales (*Eubalaena glacialis*) in the western North Atlantic has been studied in a series of projects. Data from European archives on early Basque whaling, centred in the Strait of Belle Isle, showed that there were at least a few thousand right whales in the northern part of the range in the sixteenth century. Data from shore whaling in the eastern United States supplemented by British customs data indicated that there were still more than a thousand right whales in the southern part of the range (i.e. south from Nova Scotia) in the late seventeenth century. Right whales were depleted throughout the western North Atlantic by the middle of the eighteenth century, but small shore whaling enterprises persisted in some areas and pelagic whalers continued to kill right whales opportunistically. An increase in alongshore whaling occurred at Long Island (New York) beginning in the 1850s and in North and South Carolina, Georgia and northern Florida in the 1870s-1880s. By the start of the twentieth century only a few crews of shore whalers remained active in Long Island and North Carolina, and their whaling efforts were desultory. All evidence points to stock

depletion as the primary reason for the demise of organised whaling for right whales in eastern North America. Recent sightings indicate that some right whales travel from the Bay of Fundy and Scotian Shelf far to the north and east, at least occasionally reaching the historic Cape Farewell Ground. Areas known to have been used regularly by right whales in the past (e.g. Gulf of St Lawrence, Delaware Bay) are now visited seasonally by only a few individuals. Recent surveys of Cintra Bay, a historic right whale wintering ground in the eastern North Atlantic, provided no evidence of continued use by right whales.

Rodrigues, A. S. L., Charpentier, A., Bernal-Casasola, D., Gardeisen, A., Nores, C., Millan, J. A. P., . . . Speller, C. F. (2018). Forgotten Mediterranean Calving Grounds of Grey and North Atlantic Right Whales: Evidence from Roman Archaeological Records. *Proceedings of the Royal Society B-Biological Sciences, 285*(1882). https://doi.org/10.1098/rspb.2018.0961

Right whales (*Eubalaena glacialis*) were extirpated from the eastern North Atlantic by commercial whaling. Grey whales (Eschrichtius robustus) disappeared from the entire North Atlantic in still-mysterious circumstances. Here, we test the hypotheses that both species previously occurred in the Mediterranean Sea, an area not currently considered part of their historical range. We used ancient DNA barcoding and collagen fingerprinting methods to taxonomically identify a rare set of 10 presumed whale bones from Roman and pre-Roman archaeological sites in the Strait of Gibraltar region, plus an additional bone from the Asturian coast. We identified three right whales, and three grey whales, demonstrating that the ranges of both of these species historically encompassed the Gibraltar region, probably including the Mediterranean Sea as calving grounds. Our results significantly extend the known range of the Atlantic grey whale, and suggest that 2000 years ago, right and grey whales were common when compared with other whale species. The disappearance of right and grey whales from the Mediterranean region is likely to have been accompanied by broader ecosystem impacts, including the disappearance of their predators (killer whales) and a reduction in marine primary productivity. The evidence that these two coastal and highly accessible species were present along the shores of the Roman Empire raises the hypothesis that they may have formed the basis of a forgotten whaling industry.

Root-Gutteridge, H., Cusano, D. A., Shiu, Y., Nowacek, D. P., Van Parijs, S. M., & Parks, S. E. (2018). A Lifetime of Changing Calls: North Atlantic Right Whales, *Eubalaena glacialis*, Refine Call Production as They Age. *Animal Behaviour, 137*, 21-34. https://doi.org/10.1016/j.anbehav.2017.12.016

The trajectory of development and refinement of communication signals closely map physical and social development in many vertebrate species. Although marine mammals exhibit highly complex and diverse communication signals, asking similar questions about signal development can be challenging when dealing with long-lived species that roam widely at sea. North Atlantic right whales, a large baleen whale species, are intensely studied due to their endangered status. We examine whether right whale acoustic signals vary with the physical and social development of individuals from birth to adulthood using a latitudinal analysis. Data included 986 high-quality calls recorded from 49 individuals of known age spanning from 1 month to 37 years, with two individuals measured at different ages. Calls produced by calves younger than 1 year were easily distinguished by their short duration, a high degree of frequency modulation and a high percentage of nonlinear phenomena. Nonlinear phenomena within calls shifted from disorder (deterministic chaos) to increased control (biphonation and subharmonics) with increasing age. The overall percentage of calls containing nonlinear phenomena decreased with

increasing age. Duration of the calls and calling bouts increased in direct correlation with age. Notably there was no clear indication of fixation in any of the measured parameters with age, with directional changes continuing over the entire age range studied. This study presents the first evidence that acoustic maturation does not stop at sexual maturity (similar to 9 years) in right whales and that refinement of calls continues through adulthood. Clear age-related voice cues have been documented in a range of terrestrial species with increases in call duration often reflecting increased stamina or condition in older adults. This study shows a similar trend in right whale sound production, with changes detectable across three-decade age range of available data.

Ross, C. H., Pendleton, D. E., Tupper, B., Brickman, D., Zani, M. A., Mayo, C. A., & Record, N. R. (2021). Projecting Regions of North Atlantic Right Whale, *Eubalaena glacialis* , Habitat Suitability in the Gulf of Maine for the Year 2050. *Elementa: Science of the Anthropocene, 9*(1). https://doi.org/10.1525/elementa.2020.20.00058

North Atlantic right whales (*Eubalaena glacialis*) are critically endangered, and recent changes in distribution patterns have been a major management challenge. Understanding the role that environmental conditions play in habitat suitability helps to determine the regions in need of monitoring or protection for conservation of the species, particularly as climate change shifts suitable habitat. This study used three species distribution modeling algorithms, together with historical whale abundance data (1993–2009) and environmental covariate data, to build monthly ensemble models of past *E. glacialis* habitat suitability in the Gulf of Maine. The model was projected onto the year 2050 for a range of climate scenarios. Specifically, the distribution of the species was modeled using generalized additive models, boosted regression trees, and artificial neural networks, with environmental covariates that included sea surface temperature, bottom water temperature, bathymetry, a modeled *Calanus finmarchicus* habitat index, and chlorophyll. Year-2050 projections used downscaled climate anomaly fields from Representative Concentration Pathway 4.5 and 8.5. The relative contribution of each covariate changed seasonally, with an increase in the importance of bottom temperature and *C. finmarchicus* in the summer, when model performance was highest. A negative correlation was observed between model performance and sea surface temperature contribution. The 2050 projections indicated decreased habitat suitability across the Gulf of Maine in the period from July through October, with the exception of narrow bands along the Scotian Shelf. The results suggest that regions outside of the current areas of conservation focus may become increasingly important habitats for *E. glacialis* under future climate scenarios.

Silber, G. K., Lettrich, M. D., Thomas, P. C., Baker, J. D., Baumgartner, M. F., Becker, E. A., . . . Waples, R. S. (2017). Projecting Marine Mammal Distribution in a Changing Climate. *Frontiers in Marine Science, 4*, 1-14. https://doi.org/10.3389/fmars.2017.00413

Climate-related shifts in marine mammal range and distribution have been observed in some populations; however, the nature and magnitude of future responses are uncertain in novel environments projected under climate change. This poses a challenge for agencies charged with management and conservation of these species. Specialized diets, restricted ranges, or reliance on specific substrates or sites (e.g., for pupping) make many marine mammal populations particularly vulnerable to climate change. High-latitude, predominantly ice-obligate, species have experienced some of the largest changes in habitat and distribution and these are expected to continue. Efforts to predict

and project marine mammal distributions to date have emphasized data-driven statistical habitat models. These have proven successful for short time-scale (e.g., seasonal) management activities, but confidence that such relationships will hold for multi-decade projections and novel environments is limited. Recent advances in mechanistic modeling of marine mammals (i.e., models that rely on robust physiological and ecological principles expected to hold under climate change) may address this limitation. The success of such approaches rests on continued advances in marine mammal ecology, behavior, and physiology together with improved regional climate projections. The broad scope of this challenge suggests initial priorities be placed on vulnerable species or populations (those already experiencing declines or projected to undergo ecological shifts resulting from climate changes that are consistent across climate projections) and species or populations for which ample data already exist (with the hope that these may inform climate change sensitivities in less well observed species or populations elsewhere). The sustained monitoring networks, novel observations, and modeling advances required to more confidently project marine mammal distributions in a changing climate will ultimately benefit management decisions across time-scales, further promoting the resilience of marine mammal populations.

Simard, Y., Kirsebom, O. S., Frazao, F., Roy, N., Matwin, S., & Giard, S. (2020). Acoustic Recordings of North Atlantic Right Whale Upcalls in the Gulf of St. Lawrence. In.

The acoustic data were collected between 2015 and 2019 at six stations in the southern Gulf of St. Lawrence using two different deployment configurations. The dataset also includes audio samples from the Gulf of Maine recorded in 2009, which were part of the DCLDE 2013 Challenge dataset (https://soi.st-andrews.ac.uk/static/soi/dclde2013/documents/WorkshopDataset2013.pdf). The acoustic data are supplemented by expert annotations indicating the presence/absence of North Atlantic right whale upcalls. Spectrogram images are also provided. These data have been used to train a deep neural network to detect North Atlantic right whale upcalls, as described in the article "Performance of a Deep Neural Network at Detecting North Atlantic Right Whale Upcalls" by Kirsebom, Frazao, Simard, Roy, Matwin, and Giard (doi:10.1121/10.0001132), which also contains a detailed description of the data. The software developed as part of this work is available on Zenodo (doi:10.5281/zenodo.3736625) under a GPLv3 license. This includes Python scripts for building training and test datasets, computing signal-to-noise ratios, visualizing spectrograms, training the deep neural network, and using the network to analyze continuous audio recordings.

Simard, Y., Roy, N., Giard, S., & Aulanier, F. (2019). North Atlantic Right Whale Shift to the Gulf of St. Lawrence in 2015, Revealed by Long-Term Passive Acoustics. *Endangered Species Research, 40*, 271-284. https://doi.org/10.3354/esr01005

This paper contributes to documenting a change in the distribution of North Atlantic right whales *Eubalaena glacialis* (NARWs) that occurred in the 2010s, when the whales largely abandoned their traditional summering grounds in the Gulf of Maine/Bay of Fundy/Scotian shelf. Data from a year-round passive acoustic monitoring (PAM) network in the Gulf of St. Lawrence were exploited to build the time series of NARW incursions into this inland sea of the Northwest Atlantic, from June 2010 to November 2018. NARWs visited the southern Gulf of St. Lawrence every year from June to January, until ice freeze-up. The earliest detections were made at the end of April and the latest in mid-January. Call occurrence peaked between August and the end of October. NARW contact calls were not detected at the most upstream station at Les Escoumins, in the Lower St. Lawrence estuary, or at the northeastern

connection of Belle Isle Strait with the Atlantic, which was monitored from November 2010 to November 2011. The mean daily occurrence of NARWs in the feeding grounds off Gaspe quadrupled after 2015 compared to 2011-2014. Long-term continuous PAM data provided invaluable information to document this marine mammal distribution shift.

Sorochan, K. A., Plourde, S., Morse, R., Pepin, P., Runge, J., Thompson, C., & Johnson, C. L. (2019). North Atlantic Right Whale (*Eubalaena glacialis*) and Its Food: (Ii) Interannual Variations in Biomass of Calanus Spp. On Western North Atlantic Shelves. *Journal of Plankton Research, 41*(5), 687-708. https://doi.org/10.1093/plankt/fbz044

The North Atlantic right whale (NARW), *Eubalaena glacialis*, feeds on zooplankton, particularly copepods of the genus Calanus. We quantified interannual variation in anomalies of abundance and biomass of Calanus spp. and near-surface and near-bottom ocean temperature and salinity from 19 subregions spanning the Gulf of Maine-Georges Bank (GoM-GBK), Scotian Shelf (SS), Gulf of St. Lawrence (GSL) and Newfoundland and Labrador Shelves. We analyzed time series from 1977 to 2016 in GoM-GBK, 1982 to 2016 in southwest GSL and 1999 to 2016 in remaining areas. *Calanus finmarchicus* dominated abundance and biomass, except in the GSL where *Calanus hyperboreus* was abundant. The biomass of Calanus spp. declined in many subregions over years 1999-2016 and was negatively correlated with sea surface temperature in GoM-GBK and on the SS. We detected "regime shifts" to lower biomass of Calanus spp. in the GoM-GBK in 2010 and on the SS in 2011. In the GoM-GBK, shifts to lower biomass of *C. finmarchicus* coincided with shifts to warmer ocean temperature and with published reports of changes in spatial distribution and reduced calving rate of NARW. We hypothesize that warming has negatively impacted population levels of Calanus spp. near their southern range limit, reducing the availability of prey to NARW.

Southall, B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., . . . Tyack, P. L. (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals, 45*(2). https://doi.org/10.1578/AM.45.2.2019.125

This article evaluates Southall et al. (2007) in light of subsequent scientific findings and proposes revised noise exposure criteria to predict the onset of auditory effects in marine mammals. Estimated audiograms, weighting functions, and underwater noise exposure criteria for temporary and permanent auditory effects of noise are presented for six species groupings, including all marine mammal species. In-air criteria are also provided for amphibious species. Earlier marine mammal hearing groupings were reviewed and modified based on phylogenetic relationships and a comprehensive review of studies on hearing, auditory anatomy, and sound production. Auditory weighting functions are derived for each group; those proposed here are less flattened and closer to audiograms than the Southall et al. M-weightings. As in Southall et al., noise sources are categorized as either impulsive or non-impulsive, and criteria use multiple exposure metrics to account for different aspects of exposure. For continuous (non-impulsive) noise sources, exposure criteria are given in frequencyweighted sound exposure level (SEL, given in units relative to 1 µPa2 -s or (20 µPa2 William T. Ellison,8)-s for water and air, respectively). Dual exposure metrics are provided for impulsive noise criteria, including frequency-weighted SEL and unweighted peak sound pressure level (SPL, given in units relative to 1 µPa or 20 µPa for water and air, respectively). Exposures exceeding the specified respective criteria level for any exposure metric are interpreted as resulting in predicted temporary threshold shift (TTS) or permanent threshold shift (PTS) onset. Scientific findings in the last decade provide substantial new insight but also underscore

remaining challenges in deriving simple, broadly applicable quantitative exposure criteria for such diverse taxa. These criteria should be considered with regard to relevant caveats, recommended research, and with the expectation of subsequent revision.

Stöber, U., & Thomsen, F. (2019). Effect of Impact Pile Driving Noise on Marine Mammals: A Comparison of Different Noise Exposure Criteria. *Journal of the Acoustical Society of America, 145*(5), 3252-3259. https://doi.org/10.1121/1.5109387

Regulators in Europe and in the United States have developed sound exposure criteria. Criteria range from broadband levels to frequency weighted received sound levels. The associated differences in impact assessment results are, however, not yet understood. This uncertainty makes environmental management of transboundary anthropogenic noise challenging and causes confusion for regulators who need to choose appropriate exposure criteria. In the present study, three established exposure criteria frameworks from Germany, Denmark, and the US were used to analyse the effect of impact pile driving at a location in the Baltic Sea on harbor porpoise and harbor seal hearing. The acoustic modeling using MIKE showed that an unmitigated scenario would lead to auditory injury for all three criteria. Despite readily apparent variances in impact ranges among the applied approaches, it was also evident that noise mitigation measures could reduce underwater sound to levels where auditory injuries would be unlikely in most cases. It was concluded that each of the frameworks has its own advantages and disadvantages. Single noise exposure criteria follow the precautionary principle and can be enforced relatively easily, whereas criteria that consider hearing capabilities and animal response movement can improve the accuracy of the assessment if data are available.

Stone, K. M., Leiter, S. M., Kenney, R. D., Wikgren, B. C., Thompson, J. L., Taylor, J. K. D., & Kraus, S. D. (2017). Distribution and Abundance of Cetaceans in a Wind Energy Development Area Offshore of Massachusetts and Rhode Island. *Journal of Coastal Conservation, 21*(4), 527-543. https://doi.org/10.1007/s11852-017-0526-4

Two wind energy areas (WEAs), designated by the Bureau of Ocean Energy Management, offshore of Massachusetts and Rhode Island were surveyed between October 2011 and June 2015. A total of 969 cetacean sightings of over 10,000 animals were documented during systematic line-transect aerial surveys (67,525 km flown). Twelve cetacean species were documented, including seven odontocete and five mysticete species. Cetaceans were recorded in all seasons demonstrating inter-annual, seasonal, and spatial use of the WEAs. Peak presence occurred in the spring and summer for most species, with the exception of North Atlantic right whales, which occurred primarily in the winter and spring. Right and sei whales were documented regularly throughout the study and in higher numbers than expected. Seasonal estimates of abundance were calculated for seven species, including five baleen whales (fin, minke, humpback, right, and sei) and two dolphins (common and bottlenose). The results suggest the area is a previously underestimated seasonal habitat for cetaceans including several endangered baleen whale species. These data will help inform mitigation strategies for future wind energy development. Climate change effects, increased coastal urbanization, and other factors argue for continued monitoring of cetaceans in the WEAs offshore of New England.

van der Hoop, J. M., Nousek-McGregor, A. E., Nowacek, D. P., Parks, S. E., Tyack, P., & Madsen, P. T. (2019). Foraging Rates of Ram-Filtering North Atlantic Right Whales. *Functional Ecology, 33*(7), 1290-1306. https://doi.org/10.1111/1365-2435.13357

North Atlantic right whales spend their summer months foraging primarily in American and Canadian Atlantic waters on high-energy-density prey. Here, they rapidly accumulate and store energy obtained within a few months to support future migrations and reproduction while fasting. High drag from their ram-filter foraging strategy places a limit on what prey densities will be energetically efficient to target. Our understanding of the volume of prey-laden water filtered by right whales during a dive or foraging bout, and what information they use to decide to forage or not, has been limited by the difficulties of measuring when they feed at depth, how fast they swim during continuous ram filtration and how often they might swallow accumulated prey. We used 10 DTAG deployments from right whales in the Bay of Fundy, Canada, to quantify swimming speeds and estimate the volume of prey-laden water filtered per dive. We used the tag's inertial sensors to evaluate the timing of frequent biomechanical changes that likely indicate the truncation of continuous filtration, and whether the number or timing of these fluking bouts relates to longer feeding dives or other foraging decisions. During foraging dives, right whales descended at 1.4 (+/- 0.2 SD) m/s and slowed to swim at 1.1 (+/- 0.3) m/s while filtering. We found consistent pauses in the fluking behaviour of foraging right whales, every 56 (+/- 22) s. Whales filtered on average 78 (+/- 30) m(3) of water per fluking bout and on average 673 (+/- 201) m(3) per dive. Right whales filter large volumes of water at low speeds with a high duty cycle, but require sufficiently high prey energy densities to compensate for a high-drag foraging strategy. Closely related bowhead whales have a larger gape but swim more slowly, filtering greater volumes with lower drag. Our findings highlight that right whales acquire their energy in a relatively short period of intense foraging; even moderate changes in their feeding behaviour or their prey energy density are likely to negatively impact their yearly energy budgets and therefore reduce fitness substantially.

Vickers, W., Milner, B., Risch, D., & Lee, R. (2021). Robust North Atlantic Right Whale Detection Using Deep Learning Models for Denoising. *Journal of the Acoustical Society of America, 149*(6), 3797-3812. https://doi.org/10.1121/10.0005128

This paper proposes a robust system for detecting North Atlantic right whales by using deep learning methods to denoise noisy recordings. Passive acoustic recordings of right whale vocalisations are subject to noise contamination from many sources, such as shipping and offshore activities. When such data are applied to uncompensated classifiers, accuracy falls substantially. To build robustness into the detection process, two separate approaches that have proved successful for image denoising are considered. Specifically, a denoising convolutional neural network and a denoising autoencoder, each of which is applied to spectrogram representations of the noisy audio signal, are developed. Performance is improved further by matching the classifier training to include the vestigial signal that remains in clean estimates after the denoising process. Evaluations are performed first by adding white, tanker, trawler, and shot noises at signal-to-noise ratios from 10 to þ5 dB to clean recordings to simulate noisy conditions. Experiments show that denoising gives substantial improvements to accuracy, particularly when using the vestigial-trained classifier. A final test applies the proposed methods to previously unseen noisy right whale recordings and finds that denoising is able to improve performance over the baseline clean-trained model in this new noise environment.

Xu, K., Cai, H., Liu, X., Gao, Z., & Zhang, B. (2017). North Atlantic Right Whale Call Detection with Very Deep Convolutional Neural Networks. *Journal of the Acoustical Society of America, 141*(5), 3944-3945. https://doi.org/10.1121/1.4988946

Ship collision is one of the main threats to the North Atlantic right whale, which is in danger of extinction. One popular way to reduce the collision is monitoring for the occurrences of whales by detecting their sounds on data recordings. We explore the application of very deep convolutional neural network in this detection problem. For feature extraction, we compute Mel-frequency cepstral coefficients (MFCCs) along with their first and second temporal derivatives, and Fourier-transform-based filterbanks for all sound clips. MFCCs were calculated with Hamming window, and the filter-banks were calculated in range of 50—650 Hz, and include 72 coefficients, distributed on mel-scale, for each of the 97 time steps. For classifier modeling method, we apply the very deep convolutional Neural Network (CNN) in our task. The CNN architecture s 22 layers, which consists of alternating convolutional layer and pooling layer, while the last layers are full-connected neural network. Dropout is used in our fully connected layers with a rate of 0.4. By using the data provided by the Cornell University Whale Detection data, our model provides area under the ROC curve (AUC) performance of 0.985, which achieves the state-ofthe-art performance presently.

Section III: Population Abundance

Bogucki, R., Cygan, M., Khan, C. B., Klimek, M., Milczek, J. K., & Mucha, M. (2019). Applying Deep Learning to Right Whale Photo Identification. *Conservation Biology, 33*(3), 676-684. https://doi.org/10.1111/cobi.13226

Photo identification is an important tool for estimating abundance and monitoring population trends over time. However, manually matching photographs to known individuals is time-consuming. Motivated by recent developments in image recognition, we hosted a data science challenge on the crowdsourcing platform Kaggle to automate the identification of endangered North Atlantic right whales (*Eubalaena glacialis*). The winning solution automatically identified individual whales with 87% accuracy with a series of convolutional neural networks to identify the region of interest on an image, rotate, crop, and create standardized photographs of uniform size and orientation and then identify the correct individual whale from these passport-like photographs. Recent advances in deep learning coupled with this fully automated workflow have yielded impressive results and have the potential to revolutionize traditional methods for the collection of data on the abundance and distribution of wild populations. Presenting these results to a broad audience should further bridge the gap between the data science and conservation science communities.

Cole, T. V. N., Crowe, L. M., Corkeron, P. J., & Vanderlaan, A. S. M. (2020). *North Atlantic Right Whale Abundance, Demography and Residency in the Southern Gulf of St. Lawrence Derived from Directed Aerial Surveys.* 52-77.

During summer 2015, 2017 and 2018, we used aerial photo-identification to obtain estimates of stock size, abundance and residency time of North Atlantic right whales (*Eubalaena glacialis*) in the southern Gulf of St. Lawrence (GSL). Flights were made on four days in 2015, 15 days in 2017 and 26 days in 2018. Preliminary matching to the North Atlantic Right Whale Catalog identified a total of 153 individuals, of which 144 were matched to cataloged individuals and of the nine that were not, four were calves from

the previous year. The proportions of sex and age classes we saw in the GSL did not differ substantially from the North Atlantic population as a whole. Based on recognized individuals of known sex, adult males comprised 48.6-55.9% of the individuals seen each year, adult females 23.5-28.2%, juvenile males 8.4-12.4%, and juvenile females 4.6-9.5%. Mark-recapture techniques applied to the photographic capture of individuals in the study area during 2017 and 2018 resulted in abundance estimates of 111 and 132 whales, respectively, with few individuals undetected and apparent extended residency of individuals.

Crum, N. J., Neyman, L. C., & Gowan, T. A. (2021). Abundance Estimation for Line Transect Sampling: A Comparison of Distance Sampling and Spatial Capture-Recapture Models. *PLOS ONE, 16*(5), 1-17. https://doi.org/10.1371/journal.pone.0252231

Accurate and precise abundance estimation is vital for informed wildlife conservation and management decision-making. Line transect surveys are a common sampling approach for abundance estimation. Distance sampling is often used to estimate abundance from line transect survey data; however, search encounter spatial capture-recapture can also be used when individuals in the population of interest are identifiable. The search encounter spatial capture-recapture model has rarely been applied, and its performance has not been compared to that of distance sampling. We analyzed simulated datasets to compare the performance of distance sampling and spatial capture-recapture abundance estimators. Additionally, we estimated the abundance of North Atlantic right whales in the southeastern United States with two formulations of each model and compared the estimates. Spatial capture-recapture abundance estimates had lower root mean squared error than distance sampling estimates. Spatial capture-recapture 95% credible intervals for abundance had nominal coverage, i.e., contained the simulating value for abundance in 95% of simulations, whereas distance sampling credible intervals had below nominal coverage. Moreover, North Atlantic right whale abundance estimates from distance sampling models were more sensitive to model specification compared to spatial capture-recapture estimates. When estimating abundance from line transect data, researchers should consider using search encounter spatial capture-recapture when individuals in the population of interest are identifiable, when line transects are surveyed over multiple occasions, when there is imperfect detection of individuals located on the line transect, and when it is safe to assume the population of interest is closed demographically. When line transects are surveyed over multiple occasions, researchers should be aware that individual space use may induce spatial autocorrelation in counts across transects. This is not accounted for in common distance sampling estimators and leads to overly precise abundance estimates.

Estabrook, B. J., Hodge, K. B., Salisbury, D. P., Ponirakis, D., Harris, D. V., Zeh, J. M., . . . Rice, A. N. (2019). *Year-1 Annual Survey Report for New York Bight Whale Monitoring Passive Acoustic Surveys: October 2017 – October 2018.* D. o. M. Resources. Retrieved from https://www.dec.ny.gov/lands/113828.html

The Bioacoustics Research Program (BRP) at Cornell University's Lab of Ornithology was contracted by the NYSDEC, Division of Marine Resources to conduct a three-year passive acoustic monitoring survey within New York Bight (NY Bight) to assess marine mammal occurrence and patterns of ambient noise in this region. Six large whale species known to occur within NY Bight are the focus of this passive acoustic monitoring effort: North Atlantic right whales (*Eubalaena glacialis*), humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), sei whales (*Balaenoptera borealis*), blue whales

(*Balaenoptera musculus*), and sperm whales (*Physeter macrocephalus*). The objectives for this project are to: 1) Quantify the daily, monthly, and seasonal presence of the six large whale species found in NY Bight at all recording units. 2) Identify the spatial distribution of calling occurrence of focal whale species across NY Bight. 3) Characterize spatial and temporal patterns of ambient noise across NY Bight. 4) Describe acoustic masking potential that the different whale species encounter as they move through NY Bight. Fifteen archival recording devices were deployed along two transect lines spanning the NY Bight to record whale sounds and noise levels in the study area. These transects parallel the two major shipping lanes entering and leaving NY Harbor (Nantucket-Ambrose and Ambrose-Hudson Canyon Lanes). Of these 15 recording devices, 10 were Cornell University's Marine Autonomous Recording Units (MARUs), and 5 were JASCO's third generation Autonomous Multichannel Acoustic Recorders (AMARs). Each deployment of MARUs recorded continuously for approximately 4 months at a 5 kHz sampling frequency, while AMARs recorded continuously for approximately 8 months at an 8 kHz sampling frequency. Whale sounds were identified using a combination of human visual analysis and species-specific automated detection algorithms with human review to eliminate false positives. Whale presence and noise levels were reported at daily, monthly, and seasonal temporal resolution across Year-1. All of the focal species were detected in the New York Bight in Year-1. North Atlantic right whales, fin whales, and humpback whales were detected during every month of the recording period. Right whales showed peak presence between November and January. Humpback whales had the lowest daily presence per month in October and highest in February and May. Sei whales were present during all months except September. Fin whales were the most commonly detected large whale species, with presence throughout the year. Peak fin whale presence was bimodal, occurring in winter and again during the summer. Blue whales were only detected at sites in the northern transect, between November and February, with peak daily presence in February. Sperm whales were detected at low levels (<10% of days per month) in all months analyzed on the AMARs. Ambient noise levels in the NY Bight were high. The median sound level was estimated to reduce the typical whale detection range distances by more than 50-75%, significantly reducing the effective communication range of these whale species as well as their detectability on passive acoustic survey instruments.

Fitzgerald, K. (2018). Combing Genetic and Photo-Identification Data to Improve Abundance Estimates for the North Atlantic Right Whale. In *Saint Mary's University*. Halifax Nova Scotia. Retrieved from http://library2.smu.ca/handle/01/27525

Accurate abundance estimates are important for the management of species. Many abundance estimates are based off of capture-mark-recapture analyses which have several limitations that can reduce the accuracy of abundance estimates. By integrating pedigrees into abundance estimates, the accuracy of these estimates can be improved. In this study, a method created by Creel and Rosneblatt (2013) was adapted and used to estimate abundance of the North Atlantic Right Whale (*Eubalaena glacialis*). Both genetic and sightings data, obtained from the North Atlantic Right Whale Consortium, were used to estimate abundance. This method is compared to the photo-identification method typically used to estimate abundance for this species. The results of this study suggest that the photoidentification method for this species is actually more accurate than other researchers have previously believed.

Ganley, L. C. (2020). Identifying Drivers of and Quantifying North Atlantic Right Whale Local Abundance. In *University of Massachusetts Boston*: University of Massachusetts Boston.

North Atlantic right whales (*Eubalaena glacialis*) are verging on extinction. The purpose of this dissertation is to quantify local right whale abundance and use biological and physical predictors to explain the variations in abundance. I estimated local abundance using distance sampling methodology of line transect aerial survey data collected in and around Cape Cod Bay. I measured the time a whale would be in view from the aircraft, and collected dive and surface time data to estimate availability bias, which varied monthly (from 0.27 to 0.85). Right whale population estimates increased from 1990 to 2010, and have since declined; however, local abundance estimates in peak months increased at a faster rate (10% yr-1) than the population, with large monthly and yearly variations. To identify the mechanisms driving local abundance I constructed three structural equation models including local (Cape Cod Bay), regional (Gulf of Maine), and basin-wide (North Atlantic) variables. Population size and zooplankton patchiness had a direct positive relationship (90% credible intervals (CI) = 1.00 = 1.01, and 1.02 = 1.18), and the spring transition date had a direct negative effect on local abundance (90% CI = 0.88 – 0.97). The direct relationship between regional *C. finmarchicus* density and local abundance varied by month (90% CIs: January = 0.9997 – 0.9999, February = 0.99 – 1.00, March = 0.99 – 1.00, April = 0.99 – 1.00, May = 0.99 – 1.00). It is virtually certain that years of earlier spring transition dates had higher local abundance than years of later spring transition dates (>= 99%). The total effect of the NAO 2 yr-lag on local abundance depended on the month. It was about as likely as not that higher Gulf Stream North Wall latitudes had higher local abundance than years of lower latitudes (51% - 63%). My study identifies key variables to track when predicting local habitat use as the Gulf of Maine continues to change. Understanding the differential impact of climate change on these drivers will be imperative for crafting conservation measures.

Ganley, L. C., Brault, S., & Mayo, C. A. (2019). What We See Is Not What There Is: Estimating North Atlantic Right Whale *Eubalaena glacialis* Local Abundance. *Endangered Species Research, 38*, 101-113. https://doi.org/10.3354/esr00938

Aerial surveys can be used to estimate animal abundance, but animals unavailable for detection for portions of the survey can cause biased abundance estimates. Moreover, these biases may be variable owing to changes in behavior. We conducted focal follows to obtain surface and dive times of North Atlantic right whales *Eubalaena glacialis* in Cape Cod Bay (CCB) and measured the aircraft field of view; these metrics were combined to estimate availability and correct monthly abundance estimates from 1998 to 2017 generated via distance sampling methodology. We used a general least squares model to test for trends in abundance. Availability varied with month (0.27-0.85), likely linked to changes in the depth of copepod food resources. Detection probability varied across the years (0.43-0.87). Sightings per unit effort and counts of whales were significant, but downward-biased indicators of abundance and availability caused changes in bias over the season. Estimated abundance in CCB increased during the study period (4.9 whales yr(-1)), and estimated abundance in peak months increased at a faster rate (10% yr(-1) for 1998-2017) than for the overall population (2.8% yr(-1) for 1990-2010). Accurate abundance estimates are necessary to monitor long-term changes in abundance of right whales in CCB, to understand the importance of CCB relative to other areas, and improve management strategies to protect this endangered species from entanglements in fishing gear and ship-strikes. Failing to correct for seasonal variation in availability results in substantial and variable underestimation of abundance.

Gowan, T. A., Crum, N. J., & Roberts, J. J. (2021). An Open Spatial Capture–Recapture Model for Estimating Density, Movement, and Population Dynamics from Line-Transect Surveys. *Ecology and Evolution*. https://doi.org/10.1002/ece3.7566

The purpose of many wildlife population studies is to estimate density, movement, or demographic parameters. Linking these parameters to covariates, such as habitat features, provides additional ecological insight and can be used to make predictions for management purposes. Line-transect surveys, combined with distance sampling methods, are often used to estimate density at discrete points in time, whereas capture-recapture methods are used to estimate movement and other demographic parameters. Recently, open population spatial capture-recapture models have been developed, which simultaneously estimate density and demographic parameters, but have been made available only for data collected from a fixed array of detectors and have not incorporated the effects of habitat covariates. We developed a spatial capture-recapture model that can be applied to line-transect survey data by modeling detection probability in a manner analogous to distance sampling. We extend this model to a) estimate demographic parameters using an open population framework and b) model variation in density and space use as a function of habitat covariates. The model is illustrated using simulated data and aerial line-transect survey data for North Atlantic right whales in the southeastern United States, which also demonstrates the ability to integrate data from multiple survey platforms and accommodate differences between strata or demographic groups. When individuals detected from line-transect surveys can be uniquely identified, our model can be used to simultaneously make inference on factors that influence spatial and temporal variation in density, movement, and population dynamics.

Kabani, A., & El-Sakka, M. R. (2017). North Atlantic Right Whale Localization and Recognition Using Very Deep and Leaky Neural Network. *Mathematics for Applications, 5*(2), 155-170. https://doi.org/10.13164/ma.2016.11

We describe a deep learning model that can be used to recognize individual right whales in aerial images. We developed our model using a data set provided by the National Oceanic and Atmospheric Administration. The main challenge we faced when working on this data set is that the size of the training set is very small (4,544 images) with some classes having only 1 image. While this data set is by far the largest of its kind, it is very difficult to train a deep neural network with such a small data set. However, we were able to overcome this challenge by dividing this problem into smaller tasks and by reducing the viewpoint variance in the data set. First, we localize the body and the head of the whale using deep learning. Then, we align the whale and normalize it with respect to rotation. Finally, a network is used to recognize the whale by analyzing its callosities. The top-1 accuracy of the model is 69.7% and the top-5 accuracy is 85%. The solution we describe in this paper was ranked 5th (out of 364 teams) in a challenge to solve this problem.

Kenney, R. D. (2018). What If There Were No Fishing? North Atlantic Right Whale Population Trajectories without Entanglement Mortality. *Endangered Species Research, 37*, 233-237. https://doi.org/10.3354/esr00926

The North Atlantic right whale *Eubalaena glacialis*, one of the world's rarest mammals, experienced an alarming level of mortality in 2017. The estimated abundance as of 2016 was 451 animals. After 20 yr of relatively steady but slow growth, the population has declined since 2010. Mortality and serious injury from entanglement in commercial fishing gear have had a significant impact on recovery. Despite legal

requirements to reduce fishery-related mortality, little or no real progress has been made over the last 2 decades. Here I took a relatively simple approach to estimate what the population trajectory since 1990 might have been under 4 different scenarios of reduced entanglement mortality. Under the best-case scenarios, the population at the end of the time-series would have been 25-30% higher than observed at present. If the population had not experienced nearly 3 decades of increasing entanglement, it could have been much more resilient to a disaster year like 2017.

Laist, D. W. (2017). Estimating Pre-Exploitation Population Size. In *North Atlantic Right Whales: From Hunted Leviathan to Conservation Icon.* (pp. 251-265): JOHNS HOPKINS UNIV PRESS

No abstract.

New, L. (2020). *Center for Independent Experts (CIE) External Independent Peer Review for "Predictive Modeling of North Atlantic Right Whale Population".*

To meet their requirements to use the best scientific information available, and to strengthen scientific quality assurance on issues related to fishery conservation and management action, the National Marine Fisheries Service (NMFS) has sought external, independent review of their predictive model exploring the effects of mortality due to entanglement in fishing gear on North Atlantic right whales (*Eubalaena glacialis*). The Terms of Reference requested that reviewers consider whether NMFS has used the best available data, chose to use an appropriate time period (2010-2018), and whether the scientific conclusions and interpretations were sound. NMFS has used the best available data in their assessment, although it should be acknowledged that assumptions that were made regarding an independent relationship between a female's fecundity and entanglement represent a worst case scenario. While currently there are no data available on this topic that could be incorporated into NMFS' model, so there is no need change the current approach in this regard, it is something that needs to be made explicit in the report as it may result in overly pessimistic conclusions. The time-period NMFS has chosen, 2010-2018, is in many ways the most appropriate. However, the assumption that the conditions of those eight years will continue for 50 years into the future is a strong one, especially given the observed variability in calving from 1990-2018. NMFS partially addresses this assumption in Supplement 4 of their report (which contained the population projections using fertility rates from 1990-2018), but it needs to be explored more fully through explicit scenarios. The scientific conclusions and interpretations in the report are sound, but need to be better supported analytically in order to have greater confidence in their use within the Section 7 consultation. Model validation and testing (i.e., asymptotic, ergodic and perturbation analyses) need to be conducted, and the uncertainty inherent in the estimates of the number of whales to die as a result of entanglement in fishing gear needs to be accounted for in the model. Overall, NMFS has used the best scientific information available to inform their predictive model of the North Atlantic right whale population. All the recommendations are to add information that will strengthen NMFS' science and increase the transparency of the assessment.

Pace, R. M., Corkeron, P. J., & Kraus, S. D. (2017). State–Space Mark–Recapture Estimates Reveal a Recent Decline in Abundance of North Atlantic Right Whales. *Ecology and Evolution, 7*(21), 8730-8741. https://doi.org/10.1002/ece3.3406

North Atlantic right whales (*Eubalaena glacialis* Muller 1776) present an interesting problem for abundance and trend estimation in marine wildlife conservation. They are long lived, individually identifiable, highly mobile, and one of the rarest of cetaceans. Individuals are annually resighted at different rates, primarily due to varying stay durations among several principal habitats within a large geographic range. To date, characterizations of abundance have been produced that use simple accounting procedures with differing assumptions about mortality. To better characterize changing abundance of North Atlantic right whales between 1990 and 2015, we adapted a state-space formulation with Jolly-Seber assumptions about population entry (birth and immigration) to individual resighting histories and fit it using empirical Bayes methodology. This hierarchical model included accommodation for the effect of the substantial individual capture heterogeneity. Estimates from this approach were only slightly higher than published accounting procedures, except for the most recent years (when recapture rates had declined substantially). North Atlantic right whales' abundance increased at about 2.8% per annum from median point estimates of 270 individuals in 1990 to 483 in 2010, and then declined to 2015, when the final estimate was 458 individuals (95% credible intervals 444-471). The probability that the population's trajectory post-2010 was a decline was estimated at 99.99%. Of special concern was the finding that reduced survival rates of adult females relative to adult males have produced diverging abundance trends between sexes. Despite constraints in recent years, both biological (whales' distribution changing) and logistical (fewer resources available to collect individual photo-identifications), it is still possible to detect this relatively recent, small change in the population's trajectory. This is thanks to the massive dataset of individual North Atlantic right whale identifications accrued over the past three decades. Photo-identification data provide biological information that allows more informed inference on the status of this species.

Pace, R. M., Williams, R., Kraus, S. D., Knowlton, A. R., & Pettis, H. M. (2021). Cryptic Mortality of North Atlantic Right Whales. *Conservation Science and Practice, 3*(2). https://doi.org/10.1111/csp2.346

Evaluations of the conservation status of the endangered North Atlantic right whale as well as many other wildlife species often rely extensively on counts and cause-of-death determinations of carcasses found accidentally or during dedicated surveys. Even when survey effort dedicated to a population is extensive, many deaths may go unseen. We used an abundance estimation model to derive estimates of cryptic mortality for North Atlantic right whales and found that observed carcasses accounted for only 36% of all estimated death during 1990-2017. We found strong evidence that total mortality varied over time, and that observed carcass counts were poor predictors of estimated annual numbers of whales dying. Importantly, there were substantial differences between fractions of deaths determined to be entanglement related during necropsy (49%) and the fraction of cryptic deaths suffering serious injuries related to entanglement (87%). Although we concluded that a single year's observations produced poor estimates of carcass detection rates due to the volatility of ratios of small counts, ratio estimates of data pooled over periods of consistent survey may offer better information on detection rates. Additionally, it appears unwise to consider cause of death determinations from detected carcasses as representative of cause-specific mortality rates in right whales given the large number of seriously injured whales from entanglement that are likely part of the unseen mortality.

Surrey-Marsden, C., Accardo, C., White, M., George, C., Gowan, T., Hamilton, P. K., . . . Zoodsma, B. J. (2018). *North Atlantic Right Whale Calving Area Surveys: 2016/2017 Results.* https://doi.org/10.25923/ybgc-k086

Aerial surveys are flown December 1 through March 31 each year in the Southeast United States (U.S.) to detect North Atlantic right whales (*Eubalaena glacialis*) in their primary calving area. The purpose of the aerial surveys is to contribute to (in prioritized order): Population monitoring via detection and identification of individual right whales including cow/calf pairs occurring in the Southeast U.S. Monitoring trends in human-related serious injuries and mortality. Vessel-strike reduction.

Tetra Tech Inc., & LGL. (2019). *Year 2 Annual Survey Report for New York Bight Whale Monitoring Aerial Surveys, March 2018 – February 2019.* Division of Marine Resources.Albany, NY.

Tetra Tech, Inc. (Tetra Tech), in coordination with LGL Ecological Research Associates, Inc. and subcontractor Aspen Helicopters, Inc. (collectively, the "survey team"), was contracted by the New York State Department of Environmental Conservation (NYSDEC) Division of Marine Resources to conduct 36 monthly aerial line-transect visual observation surveys focused on six priority large whale species found in the New York Bight (NYB). The project is titled "New York Bight Whale Monitoring Aerial Surveys." This report presents data collected during Survey Year 2 (March 2018 through February 2019), and includes survey goals, objectives, data collection and analysis methodologies, and results. Results from Survey Year 1 (March 2017 through February 2018) were presented in the first-year summary report submitted to the NYSDEC in May of 2018 and available online (Tetra Tech 2018). The six large whale species that are the focus of aerial surveys and are referred to herein as "priority" or "priority large" whales are the North Atlantic right whale (*Eubalaena glacialis*), fin whale (*Balaenoptera physalus*), humpback whale (Megaptera novaeangliae), sei whale (B. borealis), sperm whale (*Physeter macrocephalus*), and blue whale (B. musculus). However, since all large whales are of interest to NYSDEC, all whale sightings were documented regardless of species. Of the priority large whales, five are listed as "endangered" under the U.S. Endangered Species Act (ESA): North Atlantic right, fin, sei, sperm, and blue. The humpback whale stock in the NYB was delisted from the ESA in 2016 (81 Federal Register 62259). The survey team opportunistically documented sightings of sea turtles when it would not interfer with efforts to search for priority large whales. The four species of sea turtles known to occur in the survey region are the green sea turtle (Chelonia mydas), Kemp's ridley sea turtle (Lepidochelys kempii), loggerhead sea turtle (Caretta caretta), and leatherback sea turtle (Dermochelys coriacea). The survey team also opportunistically documented sightings of other marine mammals such as small cetaceans, and other marine species such as sharks, rays, fish schools, etc., when it would not interfere with efforts to detect large whales.

Tetra Tech Inc., & Smuelta Environmental Sciences LLC. (2018). *February 2018 Survey Report for New York Bight Whale Monitoring Aerial Surveys.* division of Marine Resources.Albany, NY. Retrieved from https://www.dec.ny.gov/lands/113818.html

Tetra Tech, Inc., in coordination with Smultea Environmental Sciences, LLC and Aspen Helicopters, Inc. (collectively, the "survey team"), is contracted by the New York State Department of Environmental Conservation (NYDEC), Division of Marine Resources to conduct 36 monthly line-transect aerial surveys focused on the six large whale species most likely to occur in the New York Bight. This survey report

documents the survey effort and sightings from the February 2018 survey, representing the 12th of the 36 surveys scheduled to occur under this contract.

Tetra Tech Inc., & Smuelta Environmental Sciences LLC. (2018). *January 2018 Survey Report for New York Bight Whale Monitoring Aerial Surveys.* Division of Marine Resources.Albany, NY. Retrieved from https://www.dec.ny.gov/lands/113818.html

Tetra Tech, Inc., in coordination with Smultea Environmental Sciences, LLC and Aspen Helicopters, Inc. (collectively, the "survey team"), is contracted by the New York State Department of Environmental Conservation (NYDEC), Division of Marine Resources to conduct 36 monthly line-transect aerial surveys focused on the six large whale species most likely to occur in the New York Bight. This survey report documents the survey effort and sightings from the January 2018 survey, representing the eleventh of the 36 surveys scheduled to occur under this contract.

Tetra Tech Inc., & Smultea Environmental Sciences LLC. (2018). *March 2018 Survey Report for New York Bight Whale Monitoring Aerial Surveys.* Division of Marine Resources.Albany, NY. Retrieved from https://www.dec.ny.gov/lands/113818.html

Tetra Tech, Inc., in coordination with Smultea Environmental Sciences, LLC and Aspen Helicopters, Inc. (collectively, the "survey team"), is contracted by the New York State Department of Environmental Conservation (NYDEC), Division of Marine Resources to conduct 36 monthly line-transect aerial surveys focused on the six large whale species most likely to occur in the New York Bight. This survey report documents the survey effort and sightings from the March 2018 survey, representing the 13th of the 36 surveys scheduled to occur under this contract.

Tetra Tech Inc., & Smultea Environmental Sciences LLC. (2018). *Year 1 Annual Survey Report for New York Bight Whale Monitoring Aerial Surveys.* Division of Marine Resources.Albany, NY. Retrieved from https://www.dec.ny.gov/lands/113818.html

Tetra Tech, Inc. (Tetra Tech), in coordination with subcontractor Smultea Environmental Sciences, LLC (Smultea Sciences), and subcontractor Aspen Helicopters, Inc., has been contracted by the New York State Department of Environmental Conservation (NYSDEC) Division of Marine Resources to conduct 36 monthly line-transect aerial surveys. Surveys focused on six large whale species (referred to herein as "priority" or "priority large") in the New York Bight (NYB), for the project titled "New York Bight Whale Monitoring Aerial Surveys." The NYB study area (NYB Survey Area) is a 43,449 square kilometers (km2) (12,668-square nautical mile [nm2]) area of ocean from the south shore of Long Island to the continental shelf break, matching the New York Department of State's "Offshore Planning Area (OPA)." The six species of large whales that are the focus of aerial surveys are the North Atlantic right whale (*Eubalaena glacialis*), fin whale (*Balaenoptera physalus*), humpback whale (Megaptera novaeangliae), sei whale (B. borealis), sperm whale (*Physeter macrocephalus*), and blue whale (B. musculus). The reported results of Survey Year 1 findings from the first longitudinal multi-year intensive systematic visual aerial survey effort in the NYB Survey Area focused on the target priority large whale species. Although numbers of sightings by species are relatively small, results provide new insight into the occurrence, relative abundance, distribution, behavior, and preliminary densities and abundance of these species in the NYB.

Yeager, A. (2018). Endangered Whale Not Having Babies. *The Scientist, 237,* 6-6. https://doi.org/10.1016/S0262-4079(18)30366-X

The article reports that whales (*Eubalaena glacialis*) are known as endangered species with zero record of calves born on the breeding season of November to February wherein mostly are due to entangled in fishing gear in North Atlantic.

Section IV: Threats & Conservation

Anonymous. (2018). Canada Protects Critical Habitat for Eight Species. *Sea Technology, 59*(2), 36.

The government of Canada has signed eight Critical Habitat Orders under the Species at Risk Act. The approved orders will allow for further protection of eight at-risk species, including two whales (the North Atlantic right whale and beluga whale of the St. Lawrence Estuary), three fish species (spotted gar, eastern sand darter, Rocky Mountain sculpin), and one mollusc species (northern abalone). Also approved is the Proposed Critical Habitat Orders of the northern bottlenose whale and the lake chubsucker fish species.

Baumgartner, M. F., Ball, K., Partan, J., Pelletier, L.-P., Bonnell, J., Hotchkin, C., . . . Van Parijs, S. M. (2021). Near Real-Time Detection of Low-Frequency Baleen Whale Calls from an Autonomous Surface Vehicle: Implementation, Evaluation, and Remaining Challenges. *The Journal of the Acoustical Society of America, 149*(5), 2950-2962. https://doi.org/10.1121/10.0004817

Mitigation of threats posed to marine mammals by human activities can be greatly improved with a better understanding of animal occurrence in real time. Recent advancements have enabled low-power passive acoustic systems to be integrated into long-endurance autonomous platforms for persistent near real-time monitoring of marine mammals via the sounds they produce. Here, the integration of a passive acoustic instrument capable of realtime detection and classification of low-frequency (LF) tonal sounds with a Liquid Robotics wave glider is reported. The goal of the integration was to enable monitoring of LF calls produced by baleen whales over periods of several months. Mechanical noises produced by the platform were significantly reduced by lubricating moving parts with polytetrafluoroethylene, incorporating rubber and springs to decelerate moving parts and shock mounting hydrophones. Flow noise was reduced with the development of a 21-element hydrophone array. Surface noise produced by breaking waves was not mitigated despite experimentation with baffles. Compared to a well-characterized moored passive acoustic monitoring buoy, the system greatly underestimated the occurrence of sei, fin, and North Atlantic right whales during a 37-d deployment, and therefore is not suitable in its current configuration for use in scientific or management applications for these species at this time.

Baumgartner, M. F., Bonnell, J., Van Parijs, S. M., Corkeron, P. J., Hotchkin, C., Ball, K., . . . Kraus, S. D. (2019). Persistent near Real-Time Passive Acoustic Monitoring for Baleen Whales from a Moored Buoy: System Description and Evaluation. *Methods in Ecology and Evolution, 10*(9), 1476-1489. https://doi.org/10.1111/2041-210x.13244

Managing interactions between human activities and marine mammals often relies on an understanding of the real-time distribution or occurrence of animals. Visual surveys typically cannot provide persistent monitoring because of expense and weather limitations, and while passive acoustic recorders can monitor continuously, the data they collect are often not accessible until the recorder is recovered. We have developed a moored passive acoustic monitoring system that provides near real-time occurrence estimates for humpback, sei, fin and North Atlantic right whales from a single site for a year, and makes those occurrence estimates available via a publicly accessible website, email and text messages, a smartphone/tablet app and the U.S. Coast Guard's maritime domain awareness software. We evaluated this system using a buoy deployed off the coast of Massachusetts during 2015-2016 and redeployed again during 2016-2017. Near real-time estimates of whale occurrence were compared to simultaneously collected archived audio as well as whale sightings collected near the buoy by aerial surveys. False detection rates for right, humpback and sei whales were 0% and nearly 0% for fin whales, whereas missed detection rates at daily time scales were modest (12%-42%). Missed detections were significantly associated with low calling rates for all species. We observed strong associations between right whale visual sightings and near real-time acoustic detections over a monitoring range 30-40 km and temporal scales of 24-48 hr, suggesting that silent animals were not especially problematic for estimating occurrence of right whales in the study area. There was no association between acoustic detections and visual sightings of humpback whales. The moored buoy has been used to reduce the risk of ship strikes for right whales in a U.S. Coast Guard gunnery range, and can be applied to other mitigation applications.

Best, B. D., & Halpin, P. N. (2019). Minimizing Wildlife Impacts for Offshore Wind Energy Development: Winning Tradeoffs for Seabirds in Space and Cetaceans in Time. *PLOS ONE, 14*(5), e0215722. https://doi.org/10.1371/journal.pone.0215722

Although offshore wind energy development (OWED) offers a much-needed renewable energy alternative to fossil fuels, holistic and effective methods for evaluating environmental impacts on wildlife in both space and time have been lacking. The lengthy environmental compliance process, estimated to incur a 7-10 year permitting timeline [1], has been identified as a significant impediment to offshore energy development in U.S. waters. During operation, seabirds can collide and be displaced by turbines. During episodic pre-operation phases, cetaceans are most heavily impacted acoustically by pile driving (and similarly seismic air gun surveys for oil and gas exploration). The varying nature of impacts in space and time leads us to conclude that sites should be selected in space to minimize long-term operational impacts on seabirds, and timing of surveying and construction activities to be conducted in times of the year when sensitive migratory marine mammals are least present. We developed a novel spatiotemporal decision support framework that interactively visualizes tradeoffs between OWED industry profits and wildlife sensitivities, in both space and time. The framework highlights sites on a map that are the most profitable and least sensitive to seabirds. Within the U.S. Mid-Atlantic study area, the New York Call Areas are particularly well optimized for minimal impact on seabirds with maximal profits to OWED. For a given site, pre-operational activities (e.g. pile driving and seismic air gun surveying) are advised by cetacean sensitivity across months of the year that minimize impacts on migratory cetaceans, particularly those of highest conservation concern such as the North Atlantic right

whale (*Eubalaena glacialis*). For instance, within optimal sites for the New York Call Area the least impacting months are May and June. Other taxa are certainly affected by OWED and should be incorporated into this framework, but data on their distributions and/or sensitivities is currently less well known. Built with open-source software made publicly available, the authors hope this framework will be extended even more comprehensively into the future as our knowledge on species distributions and OWED sensitivities expands for streamlining environmental compliance.

Boivin-Rioux, A., Starr, M., Chasse, J., Scarratt, M., Perrie, W., & Long, Z. X. (2021). Predicting the Effects of Climate Change on the Occurrence of the Toxic Dinoflagellate Alexandrium Catenella Along Canada's East Coast. *Frontiers in Marine Science, 7*. https://doi.org/10.3389/fmars.2020.608021

Alexandrium catenella produces paralytic shellfish toxins that affect marine fisheries and aquaculture as well as ecosystem and human health worldwide. This harmful algal species is extremely sensitive to environmental conditions and potentially to future climate change. Using a generalized additive mixed model (GAMM) we studied the potential effects of changing salinity and temperatures on A. catenella bloom (>= 1000 cells L-1) occurrence along Canada's East Coast throughout the 21st century. Our GAMM was applied to two high greenhouse gas emissions scenarios (RCP 8.5) and one mitigation scenario (RCP 4.5). Under present-day conditions, our model successfully predicted A. catenella's spatio-temporal distribution in Eastern Canada. Under future conditions, all scenarios predict increases in bloom frequency and spatial extent as well as changes in bloom seasonality. Under one RCP 8.5 scenario, A. catenella bloom occurrences increased at up to 3.5 days per decade throughout the 21st century, with amplified year-to-year variability. Blooms expended into the Gulf of St. Lawrence and onto the Scotian Shelf. These conditions could trigger unprecedented bloom events in the future throughout our study region. In all climate scenarios, the bloom season intensified earlier (May-June) and ended later (October). In some areas of the Gulf of St. Lawrence, the thermal habitat of *A. catenella* was exceeded, thereby locally reducing bloom risk during the summer months. We conclude that an increase in *A. catenella's* environmental bloom window could further threaten marine fauna including endangered species as well as fisheries and aquaculture industries on Canada's East Coast. Similar impacts could be felt in other coastal regions of the globe where warming and freshening of waters are intensifying.

Borggaard, D. L., Gouveia, D. M., Colligan, M. A., Merrick, R., Swails, K. S., Asaro, M. J., . . . Higgins, J. (2017). Managing Us Atlantic Large Whale Entanglements: Four Guiding Principles. *Marine Policy, 84*, 202-212. https://doi.org/10.1016/j.marpol.2017.06.027

Fatal entanglements in fishing gear threaten marine mammal populations worldwide. The management of entanglements of large whales, such as the North Atlantic right whale (*Eubalaena glacialis*), with commercial fisheries, is a challenge given the species' small population size, economic consequences of regulations, and the general lack of data on entanglements. The U.S. Marine Mammal Protection Act (MMPA) requires development of programs to limit marine mammal entanglement in commercial fishing gear. Following a retrospective look at implementing aspects of the MMPA, a set of guiding principles were developed with associated best practices useful in reducing fatal large whale entanglement in fishing gear. Among these are: 1) involve stakeholders early in the decision making process; 2) establish a transparent management strategy that includes critical needs to guide research; 3) use a variety of tools such as an established process for receiving new information and ideas; and 4) incorporate adaptive management which considers the constraints of dynamic (rapid) changes to some

fixed fishing gear. Efforts to reduce worldwide marine mammal bycatch will typically occur in a data limited environment as experienced with U.S. Atlantic large whale entanglements. The guiding principles will remain as key tools for reducing large whale bycatch in fisheries as they build upon common practices. These insights developed over two decades of management can potentially help others to address similar bycatch problems.

Bowen, W. (2019). *Independent Peer Review of the North Atlantic Right Whale Decision Support Tool.*

The Atlantic Large Whale Take Reduction Team (ALWTRT) is responsible for the development and implementation of measures to reduce the risks of entanglement of North Atlantic Right Whales (NARW) in vertical lines associated with lobster trap/pot gear, or other fixed gear in Atlantic USA waters. To better understand this risk and, particularly, the potential impact of management measures designed to address it, NMFS requires information on the risks of entanglement and injury associated with vertical line used by fishing operations. In April 2019, the National Marine Fisheries Service (NMFS) introduced a North Atlantic Right Whale Decision Support Tool (DST) to help understand relative risk of entanglement in different geographic locations, and, most importantly, the reduction in relative risk based on different proposed mitigation scenarios. This report represents my independent review of the scientific information and mathematical approach used in the DST based on the following Terms of Reference: 1. Evaluate the data inputs (e.g., spatial and seasonal gear configuration, spatial and seasonal right whale distribution, etc.) used in the Decision Support Tool. 2. Evaluate the data outputs (e.g., vertical line estimates, relative risk to right whales, etc.) produced by the Decision Support Tool. 3. Comment on the appropriateness of using the Decision Support Tool as an approach to evaluate relative entanglement risk to right whales and advise on the strengths and weaknesses of using the DST to compare management measures. The goal is to understand the relative risk of entanglement in different geographic locations and the reduction in relative risk based on different proposed mitigation scenarios. 4. Provide research recommendations for further improvement of the Decision Support Tool. 5. Evaluate whether the methods represent the best available scientific approach for apportioning anthropogenic mortality by country.

Brillant, S. W., Wimmer, T., Rangeley, R. W., & Taggart, C. T. (2017). A Timely Opportunity to Protect North Atlantic Right Whales in Canada. *Marine Policy, 81*, 160-166. https://doi.org/10.1016/j.marpol.2017.03.030

The survival of federally protected North Atlantic right whales (*Eubalaena glacialis*) requires an immediate reduction in the risk of entanglement in commercial fishing gear. This paper argues that at least a 30% reduction in risk is needed to meaningfully contribute to the conservation of right whales. The argument follows from risk estimates calculated using time and space intersections of right whales and fishing gear in Canadian waters. Almost all the risk occurs during July, August and September (12%, 50%, 37% respectively) and the groundfish fishery contributed the greatest proportion (86%) of annual risk. Given that efforts in the USA to reduce entanglement risk through modified fishing gear have been unsuccessful to date, we address the alternative option of restricting certain fishing gear at times and locations where entanglement risk is elevated. There are many options that Canada could employ to achieve the above risk reduction and our results clearly point to the most effective and efficient action being seasonally restricted fishing in two relatively small regions; the Grand Manan Basin and the Roseway Basin. Fully a third (34% +/- 4%) of the annual risk is associated with these two basins, though fishery catch estimates in the basins are relatively small and declining.

Canadian Science Advisory Secretariat. (2019). *Review of North Atlantic Right Whale Occurrence and Risk of Entanglements in Fishing Gear and Vessel Strikes in Canadian Waters.* Fisheries and Oceans Canada Ottawa.

In Canada, the North Atlantic Right Whale (NARW) is listed as Endangered under Schedule 1 of the Species at Risk Act (SARA). SARA specifies requirements for legal protection and mandatory recovery planning, which is managed by the Department of Fisheries and Oceans (DFO). The NARW SARA Recovery Strategy describes threats to the species, recovery objectives, and approaches for achieving these objectives. Recovery objectives include reducing mortality and injury from vessel strikes and entanglements in fishing gear, the two main documented sources of mortalities. In 2017, twelve NARW were found dead in the Gulf of St. Lawrence (GSL). Necropsies conducted on seven of these carcasses concluded that four animals died from blunt trauma consistent with vessel strikes, two from entanglement in fishing gear, and in one case the cause of death was not conclusive. In addition, there were five live entanglements documented, two of which were disentangled while one animal shed the gear. The outcome of the final two entanglements is unknown. In response to the vessel strike mortalities, the Government of Canada implemented a voluntary 10- knot speed restriction zone for vessels greater than 20 metres [65 feet] in length navigating in the GSL beginning 10 July 2017. On 11 August, this measure was revised to a mandatory 10 knot speed restriction zone which remained in place until January 2018. In 2018, a combination of areas with no restrictions and static and dynamic speed restriction zones for vessels 20 metres or longer was established in the GSL. This management approach ran from 28 April until 15 November. After 15 November, 2018 vessels were asked to voluntarily reduce their speed to not exceed 10 knots in the presence of NARW. The objectives of this meeting were to (1) determine, to the extent possible with available data, the spatial and temporal distribution of NARW in Canadian waters, based on aerial and vessel-based surveys, acoustic data collected from moorings, buoys and autonomous underwater vehicles (gliders), and other biological data; and, (2) determine the risks to NARW from entanglement in invertebrate fishing gear and from vessel strikes in the Gulf of St. Lawrence. These objectives were met by providing answers to a series of questions that were provided. This Science Advisory Report is from the National Marine Peer Review Committee (NMMPRC) 2018 Meeting I: Review of North Atlantic right whale occurrence and risk of interactions with fishing gear and collision with vessels, held November 26-30, 2018, in Montreal, Quebec.

Cholewiak, D., Clark, C. W., Ponirakis, D., Frankel, A., Hatch, L. T., Risch, D., . . . Van Parijs, S. M. (2018). Communicating Amidst the Noise: Modeling the Aggregate Influence of Ambient and Vessel Noise on Baleen Whale Communication Space in a National Marine Sanctuary. *Endangered Species Research, 36*, 59-75. https://doi.org/10.3354/esr00875

Anthropogenic noise negatively impacts many species One of the more insidious effects of elevated noise levels is the reduction in area ovei which animals are able to acoustically communicate, often termed communication masking. This study utilizes modeling approaches to evaluate relative levels of masking for 4 baleen whale species from the combination of current ambient noise conditions and noise from discrete vessels operating in the Stellwagen Bank National Marine Sanctuary. Acoustic data were collected using bottom-mounted autonomous recorders. One day was analyzed for each of 5 different species-specific sound types, corresponding to peaks in occurrence of fin and humpback whale songs, humpback whale social sounds, minke whale pulse trains and North Atlantic right whale gunshots.

Source levels for animals and 3 categories of vessels were calculated empirically, sound propagation was modeled using Bellhop ray tracing. An agent-based modeling framework was used to calculate changes in communication space (CS) in comparison to reference conditions (10 dB lower than current ambient noise) In these singleday snapshots, current ambient noise and noise from vessels for which automatic identification system (AIS) data were available contribute most heavily to loss of CS, followed by whale-watching and fishing vessels Right whale gunshots experience the least amount of masking, while fin, humpback and minke whale signals experience masking levels of 80% or more. While these results incorporate several simplifying assumptions, this study further develops the framework by which to comparatively quantify masking, providing information on the relative degree of masking experienced between species and allowing for important insights on the relative contributions of different anthropogenic sound sources

Clark, C. W. (2019). *Written Testimony of Dr. Christopher W. Clark before the House Natural Resource Committee, Subcommittee on Water, Oceans, and Wildlife Hearing on "Examining the Threats to the North Atlantic Right Whale"*. House Natural Resource Committee, Subcommittee on Water, Oceans, and Wildlife,

No abstract.

Cole, A. (2018). Modelling Fishing Effort Displacement in the Southern Gulf of St Lawrence Snow Crab (Chionoecetes Opilio) Fishery: Quantifying Management Measures for North Atlantic Right Whale (*Eubalaena glacialis*) Entanglement Prevention. In *Dalhousie University*. Retrieved from https://dalspace.library.dal.ca/handle/10222/75138

Anthropogenic mortality is the leading factor inhibiting the recovery of the endangered North Atlantic right whale (NARW), in which 85% of human-induced deaths are caused by entanglement in commercial fishing gear. In 2017, a large number of NARW entanglements and deaths occurred in the Gulf of St Lawrence, many of which were attributed to the snow crab fishery. This led to the establishment of new management measures, including spatio-temporal fishery closures in the form of static and dynamic exclusion zones that encompassed 90% of the 2017 NARW sightings. These measures raised concerns related to the costs to the fishery and effectiveness of entanglement prevention. Using fishing data from 2005 through 2012, a model was built that predicted weekly fishing effort displacement caused by these closures, the approximated socioeconomic costs of movement, and relative change in co-occurrence, or risk, of a NARW coming into contact with fishing gear. The model examined four alternative closure arrangements to evaluate NARW protection efficacy versus costs to the fishery of different management strategies. Results show that lost fishing opportunity was minimal, and estimated costs were highest and most variable in the current strategy, and lowest and most consistent in a strictly dynamic management regime. While displaced effort resulted in a fishing-the-line scenario, all strategies were successful at reducing the threat of entanglement. Subsequently, this study quantifies and examines the tradeoffs of spatio-temporal fishery closures for species-at-risk protection, while providing managers with an adaptive management tool in the form of the displacement model.

Cole, A. K., Brillant, S. W., & Boudreau, S. A. (2021). Effects of Time-Area Closures on the Distribution of Snow Crab Fishing Effort with Respect to Entanglement Threat to North Atlantic Right Whales. *ICES Journal of Marine Science*. https://doi.org/10.1093/icesjms/fsab103

Time-area closures are increasingly used to mitigate cetacean entanglement by temporarily excluding fishing effort from areas where high densities of cetaceans and fishing overlap. The effort displaced by these closures can be redistributed to the areas that remain open, changing the distribution and density of fishing effort outside the closures. These patterns were evaluated for the southern Gulf of St. Lawrence snow crab fishery by comparing recent years (2015–2017) with 2018 when time-area closures were implemented to protect North Atlantic right whales. A predictive model framework was created to test how well we could predict the response of fishers to closures. Approximately 29% of the total fishing effort was displaced by the 2018 closures, increasing effort density outside the closures by 41%. Displaced fishing effort shifted farther from the closures than predicted, into areas which, prior to 2018, had low effort density, producing a higher threat of entanglement in these new areas. Fishing effort in 2018 remained as high as 2017, despite a lower quota and reduced trap limit. Consequently, the resulting effects of time-area closures on fishing patterns outside of the closures cannot be discounted if entanglement threat to whales is to be successfully mitigated.

Convertino, M., & Valverde, L. J. (2018). Probabilistic Analysis of the Impact of Vessel Speed Restrictions on Navigational Safety: Accounting for the Right Whale Rule. *Journal of Navigation, 71*(1), 65-82. https://doi.org/10.1017/S0373463317000480

The Right Whale Sighting Advisory System (RWSAS) is a National Oceanic and Atmospheric Administration (NOAA) Fisheries program designed to reduce collisions between vessels and critically endangered North Atlantic right whales. The vessel speed restriction that is part of the RWSAS presents navigation stakeholders with numerous challenges, owing to concerns about increased risks of ship grounding and collisions within ports. In this paper, we present a multi-methodology framework for assessing the impact of the vessel speed restriction on navigational safety. Empirically, we base our discussion in a first-order analysis of ship grounding risk for the Charleston Entrance Channel. Our analysis proceeds in three parts. We begin by using fault and event tree analyses to assess a relevant set of grounding-related event progression and failure probabilities. The influence of alternative vessel speed restrictions on ship grounding risk are then explored via a Bayesian network model that utilises the previously specified fault and event tree models for its partial specification and enumeration. Our analysis suggests that the speed restriction can, under certain reasonable assumptions, be seen to adversely impact the risk of ship grounding accidents in the Charleston Entrance Channel. We conclude with a summary of our findings and recommendations for future research.

Cooke, J. G. (2020, 2020/01/01). *Eubalaena glacialis*: The Iucn Red List of Threatened Species 2020. Retrieved from https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T41712A162001243.en

No abstract.

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. https://doi.org/10.1098/rsos.180892

North Atlantic right whales (NARW), *Eubalaena glacialis*, were nearly exterminated by historical whaling. Their abundance slowly increased up until 2010, to a maximum of fewer than 500 whales, and since then they have been in decline. We assessed the extent to which the relatively slow increase demonstrated by NARW was intrinsic, and how much could be due to anthropogenic impacts. In order to do so, we first compared calf counts of three populations of Southern right whales (SRW), E. australis, with that of NARW, over the period 1992-2016. By this index, the annual rate of increase of NARW was approximately one-third of that of SRW. Next we constructed a population projection model for female NARW, using the highest annual survival estimates available from recent mark-resight analysis, and assuming a four-year calving interval. The model results indicated an intrinsic rate of increase of 4% per year, approximately twice that observed, and that adult female mortality is the main factor influencing this rate. Necropsy records demonstrate that anthropogenic mortality is the primary cause of known mortality of NARW. Anthropogenic mortality and morbidity has limited the recovery of NARW, and baseline conditions prior to their recent decline were already jeopardizing NARW recovery.

Coutinho, R. W. L., & Boukerche, A. (2021). North Atlantic Right Whales Preservation: A New Challenge for Internet of Underwater Things and Smart Ocean-Based Systems. *IEEE Instrumentation & Measurement Magazine, 24*(3), 61-67. https://doi.org/10.1109/mim.2021.9436096

North Atlantic Right Whales (NARWs) are at a dangerous risk of extinction. Nowadays, there are approximately 360 individuals. These animals have been listed in the Endangered Species Act since 1970. While whaling was the principal source of risk for the survival of right whales in the past centuries, their current threats are vessel strikes, entanglements, and degradation of their habitats. Hence, protection measurements have taken place in Canada and the United States, where they are encountered, aimed at reducing the mortality of these marine mammals and increasing their population. In this regard, instrumentation technologies have been used for detecting and tracking of NARWs, as well as for monitoring their environment. In this paper, we discuss some of the current methods and instruments used for the detection and monitoring of NARWs, and we shed light on the advantages and disadvantages of each method and employed sensing instruments. Furthermore, we highlight the potential of networked sensing instruments and envisioned Internet of Underwater Things (IoUTs) for improving the performance of NARW monitoring and data collection, with the objective of guiding and supporting efficient measures and policies for protecting the NARW population.

Crum, N., Gowan, T., Krzystan, A., & Martin, J. (2019). Quantifying Risk of Whale-Vessel Collisions across Space, Time, and Management Policies. *Ecosphere, 10*(4). https://doi.org/10.1002/ecs2.2713

Transportation industries can negatively impact wildlife populations, including through increased risk of mortality To mitigate this risk successfully, managers and conservationists must estimate risk across space, time, and alternative management policies. Evaluating this risk at fine spatial and temporal scales can be challenging, especially in systems where wildlife-vehicle collisions are rare or imperfectly detected. The sizes and behaviors of wildlife and vehicles influence collision risk, as well as how much they co-occur in space and time. We applied a modeling framework based on encounter theory to

quantify the risk of lethal collisions between endangered North Atlantic right whales and vessels. Using Automatic Identification System vessel traffic data and spatially explicit estimates of right whale abundance that account for imperfect detection, we modeled risk at fine spatiotemporal scales before and after implementation of a vessel speed rule in the southeastern United States. The expected seasonal mortality rates of right whales decreased by 22% on average after the speed rule was implemented, indicating that the rule is effective at reducing lethal collisions. The rule's effect on risk was greatest where right whales were abundant and vessel traffic was heavy, and its effect varied considerably across time and space. Our framework is spatiotemporally flexible, process-oriented, computationally efficient and accounts for uncertainty, making it an ideal approach for evaluating many wildlife management policies, including those regarding collisions between wildlife and vehicles and cases in which wildlife may encounter other dangerous features such as wind farms, seismic surveys, or fishing gear.

Daoust, P.-Y. (2017). *Incident Report: North Atlantic Right Whale Mortality Event in the Gulf of St. Lawrence, 2017.* Fisheries and Oceans Canada

The present incident report provides the details and conclusions of the investigation into the North Atlantic right whale mortality event experienced in 2017 in the Gulf of St. Lawrence. The report focusses primarily on the necropsy findings which were prepared by lead veterinarians affiliated with the Canadian Wildlife Health Cooperative (CWHC). These findings were analysed collaboratively amongst the lead veterinarians (authors) and in consultation with other North American veterinarians and researchers. The Marine Animal Response Society (MARS) and Fisheries and Oceans Canada (DFO) have provided analyses and contextual information relevant to the interpretation of the key findings presented by the lead veterinarians. Given the desire for producing timely findings which are relevant in addressing the North Atlantic right whale mortality event in the Gulf of St. Lawrence, the scope of this report addresses only key relevant information on North Atlantic right whales and human activities which are considered to have played a role in this incident. As such, it is not intended to provide a complete portrait of the North Atlantic right whale population nor of the human activities occurring in the Gulf of St. Lawrence. These findings are meant to provide a basis for the advancement of conservation actions, including decisions in response to this unprecedented mortality event.

Davies, K. T. A., & Brillant, S. W. (2019). Mass Human-Caused Mortality Spurs Federal Action to Protect Endangered North Atlantic Right Whales in Canada. *Marine Policy, 104*, 157-162. https://doi.org/10.1016/j.marpol.2019.02.019

If we don't take robust, science-based, coherent measures to protect these highly endangered North Atlantic right whales, we're really playing Russian roulette with the entire future of the Canadian fish and seafood industry," Fisheries and Oceans Minister Dominic LeBlanc, CBC New Brunswick, 16 June 2018. Governments are required to demonstrate that they manage natural resources in an environmentally and economically sustainable manner. Evidence of an environmental conservation problem is often not considered sufficient by government to warrant a change in the way human activities are managed until the problem becomes a societal crisis (e.g., large effects on economics, operations or infrastructure). Governments are then challenged to nimbly implement effective reactionary measures that both solve the problem and protect livelihoods. The mass mortality of North Atlantic right whales (*Eubalaena glacialis*) that occurred over a 3 month period in Canadian waters in 2017 due at least in part to fishing gear entanglements and ship strike is an example of a situation

wherein evidence of a growing conflict between whales and humans was not acted upon until it became an emergency. The disaster galvanized a number of recent federal environmental initiatives into a powerful government force that was able to collaborate with many non-government groups in promptly responding to the problem. This led to commendable implementation and enforcement of crisis management measures. However, implementation came after many mortalities had already occurred because management plans were developed extemporaneously. Further, the need for crisis management negatively impacted local communities and industries. The eventual implementation of federal regulations led to zero attributable right whale deaths and a profitable fishery in the area of highest whale densities the following year. This shows that government leaders can act effectively on issues of environmental conservation, but that these actions can be drastic (i.e., requiring significant and rapid change to human activities) if there is a historic lack of action to address chronic conservation problems. Being proactive requires acting in proportion to evidence, using plans that are adaptive, precautionary and based on science. Canada must now look to sustainable, preventative measures to reduce right whale mortality risk.

Davis, R. (2019). Ocean Gliders in Eastern Canada. *Geophysical Research Abstracts, 21*, 1-1.

Since 2010 the Ocean Tracking Network (OTN), the Marine Environmental Observation, Prediction and Response (MEOPAR) Network of Centres of Excellence and the Ocean Frontier Institute (OFI) have jointly funded Dalhousie University's glider program. Our fleet of autonomous ocean vehicles (7 Teledyne Webb Slocum gliders & 2 Liquid Robotics wave gliders) has traversed more than 78 000 km in support of investigators across Canada and the USA. Data collected have been used to augment and complement various monitoring programs in Canadian marine waters related to: validating models of ocean temperature and salinity; tracking acoustically tagged animals; environmental assessments; ocean conditions and salmon migration; quantifying marine mammal distribution and habitat on the east and west coasts of Canada. This presentation will focus on the use of ocean gliders to monitor baleen whale presence through acoustic detection and identification on the Scotian Shelf and in the Gulf of St. Lawrence (GSL). In 2017 there were 18 known deaths of the endangered North Atlantic right whale in the NW Atlantic, including the GSL. Such mortality rates may render right whales functionally extinct in ~25 years. In 2017 and 2018 the government of Canada instituted static and dynamic fisheries closures and vessel speed restrictions in the GSL to reduce the risk of fishing gear entanglement and vessel strikes. Such measures may have contributed to the reduction in observed right whale deaths and entanglements in the GSL, though they have likely impacted regional fishing and shipping economies. Starting in 2015, OTN/MEOPAR gliders equipped with passive acoustic monitoring systems used to report whale species and presence and location in near-real time, echosounders used to measure right whale food concentrations, and additional sensors to measure physical and chemical water mass properties, have been providing data essential for research and for guiding management of fishing and shipping practices. With recent additional support from Fisheries and Oceans Canada, the program has successfully provided near real-time data to government, research, industry, and public agencies that have proven to be instrumental in mitigating risks faced by North Atlantic right whales.

Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J. N., Trigg, L. E., & Embling, C. B. (2019). The Effects of Ship Noise on Marine Mammals - a Review. *Frontiers in Marine Science, 6*, 606. https://doi.org/10.3389/fmars.2019.00606

The number of marine watercraft is on the rise—from private boats in coastal areas to commercial ships crossing oceans. A concomitant increase in underwater noise has been reported in several regions around the globe. Given the important role sound plays in the life functions of marine mammals, research on the potential effects of vessel noise has grown—in particular since the year 2000. We provide an overview of this literature, showing that studies have been patchy in terms of their coverage of species, habitats, vessel types, and types of impact investigated. The documented effects include behavioural and acoustic responses, auditory masking, and stress. We identify knowledge gaps: There appears a bias to more easily accessible species (i.e., bottlenose dolphins and humpback whales), whereas there is a paucity of literature addressing vessel noise impacts on river dolphins, even though some of these species experience chronic noise from boats. Similarly, little is known about the potential effects of ship noise on pelagic and deep-diving marine mammals, even though ship noise is focussed in a downward direction, reaching great depth at little acoustic loss and potentially coupling into sound propagation channels in which sound may transmit over long ranges. We explain the fundamental concepts involved in the generation and propagation of vessel noise and point out common problems with both physics and biology: Recordings of ship noise might be affected by unidentified artefacts, and noise exposure can be both under- and over-estimated by tens of decibel if the local sound propagation conditions are not considered. The lack of anthropogenic (e.g., different vessel types), environmental (e.g., different sea states or presence/absence of prey), and biological (e.g., different demographics) controls is a common problem, as is a lack of understanding what constitutes the 'normal' range of behaviours. Last but not least, the biological significance of observed responses is mostly unknown. Moving forward, standards on study design, data analysis, and reporting are badly needed so that results are comparable (across space and time) and so that data can be synthesised to address the grand unknowns: the role of context and the consequences of chronic exposures.

Fisheries and Oceans Canada (DFO). (2021). *Action Plan for the North Atlantic Right Whale (Eubalaena glacialis) in Canada.* Ottawa.

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996) agreed to establish complementary legislation and programs that provide for protection of species at risk throughout Canada. Under the Species at Risk Act (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of action plans for species listed as extirpated, endangered, or threatened for which recovery has been deemed feasible. They are also required to report on progress five years after the publication of the final document on the Species at Risk Public Registry. The North Atlantic Right Whale (Right Whale) was listed as endangered under the Species at Risk Act (SARA) in 2005. Fisheries and Oceans Canada (DFO) works with its partners to plan and implement the recovery of this species, according to the requirements of SARA. A SARA recovery strategy was published in 2009 (Brown et al. 2009) and updated in 2014 (DFO 2014). An action plan addressing the threat of fishery interactions was nearing completion in 2016. In 2018, the scope of the action plan was expanded to include all threats to Right Whales identified in the SARA recovery strategy. Right Whale mortalities have been documented in Canadian waters since 1987 (Knowlton and Kraus 2001; Sharp et al. 2019). Since 2015, the rate of identified mortalities has increased throughout their range (Bourque et al. 2020). The majority of identified mortalities since 2015 occurred in 2017 and 2019, when unprecedented numbers of Right Whales were discovered dead or entangled in the Gulf of St.

Lawrence. The Government of Canada responded in 2017 with increased and expanded surveillance for Right Whales, and with management measures designed to reduce entanglement risk and vessel collision risk to Right Whales. Since 2017, DFO and Transport Canada (TC) have continued to refine those measures with the input of scientists and partners in the fishing and marine transportation industries. The Government of Canada has demonstrated its commitment to the protection and recovery of Right Whales through several investments in recent years.Alternate abstract:La baleine noire de l'Atlantique Nord (baleine noire) a été inscrite en tant qu'espèce en voie de disparition en vertu de la Loi sur les espèces en péril (LEP) en 2005. Pêches et Océans Canada (MPO) collabore avec ses partenaires pour planifier et mettre en oeuvre le rétablissement de cette espèce. Un programme de rétablissement en vertu de la LEP a été publié en 2009 (Brown et al. 2009) et mis à jour en 2014 (MPO 2014). Un plan d'action visant à lutter contre la menace des interactions entre les pêches était presque terminé en 2016. En 2018, la portée du plan d'action a été élargie pour inclure toutes les menaces qui pèsent sur les baleines noires et qui figurent dans le programme de rétablissement en vertu de la LEP. La mortalité des baleines noires dans les eaux canadiennes est documentée depuis 1987 (Knowlton et Kraus 2001; Sharp et al. 2019). Depuis 2015, le taux de mortalités observées a augmenté dans toute l'aire de répartition de l'espèce (Bourque et al. 2020). La majorité des mortalités recensées depuis 2015 se sont produites en 2017 et en 2019, alors qu'un nombre sans précédent de baleines noires ont été trouvées mortes ou empêtrées dans le golfe du Saint-Laurent. En 2017, le gouvernement du Canada a réagi en augmentant et en élargissant la surveillance des baleines noires et en adoptant des mesures de gestion visant à réduire les risques d'empêtrement et de collision avec les navires. Depuis 2017, le MPO et Transports Canada (TC) poursuivent la mise au point de ces mesures avec la contribution des scientifiques et des partenaires des industries de la pêche et du transport maritime.

Fox, C. H., & Taggart, C. T. (2020). Vessel Strikes and North Atlantic Right Whales. In *Environmental Impact of Ships.* (pp. 250-281) https://doi.org/10.1017/9781108381598.011

Shipping is responsible for transporting 90 per cent of the world's trade. This book provides a comprehensive review of the impact shipping has on the environment. Topics covered include pollutant discharges, such as atmospheric emissions, oil, chemical waste, sewage and biocides, as well as non-pollutant impacts, including invasive species, wildlife collisions, noise, physical damage and the environmental effects associated with shipwrecks and shipbreaking. The history of relevant international legislation is also covered. With chapters written by eminent international authors, this book provides a global perspective on the environmental impact of ships, making it a useful reference for advanced students and researchers of environmental science, as well as practitioners of maritime law and policy and marine business.

Frasier, T. R., & Reeves, R. R. (2017). Lessons Learned from Cetacean Tragedies. *Science, 358*(6369), 1396-1396. https://doi.org/10.1126/science.aar5529

Two November issues of *Science* recounted tragic events involving cetaceans. To prevent future tragedies, we must take to heart the important lessons from these events and apply them to wildlife conservation.

Gende, S. M., Vose, L., Baken, J., Gabriele, C. M., Preston, R., & Hendrix, A. N. (2019). Active Whale Avoidance by Large Ships: Components and Constraints of a Complementary Approach to Reducing Ship Strike Risk. *Frontiers in Marine Science, 6*(592). https://doi.org/10.3389/fmars.2019.00592

The recurrence of lethal ship-whale collisions ('ship strikes') has prompted management entities across the globe to seek effective ways for reducing collision risk. Here we describe 'active whale avoidance' defined as a mariner making operational decisions to reduce the chance of a collision with a sighted whale. We generated a conceptual model of active whale avoidance and, as a proof of concept, apply data to the model based on observations of humpback whales surfacing in the proximity of large cruise ships, and simulations run in a full-mission bridge simulator and commonly used pilotage software. Application of the model demonstrated that (1) the opportunities for detecting a surfacing whale are often limited and temporary, (2) the cumulative probability of detecting one of the available 'cues' of whale's presence (and direction of travel) decreases with increased ship-to-whale distances, and (3) following detection time delays occur related to avoidance operations. These delays were attributed to the mariner evaluating competing risks (e.g., risk of whale collision vs. risk to human life, the ship, or other aspects of the marine environment), deciding upon an appropriate avoidance action, and achieving a new operational state by the ship once a maneuver is commanded. We thus identify several options for enhancing whale avoidance including training Lookouts to focus search efforts on a 'Cone of Concern,' defined here as the area forward of the ship where whales are at risk of collision based on the whale and ship's transit/swimming speed and direction of travel. Standardizing protocols for rapid communication of relevant sighting information among bridge team members can also increase avoidance by sharing information on the whale that is of sufficient quality to be actionable. We also found that, for marine pilots in Alaska, a slight change in course tends to be preferable to slowing the ship in response to a single sighted whale, owing, in part, to the substantial distance required to achieve an effective speed reduction in a safe manner. However, planned, temporary speed reductions in known areas of whale aggregations, particularly in navigationally constrained areas, provide a greater range of options for avoidance, highlighting the value of real-time sharing of whale sighting data by mariners. Development and application of these concepts in modules in full mission ship simulators can be of significant value in training inexperienced mariners by replicating situations and effective avoidance maneuvers (reducing the need to 'learn on the water'), helping regulators understand the feasibility of avoidance options, and, identifying priority research threads. We conclude that application of active whale avoidance techniques by large ships is a feasible yet underdeveloped tool for reducing collision risk globally, and highlight the value of local collaboration and integration of ideas across disciplines to finding solutions to mutually desired conservation outcomes.

Hamilton, P. K., & Kraus, S. D. (2019). Frequent Encounters with the Seafloor Increase Right Whales' Risk of Entanglement in Fishing Groundlines. *Endangered Species Research, 39*, 235-246. https://doi.org/10.3354/esr00963

North Atlantic right whales *Eubalaena glacialis* utilize the entire water column and are frequently entangled in ropes from fishing gear. Data from telemetry tags have shown that right whales can swim/feed at or near the seafloor. Because those data are limited, some uncertainty remains regarding the frequency of dives to the seafloor and thus the likelihood of right whale encounters with fishing ropes there. The North Atlantic right whale photo-identification catalog was used to determine the number of sightings of right whales with seafloor sediment on their bodies and the relative frequency and geographic location of those seafloor encounters. Between 1980 and 2016, there were 2053

detections of right whales with 'mud' on their bodies, which represents 2.9% of all sightings (n = 70593), or 58.2% of all cataloged whales (n = 730). Although muddy right whales were found throughout their range and in all months, 92.7% of all detections occurred in the Bay of Fundy in the summer where there was an average annual detection rate of 7.3%, with a maximum of 26% of sightings in 2010. Mud was found on whales of all age classes including calves of the year, and equally among males and females. These seafloor encounters suggest that any rope resting on, or floating above, the seafloor could pose an entanglement hazard. The use of sinking groundlines likely reduces the risk of entanglements for whales swimming near the seafloor, but may not eliminate the risk for whales making contact with the sediment.

Hamilton, S., & Baker, G. B. (2019). Technical Mitigation to Reduce Marine Mammal Bycatch and Entanglement in Commercial Fishing Gear: Lessons Learnt and Future Directions. *Reviews in Fish Biology and Fisheries, 29*(2), 223-247. https://doi.org/10.1007/s11160-019-09550-6

Fisheries bycatch is one of the biggest threats to marine mammal populations. A literature review was undertaken to provide a comprehensive assessment and synopsis of gear modifications and technical devices to reduce marine mammal bycatch in commercial trawl, purse seine, longline, gillnet and pot/trap fisheries. Successfully implemented mitigation measures include acoustic deterrent devices (pingers) which reduced the bycatch of some small cetacean species in gillnets, appropriately designed exclusion devices which reduced pinniped bycatch in some trawl fisheries, and various pot/trap guard designs that reduced marine mammal entrapment. However, substantial development and research of mitigation options is required to address the bycatch of a range of species in many fisheries. No reliably effective technical solutions to reduce small cetacean bycatch in trawl nets are available, although loud pingers have shown potential. There are currently no technical options that effectively reduce marine mammal interactions in longline fisheries, although development of catch and hook protection devices is promising. Solutions are also needed for species, particularly pinnipeds and small cetaceans, that are not deterred by pingers and continue to be caught in static gillnets. Large whale entanglements in static gear, particularly buoy lines for pots/traps, needs urgent attention although there is encouraging research on rope-less pot/trap systems and identification of rope colours that are more detectable to whale species. Future mitigation development and deployment requires rigorous scientific testing to determine if significant bycatch reduction has been achieved, as well as consideration of potentially conflicting mitigation outcomes if multiple species are impacted by a fishery.

Hayes, S. A., Gardner, S., Garrison, L. P., Henry, A., & Leandro, L. (2018). *North Atlantic Right Whales-Evaluating Their Recovery Challenges in 2018.* https://doi.org/10.25923/w9cy-5844

The North Atlantic right whale (*Eubalaena glacialis*) population has been in decline for 8 years due to increased mortality and sublethal effects from multiple factors. Together these have contributed to a decrease in calving. Shifting ecosystem conditions have also changed North Atlantic right whale behavior and fishing patterns.

Henry, A., Barco, S. G., Cole, T. V. N., Johnson, A., Knowlton, A. R., Landry, S., . . . Asmutis-Silvia, R. (2017). Don't Assume It's Ghost Gear : Accurate Gear Characterization Is Critical for Entanglement Mitigation [Poster]. In: Woods Hole Oceanographic Institution.

Entanglement is a significant conservation and welfare issue limiting the recovery of many marine species, including marine mammals. It is important to specifically determine whether entangling gear was being actively fished or derelict when the entanglement occurred. Inaccurate identification can hamper efforts to reduce or prevent entanglements in the future.

Henry, A., Garron, M., Morin, D. M., Reid, A., Ledwell, W., & Cole, T. V. N. (2020). *Serious Injury and Mortality Determinations for Baleen Whale Stocks Along the Gulf of Mexico, United States East Coast, and Atlantic Canadian Provinces, 2013-2017.* https://doi.org/10.25923/fbc7-ky15

Opportunistic reports were used to calculate rates of human-caused serious injury and mortality to baleen whale stocks along the Gulf of Mexico, United States east coast, and Atlantic Canadian provinces from 2013 through 2017. All available information for reported whale injury and mortality events was evaluated by using criteria to assign injury severity and cause of injury or death for each event. The minimum annual rate of human-caused serious injury and mortality during the period was 6.85 for North Atlantic right whales (*Eubalaena glacialis*), 12.15 for Gulf of Maine humpback whales (*Megaptera novaeangliae*), 2.35 for western North Atlantic fin whales (*Balaenoptera physalus*), 8.2 for Canadian East Coast minke whales (*B. acutorostrata*), 1.0 for Nova Scotian sei whales (*B. borealis*), and 0 for western North Atlantic blue whales (*B. musculus*) and northern Gulf of Mexico Bryde's whales (*B. edeni*). The number of serious injuries and mortalities not reported is unknown, and actual levels may be much higher.

Henry, A. G., Garron, M., Morin, D., Smith, A., Reid, A., Ledwell, W., & Cole, T. V. N. (2021). *Serious Injury and Mortality Determinations for Baleen Whale Stocks Along the Gulf of Mexico, United States East Coast, and Atlantic Canadian Provinces, 2014-2018.* https://doi.org/10.25923/ey0b-fw22

Opportunistic reports were used to calculate rates of human-caused serious injury and mortality to baleen whale stocks along the Gulf of Mexico, United States east coast, and Atlantic Canadian provinces from 2014 through 2018. All available information for reported whale injury and mortality events was evaluated by using established criteria to assign injury severity and cause of injury or death for each event. The average annual rate of detected human-caused serious injury and mortality during the period was 8.15 for North Atlantic right whales (*Eubalaena glacialis*), 15.25 for Gulf of Maine humpback whales (Megaptera novaeangliae), 2.35 for western North Atlantic fin whales (*Balaenoptera physalus*), 10.15 for Canadian east coast minke whales (B. acutorostrata), 1.2 for Nova Scotian sei whales (B. borealis), and 0 for western North Atlantic blue whales (B. musculus) and northern Gulf of Mexico Bryde's whales (B. edeni). The number of serious injuries and mortalities not reported is unknown, and actual levels may be much higher.

Howle, L. E., Kraus, S. D., Werner, T. B., & Nowacek, D. P. (2019). Simulation of the Entanglement of a North Atlantic Right Whale (*Eubalaena glacialis*) with Fixed Fishing Gear. *Marine Mammal Science, 35*(3), 760-778. https://doi.org/10.1111/mms.12562

Population estimates of the critically endangered North Atlantic right whale (*Eubalaena glacialis*) put the number of individuals at 458 with the actual number likely being lower due to a recent unusual mortality event. Entanglement with fixed fishing gear is the most significant cause of mortality of North Atlantic right whales. There remains little documentation of how North Atlantic right whales become enwrapped during an encounter with fixed fishing gear. In order to gain a better understanding of how entanglements might occur, an interactive simulator was developed that allows the user to swim a virtual whale model using a standard game controller through a gear field in an attempt to re-create an entanglement. The morphologically accurate right whale model produces realistic swimming motions and is capable of pectoral fin motions in response to user input. Using the simulator, gear entanglements involving the pectoral flippers including ropes wrapping around the body and entanglements involving the tailstock were re-created. Entanglements involving the pectoral flippers with body wraps were more easily generated than entanglements involving the tailstock only. The simulator should aid scientists, fisheries experts, fishing gear designers, and bycatch reduction scientists in understanding entanglement dynamics and testing potential new gear configurations.

Kadwa, F. (2020). Assessing Relative Lethal Entanglement Threat to North Atlantic Right Whales (*Eubalaena glacialis*) in the Maritimes Lobster Fishery. In *University of Toronto Scarborough*: University of Toronto Scarborough.

North Atlantic right whales are one of the most endangered whale species in the world with historical and recent anthropogenic threats hindering its recovery. One of the major threats to the species is entanglement in vertical fishing rope found in fixed trap/pot fisheries such as lobster. The DFO-Maritimes lobster fishery overlaps with right whale habitat, thus knowing the relative lethal entanglement threat posed by each area of the inshore lobster fishery can inform areas of high threat and priority for management. In this study, I constructed an entanglement threat model that used information on fishing gear in each lobster fishing area and factors expected to affect entanglement to estimate a value of relative lethal entanglement threat for each fine scale fishing area and month in the DFO- Maritimes inshore lobster fishery. Areas with highest relative lethal entanglement threat that overlapped with high right whale season included grid cells in LFA 36 and 38 North-west of Grand Manan (May, June), LFA 27 close to Cabot Strait (June), and LFA 33 (May). Based on probabilities that contributed to high relative threat values, I suggested feasible area-specific measures for fishery managers to potentially adapt which primarily included reducing the number of vertical endlines by enforcing trawl usage. Estimates of threat from this study and additional right whale occurrence data can be used to create future assessments of risk which can better inform scientific management decisions to reduce entanglement threat to right whales and allow their population to recover

Kelley, D. E., Vlasic, J. P., & Brillant, S. W. (2021). Assessing the Lethality of Ship Strikes on Whales Using Simple Biophysical Models. *Marine Mammal Science, 37*(1), 251-267. https://doi.org/10.1111/mms.12745

Studies of ship strikes on whales often focus on large vessels (>20 m), with attention to their speeds and the resulting risk of lethality. Smaller coastal vessels also co-occur with whales, resulting in collisions

that merit study. To cast light on injuries caused by vessels of all sizes, we used knowledge of right whale anatomy and Newtonian mechanics to construct simple models that predict the mechanical stresses experienced by whales during collisions. By comparing our predictions with published models and with data from ship strikes on various whale species, we developed a model for lethal injury as a function of several vessel and whale properties, finding that collisions that create stresses in excess of 0.241 MPa were likely to cause lethal injuries to large whales. Furthermore, this model has revealed that (1) vessels of all sizes can yield stresses higher than this critical level, and (2) large vessels produce stresses much larger than this even when travelling at reduced speeds (i.e., 10 knots). The model is fast enough to power an interactive GUI-based tool (in R) and flexible enough to simulate strikes by vessels of different masses and speeds upon whales of different species, sizes, and physical conditions.

Knowlton, A. R., & Kraus, S. D. (2020). Mortality and Serious Injury of Northern Right Whales (*Eubalaena glacialis*) in the Western North Atlantic Ocean. *IWC Journal of Cetacean Research and Management*, 193-208. https://doi.org/10.47536/jcrm.vi.288

Northern right whales in the western North Atlantic number about 300 animals and have shown little sign of recovery in recent decades. Mortality and serious injury due to human activities, particularly commercial fishing and shipping, are thought to be significant factors limiting their recovery. From 1970-1999, 45 right whale deaths were reliably documented. Sixteen of these fatalities (35.5%) were due to ship collisions, and three (6.7%) were due to entanglement in fishing gear. The remainder were neonates (13; 28.9%) and 'unknown cause' mortalities (13; 28.9%). Criteria for defining serious injuries and mortalities from entanglement or ship strikes were developed and include any animal carrying fishing gear, cuts from entanglement or ship strike deeper than 8cm, swelling or necrosis, evidence of poor health from such interactions, and, in carcasses, evidence of haematoma, haemorrhaging or broken bones. A total of 56 animals fitting the defined criteria were documented from 1970-1999: 31 (55.4%) from entanglement and 25 (44.6%) from ship strikes. Nineteen were fatal (16 ship strikes, 3 entanglements), 10 were possibly fatal (2 ship strikes, 8 entanglements) and 27 were non-fatal (7 ship strikes, 20 entanglements). The breakdown of potentially serious injuries by age and sex reveals no difference in levels between sexes but shows a 3.3:1 higher level of interaction in juveniles and calves versus adults. The data show that ship strikes are more immediately lethal, but entanglements can result in long term deterioration of an animal and may be responsible for higher levels of mortality than previously thought. Considering that some animals become entangled, drown and never return to the surface, even these levels may be underestimated. Between 1986 and 1999, 84 animals were presumed dead based on a lack of resightings for six years. There were 32 confirmed deaths during this time period suggesting that at least as many unreported deaths occurred as carcasses were reported. Definitive actions need to be taken to reduce the level and severity of anthropogenic injuries and deaths. Actions could include continued disentanglement efforts, gear modifications, seasonal closures for fisheries, mandatory ship reporting, ships' routing measures and speed restrictions for commercial shipping.

Koubrak, O., VanderZwaag, D. L., & Worm, B. (2021). Saving the North Atlantic Right Whale in a Changing Ocean: Gauging Scientific and Law and Policy Responses. *Ocean & Coastal Management, 200*. https://doi.org/10.1016/j.ocecoaman.2020.105109

North Atlantic right whales (NARW) are one of the most endangered marine animals with a global population of -400 individuals left. Recent climate-driven shifts in distribution have significantly increased their mortality risk from human activities. After twelve NARWs died in the Gulf of St. Lawrence

in 2017 from fishing gear entanglement and ship strikes, Canada adopted measures designed to decrease overlap between these whales and relevant threats. Real-time monitoring of whale distribution combined with dynamic management of shipping corridors and fishing areas proved to be effective in reducing regional mortality to zero in 2018. Yet, this complex system was expensive to implement and caused tension with affected sectors. Following stakeholder consultations, Canada modified the system of static and dynamic measures for the 2019 season. These measures were less effective and eight observed right whale deaths triggered additional emergency responses. This paper reviews scientific and legal tools that were used to implement spatial management of NARW and marine activities between 2017 and 2019. It identifies key legislation that directs the government to protect NARW, such as the Species at Risk Act (SARA), as well as the regulatory tools under the Fisheries Act and Canada Shipping Act and discusses weaknesses in the implementation of these legal frameworks that contributed to compromised outcomes. The paper concludes with recommendations designed to promote recovery and protect endangered species that may undergo similar changes in distributions and threats under ongoing climate and environmental change. The need to strengthen the role of Canada's Species at Risk Act in future conservation efforts is highlighted, specifically the need to address the effects of climate change in recovery planning and the importance of expanding critical habitat protections.

Kowarski, K. A., Gaudet, B. J., Cole, A. J., Maxner, E. E., Turner, S. P., Martin, S. B., . . . Moloney, J. E. (2020). Near Real-Time Marine Mammal Monitoring from Gliders: Practical Challenges, System Development, and Management Implications. *Journal of the Acoustical Society of America, 148*(3), 1215-1230. https://doi.org/10.1121/10.0001811

In 2017, an endangered North Atlantic right whale mortality event in the Gulf of St. Lawrence, Canada, triggered the implementation of dynamic mitigation measures that required real-time information on whale distribution. Underwater glider-based acoustic monitoring offers a possible solution for collecting near real-time information but has many practical challenges including self-noise, energy restrictions, and computing capacity, as well as limited glider-to-shore data transfer bandwidth. This paper describes the development of a near real-time baleen whale acoustic monitoring glider system and its evaluation in the Gulf of St. Lawrence in 2018. Development focused on identifying and prioritizing important acoustic events and on sending contextual information to shore for human validation. The system performance was evaluated post-retrieval, then the trial was simulated using optimized parameters. Trial simulation evaluation revealed that the validated detections of right, fin, and blue whales produced by the system were all correct; the proportion of species occurrence missed varied depending on the timeframe considered. Glider-based near real-time monitoring can be an effective and reliable technique to inform dynamic mitigation strategies for species such as the North Atlantic right whale.

Lysiak, N. S. J., Trumble, S. J., Knowlton, A. R., & Moore, M. J. (2018). Characterizing the Duration and Severity of Fishing Gear Entanglement on a North Atlantic Right Whale (*Eubalaena glacialis*) Using Stable Isotopes, Steroid and Thyroid Hormones in Baleen. *Frontiers in Marine Science, 5*. https://doi.org/10.3389/fmars.2018.00168

North Atlantic right whales (*Eubalaena glacialis*) are highly endangered and frequently exposed to a myriad of human activities and stressors in their industrialized habitat. Entanglements in fixed fishing gear represent a particularly pervasive and often drawn-out source of anthropogenic morbidity and mortality to the species. To better understand both the physiological response to entanglement, and to

determine fundamental parameters such as acquisition, duration, and severity of entanglement, we measured a suite of biogeochemical markers in the baleen of an adult female that died from a well-documented chronic entanglement in 2005 (whale Eg2301). Steroid hormones (cortisol, corticosterone, estradiol, and progesterone), thyroid hormones (triiodothyronine (T-3) and thyroxine (T-4)), and stable isotopes (delta C-1(3) and delta N-15) were all measured in a longitudinally sampled baleen plate. This yielded an 8-year profile of foraging and migration behavior, stress response, and reproduction. Stable isotopes cycled in annual patterns that reflect the animal's north-south migration behavior and seasonally abundant zooplankton diet. A progesterone peak, lasting approximately 23 months, was associated with the single known calving event (in 2002) for this female. Estradiol, cortisol, corticosterone, T-3, and T(4)were also elevated, although variably so, during the progesterone peak. This whale was initially sighted with a fishing gear entanglement in September 2004, but the hormone panel suggests that the animal first interacted with the gear as early as June 2004. Elevated delta N-15, T-3, and T-4 indicate that Eg2301 potentially experienced increased energy expenditure, significant lipid catabolism, and thermal stress approximately 3 months before the initial sighting with fishing gear. All hormones in the panel (except cortisol) were elevated above baseline by September 2004. This novel study illustrates the value of using baleen to reconstruct recent temporal profiles and as a comparative matrix in which key physiological indicators of individual whales can be used to understand the impacts of anthropogenic activity on threatened whale populations.

McLeod, A. (2017). AIS Whale-Alert! Assessing the Fleet Preferences for near Real-Time Whale Conservation in the Atlantic Canada. In *Dalhousie University*: Dalhousie University. Retrieved from https://dalspace.library.dal.ca/handle/10222/73835

North Atlantic Right Whales are an endangered species that face many anthropogenic threats, including vessel strikes. A recent morality event in Atlantic Canada has emphasized the need to implement a flexible method to monitor and protect right whales in real-time. Passive Acoustic Monitoring (PAM) technology is currently used in conjunction with ocean glider technology to detect and identify whales and their location in near real-time based on vocalizations. This novel technology can allow for real-time whale conservation by linking PAM to vessel communication technology, such as the automatic identification system (AIS), to broadcast whale locations directly to vessels in the local fleet. The implementation of the MEOPAR (Marine Environmental Observation, Prediction and Response) AIS Whale Alert is nearing completion, but a paucity of information remains about the fleet’s preferences and limitations towards implementing this real-time conservation technology into the bridge protocol. In my study, I surveyed and characterized the fleet and determined the implications for real-time management. The survey results provide insight to fleet receptivity and perceived utility of receiving real-time alerts, as well as their preferred response protocol. AIS analyses determined the Atlantic Canada fleet is dynamic with a high turn over rate. The information gained from this study will inform management plan to implement this novel conservation technology based on stakeholder needs and preferences. The dynamic nature of the ever-changing fleet requires special consideration. By considering fleet preferences towards implementing this technology, it is more likely that the fleet will comply with real-time conservation in Atlantic Canada.

Meyer-Gutbrod, E. L. (2017). *Impacts of Climate-Associated Changes in Prey Availability on North Atlantic Right Whale Population Dynamics*. Cornell University

Today's oceans are undergoing rapid and unprecedented changes resulting from anthropogenic impacts. The North Atlantic right whale, one of the most endangered baleen whales with just over 500 animals remaining in the species, is one example of a species at risk resulting from human influence. Modern right whale research is focused on elevated mortality rates due to vessel collisions and fishing gear entanglement. Although understudied, depressed calving rates also contribute significantly to slow growth. Here we analyze the effect of climate-driven fluctuations in prey abundance on right whale reproductive dynamics since 1980. *Calanus finmarchicus*, the lipid-rich copepod that right whales prey on, were anomalously abundant in the 1980s and 2000s, while concentrations were low in the 1990s. These fluctuations in copepod abundance were driven remotely by freshwater pulses from the Arctic Ocean, and by changes in advective supply to the Gulf of Maine related to North Atlantic circulation patterns. Synchronized with the low prey regime, right whale calf production in the 1990s was depressed relative to the surrounding decades.

Meyer-Gutbrod, E. L., & Greene, C. H. (2018). Uncertain Recovery of the North Atlantic Right Whale in a Changing Ocean. *Global Change Biology, 24*(1), 455-464. https://doi.org/10.1111/gcb.13929

Human activities have placed populations of many endangered species at risk and mitigation efforts typically focus on reducing anthropogenic sources of mortality. However, failing to recognize the additional role of environmental factors in regulating birth and mortality rates can lead to erroneous demographic analyses and conclusions. The North Atlantic right whale population is currently the focus of conservation efforts aimed at reducing mortality rates associated with ship strikes and entanglement in fishing gear. Consistent monitoring of the population since 1980 has revealed evidence that climate-associated changes in prey availability have played an important role in the population's recovery. The considerable interdecadal differences observed in population growth coincide with remote Arctic and North Atlantic oceanographic processes that link to the Gulf of Maine ecosystem. Here, we build capture-recapture models to quantify the role of prey availability on right whale demographic transitional probabilities and use a corresponding demographic model to project population growth rates into the next century. Contrary to previous predictions, the right whale population is projected to recover in the future as long as prey availability and mortality rates remain within the ranges observed during 1980-2012. However, recent events indicate a northward range shift in right whale prey, potentially resulting in decreased prey availability and/or an expansion of right whale habitat into unprotected waters. An annual increase in the number of whale deaths comparable to that observed during the summer 2017 mass mortality event may cause a decline to extinction even under conditions of normal prey availability. This study highlights the importance of understanding the oceanographic context for observed population changes when evaluating the efficacy of conservation management plans for endangered marine species.

Meyer-Gutbrod, E. L., Greene, C. H., & Davies, K. T. A. (2018). Marine Species Range Shifts Necessitate Advanced Policy Planning the Case of the North Atlantic Right Whale. *Oceanography, 31*(2), 19-23. https://doi.org/10.5670/oceanog.2018.209

Rising global temperatures are causing a poleward shift in species distribution. Range shift velocities are higher in the marine environment, with observed rates of 30-130 km per decade. Both protected and

exploited species will be at risk if marine species management policies are not structured to anticipate these range shifts. The 2017 mass mortality event of the North Atlantic right whale showcases the detrimental impact of unanticipated climate-mediated behavior in a species protected by geographically and seasonally fixed policies. Based on the results of a demographic capture-recapture model, right whales may face extinction in fewer than 30 years unless protective policies are expanded to cover their shifting distribution. Increased support of long-term monitoring programs paired with environmental modeling research is critical to developing more proactive conservation management strategies and preventing further ecological crises.

Montes, N., Swett, R., Jacobson, S. K., & Sidman, C. (2018). Factors Influencing Recreational Boaters' Intentions to Comply with Right Whale Regulations in the Southeastern United States. *Society & Natural Resources, 31*(4), 1-16. https://doi.org/10.1080/08941920.2017.1377795

Regulations for boaters can help mitigate adverse effects on threatened marine mammals. One management tool to protect endangered North Atlantic right whales is a 460-m distance restriction rule for all vessels. This study is the first effort to analyze factors that influence recreational boaters' intentions to comply with this regulation. Using the theory of planned behavior, we analyzed 362 mail surveys of recreational boaters using the offshore waters of the southeastern United States. We found that two constructs of the theory significantly explained 58% of the intention to comply with the rule: (1) positive attitude toward the rule and (2) stronger belief that other people are complying. Boaters recommended increasing knowledge about whales to improve compliance, but they were divided with respect to increasing fines for violators to increase compliance. This information can be useful for designing outreach strategies to protect whales.

Montes, N. L., Swett, R., & Gowan, T. A. (2020). Risk of Encounters between North Atlantic Right Whales and Recreational Vessel Traffic in the Southeastern United States. *Ecology and Society, 25*(4). https://doi.org/10.5751/es-11923-250412

Collisions with and disturbance from watercraft represent significant threats to endangered North Atlantic right whales (*Eubalaena glacialis*). Although several studies have investigated whale cooccurrence with commercial vessels, none has considered recreational vessels. We estimated an index between relative encounter risk of North Atlantic right whales and recreational vessel traffic in the southeastern USA calving grounds. Sightings of recreational vessels and right whales were recorded during aerial surveys in 2009-2014. We use generalized additive models to estimate relative occurrence of recreational vessels in the study area. We used estimates of relative North Atlantic right whale occurrence from Gowan and Ortega-Ortiz (2014). Results suggest that areas with elevated relative encounter risk were concentrated near navigable inlets. Additionally, temporal variability in these probabilities was influenced more by the spatial migratory patterns of North Atlantic right whales than by the distribution of recreational vessels. Our results can be used to inform the conservation of the North Atlantic right whales by identifying and mitigating areas with high risk of recreational vessel disturbance and collisions.

Moore, K. (2019). Another Bad Year Looms for North Atlantic Right Whales. *National Fisherman, 100*(5), 10-11.

Six right whales in all have been found dead so far this year, putting 2019 on track to be the deadliest for the endangered species since 2017, when a dozen died in the gulf, spurring new efforts to reduce fatalities from ship strikes and fishing gear entanglement. The North Atlantic right whale populanon has declined to just over 400 animals that migrate off the coast from Canada to Georgia, and U.S. government agencies and states ire engaged in the same kinds of efforts to reduce the danger from ship strikes in sea lanes off the East Coast ports, and fishing gear entanglements. Canada came under pressure in 2018 with demands from U.S. lawmakers that steps be taken to avoid a repeat of the 2017 whale deaths, and is trying :o show its fisheries mee: requirements of the U.S. Marine Mammal Protection Act. -

Moore, M. J. (2019). How We Can All Stop Killing Whales: A Proposal to Avoid Whale Entanglement in Fishing Gear. *ICES Journal of Marine Science, 76*(4), 781-786. https://doi.org/10.1093/icesjms/fsy194

Whales are federally protected by the Marine Mammal Protection Act; endangered species, such as the North Atlantic right whale, receive additional protection under the Endangered Species Act. However, their regulations have failed to satisfy conservation and animal welfare concerns. From 1990 to 2011 the North Atlantic right whale (*Eubalaena glacialis*, NARW) population grew at a mean of 2.8% annually. However, population trends reversed since 2011; the species is in decline, with only similar to 100 reproductively active females remaining. This failure is driven by vessel collisions and increasingly fatal and serious entanglement in fixed fishing gear, whose rope strength has increased substantially. Chronic entanglement, drag, and associated morbidity have been linked to poor fecundity. Genuine solutions involve designating areas to be avoided and speed restrictions for ships and removing fishing trap ropes from the water column. A trap fishing closure for NARW habitat in the Cape Cod Bay (U.S.) area has been in place seasonally since 2015. 2017 mortalities in Eastern Canada elicited substantive management changes whereby the 2018 presence of NARW in active trap fishing areas resulted in an effective closure. To avoid these costly closures, the traditional trap fishery model of rope end lines attached to surface marker buoys has to be modified so that traps are marked virtually, and retrieved with gear that does not remain in the water column except during trap retrieval. Consumer demand for genuinely whale-safe products will augment and encourage the necessary regulatory changes so that trap fisheries conserve target and nontarget species.

Muirhead, C. A., Warde, A. M., Biedron, I. S., Mihnovets, A. N., Clark, C. W., & Rice, A. N. (2018). Seasonal Acoustic Occurrence of Blue, Fin, and North Atlantic Right Whales in the New York Bight. *Aquatic Conservation-Marine and Freshwater Ecosystems, 28*(3), 744-753. https://doi.org/10.1002/aqc.2874

The New York Bight is an extremely busy maritime region, with extensive shipping traffic and commercial fishing activity. It is part of the migratory ranges of a number of cetacean species, and includes threats from ship strikes, noise exposure, and line entanglements. Previous cetacean surveys of the Bight offer limited information on cetacean occurrence and distribution in the region, having been restricted to visual sightings with limited temporal coverage. A passive acoustic monitoring survey was conducted over a 258-day period to broaden understanding of the seasonal occurrences of blue

(*Balaenoptera musculus*), fin (*Balaenoptera physalus*), and North Atlantic right (*Eubalaena glacialis*) whales during late summer, autumn, winter, and early spring. Stationary acoustic recorders were positioned near the entrance to New York Harbour and as a linear transect extending from Long Island to the continental shelf edge. Blue, fin, and right whales were detected on 11%, 100%, and 16% of the survey days, respectively. Blue whales were detected offshore during January, February, and March. Fin whales were detected offshore every day, and less often near-shore. Right whales occurred sporadically during every month, but were most often detected at near-shore recorders between late February and mid-May. Based on the acoustic data alone, it is unclear exactly how these species are using this habitat, although it is clear that they occur in the area longer than was previously thought. Thus, management practices should incorporate this extended seasonal presence to mitigate any effects on the whales from shipping and fishing activities.

Mustain, P., Oceana, Webber, W., Elmslie, K., Brogan, G., & Pfleger, M. (2019). No Time to Lose: Last Chance for Survival for North Atlantic Right Whales. *MarXiv*. https://doi.org/10.31230/osf.io/4mnwp

The U.S. and Canada must work together to prevent these ocean giants from becoming extinct. Without immediate action, it will be too late. The survival of right whales depends on leadership from the U.S. and Canadian governments, the fishing and shipping industries, and others.

Myers, H. J., & Moore, M. J. (2020). Reducing Effort in the US American Lobster (*Homarus americanus*) Fishery to Prevent North Atlantic Right Whale (*Eubalaena glacialis*) Entanglements May Support Higher Profits and Long-Term Sustainability. *Marine Policy, 118*. https://doi.org/10.1016/j.marpol.2020.104017

North Atlantic right whales (*Eubalaena glacialis*) feed and migrate in areas of the inshore and offshore trap fishery for American lobster (*Homarus americanus*) in the Northeast U.S. In addition to a recent increase in lethal and sub-lethal interactions with Canadian snow crab gear, entanglement in both Canadian and U.S. lobster trap gear threatens the continued existence of this endangered species. The U.S. National Marine Fisheries Service is considering a number of measures to prevent right whale entanglement bycatch that could impact lobster fishing effort. The U.S. lobster fishery in Maine expends approximately 7.5 times as much effort as the Canadian fishery in Lobster Fishing Area 34, where Canadian fishers catch about 3.7 times more lobster per trap than their counterparts in Maine. From 2007 to 2013 in Maine, lobster landings doubled as the number of traps fell 10.5% and landings per trap increased by about 125%. The state of Massachusetts has achieved record high landings since trap/pot seasonal closures have been implemented to protect right whales, especially within the Statistical Reporting Areas most affected by the closures. Therefore, a negative economic impact should not be assumed with effort reduction. In fact, reducing effort may serve to increase fishing profits while supporting the protection of endangered North Atlantic right whales and the long-term sustainability of the lobster fishery.

Myers, H. J., Moore, M. J., Baumgartner, M. F., Brillant, S. W., Katona, S. K., Knowlton, A. R., . . . Werner, T. B. (2019). Ropeless Fishing to Prevent Large Whale Entanglements: Ropeless Consortium Report. *Marine Policy, 107*, 103587. https://doi.org/10.1016/j.marpol.2019.103587

The 2017 North Atlantic right whale (NARW) unusual mortality event and an increase in humpback whale entanglements off the U.S. West Coast have driven significant interest in ropeless trap/pot fishing. Removing the vertical buoy lines used to mark traps on the sea floor and haul them up would dramatically reduce or eliminate entanglements, the leading cause of NARW mortality, while potentially allowing fishermen to harvest in areas that would otherwise need to be closed to protect whales. At the first annual Ropeless Consortium meeting, researchers, fishing industry representatives, manufacturers, conservationists, and regulators discussed existing and developing technological replacements for the marking and retrieval functions of buoy lines. Fishermen and NGO partners shared their experience demonstrating ropeless systems and provided feedback to improve the designs. U.S. and Canadian federal regulators discussed prospects to use ropeless fishing gear in areas closed to fishing with vertical lines, as well as other options to reduce entanglements, and a Massachusetts official shared additional regulatory considerations involved in ropeless fishing in state waters. Sustainable seafood experts discussed consumer market advantages and endangered, threatened, and protected species impacts in sustainability standards and certifications. Moving forward, there is an immediate need to (1) work with industry partners to iteratively test and improve ropeless retrieval and marking systems to adapt them to the specific conditions of the relevant trap/pot fisheries, (2) create data sharing and communications protocols for ropeless gear location marking, and (3) develop regulatory procedures and enforcement capacity to allow legal ropeless gear use.

National Marine Fisheries Service. (2017). *North Atlantic Right Whale (Eubalaena glacialis) 5-Year Review: Summary and Evaluation.* https://doi.org/10.1016/0026-0495(77)90004-x

The Greater Atlantic Regional Fisheries Office led the 5-year review and requested review by the Northeast Fisheries Science Center, Office of Protected Resources, and Southeast Regional Office. The Recovery Plan for the North Atlantic Right Whale (*Eubalaena glacialis*), Marine Mammal Stock Assessment Reports, and a review of the scientific literature provided the information in this document. The literature review included publications related to the North Atlantic right whale made available through August 2017. We published a notification in the Federal Register on July 29, 2016 (81 FR 49957) initiating this review and requesting the submission of relevant scientific literature. Documents received through this submission process were included in this review. This included four submissions containing peer-reviewed literature.

National Marine Fisheries Service. (2018). *2018 Revision To: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing : Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts.* Retrieved from https://repository.library.noaa.gov/view/noaa/17892

This document provides voluntary technical guidance for assessing the effects of underwater anthropogenic (human-made) sound on the hearing of marine mammal species under the jurisdiction of the National Marine Fisheries Service (NMFS) and was completed in collaboration with the National Ocean Service (NOS), Office of National Marine Sanctuaries. Specifically, it identifies the received levels, or thresholds, at which individual marine mammals are predicted to experience changes in their hearing

sensitivity (either temporary or permanent) for acute, incidental exposure to underwater anthropogenic sound sources. This Technical Guidance may be used by NMFS analysts/managers and other relevant action proponents/stakeholders, including other federal agencies, when seeking to determine whether and how their activities are expected to result in potential impacts to marine mammal hearing via acoustic exposure. Please note that action proponents have discretion as to whether to use the Technical Guidance; other scientifically rigorous methods are acceptable. This document outlines the development of NMFS' thresholds and describes how they will be updated in the future."

Nielsen Delaney + Associates, & PubliVate. (2018). *Engagement on the Science-Based Whale Review a Summary of What Was Heard. Executive Summary March 2018.*

In November 2016, the Government of Canada announced its Oceans Protection Plan, which outlined several new initiatives aimed at addressing threats to populations of marine mammals in Canadian waters. To support this effort, Fisheries and Oceans Canada led a science-based review of the effectiveness of the current management and recovery actions for three at-risk whale populations: the Southern Resident Killer Whale, the North Atlantic Right Whale and the St. Lawrence Estuary Beluga. While Fisheries and Oceans Canada has worked with Indigenous groups, stakeholders and industry for many years to identify recovery actions for these endangered whale populations, this engagement process focused on the timely and efficient implementation of priority management actions. The three key objectives of the engagement were to: 1. Educate parties about the ongoing threats to the three endangered whale populations and the priority management actions identified by scientists to support their recovery. 2. Identify specific actions and clarify roles of those able to reduce negative impacts of human activities on these whales. 3. Confirm the role of different sectors and collaborative approaches to support and implement effective management actions. The report summarizes the common themes that emerged in meetings, written submissions, and the online Let's Talk Whales public engagement. It presents feedback on priority management actions to address five of the threats to one or more of these endangered whale species: prey availability, entanglements, acoustic disturbance and vessel presence, contaminants, and vessel strikes.Alternate abstract:En novembre 2016, le gouvernement du Canada a fait l'annonce de son Plan de protection des océans, qui souligne plusieurs nouvelles initiatives en vue de réduire les menaces qui pèsent sur les mammifères marins dans les eaux canadiennes. Pour appuyer ces efforts, Pêches et Océans Canada a mené un examen scientifique de l'efficacité des mesures de gestion et de rétablissement actuelles pour trois populations de baleines en péril : l'épaulard résident du sud, la baleine noire de l'Atlantique Nord et le béluga de l'estuaire du Saint-Laurent. Tandis que Pêches et Océans Canada a travaillé avec les groupes autochtones, les intervenants et l'industrie pendant de nombreuses années afin de déterminer les mesures de rétablissement pour ces populations de baleines en voie de disparition, ce processus de mobilisation porte sur la mise en œuvre efficace et en temps opportun des mesures de gestion prioritaires. Les trois objectifs principaux de la mobilisation étaient les suivants : 1. Éduquer les parties sur les menaces permanentes qui pèsent sur les trois populations de baleines en voie de disparition et les mesures de gestion prioritaires déterminées par les scientifiques en vue de soutenir leur rétablissement. 2. Déterminer les mesures particulières et préciser les rôles de ceux qui sont en mesure de réduire les répercussions négatives des activités humaines sur ces baleines. 3. Confirmer le rôle des différents secteurs et des approches collaboratives visant à soutenir et à mettre en œuvre des mesures de gestion efficaces. Le rapport résume les thèmes communs qui sont ressortis des réunions, des présentations écrites et de la mobilisation publique en ligne Parlons des baleines. Il présente les commentaires formulés sur les mesures de gestion prioritaires visant à réduire cinq des menaces qui pèsent sur l'une ou plusieurs de ces espèces de baleines en voie

de disparition : la disponibilité des proies, les empêtrements, les perturbations acoustiques et la présence de navires, les contaminants, et les collisions avec des navires.

Oceana, Lake, H., Elmslie, K., & Wilmot, L. (2019). The Last 400 - Strategies for Saving North Atlantic Right Whales in Canada. *MarXiv*. https://doi.org/10.31230/osf.io/qudg5

Tragically, endangered North Atlantic right whales are killed each year in the waters along the Atlantic Coast of Canada and the United States. Between 2012 and 2016, human activity killed an average of 5.6 of them every year.The summer of 2017 was devastating for the population. A total of 17 North Atlantic right whale deaths were reported – 12 of them in Canadian waters. The first dead whale was found on June 7 that year and by the end of the month, six had been found floating or washed ashore in the Gulf of St. Lawrence. In recent years, more right whales are being spotted in the Gulf of St. Lawrence, likely due to the effects climate change is having on the distribution of their food source, and they have experienced alarmingly high death rates in areas that are busy with commercial fishing activity and shipping traffic.

Oleson, E. M., Baker, J., Barlow, J., Moore, J. E., & Wade, P. (2020). *North Atlantic Right Whale Monitoring and Surveillance : Report and Recommendations of the National Marine Fisheries Service's Expert Working Group.* https://doi.org/10.25923/xnwj-5629

The National Marine Fisheries Service (NMFS) North Atlantic right whale (NARW) Steering Committee convened an expert Working Group to address two objectives related to monitoring NARWs: (1) improving our understanding of population status by identifying and tracking essential population metrics, and (2) improving our understanding of distribution and habitat use. The Working Group consisted of five NMFS researchers (the authors of this report) with expertise in marine mammal monitoring, but not directly involved in current NARW monitoring efforts. The Working Group was convened during a three-day workshop (held at NMFS Southwest Fisheries Science Center in La Jolla, California, from October 22-24, 2019, with remote participants on Day 1), and on a series of follow up conference calls. This report provides a brief summary of the information provided to the Working Group, including historic and current NARW monitoring efforts conducted by NMFS and partner institutions, information on the status and trends of NARWs, and analyses conducted during the workshop or at the Working Group's request. Moreover, the report primarily presents the Working Group's recommendations for a comprehensive monitoring strategy to guide future analyses and data collection on (1) NARW demographics and population status, (2) distribution shifts and habitat use range-wide, and (3) the health of individuals and the population. The Working Group's recommendations are intended to improve NMFS' overall monitoring strategy for NARW, with recognition of the significant contribution to NARW research and monitoring carried out by NMFS and partner institutions and agencies.

Pendleton, D., Pettis, H. M., Hamilton, P. K., Knowlton, A. R., Landry, S., Moore, M. J., . . . Kraus, S. D. (2019). *Entanglements of North Atlantic Right Whales Increase as Their Distribution Shifts in Response to Climate Change: The Need for a New Management Paradigm [Poster]*. https://doi.org/10.1575/1912/24974

No abstract.

Pennisi, E. (2017). North Atlantic Right Whale Faces Extinction: Entanglements and Ship Strikes Are Taking a Grave Toll, Reversing Past Population Gains. *Science, 358*(6364), 703-704. https://doi.org/10.1126/science.358.6364.703

The article discusses the concerns related to extinction faced by North Atlantic right whale as a result of their decreasing population due to entanglements and ship strikes. It presents an estimation of existing population of reproductively mature females and their survival ratio along with adverse impact of commercial fishing gear and fatal entanglements. It also mentions adoption of several measures to protect them such as closing of fisheries.

Pettis, H. M., Rolland, R. M., Hamilton, P. K., Knowlton, A. R., Burgess, E. A., & Kraus, S. D. (2017). Body Condition Changes Arising from Natural Factors and Fishing Gear Entanglements in North Atlantic Right Whales *Eubalaena glacialis*. *Endangered Species Research, 32*, 237-249. https://doi.org/10.3354/esr00800

Body condition has been correlated with survival and reproductive success in both terrestrial and marine mammals, including North Atlantic right whales *Eubalaena glacialis*. We used photographs of individually identified right whales to assess visual changes in body condition in reproductive females, adult males, juveniles, and entangled whales. Images from sightings of individual whales were grouped sequentially by habitat region, and each group of images was assigned a body condition score of good, fair, or poor based on the dorsal profile posterior to the blowholes. Temporally consecutive groups of images (n = 1496) of 340 individual whales were compared to investigate the frequency, direction, and minimum timeframe between changes in body condition. Changes in body condition scores of right whales were significantly influenced by group category. Lactating females and severely entangled right whales were more likely to exhibit declining body condition than other groups. Resting females were significantly more likely to improve in condition than other groups but exhibited the longest timeframe for improving condition. Young juveniles were less likely to improve in condition compared to adult males, but remained in compromised condition less frequently than older juveniles and adult males. The shortest timeframes between changing body condition scores were 11 d for declining condition and 12 d for improving condition. This study demonstrates that photographic analysis can detect rapid body condition changes and identifies groups of right whales that are particularly vulnerable to declining condition and delayed recovery from energetically taxing events.

Pirotta, V., Grech, A., Jonsen, I. D., Laurance, W. F., & Harcourt, R. (2018). Consequences of Global Shipping Traffic for Marine Giants. *Frontiers in Ecology and the Environment, 17*(1), 39-47. https://doi.org/10.1002/fee.1987

Shipping routes in the ocean are analogous to terrestrial roads, in that they are regularly used thoroughfares that concentrate the movement of vessels between multiple locations. We applied a terrestrial road ecology framework to examine the ecological impacts of increased global shipping on "marine giants" (ie great whales, basking sharks [*Cetorhinus maximus*], and whale sharks [*Rhincodon typus*]). This framework aided in identifying where such "marine roads" and marine giants are likely to interact and the consequences of those interactions. We also reviewed known impacts of shipping routes on these species, and then applied the road ecology framework to detect unknown and potentially threatening processes. In the marine environment, such a framework can be used to

incorporate knowledge of existing shipping impacts into management practices, thereby reducing the detrimental effects of future expansion of shipping routes on marine giants.

Poeta, G., Staffieri, E., Acosta, A. T. R., & Attisti, C. B. (2017). Ecological Effects of Anthropogenic Litter on Marine Mammals: A Global Review with a "Black-List" of Impacted Taxa. *Hystrix-Italian Journal of Mammalogy, 28*(2), 253-264. https://doi.org/10.4404/hystrix-00003-2017

In this work we would define an historical arrangement of the state of knowledge regarding the ecological impact of anthropogenic litter on marine mammals, assessing the role of different type of impacts (ingestion vs. entanglement) and pressures (three size-based categories). Analyzing 203 references (from 1976 to 2016), we obtained a "black-list" of 101 species impacted by marine litter (78.9% on 128 species totally known). At species level, four cetacean (*Megaptera novaeangliae*, *Physeter macrocephalus*, *Tursiops truncatus*, *Eubalaena glacialis*) showed the highest number of bibliographic citations. A significant higher number of species was impacted by entanglement when compared to ingestion. Macro-litter represents the main factor of pressure in all groups; micro-litter showed the highest frequency in Mysticeti, probably explained from their food filtration behaviour. Both intrinsic eco-biogeographic traits (e.g. trophic niche, food catching behaviour, species range) and extrinsic methodological biases could explain our patterns. Since the entanglement is easier to record because of imply only an external observation without further post-mortem examination, and that large litter is easier to detect in respect to meso-and micro-litter, we hypothesize that both this information could be largely biased. Moreover, we observed a direct correlation between the research effort on species (obtained from Scholar recurrences) and the number of citations related to marine litter events, although some exceptions are present: therefore our "black" list of impacted species is not complete and could be increased focusing research on poor-studied neglected species. After 2005 the number of studies on this topic showed a large increase: however, literature appeared extremely heterogeneous. In this sense, we suggest the use of a standardized nomenclature for pressures and impacts to reduce the loss of information.

Record, N. R., Runge, J. A., Pendleton, D. E., Balch, W. M., Davies, K. T. A., Pershing, A. J., . . . Thompson, C. R. S. (2019). Rapid Climate-Driven Circulation Changes Threaten Conservation of Endangered North Atlantic Right Whales. *Oceanography, 32*(2), 162-169. https://doi.org/10.5670/oceanog.2019.201

As climate trends accelerate, ecosystems will be pushed rapidly into new states, reducing the potential efficacy of conservation strategies based on historical patterns. In the Gulf of Maine, climate-driven changes have restructured the ecosystem rapidly over the past decade. Changes in the Atlantic meridional overturning circulation have altered deepwater dynamics, driving warming rates twice as high as the fastest surface rates. This has had implications for the copepod *Calanus finmarchicus*, a critical food supply for the endangered North Atlantic right whale (*Eubalaena glacialis*). The oceanographic changes have driven a deviation in the seasonal foraging patterns of *E. glacialis* upon which conservation strategies depend, making the whales more vulnerable to ship strikes and gear entanglements. The effects of rapid climate-driven changes on a species at risk undermine current management approaches.

Rickard, M. (2018). Battle for Survival -- the Plight of North Atlantic Right Whales. *New York State Conservationist, 73*(2), 12-15.

The article offers information about North Atlantic right whales (NARW) and the story of their plight and discusses the efforts to protect them and conserve their population. Topics mentioned include the physical characteristics of NARW, their differences with their North Pacific and South Pacific counterparts, the causes of RW deaths including ship strikes, and the goals of the New York Department of Environmental Conservation's New York Bight Whale Monitoring Proram.

Rockwood, R., Adams, J., Silber, G., & Jahncke, J. (2020). Estimating Effectiveness of Speed Reduction Measures for Decreasing Whale Strike Mortality in a High-Risk Region. *Endangered Species Research, 43*. https://doi.org/10.3354/esr01056

Recent estimates of blue (*Balaenoptera musculus*) and humpback (*Megaptera novaeangliae*) whale ship-strike deaths on the US west coast are above the Potential Biological Removal limit determined by the National Marine Fisheries Service. Beginning in 2015, the National Oceanographic and Atmospheric Administration requested voluntary Vessel Speed Reductions (VSR) in the designated shipping routes off San Francisco, California, USA, in order to decrease whale mortality from ship strikes. We applied a ship strike model based on whale density and Automatic Identification System (AIS) vessel data. We bootstrapped speeds from vessels that transited when no VSR was in place to assess the effect of the VSR on strike mortality rates. Finally, we calculated the expected mortality for hypothetical compliance scenarios by programmatically imposing speed caps. Average predicted mortality for the region was 2.7 blue whales and 7.0 humpback whales in a 4 month period. Compared to years prior to the VSR (2012-2014), vessel speeds during the VSR were slower. This lowered blue whale deaths within the shipping lanes by 11-13% and humpback whale deaths by 9-10% in 2016-2017. If 95% of mariners adhered to recommended 10 knot (kn) limits in the shipping lanes alone, we predicted twice as many blue whale and 3 times as many humpback whale deaths would be avoided relative to current adherence. Adding a 10 kn speed limit (with 95% cooperation) at the ends of each of the lanes would result in about 5- and 4-fold reductions in blue whale and humpback whale mortality, respectively, relative to current practices. Our approach can evaluate ship strikes and mitigation measures for whale populations around the globe.

Schluter, C. (2021). *Opportunities for Public Comments on Pending Trap/Pot Fishery Regulations to Protect the North Atlantic Right Whale.*

The National Marine Fisheries Service (NMFS) is currently in the process of developing new regulations to protect the North Atlantic right whale (right whale). The recent court decision in Center for Biological Diversity v. Ross requires NMFS to finalize the new regulations by May 31, 2021. If NMFS does not finalize regulations by that time, lobster fishing will have to immediately shut down. As part of the process of developing new regulations, the public will have the opportunity to voice their thoughts and opinions. This fact sheet explains the issues and reasoning behind Center for Biological Diversity v. Ross, as well as why the lobster industry must be a part of right whale protection. It will then explain the process NMFS will follow to develop new regulations so that lobster fishing can continue, with an emphasis on opportunities for public participation.

Schoeman, R. P., Patterson-Abrolat, C., & Plön, S. (2020). A Global Review of Vessel Collisions with Marine Animals. *Frontiers in Marine Science, 7*(292). https://doi.org/10.3389/fmars.2020.00292

Concern about the effects of maritime vessel collisions with marine animals is increasing worldwide. To date, most scientific publications on this topic have focused on the collisions between large vessels and large whales. However, our review found that at least 75 marine species are affected, including smaller whales, dolphins, porpoises, dugongs, manatees, whale sharks, sharks, seals, sea otters, sea turtles, penguins, and fish. Collision incidents with smaller species are scarce, likely as a result of reporting biases. Some of these biases can be addressed through the establishment of species-specific necropsy protocols to ensure reliable identification of collision-related injury, particularly blunt force trauma. In addition, creating a ship strike database for smaller species can assist in identifying the species most frequently involved in collisions, identifying high-risk areas, and determining species-specific relationships between vessel speed and lethal injury. The International Whaling Commission database on collisions with large whales provides a good example of this type of database and its potential uses. Prioritizing the establishment of a species-specific necropsy protocol and a database for smaller species as well as the identification of high-risk areas for species other than large whales, would be a valuable step toward the mitigation of collisions with smaller species.

Sèbe, M., Kontovas, C. A., & Pendleton, L. (2019). A Decision-Making Framework to Reduce the Risk of Collisions between Ships and Whales. *Marine Policy, 109*, 103697. https://doi.org/10.1016/j.marpol.2019.103697

Ship strikes are one of the main human-induced threats to whale survival. A variety of measures have been used or proposed to reduce collisions and subsequent mortality of whales. These include operational measures, such as mandatory speed reduction, or technical ones, such as detection tools. There is, however, a lack of a systematic approach to assessing the various measures that can mitigate the risk of ship collisions with whales. In this paper, a holistic approach is proposed to evaluate mitigation measures based on a risk assessment framework that has been adopted by the International Maritime Organization (IMO), namely the Formal Safety Assessment (FSA). Formal Safety Assessment (FSA) is “a rational and systematic process for assessing the risk related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks”. The paper conceptualizes the use of a systematic risk assessment methodology, namely the FSA, to assess measures to reduce the risk of collisions between ships and whales.

Sharp, S. M., McLellan, W. A., Rotstein, D. S., Costidis, A. M., Barco, S. G., Durham, K., . . . Moore, M. J. (2019). Gross and Histopathologic Diagnoses from North Atlantic Right Whale *Eubalaena glacialis* Mortalities between 2003 and 2018. *Diseases of Aquatic Organisms, 135*(1), 1-31. https://doi.org/10.3354/dao03376

Seventy mortalities of North Atlantic right whales *Eubalaena glacialis* (NARW) were documented between 2003 and 2018 from Florida, USA, to the Gulf of St. Lawrence, Canada. These included 30 adults, 14 juveniles, 10 calves, and 16 of unknown age class. Females represented 65.5% (19/29) of known-sex adults. Fourteen cases had photos only; 56 carcasses received external examinations, 44 of which were also necropsied. Cause of death was determined in 43 cases, of which 38 (88.4%) were due to anthropogenic trauma: 22 (57.9%) from entanglement, and 16 (42.1%) from vessel strike. Gross and

histopathologic lesions associated with entanglement were often severe and included deep lacerations caused by constricting line wraps around the flippers, flukes, and head/mouth; baleen plate mutilation; chronic extensive bone lesions from impinging line, and traumatic scoliosis resulting in compromised mobility in a calf. Chronically entangled whales were often in poor body condition and had increased cyamid burden, reflecting compromised health. Vessel strike blunt force injuries included skull and vertebral fractures, blubber and muscle contusions, and large blood clots. Propeller-induced wounds often caused extensive damage to blubber, muscle, viscera, and bone. Overall prevalence of NARW entanglement mortalities increased from 21% (1970-2002) to 51% during this study period. This demonstrates that despite mitigation efforts, entanglements and vessel strikes continue to inflict profound physical trauma and suffering on individual NARWs. These cumulative mortalities are also unsustainable at the population level, so urgent and aggressive intervention is needed to end anthropogenic mortality in this critically endangered species.

Shiu, Y., Palmer, K. J., Roch, M. A., Fleishman, E., Liu, X. B., Nosal, E. M., . . . Klinck, H. (2020). Deep Neural Networks for Automated Detection of Marine Mammal Species. *Scientific Reports, 10*(1), 607. https://doi.org/10.1038/s41598-020-57549-y

Deep neural networks have advanced the field of detection and classification and allowed for effective identification of signals in challenging data sets. Numerous time-critical conservation needs may benefit from these methods. We developed and empirically studied a variety of deep neural networks to detect the vocalizations of endangered North Atlantic right whales (*Eubalaena glacialis*). We compared the performance of these deep architectures to that of traditional detection algorithms for the primary vocalization produced by this species, the upcall. We show that deep-learning architectures are capable of producing false-positive rates that are orders of magnitude lower than alternative algorithms while substantially increasing the ability to detect calls. We demonstrate that a deep neural network trained with recordings from a single geographic region recorded over a span of days is capable of generalizing well to data from multiple years and across the species' range, and that the low false positives make the output of the algorithm amenable to quality control for verification. The deep neural networks we developed are relatively easy to implement with existing software, and may provide new insights applicable to the conservation of endangered species.

Silber, G. K., & Wallmo, K. (2017). Assessing a Long-Standing Conservation Program: Mariner's Perspectives on the North Atlantic Right Whale, *Eubalaena glacialis*, Mandatory Ship Reporting System. *Marine Fisheries Review, 78*(3-4), 22-36. https://doi.org/10.7755/mfr.78.3-4.3

Measures established to protect living marine resources, including those for endangered marine species, are only infrequently evaluated. In this paper we report fi ndings of an online survey designed to solicit the views of maritime industries about a long-standing endangered large whale conservation program: the Mandatory Ship Reporting (MSR) system. The MSR was established in 1999 to aid in reducing the threat of vessel collisions with the highly depleted North Atlantic right whale, *Eubalaena glacialis*. Under MSR provisions, vessels >300 gross tons are required to report their location, speed, and destination when entering two key right whale aggregation areas. In return, reporting ships are sent an automated message about right whale vulnerability to ship collisions. The survey was intended to obtain views about the extent to which vessel operations were interrupted by the reporting requirement; how mariners utilize, if at all, information provided in the return message; whether vessel operations were modifi ed in response to guidance provided; and the overall importance and effectiveness of the

reporting systems in helping ships avoid right whale interactions. A total of 119 mariners with broad representation of vessel types and decades of experience at sea took part in the survey; 56 of these indicated they had entered one of the MSR areas at least once. Most (ca. 70%) indicated that they comply with the reporting requirement, distribute information on right whales and ship strikes to crew members, that they were more alert about avoiding/watching for right whales, and that the ships operation may change to avoid an interaction. Of the survey-takers who had entered the system, about half indicated the MSR system is useful for educating captains and crew about right whales and important for right whale conservation, but only about a quarter indicated that it is useful in helping ships avoid right whales. About 40% said it is an unnecessary requirement for ships. We conclude that as an outreach tool and a means to provide information directly to domestic and international mariners entering right whale habitat for over 15 years (thus, tens of thousands of ships entering these waters have received the message), the MSR almost certainly has been benefi cial in educating mariners about the issue of ship strike and in providing guidance on avoiding ship strikes. Views reflected in the survey suggest that, at least from the mariners' perspective, the MSR program has provided positive conservation value; however, not all mariners took specific strike avoidance action after having received the message.

Sisson, N. B., & Long, K. J. (2018). *Evaluating Effectiveness of U.S. Management Measures: Summary of the North Atlantic Right Whale Technical Expert Working Group on Evaluating Effectiveness of U.S. Management Measures, 21-23 May 2018, Woods Hole, Massachusetts.* https://doi.org/10.25923/mzmf-7q91

NOAA's National Marine Fisheries Service (NMFS) convened an expert working group at the Northeast Fisheries Science Center (NEFSC) in Woods Hole, Massachusetts, May 21-23, 2018, to gather input on how NMFS should evaluate the effectiveness of U.S. management measures for reducing ship strikes and entanglements of North Atlantic right whales. The primary purpose of the meeting was to: (1) review available data sets and analyses (for both the U.S. and Canada) on the rates and types of entanglements and vessel strikes with right whales to better understand their potential impact on population dynamics, and (2) identify potential methods/analytical tools (and associated pros/cons) available to address the key questions.

Southall, B. L., Hatch, L., Scholik-Schlomer, A. R., Bergmann, T., Jasny, M., Metcalf, K., . . . Perera, M. E. (2018). *Reducing Noise from Large Commercial Ships Progress and Partnerships.* Paper presented at the Marine Safety and Security Council - Coast Guard Journal of Safety and Security at Sea.

Increasing ensonification of our oceans by human sound sources has been identified as an important environmental concern, spurring intensive study by marine scientists during the past few decades. Guidelines and mitigation measures have been developed by regulators, and various sectors have sought ways to reduce noise in the ocean and its effects on marine life. Scientific research and recent national and international efforts continue in their attempts to quiet commercial ships, one of the leading contributors to noise in the ocean

Stokstad, E. (2017). Surge in Right Whale Deaths Raises Alarms. *Science, 357*(6353), 740-741. https://doi.org/10.1126/science.357.6353.740

The highly endangered North Atlantic right whale is having its worst year in decades. At least 13 of the whales—out of a population thought to be only about 450—have died this year, most of them during the past 2 months in the Gulf of Saint Lawrence off Canada's eastern coast. At least three appear to have been hit by ships, and one perished after becoming entangled in fishing gear. In a bid to prevent more losses, Canadian officials have imposed new restrictions on shipping and fishing until the whales migrate south later this year. In September, Canadian officials plan to start consulting with the fishing and shipping industries about what to do next. Some scientists speculate that the whales are looking for new sources of food, perhaps driven north by warming seas. Others are testing underwater gliders equipped with sound sensors that can detect right whales, part of a system that could send alerts to nearby ships.

Summers, E. (2019). The Regulation of the Maine Lobster Fishery to Protect the Endangered North Atlantic Right Whale. *Lobster Newsletter, 32*(1), 6-8.

The decline of the North Atlantic right whale, *Eubalaena glacialis* (Fig. 1), has set up a conflict in the US lobster fishery. There are two perceived sides to the issue, those who want to make sweeping changes to the US American lobster fishery and those who execute that fishery. But, as in most conflicts, there is more gray to the issue than black or white, and the plight of the right whale is one that is plagued by a severe lack of information to guide the dialogue. After years of growth and robust calving, the right whale population began to decline from its peak in 2010 to its current status of 411 individuals (Fig. 2; Pettis et al. 2018; Pace et al. 2017). This prompted the initiation of US action in 2017 under the Marine Mammal Protection Act, action which was accelerated later that same year when 17 right whales were found dead between the Gulf of St. Lawrence in Canada and along the East Coast of the US (Unusual Mortality Event). This loss is equivalent to roughly 4% of the population. Human-caused serious injury and mortality in this species is made up of ship strikes and entanglements in fixed fishing gear, such as trap fisheries and gillnets (Knowlton and Kraus 2001). In Maine, the largest fixed gear fishery is the lobster fishery.

Taylor, S., & Walker, T. R. (2017). North Atlantic Right Whales in Danger. *Science, 358*(6364), 730-731. https://doi.org/10.1126/science.aar2402

The article offers information on death of several endangered North Atlantic right whales in the Gulf of St. Lawrence, Canada in 2017 due to instances of fishing gear entanglement and ship strikes, and mentions the federal laws of the U.S. and Canada, for protection of these species.

Terhune, J., & Killorn, D. (2021). A Method for Preliminary Assessment of the Masking Potential of Anthropogenic Noise to Baleen Whale Calls. *Aquatic Mammals, 47*, 283-291. https://doi.org/10.1578/AM.47.3.2021.283

Models of cetacean communication range reductions associated with anthropogenic noises are complex. They often require assumptions related to the hearing abilities and vocalization source levels of the species concerned. The maximum range of a call is limited by transmission losses which reduce

the signal amplitude until it is masked by ambient noise. We propose a simple method to estimate the proportional reductions in communication range associated with anthropogenic noise sources, relative to the maximum range under ambient noise-level conditions, that can be calculated using only noise-level measurements and is independent of the hearing sensitivity of the species concerned. The remaining communication range (% of maximum) = 10-Δ/k × 100 where Δ is the dB difference between the anthropogenic noise level and the ambient noise level while assuming a spreading loss of klog (range). This enables indexing the remaining communication ranges and, by 10 observation of plots of the data, identifying duty cycles associated with anthropogenic noises. The proposed method was tested with the analysis of underwater ferry noise in a baleen whale habitat in the Bay of Fundy, Canada. The relative communication range and duty cycle were estimated using data from autonomous underwater recorders. Three one-third octave band levels at the same frequencies as vocalizations of the local mysticete species were analyzed. Calls at 20 Hz would not be masked by ferry noises. Calls at 125 and 500 Hz would have severely reduced communication ranges for eight one-hour periods per day when the ferries were operating. Collection and analyses of only noise-level data are faster and much less expensive than more sophisticated studies. Computing remaining communication range analyses may be a useful first step in identifying and ranking anthropogenic noise sources and their potential for animal communication masking.

Tittensor, D. P., Beger, M., Boerder, K., Boyce, D. G., Cavanagh, R. D., Cosandey-Godin, A., . . . Worm, B. (2019). Integrating Climate Adaptation and Biodiversity Conservation in the Global Ocean. *Science advances, 5*(11), eaay9969. https://doi.org/10.1126/sciadv.aay9969

The impacts of climate change and the socioecological challenges they present are ubiquitous and increasingly severe. Practical efforts to operationalize climate-responsive design and management in the global network of marine protected areas (MPAs) are required to ensure long-term effectiveness for safeguarding marine biodiversity and ecosystem services. Here, we review progress in integrating climate change adaptation into MPA design and management and provide eight recommendations to expedite this process. Climate-smart management objectives should become the default for all protected areas, and made into an explicit international policy target. Furthermore, incentives to use more dynamic management tools would increase the climate change responsiveness of the MPA network as a whole. Given ongoing negotiations on international conservation targets, now is the ideal time to proactively reform management of the global seascape for the dynamic climate-biodiversity reality.

Truchon, M.-H., Measures, L., Brêthes, J.-C., Albert, É., & Michaud, R. (2018). Influence of Anthropogenic Activities on Marine Mammal Strandings in the Estuary and Northwestern Gulf of St. Lawrence, Quebec, Canada, 1994–2008. *Journal of Cetacean Research & Management, 18*, 11-21.

Stranding records have long been used to monitor marine mammal mortalities and to help identify threats to populations. In coastal areas, marine mammals face numerous anthropogenic threats such as marine traffic and commercial fishing. The objective of this study was to investigate marine mammal stranding records from the St. Lawrence Estuary (SLE) and the northwestern Gulf of St. Lawrence (NWGSL), Quebec, Canada from 1994 to 2008 for evidence of anthropogenic trauma caused by entanglement in fishing gear, ship collisions and gunshots. Of 1,590 marine mammal stranding records, 12% (n = 192) had evidence of anthropogenic trauma, most incidents being reported during summer when activities such as marine traffic, most commercial fishing and recreational boating, occurred and a

greater number of species were present in the area. These incidents were classified into five categories (Incidental catch, Ship collision, Severe injury, Gunshot, Other). There were 1,245 mortalities and observations on carcasses suggested that anthropogenic trauma led to the death of 11% (141/1,245) of marine mammals: 14% (87/627) of cetaceans and 9% (54/618) of seals. Mortality of seals due to anthropogenic trauma was low, involving mainly Gunshot for grey (26% or 8/31) and harbour seals (26% or 8/31). Over the study period, marine mammal incidents with evidence of anthropogenic trauma increased significantly, driven by an increase in Incidental catch for two mysticete species, the common minke whale, 42% (39/92) and humpback whale, 13% (12/92) and Other for harbour porpoise 67% (16/24). Ship collision was the most common anthropogenic trauma for fin whales (22% or 8/36) and SLE beluga5 (22% or 8/36). Severe injury was reported for 22% (2/9) of small cetaceans and 78% (7/9) of seals. Evidence from some harbour porpoise stranding records (categorised as Other) suggests illegal hunting, incidental catch, predation or scavenging by grey seals in a marine protected area. The observed increase in Incidental catch of common minke and humpback whales may be due to: (1) a shift in distribution of these two species into the SLE and NWGSL, possibly related to changes in the ecosystem; (2) changes in fishery practices; and (3) an increase in detection of marine mammal strandings. Anthropogenic trauma affecting marine mammals was documented including some species at risk, such as the harbour porpoise, the St. Lawrence Estuary beluga population, blue and North Atlantic right whales, in the St. Lawrence ecosystem including in a marine protected area. This study demonstrates the usefulness of stranding records in helping to monitor human-caused mortality in marine mammal populations.

van der Hoop, J., Corkeron, P., & Moore, M. (2017). Entanglement Is a Costly Life-History Stage in Large Whales. *Ecology and Evolution, 7*(1), 317-319. https://doi.org/10.1002/ece3.2615

Individuals store energy to balance deficits in natural cycles; however, unnatural events can also lead to unbalanced energy budgets. Entanglement in fishing gear is one example of an unnatural but relatively common circumstance that imposes energetic demands of a similar order of magnitude and duration of life-history events such as migration and pregnancy in large whales. We present two complementary bioenergetic approaches to estimate the energy associated with entanglement in North Atlantic right whales, and compare these estimates to the natural energetic life history of individual whales. Differences in measured blubber thicknesses and estimated blubber volumes between normal and entangled, emaciated whales indicate between 7.4 × 1010 J and 1.2 × 1011 J of energy are consumed during the course to death of a lethal entanglement. Increased thrust power requirements to overcome drag forces suggest that when entangled, whales require 3.95 × 109 to 4.08 × 1010 J more energy to swim. Individuals who died from their entanglements performed significantly more work (energy expenditure × time) than those that survived; entanglement duration is therefore critical in determining whales' survival. Significant sublethal energetic impacts also occur, especially in reproductive females. Drag from fishing gear contributes up to 8% of the 4-year female reproductive energy budget, delaying time of energetic equilibrium (to restore energy lost by a particular entanglement) for reproduction by months to years. In certain populations, chronic entanglement in fishing gear can be viewed as a costly unnatural life-history stage, rather than a rare or short-term incident.

van der Hoop, J. M., Corkeron, P., Henry, A. G., Knowlton, A. R., & Moore, M. J. (2017). Predicting Lethal Entanglements as a Consequence of Drag from Fishing Gear. *Marine Pollution Bulletin, 115*(1-2), 91-104. https://doi.org/10.1016/j.marpolbul.2016.11.060

Large whales are frequently entangled in fishing gear and sometimes swim while carrying gear for days to years. Entangled whales are subject to additional drag forces requiring increased thrust power and energy expenditure over time. To classify entanglement cases and aid potential disentanglement efforts, it is useful to know how long an entangled whale might survive, given the unique configurations of the gear they are towing. This study establishes an approach to predict drag forces on fishing gear that entangles whales, and applies this method to ten North Atlantic right whale cases to estimate the resulting increase in energy expenditure and the critical entanglement duration that could lead to death. Estimated gear drag ranged 11-275 N. Most entanglements were resolved before critical entanglement durations (mean +/- SD +/- 216 +/- 260 days) were reached. These estimates can assist real-time development of disentanglement action plans and U.S. Federal Serious Injury assessments required for protected species.

van der Hoop, J. M., Nowacek, D. P., Moore, M. J., & Triantafyllou, M. S. (2017). Swimming Kinematics and Efficiency of Entangled North Atlantic Right Whales. *Endangered Species Research, 32*, 1-17. https://doi.org/10.3354/esr00781

Marine mammals are streamlined for efficient movement in their relatively viscous fluid environment and are able to alter their kinematics (i.e. fluke stroke frequency, amplitude, or both) in response to changes in force balance. Entanglement in fishing gear adds significant drag and buoyant forces that can impact swimming behaviors across a range of timescales. We deployed biologging tags during the disentanglement of 2 North Atlantic right whales *Eubalaena glacialis* to (1) examine how their kinematics changed in response to drag and buoyancy from entanglement in fishing gear, and (2) calculate resultant changes in swimming efficiency for one individual. We observed variable responses in dive behavior, but neither whale appeared to exploit added buoyancy to reduce energy expenditure. While some of the observed changes in behavior were individually specific, some swimming kinematics were consistently modulated in response to high drag and buoyancy associated with entangling gear, affecting thrust production. In high drag and buoyancy conditions, fluke strokes were significantly shorter and more variable in shape, and gliding was less frequent. Thrust and efficiency significantly differed among dive phases. Disentanglement reduced thrust coefficients similar to 4-fold, leading to 1.2 to 1.8-fold lower power (W). Ideal propulsive efficiency was significantly lower when entangled, though we detected no difference in observed propulsive efficiency between the conditions. Similar to carrying heavy objects or changing shoes, we present another condition where animals perceive unique movement constraints over seconds to minutes and develop compensatory strategies, altering their movement accordingly.

Welsh, H. (2018). Managing Canada's Endangered: An Analysis of Canada's Efforts to Mitigate Shipping Impacts on North Atlantic Right Whales. In *Dalhousie University*.

North Atlantic Right Whales are vulnerable to anthropogenic impacts from commercial shipping and fishing practices. After the 2017 NARW season, that left 17 NARWs killed in Canadian and U.S waters, the U.S defined the situation as an “unusual mortality event”. Necropsies confirmed that a large proportion of dead NARWs showed evidence of blunt force trauma, a trauma experienced through

lethal vessel to whale encounters. In the past, management measures have been put in place to address ship-strikes and NARWs, however due to an unexpected presence of NARWs in the Gulf of St. Lawrence these management measures have been deemed ineffective. This research project involves the implementation of dynamic ocean management (DOM) in the Gulf of St. Lawrence in an attempt to mitigate ship-strikes on NARWs. This graduate project analyses the effectiveness of previous vessel measures, the challenges in implementing DOM and how the Government of Canada can protect NARWs in the years to come.

Wu, C., Howle, L. E., McGregor, A. E., McGregor, R., & Nowacek, D. P. (2019). Computational Fluid Dynamics Simulations of a 10m North Atlantic Right Whale (*Eubalaena glacialis*). *Integrative and Comparative Biology, 59*, E254-E254.

Drag occurs when an object moves through a fluid due to the viscosity of the fluid. Accurate estimations of drag on marine animals are required if one wants to investigate the locomotive cost, the propulsive efficiency, and, in our case, the impacts of entanglement while the animal is carrying fishing gear. In this study, we performed computational fluid dynamics (CFD) analysis over a 10m (length of animal, LOA) static right whale model in a commercial flow solver (SolidWorks Fluid Simulation 2015) to obtain baseline measurements of drag on the animal. Swimming speeds covering known right whale speed range (0.125 m/s to 8 m/s) were tested. We found a weak dependence between drag coefficient and Reynolds number. At a swimming speed of 2 m/s, we analyzed the boundary layer thicknesses, the flow regimes, and drag components. We found the thickest boundary layer at the lateral sides of the peduncle whereas the boundary layer thickness over the outer part of the flukes was less than 1.7cm. Laminar flow occurred over the anterior ~0.6 LOA and fully turbulent flow from ~0.8 LOA to the fluke notch. On surfaces of the flukes outside of the body wake region, flow was laminar. Our most significant finding is that the drag coefficient (0.0071-0.0059) of a right whale, which is associated with the morphology the animal, for swimming speeds ranging from 0.25 m/s to 2 m/s is approximately twice that of many previous drag coefficient estimates for cetaceans.

Wu, C. Y., Nowacek, D. P., Nousek-McGregor, A. E., McGregor, R., & Howle, L. E. (2021). Computational Fluid Dynamics of Flow Regime and Hydrodynamic Forces Generated by a Gliding North Atlantic Right Whale (*Eubalaena glacialis*). *Marine Mammal Science*. https://doi.org/10.1111/mms.12798

Accurate estimates of drag on marine animals are required to investigate the locomotive cost, propulsive efficiency, and the impacts of entanglement if the animal is carrying fishing gear. In this study, we performed computational fluid dynamics analysis of a 10 m (length over all) right whale to obtain baseline measurements of drag on the animal. Swimming speeds covering known right whale speed range (0.125 m/s to 8 m/s) were tested. We found a weak dependence between drag coefficient and Reynolds number. At a swimming speed of 2 m/s, we analyzed the boundary layer thicknesses, the flow regimes, and drag components. We found the thickest boundary layer at the lateral sides of the peduncle, whereas the boundary layer thickness over the outer part of the flukes was less than 1.7 cm. Laminar flow occurred over the anterior similar to 0.6 LoA and turbulent flow from similar to 0.8 LoA to the fluke notch. On the surfaces of the flukes outside of the body wake region, flow was laminar. Our most significant finding is that the drag coefficient (0.0071-0.0059) of a right whale for swimming speeds ranging from 0.25 m/s to 2 m/s is approximately twice that of many previous estimates for cetaceans.

Section V: General

Benjamin, G., & Porter, R. (2021). *Understanding the North Atlantic Right Whale Litigation.*

The North Atlantic right whale is critically endangered, with a population of fewer than 400 individuals. Federal laws, including the Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA), protect the right whale and require the government to consider and avoid harm to the species before taking actions that may affect them. Entanglement with fishing gear is among the most common ways that right whales are harmed, so regulators cannot authorize fishing without first considering how much of a risk entanglement poses and adopting measures to avoid and minimize the frequency and severity of interactions between whales and fishing gear. Disagreement about the effectiveness of these measures has recently resulted in challenges to the legality of the American lobster, Jonah crab, gillnet, and other fisheries in waters off New England. While both state and federal fishing regulators have been sued, this document only discusses litigation challenging federal fisheries. These fisheries occur in waters between 3 and 200 nautical miles from shore. While long-standing efforts to recover the North Atlantic right whale were successful in rebuilding the species from historic lows, a 2017 "Unusual Mortality Event" resulted in the loss of more than 10% of all known individuals.1 In 2018, environmental plaintiffs responded by suing the National Marine Fisheries Service (NMFS) for violating the ESA. In August 2020, the court in Center for Biological Diversity v. Ross issued the latest in a series of rulings holding that NMFS did violate the ESA when it authorized the American lobster fishery.2 NMFS therefore was required to reconsider the effect of fishing on whales and issue new, legally-valid rules for the fishery based on its findings. If it failed to complete this process by May 31, 2021, the federal lobster fishery would be shut down. This case has generated a high level of interest as it has inspired a narrative that places one of the nation's most iconic fisheries at odds with one of its most recognizable endangered species. However, it is important to acknowledge that the case turns on complex legal issues and has resulted in multiple separate, but related, regulatory processes that may be difficult for the general public to fully understand despite efforts to remain well-informed. This fact sheet supports a more informed public understanding by explaining: (i) how the ESA and MMPA work (and work together); (ii) how these laws apply to the North Atlantic right whale; (iii) the holdings in Center for Biological Diversity v. Ross; and (iv) NMFS's progress towards addressing the violations so that the fishery can continue without jeopardizing the continued existence of the whales.

Fraenkel, A., & Evans, P. G. H. (2020). Infraorder Mysticeti, the Baleen Whales Family Balaenidae (Right Whales) North Atlantic Right Whale *Eubalaena glacialis*. In *European Whales, Dolphins, and Porpoises: Marine Mammal Conservation in Practice.* (pp. 136-138)

No abstract.

Garcia-Gallego, A., Borrell, Y. J., Nores, C., & Miralles, L. (2021). Whaling Tradition Along the Cantabrian Coast: Public Perception Towards Cetaceans and Its Importance for Marine Conservation. *Biodiversity and Conservation, 30*(7), 2125-2143. https://doi.org/10.1007/s10531-021-02187-7

Whaling is currently a controversial practice and the focus of a relevant public debate. According to records, it represented an important socio-economic activity in the North of Spain from the thirteenth to the eighteenth century. The North Atlantic Right Whale (*Eubalaena glacialis*) was the main target species of this activity. As a consequence of the rising of whaling, the North-East Atlantic population of

this species was severely depleted, and it has not recovered since then. This work presents a study on public perception of cetaceans and whaling along the Cantabrian coast (North of Spain) and evaluates the differences with respect to several non-coastal regions. More than 400 anonymous surveys were conducted in 12 study areas to examine knowledge about cetaceans and whaling, as well as attitudes and willingness to take action in whale and dolphin conservation. Results showed that whaling has a great cultural imprint on the Cantabrian coast inhabitants, which plays a relevant role in citizens' perception. Participants from areas with whaling tradition demonstrated higher levels of knowledge about the history of this activity, but less positive attitudes with respect to cetacean conservation than respondents from inland provinces. Additionally, we observed that there are other influencing factors, such as gender or age. Our findings indicate that positive attitudes towards the protection of whales and dolphins are not always sufficient for citizens to collaborate for this cause. Therefore, an improvement in education programmes and awareness campaigns about the importance of protecting cetaceans and their environment is needed to achieve real and effective marine citizenship.

Hunt, K. E., Ajó, A. F., Lowe, C., Burgess, E. A., & Buck, C. L. (2020). A Tale of Two Whales: Putting Physiological Tools to Work for North Atlantic and Southern Right Whales. In *Conservation Physiology.* (pp. 205-226): Oxford University Press https://doi.org/10.1093/oso/9780198843610.003.0012

Conservation physiology tools can be difficult to employ in the wild. Here we discuss developments in conservation physiology research of large whales, a taxonomic group that is famously difficult to study with traditional tools. We focus on the North Atlantic right whale *Eubalaena glacialis* and southern right whale *Eubalaena australis*, two closely related species that present similar logistical challenges for research, yet differ in population status and conservation pressures. Research has advanced via a suite of creative approaches including photo-identification, visual health assessment, remote methods of assessing body condition, and endocrine research on non-plasma sample types such as faeces, respiratory vapour, and baleen. These efforts have illuminated conservation-relevant physiological questions for both species, such as discrimination of acute from chronic stress, identification of likely causes of mortality, and monitoring causes and consequences of changes in body condition and reproduction.

Jones, O. P., & Stephenson, R. L. (2019). Practical Use of Full-Spectrum Sustainability in the Bay of Fundy. *Ecology and Society, 24*(3). https://doi.org/10.5751/ES-11010-240325

It is increasingly recognized that sustainability is composed of four key components: environmental, economic, social (including cultural), and institutional (or governance). Fisheries and coastal management systems, however, are heavily weighted toward biophysical and ecological aspects, thus leaving the “human dimension,” i.e., social, economic, and institutional, relatively neglected. Full-spectrum sustainability (FSS) is an approach to resource management that aims to address this imbalance. Management plans are beginning to include elements of FSS, yet there are very few practical examples of successfully implemented FSS strategies. We examined and compared the potential application of two proposed FSS frameworks in the Bay of Fundy, one based on the Southwest New Brunswick Marine Advisory Committee Community Values Criteria, and the other on the Framework for Comprehensive Evaluation from the Canadian Fisheries Research Network. These were compared in structure and in their practical application to evaluation of plans for herring (*Clupea harengus*) management and the recovery of the North Atlantic right whale (*Eubalena glacialis*) in the Maritime

region of Canada. Although the two frameworks differ in specific structure, both frameworks are useful in demonstrating the strengths and weaknesses of current management plans. This evaluation demonstrates that the management plans are strong in attention to ecological objectives but have gaps in the spectrum of considerations in current management planning, especially in relation to social, economic, and governance considerations. We propose that FSS frameworks can provide and should be used routinely as the basis for analysis of policies and management plans, engagement and discussion among stakeholders in participatory governance, comparison of alternative management scenarios, and the generation of advice. Use of FSS frameworks will allow better decisions on coastal activities within the context of "balanced" FSS.

Moulton, S. (2019). *H.R.1568 - 116th Congress (2019-2020): To Assist in the Conservation of the North Atlantic Right Whale by Supporting and Providing Financial Resources for North Atlantic Right Whale Conservation Programs and Projects of Persons with Expertise Required for the Conservation of North Atlantic Right Whales, and for Other Purposes*. Retrieved from https://naturalresources.house.gov/legislation/bills/hr1568

To assist in the conservation of the North Atlantic right whale by supporting and providing financial resources for North Atlantic right whale conservation programs and projects of persons with expertise required for the conservation of North Atlantic right whales, and for other purposes.

O'Callaghan. (2019). North Atlantic Right Whales (*Eubalaena glacialis*) in Irish Waters: 1300-1987. *Biology & Environment Proceedings of the Royal Irish Academy, 119B*(2-3), 111. https://doi.org/10.3318/bioe.2019.10

North Atlantic right whales (*Eubalaena glacialis*) once occurred seasonally in Irish waters but in recent decades their presence has declined. This study reviews the existing literature to develop an understanding of the past distribution of North Atlantic right whales, their abundance, temporal occurrence, interspecies associations and apparent use of Irish waters. Ancillary information supporting these core aims was investigated to provide a context for the historical misidentification of North Atlantic right whales and the development of Irish whaling to evaluate the presence of this species in Irish waters. Records of the species within the Irish Exclusive Economic Zone (EEZ), between 1300–1987 were validated based on the available data to three confidence levels: definite, probable and possible right whales. Seventeen records comprising at least 42 individual whales exist (including probable Basque whaling effort from the fourteenth century to the sixteenth century). Of the records available, 52% were considered 'definitely' right whales with eight comprising 22 individuals from two early twentieth century and two mid-seventeenth century commercial whaling stations operating in the northwest of Ireland. Six 'probable' right whale records involving 15 individuals were identified, including two sightings from the late twentieth century while two 'possible' records of five individuals were also noted. The previous importance of Ireland's north western coastline as a potential early summer feeding area in the Northeast Atlantic for migrating right whales, along with the apparent extirpation of the species in the region are also discussed.

Pettis, H., Pace, R., & Hamilton, P. (2021). North Atlantic Right Whale Consortium 2020 Annual Report Card. *Report to the North Atlantic Right Whale Consortium*.

The North Atlantic right whale (*Eubalaena glacialis*) remains one of the most endangered large whales in the world. Over the past two decades, there has been increasing interest in addressing the problems hampering the recovery of North Atlantic right whales by using innovative research techniques, new technologies, analyses of existing databases, and enhanced conservation and education strategies. This increased interest demanded better coordination and collaboration among all stakeholders to ensure that there was improved access to data, research efforts were not duplicative, and that findings were shared with all interested parties. The North Atlantic Right Whale Consortium, initially formed in 1986 by five research institutions to share data among themselves, was expanded in 1997 to address these greater needs. Currently, the Consortium membership is comprised of representatives from more than 100 entities including: research, academic, and conservation organizations; shipping and fishing industries; whale watching companies; technical experts; United States (U.S.) and Canadian Government agencies; and state authorities.

Rey-Iglesia, A., Martínez-Cedeira, J., López, A., Fernández, R., & Campos, P. F. (2018). The Genetic History of Whaling in the Cantabrian Sea During the 13th–18th Centuries: Were North Atlantic Right Whales (*Eubalaena glacialis*) the Main Target Species? *Journal of Archaeological Science: Reports, 18*, 393-398. https://doi.org/10.1016/j.jasrep.2018.01.034

For millennia, whales have been used as a food source, initially probably opportunistically, with the use of stranded animals on beaches, and later by active hunting. The Basques pioneered commercial whaling first in the neighbouring Cantabrian Sea (11th century) and then in Newfoundland and Labrador (16th century). The North Atlantic right whale (*Eubalaena glacialis*) is believed to have been the main target species of the Cantabrian fleets off the coast of Spain although other large whale species could have occasionally been targeted. At present, no molecular identification study has been performed to corroborate which species constituted the main catch for local whalers. Here we use historical bone remains to identify the main target species of medieval whaling in the Cantabrian Sea (13–18th centuries). Our results confirm the North Atlantic right whale as the main target species in Iberia suggesting that direct hunting could have played a role in the depletion of the species.

van den Hurk, Y., Spindler, L., McGrath, K., & Speller, C. (2020). Medieval Whalers in the Netherlands and Flanders: Zooarchaeological Analysis of Medieval Cetacean Remains. *Environmental Archaeology*, 1-15. https://doi.org/10.1080/14614103.2020.1829296

Medieval historical sources suggest that cetacean exploitation was, for large parts of Europe, restricted to the social elite. This appears to have also been the case for the Netherlands and Flanders. It remains unclear, however, how frequently active hunting was undertaken, and which species were targeted. Zooarchaeological cetacean remains are often recovered from Medieval (AD 400-1600) sites in the Netherlands and Flanders, however the majority of these specimens have not been identified to the species level, leaving a substantial gap in our knowledge of past cetacean exploitation. By applying ZooMS, as well as morphological and osteometric analyses, these zooarchaeological specimens were identified to the species level. This analysis revealed that the North Atlantic right whale (*Eubalaena glacialis*), sperm whale (*Physeter macrocephalus*), and grey whale (*Eschrichtius robustus*) were frequently exploited. Active whaling appears to have been undertaken as well, especially in Flanders and

in Frisia (the northern part of the Netherlands). Zooarchaeological cetacean remains appear to be present with relative frequency at high-status sites such as castles, as well as ecclesiastical sites, confirming the historical evidence that the social elite indeed did have a taste for cetacean meat. However, cetacean products were also available outside of elite and ecclesiastical contexts.