Report of the Health Assessment Workshop for North Atlantic Right Whales (*Eubalaena glacialis*), June 24-26, 2019

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[1]National Marine Fisheries Service Office of Protected Resources, Silver Spring, MD 20910
[2]National Marine Fisheries Service Northeast Fisheries Science Center, Woods Hole, MA 02543
[3]National Marine Fisheries Service Greater Atlantic Regional Office, Gloucester, MA 01930
[4]National Marine Fisheries Service Southeast Regional Office, St. Petersburg, FL 33701
[5]National Marine Fisheries Service Pacific Islands Fisheries Science Center, Honolulu, HI 96818
[6]Working Group on Marine Mammal Unusual Mortality Events, Silver Spring, MD 20910
[7]University of California, Davis, School of Veterinary Medicine, Wildlife Health Center, Davis, CA 95616

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EXECUTIVE SUMMARY

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.

As explained by Stephen (2014): *"Health is the result of interacting biologic, social, and environmental determinants that interact to affect the animal's or population's capacity to cope with change. Health cannot be measured solely by what is absent, but rather by characteristics of the animals and their ecosystem that affect their vulnerability and resilience. Wildlife health is not a biologic state but rather a dynamic social construct based on human expectations and knowledge. This includes the need to study interrelated conditions and factors that influence population health over time and apply the resulting knowledge to actions that improve health. Therefore, the determinants of health include those affiliated with animal biology and ecology and those associated with human actions influencing animals."* These principles helped shape and guide the discussions at the workshop.

Over the course of three days, the workshop participants helped the National Marine Fisheries Service summarize North Atlantic right whale population status and existing health-assessment information; provided individual input on several ways to prioritize health data collection, tools and methods; and ways to increase the use of health data to aid in monitoring individual health, informing population health, and identifying the population consequences of multiple stressors, including the connection between human activities (*e.g.*, entanglement) and health.

Some of the highest health priorities identified included new or continued support for the following activities:

1. Continue to support the photo-identification catalog that provides the ability to track health at the individual level.
2. Continue to support the development of the Population Evaluation Tool model and support development of a population-level state-space model with integrated health metrics.
3. Continue and expand vessel and aerial photo-identification efforts to acquire population-level seasonal distribution and demographic data. Revisit and optimize survey effort based on our current understanding of the changing seasonal distribution of whales.
4. Evaluate seasonal presence of whales in new or unknown habitats, by further developing acoustic surveys of potentially important areas, potentially informed by current habitat modelling.
5. Continue and expand collection of health assessment data (*e.g.*, biopsy, photos, photogrammetric length and width measurements, blow, feces) and continue longitudinal studies. Specifically, visual health assessment and scarring assessments should continue;

photogrammetry should be expanded, standardized, and inter-calibrated with the visual health assessment data and other measures of health.

6. Necropsy response efforts should be continued and enhanced, including continued support for training of large whale necropsy techniques. Several trans-boundary activities should be established including a necropsy case review committee; a necropsy sampling workshop; and development of a comprehensive plan for North Atlantic right whale sample collection and management.

1. INTRODUCTORY ITEMS

The workshop was held at the Civic Center in Silver Spring, Maryland, USA from June 24 through 26, 2019. The agenda of the meetings is provided in Appendix A.

Under the auspices of the Working Group on Marine Mammal Unusual Mortality Events (Working Group), 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. Funding for the workshop was provided by the National Marine Fisheries Service/National Oceanic and Atmospheric Administration (NMFS/NOAA). A total of 35 participants, including biologists, veterinarians, modelers, managers, and representatives of governmental and inter-governmental agencies, from three different countries (U.S., Canada, and Argentina) attended the workshop. The list of participants and additional information on contributions are provided in Appendix B.

1.1 Introduction of Workshop Moderator and Rapporteurs

Michael Moore moderated the meeting with Ingrid Biedron, Sarah Wilkin, and Deborah Fauquier as rapporteurs. Catherine Marzin, Deputy Director of the NMFS Office of Protected Resources, welcomed participants.

1.2 Expected Outcomes

Moore summarized the main goals of the workshop, which 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.

On Day 1, the status of North Atlantic right whale (NARW) health and population research was reviewed by the workshop participants. On Day 2 and 3, the participants provided their individual input as well as had group discussions on several topics. Specifically, on Day 2, the workshop participants focused on available tools and priorities, and provided input on an outline of a strategy for individual and population monitoring and management; Day 3 was devoted to summary discussions. A peer-reviewed publication of the workshop findings is planned. Throughout the workshop there was no collective decision-making on the part of the workshop participants. NMFS may consider the individual participant input from this workshop in future NMFS decision-making.

Using the Workshop Summary Report, NMFS and the Working Group may:

- Develop ways to prioritize, standardize and improve current health-assessment data, technologies, tools, and techniques (including identifying, developing, and validating new tools and technologies), to provide health data that may affect survival and fecundity for future population management and research activities, especially data gaps and tools needed to address human caused stressors (especially entanglement,

vessel strikes); and

- Draft an outline for a longer-term five-year science plan outlining the best means (*e.g.*, approaches, techniques, data types, platforms) to monitor individual health, inform population health, and identify the population consequences of multiple stressors, including the connection between human activities (*e.g.*, entanglement), health, and outcomes (survival, fecundity).

Moore concluded his opening remarks at the workshop by noting that William E. Schevill rediscovered the NARW to modern-day science in 1955 during his research on whales in Cape Cod Bay (Watkins & Schevill 1982), humankind landed on the moon in 1969, but today there is grave concern about NARWs going extinct (Hayes *et al.* 2018) despite our recent advancements in technology and conservation. Therefore, there is an urgency to make a difference for a species that was almost driven to extinction by Yankee whalers and that has been unable to fully recover due to other present-day anthropogenic threats such as ship strikes, entanglement in fishing gear or marine debris, and habitat degradation.

The most recent NARW Unusual Mortality Event began in 2017 and was ongoing at the time of the workshop. From 2017 through June 2019, at least 27 dead NARWs were documented, with most of the mortalities attributed to either entanglements or ship strikes (*i.e.*, human interactions). Specifically in 2019, at the time of the workshop, seven NARWs had died within the first six months of the calendar year, and several of those mortalities were attributed to human interactions. The urgency of this situation for the species raised substantial concern that the developments and input achieved at this workshop should be used as quickly as possible to aid in protecting the species. As of August 2020 (the date of this report), the number of confirmed NARW mortalities in the Unusual Mortality Event is 31.

2. TERMINOLOGY

Below are specific survival or reproductive terms that are used within this report. Common abbreviations are listed in Appendix C.

Available to calve: any female who calved at least once before and has not calved in at least 3 years, and/or primiparous females. Females included in this count can be those presumed alive (less than 6 years since last sighting) OR all females who are not confirmed to be dead.

Calving index: annual percentage of reproductive females presumed alive and available to calve who did produce a calf that was observed.

Inter-birth interval/inter-calving interval: interval in years between births/observed calving events (female seen with a neonate or perinate).

Presumed alive: individual seen in the last 6 years.

Presumed dead: individual not seen in the last 6 years.

Reproductively active: a presumed living female who has had a calf at least once.

3. PRESENTATIONS

On Day 1 of the workshop, several presentations were given on various aspects of NARW health and population research as well as examples from other species. A list of presentations and presenters can be found in Appendix D. A summary of each presentation is below.

3.1 Background Presentations

3.1.1 Overview of previous right whale workshops (Michael Moore)

Moore reviewed previous right whale workshops that were conducted over the past four decades. In 1983, a group met in Boston, Massachusetts to discuss right whale past and present population status (Brownell *et al.* 1986), wherein the health status of the NARW population was first raised as a concern. In 1998, a group met in Cape Town, South Africa to review the worldwide status of all species and populations of right whales. Inbreeding depression, trophic structure, productivity, body condition, chemical pollution, vessel and entanglement related mortality, habitat loss, climate change and disease were all discussed and evaluated (Best *et al.* 2001). In 2000, following declining reproductive success of NARWs, a meeting in Falmouth, Massachusetts focused on causes of reproductive failure in wildlife, particularly cetaceans (Reeves *et al.* 2001). Causes of reproductive dysfunction were reviewed, with findings that anthropogenic mortality needed to be reduced to zero to allow for improved recruitment and potential recovery of the species. Moore highlighted a workshop held in Boston, Massachusetts in 2003 that compared and contrasted data from NARWs and bowhead whales (*Balaena mysticetus*), and how the information from these different species could complement and inform management and science of each species (O'Hara *et al.* 2003). Although long-term monitoring studies were conducted on live NARWs, the carcasses of dead NARWs found stranded at sea or on land were generally too decomposed for post-mortem examinations. In contrast, with bowheads, fewer studies were conducted on living whales and more data were available from freshly dead animals that had been harvested as part of regulated subsistence hunting. In 2006, a workshop was held to discuss and compare health assessment studies in all species of right whales (*Eubalaena sp.*), bowhead whales, and gray whales (*Eschrichtius robustus*) (Rowles *et al.* 2006). That workshop discussed the importance of building a dialog across a variety of disciplines and comparative studies among species. In 2010, a workshop in Puerto Madryn, Argentina considered the basis for a major multi-year mortality event of Southern right whale (*Eubalaena australis*) calves (IWC 2010). That mortality event began in 2005, and recent reports showed it was ongoing to a lesser degree at least through 2017 (Sironi *et al.* 2018), and 623 dead newborn Southern right whale calves were documented between 2005 and 2015. The leading hypotheses for those mortalities included nutrition, harmful algal blooms, and infectious disease. Sironi *et al.* (2018) stated: *"new lines of research are being developed at present to test the hypothesis that stress from injuries in southern right whales (predominantly due to Kelp Gull attacks) negatively affects their physiological homeostasis and could be a contributing factor to calf deaths in this population."* In 2018, a NMFS workshop in Woods Hole, Massachusetts

examined the effectiveness of U.S. management activities for NARWs (Sisson & Long 2018). The primary purpose of the meeting was to review available data sets and analyses on the rates and types of entanglements and vessel strikes in NARWs to better understand their potential impact on population dynamics, and to identify potential methods/analytical tools available to address the key questions.

After reviewing previous workshops, Moore shifted to discussions on reproduction and health. To evaluate impacts on reproduction, he described a need to partition the impacts of nutrition vs. chronic entanglement to changes in fecundity, and assess whether increased inter-birth intervals can be attributed to the stress of entanglement (based on available energetic analyses or observational data), with the remainder due to environmental changes in prey availability, etc. Moore concluded with a review of a paper on a definition of wildlife health (Stephen 2014) which outlined the full complement and complexity of wildlife health. "*More than pathogens and parasites, wildlife health includes habitat loss, globalization of trade, land-use pressure, and climate change. Health is the result of interacting biologic, social, and environmental determinants that interact to affect the animal's or population's capacity to cope with change. Health cannot be measured solely by what is absent, but rather by characteristics of the animals and their ecosystem that affect their vulnerability and resilience. Wildlife health is not a biologic state but rather a dynamic social construct based on human expectations and knowledge. This includes the need to study interrelated conditions and factors that influence population health over time and apply the resulting knowledge to actions to improve health. Therefore, the determinants of health include those affiliated with animal biology and ecology and those associated with human actions influencing animals."* Moore concluded that setting standards for animal health based on the presence or absence of disease alone seems ill advised, particularly for this species.

3.1.2 Summary of reproductive failure, reduced survival and inflammation drivers in bottlenose dolphins: captive and wild – lessons learned (Cynthia Smith)

Smith presented on the reproductive failure observed in bottlenose dolphins (*Tursiops truncatus*) in the aftermath of the Deepwater Horizon (DWH) oil spill. As part of the Natural Resource Damage Assessment (NRDA) for the DWH oil spill, impacts to bottlenose dolphins in coastal areas of the northern Gulf of Mexico (NGOM) were well documented (NOAA 2015, Schwacke *et al.* 2013, Smith *et al.* 2017). Studies of live dolphins and necropsies of recovered carcasses within the DWH oil spill footprint confirmed lung injury and adrenal gland lesions consistent with known effects of oil or petroleum-associated compounds in laboratory species (Venn-Watson *et al.* 2015). Reproductive impacts were also observed in studies of both live and dead dolphin, with a focus on the heaviest oiled coastal regions. For live animal studies, reproductive failure rates were evaluated in two NGOM bottlenose dolphin stocks exposed to DWH oil (Barataria Bay, Louisiana, and Mississippi Sound, Mississippi/Alabama). Pregnancy was determined from either ultrasound examinations during capture-release health assessments or endocrine evaluations of blubber tissue collected from dart biopsies. Follow-up photo-identification surveys of the two stocks were used to track the status of pregnant females and any associated neonate calves for a minimum of one year after the initial pregnancy detection. For all pregnant females tracked, individuals seen with a calf (reproductive success) and without one (reproductive failure) were recorded.

The resulting estimated reproductive success rates for dolphins living in areas not impacted by the DWH oil spill (*i.e.*, Sarasota Bay, Florida; Indian River Lagoon, Florida; and Charleston Harbor, South Carolina) were three-fold higher than the reproductive success rates for both NGOM stocks within the DWH oil spill footprint (Lane *et al.* 2015, Kellar *et al.* 2017). Results from the stranded animal studies showed that dead perinate dolphins in the oil spill footprint had a higher prevalence of atelectasis (88% vs. 15%), fetal distress (87% vs. 27%), and in utero pneumonia (65% vs. 19%) compared to reference perinates (Colegrove *et al.* 2016). This indicates that most perinates died prior to or shortly after birth, experienced adverse conditions in utero, and most had in utero infections. Therefore, findings from both the live and dead animal studies confirmed low reproductive success from heavily oiled estuaries when compared with other populations. Follow-up studies are ongoing to understand the long-term implications of this sustained high reproductive failure rate on population recovery trajectories. The NGOM investigation illustrated how close coordination between the live dolphin health assessment team, field biologists, and pathologists examining the stranded carcasses enabled success in making broad conclusions about the reproductive health of a free-ranging population.

Smith acknowledged and expressed appreciation for the efforts of the multi-institutional field teams involved in the acquisition of data she described. Data collected from 2010 – 2015 were part of the DWH NRDA conducted cooperatively among NOAA, other Federal and State Trustees and BP PLC. Data collected during follow on studies were made possible by a grant from the Gulf of Mexico Research Initiative (GoMRI). GoMRI-funded data are publicly available through the Gulf of Mexico Research Initiative Information & Data Cooperative (GRIIDC) at https://data.gulfresearchinitiative.org.

3.1.3 Tabular summary of relevant North Atlantic right whale and other health literature (Ingrid Biedron)

Biedron summarized the methodology for and the synthesis of the literature review on *Health Assessments of North Atlantic Right Whales* (https://repository.library.noaa.gov/) that the NMFS Central Library completed for the NMFS Office of Protected Resources (Appendix E). The purpose of this presentation was to establish a starting point for the 2019 North Atlantic Right Whale Health Assessment Workshop participants to identify gaps in health assessment efforts to advance NARW recovery.

The content of the literature review was:
Section I – Assessment Methods
Section II – Health Metrics in Right Whales
Section III – Health Assessments of Other Marine Mammals
Section IV – Organizations Doing Health Assessments
Section IV – Peripheral Materials

Along with an online search for relevant materials, the following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded; EBSCO Academic Search Complete; Nexis.com; ProQuest's Aquatic Sciences and Fisheries Abstracts; BioOne; and JSTOR. Priority was given to publications from the last twenty years. Only English language materials were included. Future literature reviews or searches for NARWs should also include French language materials. Each source was evaluated to determine which health system

category (or categories) it substantially covered. The results of this categorization were as follows with the number of sources listed in parentheses after each category: respiratory (2); endocrine (14); immune (2); nutrition/body condition (21); growth/energetics (4); health score/risks (15); pathogen (3); integument/visual assessment (3); musculoskeletal (2); injury (0); and necropsy summary (3). See Appendix E for the literature review table.

3.1.4 North Atlantic right whale distribution shift and its impacts on data we have available, including our ability to do health and scar assessments (Phil Hamilton)

Hamilton summarized information on the recent broad scale distribution shift that NARWs exhibited starting around 2010 or 2011. Since 2010, sightings decreased drastically on the calving ground off the southeastern U.S. and in three northern feeding habitats (Davies *et al.* 2019, Gowan *et al.* 2019): the Great South Channel east of Cape Cod, the Bay of Fundy, and Roseway Basin south of Nova Scotia, Canada. More than 50% of the population had been seen in each of these habitats in some years prior to 2010. Recently, as few as a dozen whales, or fewer, have been seen in each habitat. At the same time, sightings increased in one well-studied habitat, Cape Cod Bay, and two lesser historically known feeding habitats -- one south of Nantucket, Massachusetts and one in the Gulf of St. Lawrence, Canada. Since 2010, over 250 whales have been seen in the former annually, and 100 to 150 have been seen annually in the latter two, respectively. In addition to sightings, passive acoustic data show an increased occurrence of right whale calls off the mid-Atlantic, herein described as north of Cape Hatteras to south of Cape Cod, and some calls along the edge of the continental shelf (Davis *et al.* 2017). While there are seasonal concentrations of whales in some habitats, historically a large proportion of the population has always been, and continues to be, unaccounted for in most months of the year.

Hamilton noted we are able to monitor individual right whales through the photo-identification catalog, but these distribution shifts have impacted the collection of sightings and photos and the data derived from those observations. Specifically, the reduced access to these observations and data affect population counts, health, and scarring assessments, and have hampered our ability to photo-identify calves (requires sighting an identifiable calf with its mother). A smaller percentage of the population are observed annually, which impacts the overall whale count. The decrease in shipboard photographs, which had been primarily collected from the Bay of Fundy and off the southeastern U.S. in the 2000s, affects our ability to assess health and scarring because body condition and smaller entanglement scars are best detected from shipboard images. Finally, mothers are seen with their calves less frequently on the northern feeding grounds, making it harder to photo-identify those calves (their callosities are generally not well developed until the latter half of the year). At the very least, this has delayed our ability to catalog those calves. These impacts on the photo-identification data should be considered when analyzing the data. An effort should be made to increase shipboard surveys in the recently recognized important habitats to improve our ability to track changes in health and entanglement scarring, as well as to collect biological samples. Further, an effort should be made to increase our photographic capture of a larger portion of the population annually.

3.2 North Atlantic Right Whale Injury Presentations

3.2.1 North Atlantic right whale overt mortality trend summary with a focus on chronic skin, oral and other lesion patterns (Sarah Sharp)

Sharp presented data from the recent Diseases of Aquatic Organisms publication from June 2019 entitled "Gross and histopathologic diagnoses from North Atlantic right whale mortalities between 2003 and 2018" by Sharp *et al.* (2019). Following is the summary abstract outlining the data presented in that review paper as well as some additional data not included in the abstract:

"Seventy deaths of NARWs were documented between 2003 and 2018 from Florida, U.S.A. to the Gulf of St. Lawrence, Canada. This included 29 adults, 14 juveniles, 10 calves, and 17 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, 38 (88.4%) of which 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" (Sharp *et al.* 2019).

Observed non- traumatic lesions included multifocal glossal ulcers (n=2), intestinal adhesions and a colic-like condition (n=1), absence of thoracic and caudal lumbar neural spines (n=1), enterocolitis and mild interstitial pneumonia (n=1), a penile lesion (n=1), alveolar luminar granulocutes (n=1), hyperplastic chelitis and pulmonary granuloma (n=1), and nematode ova in the kidney (n=1). Most non-traumatic lesions were present in calves.

"*Overall prevalence of NARW entanglement mortalities increased from 21% (1970-2002) to 51% during this study period (2003-2018). This demonstrates that despite mitigation efforts, entanglements and vessel strikes continue to inflict profound physical trauma and suffering on individual NARWs. Their cumulative impacts at the population level are unsustainable. Urgent and aggressive intervention is needed to end anthropogenic mortality in this critically endangered species"* (Sharp *et al.* 2019).

3.2.2 New England Aquarium Injury Database and Visual Health Assessments (Heather Pettis)

Pettis presented an overview of the Visual Health Assessment (VHA) method (Pettis *et al.* 2004, Rolland *et al.* 2016), developed as a means to non-invasively assess right whale visual health using photographs routinely taken for photo-identification purposes. The VHA method is based on the evaluation of four parameters that can be assessed using shipboard and/or aerial images: body condition, skin condition, rake marks forward of the blowholes, and cyamids around the blowholes. VHA scores and associated data are entered in the VHA Database (New England Aquarium; NEAq) and currently has ~18,000 health assessment records from ~65,000 sightings.

The database is linked to the North Atlantic Right Whale Database (https://www.narwc.org/narwc-databases.html), allowing for links between health and individual life-history information.

Pettis provided an overview of past and ongoing analyses that established links between health, reproduction, and anthropogenic impacts. Two health conditions, "emaciated body condition" and "swath lesions," are now considered important indicators of right whale survival. The incidence of these conditions has varied over time, with the highest incidence of both documented in 2011-2016. Pettis noted that other types of lesions are regularly observed on right whales, though the etiology and their impact on survival and reproduction is unknown. Pettis described varying prevalence of compromised body and skin condition over time, highlighting a marked divergence of compromise in the conditions beginning in 2009, with far more whales being scored as thin at least once annually than those scored with poor skin condition. Shifts in distribution and survey efforts impact our ability to assess the health of whales, particularly body condition. Pettis described recent observations of unresolved wounds and emerging skin anomalies that highlight the need for rigorous assessments of wound healing and etiology of various lesion types.

Pettis highlighted the VHA method's utility in retrospective analysis and described its use as a tool to evaluate anthropogenic injury impact on health and inform annual injury determinations and estimates of human impact on this species. Additionally, these assessments show promise in providing better estimates of a mortality window when whales are not sighted post injury. Lastly, Pettis emphasized the importance of the VHA in monitoring this endangered species, particularly given its utility in longitudinal comparisons of individual and population-wide health. Maintaining and updating the database allows it to be integrated with other databases, with population health as examined by researchers and managers, with the impact(s) of injuries on health, and comparisons of individual and population health trends over time.

3.2.3 NMFS Serious Injury Assessments (Allison Henry)

Henry presented data on NMFS' Serious Injury Assessments (NOAA 2012). NMFS is mandated to provide annual rates of human-caused serious injury and mortality to marine mammal stocks. Northeast Fisheries Science Center (NEFSC) has made serious injury determinations for western North Atlantic large whale stocks since 1999 using all available relevant injury event information including sighting history, necropsy reports, and health assessments when available. NEFSC used Center-established criteria to assess large whale injuries until 2012 when national serious injury determination guidelines were published. NEFSC criteria were conservative and did not count data-poor events against potential biological removal (PBR). The National criteria addresses data-poor events by providing prorated values that count against PBR. Henry retroactively applied the National criteria to all right whale injury events from 2000 to present. Only 14 events (of 184) between 2000 and 2011 were changed from a 0 value to a prorated value, which illustrates that injury determinations of this stock have been relatively consistent across the years despite evolving serious injury determination criteria. This is primarily due to the data-rich nature of right whale injury events. A plot of annual entanglement, vessel strike, and total human interaction rates over time supports what other studies have shown - rate of entanglement, serious injury and mortality is increasing in the last decade and that of vessel

strike has decreased. The entanglement rate alone has remained above PBR throughout the timeline (*i.e.*, since 2000).

3.2.4 Frequency and effects of entanglements and vessel strikes on North Atlantic right whale reproduction (Amy Knowlton)

Knowlton presented information on the frequency and effects of entanglements and vessel strikes on NARWs. Using the Right Whale Consortium's identification catalog curated by the NEAq, all sightings have been reviewed for evidence of external trauma from vessel strikes (propeller cuts or gashes) or entanglements (attached fishing or wrapping scars from a prior interaction). These wounds are categorized as superficial, shallow, or deep for vessel strikes; and minor, moderate, or severe for entanglements based on the depth and extensiveness of the injuries.

For vessel strikes, with blunt trauma cases included, a total of 91 vessel strikes have been documented from 1972 through 2017. An assessment of fate by wound category revealed that superficial and shallow cuts did not affect three year survival but deep cuts were lethal the majority of the time. With the implementation of the U.S. ship-speed rule in 2008, there appeared to be some reduction in the frequency of blunt trauma and deep cuts although this was counteracted by the high number of blunt-trauma cases in the Gulf of St. Lawrence in 2017. A forensic assessment of propeller cuts, carried out for 39 cases, showed that vessels >65 feet were involved in most of the deep cut cases, although there were two cases of vessels in the 40-65 foot range that resulted in deep cuts and subsequent fatality.

For entanglements, 1,461 interactions have been documented from 1980 – 2016 involving 85% of the population, and 115 (<10%) of these cases involved attached gear. Some whales have evidence of as many as eight entanglement interactions over the course of a lifetime. Incidents of moderate and severe entanglements have become more prevalent in the last decade, and are known to cause health impacts and reduced survival, especially in reproductive females. Entanglement configurations have also been assessed for risk level and the majority of entanglements since the mid-1990's have been deemed high-risk, *i.e.*, likely to be lethal without intervention (Knowlton *et al.* 2016). Knowlton *et al.* (2016) provided evidence that increasing rope strengths, resulting from manufacturing changes, may be partially responsible for the increasing level of severe and high-risk entanglements. The authors of that study recommended rope strengths of 1,700 pounds be considered for fixed fishing gear throughout the NARW range.

An assessment of reproductive females *(i.e.,* females that have had a calf) considered "lost" (*i.e.*, dead or disappeared) since 1980 indicated 76 of 180 (42%) have been lost, with at least one third of those losses attributed to either vessel strikes or entanglements. A preliminary assessment of the severity of entanglement injuries on fecundity indicates a cessation in calving for a period of time after a severe injury and, for those that survive, there is a more sluggish recovery in comparison to minor or moderate injuries. Additionally, it appears that during times of decadal prey declines (Meyer-Gutbrod *et al.* 2015) calving output and recovery are lower. Future work needs to include an assessment of multiple stressors, a thorough investigation of all injuries and associated data to better define potential region and country of origin, and continued work to model how broad scale management measures will influence health and reproduction (*e.g.*, Population Evaluation Tool).

3.3 Condition Presentations

3.3.1 Trends in growth and body condition from photogrammetry (John Durban)

Durban presented results of ongoing aerial photogrammetry studies to assess trends in growth and body condition of NARWs. This included inference from aerial images collected by NMFS's Southwest Fisheries Science Center (SWFSC) during August 2000-2002 using manned aircraft flying over the Bay of Fundy, as well as more recent images from unmanned drones operated from boat platforms in Cape Cod Bay, Massachusetts in March and April 2016-2019, collected by NMFS/SWFSC in collaboration with Woods Hole Oceanographic Institution and SR3 Sealife Response, Rehab and Research. For both datasets, matching whales to NEAq's long-term photo-identification catalog enabled photogrammetric measurements of body length and width profiles to be linked to whales of known age, sex, and life histories, and to assess changes in the same whales over time. A recent comparison to similar drone-derived measurements of Southern right whales in Argentina, New Zealand, and Australia revealed NARWs to be in generally poorer body condition and to be attaining shorter adult lengths than they did previously as compared to whaling records or to Southern right whales (Christiansen *et al.* 2020). Underpinning this current status, analysis of the NARW time series revealed some whales are growing remarkably slowly in recent years, compared to those growing prior to the 2000-2002 sampling, and whales are in poorer body condition in recent spring sampling compared to their body profiles during previous summer sampling. Although this may be explained by seasonal changes in the condition of these capital breeders, ongoing longitudinal monitoring during consistent spring sampling in Cape Cod Bay is being used to assess trends in body condition over time. High-resolution drone images also provide information on skin condition, whale lice burdens, and the severity/incidence of entanglement wounds, notably coupled with quantitative photogrammetry measures from the same whales.

3.3.2 Energetic cost of entanglement (Michael Moore)

Moore presented on behalf of van der Hoop, himself and many collaborators, on the energetic impacts of entanglement in fishing gear. Chronically entangled right whales may carry fishing gear for months to years, and often show signs of considerable loss in energy reserves over that time period.

Moore mentioned relevant information from recent publications that present a framework to evaluate lethality, serious injury, or reproductive impacts of entanglement by:

- measuring drag from gear that was removed from entangled right whales (van der Hoop *et al.* 2013, van der Hoop *et al.* 2016);
- estimating the energetic cost of entanglement from biomechanics and physical models, and blubber thickness and body condition measurements (van der Hoop *et al.* 2017b); and
- comparing the energetic and time investment of entanglement to other life-history costs; as wells as predicting drag on new entanglement cases at the time of their observation (van der Hoop *et al.* 2017a).

Chronic entanglement cases can have energetic costs comparable to pregnancy, migration, and foraging, and up to 34% of the daily cost of lactation. Many entanglements are <1 year in duration, while others exceed the historic 4-year calving interval; impacts are likely seen beyond disentanglement due to time needed for recovery. For the cases evaluated in these studies, the

median energetic recovery is 1.3-3 months (max. 16 months) though this did not consider the female's nutritive or reproductive status at the time of entanglement. Moore presented a framework by which these drag measurements and various modelling approaches can be extended to the population, with the inclusion of other data types and sources, as presented at this workshop.

3.4 Reproduction Presentations

3.4.1 North Atlantic Right Whale Female Reproduction- Catalog Perspective (Phil Hamilton)

Hamilton provided a summary of NARW female reproductive parameters. In 2012, calf counts dropped from an annual average of 24 in the previous ten years to an average of 12 per year until 2018 in which no calves were born. The calving index (annual percentage of reproductive females presumed alive and available to calve that did produce a calf that was observed) averaged 46% from 2001 to 2011 (last decade) and has dropped to an average of 13% since then. In 2019, there were 92 known reproductively active females who had been seen alive in the previous six years. There were another 36 females ages 10 to 19 who have not been observed with a calf yet and 30 known immature females, which suggests the pool of future reproductive recruits is low. However, the recent calves who have not yet been cataloged are not captured in that analysis, so that future female pool is likely larger. The inter-birth interval, which averaged 4.3 years in the last decade from 2000-2010, increased to an average of 6.3 years from 2011-2018, with a peak of 10.2 years in 2017. The age of first parturition for all known age cows is 10.2 years, but more than half of the females that are a minimum of 10 to 19 years old (y.o.) have not yet been observed with a calf. The combination of the changes in the inter-birth interval data and the age to first reproduction, suggests that both experienced cows and first-time moms are delaying their calving. It remains unknown how many of the current nulliparous 10-19-y.o. females are biologically able to successfully get pregnant and reproduce. These calving delays seem to correlate with the distribution shifts described earlier, and those shifts may correlate with changing environmental conditions.

Hamilton explored several aspects of reproductive dysfunction. Many of the cows that have only calved once disappeared from the sighting record soon after that calving, but 23 were seen three or more years after and thus were available to calve again. Six percent of females over 19 y.o. have never calved. That percentage increases to 33.6% if the 10-19 y.o. nulliparous females are included. One cow has had six calves, but the last four have not survived; at least some of them because they were apparently not successfully nursed.

Hamilton and Cooper (2010) showed that 70% of all calves born in 2001 stayed with their moms into the second year. Hamilton analyzed the fitness of those 2001 calves that were female and found that they exhibited no clear reproductive advantage over other female calves from that cohort that did not stay with their mothers into the second year (*i.e.*, they did not give birth earlier or have more calves). Hamilton noted an interesting signal that some females that are seen less frequently, and may feed in unknown habitats, continue to calve when other females stop. In the previous calving downturn in 1998-2000, 100% of the cows that calved fit this profile. The percentage was 60% in 2017, but only 14% in 2019 (when only 8% of the available females calved), so the pattern is not consistent. In addition, we do not have a consistent or rigorous way

to define and categorize these females. Finally, the percent of sightings involved in surface-active groups tracks the number of calves born. This preliminary result could be explored by habitat to see if the occurrence of these groups, some of which are related to mating, can be correlated with population-wide health.

3.4.2 Reproductive and stress hormones - any evidence for pregnancy loss (Rosalind Rolland)

Rolland presented data on endocrine studies on NARW that started in 1999 with validation of immunoassays to measure steroid reproductive and stress hormone metabolites in fecal samples. Currently, the NEAq has validated immunoassays for a panel of six hormone classes including estrogen, progesterone, androgens, glucocorticoids, aldosterone, and thyroid hormone (Rolland *et al.* 2005). These assays have been validated for multiple biological matrices including: feces, respiratory vapor (”blow”), baleen, blubber, and serum (Hunt *et al.* 2014). The temporal signature of hormones differ between these matrices from real-time or near-real-time (serum and respiratory vapor), days to months (feces and blubber), to years (baleen). Hormone measures from blubber, feces, and blow integrate circulating levels of hormones over these different temporal scales, and are especially valuable for assessment of chronic stress.

Over 400 fecal samples collected from 1999-2019 have been assayed for this hormone panel constituting a long-term endocrine database spanning two decades. Approximately one-third of the samples have been linked to known right whales with known life-history data. Results showed that concentrations of fecal estrogens, progesterone, and androgens are reliable predictors of sex, pregnancy, and lactation in females and sexual maturity in males (Rolland et al. 2005). Three cases of pregnancy loss have been inferred using highly elevated fecal progesterone metabolites and sighting records on the calving grounds the following winter without a calf (Rolland *et al.* In Prep). Levels of adrenal stress hormone metabolites vary with reproductive status, sex and physiological state, and reflect relative adrenal cortical activity (Rolland *et al.* 2017). Comparison of fecal glucocorticoids (FGCs) in healthy right whales, whales killed acutely (vessel strike), or suffering long-term entanglement, or prolonged live stranding (chronic), found extreme elevations of FGCs in cases of severe, chronic illness or injury (Rolland *et al.* 2017). FGCs have been used to link shipping-noise exposure in NARW to elevated FGCs indicating chronic stress (Rolland *et al.* 2012). Fecal aldosterone levels provide an additional measure of adrenal cortical activation. Fecal thyroid is a biomarker of nutritional status in right whales, as it decreases during nutritional deficits and increases during periods of energy abundance (Rolland *et al.* In Prep).

Further investigations are needed to identify pregnancy and pregnancy loss in the reproductively viable female population to explore fecundity rates, as well as underpin potential remediation actions to increase population growth. Additionally, further investigation is needed to identify the causes for the observed nulliparous females that are old enough to be reproductively active but have not calved. Increased effort in biopsy collection among adult females without a calf present are suggested for the purpose of running endocrine profiles to assess pregnancy, pregnancy loss, and resting female rates. Exploration into the point of gestation at which pregnancy loss occurs could potentially be captured through this investigation as well, to suggest potential stressors that are inducing pregnancy loss.

3.5 Biota Presentations

3.5.1 North Atlantic right whale respiratory microbiome, bowhead gut microbiome and lipidome, and humpback skin microbiome (Carolyn Miller)

Clear links continue to be established between human microbiomes, assemblages of microorganisms, and human health, including links to body fat accumulation, energy harvest from food, lipid accumulation, immune function, inflammation, and behavior. Miller summarized results of epidermal, gut and blow microbiomes of whales as determined by amplicon sequencing of the 16S rRNA gene. Epidermal and blow microbiomes of humpback whales (*Megaptera novaeangliae*) were highly similar and contained common bacterial groups despite differences in population (whales in different ocean basins) and for epidermis, age and sex. Altered epidermal microbiomes were seen in a few whales with compromised health; hence, it has been proposed that changes to the signatures of the epidermal microbiomes could be used to monitor health by looking at the diversity of the microbiomes, the composition and abundance of the core bacterial species, and the presence of any non-typical bacteria (Apprill *et al.* 2014, Apprill *et al.* 2011). In humpback blow microbiomes, more than 300 relatives of known pathogens in mammals were detected at the genus level (Apprill *et al.* 2017). Since the humpback whales appeared healthy, these relatives likely were not currently acting as pathogens, but such screening methods could be used to quickly identify samples that need to be examined for pathogens with finer resolution methods.

Next, Miller summarized the results of a recent study where lipid digestion and microbial communities were mapped along the gastrointestinal (GI) tract (stomach chamber through colon) of harvested bowhead whales by characterizing the lipidomes using HPLC-MS/MS and the microbiomes (Miller *et al.* 2020*)*. The lipidomes and microbiomes were tightly correlated throughout the GI tract. The primary prey lipids, wax esters, which are also a prominent type of lipid in right whale prey, are digested in the mid- to distal small intestine; specific bacterial groups may play a role. The types of microbes found in the bowhead gastrointestinal tract have been associated with increased energy harvest from food and hence, accumulation of body fat in humans.

Miller also summarized the preliminary results of the multi-year, multi-habitat study on the microbiomes of 143 blow samples collected from North Atlantic and Southern right whales (both Argentina and Auckland Islands). Microbial communities were significantly different between NARW and Southern right whales when compared by habitat and collection year (PERMANOVA, $p < 0.001$). This difference in blow-associated microbiomes among right whale populations is intriguing given the conspicuous differences in population growth and health, and will be explored further in the context of body condition measurements, (aerial photogrammetry was conducted on some of the same individuals), life history traits, and other indices of health. The team also will be screening the dataset at the genus level for relatives of pathogens and likely will be sequencing deeper to examine the function of the microbes, viruses, and genes involved in virulence, which is often indicative of pathogenicity.

Overall, skin and blow show potential for usefulness in monitoring health, and especially blow as a non-invasive sample. The gut microbiome and lipidome study has the potential to provide insights into nutrition and body condition, and this combined study type may be useful in

evaluating the mechanisms involved in balaenid whale nutrition. The Apprill Lab (Woods Hole Oceanographic Institution) is currently developing and implementing on-site sequencing techniques that could be used to rapidly screen for, and identify, altered microbiomes in the field. Finally, the growth rates for bacteria are on the order of minutes and hours and the bacteria are where they are because of the conditions and substrates. As such, any change in the conditions/substrates will result in a change in which types of bacteria are thriving and growing. Therefore, microbiomes can serve as sensitive indicators of changes in health that may not be detected by other assays.

3.5.2 Fecal Parasites & Harmful Algal Blooms (Rosalind Rolland)

Rolland presented a six-year (2001-2006) analysis of fecal samples that showed NARWs were exposed to at least two classes of algal biotoxins – paralytic shellfish poisoning toxins (PSP) and domoic acid (DA) (Doucette *et al.* 2012). Over the six-year study, 83% of samples tested positive for PSP toxins and 29% tested positive for DA. The results demonstrated right whales are exposed to both of these algal biotoxins on virtually an annual basis in multiple habitats for periods of up to six months (April through September). There were similar exposure rates for females and males (PSP: ~70-80%; DA: ~25-30%). Both pregnant and lactating females are exposed to both biotoxins, suggesting the potential for maternal toxin transfer and possible effects on neonates. Additionally, 22% of the fecal samples tested for PSP and DA showed concurrent exposure to both neurotoxins, leading to questions of interactive effects (Doucette *et al.* 2012). While exposure to these biotoxins could not be linked with health effects, and the sensitivity of right whales to these toxins remains unknown, there is a potential for indirect effects of these neurotoxins (*e.g.*, increased susceptibility to vessel strike). These data provide baseline levels of these two biotoxins for comparison to exposure levels in the future.

Rolland also presented on a five-year study that assessed the prevalence of *Giardia* and *Cryptosporidium* spp. using analysis of fecal samples. From 2002-2006, 125 fecal samples were examined for the presence of *Giardia* and *Cryptosporidium* cysts/oocysts using an immunofluorescent assay procedure (Hughes-Hanks *et al.* 2005, Rolland *et al.* 2007). The overall prevalence of *Giardia* was 68% annually (range = 38-77%), and *Cryptosporidium* oocysts were detected in 14% of samples (range=7-38%), and all positive samples were co-infected with *Giardia*. Molecular characterization and phylogenetic analysis of the right whale isolates were unsuccessful, so species and genotypes remain unknown. While the effects of these organisms on right whales are generally unknown, co-infection of NARWs with both *Giardia* and *Cryptosporidium* was correlated with a decline in body condition using a visual assessment method.

3.6 Modeling Presentations

3.6.1 Survival assessments and trends with emphasis on reproductive females (Rob Schick)

On behalf of co-authors, Schick presented work on the impacts of entanglements on both the health and survival of NARWs, with a focus on the differential impacts of severity on males and females. Schick presented a brief overview of the modeling framework (Knowlton *et al.* In Prep, Rolland *et al.* 2016, Schick *et al.* 2013, Schick *et al.* 2016), *i.e.*, the state-space model for individual health that arose from the Population Consequences of Acoustic Disturbance (PCAD) working group. Then he presented the intersection of the entanglement injuries with estimates of

health, showing first the decline over the course of an event, and second the overall average health during the period of the injury. Results were parsed by entanglement severity and category, by sex, and, for females, by reproductive class (Knowlton *et al*. In prep). In both cases, the declines in health were greater among whales categorized as having severe entanglements, both with and without gear present. Average health scores during entangled periods was poorer for reproductively active females. Mentioned, but not shown, was the fact that these declines in health translated to lower reproductive output. In addition, Schick presented results from a survival analysis as a function of sex and entanglement severity, and highlighted how severe injuries resulted in steep declines in individual survival, with the decline in survival being greater for females.

Schick highlighted how these results were for pre-2011 data; as they have begun to inspect the impacts of more recent entanglements since 2011, they have had difficulty getting the model fit to the data. Schick also highlighted elements of both Philip Hamilton's and Heather Pettis' presentations, which indicated that movement patterns are changing as are the VHA data. While discussing what this means for the modelling going forward, Schick noted that one of the goals of the PCAD working group was to see if we could estimate latent health of individuals at a monthly time step as a function of observed health, *i.e.*, the VHA data collected and curated by NEAq, and region (observed or imputed). To date, we have had difficulty doing this, and this difficulty will increase as the movement and residency patterns continue to change. Schick mentioned the need to fuse and assimilate more of the spatial data to help explain the changes in movement patterns. In addition, if the VHA data collection as a function of observation platform changes, then some modeling assumptions will need to be revisited.

3.6.2 Population models and assessment tool (Richard Pace)

Pace sketched a characterization of an ongoing NMFS-sponsored program: the North Atlantic right whale Population Evaluation Tool (PET). Objectives for tool development include addressing requests for Endangered Species Act-related evaluations (Recovery plan and 5-year review) for prospective estimates of extinction risk and other demographic characterizations over various time scales. He noted that accompanying a baseline scenario projection, would be a quantitative threat assessment and opportunities to examine the effects of modifying projected threat influences on demographic processes (*i.e.*, scenarios modified from baseline). Although the lethal impacts of threats are relatively straightforward to include in a population viability model, the non-lethal influence of entanglement wounding, vessel-collision wounding, anthropogenic noise, changes in prey distribution and quality, and contaminants on reproduction and survival needs input from experts. The PET authors have concluded that they need to develop projections with structure that includes all the listed threats in spite of the lack of actual functional relationships defined between threat and health outcome. The more these relationships can be bounded by expert opinion, the less uncertainty will be imputed into projection models.

3.6.3 Modeling with *Tursiops* health assessment data (Len Thomas)

Thomas presented a summary of an ongoing project, Veterinary Expert System for Outcome Prediction (VESOP). Led by Lori Schwake with Cynthia Smith as a Co-PI, the team are developing models linking measurements of wild dolphin health made during hands-on sampling of inshore dolphins, with two-year-ahead survival and successful reproduction for pregnant females observed by follow-up surveys. Data from eight populations were included (see

presentation by Smith for more details). The team have organized the numerous measurements of blood and other parameters taken during health assessments into panels of organ status or specified disease condition and identified abnormal cases for each panel using previously established reference ranges. These panels and the identified outcomes were reviewed and refined by a veterinary expert panel. Binary logistic regression models are being used to link the panels to survival and reproduction outcomes. The modeling is complicated by cases where outcome is not known, because the animal was not seen again in follow-up surveys or found stranded; in this case, mark-recapture analyses are used to estimate survival probability and these estimates, with associated uncertainty are incorporated into the outcome model. One future component of the project is to assess how the models and methods developed may be applied to other species for which such comprehensive hands-on health assessments are not available.

4. DISCUSSION OF CURRENT HEALTH ASSESSMENT TOOLS and TECHNOLOGIES

During the workshop, participants explored current health assessment technologies, existing protocols, data sharing, and how these items contribute to health information (strengths and weaknesses), especially regarding survival and fecundity of right whales. A tool matrix was developed highlighting what tools exist or need development to maximize collection of health data from live and dead whales. The draft tool matrix is presented in Appendix F, which highlights data collection from live animals.

Discussions regarding the tool matrix table included the following:

- Visual Health Assessments
- Photogrammetry
- Non-invasive sampling (fecal collection, breath collection, sloughed skin, etc.)
- Invasive sampling (biopsy collection, tagging, etc.)
- Necropsy collection and data
- Sample banking
- Sampling protocols and prioritized sampling guidelines

One of the main take homes from the tool matrix discussion was the importance of vessel surveys for collecting a variety of current and future health data, including data collected from photographs and unmanned aerial systems for body condition, VHAs, direct sampling (respiratory vapor, biopsy), and opportunistic sampling (feces). The discussion also highlighted the need to continue and expand these vessel-based longitudinal studies. An additional point was made that health sampling priorities should be aligned with the current or new permitting process, to ensure there is a strategic plan for any new method development and permitting priorities for NARWs.

A Necropsy Subgroup developed a list of necropsy sampling and data priorities from dead whales that is listed in Appendix G. Some main highlights included support for establishing a trans-boundary necropsy case review committee, and holding a NARW necropsy sampling workshop to address long-term sampling, archiving, and curating needs and to develop a trans-boundary comprehensive plan for NARW sample collection and management.

5. DISCUSSION OF HEALTH ASSESSMENT PRIORITIES

5.1 Modeler Data Discussion

Participants with modelling experience led discussions to outline and prioritize the type of health data that are most important to inform existing population management models (*e.g.*, survival and fecundity) and future models. A model parameter table was developed highlighting the health data available in rank order that could inform various items included in the model (states, stressors, etc.). Those health data that are most important for the model are presented in Appendix H.

Discussion and participant inputs from the modeler data conversation identified some priorities. Specifically, photo identification, mark-recapture and photogrammetry were identified as among the most important tools for obtaining the health data necessary for model development. Additionally, for the PET model, participants suggested combining all health data, except for entanglement and vessel strikes, in a general health index because entanglement and vessel strikes would be considered as their own categories in the model.

5.1.1 Breakout Groups

To support the tool development and modeler discussions three additional subgroups were convened during the meeting.

The first subgroup was the Modeling Subgroup that outlined the different types of models, data needed, and participant input that are listed in Appendix I. Participants in the Modeler Subgroup identified continued support of the development of the PET model as a high priority, and also prioritized significant investment into development of a population-level state-space model of the type outlined in Model Class 2 in Appendix I.

The second subgroup discussed whether a Health Score for NARWs could be developed building upon previous work in bottlenose dolphins. The results of that discussion are listed in Appendix J. For the NARW Health Score subgroup, each participant concluded that based upon the existing longitudinal data available, a health score could be attempted for known NARW individuals. Subgroup members suggested trying to categorize a few individuals with significant data as a pilot project in the future.

Lastly, the third subgroup focused on some Priority Research Questions regarding sampling and health data that focused on biopsy sampling and their discussions are listed in Appendix K. Members of the Biopsy Priority Research Subgroup concluded that priorities could include: 1) analyzing existing samples (primarily biopsies) from entangled whales for stress, and females for reproductive outcomes; and 2) increasing vessel surveys to obtain more health data since many questions can be answered with data collected from this platform.

5.2 Develop a draft outline for a longer-term science plan

The meeting ended with a broad discussion and individual input on a draft outline for a longer-term (5-10 year) science plan to improve efficiency and effectiveness of health data collection, analysis, and incorporation into current and future modeling efforts. Several participants

developed the two figures in Appendix L and M. The first figure helps visualize some of the threats and methods available to evaluate health data for NARWs (Appendix L). The other figure is a Population Consequences of Disturbance (PCOD) (New *et al.* 2014, Pirotta *et al.* 2018) figure that shows the changes in physiology with multiple stressors and the methods/tools that can measure those physiological changes (Appendix M). Lastly, based upon the discussions, NMFS developed a draft Science Plan Matrix in Appendix N outlining some specific actions and the data/methodology needed to collect health data to answer those actions.

These broad discussions highlighted that there is currently a long-term strong demographic data set for NARW that is supported by the photo-identification/mark recapture catalog, and this catalog is the single most important data stream for evaluating many health parameters, including individual life history as well as population wide dynamics. All participants strongly supported maintaining the photo-identification/mark recapture catalog. Additionally, participants highlighted that the long-term investment in the stranding program, including standardizing necropsies to aid in forensically identifying cause of death, has been a great asset for health data collection. The participants strongly supported continued investment in stranding and necropsy investigations.

Finally, participants developed some overarching individual input on items to support and improve health data collection from NARWs to aid in monitoring individual health, informing population health, and identifying the population consequences of multiple stressors, including the connection between human activities (*e.g.*, entanglement) and health. This input is listed in Appendix O. NMFS may consider the individual participant input in this Appendix in future NMFS decision-making.

6. CONCLUSIONS

Over the course of three days, the workshop participants through their individual input helped NMFS summarize NARW population status and existing health-assessment information; identified several ways to prioritize health data collection, tools, and methods; and prioritized ways to increase the use of health data to aid in monitoring individual health, informing population health, and identifying the population consequences of multiple stressors, including the connection between human activities (*e.g.*, entanglement) and health.

Some of the highest priorities mentioned by participants included new or continued support for the following activities:

1. Continue to support the photo-identification catalog that provides the ability to track health at the individual level.
2. Continue to support the development of the PET model. In addition, support development of a population-level state-space model with integrated health metrics.
3. Evaluate seasonal presence of whales in new or unknown habitats, by further development of acoustic surveys of potentially important areas, potentially informed by current habitat modelling.
4. Continue and expand collection of health assessment data (*e.g.*, biopsy, photos, photogrammetric length and width measurements, blow, feces) and continue longitudinal

studies. Specifically, VHA and scarring assessments should continue; photogrammetry should be expanded, standardized, and inter-calibrated with the VHA data and other measures of health.

5. Necropsy response effort should be continued and enhanced, including continued support for training of large whale necropsy techniques. Floating carcass discovery, tracking, and recovery is critical and capacity should be further developed with relevant agencies. A trans-boundary necropsy case review committee should be established. A trans-boundary NARW necropsy sampling workshop should be held to develop a trans-boundary comprehensive plan for NARW sample collection and management.

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8. APPENDICES LIST

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Appendix A: AGENDA for 2019 North Atlantic Right Whale Health Assessment Workshop

MONDAY, JUNE 24TH: DAY 1 –

Welcome and Introductions

09:00 Catherine Marzin & Teri Rowles - Welcome & Overview: context of NOAA recovery and take reduction goals,

09:15 Michael Moore (Moderator) - Workshop format and outcomes: Meeting Report (Draft authored by NOAA staff); Peer reviewed review paper with longer-term science/ strategic plan as supplement (Authored by workshop participants).

Background Presentations

09:25 Michael Moore - Summary of previous workshops

09:40 Cynthia Smith (Len Thomas & Katie Colegrove) – Summary of reproductive failure, reduced survival and inflammation drivers in bottlenose dolphins: captive and wild – lessons learned.

09:55 Ingrid Biedron - Tabular summary of relevant NARW and other health literature

10:10 Philip Hamilton - NARW distribution shift and its impacts on data we have available, including our ability to do health and scar assessments

10:15 Discussion

10:30 Break

Injury Presentations

10:45 Sarah Sharp (Bill McLellan) – NARW overt mortality trend summary with a focus on chronic skin, oral and other lesion patterns

11:00 Heather Pettis - NEAQ Injury Database and Visual Health Assessments (include animals with poor healing)

11:15 Allison Henry - NMFS Serious Injury Assessments

11:30 Amy Knowlton – NARW live animal line and prop scar analysis & effect on reproduction.

11:45 Discussion

12:30 Lunch on your own

Condition Presentations

13:30 John Durban – Trends in growth and body condition from photogrammetry

13:45 Michael Moore - Energetic cost of entanglement (van der Hoop papers).

14:00 Discussion

Reproduction Presentations

14:30 Philip Hamilton – NARW catalog data, what it can tell us about interbirth interval, calving index, age structure of female reproduction, calf mortality (incl. suckling success) and how distribution and migration has changed with time.
14:55 Roz Rolland - Reproductive and stress hormones - any evidence for pregnancy loss.
15:10 Discussion

15:30 Break

Biota Presentations

15:45 Carolyn Miller – NARW respiratory microbiome, bowhead gut microbiome and lipidome, and humpback skin microbiome
16:00 Roz Rolland - fecal parasites & HABs
16:15 Discussion

Modeling Presentations

16:30 Rob Schick - Survival assessments and trends with emphasis on reproductive females
16:45 Richard Pace - Population models and assessment tool
17:00 Len Thomas - Health assessment model bottlenose dolphin
17:05 Discussion
17:20 Adjourn

<u>TUESDAY, JUNE 25th: DAY 2</u>

Tools Discussion

09:00 Ingrid Biedron - Draft Tool Matrix
09:10 Visual Health Assessments, including photographic and in-situ data collection (respiration rate, character, etc.)
09:50 Photogrammetry
10:15 Non-invasive sampling (fecal collection, breath collection, sloughed skin, etc.)

10:40 Break

11:00 Invasive sampling (biopsy collection, tagging, etc.)
11:25 Necropsy collection and data
11:50 Sample banking

12:15 Lunch on your own

Priorities and Input Discussion

13:15 Modeler Data Discussion
Discuss with modelers what types of data are most important to include in existing population management models (*e.g.*, survival and fecundity) and future models.

14:00 Prioritize and provide input on standardizing and improving current health assessment data, technologies and techniques (including validate/develop new technologies);

- to provide health information for future population management (survival and fecundity) and research activities;
- include discussion of data and tools needed to address human caused stressors (*e.g.*, entanglement, vessel strikes). Shovel ready short term and longer term.

15:00 Break

15:30 Develop a draft outline (using the above input) for a longer-term science plan and/or strategic plan;

- for the best means (*e.g.*, approaches, techniques, data types, platforms) to monitor individual health,
- inform population health, and
- identify the population consequences of multiple stressors,
- including the connection between human activities (*e.g.*, entanglement) and health.

17:00 Evening Break

WEDNESDAY, JUNE 26TH: DAY 3 -

09:00 Discussion of Workshop Report Structure and Drafting

12:00 Lunch on your own

13:00 Continue Workshop Report, Strategic Plan and Peer-reviewed Manuscript Discussions

15:00 Adjourn; Return Home

Appendix B: List of Participants

Number	First Name	Last Name	Affiliation
Federal or Working Group Members			
1	Jason	Baker	NMFS Pacific Islands Fisheries Science Center /Working Group Member
2	Ingrid	Biedron	NMFS Office of Protected Resources
3	Ashley	Boggs	National Institute of Standards and Technology
4	Katie	Colegrove (remote participation)	University of Illinois/Working Group Member
5	John	Durban (remote participation)	NMFS Southwest Fisheries Science Center
6	Nick	Farmer	NMFS Southeast Regional Office
7	Deborah	Fauquier	NMFS Office of Protected Resources
8	Erin	Fougeres	NMFS Southeast Regional Office
9	Mendy	Garron	NMFS Greater Atlantic Regional Office
10	Caroline	Good	NMFS Office of Protected Resources
11	Allison	Henry	NMFS Northeast Fisheries Science Center
12	Nick	Kellar (remote participation)	NMFS Southwest Fisheries Science Center
13	Kristy	Long	NMFS Office of Protected Resources
14	Richard	Pace	NMFS Northeast Fisheries Science Center
15	Eric	Patterson	NMFS Office of Protected Resources
16	Teri	Rowles	NMFS Office of Protected Resources
17	Sarah	Wilkin	NMFS Office of Protected Resources
18	Michael	Ziccardi	University of California Davis/Working Group Chair
External Participants			
1	Kim	Durham (observer)	Atlantic Marine Conservation Society
2	Phil	Hamilton	New England Aquarium
3	Katie	Jackson	Florida Fish and Wildlife Conservation Commission
4	Amy	Knowlton	New England Aquarium
5	Bill	McLellan	University of North Carolina, Wilmington
6	Carolyn	Miller	Woods Hole Oceanographic Institution
7	Michael	Moore	Woods Hole Oceanographic Institution

Number	First Name	Last Name	Affiliation
8	Ann	Pabst	University of North Carolina, Wilmington
9	Heather	Pettis	New England Aquarium
10	Stephen	Raverty	British Columbia Animal Health Center
11	Roz	Rolland	New England Aquarium
12	Rob	Schick	Duke University
13	Sarah	Sharp	International Fund for Animal Welfare
14	Cynthia	Smith	National Marine Mammal Foundation
15	Len	Thomas	Sea Mammal Research Unit
16	Marcy	Uhart	University of California, Davis
17	Julie	van der Hoop (remote participation)	Woods Hole Oceanographic Institution

External Participants Contributions to the Workshop:

Kim Durham, Atlantic Marine Conservation Society (Observer)
Ms. Durham is a stranding network member and necropsy team leader based in New York. She contributed to discussions on necropsy sampling and participated in the Necropsy subgroup.

Phil Hamilton, New England Aquarium
Mr. Hamilton is a NARW researcher and oversees the NARW photo-identification catalog. He gave two presentations on the NARW distributions shifts and reproduction status. He contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Biopsy Focused Priority Research subgroup.

Katie Jackson, Florida Fish and Wildlife Conservation Commission
Ms. Jackson is a NARW field researcher and entanglement responder. She contributed to the health assessment tools and technologies discussion and participated in the Biopsy Focused Priority Research subgroup.

Amy Knowlton, New England Aquarium
Ms. Knowlton is a NARW researcher and oversees the NARW photo-identification catalog. She gave a presentation on the impact of entanglements and vessel strikes on NARW reproduction. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the NARW Health Score subgroup.

Bill McLellan, University of North Carolina, Wilmington
Mr. McLellan is a state stranding coordinator and necropsy team leader based in North Carolina. He contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Necropsy and Biopsy Focused Priority Research subgroups.

Carolyn Miller, Woods Hole Oceanographic Institution
Dr. Miller researches microbiomes of large whales. She gave a presentation on NARW microbiomes. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the NARW Health Score subgroup.

Michael Moore, Woods Hole Oceanographic Institution
Dr. Moore is a veterinarian, stranding network member, and necropsy team leader based in Massachusetts. He moderated the workshop as well as gave two presentation summarizing previous NARW workshops and presented on the energetic costs of entanglements in NARWs.

Ann Pabst, University of North Carolina, Wilmington
Dr. Pabst is a professor, marine mammal anatomist, and stranding network member. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Necropsy and Biopsy Focused Priority Research subgroups.

Heather Pettis, New England Aquarium
Ms. Pettis is a NARW researcher and oversees the NARW consortium. She gave a presentation on the NARW injury data base and visual health assessments. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the NARW Health Score subgroup.

Stephen Raverty, Animal Health Center, British Columbia, Canada
Dr. Raverty is a veterinary pathologist, stranding network member, and necropsy team leader based in Canada. He contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Necropsy and NARW Health Score subgroups.

Rosalind Rolland, New England Aquarium
Dr. Rolland is a veterinarian and NARW researcher. She gave two presentations on reproductive and stress hormones, and fecal pathogens and harmful algal bloom toxins in NARWs. She contributed to the health assessment tools and technologies, and health assessment priorities discussions.

Rob Schick, Duke University
Dr. Schick is a modeler. He gave a presentation on survival assessments for NARWs. He contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Modeler subgroup.

Sarah Sharp, International Fund for Animal Welfare
Dr. Sharp is a veterinarian, stranding network member, and necropsy team leader apprentice based in Massachusetts. She gave a presentation on causes of mortality in necropsied NARWs. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Necropsy and NARW Health Score subgroups.

Cynthia Smith, National Marine Mammal Foundation
Dr. Smith is a veterinarian based in California. She gave a presentation on reproductive failure in bottlenose dolphins. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the NARW Health Score subgroups.

Len Thomas, Sea Mammal Research Unit
Dr. Thomas is a modeler. He gave a presentation on population modeling in bottlenose dolphins. He contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the Modeler subgroup.

Marcy Uhart, University of California, Davis
Dr. Uhart is a veterinarian based in Argentina that works extensively with Southern right whales. She contributed to the health assessment tools and technologies, and health assessment priorities discussions, and participated in the NARW Health Score subgroups.

Julie van der Hoop, Woods Hole Oceanographic Institution
Dr. van der Hoop is a marine mammal researcher. She attended the workshop remotely and contributed to the health assessment tools and technologies, and health assessment priorities discussions.

Appendix C: Abbreviations

DA – Domoic acid
DWH – Deepwater Horizon
FCGs – Fecal glucocorticoids
FLIR- Forward-looking infrared camera
GOMRI – Gulf of Mexico Research Initiative
GRIIDC - Gulf of Mexico Research Initiative Information & Data Cooperative
HAB-Harmful algal bloom
HI – Human interaction
IR- Infrared
NARW – North Atlantic right whale
NEAq – New England Aquarium
NGOM – Northern Gulf of Mexico
NMFS – National Marine Fisheries Service
NOAA – National Oceanic and Atmospheric Administration
PBR – Potential biological removal
PCAD – Population Consequences of Acoustic Disturbance
PET – Population Evaluation Tool
UAS – Unmanned aircraft systems
VESOP - Veterinary Expert System for Outcome Prediction
VHA – Visual health assessment
Working Group – Working Group on Marine Mammal Unusual Mortality Events

Appendix D: Name of Workshop Presenters and Title of Presentations

Presenters	**Title**
Moore, M.	Overview of previous right whale workshops
Smith, C.	Summary of reproductive failure, reduced survival and inflammation drivers in bottlenose dolphins: captive and wild – lessons learned
Biedron, I.	Tabular summary of relevant North Atlantic right whale and other health literature
Hamilton, P.	North Atlantic right whale distribution shift and its impacts on data we have available, including our ability to do health and scar assessments
Sharp, S.	North Atlantic right whale overt mortality trend summary with a focus on chronic skin, oral and other lesion patterns
Pettis, H.	New England Aquarium Injury Database and Visual Health Assessments
Henry, A.	NMFS Serious Injury Assessments
Knowlton, A.	Frequency and effects of entanglements and vessel strikes on North Atlantic right whale reproduction
Durban, J.	Trends in growth and body condition from photogrammetry
Moore, M.	Energetic cost of entanglement
Hamilton, P.	North Atlantic right whale female reproduction- catalog perspective
Rolland, R.	Reproductive and stress hormone studies in North Atlantic right whales - any evidence for pregnancy loss?
Miller, C.	North Atlantic right whale respiratory microbiome, bowhead gut microbiome and lipidome, and humpback skin microbiome
Rolland, R.	Overview of marine biotoxin and protozoa studies in North Atlantic right whales
Schick, R.	Survival assessments and trends with emphasis on reproductive females
Pace, R.	Population models and assessment tool
Thomas, L.	Modeling with Tursiops health assessment data

Appendix E: Literature Review Table

*Adapted from Health Assessments of North Atlantic Right Whales Bibliography - https://repository.library.noaa.gov/view/noaa/20221

Authors/ Editors	Title	Publication Year	Abstract/Description	Species	Health parameter assessed; data collected	Indicator, protocol, technology, or technique	Platform	Year (During what time frame was/is this approach used?)	Location data collected	Research Institution, State, Country (first listed in publication)	Source	Comments/ Management applications
Sharp, S., W. McLellan, D. Rotstein, A. Costidis, S. Barco, K. Durham, T. Pitchford, P.-Y. Daoust, T. Wimmer, E. Couture, L. Bourque, T. Frasier, B. Frasier, D. Fauquier, T. Rowles, P. Hamilton and M. Moore	Gross and histopathologic diagnoses from North Atlantic right whale Eubalaena glacialis mortalities between 2003 and 2018 (Including Electronic Supplement)	2019	Seventy mortalities of North Atlantic right whales, Eubalaena glacialis (NARW) were documented between 2003 and 2018 from Florida, U.S.A. to the Gulf of St. Lawrence, Canada including 28 adults, 15 juveniles, 10 calves, and 17 unknown age class. Females represented 66.7% (18/27) of known-sex adults. Fifty-six carcasses were examined, 44 of which were 38 necropsied. Cause of death was determined in 43 cases, (88.4%) of which were due to anthropogenic trauma: 22 from entanglement and 16 from vessel strike. Gross and histopathologic entanglement lesions included: constrictive wraps and deep lacerations caused by line around the flippers, flukes, and head/mouth; baleen plate separation and/or mutilation; exuberant periosteal proliferation, osteolysis, and osteopenia from chronically impinging line; poor body condition and increased cyamid burden in chronic cases; and soft tissue dystrophic mineralization and traumatic scoliosis resulting in compromised mobility in a calf. Vessel strike blunt force injuries included skull and vertebral fractures, well-defined regions of blubber and muscle contusion with patchy blubber hemorrhage, and antemortem peri-vertebral, body cavity and fracture site blood clots. Propeller-induced lacerations presented in blubber, muscle, viscera and bone. Compared to previous time periods, NARW entanglement mortalities were on the rise during the study period. Entanglements and vessel strikes continue to inflict profound physical trauma and suffering on individual North Atlantic right whales and their cumulative impacts at the population level are unsustainable. Urgent and aggressive mitigation efforts throughout their range are needed to end anthropogenic mortality in this critically endangered species.	North Atlantic right whales				2003-2018		International Fund for Animal Welfare, MA, USA	https://www.int-res.com/prepress/d03376.html.	
Alejandro A. Fernández Ajó, Kathleen E. Hunt, Marcela Uhart, Victoria Rowntree, Mariano Sironi, Carina F. Marón, Matias Di Martino and C. Loren Buck	Lifetime glucocorticoid profiles in baleen of right whale calves: potential relationships to chronic stress of repeated wounding by Kelp Gulls	2018	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 (Larus 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.	North Atlantic right whale and Southern right whale calves	"Retrospective assessment and evaluation of long-term trends in the whales' physiological condition."	Lifetime profiles of cortisol and corticosterone in baleen	Stranded animals	2003-2010 SRWHMP database; 2016 NARW necropsy; Cape Cod, MA, USA	Peninsula Valdés-Argentina by the Southern Right Whale Health Monitoring Program (SRWHMP)	Department of Biological Sciences, Northern Arizona University, AZ, USA	https://academic.oup.com/conphys/article/6/1/coy045/5076881	"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."
Fredrik Christiansen, Fabien Vivier, Claire Charlton, Rhianne Ward, Alicia Amerson, Stephen Burnell, Lars Bejder	Maternal body size and condition determine calf growth rates in southern right whales	2018	The cost of reproduction is a key parameter determining a species' life history strategy. Despite exhibiting some of the fastest offspring growth rates among mammals, the cost of reproduction in baleen whales is largely unknown since standard field metabolic techniques cannot be applied. We quantified the cost of reproduction for southern right whales Eubalaena australis over a 3-mo. breeding season. We did this by determining the relationship between calf growth rate and maternal rate of loss in energy reserves, using repeated measurements of body volume obtained from unmanned aerial vehicle photogrammetry. We recorded 1118 body volume estimates from 40 female and calf pairs over 40 to 89 d. Calves grew at a rate of 3.2 cm d−1 (SD = 0.45) in body length and 0.081 m3 d−1 (SD = 0.011) in body volume, while females decreased in volume at a rate of 0.126 m3 d−1 (SD = 0.036). The average volume conversion efficiency from female to calf was 68% (SD = 16.91). Calf growth rate was positively related to the rate of loss in maternal body volume, suggesting that maternal volume loss is proportional to the energy investment into her calf. Maternal investment was determined by her body size and condition, with longer and more rotund female investing more volume into their calves compared to shorter and leaner females. Lactating females lost on average 25%of their initial body volume over the 3 mo. breeding season. This study demonstrates the considerable energetic cost that females face during the lactation period, and highlights the importance of sufficient maternal energy reserves for reproduction in this capital breeding species.	Southern right whales	Relationship between calf growth rate and maternal rate of loss in energy reserves; quantified the cost of reproduction	Measurements of body volume	UAV	June - September 2016	South Australia	School of Veterinary and Life Sciences, Murdoch University, Western Australia, Australia	https://www.int-res.com/abstracts/meps/v592/p267-281/	"This study demonstrate the considerable energetic cost that females face during the lactation period, and highlights the importance of sufficient maternal energy reserves for reproduction in this capital breeding species."
Nadine S. J. Lysiak, Stephen J. Trumble, Amy R. Knowlton and Michael J. Moore	Characterizing the Duration and Severity of Fishing GearEntanglement on a North AtlanticRight Whale (Eubalaena glacialis) Using Stable Isotopes, Steroid and Thyroid Hormones in Baleen	2018	North Atlantic right whales (Eubalaena glacialis) are highly endangered and frequentlyexposed to a myriad of human activities and stressors in their industrialized habitat.Entanglements in fixed fishing gear represent a particularly pervasive and often drawn-outsource of anthropogenic morbidity and mortality to the species. To better understandboth the physiological response to entanglement, and to determine fundamentalparameters such as acquisition, duration, and severity of entanglement, we measureda suite of biogeochemical markers in the baleen of an adult female that died froma well-documented chronic entanglement in 2005 (whale Eg2301). Steroid hormones (cortisol, corticosterone, estradiol, and progesterone), thyroid hormones [(triiodothyronine (T3) and thyroxine (T4)], and stable isotopes (d13C and d15N) were all measuredin a longitudinally sampled baleen plate. This yielded an 8-year profile of foragingand migration behavior, stress response, and reproduction. Stable isotopes cycled inannual patterns that reflect the animal's north-south migration behavior and seasonallyabundant 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, T3, and T4 were also elevated, although variably so, during theprogesterone peak. This whale was initially sighted with a fishing gear entanglementin September 2004, but the hormone panel suggests that the animal first interactedwith the gear as early as June 2004. Elevated d15N, T3, and T4 indicate that Eg2301potentially experienced increased energy expenditure, significant lipid catabolism, andthermal stress approximately 3 months before the initial sighting with fishing gear. Allhormones in the panel (except cortisol) were elevated above baseline by September2004. This novel study illustrates the value of using baleen to reconstruct recent temporalprofiles and as a comparative matrix in which key physiological indicators of individualwhales can be used to understand the impacts of anthropogenic activity on threatenedwhale populations.	North Atlantic right whale	"The physiological response to entanglement ...fundamental parameters such as acquisition, duration, and severity of entanglement."	Steroid hormones (cortisol, corticosterone, estradiol, and progesterone), thyroid hormones (triiodothyronine (T3) and thyroxine (T4)), and stable isotopes (d13C and d15N) were all measured in a longitudinally sampled baleen plate."	NARW Catalog; stranded in Virginia, U.S. (barrier island)	March 2005	Virginia, U.S. (barrier island)	Department of Biology, University of Massachusetts MA, USA	https://www.frontiersin.org/articles/10.3389/fmars.2018.00168/full	"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."

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Hayes, Sean A. Gardner, Susan Garrison, Lance Henry, Allison Leandro, Luis	North Atlantic Right Whales - Evaluating Their Recovery Challenges in 2018	2018	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.	North Atlantic right whale		N/A					N/A	
Burgess, E. A. Hunt, K. E. Kraus, S. D. Rolland, R. M.	Quantifying hormones in exhaled breath for physiological assessment of large whales at sea	2018	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.	North Atlantic right whale	Physiological assessment of whales/adrenal activity	Exhaled breath analysis		Emerging (2018...and on)		New England Aquarium, MA, USA	https://doi.org/10.1038/s41598-018-28200-8	
Fearnbach, H. Durban, J. W. Ellifrit, D. K. Balcomb, K. C.	Using aerial photogrammetry to detect changes in body condition of endangered southern resident killer whales	2018	The endangered population of southern resident killer whales, Orcinus orca, is hypothesized to be food-limited, but uncertainty remains over if and when the availability of their primary prey, Chinook salmon, Oncorhynchus tshawytscha, is low enough to cause nutritional stress. To measure changes in body condition, we collected 1635 measurable images from a helicopter hovering 230-460 m above whales, and linked these to individuals with distinctive natural markings. Head width (HW), measured at 15% of the distance between the blowhole and the dorsal fin (BHDF), was measured from images of 59 individuals in 2008 (from a population of 84) and 66/81 individuals in 2013, enabling assessment of between-year changes for 44 individuals (26 females, 18 males). Of these, 11 had significant declines in the ratio of HW/BHDF compared to 5 with significant increases. Two whales with declines died shortly after being photographed, suggesting a link between body condition and mortality. Most (8/11) of the significant declines in condition were from 1 social pod (J-pod), and all the whales that increased in condition were from one of the other 2 pods, K-pod (n = 3) and L-pod (n = 2). Notably, 11/16 whales that changed condition were re productive-aged females and there were no adult males with significant changes. This likely reflects the increased energetic costs of lactation to reproductive females, and the nutritional help provided to adult males through prey sharing. These data demonstrate the utility of aerial photogrammetry as a non-invasive approach for providing quantitative data on body condition, and support monitoring the condition of reproductive females as key indicators of nutritional stress.	Southern resident killer whales	Body condition/nutritional stress	Aerial photogrammetry		September 2008 & September 2013	Primarily in US waters, near San Juan Island, Washington		https://www.int-res.com/articles/esr2018/35/n035p175.pdf	
Burgess, E. A. Hunt, K. E. Kraus, S. D. Rolland, R. M.	Adrenal responses of large whales: Integrating fecal aldosterone as a complementary biomarker to glucocorticoids	2017	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 cecentrations (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.	North Atlantic right whale	"Intrinsic and external causes of stress hormone elevations in large whales, as well as other free-living wildlife species; a more comprehensive approach for associating adrenal activation with specific natural and anthropogenic stressors."	"Adrenal responses of large whales: Integrating fecal aldosterone as a complementary biomarker to glucocorticoids"		2000-2015	Northeastern Atlantic NARW feeding areas	New England Aquarium, MA, USA	https://doi.org/10.1016/j.ygcen.2017.07.026	"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."
Corkeron, P.Rolland, R. M.Hunt, K. E.Kraus, S. D.	A right whale pootree: classification trees of fecal hormones identify reproductive states in North Atlantic right whales (Eubalaena glacialis)	2017	Immunoassay of hormone metabolites extracted from fecal 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 fecal 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 analyzing 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 fecal 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.	North Atlantic right whale	Reproductive state/stress responses	Classification trees of fecal hormones identify reproductive states in North Atlantic right whales (Eubalaena glacialis)		1999-2011	NARW summer habitats	National Marine Fisheries Service, Northeast Fisheries Science Center, MA, USA	https://doi.org/10.1093/conphys/cox006	"Our analysis reiterates the importance of considering the reproductive state of whales when assessing the relationship between cortisol concentrations and stress."

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Hunt, K. E. Lysiak, N. S. Moore, M. Rolland, R. M.	Multi-year longitudinal profiles of cortisol and corticosterone recovered from baleen of North Atlantic right whales (Eubalaena glacialis)	2017	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.	North Atlantic right whale	Physiological stress	Multi-year longitudinal profiles of cortisol and corticosterone recovered from baleen		~2017	NA	New England Aquarium, MA, USA	https://doi.org/10.1016/j.ygcen.2017.09.009	
Kershaw, J. L. Sherrill, M. Davison, N. J. Brownlow, A. Hall, A. J.	Evaluating morphometric and metabolic markers of body condition in a small cetacean, the harbor porpoise (Phocoena phocoena)	2017	Mammalian body condition is an important individual fitness metric as it affects both survival and reproductive success. The ability to accurately measure condition has key implications for predicting individual and population health, and therefore monitoring the population-level effects of changing environments. No consensus currently exists on the best measure to quantitatively estimate body condition in many species, including cetaceans. Here, two measures of body condition were investigated in the harbor porpoise (Phocoena phocoena). First, the most informative morphometric body condition index was identified. The mass/length(2) ratio was the most appropriate morphometric index of 10 indices tested, explaining 50% of the variation in condition in stranded, male porpoises with different causes of death and across age classes (n = 291). Mass/length (2) was then used to evaluate a second measure, blubber cortisol concentration, as a metabolic condition marker. Cortisol is the main glucocorticoid hormone involved in the regulation of lipolysis and overall energy balance in mammals, and concentrations could provide information on physiological state. Blubber cortisol concentrations did not significantly vary around the girth (n = 20), but there was significant vertical stratification through the blubber depth with highest concentrations in the innermost layer. Concentrations in the dorsal, outermost layer were representative of concentrations through the full blubber depth, showed variation by sex and age class, and were negatively correlated with mass/length(2). Using this species as a model for live cetaceans from which standard morphometric measurements cannot be taken, but from which blubber biopsy samples are routinely collected, cortisol concentrations in the dorsal, outermost blubber layer could potentially be used as a biomarker of condition in free-ranging animals.	Harbor porpoise	Used as a biomarker of condition in free-ranging animals	Cortisol concentrations in the dorsal, outermost blubber layer		January 2006 and January 2016	Data collected by the Scottish Marine Animal Strandings Scheme (SMASS) from stranded male harbor porpoises (n = 291) around Scotland, UK	Sea Mammal Research Unit, University of St Andrews, Fife, UK	https://doi.org/10.1002/ece3.2891	
Krause, D. J. Hinke, J. T. Perryman, W. L. Goebel, M. E. LeRoi, D. J.	An accurate and adaptable photogrammetric approach for estimating the mass and body condition of pinnipeds using an unmanned aerial system	2017	Measurements of body size and mass are fundamental to pinniped population management and research. Manual measurements tend to be accurate but are invasive and logistically challenging to obtain. Ground-based photogrammetric techniques are less invasive, but inherent limitations make them impractical for many field applications. The recent proliferation of unmanned aerial systems (UAS) in wildlife monitoring has provided a promising new platform for the photogrammetry of free-ranging pinnipeds. Leopard seals (Hydrurga leptonyx) are an apex predator in coastal Antarctica whose body condition could be a valuable indicator of ecosystem health. We aerially surveyed leopard seals of known body size and mass to test the precision and accuracy of photogrammetry from a small UAS. Flights were conducted in January and February of 2013 and 2014 and 50 photogrammetric samples were obtained from 15 unrestrained seals. UAS-derived measurements of standard length were accurate to within 2.01 +/- 1.06%, and paired comparisons with ground measurements were statistically indistinguishable. An allometric linear mixed effects model predicted leopard seal mass within 19.40 kg (4.4% error for a 440 kg seal). Photogrammetric measurements from a single, vertical image obtained using UAS provide a noninvasive approach for estimating the mass and body condition of pinnipeds that may be widely applicable.	Pinnipeds	Mass and body condition of pinniped	Photogrammetric measurements from a single, vertical image from a UAS (unmanned aerial system)		2013-2014	Cape Shirreff, Livingston Island, Antarctic Peninsula	Southwest Fisheries Science Center, CA, USA	https://doi.org/10.1371/journal.pone.0187465	
Rolland, R. M. McLellan, W. A. Moore, M. J. Harms, C. A. Burgess, E. A. Hunt, K. E.	Fecal glucocorticoids and anthropogenic injury and mortality in North Atlantic right whales Eubalaena glacialis	2017	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 metabolites in dead whales. These results provide biological validation for using fGCs as a biomarker of chronic stress in NARWs.	North Atlantic right whale	Reproductive state, stress responses to disturbance, evaluating metabolic state in relation to prey availability; chronic stress	Fecal glucocorticoid metabolites (fGCs)		1999-2014	Southeastern US winter calving grounds to summer habitats off Nova Scotia, Canada	New England Aquarium, MA USA	https://www.int-res.com/articles/esr2017/34/n034p417.pdf	

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Vighi, M.Borrell, A.Aguilar, A.	Bone as a surrogate tissue to monitor metals in baleen whales	2017	Metals are massively deposited in the marine environment through direct emissions or atmospheric dry and wet depositions, a process since long enhanced by human activities. Metal contamination in the marine organisms has been increasingly investigated, but most research focuses on few tissues, elements and species considered indicative. Baleen whales have been scarcely studied in this respect. Here we contribute to the fragmented knowledge on this field examining the concentrations of zinc, copper, lead, titanium and strontium in the bone of fin whales (Balaenoptera physalus) from NW Spain and W Iceland. Bone was selected because it is a tissue commonly available in archival historic collections, and it is therefore useful to examine long-term trends in metal pollution. We tested differences between populations and we investigated age- and sex-related accumulation trends, as well as the occurrence of placental transfer. Sr concentrations and Pb accumulation rates with age were significantly higher in individuals from NW Spain than in those from W Iceland. Placental transfer occurred, at different levels, for all metals: as a result, fetuses showed significantly higher Cu, Pb and Zn concentrations than adults. After birth, only Zn and Pb concentrations significantly increased with age. Through this study, we contributed to fill some gaps in the knowledge regarding metal contamination in marine mammals, and we concluded that bone can be a suitable surrogate tissue to monitor a number of trace elements, provided that dissimilarities in tissue-specific deposition are taken into account when comparing concentrations from different tissues.	Fin whales	Metals in baleen whales	Bone as surrogate tissue		2016-?	NW Spain and W Iceland; University of Barcelona	University of Barcelona, Barcelona, Spain	https://doi.org/10.1016/j.chemosphere.2016.12.036	
Christiansen, F. Dujon, A. M. Sprogis, K. R. Arnould, J. P. Y. Bejder, L.	Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales	2016	An animal's body condition will affect its survival and reproductive success, which influences population dynamics. Despite its importance, relatively little is known about the body condition of large whales and its relationship to reproduction. We assessed the body condition of humpback whales (Megaptera novaeangliae) at a breeding/resting ground from aerial photographs recorded using an unmanned aerial vehicle (UAV). Photogrammetry methods were used to measure the surface area of individual whales, which was used as an index for body condition. Repeated measurements of the same individuals were not possible; hence, this study represents a cross-sectional sample of the population. Intraseasonal changes in the body condition of four reproductive classes (calves, immature, mature, and lactating) were investigated to infer the relative energetic cost that each class faces during the breeding season. To better understand the costs of reproduction, we investigated the relationship between female body condition (FBC) and the linear growth and body condition of their dependent calves (CBC). We documented a linear decline in the body condition of mature whales (0.027 m (2)/d; n = 20) and lactating females (0.032 m (2)/d; n = 31) throughout the breeding season, while there was no change in body condition of immature whales (n = 51) and calves (n = 32). The significant decline in mature and lactating female's body condition implies substantial energetic costs for these reproductive classes. In support of this, we found a positive linear relationship between FBC and CBC. This suggests that females in poorer body condition may not have sufficient energy stores to invest as much energy into their offspring as better conditioned females without jeopardizing their own body condition and survival probability. Measurement precision was investigated from repeated measurements of the same animals both from the same and different photographs, and by looking at residual errors in relation to the positioning of the whales in the photographs. The resulting errors were included in a sensitivity analysis to demonstrate that model parameters were robust to measurement - errors. Our findings provide strong support for the use of UAVs as a noninvasive tool to measure the body condition of whales and other mammals.	Humpback whale	Relationship of body condition of large whales and reproduction; estimates of energetic cost of reproduction in humpback whales.	Use of UAVs as a noninvasive tool to measure the body condition of whales and other mammals.		August - September 2015	Exmouth Gulf, Western Australia	Murdoch University, Western Australia, Australia	https://doi.org/10.1002/ecs2.1468	Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales.
Durban, J. W. Moore, M. J. Chiang, G. Hickmott, L. S. Bocconcelli, A. Howes, G. Bahamonde, P. A. Perryman, W. L. LeRoi, D. J.	Photogrammetry of blue whales with an unmanned hexacopter	2016	Baleen whales are the largest animals ever to live on earth, and many populations were hunted close to extinction in the 20th century (Clapham et al. 1999). Their recovery is now a key international conservation goal, and they are important in marine ecosystems as massive consumers that can promote primary production through nutrient cycling (Roman et al. 2014). However, although abundance has been assessed to monitor the recovery of some large whale populations (e.g., Barlow et al. 2011, Laake et al. 2012) many populations are wide-ranging and pelagic, and this inaccessibility has generally impeded quantitative assessments of recovery (Peel et al. 2015).To augment traditional abundance monitoring, we suggest that photogrammetric measures of individual growth and body condition can also inform about population status, enabling assessment of individual health as well as population numbers. Photogrammetry from manned aircraft has used photographs taken from directly above whales to estimate individual lengths (Gilpatrick and Perryman 2008) and monitor growth trends (Fearnbach et al. 2011), and shape profiles can be measured to assess body condition to infer reproductive and nutritional status (e.g., Perryman and Lynn 2002, Miller et al. 2012). Recently, Durban et al. (2015) demonstrated the utility of an unmanned hexacopter for collecting aerial photogrammetry images of killer whales (Orcinus orca); this provided a noninvasive, cost-effective, and safe platform that could be deployed from a boat to obtain vertical images of whales. Here we describe the use of this small, unmanned aerial system (UAS) to measure length and condition of blue whales (Balaenoptera musculus), the largest of all whales.	Blue whale	To augment traditional abundance monitoring, we suggest that photogrammetric measures of individual growth and body condition can also inform about population status, enabling assessment of individual health as well as population numbers.	Unmanned hexacopter (small, unmanned aerial system (UAS)) for collecting aerial photogrammetry images		February - March 2015	Southern Chile	Southwest Fisheries Science Center, CA, USA	https://doi.org/10.1111/mms.12328	To augment traditional abundance monitoring, we suggest that photogrammetric measures of individual growth and body condition can also inform about population status, enabling assessment of individual health as well as population numbers.
Harshaw, L. T. Larkin, I. V. Bonde, R. K. Deutsch, C. J. Hill, R. C.	Morphometric Body Condition Indices of Wild Florida Manatees (Trichechus manatus latirostris)	2016	In many species, body weight (W) increases geometrically with body length (L), so W/L-3 provides a body condition index (BCI) that can be used to evaluate nutritional status once a normal range has been established. No such index has been established for Florida manatees (Trichechus manatus latirostris). This study was designed to determine a normal range of BCIs of Florida manatees by comparing W in kg with straight total length (SL), curvilinear total length (CL), and umbilical girth (UG) in m for 146 wild manatees measured during winter health assessments at three Florida locations. Small calves to large adults of SL from 1.47 to 3.23 m and W from 77 to 751 kg were compared. BCIs were significantly greater in adult females than in adult males ($p < 0.05$). W scaled proportionally to L-3 in females but not in males, which were slimmer than females. The logarithms of W and of each linear measurement were regressed to develop amended indices that allow for sex differences. The regression slope for log W against log SL was 2.915 in females and 2.578 in males; W/SL2.915 ranged from 18.9 to 29.6 (mean 23.2) in females and from 24.6 to 37.3 (mean 29.8) in males. Some BCIs were slightly (4%), but significantly ($p <= 0.05$), higher for females in Crystal River than in Tampa Bay or Indian River, but there was no evidence of geographic variation in condition among males. These normal ranges should help evaluate the nutritional status of both wild and rehabilitating captive manatees.	Wild Florida Manatees	Determine a normal range of Body Condition Index (BCIs) of Florida manatees	Morphometric Body Condition Indices		Winter 2002-2006 (Apollo Beach, Tampa Bay, FL); Winter 2007-2011 (Kings Bay, Crystal River, FL); and Winter 2009-2010 (northern Indian River near Port St. John, Brevard County, FL)		College of Veterinary Medicine, University of Florida, FL, USA	https://doi.org/10.1578/am.42.4.2016.428	"These normal ranges should help evaluate the nutritional status of both wild and rehabilitating captive manatees."

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McAloose, D.Rago, M. V.Di Martino, M.Chirife, A.Olson, S. H.Beltramino, L.Pozzi, L. M.Musmeci, L.La Sala, L.Mohamed, N.Sala, J. E.Bandieri, L.Andrejuk, J.Tomaszewicz, A.Seimon, T.Sironi, M.Samartino, L. E.Rowntree, V.Uhart, M. M.	Post-mortem findings in southern right whales Eubalaena australis at Peninsula Valdes, Argentina, 2003-2012	2016	Between 2003 and 2012, 605 southern right whales (SRW; Eubalaena australis) were found dead along the shores of Peninsula Valdes (PV), Argentina. These deaths included alarmingly high annual losses between 2007 and 2012, a peak number of deaths (116) in 2012, and a significant number of deaths across years in calves-of-the-year (544 of 605 [89.9%]; average = 60.4 yr (-1)). Postmortem examination and pathogen testing were performed on 212 whales; 208 (98.1%) were calves-f-the-year and 48.0% of these were newborns or neonates. A known or probable cause of death was established in only a small number (6.6%) of cases. These included ship strike in a juvenile and blunt trauma or lacerations (n = 5), pneumonia (n = 4), myocarditis (n = 2), meningitis (n = 1), or myocarditis and meningitis (n = 1) in calves. Ante-mortem gull parasitism was the most common gross finding. It was associated with systemic disease in a single 1-2 mo. old calf. Immunohistochemical labeling for canine distemper virus, Toxoplasma gondii and Brucella spp., and PCR for cetacean morbillivirus (CeMV), influenza A, and apicomplexan protozoa were negative on formalin-fixed, paraffin-embedded lung and brain samples from a subset of whales; PCR for Brucella spp. was positive in a newborn/neonate with pneumonia. Skin samples from whales with gull parasitism were PCR negative for CeMV, poxvirus, and papillomavirus. This is the first long-term study to investigate and summarize notable post-mortem findings in the PV SRW population. Consistent, significant findings within or between years to explain the majority of deaths and those in high-mortality years remain to be identified.	Southern right whales		NA		2003-2012	Peninsula Valdes (PV), Argentina	Wildlife Conservation Society Zoological Health Program, NY, USA		
Rolland, R. M. Schick, R. S. Pettis, H. M. Knowlton, A. R. Hamilton, P. K. Clark, J. S. Kraus, S. D.	Health of North Atlantic right whales Eubalaena glacialis over three decades: from individual health to demographic and population health trends	2016	Marine mammals are faced with increasing challenges from environmental fluctuation, climate change, and disturbances from human activities. Anthropogenic mortalities have been well documented, but it is difficult to assess the sub-lethal effects of disturbance on the fitness of marine wildlife, and to distinguish these impacts from natural variations in health and reproduction. Here, we used photographic data on body and skin condition, blowhole cyamids, and rake marks, to evaluate the health of North Atlantic right whales Eubalaena glacialis from 1980 to 2008. We applied a hierarchical Bayesian model to these data to estimate the underlying continuous health status of individuals, demographic groups, and the population to characterize health patterns and temporal trends. Visual health scores (scaled from 0 to 100) from 48560 sighting events were used to estimate the health of 622 identified right whales on a monthly basis. Health in most whales fluctuated between 70 and 90, and health scores of <60 were observed in whales in poor condition. Health varied by sex, age-class and reproductive state, with the greatest annual variability occurring in actively reproducing females. Calving females had significantly higher health scores than non-calving females, and a steep deterioration in population health coincided with a dramatic decline in calving from 1998 to 2000. Health in all demographic groups and the population declined over the 3 decades of observations. Given the inevitable data gaps that occur in most marine wildlife research, modeling advances such as the one presented here offer a promising approach to assess the complex interactions between biology, ecology, and sub-lethal anthropogenic disturbance on marine mammals.	North Atlantic right whale	Health score	Visual health scores were used to estimate the health of NAWR on a monthly basis		1980-2008	NARW Consortium catalog of photographs	New England Aquarium, MA, USA	https://www.int-res.com/articles/meps2015/542/m542p265.pdf	
Schick, R. S. Kraus, S. D. Rolland, R. M. Knowlton, A. R. Hamilton, P. K. Pettis, H. M. Thomas, L. Harwood, J. Clark, J. S.	Effects of Model Formulation on Estimates of Health in Individual Right Whales (Eubalaena glacialis)	2016	Right whales are vulnerable to many sources of anthropogenic disturbance including ship strikes, entanglement with fishing gear, and anthropogenic noise. The effect of these factors on individual health is unclear. A statistical model using photographic evidence of health was recently built to infer the true or hidden health of individual right whales. However, two important prior assumptions about the role of missing data and unexplained variance on the estimates were not previously assessed. Here we tested these factors by varying prior assumptions and model formulation. We found sensitivity to each assumption and used the output to make guidelines on future model formulation.	North Atlantic right whales		NA					Y	
Clegg, I. L. K. Borger-Turner, J. L. Eskelinen, H. C.	C-Well: The development of a welfare assessment index for captive bottlenose dolphins (Tursiops truncatus)	2015	The field of welfare science and public concern for animal welfare is growing, with the focus broadening from animals on farms to those in zoos and aquaria. Bottlenose dolphins (Tursiops truncatus) are the most common captive cetaceans, and relevant regulatory standards are principally resource-based and regarded as minimum requirements. In this study, the farm animal Welfare Quality (R) assessment was adapted to measure the welfare of bottlenose dolphins, with a similar proportion of animal-based measures (58.3%). The 'C-Well (R)' assessment included eleven criterion and 36 species-specific measures developed in situ at three marine mammal zoological facilities, tested for feasibility and accuracy, and substantiated by published literature on wild and captive dolphins and veterinary and professional expertise. C-Well (R) scores can be calculated for each measure or combined to achieve an overall score, which allows for the comparison of welfare among individuals, demographics, and facilities. This work represents a first step in quantifying and systematically measuring welfare among captive cetaceans and can be used as a model for future development in zoos and aquaria, as well as a means to support benchmarking, industry best practices, and certification.		Dolphin welfare assessment index for captive bottlenose dolphins (Tursiops truncatus)	NA						
Hunt, K. E. Rolland, R. M. Kraus, S. D.	Conservation Physiology of an Uncatchable Animal: The North Atlantic Right Whale (Eubalaena glacialis)	2015	The North Atlantic right whale, Eubalaena glacialis (NARW), a critically endangered species that has been under intensive study for nearly four decades, provides an excellent case study for applying modern methods of conservation physiology to large whales. By combining long-term sighting histories of known individuals with physiological data from newer techniques (e.g., body condition estimated from photographs; endocrine status derived from fecal samples), physiological state and levels of stress can be estimated despite the lack of any method for nonlethal capture of large whales. Since traditional techniques for validating blood assays cannot be used in large whales, assays of fecal hormones have been validated using information on age, sex, and reproductive state derived from an extensive NARW photo-identification catalog. Using this approach, fecal glucocorticoids have been found to vary dramatically with reproductive state. It is therefore essential that glucocorticoid data be interpreted in conjunction with reproductive data. A case study correlating glucocorticoids with chronic noise is presented as an example. Keys to a successful research program for this uncatchable species have included: consistent population monitoring over decades, data-sharing across institutions, an extensive photo-identification catalog that documents individual histories, and consistent efforts at noninvasive collection of samples over years. Future research will require flexibility to adjust to changing distributions of populations.	North Atlantic right whale	Physiological state and levels of stress	Body condition estimated from photographs; endocrine status derived from fecal samples		Long-term data sights/NARW Consortium Catalog	NARW habitat	New England Aquarium, MA, USA	https://doi.org/10.1093/icb/icv071	"By combining long-term sighting histories of known individuals with physiological data from newer techniques (e.g., body condition estimated from photographs; endocrine status derived from fecal samples), physiological state and levels of stress can be estimated despite the lack of any method for nonlethal capture of large whales."

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Hunt, K. E. Rolland, R. M. Kraus, S. D.	Detection of steroid and thyroid hormones via immunoassay of North Atlantic right whale (Eubalaena glacialis) respiratory vapor	2014	Steroid and thyroid hormone analyses can potentially provide valuable information about many aspects of physiology in marine mammals, including stress responses, reproductive maturity, reproductive cyclicity, pregnancy status, and metabolic rate (Rolland et al. 2005; Hunt et al. 2006, 2013; Biancani et al. 2009; Wasser et al. 2010; Kusuda et al. 2011; Ayres et al. 2012). However, it has been difficult to collect the relevant biological samples from living, large cetaceans for endocrine studies (Rolland et al. 2007, Amaral 2010). Analysis of fecal hormone metabolites has proved quite biologically informative (Rolland et al. 2005, 2012; Hunt et al. 2006), but feces can only be collected opportunistically. Blubber hormone analysis shows promise but is somewhat invasive, permitting issues can restrict repeated sampling of individuals, and the pharmacokinetics of blubber hormone turnover and timeframe of deposition are still uncertain (Mansour et al. 2002; Keller et al. 2006, 2009; Perez et al. 2011; Hunt et al. 2013). A novel method that has been receiving increasing attention is analysis of hormones in condensed droplets of respiratory vapor ("blow"). Large whales usually blow several times at the surface after extended dives, and previous research has demonstrated that blow droplets can be collected successfully from free-swimming large whales using pole-based methods or remote-controlled helicopters (Hogg et al. 2005, 2009; Acevedo-Whitehouse 2010). Hogg et al. (2009) reported detectable testosterone and progesterone in blow samples collected from North Atlantic right whales (Eubalaena glacialis, NARW) and humpback whales (Megaptera novaeangliae) using liquid chromatography-mass spectrometry (LC-MS). However, LC-MS is relatively expensive, requires specialized equipment, and is not widely available to many researchers. Further, mass spectrometry can be vulnerable to hormone degradation, e.g., if a hormone is chemically modified it may not be recognized (Wood et al. 2008, Hogg et al. 2009).	North Atlantic right whales (other studies looked at humpback whales)	Physiological information from large whales (e.g. stress responses, reproductive maturity, reproductive cyclicity, pregnancy status, and metabolic rate)	Blow sampling/noninvasive hormone sampling: Assess whether immunoassays can detect steroid and thyroid hormones in blow samples.		August - September 2011	Bay of Fundy, Canada	New England Aquarium, MA, USA	https://doi.org/10.1111/mms.12073	This was a pilot study; this technique could be used for many large whale species.
Hunt, K. E.Stimmelmayr, R.George, C.Hanns, C.Suydam, R.Brower, H.Rolland, R. M.	Baleen hormones: a novel tool for retrospective assessment of stress and reproduction in bowhead whales (Balaena mysticetus)	2014	Arctic marine mammals are facing increasing levels of many anthropogenic stressors. Novel tools are needed for assessment of stress physiology and potential impacts of these stressors on health, reproduction and survival. We have investigated baleen as a possible novel tissue type for retrospective assessment of stress and reproductive hormones. We found that pulverized baleen powder from bowhead whales (Balaena mysticetus) contained immunoreactive cortisol and progesterone that were detectable with commercially available enzyme immunoassay kits. Both assays passed parallelism and accuracy validations using baleen extracts. We analyzed cortisol and progesterone at the base of the baleen plate (most recently grown baleen) from 16 bowhead whales of both sexes. For a subset of 11 whales, we also analyzed older baleen from 10, 20 and 30 cm distal to the base of the baleen plate. Immunoreactive cortisol and progesterone were detectable in all baleen samples tested. In base samples, females had significantly higher concentrations of cortisol and progesterone compared with males. Cortisol concentrations in older baleen (10, 20 and 30 cm locations) were significantly lower than at the base and did not exhibit correlations with age-class or sex. Progesterone concentrations were significantly higher in females than in males at all baleen locations tested and were significantly higher in pregnant females than in non-pregnant females. Four of five mature females showed dramatic variation in progesterone concentrations at different locations along the baleen plate that may be indicative of previous pregnancies or luteal phases. In contrast, all males and all immature females had uniformly low progesterone. Baleen hormone analysis is a novel approach that, with further methodological development, may be useful for determining individual longitudinal profiles of reproductive cycles and stress responses.	Bowhead whale	Retrospective assessment of stress and reproduction	Baleen hormone analysis		Baleen plates collected between 2003 and 2012	Alaska	New England Aquarium, MA, USA	https://doi.org/10.1093/conphys/cou030	"Could compare samples from museum archives to present-day population data; continue collection of baleen from current populations to track population changes through time. Hormone analysis of baleen could provide an innovative means to evaluate long-term trends of stress and reproduction in whale populations exposed to a changing marine environment."
Barratclough, A. Jepson, P. D. Hamilton, P. K. Miller, C. A. Wilson, K. Moore, M. J.	How much does a swimming, underweight, entangled right whale (Eubalaena glacialis) weigh? Calculating the weight at sea, to facilitate accurate dosing of sedatives to enable disentanglement	2014	Producing a simple, accurate method of establishing a body weight will facilitate more accurate sedative dosing, reducing the associated risks. Improving techniques will encourage increased use of sedation to assist disentangling if the whale is identified early, rather than intervening when the whale has already deteriorated too far. North Atlantic right whales are the least tractable species to disentangle due to their persistent and successful avoidance of close-approaching vessels (Moore et al. 2010). Due to their increased muscle strength compared to other species right whales have been shown to be less tolerant to the additional drag placed upon them during a disentanglement effort (Johnson et al. 2005). Effective sedation methods are therefore even more applicable to this species to facilitate approach. However, no matter how well the disentanglement process is developed, the only lasting solution to the entanglement problem is avoidance of entanglement in the first place.	North Atlantic right whales	Sedation dosing	Calculating the weight at sea, to facilitate accurate dosing of sedatives to enable disentanglement		Postmortem reports from the North Atlantic Right Whale Consortium Database extending back to 1970		Zoological Society of London, UK	https://doi.org/10.1111/mms.12132	"Improving techniques will encourage increased use of sedation to assist disentangling if the whale is identified early, rather than intervening when the whale has already deteriorated too far."
Apprill, A. Robbins, J. Eren, A. M. Pack, A. A. Reveillaud, J. Mattila, D. Moore, M. Niemeyer, M. Moore, K. M. T. Mincer, T. J.	Humpback Whale Populations Share a Core Skin Bacterial Community: Towards a Health Index for Marine Mammals?	2014	Microbes are now well regarded for their important role in mammalian health. The microbiology of skin - a unique interface between the host and environment - is a major research focus in human health and skin disorders, but is less explored in other mammals. Here, we report on a cross-population study of the skin-associated bacterial community of humpback whales (Megaptera novaeangliae), and examine the potential for a core bacterial community and its variability with host (endogenous) or geographic/environmental (exogenous) specific factors. Skin biopsies or freshly sloughed skin from 56 individuals were sampled from populations in the North Atlantic, North Pacific and South Pacific oceans and bacteria were characterized using 454 pyrosequencing of SSU rRNA genes. Phylogenetic and statistical analyses revealed the ubiquity and abundance of bacteria belonging to the Flavobacteria genus Tenacibaculum and the Gammaproteobacteria genus Psychrobacter across the whale populations. Scanning electron microscopy of skin indicated that microbial cells colonize the skin surface. Despite the ubiquity of Tenacibaculum and Psychrobater spp., the relative composition of the skin-bacterial community differed significantly by geographic area as well as metabolic state of the animals (feeding versus starving during migration and breeding), suggesting that both exogenous and endogenous factors may play a role in influencing the skin-bacteria. Further, characteristics of the skin bacterial community from these free-swimming individuals were assembled and compared to two entangled and three dead individuals, revealing a decrease in the central or core bacterial community members (Tenacibaculum and Psychrobater spp.), as well as the emergence of potential pathogens in the latter cases. This is the first discovery of a cross-population, shared skin bacterial community. This research suggests that the skin bacteria may be connected to humpback health and immunity and could possibly serve as a useful index for health and skin disorder monitoring of threatened and endangered marine mammals.	Humpback whale	Index for health and skin disorder monitoring of threatened and endangered marine mammals; connection to health and immunity.	Skin bacterial community		2007-2009	Southeast Alaska, Hawaiian Islands, American Samoa, and Gulf of Maine	WHOI, MA, USA	https://doi.org/10.1371/journal.pone.0090785	

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Schick, Robert S Kraus, Scott D Rolland, Rosalind M Knowlton, Amy R Hamilton, Philip K Pettis, Heather M Kenney, Robert D Clark, James S	Using hierarchical Bayes to understand movement, health, and survival in the endangered North Atlantic right whale	2013	Body condition is an indicator of health, and it plays a key role in many vital processes for mammalian species. While evidence of individual body condition can be obtained, these observations provide just brief glimpses into the health state of the animal. An analytical framework is needed for understanding how health of animals changes over space and time. Through knowledge of individual health, we can better understand the status of populations. This is particularly important in endangered species, where the consequences of disruption of critical biological functions can push groups of animals rapidly toward extinction. Here we built a state-space model that provides estimates of movement, health, and survival. We assimilated 30+ years of photographic evidence of body condition and three additional visual health parameters in individual North Atlantic right whales, together with survey data, to infer the true health status as it changes over space and time. We also included the effect of reproductive status and entanglement status on health. At the population level, we estimated differential movement patterns in males and females. At the individual level, we estimated the likely animal locations each month. We estimated the relationship between observed and latent health status. Observations of body condition, skin condition, cyamid infestation on the blowholes, and rake marks all provided measures of the true underlying health. The resulting time series of individual health highlight both normal variations in health status and how anthropogenic stressors can affect the health and, ultimately, the survival of individuals. This modeling approach provides information for monitoring of health in right whales, as well as a framework for integrating observational data at the level of individuals up through the health status of the population. This framework can be broadly applied to a variety of systems – terrestrial and marine – where sporadic observations of individuals exist.	North Atlantic right whale	Infer the true health status as it changes over space and time.	Build a state-space model that provides estimates of movement, health, and survival.		1980 - 2013	NRTH = North region, BOF = Bay of Fundy, JL = Jeffreys Ledge, GOM = Gulf of Maine, RB = Roseway Basin, NE = Northeast, GSC = Great South Channel, MIDA = Mid-Atlantic, and SEUS = Southeastern US.	Duke University, Durham, NC, USA	https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0064166&type=printable	
Moore, M. J. van der Hoop, J. Barco, S. G. Costidis, A. M. Gulland, F. M. Jepson, P. D. Moore, K. T. Raverty, S. McLellan, W. A.	Criteria and case definitions for serious injury and death of pinnipeds and cetaceans caused by anthropogenic trauma	2013	Post-mortem examination of dead and live stranded beach-cast pinnipeds and cetaceans for determination of a cause of death provides valuable information for the management, mitigation and prosecution of unintentional and sometimes malicious human impacts, such as vessel collision, fishing gear entanglement and gunshot. Delayed discovery, inaccessibility, logistics, human safety concerns, and weather make these events challenging. Over the past 3 decades, in response to public concern and federal and state or provincial regulations mandating such investigations to inform mitigation efforts, there has been an increasing effort to objectively and systematically investigate these strandings from a diagnostic and forensic perspective. This Theme Section provides basic investigative methods, and case definitions for each of the more commonly recognized case presentations of human interactions in pinnipeds and cetaceans. Wild animals are often adversely affected by factors such as parasitism, anthropogenic contaminants, biotoxins, subclinical microbial infections and competing habitat uses, such as prey depletion and elevated background and episodic noise. Understanding the potential contribution of these subclinical factors in predisposing or contributing to a particular case of trauma of human origin is hampered, especially where putrefaction is significant and resources as well as expertise are limited. These case criteria descriptions attempt to acknowledge those confounding factors to enable an appreciation of the significance of the observed human-derived trauma in that broader context where possible.	North Atlantic right whale	Should this be revisited?	Criteria and case definitions for serious injury and death of pinnipeds and cetaceans caused by anthropogenic trauma		NA		WHOI, MA, USA	https://doi.org/10.3354/dao02566	
Hunt, K. E.Moore, M. J.Rolland, R. M.Kellar, N. M.Hall, A. J.Kershaw, J.Raverty, S. A.Davis, C. E.Yeates, L. C.Fauquier, D. A.Rowles, T. K.Kraus, S. D.	Overcoming the challenges of studying conservation physiology in large whales: a review of available methods	2013	Large whales are subjected to a variety of conservation pressures that could be better monitored and managed if physiological information could be gathered readily from free-swimming whales. However, traditional approaches to studying physiology have been impractical for large whales, because there is no routine method for capture of the largest species and there is presently no practical method of obtaining blood samples from free-swimming whales. We review the currently available techniques for gathering physiological information on large whales using a variety of non-lethal and minimally invasive (or non-invasive) sample matrices. We focus on methods that should produce information relevant to conservation physiology, e.g. measures relevant to stress physiology, reproductive status, nutritional status, immune response, health, and disease. The following four types of samples are discussed: fecal samples, respiratory samples ('blow'), skin/blubber samples, and photographs. Fecal samples have historically been used for diet analysis but increasingly are also used for hormonal analyses, as well as for assessment of exposure to toxins, pollutants, and parasites. Blow samples contain many hormones as well as respiratory microbes, a diverse array of metabolites, and a variety of immune-related substances. Biopsy dart samples are widely used for genetic, contaminant, and fatty-acid analyses and are now being used for endocrine studies along with proteomic and transcriptomic approaches. Photographic analyses have benefited from recently developed quantitative techniques allowing assessment of skin condition, ectoparasite load, and nutritional status, along with wounds and scars from ship strikes and fishing gear entanglement. Field application of these techniques has the potential to improve our understanding of the physiology of large whales greatly, better enabling assessment of the relative impacts of many anthropogenic and ecological pressures.	North Atlantic right whale	Stress physiology, reproductive status, nutritional status, immune response, health, and disease.	Review the currently available techniques for gathering physiological information on large whales using a variety of non-lethal and minimally invasive (or non-invasive) sample matrices.		NA		New England Aquarium, MA, USA	https://doi.org/10.1093/conphys/cot006	
Hart, L. B. Wells, R. S. Schwacke, L. H.	Reference ranges for body condition in wild bottlenose dolphins Tursiops truncatus	2013	Marine mammal body condition, as evaluated by a combination of mass, length, and/or girth measurements, is considered an indicator of nutritional status. We used measurements of total mass, total length, and maximum girth from long-term bottlenose dolphin Tursiops truncatus capture-release research conducted in Sarasota Bay, Florida, USA, (1987 to 2009) to develop 95th percentile reference ranges for 2 body condition models: (1) total mass versus total length and (2) maximum girth versus total length. Nonlinear and linear quantile regression methods were used to estimate the parameters for the reference ranges and develop predictive models to examine body condition among individual dolphins. The flexibility of these models and reliance upon commonly acquired morphometrics allows for broad application among researchers lacking data on mass or age. Ultimately, these reference ranges can be used to evaluate and compare the body condition of individual animals and provide an additional metric for evaluating the general health of coastal populations.	Bottlenose dolphin	Body condition/nutritional status	Reference ranges for body condition in wild bottlenose dolphins Tursiops truncatus		1987-20009	Sarasota Bay, Florida, USA	National Centers for Coastal Ocean Science, SC, USA	https://doi.org/10.3354/ab00491	"Ultimately, these reference ranges can be used to evaluate and compare the body condition of individual animals and provide an additional metric for evaluating the general health of coastal populations."

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Moore, Michael Andrews, Russel Austin, Trevor; Bailey, James Costidis, Alex George, Clay Jackson, Katie Pitchford, Tom Landry, Scott Ligon, Allan McLellan, William Morin, David Smith, Jamison Rotstein, David Rowles, Teresa Slay, Chris Walsh, Michael	Rope trauma, sedation, disentanglement, and monitoring-tag associated lesions in a terminally entangled North Atlantic right whale (Eubalaena glacialis)	2012	A chronically entangled North Atlantic right whale, with consequent emaciation was sedated, disentangled to the extent possible, administered antibiotics, and satellite tag tracked for six subsequent days. It was found dead 11 d after the tag ceased transmission. Chronic constrictive deep rope lacerations and emaciation were found to be the proximate cause of death, which may have ultimately involved shark predation. A broadhead cutter and a spring-loaded knife used for disentanglement were found to induce moderate wounds to the skin and blubber. The telemetry tag, with two barbed shafts partially penetrating the blubber was shed, leaving barbs embedded with localized histological reaction. One of four darts administered shed the barrel, but the needle was found postmortem in the whale with an 80º bend at the blubber-muscle interface. This bend occurred due to epaxial muscle movement relative to the overlying blubber, with resultant necrosis and cavitation of underlying muscle. This suggests that rigid, implanted devices that span the cetacean blubber muscle interface, where the muscle moves relative to the blubber, could have secondary health impacts. Thus, we encourage efforts to develop new tag telemetry systems that do not penetrate the subdermal sheath, but still remain attached for many months.	North Atlantic right whale	"This suggests that rigid, implanted devices that span the cetacean blubber muscle interface, where the muscle moves relative to the blubber, could have secondary health impacts."	NA	NA	2010-2011	NA	WHOI, MA, USA	https://doi.org/10.1111/j.1748-7692.2012.00591.x	"Thus, we encourage efforts to develop new tag telemetry systems that do not penetrate the subdermal sheath, but still remain attached for many months."
Miller, C. A. Best, P. B. Perryman, W. L. Baumgartner, M. F. Moore, M. J.	Body shape changes associated with reproductive status, nutritive condition and growth in right whales Eubalaena glacialis and E. australis	2012	Mammalian reproduction is metabolically regulated; therefore, the endangered status and high variability in reproduction of North Atlantic right whales Eubalaena glacialis necessitate accurate assessments at sea of the nutritional condition of living individuals. Aerial photogrammetry was used to measure dorsal body width at multiple locations along the bodies of free-swimming right whales at different stages of the female reproductive cycle (E. glacialis) and during the initial months of lactation (mother and calf Eubalaena australis) to quantify changes in nutritional condition during energetically demanding events. Principal components analyses indicated that body width was most variable at 60% of the body length from the snout. Thoracic, abdominal and caudal body width of E. australis thinned significantly during the initial months of lactation, especially at 60% of body length from the snout, while their calves' widths and width-to-length ratios increased. The body shape of E. glacialis that had been lactating for 8 mo. was significantly thinner than non-lactating, non-pregnant E. glacialis. Body shape of E. glacialis measured in the eighth month of lactation was significantly thinner than that of E. australis in the first month, but did not differ from that of E. australis in the third and fourth months. Body width was comparable with diameter calculated from girth of carcasses. These results indicate that mother right whales rely on endogenous nutrient reserves to support the considerable energy expenditure during the initial months of lactation; therefore, photogrammetric measurements of body width, particularly at 60% of body length from the snout, are an effective way to quantitatively and remotely assess nutritional condition of living right whales.	E. glacialis and E. australis	Reproductive status, nutritive condition and growth.	"Photogrammetric measurements of dorsal body shape are effective as quantitative assessments of nutritive condition of free-swimming right whales. This technique could be used to detect pregnancies that may otherwise be missed, which would provide a more accurate assessment of the variability in Eubalaena glacials reproduction."	Twin Otter airplane and helicopter	August 2000, 2001, & 2001	Bay of Fundy, eastern Canada	WHOI, MA, USA	https://doi.org/10.3354/meps09675	"This non-invasive remote quantitative tool is highly relevant for testing hypotheses regarding nutritive condition. These results are needed for developing and implementing effective management strategies to aid conservation of E. glacialis."
Fortune, S. M. E.cal Trites, A. W. Perryman, W. L. Moore, M. J. Pettis, H. M. Lynn, M. S.	Growth and rapid early development of North Atlantic right whales (Eubalaena glacialis)	2012	Body growth of North Atlantic right whales (Eubalaena glacialis) was described from measurements of known-age live and dead individuals to gain insights into the nutritional needs and life-history strategies of this endangered species. Body lengths from 154 individuals revealed that calves more than doubled in size and attained three-fourths of asymptotic adult size by the time they had weaned at 12 months. Calves gained on average similar to 1.7 cm and similar to 34 kg per day while nursing during this extremely rapid growth phase. Mean predicted lengths and body mass were 4.2 m and 1.1 metric tons (mt) at birth, 10.3 m and 13.5 mt at weaning, and 13.6 m and 29.6 mt when fully grown. Growth of right whales was best described using a 2-phased Gompertz growth model and could not be fit using any of the single continuous growth models commonly used for other mammals. Rapid growth during dependency may minimize the risk of predation and maximize calf survival. Rapid calf growth also may maximize development of the mouth and baleen to optimize foraging efficiency of juveniles at the time of weaning, as well as improve reproductive fitness by reducing the age at which sexual maturity is attained. However, transferring the amount of energy needed to support the rapid postnatal growth of North Atlantic right whales may ultimately affect the intervals between pregnancies (>3 years) of mature females.	North Atlantic right whale	NA	NA	NA	NA	NA	University of British Columbia, British Columbia Canada	https://doi.org/10.1644/11-mamm-a-297.1	"Our results describe the body growth of the North Atlantic right whale and provide new insights into the reproductive strategy and energetic investment employed by this large cetacean."
Chen, Tania Filipa Li	Chromium is a Potential Environmental Health Concern for the North Atlantic Right Whale and Sperm Whale	2012	Marine metal pollution is a health concern for marine mammals. Marine pollutants that pose health risks to humans were also shown to produce adverse health effects in marine mammals. Although metals can be potent human toxicants, they are not commonly studied in great whales. Chromium (Cr) is a metal present in the marine environment but rarely studied in marine mammals. A few studies reported Cr levels in marine mammal tissue but its toxicological effect was not addressed. Cr exists in the marine environment in its trivalent [Cr (III)] and hexavalent [Cr(VI)] forms. Naturally occurring Cr exist mostly as Cr (III), a less potent toxicant than Cr (VI). Cr (VI) is mainly a product of human activities. Studies in humans and animal models show that Cr (VI) cause several adverse effects in multiple biological systems. Cr (VI)-induced health effects include respiratory effects, decreased fertility, depressed immune system and cancer. Underlying these health effects are mechanisms of cellular toxicity, which include cytotoxicity and genotoxicity. The presence of Cr in the marine environment is therefore a potential health concern for marine organisms. Our study investigates Cr (Cr (VI) and Cr (III)) as potential health concerns for marine mammals focusing on great whales. We begin our study with the North Atlantic right whale, a baleen whale with a limited distribution off the eastern coast of North America. Then, we extend our study to the sperm whale, a toothed whale, with a global distribution. We assess and contextualize the toxicity of Cr in these species with two approaches. One approach, direct assessment, involves investigating Cr levels in whale tissue and the cytotoxic and genotoxic effects of Cr in cultured whale cells. The other approach, contextualization, involves comparing our results in whales with those seen in humans. Our results show that the right whale and sperm whale are exposed to environmental Cr, and that Cr compounds can induce cellular toxicity. Although with some differences, this cellular toxicity is comparable to what is observed in human cells. As a consequence, Cr is indeed a potential health concern for the whales and possibly for other marine mammal species as well.	North Atlantic right whale, Sperm whale	Cr (Cr(VI) and Cr(III)) as potential health concerns for marine mammals; toxicity of Cr in NARWs and sperm whales	Direct assessment: investigate Cr levels in whale tissue and the cytotoxic and genotoxic effects of Cr in cultured whale cells. Contextualization: compare our results in whales with those seen in humans.	NA	~2012	Unknown	University of Maine, ME, USA	https://digitalcommons.library.umaine.edu/etd/1840/	"Our results show that the right whale and sperm whale are exposed to environmental Cr, and that Cr compounds can induce cellular toxicity. Although with some differences, this cellular toxicity is comparable to what is observed in human cells. As a consequence, Cr is indeed a potential health concern for the whales and possibly for other marine mammal species as well."

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Bradford, Amanda L. Weller, David W. Punt, André E. Ivashchenko, Yulia V. Burdin, Alexander M. VanBlaricom, Glenn R. Brownell, Robert L.	Leaner leviathans: body condition variation in a critically endangered whale population	2012	The role of environmental limitation and density-dependent regulation in shaping populations is debated in ecology. Populations at low densities may offer an unobstructed view of basic environmental and physiological interactions that impact individual fitness and thus population productivity. The energy reserves of an organism are reflected in its body condition, a measure linking individual fitness and the environment. From 1997 to 2007, we monitored the critically endangered western gray whale (Eschrichtius robustus) population on its primary summer feeding ground off the northeastern coast of Sakhalin Island, Russia. This effort resulted in a large data set of photo-identification images from 5,007 sightings of 168 individual whales that we used to visually assess western gray whale body condition. We quantified temporal variation in the resulting 1,539 monthly body condition determinations with respect to observations of reproductive status and sex. Western gray whale body condition varied annually, and we identified years of significantly better (2004) and worse (1999, 2006, and 2007) body condition. This study is the 1st to track the within-season body condition of individual whales. Body condition improved significantly as the summer progressed, although results suggest that not all whales replenish their energy stores by the end of the season. The body condition of lactating females was significantly worse than that of other whales at all times and was most often determined to be compromised. The body condition of their weaning calves exhibited no temporal variation and was consistently good. It is possible lactating females provide an energetic buffer to their offspring at the expense of their own body condition and future reproductive success. Findings from the analysis establish a foundation for quantifying links between western gray whale body condition, demographic parameters, and environmental conditions; and provide a baseline for monitoring individual and population condition of an ecosystem sentinel species in a changing environment. Overall, this study highlights the presence of density-independent environmental and physiological mechanisms that affect the abundance and growth of populations.	Western gray whale (Eschrichtius robustus)	Baseline for monitoring individual and population condition of an ecosystem sentinel species in a changing environment.	Quantifying links between body condition, demographic parameters, and environmental conditions	Small-boat photo-identification surveys; biopsy samples in coordination with photo-identification efforts	1997-2007	Primary summer feeding ground off the northeastern coast of Sakhalin Island, Russia.	Pacific Islands Fisheries Science Center, HI, USA	https://doi.org/10.1644/11-MAMM-A-091.1	"Overall, this study highlights the presence of density-independent environmental and physiological mechanisms that affect the abundance and growth of populations."
Martinez-Levasseur, Laura M.	Acute sun damage and photoprotective responses in whales	2011	Rising levels of ultraviolet radiation (UVR) secondary to ozone depletion are an issue of concern for public health. Skin cancers and intraepidermal dysplasia are increasingly observed in individuals that undergo chronic or excessive sun exposure. Such alterations of skin integrity and function are well established for humans and laboratory animals, but remain unexplored for mammalian wildlife. However, effects are unlikely to be negligible, particularly for species such as whales, whose anatomical or life-history traits force them to experience continuous sun exposure. We conducted photographic and histological surveys of three seasonally sympatric whale species to investigate sunburn and photoprotection. We find that lesions commonly associated with acute severe sun damage in humans are widespread and that individuals with fewer melanocytes have more lesions and less apoptotic cells. This suggests that the pathways used to limit and resolve UVR-induced damage in humans are shared by whales and that darker pigmentation is advantageous to them. Furthermore, lesions increased significantly in time, as would be expected under increasing UV irradiance. Apoptosis and melanocyte proliferation mirror this trend, suggesting that whales are capable of quick photoprotective responses. We conclude that the thinning ozone layer may pose a risk to the health of whales and other vulnerable wildlife.	Blue, fin, sperm whales	Sunburn and photoprotection	Skin lesions photographic and histological surveys	Boat surveys; photographs; skin biopsies	2007-2009	Gulf of California (Mexico)	Institute of Zoology, London UK	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3081749/pdf/rspb20101903.pdf	"We conclude that the thinning ozone layer may pose a risk to the health of whales and other vulnerable wildlife."
Miller, C.A., Reeb, D., Best, P. B., Knowlton, A. R., Brown, M. W., and Moore, M. J.	Blubber thickness in right whales *Eubalaena glacialis* and *Eubalaena australis* related with reproduction, life history status and prey abundance	2011	The high variability in reproductive performance of North Atlantic right whales Eubalaena glacialis compared to southern right whales Eubalaena australis may reflect differences in lipid reserves. Amplitude-mode ultrasound was used to measure the thickness of right whale integument (epidermis and blubber, herein referred to as blubber thickness) in E. glacialis in the Bay of Fundy, Canada for 5 summer seasons and in E. australis off the South African coast for 2 austral winter seasons. E. glacialis had significantly thinner blubber layers (mean ±1 SD = 12.23 ± 2.16 cm, n = 172) than E. australis (16.13 ± 3.88 cm, n = 117), suggesting differing levels of nutrition between the 2 species. Blubber was thickest in females measured 3 to 6 mo. prior to the start of pregnancy (E. glacialis), thinner during lactation (E. glacialis, E. australis) and then thicker with time after weaning (E. glacialis). These results suggest that lipids in blubber are used as energetic support for reproduction in female right whales. Blubber thickness increased in calves during suckling (E. glacialis, E. australis) but subsequently decreased after weaning (E. glacialis). Juvenile and adult male E. glacialis blubber thicknesses were compared between years of differing prey Calanus finmarchicus abundances (data from Pershing et al. 2005; ICES J Mar Sci 62:1511–1523); during a year of low prey abundance whales had significantly thinner blubber than during years of greater prey abundance. Taken together, these results suggest that blubber thickness is indicative of right whale energy balance and that the marked fluctuations in North Atlantic right whale reproduction have a nutritional component.	North Atlantic right whales, Southern right whales	reproduction, life history status and prey abundance	blubber thickness	shipboard	5 summer seasons Bay of Fundy, Canada; South African coast for 2 austral winter seasons	Bay of Fundy, Canada; South African coast	WHOI, MA, USA	-	
Hall, Ailsa J., Gulland, Frances M.D., Hammond, John A., Schwacke, Lori H.	Epidemiology, disease, and health assessment	2010	Understanding marine mammal health and disease and the related impacts on populations is crucial to support effective conservation and management decisions. However, ethical issues involved in conducting experimental studies can limit the scope of marine mammal health research. This forces a focus and reliance onepidemiological studies, similar to those that have been applied to studying factors affecting human health. Marine mammal epidemiology is additionally challenging because most marine mammals are not easily observed for most of their lives, disease states are generally difficult to detect, and reporting mechanisms for disease used in human and veterinary epidemiology (i.e. birth, death, and disease records) are virtually non-existent for marine mammals. Nonetheless, despite these drawbacks, there are many ways in which robust and reliable epidemiological studies can be applied in the field of marine mammal science.	Marine mammals		Epidemiological framework for marine mammal studies (helpful schematic) (pg. 154)					https://global.oup.com/academic/product/marine-mammal-ecology-and-conservation-9780199216574?cc=us&lang=en&#	
Kraus, S. D. Rolland, R. M.	The Urban Whale: North Atlantic Right Whales at the Crossroads	2010	In 1980 a group of scientists censusing marine mammals in the Bay of Fundy was astonished at the sight of 25 right whales. It was, one scientist later recalled, "like finding a brontosaurus in the backyard." Until that time, scientists believed the North Atlantic right whale was extinct or nearly so. The sightings electrified the research community, spurring a quarter century of exploration, which is documented here. The authors present our current knowledge about the biology and plight of right whales, including their reproduction, feeding, genetics, and endocrinology, as well as fatal run-ins with ships and fishing gear. Employing individual identifications, acoustics, and population models, Scott Kraus, Rosalind Rolland, and their colleagues present a vivid history of this animal, from a once commercially hunted commodity to today's life-threatening challenges of urban waters. Hunted for nearly a millennium, right whales are now being killed by the ocean commerce that supports our modern way of life. This book offers hope for the eventual salvation of this great whale.	North Atlantic right whale		Overview of the biology of North Atlantic right whales, "including their reproduction, feeding, genetics, and endocrinology."				New England Aquarium, MA, USA		

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Tsukrov, I. DeCew, J. C. Baldwin, K. Campbell-Malone, R. Moore, M. J.	Mechanics of the right whale mandible: Full scale testing and finite element analysis	2009	In an effort to better understand the mechanics of ship-whale collision and to reduce the associated mortality of the critically endangered North Atlantic right whale, a comprehensive biomechanical study has been conducted by the Woods Hole Oceanographic Institution and the University of New Hampshire. The goal of the study is to develop a numerical modeling tool to predict the forces and stresses during impact and thereby the resulting mortality risk to whales from ship strikes. Based on post-mortem examinations, jaw fracture was chosen as a fatal endpoint for the whales hit by a vessel. In this paper, we investigate the overall mechanical behavior of a right whale mandible under transverse loading and develop a finite element analysis model of the bone. The equivalent elastic modulus of the cortical component of right whale mandible is found by comparing full-scale bending tests with the results of numerical modeling. The finite element model of the mandible can be used in conjunction with a vessel-whale collision event model to predict bone fracture for various ship strike scenarios.	North Atlantic right whale	"...Predict bone fracture for various ship strike scenarios."	"Develop a numerical modeling tool to predict the forces and stresses during impact and thereby the resulting mortality risk to whales from ship strikes."				UNH/WHOI, MA, USA	https://doi.org/10.1016/j.jembe.2009.03.012	"...an effort to better understand the mechanics of ship-whale collision and to reduce the associated mortality of the critically endangered North Atlantic right whale, the goal of the study is to develop a numerical modeling tool to predict the forces and stresses during impact and thereby the resulting mortality risk to whales from ship strikes."
Chen, T. L. Wise, S. S. Kraus, S. Shaffiey, F. Levine, K. M. Thompson, W. D. Romano, T. O'Hara, T. Wise, J. P.	Particulate Hexavalent Chromium is Cytotoxic and Genotoxic to the North Atlantic Right Whale (Eubalaena glacialis) Lung and Skin Fibroblasts	2009	Hexavalent chromium compounds are present in the atmosphere and oceans and are established mutagens and carcinogens in human and terrestrial mammals. However, the adverse effects of these toxicants in marine mammals are uncertain. Previously, we reported that North Atlantic right whales, one of the most endangered great whales, have tissue chromium levels that are high, levels that may pose a risk to the whale's health. Furthermore, the study suggested that inhalation may be an important exposure route. Exposure to chromium through inhalation is mainly because of particulate compounds. However, the toxicity of particulate chromium compounds in marine mammal cells is unknown. Accordingly, in this study, we tested the cytotoxic and genotoxic effects of particulate hexavalent chromium in primary cultured lung and skin fibroblasts from the endangered North Atlantic right whale. Cytotoxicity was measured by clonogenic survival assay, and genotoxicity was measured as production of chromosome aberrations. Particulate hexavalent chromium induced cytotoxicity and genotoxicity in a concentration-dependent manner in both right whale lung and skin fibroblasts. Lung fibroblasts were more resistant to chromium cytotoxicity, but presented with more chromosome damage than skin fibroblasts. These data further support the hypothesis that chromium may be a health concern for the endangered North Atlantic right whale.	North Atlantic right whale	Cytotoxic and genotoxic effects of particulate hexavalent chromium in primary cultured lung and skin fibroblasts					University of Southern Maine, ME, USA	https://doi.org/10.1002/em.20471	"These data further support the hypothesis that chromium may be a health concern for the endangered north Atlantic right whale."
Chen, T. L. Wise, S. S. Holmes, A. Shaffiey, F. Wise, J. P. Thompson, W. D. Kraus, S. Wise, J. P.	Cytotoxicity and genotoxicity of hexavalent chromium in human and North Atlantic right whale (Eubalaena glacialis) lung cells	2009	Humans and cetaceans are exposed to a wide range of contaminants. In this study, we compared the cytotoxic and genotoxic effects of a metal pollutant, hexavalent chromium [Cr (VI)], which has been shown to cause damage in lung cells from both humans and North Atlantic right whales. Our results show that Cr induces increased cell death and chromosome damage in lung cells from both species with increasing intracellular Cr ion levels. Soluble Cr (VI) induced less of a cytotoxic and genotoxic effect based on administered dose in right whale (Eubalaena glacialis) cells than in human (Homo sapiens) cells. Whereas, particulate Cr(VI) induced a similar cytotoxic effect but less of a genotoxic effect based on administered dose in right whale cells than in human cells. Differences in chromium ion uptake explained soluble chromate-induced cell death but not all of the soluble chromate-induced chromosome damage. Uptake differences of lead ions could explain the differences in particulate chromate-induced toxicity. The data show that both forms of Cr (VI) are less genotoxic to right whale than human lung cells, and that soluble Cr (VI) induces a similar cytotoxic effect in both right whale and human cells, while particulate Cr (VI) is more cytotoxic to right whale lung cells.	North Atlantic right whales and humans	Cytotoxic and genotoxic effects of a metal pollutant, hexavalent chromium [Cr (VI)] on North Atlantic right whale and human tissue.	"...compared the cytotoxic and genotoxic effects of a metal pollutant, hexavalent chromium [Cr (VI)], which has been shown to cause damage in lung cells from both humans and North Atlantic right whales."				University of Southern Maine, ME, USA	https://doi.org/10.1016/j.cbpc.2009.07.004 (full article not available)	
Rosa, Cheryl Blake, John E. Bratton, Gerald R. Dehn, Larissa- A. Gray, Matthew J. O'Hara, Todd M.	Heavy metal and mineral concentrations and their relationship to histopathological findings in the bowhead whale (Balaena mysticetus)	2008	The bowhead whale (Balaena mysticetus) is a species endangered over much of its range that is of great cultural significance and subsistence value to the Inuit of Northern Alaska. This species occupies subarctic and arctic regions presently undergoing significant ecological change and hydrocarbon development. Thus, understanding the health status of the Bering–Chukchi–Beaufort Sea (BCBS) stock of bowhead whales is of importance. In this study, we evaluated the concentrations of six essential and non-essential elements (Zn, tHg, Ag, Se, Cu and Cd) in liver and kidney of bowhead whales (n =64). These tissues were collected from the Inuit subsistence hunt in Barrow, Wainwright and Kaktovik, Alaska between 1983 and 2001. Reference ranges of these elements (including previously reported data from 1983–1997) were developed for this species as part of a health assessment effort, and interpreted using improved aging techniques (aspartic acid racemization and baleen isotopic 13C methods) to evaluate trends over time with increased statistical power. Interactions between element concentrations and age, sex and harvest season were assessed. Age was found to be of highest significance. Sex and harvest season did not effect the concentrations of these elements, with the exception of renal Se levels, which were significantly higher in fall seasons. In addition, histological evaluation of tissues from whales collected between 1998 and 2001 was performed. Associations between concentrations of Cd in kidney and liver and scored histopathological changes were evaluated. Liver Cd concentration was strongly associated with the degree of lung fibromuscular hyperplasia (P =0.001) and moderately associated with the degree of renal fibrosis (P =0.03). Renal Cd concentration influenced the degree of lung fibromuscular hyperplasia and renal fibrosis (P =0.01). A significant age effect was found for both pulmonary fibromuscular hyperplasia and renal fibrosis, indicating age may be a causative factor. Improvements in aging techniques and the addition of histological indices help clarify the relationships between elements and the influence of life history parameters on concentrations of these elements and potential impacts on health. These data provide essential baseline input useful for monitoring the effects of arctic ecosystem change as it relates to global climate change and industrial development, as well as help inform epidemiological studies examining the public health implications of heavy metals in subsistence foods.	Bowhead whale	Concentrations of six essential and non-essential elements (Zn, tHg, Ag, Se, Cu and Cd) in liver and kidney	Reference ranges of these elements were developed and interpreted using improved aging techniques	Tissues for chemical analysis were collected during Inuit subsistence hunts.	1983 - 2001	These tissues were collected from the Inuit subsistence hunt in Barrow, Wainwright and Kaktovik, Alaska.	University of Alaska Fairbanks, AK, USA	https://doi.org/10.1016/j.scitotenv.2008.01.062	"These data provide essential baseline input useful for monitoring the effects of arctic ecosystem change as it relates to global climate change and industrial development, as well as help inform epidemiological studies examining the public health implications of heavy metals in subsistence foods."
Gulland, F.Nutter, F.B.Dixon, K.Calambokidis, J.Schorr, G.Barlow, J.Rowles, T.Wilkin, S.Spradlin, T.Gage, L.Mulsow, J.Reichmuth, C.Moore, M.Smith, J.Folkens, P.Hanser, S.F.Jang, S.Baker, C. S	Health Assessment, Antibiotic Treatment, and Behavioral Responses to Herding Efforts of a Cow-Calf Pair of Humpback Whales (Megaptera novaeangliae) in the Sacramento River Delta, California	2008	A mother and female calf humpback whale (Megaptera novaeangliae) pair were observed at an atypical location, 72 nmi inland in the Port of Sacramento, California, on 16 May 2007. Sequencing of mtDNA from a skin biopsy showed the cow to be an E1 haplotype, which is common in the California feeding population. Both animals had lacerations, suggesting sharp trauma from a boat strike. Photographs taken over 11 d showed generalized deterioration of skin condition and necrotic wound edges. Behavioral responses were recorded during attempts to move the animals downriver to the Pacific Ocean. The attempts included playback of alarm tones, humpback and killer whale sounds, banging hollow steel pipes ("Oikami pipes"), spraying water from fire hoses on the water surface, and utilizing tug and power boat engine noise and movement. None of these deterrents resulted in significant, consistent downstream movement by the whales. Antibiotic therapy (ceftiofur) was administered by a dart, representing the first reported antibiotic treatment of free-ranging live whales. After 11 d, the animals swam downstream from fresh water at Rio Vista to brackish water, and their skin condition noticeably improved 24 h later. The animals followed the deep-water channel through the Sacramento Delta and San Francisco Bay, reaching the ocean at least 20 d after first entering the Sacramento River.	Humpback whales (mother and calf)	Behavioral responses to herding attempts and use of antibiotic therapy; skin condition in fresh water and brackish water.	Health Assessment, Antibiotic Treatment, and Behavioral Responses to Herding Efforts of a Cow-Calf Pair	Multiple	2007	72 nmi inland in the Port of Sacramento, California	The Marine Mammal Center, CA, USA	http://www.cascadiaresearch.org/publications/health-assessment-antibiotic-treatment-and-behavioral-responses-herding-efforts-cow	"...management of similar events in the future should focus on protection of the animals from disturbance and ship strikes, rather than attempting to herd them. The whale(s) should be allowed time to explore their habitat and discover exit routes without efforts to drive them out...." Regular observations using high resolution photography should be used to monitor skin integrity, and the use of satellite telemetry (without compromising the health of the animal) would be useful for long-term monitoring."

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Campbell-Malone, Regina Barco, Susan G. Daoust, Pierre-Yves Knowlton, Amy R. McLellan, William A. Rotstein, David S. Moore, Michael J.	Gross and Histologic Evidence of Sharp and Blunt Trauma in North Atlantic Right Whales (Eubalaena glacialis) Killed by Vessels	2008	Vessel-whale collision events represented the ultimate cause of death for 21 (52.5%) of the 40 North Atlantic right whales (Eubalaena glacialis) necropsied between 1970 and December 2006. Injuries seen in vessel-struck whales fall into two distinct categories: 1) sharp trauma, often resulting from contact with the propeller, and 2) blunt trauma, presumably resulting from contact with a vessel's hull. This study analyzes four trauma cases that resulted from vessel-whale collisions, which together provide a framework for a more critical understanding of lethal blunt and sharp trauma resulting from vessel collisions with right whales. In case no. 1, contact with a propeller resulted in three deep lacerations. The animal survived acute trauma only to succumb nearly 14 years later when the lesions reopened and became infected. In case no. 2, anecdotal reports linked the laceration of large arteries of the peduncle and histologic evidence of perimortem trauma at a bone fracture site to vessel-whale collision trauma. Case no. 3 had a laceration of the oral rete and a fracture of the rostrum. Both of the areas displayed histologic evidence of perimortem blunt trauma. Finally, in case no. 4, an antemortem mandibular fracture, two additional skull fractures, and widespread hemorrhage were consistent with severe blunt trauma. Evidence from each case, including the timing of trauma relative to the time of death and identifying characteristics of both trauma types, are presented. Before this study, no detailed comparative analysis of trauma pathology that resulted from lethal interactions between vessels and right whales had been conducted. This study demonstrates the importance of detailed gross and histologic examination in determining the significance and timing of traumatic events. This work represents a new paradigm for the differential diagnosis of lethal sharp and blunt trauma in right whales hit by ships and will enhance the present understanding of the impact of anthropogenic mortality on this critically endangered species.	North Atlantic right whale	Gross and Histologic Evidence of Sharp and Blunt Trauma in North Atlantic Right Whales (Eubalaena glacialis) Killed by Vessels	Detailed gross and histologic examination determined the significance and timing of traumatic events.		2003-2005		WHOI, MA, USA	https://doi.org/10.1638/2006-0057.1	"The aforementioned studies, along with data obtained from future necropsies and the appropriate characterization of trauma findings will continue to inform ongoing efforts to reduce vessel-whale collision mortalities."
Burek, Kathy A. Gulland, Frances M. D. O'Hara, Todd M.	Effects of climate change on arctic marine mammal health	2008	The lack of integrated long-term data on health, diseases, and toxicant effects in Arctic marine mammals severely limits our ability to predict the effects of climate change on marine mammal health. The overall health of an individual animal is the result of complex interactions among immune status, body condition, pathogens and their pathogenicity, toxicant exposure, and the various environmental conditions that interact with these factors. Climate change could affect these interactions in several ways. There may be direct effects of loss of the sea ice habitat, elevations of water and air temperature, and increased occurrence of severe weather. Some of the indirect effects of climate change on animal health will likely include alterations in pathogen transmission due to a variety of factors, effects on body condition due to shifts in the prey base/food web, changes in toxicant exposures, and factors associated with increased human habitation in the Arctic (e.g., chemical and pathogen pollution in the runoff due to human and domestic-animal wastes and chemicals and increased ship traffic with the attendant increased risks of ship strike, oil spills, ballast pollution, and possibly acoustic injury). The extent to which climate change will impact marine mammal health will also vary among species, with some species more sensitive to these factors than others. Baseline data on marine mammal health parameters along with matched data on the population and climate change trends are needed to document these changes.	Marine mammals and humans in the Arctic	The extent to which climate change will impact marine mammal health (indirect effects include alternations in pathogen transmission, effects on body condition, changes in toxicant exposures, and other factors associated with increased human habitation in the Arctic).	Baseline data on marine mammal health parameters along with matched data on the population and climate change trends.				Alaska Veterinary Pathology Services, AK, USA	https://doi.org/10.1890/06-0553.1	"It would be optimal for the veterinary, native, and human health communities to work together to monitor these diseases, contaminants, and marine mammals, structuring these studies to use marine mammals as sentinels for human as well as marine mammal and ecosystem health (Bradley et al. 2005, Rabinowitz et al. 2005)."
Rosa, Cheryl O'Hara, Todd M. Hoekstra, Paul F. Refsal, Kent R. Blake, John E.	Serum thyroid hormone concentrations and thyroid histomorphology as biomarkers in bowhead whales (Balaena mysticetus)	2007	Serum thyroid hormone (TH) concentrations have been used alone or with other measurements to assess health status or effects of toxicant exposure in marine mammals. Histological sections from thyroid glands of the bowhead whale (Balaena mysticetus L., 1758) were examined in conjunction with serological TH analyses. Serum was assayed for total and free triiodothyronine and total and free thyroxine via radioimmunoassay. Histomorphology of thyroid tissue was assessed by light microscopy and the utilization of an epithelial-follicular index (EFI). Age, sex, or season did not significantly affect serum TH levels. However, TH concentrations in pregnant or lactating females were found to be significantly lower than in the other sex and reproductive groups investigated. The EFI and epithelial height (EH) were greater in spring subadult and adult whales compared with those that were landed in the fall. No correlation was found between serum TH concentrations and serum, blubber, or liver levels of select polychlorinated biphenyl metabolites and organochlorine congeners examined. Low variability in concentrations of the serum THs across age, season, and sex and reproductive groups supports the existence of strong homeostatic mechanisms for maintaining TH concentrations in these presumably healthy animals. Departures from these ranges may indicate a disturbance in these regulatory mechanisms and may be a useful indication of toxicity or other health disorders.	Bowhead whale	Health status or effects of toxicant exposure in marine mammals	Serum thyroid hormone concentrations and thyroid histomorphology as biomarkers in bowhead whales (Balaena mysticetus)	Inuit subsistence harvest	1998-2002	Barrow, Alaska	University of Alaska Fairbanks, AK, USA	https://doi.org/10.1139/Z07-035	"It is important for additional data to be gathered, as this will add to our knowledge of TH dynamics and to the value of these hormones as biomarkers, not only of contaminants, but of ongoing (offshore industrial activities) and emerging (climate change) potential stressors."
Hunt, K. E. Rolland, R. A. Kraus, S. D. Wasser, S. K.	Analysis of fecal glucocorticoids in the North Atlantic right whale (Eubalaena glacialis)	2006	Very little is known about the endocrinology of the baleen whales. The highly endangered North Atlantic right whale (NARW; Eubalaena glacialis) is a good model species, because most NARW individuals are photo-identified with known histories. We used a 1 251 corticosterone assay, shown to reliably measure cortisol metabolites, to determine glucocorticoid metabolite concentrations in 177 NARW fecal samples collected between 1999 and 2004 in the Bay of Fundy, Canada. Fecal glucocorticoid metabolite concentrations varied significantly with sex and reproductive category, being highest in pregnant females (mean +/- SE: 238.14 +/- 74.37 ng/g) and mature males (71.6 +/- 11.36), intermediate in lactating females (39.33 +/- 5.82), and lower in non-reproducing females (23.11 +/- 4.25) and immature males (34.33 +/- 5.01) and females (14.0 +/- 0.41). One case also suggests that glucocorticoids rise markedly in response to severe entanglement in fishing lines. Whales with fecal glucocorticoid content over 100 ng/g (termed "high-cort" samples) were rare, and included most pregnant females, some mature males, a fatally entangled whale, and several very young animals. Glucocorticoid concentrations were highly correlated with androgen concentrations in males and pregnant females. We analyzed the elution profiles of glucocorticoid and androgen metabolites in 13 samples with high-performance liquid chromatography (HPLC) to determine the extent to which androgen metabolites cross-react with our glucocorticoid assay. Males, pregnant females, non-pregnant females, and "high-cort" whales each had distinctly different immunoreactive HPLC profiles of glucocorticoid and androgen metabolites. A major glucocorticoid metabolite was prominent in all "high-cort" whales including the fatally entangled whale. The major fecal androgen was not testosterone but was instead a more nonpolar steroid (possibly dihydrotestosterone), which may be diagnostic of males. Androgen metabolites showed only minor cross-reactivity to our glucocorticoid assay, having a slight influence on glucocorticoid results in particular individuals. We conclude that fecal glucocorticoid analysis appears to be a useful measure of adrenal activity and reproductive condition for NARW.	North Atlantic right whale	Measure of adrenal activity and reproductive condition	Fecal glucocorticoid analysis	Shipboard photo-identification surveys/detection dogs	July-September 1999-2004	Bay of Fundy	University of Washington, WA, USA	Not available	"Fecal glucocorticoid analysis appears useful for identifying a variety of stressors and discriminating diVerent reproductive and health categories of NARW. In addition, this study illustrates that HPLC can be a useful technique for interpreting fecal hormone results in baleen whales."

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Rolland, Rosalind M. Hunt, Kathleen E. Kraus, Scott D. Wasser, Samuel K.	Assessing reproductive status of right whales (Eubalaena glacialis) using fecal hormone metabolites	2005	Long-term studies of the endangered North Atlantic right whale, Eubalaena glacialis, have revealed declining reproductive parameters over the past two decades, threatening recovery of this small population if current trends continue. Little is known about right whale reproductive physiology, and investigating this reproductive decline has been limited by a lack of non-lethal methods for assessing reproductive status (e.g., sexual maturation, ovarian activity, pregnancy, lactation, and reproductive senescence) in free-swimming whales. This paper describes validation of existing radioimmunoassay techniques to study reproduction in right whales by measuring estrogens, progestins, androgens, and their related metabolites in fecal samples. Over the past decade, fecal steroid hormone assays have been used to assess reproductive status and function in a wide range of terrestrial wildlife species, but this is the first application of this methodology in wild cetaceans. Analysis of fecal hormone metabolite levels in combination with life history data from photographically identified whales shows that this non-invasive method can be used to determine gender, detect pregnancy and lactation, and to assess age at sexual maturity in right whales and potentially other endangered whale populations.	North Atlantic right whale	Reproductive status ("gender, detect pregnancy and lactation, and to assess age at sexual maturity in right whales and potentially other endangered whale populations")	Fecal hormone metabolites analysis	Shipboard photo-identification surveys	July - September 1999-2002	Bay of Fundy, Canada	New England Aquarium, MA, USA	https://doi.org/10.1016/j.ygcen.2005.02.002	"Because demographic models depend upon an accurate knowledge of reproductive parameters (e.g., age of sexual maturity and pregnancy rates), this technique may ultimately provide better information for assessment of population dynamics and management of right whales, and may also be applicable to the management of other endangered whales."
Wells, Randall S. Rhinehart, Howard L. Hansen, Larry J. Sweeney, Jay C. Townsend, Forrest I. Stone, Rae Casper, David R. Scott, Michael D. Hohn, Aleta A. Rowles, Teri K.	Bottlenose Dolphins as Marine Ecosystem Sentinels: Developing a Health Monitoring System	2004	Bottlenose dolphins (Tursiops truncatus), as long-lived, long-term residents of bays, sounds, and estuaries, can serve as important sentinels of the health of coastal marine ecosystems. As top-level predators on a wide variety of fishes and squids, they concentrate contaminants through bioaccumulation and integrate broadly across the ecosystem in terms of exposure to environmental impacts. A series of recent large-scale bottlenose dolphin mortality events prompted an effort to develop a proactive approach to evaluating risks by monitoring living dolphin populations rather than waiting for large numbers of carcasses to wash up on the beach. A team of marine mammal veterinarians and biologists worked together to develop an objective, quantitative, replicable means of scoring the health of dolphins, based on comparison of 19 clinically diagnostic blood parameters to normal baseline values. Though the scoring system appears to roughly reflect dolphin health, its general applicability is hampered by interlaboratory variability, a lack of independence between some of the variables, and the possible effects of weighting variables. High score variance seems to indicate that the approach may lack the sensitivity to identify trends over time at the population level. Potential solutions to this problem include adding or replacing health parameters, incorporating only the most sensitive measures, and supplementing these with additional measures of health, body condition, contaminant loads, or biomarkers of contaminants or their effects that can also be replicated from site to site. Other quantitative approaches are also being explored.	Bottlenose dolphins	Marine Ecosystem Sentinels (" concentrate contaminants through bioaccumulation and integrate broadly across the ecosystem in terms of exposure to environmental impacts")	Bottlenose Dolphins (Developing a health monitoring system - comparison of 19 clinically diagnostic blood parameters to normal baseline values)	Captured for examination and sampling by encircling them in shallow waters; handlers can safely support dolphins as necessary	?	Sarasota Bay, FL	Sarasota Dolphin Research Program, Chicago Zoological Society, c/o Mote Marine Laboratory, FL, USA	https://doi.org/10.1007/s10393-004-0094-6	
Pettis, Heather M. Rolland, Rosalind M. Hamilton, Philip K. Brault, Solange Knowlton, Amy R. Kraus, Scott D.	Visual health assessment of North Atlantic right whales (Eubalaena glacialis) using photographs	2004	Although trends in reproduction, mortality, and entanglement events have been analyzed for the endangered North Atlantic right whale (Eubalaena glacialis) population, no method has been available to assess individual right whale health. Here, we describe a technique for assessing health based on evaluation of selected physical parameters from archived photographs of right whales. A scoring system was developed to assess body and skin condition, blowhole cyamids, and rake marks in over 200 000 photographs. Comparison of body condition scores of females during calving and noncalving years found that females were significantly thinner in calving years and in the year after calving compared with the year before calving, showing that changes in body condition known to occur during the reproductive cycle can be successfully evaluated from photographs. Comparison of scores for all parameters between living whales and whales with more than a 5-year gap in sighting history ("presumed dead") found that presumed dead whales received health assessment scores indicating compromised health with body condition emerging as a key visual indicator. This health assessment method provides a new tool to monitor health trends in right whales at individual and population levels and may provide a model for assessments of other well-photographed cetaceans.	North Atlantic right whale	Individual right whale health (" body and skin condition, blowhole cyamids, and rake marks ")	Visual health assessment using photographs/scoring system	vessels and aircrafts	1935-2000	NARW habitats	New England Aquarium, MA, USA	https://doi.org/10.1139/z03-207	"This health assessment method provides a new tool to monitor health trends in right whales at individual and population levels and may provide a model for assessments of other well-photographed cetaceans."
Moore, M. J., Knowlton, A. R., Kraus, S. D., McLellan, W. A., and Bonde, R. K.	Morphometry, gross morphology and available histopathology in North Atlantic right whale (Eubalaena glacialis) mortalities (1970-2002)	2004	Fifty-four right whale mortalities have been reported from between Florida, USA and the Canadian Maritimes from 1970 to 2002. Thirty of those animals were examined: 18 adults and juveniles, and 12 calves. Morphometric data are presented such that prediction of body weight is possible if the age, or one or more measurements are known. Calves grew approximately linearly in their first year. Total length and fluke width increased asymptotically to a plateau with age, weight increased linearly with age, weight and snout to blowhole distance increased exponentially with total length, whereas total length was linearly related to fluke width and flipper length. Among the adults and juveniles examined in this study, human interaction appeared to be a major cause of mortality, where in 14/18 necropsies, trauma was a significant finding. In 10/14 of these, the cause of the trauma was presumed to be vessel collision. Entanglement in fishing gear accounted for the remaining four cases. Trauma was also present in 4/12 calves. In the majority of calf mortalities (8/12) the cause of death was not determined. Sharp ship trauma included propeller lacerations inducing multiple, deep lacerations that often incised vital organs including the brain, spinal cord, major airways, vessels and musculature. Blunt ship trauma resulted in major internal bruising and fractures often without any obvious external damage. In at least two cases fatal gear entanglements were extremely protracted: where the entanglements took at least 100 and 163 days respectively to be finally lethal. The sum of these findings show two major needs: (1) that extinction avoidance management strategies focused on reducing trauma to right whales from ship collisions and fishing gear entanglement are highly appropriate and need to be continued and; (2) that as mitigation measures continue to be introduced into shipping and fishing industry practices, there is a strong effort to maximize the diagnostic quality of post-mortem examination of right whale mortalities, to ensure an optimal understanding of resultant trends.	North Atlantic right whales				1970-2002		WHOI, MA, USA		

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Perryman, Wayne L.Lynn, Morgan S.	Evaluation of nutritive condition and reproductive status of migrating gray whales (Eschrichtius robustus) based on analysis of photogrammetric data	2002	Vertical aerial photographs were collected of gray whales migrating along the California Coast between 1994 and 1998 to readdress some published findings on the biology and life history of this population based on examination of specimens. For each whale, an attempt was made to measure standard total length, the width of the whale at its widest point, the distance from the tip of the rostrum to the widest point, and the width of the flukes. For southbound gray whales, early migrants were longer on average and more likely to be parturient than those migrating later. Near-term pregnant females were wider relative to their length than other southbound gray whales. This difference was easily detected by visual inspection of the images and through statistical evaluation of length and width data. There was 100% agreement between identification of parturient females based on linear regression analysis of length and width and discriminate analysis of all measurements. Based on the proportion of parturient females to those with calves during sampling of southbound whales, the median calving date was estimated to be 13 January. Southbound calves averaged 4.6m in length; those photographed northbound in late April, at an age of about three months, averaged 7.1m. Average length for yearlings, based on combined southbound and northbound data, was 8.5m. Residuals from a regression of width on length were compared, and significant changes in the relationship were detected which were consistent with changes in nutritive condition or fatness described from examination of whales taken along the California Coast between 1959 and 1969 (Rice and Wolman, 1971). Parturient females were the widest relative to their length and northbound cows with calves were the narrowest in the sample. The relationship between length and width for migrating gray whales that were not parturient or associated with a calf, showed that southbound gray whales were significantly wider than northbound whales photographed approximately 60 days later. These results indicate that the predictable but relatively small changes in condition or fatness of gray whales associated with fasting during their winter migration can be reliably detected in measurements from vertical aerial photographs.	Gray whales	Nutritive condition and reproductive status of migrating gray whales	Photogrammetric data	Aerial	1994-1998	California coast	Southwest Fisheries Science Center, CA, USA	https://swfsc.noaa.gov/uploadedFiles/Divisions/PRD/Programs/Photogrammetry/Perryman_and_Lynn_2002_Gray_Whale_JCRM.pdf	"These results indicate that the predictable but relatively small changes in condition or fatness of gray whales associated with fasting during their winter migration can be reliably detected in measurements from vertical aerial photographs."
Aguirre, A. Alonso Reif, John S. Antonelis, George A.	Hawaiian Monk Seal Epidemiology Plan: health assessment and disease status studies	1999	The Hawaiian monk seal (Monachus schauinslandi) is one of the most endangered marine mammals in the world. Populations of Hawaiian monk seals have shown a decline in recent years, which has placed the species in threat of extinction. Understanding the potential role of disease and toxins is a high priority. Several natural sources of mortality have been identified or suggested (e.g., ciguatera poisoning, starvation, shark predation, trauma/mobbing, and disease), but the relative significance of these factors and their effect on population trends are poorly understood. Efforts to enhance the recovery of the Hawaiian monk seal will require a better understanding of the health and disease status of the wild population. Thus, health and disease impacts on the population merit a cohesive, well-supported effort to mitigate potential effects. The Epidemiology Plan was developed to prioritize and implement projects regarding health and disease for the Hawaiian monk seal. As a fundamental component of the research and recovery activities conducted by the Marine Mammal Research Program (MMRP), Protected Species Investigation, National Marine Fisheries Service, Honolulu Laboratory, the Epidemiology Plan incorporates specific strategies under the broad heading of health and disease intended to enhance recovery and prevent further decline of the species. In developing this plan, consideration was given to priorities assigned to specific research tasks outlined in the Recovery Plan for the Hawaiian Monk Seal, Monachus Schauinslandi and the recommendations of the Hawaiian Monk Seal Recovery Team (HMSRT) at its annual meetings. The eventual intent is to develop a long-term plan for addressing various health and disease projects that address management and recovery of the species. For example, disease surveillance, the health and disease aspects of translocation efforts, and the development of contingency plans for unusual mortality and exposure to anthropogenic contaminants, spills, biotoxins, or natural disasters are considered. A component of the plan includes ongoing, prospective health assessment of monk seal subpopulations to monitor temporal changes in health status and to determine the effect on population abundance and reproductive success.	Hawaiian monk seal	"developed to prioritize and implement projects regarding health and disease for the Hawaiian monk seal."	Epidemiology Plan	NA			PIFSC, HI, USA	https://repository.library.noaa.gov/view/noaa/3091	"The eventual intent is to develop a long-term plan for addressing various health and disease projects that address management and recovery of the species. For example, disease surveillance, the health and disease aspects of translocation efforts, and the development of contingency plans for unusual mortality and exposure to anthropogenic contaminants, spills, biotoxins, or natural disasters are considered."
Trites, A. W. Pauly, D.	Estimating mean body masses of marine mammals from maximum body lengths	1998	Generalized survival models were applied to growth curves published for 17 species of cetaceans (5 mysticetes, 12 odontocetes) and 13 species of pinnipeds (1 odobenid, 4 otariids, 8 phocids). The mean mass of all individuals in the population was calculated and plotted against the maximum body length reported for each species. The data showed strong linearity (on logarithmic scales), with three distinct clusters of points corresponding to the mysticetes (baleen whales), odontocetes (toothed whales), and pinnipeds (seals, sea lions, and walruses). Exceptions to this pattern were the sperm whales, which appeared to be more closely related to the mysticetes than to the odontocetes. Regression equations were applied to the maximum lengths reported for 76 species of marine mammals without published growth curves. Estimates of mean body mass were thus derived for 106 living species of marine mammals.	(5 mysticetes, 12 odontocetes) and 13 species of pinnipeds (1 odobenid, 4 otariids, 8 phocids	Estimates of mean body mass derived	Generalized survival models were applied to growth curves published for 17 species of cetaceans)	NA			Univ British Columbia, BC Canada	https://doi.org/10.1139/cjz-76-5-886	"Plotting other attributes of marine mammals (related to their morphology, population dynamics, or physiology) against maximum length should generally lead to plots as tight as those we found. Such plots and the various interrelationships they imply should lead to a deeper understanding of the adaptations and evolution of marine mammals,"
	Pacific Marine Mammal Health Assessments (PMMHA)	Updated 2018	Pacific Marine Mammal Health Assessments (PMMHA), which began in Fall 2010, are an expansion of NIST marine mammal health assessment collaborations that began in 2002 with bottlenose dolphin wild populations. NIST has a history of involvement in marine mammal health assessment related work sponsored by NOAA National Marine Fishery Service, Sarasota Dolphin Research Program, and Dolphin Quest including, (1) support for the banking of marine mammal tissues in the Marine Environmental Specimen Bank (ESB), (2) designing standardized sample collection protocols, (3) providing technical assistance in the field, (4) development of standard reference and control materials (SRMs), (5) implementation of inter-laboratory comparison exercises using marine mammal tissues, and (6) analyzing samples for trace elements and organic pollutants. PMMHA samples that are archived in the Marine ESB are collected and processed according to detailed standardized protocols, which makes Marine ESB samples specifically useful for analytical analysis of organic contaminants, trace elements, and other chemical analytes. Since the Marine ESB is a long-term storage repository, PMMHA samples are available for research questions involving emerging contaminants or health concerns that arise in the future.		Activities: "Bottlenose Dolphins Under Human Care Health Assessment; Hawaiian Monk Seal Health and Disease Studies; Hawaiian Cetacean Dart Biopsy Archival; and Chemical Analysis Hawaiian Monk Seal Rehabilitation"	Goals: "Develop standardized methods and protocols for collecting, processing, and archiving samples obtained from live animals and teach collaborating researchers' protocols. Assess environmental and anthropogenic stressors along with metabolic changes that may impact health of individuals and U.S. Pacific Islands marine mammal populations."					https://www.nist.gov/programs-projects/pacific-marine-mammal-health-assessments-pmmha	
	Consortium for Advanced Research on Marine Mammal Health Assessment (CARMMHA)		The goal of this consortium is to address several of the most important scientific questions that have emerged but remain unanswered with respect to overall physiological impacts of the DWH oil spill in cetaceans, and then to synthesize that information, along with new information that has been collected since prior GoMRI and NRDA studies were ended, to model the current condition and future recovery timelines for key populations.			"CARMMHA is a team of marine mammal health scientists conducting cross-discipline research that includes veterinary assessments of managed animals, field assessments with wild populations, and integrative statistical modeling to understand how the DWH oil spill					https://www.carmmha.org/	

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						affected Gulf of Mexico marine mammal health."						
	North Atlantic Right Whale Consortium (NARWC)		Started in 1986 as a collaborative data sharing group, the North Atlantic Right Whale Consortium (NARWC) has grown to include more than 200 individuals from various research and conservation organizations, shipping and fishing industries, technical experts, U.S. and Canadian government agencies, and state and provincial authorities, all of whom are dedicated to the conservation and recovery of the North Atlantic right whale. The Consortium is internationally recognized and has been identified as a model for establishing other species-related consortia.			"Started in 1986 as a collaborative data sharing group, the North Atlantic Right Whale Consortium (NARWC) has grown to include more than 200 individuals from various research and conservation organizations, shipping and fishing industries, technical experts, U.S. and Canadian government agencies, and state and provincial authorities, all of whom are dedicated to the conservation and recovery of the North Atlantic right whale. The Consortium is internationally recognized and has been identified as a model for establishing other species-related consortia."					https://www.narwc.org/	

Appendix F: Distilled Tool Matrix

Purpose/Health indicator for...	Data/tissue collected	Method/Tool	Platform	Operational?
Abundance, distribution	Photographs	Photograph	Vessel, aerial (plane or UAS)	Yes
Abundance, distribution	Images	Satellite imagery	Remote	No
Behavior (Biomechanics, body condition, foraging rate and depth, risk exposure, habitat use, bioenergetics, costs of entanglement)	Movement, depth, biomechanics (thrust/power), diving behavior, speed, foraging, sound production, acoustic exposure, relative body density, ventilation, blubber, prey, position through time; Skin (opportunistic)	Tagging	Vessel	Yes, short attachment times
Bioenergetics model (body condition)	Blubber	Biopsy	Vessel, necropsy	Yes
Bioenergetics, wound healing, lesion characterization; open blowhole core temperature; detection of whale blow for ship avoidance (near field)	Photographs (Skin surface temperature)	Thermal IR camera	Vessel, aerial (plane or UAS)	Experimental
Body condition-qualitative, skin condition, rake marks, cyamid loads, lesions, life history), survival, fecundity, photo-id ("Visual Health Assessment")	Photographs	Photograph	Vessel, aerial (plane or UAS), necropsy	Yes
Body condition-quantitative, length: width ratios	Orthogonal planar photographs, altitude	UAS (planar, vertical images)	Vessel	Yes
Contaminants, POPs, plasticizers-microplastics, macroplastics	Blubber (Lipidome, lipid content) (quality/quantity)	Biopsy	Vessel, necropsy	Yes
Contaminants, POPs, plasticizers-microplastics, macroplastics	Skin	Biopsy	Vessel, necropsy	Yes
Contaminants, POPs, plasticizers-microplastics, macroplastics; Biotoxins (HABs)	Feces	Net collection	Vessel, necropsy	Yes
Cytology (Inflammation, parasites)	Respiratory vapor	UAS or pole	Vessel, necropsy	Yes
Distribution, individual identification/life history (photo-id), body condition	Photographs	Citizen science	Vessel (cruise ships, recreational boaters, etc.)	Yes
Genetics (Sex, genotype, paternity, etc.)	Blubber	Biopsy	Vessel, necropsy	Yes
Genetics (Sex, genotype, paternity, etc.)	Skin	Biopsy	Vessel, necropsy	Yes

Purpose/Health indicator for...	Data/tissue collected	Method/Tool	Platform	Operational?
Hormones (Reproduction, sex, relative "stress responses," metabolism/energetics, thermoregulatory stressors, chronic stress)	Baleen	Necropsy	Necropsy	Yes
Hormones (Reproduction, sex, relative "stress responses," metabolism/energetics, thermoregulatory stressors, chronic stress)	Blood	New tag for blood collection	Vessel, necropsy	No (tag under development)
Hormones (Reproduction, sex, relative "stress responses," metabolism/energetics, thermoregulatory stressors, chronic stress)	Blubber (Lipidome, lipid content) (quality/quantity)	Biopsy	Vessel, necropsy	Yes
Hormones (Reproduction, sex, relative "stress responses," metabolism/energetics, thermoregulatory stressors, chronic stress)	Respiratory vapor	UAS or pole	Vessel	Yes
Hormones (Reproduction, sex, relative "stress responses," metabolism/energetics, thermoregulatory stressors, chronic stress)	Feces	Net collection	Vessel, necropsy	Yes
Injury state (*e.g.*, wounds, entanglement)	Photographs	Photograph	Vessel, aerial (plane or UAS), necropsy	Yes
Microbiome (Condition, pathogens)	Respiratory vapor	UAS or pole	Vessel, necropsy	Yes
Microbiome (Omics)	Skin	Biopsy	Vessel, necropsy	Yes
Microbiome (Omics)	Feces	Net collection	Vessel, necropsy	Yes
Nutrition (stable isotopes - food shifts, body condition)	Blubber	Biopsy	Vessel, necropsy	Yes
Nutrition (stable isotopes - food shifts, body condition)	Skin	Biopsy	Vessel, necropsy	Yes
Nutrition (stable isotopes - food shifts, body condition)	Muscle	Biopsy	Vessel, necropsy	Yes
Nutrition (stable isotopes - food shifts, body condition)	Baleen	Necropsy	Necropsy	Yes
Nutrition (stable isotopes - food shifts, body condition)	Blood/lipidome - lipid content (quality/quantity)	New tag for blood collection	Vessel, necropsy	No (tag under development)
Nutrition (stable isotopes - food shifts, body condition)	Feces	Net collection	Vessel, necropsy	Yes
Pathogens (Microbial/viral/fungal)	Skin	Biopsy	Vessel, necropsy	Yes
Pathogens (Microbial/viral/fungal)	Respiratory vapor	UAS or pole	Vessel	Yes
Pathogens (Microbial/viral/fungal)	Feces	Net collection	Vessel, necropsy	Yes
Skin lesions (Skin health and condition)	Skin	Biopsy	Vessel, necropsy	Yes
Skin lesions (Skin health and condition)	Photographs	Photograph	Vessel, aerial (plane or UAS), necropsy	Yes

Appendix G: North Atlantic Right Whale Necropsy Sampling and Data Tool Subgroup Discussion

(*Implies transboundary sample collection protocols and materials are consistent, ready and funded)*

Overall Needs/Next Steps (in priority order)

1) Establish a triage plan for at sea sampling, towing, necropsy, & disposal for NARW, including identification of potential funding sources
2) Establish transboundary necropsy case review committee [all necropsy team leads (NTLs), apprentice NTLs, Canadian counterparts, etc.]
3) Inventory what necropsy samples are currently available and where they are located by querying the current necropsy database/necropsy reports and tracking down any gaps (may require support)
4) Hold a NARW sampling workshop to develop a transboundary comprehensive plan for NARW sample collection and management
    - Establish a sample archive plan
    - Identify sample collection and analysis priorities (and potential sources of funding/researchers for collaboration)
        - Contaminant analysis? -omics? Baleen
    - Standardize sample collection protocols, with input from researchers (sample type, size, collection methods, and storage, especially for -omics, hormones, and microbiome)
        - Create a standardized sample collection list (including all prioritized researcher requests)
        - Identify funding sources for sampling materials and storage
    - Decide if more comprehensive lung and reproductive (other systems?) pathology workup (looking at existing necropsy reports, histo slides, and other samples) is worthwhile, and identify funding if so
    - Identify import/export permit issues and discuss possible solutions, including the potential of a US-based genetic identification (ID) database to avoid delays in obtaining ID due to export

    5) Add hindcast/forecast standard operating procedures for all NARWs
    6) Train the next generation of NTLs in various locations in USA & Canada
        - Identify additional trainees in strategic locations
        - Fund travel for trainees (NTLs and pathologists) to participate in NARW necropsies (& other training opportunities)

    7) Develop (or adapt) a comprehensive database to better track NARW necropsy data and samples with remote data entry capabilities and links to other NARW databases (similar to that being created for Southern resident killer whales, SRKW)
        - Current database is not cloud-based (MS Access), is limited in its ability to track samples and does not link to other NARW databases (DBs)
        - A major DB redesign would require funding for software development and personnel time (data migration and entry)
        - Adapting the SRKW database (if possible) would require less funding for software development, but still funds for personnel time
        - Provide access for NTLs to life history data prior to necropsy through database links to key data (reproductive history, tagging history, lesions noted during live sightings)

Priorities for Sampling at Sea (in draft priority order, to be finalized at proposed sampling workshop)

General guideline is to sample from the outside inwards, without opening body cavities if planning to later tow; this is an ideal list with understanding that human safety and logistical limitations may prevent collection of these samples.

1) Extensive photo documentation, including underwater video/stills (trauma, skin lesions, +/- body condition); collect gear (if entangled) prior to towing if concerned over loss
2) Morphometrics including length, girths, weight (body condition, growth curves) – link data with photogrammetry
3) Skin – genetics, omics, microbiome, stable isotopes
4) Blowhole swabs - (if fresh) to standardize live blow samples
5) Skin lesions – for histopathology, frozen for PCR if non-traumatic
6) Muscle lesions - for histopathology (supravital response in washout regions)
7) Bone (from flipper) – genetics (likely better than skin for more decomposed whales)
8) Blubber – hormones, contaminants, stable isotopes, lipidome, lipid quality, bioenergetics Blubber thicknesses, girth, width at photogrammetry sites
9) Feces – hormones, biotoxins, microbiome (with environmental sample as control if floating), pathogens
10) Baleen – hormones (repro, stress, isotopes)
11) Vitreous humor – potassium, urea, HABS
12) Conjunctival swab – mycoplasma, viral, etc.
13) Liver sample (if fresh) – metabolomics to look for inflammation (contaminants)

Additional samples to prioritize at Necropsy (in draft priority order - to be finalized at proposed sampling workshop)

McLellan 2004 necropsy protocol is comprehensive, with a general plan to sample as many viable tissues as possible in each whale. Below are samples to be taken at necropsy that are in addition to the above and in addition to those outlined in the McLellan protocol (or an emphasis thereof).

1) Lung pathology (histopathology, culture, swabs, frozen): standardize how we look at and characterize the lungs grossly (% affected lung or lung scoring paradigm) and how we sample for histopathology and other diagnostics
2) Reproductive organs (ovaries, testes, fetus/placenta/amniotic fluid, uterus): sample for histo and frozen; need to standardize protocol for ovary examination and sampling, merge necropsy data with life history data to better interpret findings; include reproductive disease sampling for pathogens of concern
3) Gas from bronchi of euthanized whales: to standardize live animal blow sampling
4) Ear wax plug (when present)– endocrine, contaminants, isotopes, aging
5) Adrenal glands (when present) – chronic stress
6) Stomach contents (when present) - for microplastics and prey analyses (+ biotoxins)
7) Microbiome samples – in euthanized animals or VERY FRESH
    - Swabs of blowhole nasopharynx, oropharynx, trachea, lung, various locations in gastrointestinal tract
    - Link microbiome with hormone levels (*e.g.*, glucocorticoids and aldosterone)

Appendix H: Model Parameter and Data Source Table

Model parameters and relevant data sources

Note: there are many specific models possible; the assessment below attempts to capture generic parameters required

Model Parameter Category	Sub-Category	Sub-Category 2	Rank 1 Data Source	Rank 2 Data Source	Rank 3 Data Source	Rank 4 Data Source	Rank 5 Data Source	Rank 6 Data Source
Population-level demographic variables	Abundance		Photo ID_Mark recapture	New habitat discovery vs. now scattered				
	Survival, fecundity		Photo ID_Mark recapture					
Stressors	Vessel trauma		Photo ID_Mark recapture & Photogrammetry	Mortalities (necropsy; serious injury & mortality)	Vessel collision risk by area	Self-reporting		
	Entanglement trauma		Photo ID_Mark recapture & Photogrammetry	Scar assessment	Mortalities (necropsy; serious injury & mortality)	Recovered gear	Entanglement risk by area	Stress hormone assessment
	Reproduction	Pregnant	Breath, blubber, fecal, baleen analysis for sex steroids	Photo ID & Photogrammetry (incl. outcome)	Necropsy			
		Lactating	Photo ID_Mark recapture & Photogrammetry (incl. outcome)	Fecal sex steroid	Necropsy			
	Disease, microbiome & toxicants		Skin, blubber, breath, fecal analysis for agent	Clinical signs (incl. skin condition)	Necropsy			
	Noise		Passive acoustic monitoring	Soundscape modelling	Necropsy or other evidence			
	Food abundance and quality		Plankton sampling	Stable isotopes and lipid content	Physical oceanography (incl. climate events) and ocean color	Necropsy for stomach contents		

Model Parameter Category	Sub-Category	Sub-Category 2	Rank 1 Data Source	Rank 2 Data Source	Rank 3 Data Source	Rank 4 Data Source	Rank 5 Data Source	Rank 6 Data Source
Health	Body condition, nutritional state		Visual Health Assessment	Photogrammetry	Necropsy	Biopsy, fecal, blow hormone (thyroid & stress)	Blubber biopsy fatty acids	
Other state variables								
	Body length		Photogrammetry	Necropsy				
	Age		Photo ID_Mark recapture & Photogrammetry	Genetics (linking juveniles to calves)	Epigenetics once validated			
	Sex		Photo ID_Mark recapture & Photogrammetry	Genetics	Sex steroids	Necropsy		
	Reproductive stage (females):	Pregnant	see above					
		Lactating	see above					
		Resting	Photo ID_Mark recapture & Photogrammetry	Necropsy	Baleen			
		Immature	Photo ID_Mark recapture & Photogrammetry	Necropsy	Breath, blubber, fecal, baleen analysis for sex steroids			
		Senescence	Photo ID_Mark recapture & Photogrammetry	Necropsy	Breath, blubber, fecal, baleen analysis for sex steroids			
	Reproductive stage (males):	Mature	Photo ID_Mark recapture & Photogrammetry	Necropsy	Breath, blubber, fecal, baleen analysis for sex steroids			
		Immature	Photo ID_Mark recapture & Photogrammetry	Necropsy	Breath, blubber, fecal, baleen analysis for sex steroids			

Appendix I: Modeling Subgroup Discussions

Modeling Subgroup: Embedding health assessments into population models - summary and input

Background
The primary motivation in collecting information about right whale health is to make quantitative predictions of the effect of changing health on individuals' future survival and reproductive success, and to scale this up to population-level inferences about changes in abundance. Here the modelling subgroup participants consider various potential approaches and provided individual input on priorities for future modeling effort, together with data collection to support this modeling.

Significant progress has been made historically on population models for NARWs. For example, Fujiwara and Caswell (2001) used deterministic and stochastic matrix population models to infer that adult female mortality was the prime cause of the population decline occurring at that time, and that preventing the human-caused deaths of just two females per year could reverse the trend (Clark *et al*. 2005). Klanjscek *et al*. (2007) constructed a bioenergetics model for right whales to relate energetic inputs and contaminant burden to reproductive rates. Schick *et al*. (2013) constructed a state-space model linking movement, health, and survival as a function of animal location and age, and fitted this to observed data from visual health assessments using a Bayesian statistical framework.

Uses of models:

- Threats assessment - forecasting effects of (targeted) management actions.
    - *e.g.*, van der Hoop *et al*. 2012, Vanderlaan *et al*. 2009, Vanderlaan *et al*. 2011, Farmer *et al*. 2016, Chion *et al*. 2018, etc.
- Determining relative value of different data sources

Future approaches
Quantitative metrics of health

1. Integrated health metric on arbitrary scale (scale 0-100, for example)
2. Health measures that separate body condition vs. susceptibility to illness
    a. Calibrated body condition measure (*e.g.*, Joules stored)
    b. "Susceptibility to illness" metric
3. Multivariate health metric, incorporating 2a and 2b.

Note that these must be relatable to future demographic outcomes (individual level reproduction and survival; note that poor health may affect survival of the adult, but also for females that successfully breed, their poor health may affect survival of their offspring). Various metrics such as odds ratios could be derived.

Integrative models

- Model class 1: Simulation-based individual-level model informed by data and based on an integrated health metric.
  Mechanistic individual-based, parameter values and functional relationships informed by data, with integrated health metric. Similar to *e.g.*, PET. Good for hypothesis exploration and testing.
  Predicated on separate analyses linking health to demographic outcomes, etc.
- Model class 2: Mechanistic state-space population model based on an integrated health metric fitted to data. Spatial? [The pros and cons of spatial models are mentioned, given the unpredictability of whale movement patterns.]
- Model class 3: Simulation-based individual-level model informed by data based on explicit consideration of energetics, *e.g.*, DEB model.

Note that other modelling approaches are possible. For example, one could envisage a purely analytic approach to a stochastic population model -- but in practice, such models are too simplistic to be useful here. One could also envisage a bioenergetic model like model class 3 embedded within a state-space framework, but this seems exceptionally challenging. In addition, none of the above approaches explicitly includes the "susceptibility to illness" metric - this is something that should be addressed in future work.

Model class 1: Simulation-based individual-level model with integrated health metric
The particular example of this class of model that is the focus here is the PET. The basic scope and objectives of the PET encompass developing a prospective population model that will provide an informed projection of extinction risk and other demographic parameters for the NARW population over a modest time frame. Just as important, the PET aims to simulate various environmental scenarios that through their comparison with the baseline, management might gauge the influence of regulations on these projected parameters. The structure of the initial model will be limited to a population-wide characterization without explicit links to spatial structure and within-year dynamics. The stochastic simulations develop population characteristics through following individual whales though life-cycle events over time. Population characteristics are calculated at each time step (*i.e.*, 1 year or longer) as one might calculate the statistics for any sampled population.

All population projections must accommodate birth and death processes and most may accommodate considerable population structure in doing so using efficient matrix operators in their simulations. However, an individual-based approach is elected because of the appealing notion that one might, in a readily interpreted an easily manipulated manner; accommodate many of the anthropogenic stresses placed on right whales (extant or emerging, immediately subject to or not subject to management) through a general health index. It has been well documented that various factors influence right whale health including immediate and chronic mortality from entanglement and vessel collision, reduced reproduction linked to wounding and energetic impact during entanglement, and reduced reproduction from changes in prey availability. There exist other possible stressors that can influence the general health of individuals for which functional links to survival or reproduction might not be well described or documented, including noise interference with communication, noise adding to baseline levels of stress

hormones, contaminants affecting immune response and others. The goal will be to embed all the stressors presently believed important to this population into a functional relationship with a general health index and allow that index to affect the survival and reproduction outputs of the population. Many of these relationships to health within the model may be merely place holders (constants with no mean effect and no variance) for now, but by developing this structure one can provide an evaluation of sensitivity to their inclusion as well as the creative developments of scenarios that might evolve from future research.

One of the advantages contained in the scope and structure of this approach is expediency. The development of this model is being fast-tracked to include the well-evidenced relationships of entanglement and vessel collisions on survival and fecundity. There is a considerable lack of development relating other possibly important threats (contaminants, prey quality or availability, vessel interference, and noise) to individual or population demographic responses. Although this may limit realism in the model for considerations of health, the structure will be present for future considerations. Data needs then become evident: 1) links are needed between threat level and health response, and 2) individual survival and reproduction response to a health index.

Model class 2: State-space population model with integrated health metric
Overview of approach: The state-space approach differs from the above model – by providing integrated estimation of model parameters and relationships based on simultaneous analysis of all input data.
Advantages: Allows better representation of uncertainty arising from multiple overlapping data inputs; also better model checking as the fit of one data source is influenced by information coming from all other data sources
Disadvantages: Harder to do in practice.

Model class 3: Simulation-based individual-level model with explicit energy-based health metric
Overview of approach: A bioenergetic model that accounts for daily caloric needs by age, sex, life stage, location, and reproductive state (see Farmer *et al*. 2018a). This type of model can incorporate stressors at the individual level using energy consumption as a common currency, and then relate energy reserve levels to vital rates including survival probability and calf production rate (see Farmer *et al*. 2018b).
Advantages: Incorporates stressors at the individual level using energy consumption as a common currency (see Farmer *et al*. 2018a), including:

1. Movement to/from foraging and calving grounds, including the increased costs of movement to foraging grounds further from historical grounds;
2. Energetic drag costs associated with entanglement;
3. Reduced caloric uptake associated with impaired foraging (due to entanglement or wounding by vessel strike or inadequate prey resources);
4. Increased energetic demands associated with wound healing;
5. Other health impacts that translate readily into bioenergetic demands and could be easily incorporated as parameters become available.

The probabilistic threat assessment of these models could be treated within a multiple PCOD framework (see Farmer *et al*. 2018b) that integrates across:

1. Probability of selecting a given feeding ground;

2. Linked to location: Probability of vessel strike (at different levels of severity);
3. Linked to location: Probability of entanglement (at different levels of severity); see Farmer *et al*. (2016).

Disadvantages:

1. Extremely high parameter needs with associated high uncertainty;
2. Long time to deliver;
3. Model is stochastic but does not internally fit data, which reduces statistical rigor and ability to validate model predictions through dynamic updating;
4. Important to understand whale distribution relative to spatial distribution of threats to look at daily energy requirements layered with probability of encountering a threat and the lingering bioenergetic impacts of that encounter (both acute and chronic).

Additional Data Needs:

Related input for health assessments to support transition to bioenergetic models:

1. Body composition: Record blubber thickness measurements at standard locations during necropsy. Take blubber, muscle, and viscera samples from across the body (dorsal to ventral, nuchal to insertion) for fresh stranded animals. These could be evaluated for percent composition of carbohydrates, lipids, and proteins. Of these, carbohydrates are the least-critical percent composition, and viscera is the least critical body tissue. These measurements are useful from a bioenergetic perspective, especially for fresh stranded individuals killed by acute trauma (*i.e.*, representing "normal body condition") and individuals where starvation is implicated as a cause of death. These provide the upper and lower ends of energy reserves to parameterize a bioenergetic model such as Farmer *et al*. (2018). Recognizing this is not a current target of the working group, but is likely to become so in the future because of the ability to express the impacts of multiple stressors within a common energetic framework, these samples could be retained (labeled and tracked) and evaluated later.
2. Minimum time to starvation: For whales observed entangled with impaired foraging to stranding, this would involve cross-referencing photo-ID timestamps for entangled individuals with subsequent stranding/carcass recovery records. These times can be used to benchmark and ground-truth bioenergetic model predictions after accounting for the additional daily energetic demands imposed by gear drag.
3. Basal metabolic rate / Field metabolic rate: Empirical field measurements required to assess daily caloric demands of whales relative to size, sex, and life stage, following Noren (2011).

Individual Participant Input:

1. Undertake statistical analyses relating stressors to health (example: linking severity to body condition) for input to model classes 1 and 3 above, and to inform model 2.
2. Undertake analyses relating health to outcomes (example: linking body condition to probability of 1-year-ahead survival) for input to model classes 1 and 3, above, and to inform model 2.
3. Continued support to develop the PET.
4. Significant investment into development of a population-level state-space model of the type outlined in Model Class 2, above, (note some model development is part of a current

proposal to SERDP, although that proposal would not develop the model fully to the extent required here.)

5. Development of a full bioenergetic model is a lower priority, but could be undertaken with a lower level of effort in order to help guide future data collection required to parameterize such a model.
6. Note that ongoing support is required for these modeling efforts to update them etc. Monitor effectiveness.
7. Need a streamlined link between data acquisition and incorporation into the model by supporting those associated with data processing.
8. Initializing "population" of simulated individuals with the structure (ages, sizes, sexes, life stages) of known individuals and tracking their projected life history (through bootstrapped threat assessment simulations). This accomplishes two goals:
    a. Reduces uncertainty by basing the simulated population upon the actual known population. Some parameters are known for all individuals; unknown parameters can be sampled from the population distribution for that particular sex/age/life stage.
    b. This has an important outreach advantage in that projected outcomes can be linked to "real" individuals, which increases public investment in the model results. For example, a model result could be expressed as "In 520 of 1000 simulations (52%), "Echo", a 32-year old female, was killed by entanglement. In 230 of 1000 simulations (23%), sub-lethal entanglement reduced her calf production." -- This approach to expressing results, accompanied by the most recent picture of the simulated whale, would be a unique way to tell the story of the model output.
9. Encourage researchers to express their observations in a statistical framework that supports this type of modeling, such as applying a logistic modeling approach and providing outputs as odds ratios such as the likelihood of forgone calf production with a severe entanglement event in their recent past. See Figure 4 in Powell *et al*. (2018).
10. Concerning linking energetic state to vital rates, empirical measurements of body condition relative to survival, likelihood of calf production, and quality (*i.e.*, size and fitness) of calves produced would all be of great interest. Photogrammetry is probably the best method for collecting this information assuming that changes in body mass for NARW are well predicted by changes in body volume.

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Appendix J: Developing a NARW Health Score Subgroup Outline

Overall Summary:
Based upon the existing longitudinal data each participant in the subgroup felt a health score could be attempted for known NARW individuals. The participants of the subgroup suggested trying to categorize a few animals with significant data as a pilot project in the future.

Breakout group questions:

- How would we approach developing a NARW health score?
- What data would we feed into a health score?
- Do we have enough data to make it valuable?

Five Possible Subjective Prognosis Categories: Good; Fair; Guarded; Poor and Grave

- Good: Favorable outcome is expected
- Fair: Favorable outcome is possible
- Guarded: Outcome is unknown
- Poor: Unfavorable outcome is expected
- Grave: Death is considered imminent

What NARW Data could we feed into a health score – longitudinal data
Subjective weighting to categories below for total health score; percentages mentioned below are from the discussion of existing data in the current photo-identification catalog housed at NEAq

1. Signalment –Sex, Age and sexual maturity (robust data available)

- Sex: 70-80% sex (genetic or visual)
- Age-
    - 100% minimum age on animals in catalog
    - 60-70% - age class
    - 50% real age
    - Length data (photogrammetry) – sparse data available
- Sexual maturity –
    - Females – 9yr adult (a few calve at 5 yrs)
    - Males – 9yr adult (for breeding 15-20yr)

2. History –
Life history (moderate data available)–

- Paternity,
- Sighting history or movement maps for each animal to assess feeding habitats, in future possibly pathogen or HAB exposure,
- Frequency of surface active groups

Reproductive history (robust measure for females) –

- Calving interval; calving production; nulliparous, multiparous, calving dependency/lactation period; calf survival to weaning (including age at death of calf)
- Paternity for males

Injuries & recovery (robust data available) –

- Injury type
- Injury severity
- Injury body location
- Injury healing
- Entanglement duration with gear
- Reproductive state at injury detection
- Body condition at injury detection
- Body condition post-injury detection

3. Body Condition –

- Length/width body condition (UAS photogrammetry) – sparse data available
- Body shape (VHA) – robust data available
- Ultrasound blubber depth – sparse data available

4. Skin Condition (robust data available from VHA) -

- Good and poor categorization only
- Future analysis or data collection for coverage of lesions, type of lesions, skin color, lesion distribution or location on body, sampling of lesions

5. Hormones (moderate to sparse data available – blow, blubber, fecal)

- Stress hormones
- Reproductive hormones
- Nutritional hormones

6. Toxins – Contaminants & HABs (sparse data available)

7. Microbiome (sparse data available)

8. Vital signs (sparse data available) -

- Respiration rate
- Temperature – blowhole forward-looking infrared camera (FLIR; yet to be calibrated)

9. Abnormal behaviors (sparse data available) -

- Swimming motion changes (fluking, logging, etc.)

10. Diet (sparse to no data available) –

- No existing data

Appendix K: Biopsy Focused Priority Research and Sampling Plan Subgroup

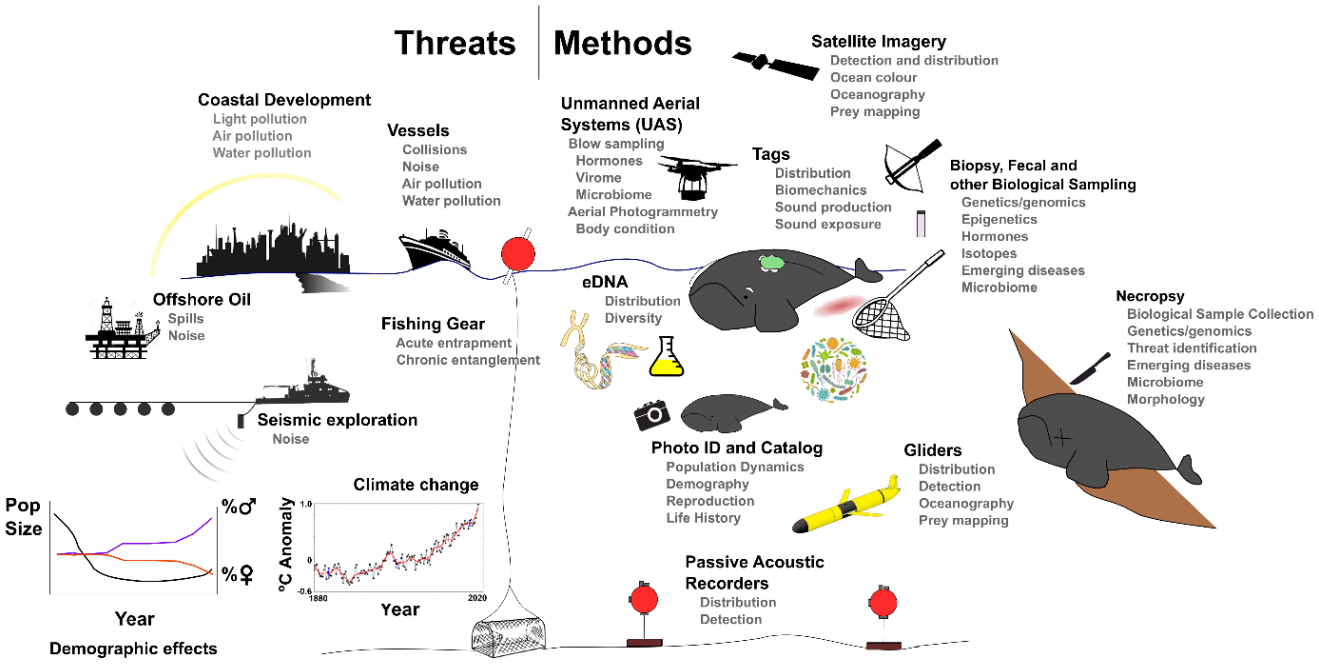
Overall Summary:
The participants of the subgroup highlighted the following priorities:
1) Analyze existing samples (primarily biopsies) from entangled whales for stress, and from females for reproduction success; and
2) Increase vessel surveys (many questions can be answered with data collected from this platform)

1. Is an animal pregnant and is it successful? – to inform recovery projections – monitoring tool to determine if a management action was effective
    a. Target available females
        i. Reproductively available females – prioritize over others
        ii. When are they being recruited?
        iii. Is the delay in first calf due to not getting pregnant or lost pregnancies
        iv. Gestational age? – develop patterns in seasonality & success/loss patterns
    b. Samples to collect:
        i. Biopsy or blood necessary – hormones LC-MS/MS (how many animals? statisticians help, use *Tursiops* data)
        ii. Feces – opportunistically – hormones ELISA
        iii. Blow (could be viable but needs more validation) - hormones
    c. Photogrammetry (validate pregnancy detection at different trimesters), body condition
    d. Continued surveys and photo-id on the calving ground – did she produce a calf?
    e. Baleen reproduction record (necropsy)
    f. Male reproduction lacking – Male seasonal reproduction – testosterone (ELISA/RIA)
    g. Readdress necropsy sample priority processing and distribution
2. What is the stress profile pre- and post-entanglement and will the whale survive?
    a. Stress hormones in biopsy pre-entanglement, while entangled, and post-entanglement
    b. Photo ID record
    c. How long does stress (cortisol) remain elevated in a post-entangled whale?
        i. Talk with SWFSC about existing data on cortisol metabolism/clearance in blubber
        ii. Cortisol in biopsy post-entanglement
        iii. Follow up progesterone to see if they are pregnant

<u>Biopsy</u>
Blubber: Hormones, lipidome, contaminants, archive
Skin: Genetics, genome, transcriptomics, stable isotopes or mercury, archive
Can also test: Lipids, stable isotopes (freshwater/marine), fatty acids, genetics, genomics, microbiome, lipidome and contaminants, histology

Prioritization of biopsy collection
1) Calves of the year
2) Adult females that have never had a calf
3) Known reproductively active female (no calf of the year present)

Appendix L: Modified Threats and Methods Figure



Appendix M: North Atlantic Right Whale Population Consequences of Disturbance (PCOD) Figure

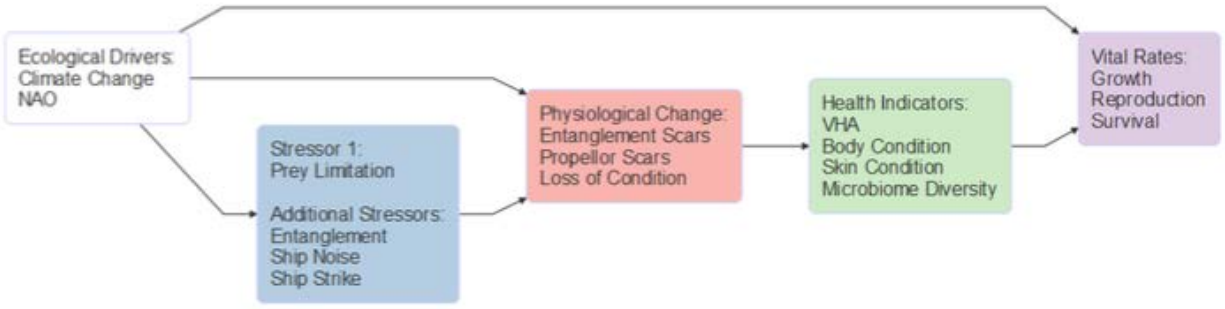


Figure 5. PCoMS model for NARW that links multiple stressors (blue box) to changes in physiology (red box) that are detected from retrospective work and drone-based studies (green box). All of these, as well as background environmental signals of climate change and the North Atlantic Oscillation, link to changes in growth (measured by the drone), reproduction and survival (purple box).

Appendix N: Draft Science Plan Matrix

Action	Information gained	Focus	Data Collected and Associated Methodology
Acquire Population-Level Seasonal Distribution and Demographic Variables	Abundance, survival, fecundity, location/distribution	Reproduction and survival	Vessel and aerial photo-ID, +/- tagging
Categorize and Quantify Stressors	Vessel trauma	Conflicts with vessels	Vessel and aerial photo-ID, photogrammetry, necropsy, serious injury and mortality determination, recovered gear analysis (for entanglement)
	Entanglement trauma	Fixed gear trap and gillnet fisheries	
	Reproduction - resting, pregnancy, lactation	Fecundity failure	Breath, blubber, fecal, & baleen sex steroid analysis, photo-ID and UAS photogrammetry
	*Food abundance and quality**	*Inadequate nutrition*	*Plankton sampling (ID, lipid content, stable isotopes), physical oceanography, climate change, ocean color, biopsy and necropsy (hormones, stable isotopes, etc.)*
	*Noise**	*Background and episodic noise pollution: shipping, energy exploration and production, defense*	*Passive acoustic monitoring and soundscape modelling*
	Disease, microbiome and toxicants	Infectious and non-infectious disease states	Skin, blubber, breath, fecal sampling and analyses
Quantify Health and Welfare Status	Body condition/ nutritional state/ pain and suffering	Reproductive failure, stress and entanglement	Disentanglement, Visual Health Assessment and UAS photogrammetry, stress hormones and adrenal gland function
Acquire State Variables	Length (& growth), age, sex, reproductive stage	Poor population health	Photo-ID, UAS photogrammetry, necropsy, genetics (sex is first priority), breath, blubber, fecal, baleen sex steroids
Individual and Population Based Models	Projections of individual and population status	Extinction risk, threats assessment, evaluation of management tradeoffs	Population projection models, mechanistic individual-based population dynamic models, and individual based bioenergetic models linked to multiple population consequences of disturbance models
Develop New Methodologies	*Blood health screens, serology, hormones and other**	*Poor health*	*Remote blood sampler*
	*Infrared thermography of skin lesions and core temperature**		*UAS FLIR imagery of skin and open blowholes*
Synthesis	Available data and sample aggregation	Collation of available data, samples and analysis thereof	TBD

Regular font: ongoing and critical to maintain;
**Italics: need development and/or lower priority*

Appendix O: Overarching Participant Input List

To enhance right whale health, we need to: a) substantially improve take reduction to reduce mortality; and b) reduce sublethal takes or trauma to enhance fertility and fecundity.

Assessment of efforts in that regard would be strengthened by NMFS collaborating with the scientific community as follows:

1. Continue to support the photo-identification catalog that provides the ability to track health at the individual level.
2. Continue to support the development of the PET model. In addition, support development of a population-level state-space model with integrated health metrics.
3. Model the relative costs to fertility and fecundity of sub-optimal foraging success, versus the sub-lethal effects of cumulative traumatic stressors (sound, vessel strikes, entanglement, and others).
4. Continue and expand vessel and aerial photo-identification efforts to acquire population-level seasonal distribution and demographic data. Revisit and optimize survey effort based on our current understanding of the changing seasonal distribution of whales.
5. Evaluate seasonal presence of whales in new or unknown habitats, by further development of acoustic survey of potentially important area, potentially informed by current habitat modelling and historic habitats. An additional approach would be using directed aerial survey and/or implanting transdermal intramuscular satellite tracking tags. The benefits versus the risk of the latter were not discussed at the workshop. The use of oceanographic data, stable isotopes, heavy metals, and eDNA for this purpose should be explored in collaboration with relevant disciplines.
6. Continue and expand collection of health assessment data (*e.g.*, photos, blow, biopsy) and continue longitudinal studies. Create and distribute prioritized sampling guidelines to field teams. Specifically, VHA and scarring assessments should continue; photogrammetry should be expanded and inter-calibrated with the VHA data and other measures of health. The low-impact value of UAS in health and scarring assessments and disentanglement should be considered and developed as appropriate. Effort should be made to sample and diagnose visible lesions in the context of environmental variables.
7. Necropsy response effort should be continued and enhanced, including continued support for training of large whale necropsy techniques. Floating carcass discovery, tracking and recovery is critical and capacity should be further developed with relevant agencies. A trans-boundary necropsy case review committee should be established. A trans-boundary NARW necropsy sampling workshop should be held to develop a trans-boundary comprehensive plan for NARW sample collection and management.
8. Support, develop, and maintain necropsy team leader group, and facilitate quicker necropsy report drafting and conclusion. Shorten diagnostic investigation time lags to allow for real-time assessment and response to outstanding health threats.
9. The entanglement response effort should be continued and enhanced.
10. Disentangled animals are often not counted against PBR, despite the inevitable knock-on health impacts. NMFS could reconsider this in their guidelines.
11. All whales should be continued to be biopsied for genetic identification to better track survival and link to parentage. Support is needed for the genetic analyses and archive.

12. Analyze baleen plates from necropsied animals for hormones, including calves that could provide data on fetal development.
13. At sea blood sampling, infrared thermography, and microbiome analysis should be supported and further developed.
14. Researchers in Canada and the US should convene a working group for genetic and genomic synchronization, to expedite genetic identification.
15. Permittees and NMFS PR2 (Marine Mammal Conservation Division) should work with PR1 (Permit Division) to permit sampling collection priorities that result from this workshop.
16. Reconcile and integrate various data streams to refine individual females' reproductive history.