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

Deborah Fauquier, Kristy Long, Ingrid Biedron, Sarah Wilkin, Teresa Rowles, Eric Patterson, Allison Henry, Mendy Garron, Erin Fougeres, Nicholas A. Farmer, Jason Baker and Michael Ziccardi

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# TABLE OF CONTENTS

EXECUTIVE SUMMARY ............................................................................................................ 1  

1. INTRODUCTORY ITEMS ........................................................................................................ 3  
   1.1 Introduction of Workshop Moderator and Rapporteurs ................................................ 3  
   1.2 Expected Outcomes ........................................................................................................... 3  

2. TERMINOLOGY ....................................................................................................................... 4  

3. PRESENTATIONS ..................................................................................................................... 5  
   3.1 Background Presentations ................................................................................................. 5  
      3.1.1 Overview of previous right whale workshops (Michael Moore) ............................... 5  
      3.1.2 Summary of reproductive failure, reduced survival and inflammation drivers in bottlenose dolphins: captive and wild – lessons learned (Cynthia Smith) ......................... 6  
      3.1.3 Tabular summary of relevant North Atlantic right whale and other health literature (Ingrid Biedron) .................................................................................................. 7  
      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) ....................... 8  
   3.2 North Atlantic Right Whale Injury Presentations ............................................................... 9  
      3.2.1 North Atlantic right whale overt mortality trend summary with a focus on chronic skin, oral and other lesion patterns (Sarah Sharp) ............................................... 9  
      3.2.2 New England Aquarium Injury Database and Visual Health Assessments (Heather Pettis) ...................................................................................................................... 9  
      3.2.3 NMFS Serious Injury Assessments (Allison Henry) .................................................. 10  
      3.2.4 Frequency and effects of entanglements and vessel strikes on North Atlantic right whale reproduction (Amy Knowlton) ................................................................. 11  
   3.3 Condition Presentations ................................................................................................... 12  
      3.3.1 Trends in growth and body condition from photogrammetry (John Durban) .......... 12  
      3.3.2 Energetic cost of entanglement (Michael Moore) ..................................................... 12  
   3.4 Reproduction Presentations ............................................................................................... 13  
      3.4.1 North Atlantic Right Whale Female Reproduction- Catalog Perspective (Phil Hamilton) ......................................................................................................................... 13  
      3.4.2 Reproductive and stress hormones - any evidence for pregnancy loss (Rosalind Rolland) ................................................................................................................ 14  
   3.5 Biota Presentations ............................................................................................................. 15  
      3.5.1 North Atlantic right whale respiratory microbiome, bowhead gut microbiome and lipidome, and humpback skin microbiome (Carolyn Miller) .................................... 15  
      3.5.2 Fecal Parasites & Harmful Algal Blooms (Rosalind Rolland) .................................. 16  
   3.6 Modeling Presentations ..................................................................................................... 16
3.6.1 Survival assessments and trends with emphasis on reproductive females (Rob Schick) ................................................................. 16

3.6.2 Population models and assessment tool (Richard Pace) .......................................................... 17

3.6.3 Modeling with *Tursiops* health assessment data (Len Thomas) ........................................ 17

4. DISCUSSION OF CURRENT HEALTH ASSESSMENT TOOLS and TECHNOLOGIES.. 18

5. DISCUSSION OF HEALTH ASSESSMENT PRIORITIES .......................................................... 19

5.1 Modeler Data Discussion ...................................................................................................... 19

5.1.1 Breakout Groups ............................................................................................................ 19

5.2 Develop a draft outline for a longer-term science plan ............................................................. 19

6. CONCLUSIONS ....................................................................................................................... 20

7. REFERENCES ........................................................................................................................... 22

8. APPENDICES LIST .................................................................................................................... 26

Appendix A: AGENDA for 2019 North Atlantic Right Whale Health Assessment Workshop ................................................................. 27

Appendix B: List of Participants ................................................................................................ 30

Appendix C: Abbreviations ......................................................................................................... 33

Appendix D: Name of Workshop Presenters and Title of Presentations .................................... 34

Appendix E: Literature Review Table ......................................................................................... 35

Appendix F: Distilled Tool Matrix .............................................................................................. 49

Appendix G: North Atlantic Right Whale Necropsy Sampling and Data Tool Subgroup Discussion .............................................................................................................. 51

Appendix H: Model Parameter and Data Source Table ............................................................... 53

Appendix I: Modeling Subgroup Discussions ........................................................................... 55

Appendix J: Developing a NARW Health Score Subgroup Outline ........................................... 61

Appendix K: Biopsy Focused Priority Research and Sampling Plan Subgroup ......................... 63

Appendix L: Modified Threats and Methods Figure .................................................................. 64

Appendix M: North Atlantic Right Whale Population Consequences of Disturbance (PCOD) Figure .................................................................................................................. 64

Appendix N: Draft Science Plan Matrix ....................................................................................... 65

Appendix O: Overarching Participant Input List ......................................................................... 66
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 intergovernmental 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 lumar 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.
7. REFERENCES


8. APPENDICES LIST

Appendix A: Agenda

Appendix B: List of Participants

Appendix C: Abbreviations

Appendix D: Name of Workshop Presenters and Title of Presentations

Appendix E: Literature Review Table

Appendix F: Tool Matrix

Appendix G: Necropsy Sampling and Data

Appendix H: Model Parameter and Data Source Table

Appendix I: Modeling Subgroup Plan

Appendix J: Developing a NARW Health Score Subgroup Outline

 Appendix K: Biopsy Focused Priority Research and Sampling Plan Subgroup (Burning Questions group)

Appendix L: Modified Threats and Methods Figure

Appendix M: NARW Population Consequence of Disturbance Figure

Appendix N: Science Plan Matrix

Appendix O: Overarching Input List
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

TUESDAY, JUNE 25th: DAY 2
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

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

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

<table>
<thead>
<tr>
<th>Authors/Editors</th>
<th>Title</th>
<th>Publication Year</th>
<th>Abstract/Description</th>
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</thead>
<tbody>
<tr>
<td>Zorn, B. S. &amp; Motahari, B. &amp; Castorena-Cantero, L.</td>
<td>The influence of entanglement and vessel strike on the long-term survival of North Atlantic right whales (Eubalaena glacialis)</td>
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<tr>
<td>Appendix E: Literature Review Table</td>
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<tr>
<td>Zorn, B. S. &amp; Motahari, B. &amp; Castorena-Cantero, L.</td>
<td>The influence of entanglement and vessel strike on the long-term survival of North Atlantic right whales (Eubalaena glacialis)</td>
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</tbody>
</table>
Nutritional stress and body condition are key indicators of changes in the body condition of large whales, providing a more comprehensive approach for associating adrenal activation with natural and anthropogenic stressors. 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.

The analysis of fecal glucocorticoids (fGC) is an 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 samples (fGC) has been challenged by variable results from different laboratories and testing methods. Here, we describe a multivariate approach that may prove useful for the multiple-analyte data sets that are specific natural and anthropogenic stressors. Using aerial photogrammetry, we describe 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, we demonstrate variation between individual whales, suggesting potential for studies of individual differences in adrenal activity. Incorporation of methodologies that minimize sample manipulation and measurement of urine could be used to improve non-invasive physiological assessment of whales.

Considerations for large whales integrating fALD as a complementary biomarker to glucocorticoids: Ecological variation in adrenal activity. Incorporation of methodologies that normalize sample variation in circulation (i.e., hormones present in narrow range in circulation) as a normalizing factor to fGC for identifying adrenal activation. Concentrations of fGC were positively correlated with fetal heart rates (r = 0.59, P < 0.001), suggesting concurrent secretion of these hormones by pregnant females (35.9 +/- 7.6 ng/g) followed by reproductively mature males (9.5 +/- 0.9 ng/g) (P < 0.05), with higher levels in pregnant and not lactating) and immature females proved the most unreliable to distinguish. Aldosterone concentrations (fALD; aldosterone and related metabolites) were measured in fecal samples from right whales (total n = 315 samples), including samples from identified individuals of different reproductive states in 1999-2016. North Atlantic right whales number <500 individuals and are subject to anthropogenic threats, including entanglement and vessel strikes. 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.

Aerial photogrammetry was/is this approach used? Yes
Publication year 2019
Country (first institution) USA
Institution, State, Country (first publication) New England Aquarium, MA, USA
Research Institution, State, Country (first listed in publication) N/A
Year (During what timeframe was this approach used?) 1999-2016
Management applications None
Abstract/Description: 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 samples (fGC) has been challenged by variable results from different laboratories and testing methods. Here, we describe a multivariate approach that may prove useful for the multiple-analyte data sets that are specific natural and anthropogenic stressors.
Hall, A. J.
Brownlow, A.
Davison, N. J.
Hunt, K. E.
Burgess, E. A.
McLellan, W. A.
Rolland, R. M.
Perryman, W. L.
Krause, D. J.

Editors
Rolland, R. M.

Phocoena (right whales in North Atlantic injury and mortality adaptable An accurate and a small cetacean, body condition in morphometric and Evaluating system an unmanned aerial approach for estimating the mass and body condition of pinnipeds that may be widely by vessels (n = 5) and healthy right whales (n = 113) to characterize concentrations in right whales chronically entangled in fishing gear (n = 6) or live-stranded (n = 1), Atlantic right whales Eubalaena glacialis (NARW). Using a general linear model, we compared fGC long-term records of glucocorticoids can be reconstructed from serial sampling along full length baleen plates (representing similar to 10 years of baleen growth), using baleen samples from stranded whales. fGCs were measured in the dorsal, outermost layer were representative of concentrations through the full blubber depth, and the stranded whale (5740.7 ng g (−1)) was significantly higher than in whales with right whales quickly killed by vessels (n = 5) and healthy right whales (n = 113) to characterize concentrations in right whales chronically entangled in fishing gear (n = 6) or live-stranded (n = 1), Atlantic right whales Eubalaena glacialis (NARW). Using a general linear model, we compared fGC

North Atlantic right whale Physiological stress Multi-year longitudinal profiles of cortisol and corticosterone measured from baleen - 2017 NA
New England Aquarium, MA, USA

Editors/Authors/LeRoi, D. J.

**hexacopter** humpback whales reproduction in vehicle provides unmanned aerial tissue to monitor Bone as a surrogate 2017-

"...metals' concentrations and the accumulation rates with age were higher in individuals from WA than in those from WA. Parental 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 Cu and Pb concentrations significantly increased with age..."

"...throughout the breeding season, while there was no change in body condition of males and females (r = -0.03; p > 0.05), higher for females in Crystal River than in Tampa Bay or Indian River, but there was no change in body condition of males (r = -0.02; p > 0.05) throughout the breeding season."

"...for all metals, the log-transformed W had higher correlations with body condition than log-transformed SL."

"...fetuses showed significantly higher Cu, Pb and Zn concentrations than adults. After birth, only Cu and Pb concentrations significantly increased with age."

"...we suggest that photogrammetric use of UAVs as a noninvasive and cost-effective tool to measure length and condition of blue whales."

"...in support of this, we found a positive linear relationship between FBC and CBC. This lactating female's body condition implies substantial energetic costs for these reproductive classes."

"...females. The logarithms of W and of each linear measurement were regressed to develop a linear relationship for body condition."

![Image of a humpback whale](https://example.com/humpback-whale-image)

**Monitoring of body condition and reproduction in humpback whales.**

"...the body condition of wild and rehabilitating captive manatees."

"...no such index has been established for Florida manatees (Trichechus manatus latirostris)."

"...we contribute 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 long-term trend in metal pollution."

"...we tested differences between populations and we observed that the metal contamination levels were higher for all metals, for all tissues, from WA than from WA."

"...no significant differences in metal contamination levels were found between populations for any of the metals analyzed, except for Ag, which was higher in WA than in WA."
Health of North Atlantic right whales: Eubalaena glacialis over three decades: from individual health to demographic and health trends

Marine mammals are faced with mounting challenges from environmental fluctuation, climate change, and disturbances from human activities. Anthropogenic morbidities have been well documented, but it is difficult to assess the relative 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 condition, welfare markers, and reproductive traits, to evaluate the health of North Atlantic right whales (Eubalaena glacialis) from 1980 to 2018. We applied a hierarchical Bayesian model to estimate the underlying health of individual right whales from photographic health scores (annual estimates from 1980 to 2018). Social and biological variables that were used to estimate the health of right whales included age, sex, season, and reproductive status. Health assessment of right whale populations was done by visual health scoring of post-mortem lung and brain samples. PCR for cetacean morbillivirus (CeMV), influenza A, and apicomplexan protozoa were negative in formalin-fixed, paraffin-embedded lung and brain samples from a subset of whales. PCR results for bacterial pathogens were also negative. Immunohistochemical labeling for canine distemper virus, Toxoplasma gondii, and Brucella spp. 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 were seen between years to explain the majority of deaths and those in high-mortality years remain to be identified. Future research will require flexibility to adjust to changing distributions of lethal anthropogenic disturbance on marine mammals.

Health of North Atlantic right whales: Eubalaena glacialis from a welfare science perspective

Health of wild and captive dolphins and veterinary and professional expertise. C-Well (R) scores can be used in large whales, assays of fecal hormones have been validated using information on age, condition estimated from photographs; endocrine status derived from fecal samples), and the development of an index for assessing the welfare of bottlenose dolphins (Tursiops truncatus). The development of a methodology for assessing the health of cetaceans from wild and captive populations has been a priority for many researchers. This approach has been developed in situ at three marine mammal zoological facilities, tested for feasibility and accuracy, and substantiated by published literature on a similar number 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. This approach is based on the development of a methodology for assessing the health of cetaceans from wild and captive populations has been a priority for many researchers. This approach has been developed in situ at three marine mammal zoological facilities, tested for feasibility and accuracy, and substantiated by published literature. This approach is based on the development of a methodology for assessing the health of cetaceans from wild and captive populations has been a priority for many researchers. This approach has been developed in situ at three marine mammal zoological facilities, tested for feasibility and accuracy, and substantiated by published literature. This approach is based on the development of a methodology for assessing the health of cetaceans from wild and captive populations has been a priority for many researchers. This approach has been developed in situ at three marine mammal zoological facilities, tested for feasibility and accuracy, and substantiated by published literature.
Microbes are now well regarded for their important role in mammalian health. The microbiology of skin is an active area of research. The bacterial communities on the skin of humpback whales (Megaptera novaeangliae) are being studied in detail, with particular emphasis on the role of probiotics in preventing skin disorders. This research suggests that the skin bacteria may be connected to humpback whale health and could possibly serve as a useful index for health and skin disorder monitoring of threatened and endangered marine mammals.

Differential expression of skin-associated microbial communities have been observed between sexes, age classes, and geographic areas. These differences may be related to stress and reproductive status. For example, male humpback whales have been shown to have higher levels of skin bacteria associated with the reproductive tract compared to females. Additionally, there is evidence that some skin bacteria species are more abundant in pregnant females than in males.

In conclusion, the skin is a vital organ for the health and survival of marine mammals, and understanding its microbiology is crucial for conservation efforts. Further research is needed to fully understand the role of skin microbiota in the health and survival of these species, as well as the potential for using skin microbiota as a tool for monitoring the health of threatened and endangered marine mammals.
<table>
<thead>
<tr>
<th>Authors/ Editors</th>
<th>Title</th>
<th>Publication year</th>
<th>Abstract/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Fauquier, D. C. E. Yeates, L. J. Raverty, S. A. Davis, Kenney, Robert D Pettis, Heather M Hamilton, Philip K Knowlton, Amy R Rolland, Rosalind M Wells, R. S. Hart, L. B. Costidis, A. M. van der Hoop, J. Kraus, Scott D Moore, K. T. Jepson, P. D. Gulland, F. M.</td>
<td>Reference ranges for available methods in physiology in large conservation challenges of endangered North Atlantic right whale.</td>
<td>Using hierarchical Bayes to understand movement, health, and survival in the endangered North Atlantic right whale. 2014 Body condition is an indicator of health, and plays a key role in many vital processes for marine mammals. While evidence of body condition can be obtained, these observations provide only brief glimpses into the health status of the animal. An analytical framework is needed for understanding how health of animals changes over time and space. Non-invasive and non-lethal sample acquisition methods have been developed to estimate body condition in individual cetaceans, and the relationship between observed body condition and survival status is of great importance to conservationists, where the consequences of disruption of critical social structures pose such threats of conservation. Here we build a state space model that provides estimates of movement, health, and survival. We assembled 30-years of photogrammetry evidence of body condition and three additional health indicators in parameters of North Atlantic right whale, together with survey data, to infer the true health status as it changes over space and time. We also included the effects of reproductive status and endanglement status on health. In the population level, we estimated differential movement patterns in space and time. At the individual level, we estimated the body condition trajectories in each month. We estimated the relationship between observed and latent health status, observations of body condition, and conditions, survival probabilities on the movement, and state space model. This framework provides useful information for understanding how health status changes over space and time. This model can be broadly applied to a variety of systems – terrestrial and marine – where individual observations of individuals exist.</td>
<td></td>
</tr>
<tr>
<td>M. Moore, M. van der Hoop, J. Hoenig, S. G. Costidis, A. M. Jepson, P. D. Jepson, P. D. Moore, K. T.</td>
<td>CRITERIA AND CASE DEFINITIONS FOR SERVICE INJURY AND DEATH OF PENGUINS CAUSED BY ANTARCTICAN WILDLIFE. 2013</td>
<td>Field monitoring consists of dead and lost stranded hardbilled penguins and estimates for determination of cause of death provides valuable information for the management mitigation and prevention of avian and sometimes marine human impacts, such as vessel collisions, fishing gear entanglement and gillnet. Detailed discovery, necropsy, histology, and tissue analysis has been used to assess impacts on public concern and federal and state or provincial regulations mandating such investigations to inform mitigation efforts, has been an increasing effort to objectively and systematically investigate these scenarios from a diagnostic and forensic perspective. This theme section provides basic investigative methods, and case definitions for each of the areas commonly recognized case presentations of human interactions in penguins and cetaceans. Wild animals are often adversely affected by factors such as pollution, antarctica contamination, lesions, cardiovascular microvascular infections and competing habitat use, such as prey depredation and elevated temperature and marine acid. Understanding the potential contribution of these subclinical or hidden factors is essential for a comprehensive understanding of the causes of death. Typically, post mortem examination is the preferred procedure to determine the cause of death, especially where justification for interventions as well as autopsy are limited. These case criteria describe attempts to acknowledge the confounding factor to enable an appreciation of the significance of the observed human element trauma in that broader context where possible.</td>
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<td>H. S. Moore, M. Mohtesham, R. Mohatt, M. M.</td>
<td>OVERCOMING THE CHALLENGE OF STUDYING CONSERVATION PHYSIOLOGY ON LARGE WHALES, USING NON-INVASIVE COLLECTED SAMPLES. 2013</td>
<td>Large whales are subjected to a variety of conservation pressures that could be better monitored and managed. Physiological information could be gathered readily from free-swimming whales. However, traditional approaches to studying physiology have been impossible for large whales. Because there is no routine method for capture of the largest species and there is presently no method of obtaining liberal ranges from the free-swimming whales. We review the current knowledge and understanding of the benefits and limitations of the available non-invasive physiological samples. Specific research questions are identified, and synthetic sample matrices are constructed. We use these sampling options to identify potential physiological responses to stress, stress physiology, reproductive status, nutritional status, immune response, health, and disease. The following four types of samples are discussed: 1) exhaled gas, respiration samples; 2) fecal, digestive samples; 3) blow, respiratory samples; and photographs. Photographic analysis have been used and presented in this context. New methods and research goals have been identified that will improve our understanding of the physiology of large whales. For example, the potential to improve our understanding of the physiology of large whales, greater, better monitoring and management of the health and survival of large whales using the available non-invasive sample matrices.</td>
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</table>
Chromium is a naturally occurring element found in the earth's crust. It is a heavy metal of great environmental concern due to its potential toxicity to organisms in the aquatic environment. Chromium has been classified as a carcinogen by the International Agency for Research on Cancer (IARC). The two main toxic forms of chromium, Cr(VI) and Cr(III), differ in their chemical and biological properties, and they have been associated with various health effects in different species.

In this study, we investigate the body growth of North Atlantic right whales (Eubalaena glacialis) and its potential health consequences. We analyzed the growth curves of 10 right whale calves born from 1984 to 2012, and we compared them with the growth curves of 82 Atlantic bottlenose dolphins (Tursiops truncatus) born in the same period. We observed that the growth curves of right whale calves and bottlenose dolphins were similar, indicating that both species rely on endogenous nutrient reserves to support the considerable energy expenditure during the early developmental period.

We also assessed the body shape of 25 right whale calves and 26 bottlenose dolphins from an initial month to 1 year of age. The body shape of the right whale calves was significantly different from that of the bottlenose dolphins, indicating that the right whale calves differ in their nutritional condition and body mass at birth and weaning. The growth curves of the right whale calves were similar to those of the bottlenose dolphins, suggesting that the nutritional condition of right whale calves is comparable to that of bottlenose dolphins.

We also analyzed the body shape of 25 right whale calves and 26 bottlenose dolphins from an initial month to 1 year of age. The body shape of the right whale calves was significantly different from that of the bottlenose dolphins, indicating that the right whale calves differ in their nutritional condition and body mass at birth and weaning. The growth curves of the right whale calves were similar to those of the bottlenose dolphins, suggesting that the nutritional condition of right whale calves is comparable to that of bottlenose dolphins.

Our results indicate that North Atlantic right whale calves gain on average similar to 1.7 cm and similar to 34 kg in mass during the first 8 months of lactation. The body shape of E. glacialis that had been lactating for 8 mo. was significantly different from 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 carcass. These results indicate that mother right whales rely on endogenous nutrient reserves to support the considerable energy expenditure during the early months of lactation; therefore, photo-grammetric measurements of body width, particularly at birth, are effective for testing hypotheses on maternal body condition.

We conclude that the body growth of North Atlantic right whale calves is comparable to that of bottlenose dolphins, indicating that both species rely on endogenous nutrient reserves to support the considerable energy expenditure during the early developmental period. Our results also indicate that the nutritional condition of right whale calves is comparable to that of bottlenose dolphins, suggesting that the nutritional condition of right whale calves is comparable to that of bottlenose dolphins.

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The report highlights the presence of density-independent environmental and physiological mechanisms that affect the abundance and growth of populations. The high variability in reproductive performance of North Atlantic right whales Eubalaena glacialis, and the importance of density-independent environmental and physiological factors in shaping populations, are 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. The focus on specific conditions and their implications for conservation and management planning, as well as the importance of understanding the role of density-independent factors in shaping populations, are essential for developing effective conservation and management strategies. The report also emphasizes the need for robust and reliable epidemiological studies to be applied in the field of marine mammal health research, as well as the importance of considering the presence of density-independent environmental and physiological mechanisms in shaping populations.
Heavy metal contamination of a considerable magnitude is evident in the tissues and blood of North Atlantic right whales (Eubalaena glacialis). 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 confidence. The concentrations of these elements, with the exception of renal Se levels, which were significantly higher in 1983–1997, showed significant decreases in most whisker, skin and kidney tissue samples, with a trend toward more trace element concentrations in the most recent samples collected. These observations are consistent with a reduction in the environmental contamination of the coastal waters of the Beaufort Sea (BCBS) stock of bowhead whales (Balaena mysticetus) collected from the Inuit subsistence hunt in Barrow, Wainwright and Kaktovik, Alaska between 2007–2011. The concentrations of several essential or non-essential elements were developed and interpreted using improved aging techniques (such as ion microprobe analysis, 62 nmi and 72 nmi coastal vessel monitoring, and use of satellite photography) to monitor the exploitation of the bowhead whale population. The data provide essential baseline information that can be used to continue to monitor the health of the bowhead whale population.
North Atlantic right whale

Serum and fecal glucocorticoid metabolites have been used as biomarkers to assess stress and disease risk in several species. For example, glucocorticoids are known to affect multiple physiological processes, including development, reproduction, and immune function. In this study, serum and fecal glucocorticoid metabolite concentrations were measured in North Atlantic right whales (Eubalaena glacialis) to assess stress and disease risk. The results showed that serum glucocorticoid concentrations were significantly higher in pregnant females compared to subadults and adult males. Fecal glucocorticoid metabolite concentrations were also higher in pregnant females compared to subadults and adult males. These findings suggest that stress and disease risk may vary by sex and reproductive status in North Atlantic right whales.

The authors concluded that serum and fecal glucocorticoid metabolites can be useful biomarkers to assess stress and disease risk in North Atlantic right whales. However, further research is needed to better understand the physiological and ecological implications of these findings.
Although historical data on North Atlantic right whale demographics, marine mammal research, and the potential of cetaceans as marine ecosurveillance systems have been developed, the right whale population is still only in the early stages of assessment. This paper describes a workshop that focused on the development of standardized health assessment methods for right whales.

Title: Report of the Workshop on North Atlantic Right Whale Health Assessment

Authors: Scott D. Kraus, Amy R. Knowlton, Solange Brault, Philip K. Hamilton, R. K. Bonde, A. R. Knowlton, M. J. Moore, and H. M. Pettis

In this first report of the Workshop on North Atlantic Right Whale Health Assessment (September 9–14, 2004, Sarasota, Florida, USA), we describe the activities of an interdisciplinary team of experts in veterinary medicine, marine biology, and marine mammal research. The objectives of the workshop were to develop a standardized approach for assessing the health of North Atlantic right whales (Eubalaena glacialis) and to identify potential indicators and biomarkers of contaminants or their effects that can also be replicated from site to site. Other quantitative approaches are also being explored.

The health assessment methods proposed by this team will be used to monitor the health of individual right whales at population and individual scales and may also be applicable to the management of other endangered whales.
The Hawaiian monk seal (M. 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 on the brink of extinction. Understanding the potential role of disease in the decline of the Hawaiian monk seal is crucial for the management and recovery of the species. To address this, the Epidemiology Plan has been developed to complement existing programs regarding health surveillance for the Hawaiian monk seal (M. schauinslandi) and the recommendations of the Hawaiian Monk Seal Recovery Plan. The plan includes ongoing health assessment projects, such as disease surveillance, the health and disease aspects of translocation efforts, and the development of contingency plans for unusual mortality and exposure to anthropogenic stressors.

The Hawaiian Monk Seal Health Assessment (HMHA) is a collaborative effort involving biologists from the Marine Mammal Research Program (MMRP), the Protected Species Investigation, and the Marine Mammal Health Assessment Program. The plan is designed to enhance our understanding of the potential role of disease and other factors in the decline of Hawaiian monk seal populations.

The Epidemiology Plan incorporates specific strategies under the broad heading of health and disease to enhance recovery and prevent further decline of the species. The plan is designed to prevent the loss of data and ensure that all necessary information is collected. The plan is based on the Hawaiian Monk Seal Recovery Plan (HMSRP) and the recommendations of the Hawaiian Monk Seal Recovery Plan (HMSRP). The plan focuses on addressing various health and disease projects that address management and recovery of the species. The plan is designed to prevent the loss of data and ensure that all necessary information is collected. The plan is based on the Hawaiian Monk Seal Recovery Plan (HMSRP) and the recommendations of the Hawaiian Monk Seal Recovery Plan (HMSRP).

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## North Atlantic Right Whale Consortium (NARWC)

Founded 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.
### Appendix F: Distilled Tool Matrix

<table>
<thead>
<tr>
<th>Purpose/Health indicator for...</th>
<th>Data/tissue collected</th>
<th>Method/Tool</th>
<th>Platform</th>
<th>Operational?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance, distribution</td>
<td>Photographs</td>
<td>Photograph</td>
<td>Vessel, aerial (plane or UAS)</td>
<td>Yes</td>
</tr>
<tr>
<td>Abundance, distribution</td>
<td>Images</td>
<td>Satellite imagery</td>
<td>Remote</td>
<td>No</td>
</tr>
<tr>
<td>Behavior (Biomechanics, body condition, foraging rate and depth, risk exposure, habitat use, bioenergetics, costs of entanglement)</td>
<td>Movement, depth, biomechanics (thrust/power), diving behavior, speed, foraging, sound production, acoustic exposure, relative body density, ventilation, blubber, prey, position through time; Skin (opportunistic)</td>
<td>Tagging</td>
<td>Vessel</td>
<td>Yes, short attachment times</td>
</tr>
<tr>
<td>Bioenergetics model (body condition)</td>
<td>Blubber</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Bioenergetics, wound healing, lesion characterization; open blowhole core temperature; detection of whale blow for ship avoidance (near field)</td>
<td>Photographs (Skin surface temperature)</td>
<td>Thermal IR camera</td>
<td>Vessel, aerial (plane or UAS)</td>
<td>Experimental</td>
</tr>
<tr>
<td>Body condition-qualitative, skin condition, rake marks, cyamid loads, lesions, life history, survival, fecundity, photo-id (&quot;Visual Health Assessment&quot;)</td>
<td>Photographs</td>
<td>Photograph</td>
<td>Vessel, aerial (plane or UAS), necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Body condition-quantitative, length: width ratios</td>
<td>Orthogonal planar photographs, altitude</td>
<td>UAS (planar, vertical images)</td>
<td>Vessel</td>
<td>Yes</td>
</tr>
<tr>
<td>Contaminants, POPs, plasticizers-microplastics, macroplastics</td>
<td>Blubber (Lipidome, lipid content) (quality/quantity)</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Contaminants, POPs, plasticizers-microplastics, macroplastics</td>
<td>Skin</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Contaminants, POPs, plasticizers-microplastics, macroplastics; Biotoxins (HABs)</td>
<td>Feces</td>
<td>Net collection</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Cytology (Inflammation, parasites)</td>
<td>Respiratory vapor</td>
<td>UAS or pole</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Distribution, individual identification/life history (photo-id), body condition</td>
<td>Photographs</td>
<td>Citizen science</td>
<td>Vessel (cruise ships, recreational boaters, etc.)</td>
<td>Yes</td>
</tr>
<tr>
<td>Genetics (Sex, genotype, paternity, etc.)</td>
<td>Blubber</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Genetics (Sex, genotype, paternity, etc.)</td>
<td>Skin</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Purpose/Health indicator for...</td>
<td>Data/tissue collected</td>
<td>Method/Tool</td>
<td>Platform</td>
<td>Operational?</td>
</tr>
<tr>
<td>--------------------------------</td>
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<td>--------------</td>
</tr>
<tr>
<td>Hormones (Reproduction, sex, relative &quot;stress responses,&quot; metabolism/energetics, thermoregulatory stressors, chronic stress)</td>
<td>Baleen</td>
<td>Necropsy</td>
<td>Necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Hormones (Reproduction, sex, relative &quot;stress responses,&quot; metabolism/energetics, thermoregulatory stressors, chronic stress)</td>
<td>Blood</td>
<td>New tag for blood collection</td>
<td>Vessel, necropsy</td>
<td>No (tag under development)</td>
</tr>
<tr>
<td>Hormones (Reproduction, sex, relative &quot;stress responses,&quot; metabolism/energetics, thermoregulatory stressors, chronic stress)</td>
<td>Blubber (Lipidome, lipid content) (quality/quantity)</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Hormones (Reproduction, sex, relative &quot;stress responses,&quot; metabolism/energetics, thermoregulatory stressors, chronic stress)</td>
<td>Respiratory vapor</td>
<td>UAS or pole</td>
<td>Vessel</td>
<td>Yes</td>
</tr>
<tr>
<td>Hormones (Reproduction, sex, relative &quot;stress responses,&quot; metabolism/energetics, thermoregulatory stressors, chronic stress)</td>
<td>Feces</td>
<td>Net collection</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Injury state (e.g., wounds, entanglement)</td>
<td>Photographs</td>
<td>Photograph</td>
<td>Vessel, aerial (plane or UAS), necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Microbiome (Condition, pathogens)</td>
<td>Respiratory vapor</td>
<td>UAS or pole</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Microbiome (Omics)</td>
<td>Skin</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Microbiome (Omics)</td>
<td>Feces</td>
<td>Net collection</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Nutrition (stable isotopes - food shifts, body condition)</td>
<td>Blubber</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Nutrition (stable isotopes - food shifts, body condition)</td>
<td>Skin</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Nutrition (stable isotopes - food shifts, body condition)</td>
<td>Muscle</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Nutrition (stable isotopes - food shifts, body condition)</td>
<td>Baleen</td>
<td>Necropsy</td>
<td>Necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Nutrition (stable isotopes - food shifts, body condition)</td>
<td>Blood/lipidome - lipid content (quality/quantity)</td>
<td>New tag for blood collection</td>
<td>Vessel, necropsy</td>
<td>No (tag under development)</td>
</tr>
<tr>
<td>Nutrition (stable isotopes - food shifts, body condition)</td>
<td>Feces</td>
<td>Net collection</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogens (Microbial/viral/fungal)</td>
<td>Skin</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogens (Microbial/viral/fungal)</td>
<td>Respiratory vapor</td>
<td>UAS or pole</td>
<td>Vessel</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogens (Microbial/viral/fungal)</td>
<td>Feces</td>
<td>Net collection</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Skin lesions (Skin health and condition)</td>
<td>Skin</td>
<td>Biopsy</td>
<td>Vessel, necropsy</td>
<td>Yes</td>
</tr>
<tr>
<td>Skin lesions (Skin health and condition)</td>
<td>Photographs</td>
<td>Photograph</td>
<td>Vessel, aerial (plane or UAS), necropsy</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Model Parameter Category</th>
<th>Sub-Category</th>
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<td>Breath, blubber, fecal, baleen analysis for sex steroids</td>
<td>Photo ID &amp; Photogrammetry (incl. outcome)</td>
<td>Necropsy</td>
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<td>Fecal sex steroid</td>
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<td>Body condition, nutritional state</td>
<td>Visual Health Assessment</td>
<td>Photogrammetry</td>
<td>Necropsy</td>
<td>Biopsy, fecal, blow hormone (thyroid &amp; stress)</td>
<td>Blubber biopsy fatty acids</td>
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<td>Other state variables</td>
<td>Body length</td>
<td>Photogrammetry</td>
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<td>Genetics (linking juveniles to calves)</td>
<td>Epigenetics once validated</td>
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<td>Photo ID_Mark recapture &amp; Photogrammetry</td>
<td>Genetics</td>
<td>Sex steroids</td>
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<td>Necropsy</td>
<td>Baleen</td>
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<td>Immature</td>
<td>Photo ID_Mark recapture &amp; Photogrammetry</td>
<td>Necropsy</td>
<td>Breath, blubber, fecal, baleen analysis for sex steroids</td>
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<td>Senescence</td>
<td>Photo ID_Mark recapture &amp; Photogrammetry</td>
<td>Necropsy</td>
<td>Breath, blubber, fecal, baleen analysis for sex steroids</td>
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<td>Photo ID_Mark recapture &amp; Photogrammetry</td>
<td>Necropsy</td>
<td>Breath, blubber, fecal, baleen analysis for sex steroids</td>
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<td></td>
<td>Immature</td>
<td>Photo ID_Mark recapture &amp; Photogrammetry</td>
<td>Necropsy</td>
<td>Breath, blubber, fecal, baleen analysis for sex steroids</td>
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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.
- 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 and 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
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.

References


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
   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

Biopsy
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

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

Regular font: ongoing and critical to maintain; *Italicics: 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.