Marine Mammal Commission

An independent agency of the U.S. Government

Marine Mammal Health Surveillance Workshop Report

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Background

Climate change has and will result in a multitude of changes to ocean and coastal ecosystems, many of which will impact marine mammal health. Increasing harmful algal blooms, changes in the prevalence and distribution of pathogens, and shifting distribution of marine mammals, their prey, and human activity in response to environmental change all have the potential to impact the health of marine mammal populations. Detection of changes in marine mammal health can serve as an early warning of population declines, broader ecosystem changes, and even threats to human health. Early detection is essential for timely interventions to prevent or mitigate the negative impacts on marine mammal populations and the ecosystems of which they are a part. This capacity for early detection can only be built through systematic health monitoring and surveillance. Integrating marine mammal health data with ocean and coastal observing systems to correlate health effects with the environmental changes that are expected to occur with a changing climate will enable prevention, mitigation, and intervention to reduce impacts and increase resilience.

On April 19-21, 2023 the Marine Mammal Commission hosted a workshop on marine mammal health surveillance in a changing climate, bringing together veterinarians, epidemiologists, and managers from multiple federal agencies, along with subject matter experts from the U.S. and abroad (see Appendix 1 for participants). The purpose of the workshop was to develop a vision for an integrated, temporally- and spatially-structured sampling plan to monitor the threats to health of marine mammals across the nation, focusing on those infectious agents, toxins, and health parameters expected to be most influenced by a changing climate. Here we present the results of that workshop and the plan, which identifies priorities for sample collection and testing that will contribute to systematic health monitoring and surveillance of marine mammals nationwide. This plan will serve as a resource for researchers, government agencies, and non-governmental organizations to guide health monitoring and surveillance of marine mammals to detect impacts of climate change.

Workshop Purpose and Goals

The purpose of the workshop was to develop a national plan for temporally- and spatially- structured marine mammal health surveillance. The plan was to incorporate components for live, by-caught, subsistence harvested, and stranded marine mammals, and parameters to be monitored or surveilled, prioritized in consideration of the pathogens, toxins, and environmental conditions that are likely to be influenced by a changing climate.

The specific workshop goals were to:

- Review primary objectives and components of a monitoring and surveillance system;
- Prioritize exposure parameters, species, and populations to be monitored;
- Discuss potential approaches for conducting monitoring and surveillance, and outline a sampling plan.

National Marine Mammal Health Monitoring and Surveillance Plan

Health *monitoring* is essential for effective management of marine mammal stocks and response to stranding events. Knowledge of baseline health conditions, including infectious disease prevalence and exposure to toxins from harmful algal blooms (HAB), as well as an understanding of the patterns, determinants, and ecology of disease, are critical for mortality or morbidity investigations and for conservation planning. Examples of management actions that can be informed by baseline health monitoring include:

1. Unusual mortality event[1] (UME) investigation and response, as mandated under the Marine Mammal Protection Act (MMPA);
2. Natural resource damage assessments[2] (NRDAs) following oil or other chemical releases, as mandated under the Oil Pollution Act or the Comprehensive Environmental Response, Compensation and Liability Act;
3. Development of recovery plans for threatened or endangered species[3], as required under the Endangered Species Act (ESA);
4. Inclusion and incorporation of information on climate change and habitat issues in marine mammal stock assessment reports[4].

Disease *surveillance*, which looks for emerging disease and includes a plan for action when disease is detected or reaches a specified threshold (see box), is also important for marine mammal management, particularly when the identification of intervention actions, development of recovery plans, or adaption of existing recovery plans is required.

Monitoring versus Surveillance

Monitoring: Ongoing efforts to assess the health and disease state of a given population. Efforts are systematic and continual, with active or passive observations. Can include routine observations of health and endemic disease prevalence, as well as observation of environmental factors.

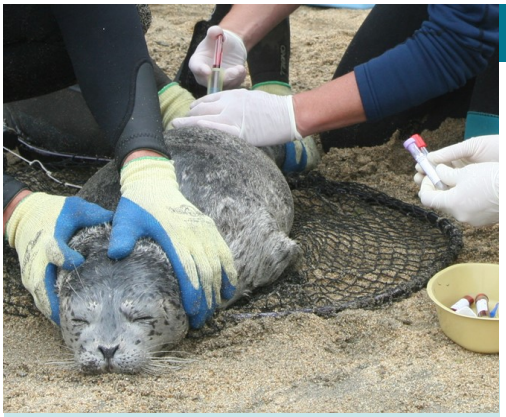
Surveillance: Implies some form of directed action will be taken if data indicate a disease level above a certain threshold. Looks for emerging disease or spread of disease to a new area/species/ population.

Objectives

Given the management drivers outlined above, the primary objectives for a National Marine Mammal Health Monitoring and Surveillance Plan include:

1. **Establish health status of populations, including prevalence of endemic disease** to understand effects on populations and aid in the planning and interpretation of mortality and morbidity investigations;
2. **Establish baseline toxin exposures** to allow interpretation of levels reported during harmful algal blooms;
3. **Improve knowledge of infectious disease ecology** to inform recovery plans and future mitigation actions;
4. **Detect changes in population health early** to allow effective response and mitigation for animals and humans.

[1] Defined under the MMPA as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response". Revised criteria published in 2006 expanded definitions to include morbidity as well as mortality.
[2] https://darrp.noaa.gov/what-we-do/natural-resource-damage-assessment
[3] https://www.fisheries.noaa.gov/national/endangered-species-conservation/recovery-species-under-endangered-species-act
[4] https://www.fisheries.noaa.gov/national/marine-mammal-protection/guidelines-assessing-marine-mammal-stocks



Examples of Sample Types

Fluids: Blood (whole or serum separated), aqueous humor, urine, gastro-intestinal contents, cerebrospinal fluid, amniotic fluid.

Swabs: Ocular, nasal, blow-hole, oral, rectal, vaginal/preputial, abscess/lesion.

Tissues: Skin, tongue, lung, lymph node, heart, liver, kidney, spleen, brain, uterus, abnormal mass.

Sample Storage Methods

Cool at 4°C < 3 days: Blood for hematology; swabs and tissues for bacterial culture, fluids for biotoxins; tissues for histology.

Freeze at -20°C < 1 week: Serum for serology; swabs and tissues for pathogen isolation (culture), biotoxins.

Freeze -70°C > 1 week: Serum for serology; swabs and tissues for pathogen isolation, DNA detection using PCR.

Add to RNA *later*™, freeze -70°C: Pathogen RNA detection; host transcriptomics.

Add to 10 % formalin: Tissues for histology.

Add to 70 % alcohol: Tissues for DNA extraction; parasites.

Components

The components of the plan are organized by 1) sampling approaches, 2) biotoxins and infectious agents to be prioritized for monitoring, and 3) priority health indicators for non-infectious disease.

Sampling Approaches

Samples may be obtained from live and dead marine mammals. Samples may be fluids, secretions and excretions from animals, or swabs of tissues, or pieces of tissues. Collection and storage methods will influence test results, so must be guided by the type of analyses that are planned. Sample storage methods (see box) are a best practices guideline; sample storage and transport protocols should be confirmed by the laboratory that will be conducting analyses. Data may also be from photogrammetry or visual assessments of skin and body condition. Sample size has an important role in detection of an effect and to achieve a desired precision in estimates of parameters of interest. In marine mammal health studies, sample sizes may be driven by logistics, but the limitations that this may confer must be recognized.

Samples and data can be obtained from marine mammals that strand or are by-caught in fisheries, during subsistence harvests, or through targeted field studies. The control in sampling design will depend on the approach employed (Figure 1), as will the cost and degree of effort required for obtaining samples. Sampling of opportunistically detected stranded marine mammals, including necropsy of dead animals, is a relatively low-cost tool that can provide a broad range of sample types. However, strandings are generally only a viable source for sampling of inshore or nearshore populations. Carcasses from offshore populations are rarely recovered as they often sink or are scavenged before they can be detected at sea or drift to shore. Stranded animals are also more likely to be young of the year, or ill or malnourished, their health changes leading to stranding. Samples from stranded animals are often obtained during case investigations, and sampling protocols are guided by the likely cause of disease. Other sampling approaches are more likely to provide samples that better represent the overall population, with targeted research sampling having the greatest control over sample size and the greatest flexibility to select sampling

demographics. However, targeted research sampling of live animals can be costly, logistically complex, and sample types are more limited. Seasonal differences in marine mammal distribution and behavioural differences related to age or sex must also be considered to avoid sampling biases. Hence, for many marine mammal species, optimal health surveillance will include both opportunistic and directed sampling approaches.

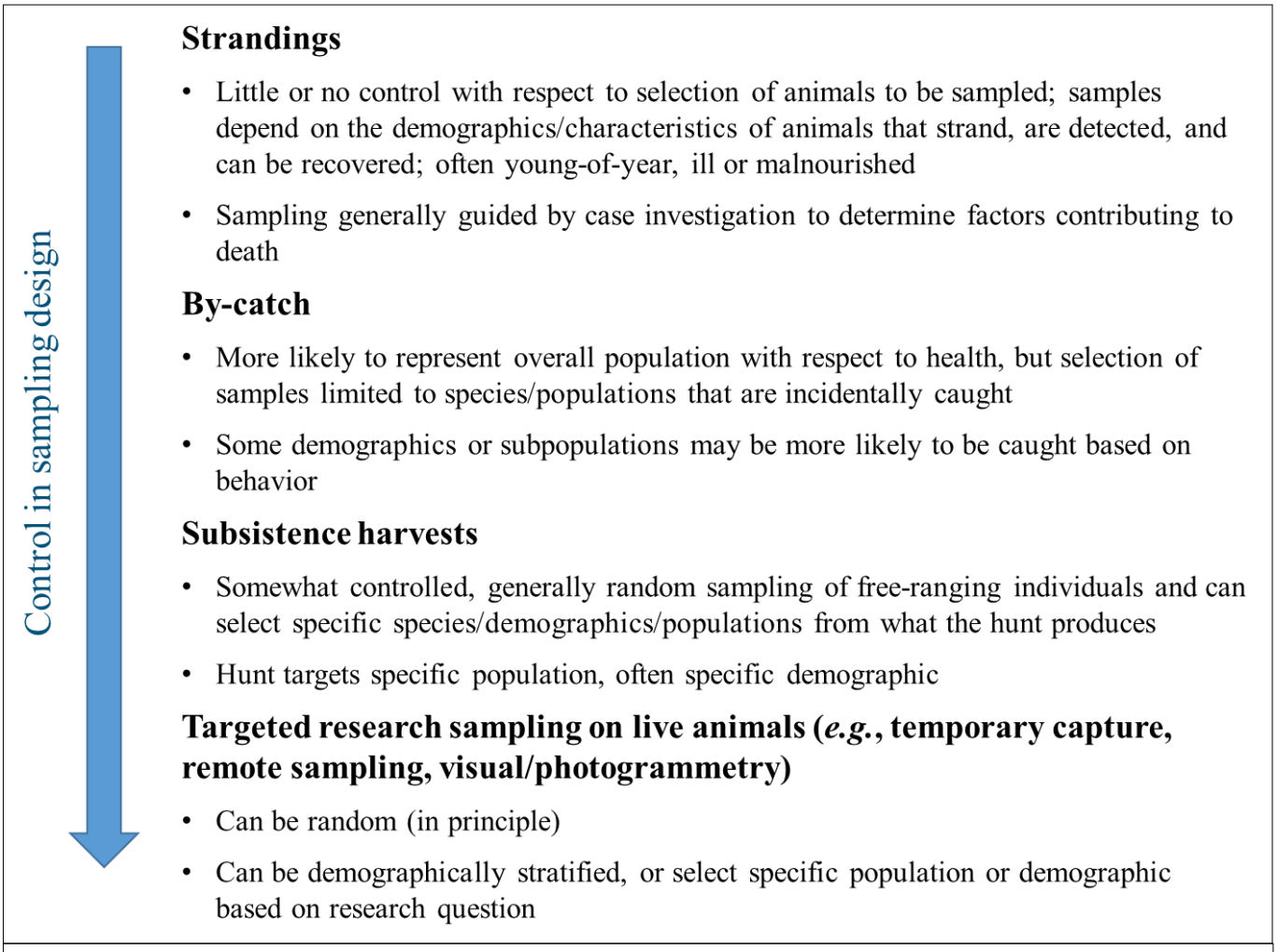


Figure 1. Overview of sampling approaches for obtaining marine mammal health data. Note that Strandings category refers to single strandings; mass strandings are more likely to be representative of the overall population, are often offshore species, and often strand alive. Mass strandings can provide high value and otherwise difficult to obtain samples (e.g., blood) for offshore delphinid species that are otherwise difficult to monitor.

Focal Species/Populations for Targeted Sampling

While sampling from strandings is necessarily driven by the species and demographics of the animals that strand, for the other sampling approaches there is utility in identifying species or populations for which targeted sampling can be focused. Having defined focal species is particularly important when there are ongoing research efforts that can be leveraged to obtain health samples. In addition, native subsistence hunts provide an opportunity for sample collection with some ability for selecting specific populations or demographics, and may be particularly important for monitoring, given the potential implications for human health.

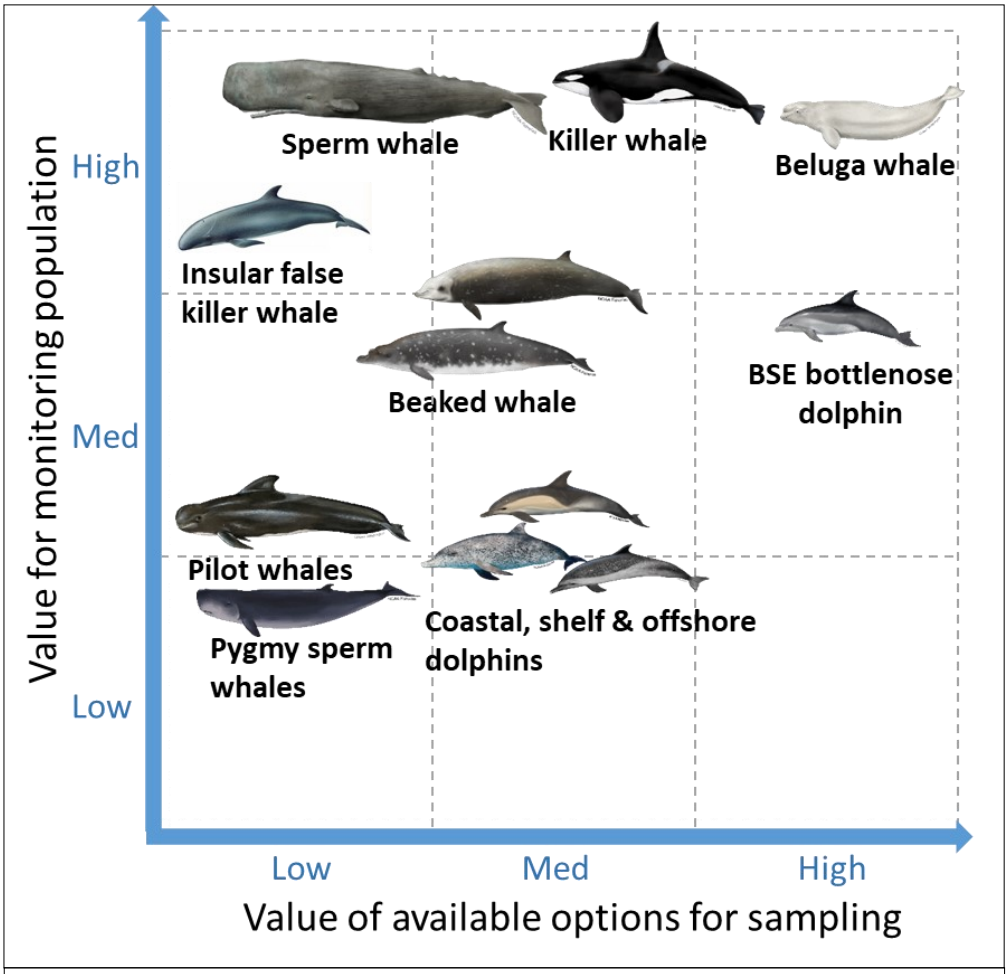


Figure 2. **Focal odontocetes for targeted health sampling**. Sperm whales and some populations of killer and beluga whales are listed as threatened or endangered, and are therefore of highest conservation value for monitoring. Coastal, shelf, and offshore dolphins can be sampled via remote biopsy, but hands-on sampling for blood is currently limited. In contrast, comprehensive hands-on health assessments are feasible for bay, sound, and estuary (BSE) bottlenose dolphins; as year-round resident populations, the BSE dolphins are important sentinels for nearshore threats.

The workshop participants discussed potential focal species and populations, considering the available options for sampling, as well as the conservation value for monitoring. Value for monitoring a population was based on management priorities, ecological importance (including importance to human health), likelihood of being affected by changing climate, and exposure to multiple stressors. Value of the available options for sampling was based on how useful the samples are for assessing health, given the options available for the population or species. For example, remote biopsy samples of skin or blubber have value for some health diagnostics (e.g., hormones, lipids); however blood, which can currently only be obtained from hands-on sampling, is a higher value sample because it can be used for a broad range of health diagnostics, some of which are predictive of survival probability. Discussions were organized around the following taxonomic groups: odontocetes, mysticetes, and pinnipeds (Figures 2-4). Sea otters, polar bears, and manatees were also discussed but are not plotted as each are single species rather than a taxonomic group; all are priority species for management (all have ESA listed populations) for which hands-on sampling is feasible.

In general, populations occupying coastal habitats were considered to be of medium to high value for targeted sampling as they are generally the most susceptible to land-based pollutants (including pathogens), algal blooms, and to habitat changes due to fresh water run-off. Fortunately, the nearshore distribution of these populations facilitates multiple sampling options, including remote biopsy, visual health assessment, and photogrammetry studies. For some species (e.g. bottlenose dolphins, beluga whales, sea otters, polar bears, manatees, multiple pinniped species), relatively small body size also makes

capture-release for hands-on sampling (including blood) feasible.

For offshore species, targeted sampling or monitoring is logistically more difficult and sampling options are limited. However, some of these species (e.g., NARW, Rice's whale) are of high conservation value and emerging technologies for remote health assessment of live, free-swimming animals are promising. Emerging sample collection and analysis approaches for tissue, feces, blow, and morphometrics provide for measurement of stress, metabolic, and reproductive hormones, nutritional condition, and molecular changes. Some of these approaches are well developed and are being applied for many species that are intractable for hands-on health assessment (e.g. Burgess et al. 2018, Hunt et al. 2019, Aoki et al. 2021). However, coordinated efforts are needed to develop baseline reference ranges for these measurements (particularly hormone measures) considering factors such as age, behavioral state, and reproductive state, for appropriate interpretation of the data. The value of epigenetic analyses for age estimation and as a potential indicator of health has also been demonstrated for multiple dolphin and whale species (e.g. Barratclough et al. 2021, Robeck et al. 2021, Parsons et al. 2023). Interpretation of data from other molecular analyses (e.g. transcriptomic, proteomic or metabolomic) requires further study but offers promise for future monitoring efforts (for review, see Mancia 2018). In addition, recent biochemistry advances have demonstrated that longitudinal samples of baleen from recovered carcasses can be analysed to explore changes in nutritional state and reproductive success over the lifetime of the whale (Hunt et al. 2016, Lysiak et al. 2018).

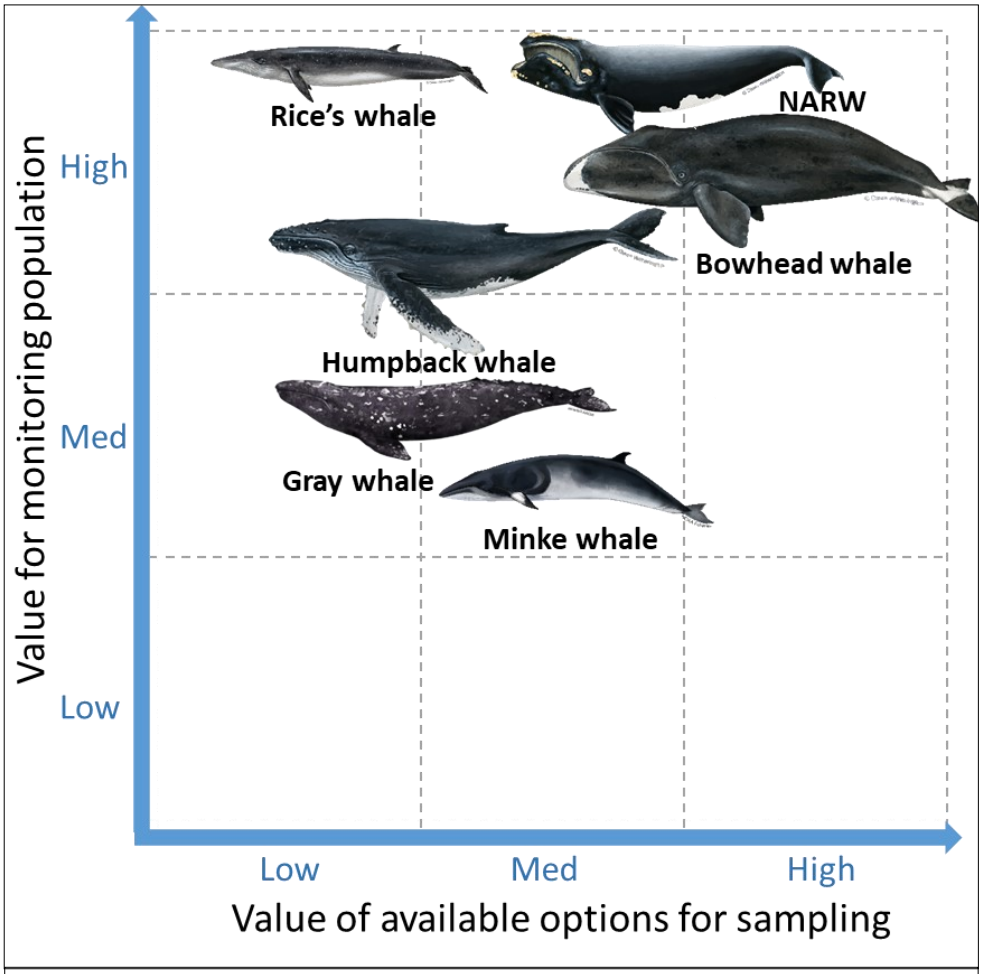


Figure 3. **Focal mysticetes for targeted health sampling.** Historical whaling led to depletion of many mysticete species, leaving most listed as endangered throughout their range or portions of their range. Critically low numbers make conservation value high for North Atlantic right whales (NARW) and Rice's whales. For NARWs, intensive monitoring over the past several decades has facilitated development of remote health sampling options. Subsistence food security and safety make the value of monitoring for species such as bowhead whales high, and subsistence hunts provide opportunities for sampling.

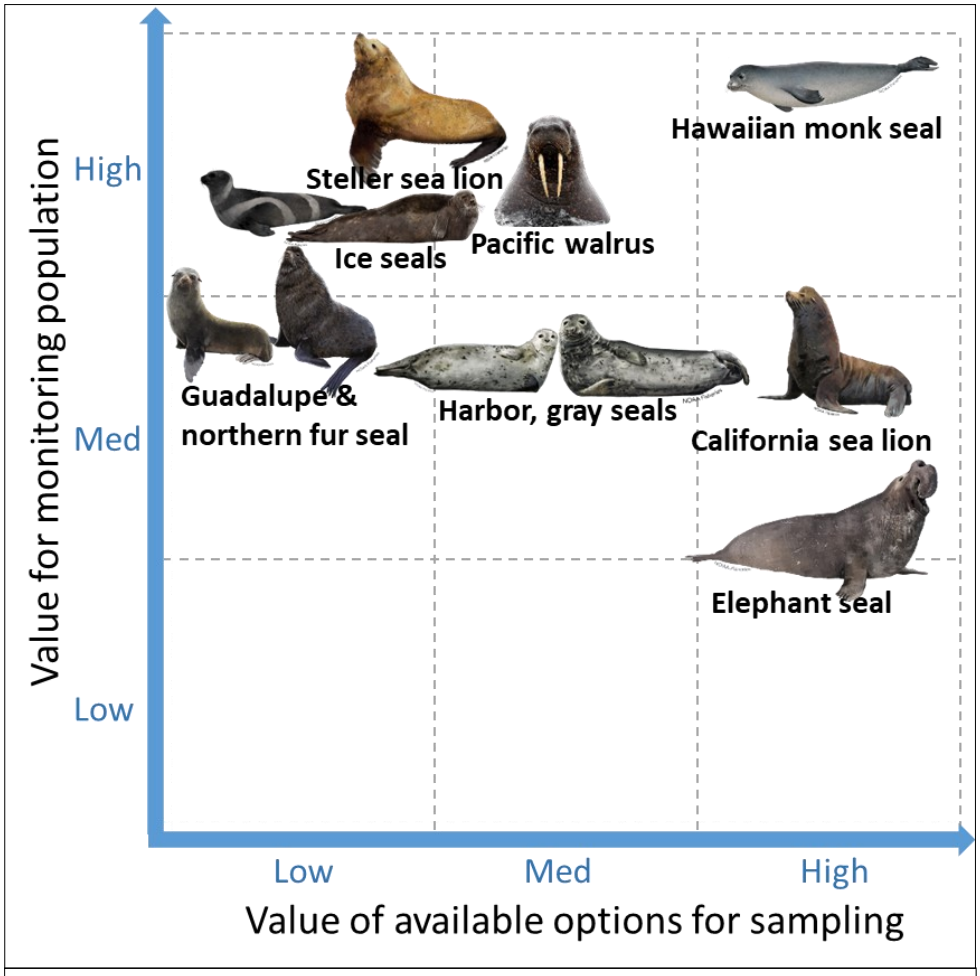
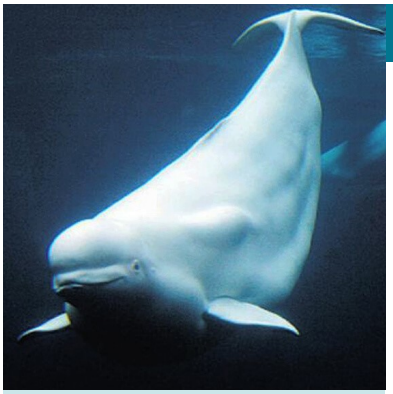


Figure 4. **Focal pinnipeds for targeted health sampling.** Hawaiian monk seals have high conservation value because of their endangered status and low population size, but NOAA's recovery efforts have made significant advances in health monitoring and surveillance/intervention, giving them high value for sampling options as well. Ongoing research programs have promoted Northern elephant seals and California sea lions as model species for understanding the effects of disturbance, infectious disease, biotoxins, and chemical pollutants. Subsistence food security and safety make the value of monitoring for species such as ice seals high, and subsistence hunts provide opportunities for sampling.

Priority Biotoxins and Pathogens

Pathogens and biotoxins that can impact marine mammal health were prioritized for sampling based on the following criteria:

1. Potential for substantial population impact (high mortality, long-term reproductive impacts), which is even more important if the marine mammal species has a small population size and is of critical conservation concern;
2. Climate sensitivity (likelihood to change in distribution or frequency/prevalence in relation to a changing climate);

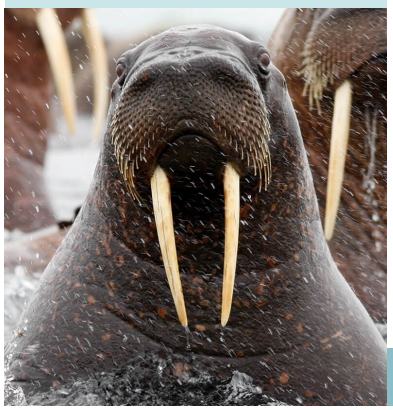


Epidemiological Terms

Exposure: Disease-causing factors, including infectious, toxic, nutritional, traumatic, genetic, degenerative, physiological, social, and behavioural.

Incidence: The number of new cases of a disease or specific health-related event over a given time period.

Prevalence: The total number of individuals in a population who have a disease or health condition at a specific point in time; usually expressed as a percentage of the population.



3. Zoonotic potential or relevance as an ecosystem health sentinel:
    a. Potential transmission to other species, including humans.
    b. Detection in the ecosystem informs risk to other threatened species (especially if they are small populations for which it is difficult to establish prevalence/incidence)
4. Importance for mortality or morbidity investigations (e.g., agents commonly detected for a given species/population that could be important for differential diagnoses in UME or NRDA investigations);
5. Mitigation potential. Note that to date in the U.S., the only mitigation measures used on free-living marine mammals are treatment with ivermectin to reduce hookworm infection in California sea lion and northern fur seal pups (DeLong et al. 2009), anti-helminthic treatment of Hawaiian monk seals to increase over-winter nutritional status (Gobush et al. 2011), and prophylactic vaccination of Hawaiian monk seals against canine distemper (Baker et al. 2017). Individual stranded animals are relocated when possible (e.g., for out-of-habitat dolphins), or treated in rehabilitation facilities for specific diseases on a case-by-case basis.

Priority pathogens and toxins for sampling grouped by species or taxa for each region are summarized in Appendix 3, Tables 1a-e. Sample collection, storage, and testing methods for key pathogens and toxins are summarized in Appendix 3, Table 2.

Priority Indicators for Non-Infectious Disease

The prevalence and incidence (see box) of some non-infectious diseases may reflect environmental changes that occur as a result of climate change. Thus, monitoring these diseases can contribute to health surveillance, in addition to surveying for specific threats.

For each region and species or taxonomic group, participants discussed the primary non-infectious stressors of concern (e.g. changes in prey abundance, distribution, or quality; salinity changes; human interaction; chemical pollutants; marine debris), the health conditions likely to be associated with the stressors, and which of those endpoints could be readily monitored with existing technology (Appendix 3, Table 3). Discussions focused on health endpoints; monitoring of chemical contaminants was considered beyond the scope of the workshop.

Research and Infrastructure Needs

Additional coordination and collaboration are needed to develop an implementation plan for a National Marine Mammal Health Monitoring and Surveillance Program, and must involve partners for collecting samples (such as the marine mammal stranding network, federal and state agencies, Alaska co-management groups and native subsistence communities) and partners for storing (e.g. NIST) and analyzing samples. The following were identified as essential needs for building the program:

Laboratory Support

- Enhanced capacity for pathogen analyses with quality assurance and control practices to ensure consistency across diagnostic tests;
- Expansion of the Wildlife Algal-toxin Research and Response Network (WARRN-West) to east coast;
- Sample archive storage capacity, ideally separate facilities for west and east coasts;

Information Management

- Infrastructure for data sharing in accessible formats to synthesize and detect change (e.g. HealthMap);
- Near real-time updates/access to data;

Analysis and Communication

- Quantitative analysis for targets, sample sizes, triggers, actions resulting from triggers (particularly for surveillance aspects);
- Analysis/models to link health data and demographic outcomes;
- Plan for relaying information to those who can take action;
- Capacity for integrating health data with environmental and oceanographic data, as well as prey data (abundance and quality), ideally as part of the Integrated Ocean Observing System (IOOS);
- Schedule for periodic review and update of the plan as new pathogens, toxins, or non-infectious disease threats emerge and management priorities shift.

Discussions also identified additional specific health research needs:

1. Better understanding of *Brucella* tissue distribution and chronic infectious states in cetaceans;
2. Determination of species susceptibility and prevalence of morbillivirus in eastern North Pacific;

3. Better understanding of how exposure to HAB toxins and infectious diseases affects susceptibility to vessel strike and entanglement (i.e., the cumulative impacts of multiple stressors, especially for NARWs);
4. Development of better assays and understanding of microcystin/cyanotoxins in the marine environment;
5. Investigation of sea otter susceptibility to coronavirus.

No specific next steps were identified by the group, but several actions were considered valuable for the implementation of a National Marine Mammal Health Surveillance Program:

1. Incorporate this surveillance plan into NOAA's One Health Strategy planning;
2. Engage with academic and community partners to share the vision for a National Marine Mammal Health Surveillance Plan;
3. Share this plan with grant (e.g., Prescott and Marine Mammal Commission) applicants and encourage sampling of animals in accordance with the plan;
4. Encourage incorporation of health monitoring and surveillance into Stock Assessment process;
5. Share training materials for sample collection and storage with subsistence hunters, bycatch observers, and biologists conducting live capture/release programs, e.g. pinniped marking.

Acknowledgments

The workshop steering committee was composed of Lori Schwacke, Frances Gulland, Teri Rowles, Peter Thomas, and Lauri Leach. Their sincere thanks go to workshop rapporteur Denise Greig for her hard work during the workshop and to Erin LaBrecque for assisting with figure graphics. The steering committee also thanks Chris Kreuder Johnson, Raphe Kudela, Katie Prager, and Katie Colegrove for providing background presentations for the workshop.

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Appendix 1: Participants

Workshop Organizers

Lori Schwacke, Marine Mammal Commission

Frances Gulland, Commission Chair, Marine Mammal Commission

Teri Rowles, National Marine Fisheries Service, Office of Protected Resources

Peter Thomas, Marine Mammal Commission

Lauri Leach, Marine Mammal Commission

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Michelle Barbieri, National Marine Fisheries Service, Pacific Islands Fisheries Science Center

Katie Colegrove, University of Illinois

Deb Fauquier (remote), National Marine Fisheries Service, Office of Protected Resources

Carrie Goertz, Alaska Sea Life Center

Denise Greig, Ocean Associates, Inc. under contract to National Marine Fisheries Service, Office of Protected Resources

Chris Kreuder Johnson (remote), University of California, Davis

Nick Kellar, National Marine Fisheries Service, Southwest Fisheries Science Center

Meg Kirchgessner (remote), US Fish & Wildlife Service, Wildlife Health Office

Kathi Lefebvre, National Marine Fisheries Service, Northwest Fisheries Science Center

Stephen Raverty (remote), Marine Mammal Research Unit, British Columbia

Sarah Sharp, International Fund for Animal Welfare

Nicole Stacy (remote), University of Florida

Len Thomas, University of St. Andrews

LeAnn White, US Geological Survey, National Wildlife Health Center

Sarah Wilkin, National Marine Fisheries Service, Office of Protected Resources

Appendix 2: Presentation Summaries

Several presentations reviewed the current state of knowledge on the impacts of climate change on marine mammal health in the U.S., and gave examples of existing health surveillance schemes for marine mammals.

1. Frances Gulland (MMC) – Marine mammal health in a changing climate.

What we know:

- Habitat loss has changed marine mammal distribution resulting indirectly in mortality.
- Extreme weather events result in decreased salinity causing "freshwater disease" in dolphins, cold stress in manatees, storms cause disruption to habitat.
- Changes in prey distribution can affect marine mammal body condition, reproduction, and survival.
- Harmful algal blooms (HABs) have become increasingly more frequent & extensive in U.S. waters since 1990, toxicosis in sea lions, dolphins, manatees.
- Geographic distribution of some marine mammal pathogens are increasing with warming oceans.

What we don't know:

- Data associating health changes with environmental measurements scant.
- While effects of HAB toxins on pinnipeds are well known, effects on cetaceans are less clear.
- Large-scale systematic sampling for specific pathogens over time and space is rare, so distribution of infectious pathogens in marine mammals are largely unknown.
- These knowledge gaps make prediction and response preparation for disease outbreaks difficult.

2. Raphe Kudela (University of California Santa Cruz) – Harmful algal blooms in a changing climate.

- With climate change, the ocean will be warmer, more acidic, and have more intense and/or longer duration HAB blooms.
- Temperature and HAB shifts attributable to anthropogenic climate change
- We may be exporting HABs to the Arctic
- Marine mammal populations will experience more extreme events and shifting spatial/temporal patterns.
- Shifts in population distributions of algae, planktivores, and mammals is exposing naïve populations to new stressors
- HABs are yet another stressor added to temperature stress, food web shifts
- For the future:
  - We are well-positioned to monitor long-term trends
  - Unknown question: will organisms evolve to adapt to a changing climate?
  - Will local areas act as refugia for sub-populations?

3. Chris Kreuder Johnson (University of California Davis) – Infectious disease in terrestrial ecosystems and a changing climate.

- Ecosystem integrity provides an important disease regulating service, and emerging infectious disease often results as an abrupt consequence of ecological change
- Risk is often highest at the edge of ecosystems where animal-human interfaces facilitate disease transmission
- For marine mammals, there are climate-related threats on the horizon from:
  - Land-to-sea pathogen pollution (e.g. protozoal parasites linked to domestic pets or other non-native species coupled with extreme precipitation and loss of filtering wetlands)
  - Harmful algal blooms, which are expected in increase in magnitude, persistence, and frequency
  - Increases in bacteria (e.g. Vibrio spp.) that are associated with warming trends in sea surface temperature
- Major concerns come from the emerging viruses, coupled with the knowledge gaps for detection, intra- and cross-species transmission, and ecological niches in the marine system

4. Katie Prager (University of California Los Angeles) – Surveillance for leptospirosis in California sea lions.

- Used data and samples collected over decades, intensively 2010-2019
- Demonstrated that *Leptospira interrogans* serovar Pomona circulated endemically for 3 decades in California sea lions
- Disappeared from population in early 2013, likely driven by climatic perturbations that altered host demography and seasonal movements, disrupting conditions favorable to *Leptospira* transmission
- Re-emerged 4 years later with climate-associated shifts back to favorable conditions and reintroduction from unknown source
- This unique, long-term study provides insight into how climatic and intrinsic host factors may interact to influence infectious disease

5. Katie Colegrove (University of Illinois) – Surveillance for Brucella infections in U.S. cetaceans.

- Most commonly affected species:
  - Bottlenose dolphin (*Tursiops truncatus)*
  - Striped dolphin (*Stenella coeruleoalba*)
  - Common dolphin (*Delphinus sp.*)
  - Minke whale (*Balaenoptera acutorostrata*)
- Brucella surveillance in cetaceans has been conducted based on suspect lesions on gross or histologic evaluation, guided by pathology findings
- For some areas, PCR surveys have been conducted utilizing banked frozen tissue (lung, CNS tissue/fluid), driven largely by individual stranding networks
- PCR surveys are becoming more frequent, background prevalence ~20-30% in common bottlenose dolphins

6. Teri Rowles and Denise Greig (NMFS Marine Mammal Health and Stranding Response Program) - Marine Mammal Health Surveillance Workgroup.

- Health surveillance was identified as a priority for NMFS needing additional strategic planning and investment, leading to the development of an internal NMFS Marine Mammal Health Surveillance Workgroup. The Workgroup goal and focus are to:
- Maximize strategic sampling and health data collection from current taxa to answer health priorities and modeling needs to assess population impacts.
- Develop a prospective long-term research strategy, with an epidemiology and health perspective, to consider indicator taxa/species, diseases of concern, pathways of concern, and changing environments to predict/monitor wild populations before strandings or declines occur.
- Workgroup Participants: are the Marine Mammal Health and Stranding Response Program, Science Centers, Regional staff, Working Group on MMUME, +/- external partners (add for long-term plan), other NOAA offices (ONMS, ORR).
- Products will be:
    - Compilation of annual list of ongoing NMFS live marine mammal research field projects, sample analyses and uses, and health modeling (Regional Offices and Science Centers);
    - Integration of health surveillance using live and dead strandings as well as subsistence harvests;
    - Development health surveillance science strategy for monitoring, analyses, and information; this strategy will also be used to inform an archival and information management strategy (including for the National Marine Mammal Tissue Bank).

Appendix 3: Tables

Table 1a. Alaska sampling priority pathogens and toxins

	Climate sensitive	Potential for population level impact	Zoonotic	Ecosystem health sentinel	Comments
Steller sea lion, Northern fur seal					
Viruses		Morbilliviruses Influenza	Influenza	Herpesviruses	OtHV1 associated with cancer in CSLs, origin unknown but potentially another otariid
Bacteria	*Vibrio* spp.	*Leptospira* spp.	*Brucella* spp.	*Campylobacter* spp., *Salmonella* spp., *Klebsiella* spp., Antibiotic resistant bacteria	
Parasites	*Dirofilaria, Acanthocheilonema spirocauda, Coccidiodes immitis*	*Uncinaria* spp.		*Toxoplasma gondii, Sarcocystis neurona*	*Uncinaria* only pathogenic in newborn pups.
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin		Domoic acid, saxitoxin	
Walrus					
Viruses		Morbilliviruses Influenza			
Protozoa, Parasites			*Toxoplasma gondii, Trichinella*	*Toxoplasma gondii,*	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin		Domoic acid	
Ice seals					
Viruses	Flaviviruses e.g. West Nile Virus	Morbilliviruses Influenza	Influenza		
Bacteria, fungi	*Vibrio* spp., Dermatophytes				
Protozoa, Parasites				*Toxoplasma gondii, Otostrongylus circumlitis, Sarcocystis* spp.	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin			
Sea otter					
Viruses		Morbilliviruses, Influenza Coronavirus	Influenza		
Bacteria, fungi	*Vibrio* spp., Histoplasma		MRSA	MRSA	

Protozoa, Parasites		*Toxoplasma gondii, Sarcocystis neurona, Acanthocephala* spp.		*Toxoplasma gondii, Sarcocystis neurona*	Clusters of otter mortalities from *S. neurona* associated with storm-water run off
Biotoxins	Microcystins, domoic acid, saxitoxin	Microcystins, domoic acid, saxitoxin		Microcystins, domoic acid, saxitoxin	
Killer whale, harbor porpoise, beluga					
Viruses	Flaviviruses	Morbillivirus	Influenza		
Bacteria, fungi	*Erysipelothrix rhusiopatheae*, *Vibrio* spp., *Cryptococcus gatti*	*Brucella* spp.			
Protozoa, Parasites			*Toxoplasma gondii, Trichinella*	*Toxoplasma gondii, Sarcocystis* spp.	
Biotoxins	Domoic acid, saxitoxin			Domoic acid, saxitoxin	
Gray whale					
Viruses	Flaviviruses	Morbilliviruses	Influenza		
Bacteria		*Brucella* spp.			
Protozoa, Parasites				Toxoplasma gondii	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin		Domoic acid, saxitoxin	Exposure during feeding season may cause abortion in breeding grounds
Baleen whales					
Viruses		Morbillivirus	Influenza		
Bacteria, fungi		*Brucella* spp.			
Protozoa, parasites			*Toxoplasma gondii, Sarcocystis* spp.		
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin		Domoic acid, saxitoxin	

Table 1b. West Coast sampling priority pathogens and toxins

	Climate sensitive	Potential for population level impact	Zoonotic	Ecosystem health sentinel	Comments
California sea lion, Steller sea lion					
Viruses		Morbilliviruses Influenza	Influenza	Herpesviruses	OtHV1 associated with cancer in CSLs, origin unknown but potentially another otariid
Bacteria	*Vibrio* spp., *Leptospira* spp.	*Leptospira* spp.	*Brucella* spp.	*Campylobacter* spp., *Klebsiella* spp., Antibiotic resistant bacteria	
Parasites	*Dirofilaria, Acanthocheilonema spirocauda, Coccidiodes immitis*	*Uncinaria* spp.		*Toxoplasma gondii, Sarcocystis neurona*	*Uncinaria* only pathogenic in newborn pups.
Biotoxins	Domoic acid	Domoic acid		Domoic acid	
Northern fur seal, Guadalupe fur seal					
Viruses		Morbilliviruses Influenza		Herpesviruses	
Bacteria, fungi	*Vibrio* spp., *Coccidiodes immitis, Leptospira*	*Leptospira* spp.	*Coxiella burnetti*		
Protozoa, Parasites	*Dirofilaria, Acanthocheilonema spirocauda, Coccidiodes immitis*	*Uncinaria* spp.		*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins	Domoic acid	Domoic acid		Domoic acid	
Northern elephant seal					
Viruses	Flaviviruses e.g. West Nile Virus	Morbilliviruses Influenza	Influenza		Mortality associated with WNV reported in phocids in display facilities
Bacteria, fungi	*Vibrio* spp.	*Leptospira* spp.		*Campylobacter* spp., *Salmonella* spp., Antibiotic resistant bacteria	
Protozoa, Parasites	*Dirofilaria, Acanthocheilonema spirocauda, Coccidiodes immitis*			*Toxoplasma gondii, Otostrongylus circumlitis, Sarcocystis neurona*	

Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin			
Harbor seal					
Viruses	Flaviviruses e.g. West Nile Virus	Morbilliviruses Influenza	Influenza		Mortality associated with WNV reported in phocids in display facilities eastern US
Bacteria, fungi	*Vibrio* spp.		Brucella spp., MRSA	*Campylobacter* spp., *Salmonella* spp., Antibiotic resistant bacteria	
Protozoa, Parasites	*Dirofilaria, Acanthocheilonema spirocauda, Otostrongylus circumlitis,*			*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin			
Sea otter					
Viruses		Morbilliviruses, Influenza Coronavirus	Influenza		
Bacteria, fungi	*Vibrio* spp., *Coccidiodes immitis*		MRSA	MRSA	
Protozoa, Parasites		*Toxoplasma gondii, Sarcocystis neurona, Acanthocephala* spp.		Toxoplasma gondii, Sarcocystis neurona	Clusters of otter mortalities from *S. neurona* associated with storm water run off
Biotoxins	Microcystins, domoic acid, saxitoxin	Microcystins, domoic acid, saxitoxin		Microcystins, domoic acid, saxitoxin	
Bottlenose dolphin, harbor porpoise, common dolphin, killer whale					
Viruses	Flaviviruses	Morbilliviruses	Influenza		
Bacteria, fungi	*Erysipelothrix rhusiopatheae, Vibrio* spp., *Coccidiodes immitis, Cryptococcus gatti*	*Brucella* spp.			
Protozoa, Parasites				*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins	Domoic acid				

Gray whale					
Viruses	Flaviviruses	Morbilliviruses	Influenza		
Bacteria		*Brucella* spp.			
Protozoa, Parasites				*Toxoplasma gondii*	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin		Domoic acid, saxitoxin	Exposure during feeding season may cause abortion in breeding grounds
Offshore cetaceans					
Viruses		Morbilliviruses			
Bacteria		*Brucella* spp.			

Table 1c. Pacific Islands sampling priority pathogens and toxins

	Climate sensitive	**Potential for population level impact**	**Zoonotic**	**Ecosystem health sentinel**	**Comments**
Hawaiian monk seal					
Viruses	Flaviviruses e.g. West Nile Virus	Morbilliviruses Influenza	Influenza		
Bacteria, fungi	*Vibrio* spp., *Leptospira*	*Brucella* spp.	*Leptospira* spp.	*Leptospira* spp.	
Protozoa, Parasites		*Toxoplasma gondii*		*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins	Microcystins	Ciguatoxin, microcystin		Ciguatoxin, microcystin	
Cetaceans					
Viruses	Flaviviruses	Morbillivirus	Influenza		
Bacteria, fungi	*Erysipelothrix rhusiopatheae, Vibrio* spp.	*Brucella* spp.			
Protozoa, Parasites				*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins				Ciguatoxin	

Table 1d. Northeast U.S. and mid-Atlantic sampling priority pathogens and toxins

	Climate sensitive	Potential for population level impact	Zoonotic	Ecosystem health sentinel	Comments
Harbor and gray seals					
Viruses	Flaviviruses e.g. West Nile Virus	Morbilliviruses Influenza	Influenza		
Bacteria, fungi	*Vibrio* spp.				
Protozoa, Parasites				*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin			
Bottlenose, common, and white-sided dolphins, harbor porpoise					
Viruses	Flaviviruses	Morbilliviruses	Influenza		
Bacteria, fungi	*Erysipelothrix rhusiopatheae, Vibrio* spp., *Paracoccidioides brasiliensis, Cryptococcus* spp.	*Brucella* spp.			
Protozoa, Parasites				*Toxoplasma gondii*, *Sarcocystis neurona*	
Biotoxins	Domoic acid, saxitoxin			Domoic acid, saxitoxin	
North Atlantic right whale and other baleen whales					
Viruses	Flaviviruses	Morbilliviruses	Influenza		
Bacteria		*Brucella* spp.			Lesions in minke whales suggest exposure may occur
Protozoa, Parasites				*Toxoplasma gondii*	
Biotoxins	Domoic acid, saxitoxin	Domoic acid, saxitoxin		Domoic acid, saxitoxin	Exposure during feeding season may cause reproductive failure

Table 1e. Southeast sampling priority pathogens and toxins

	Climate sensitive	Potential for population level impact	Zoonotic	Ecosystem health sentinel	Comments
BSE Bottlenose dolphin					
Viruses	Flaviviruses	Morbilliviruses	Influenza		
Bacteria, fungi	*Erysipelothrix rhusiopatheae, Vibrio* spp., *Paracoccidioides brasiliensis*	*Brucella* spp.			
Protozoa, Parasites				*Toxoplasma gondii, Sarcocystis neurona*	
Biotoxins	Brevetoxin, domoic acid, saxitoxin	Brevetoxin		Brevetoxin, domoic acid, saxitoxin	
Coastal, shelf, and offshore dolphins & whales					
Viruses	Flaviviruses	Morbillivirus	Influenza		Arthropod -borne viruses more likely in coastal populations
Bacteria		*Brucella* spp.			
Protozoa, Parasites				*Toxoplasma gondii*	
Biotoxins	Domoic acid, saxitoxin, brevetoxin	Domoic acid, saxitoxin, brevetoxin		Domoic acid, saxitoxin, brevetoxin	Exposure during feeding season may cause reproductive failure
Manatee					
Viruses		Morbillivirus	Influenza	Papillomavirus	
Bacteria, fungi	*Leptospira* spp.				
Protozoa, parasites				*Toxoplasma gondii*	
Biotoxins	Brevetoxin	Brevetoxin		Brevetoxin, saxitoxin	

Table 2. Sample Collection and storage methods (* indicates preferred sample type)

List is not exhaustive and recommended samples and storage method may be updated over time. It is recommended to contact the laboratory that will be processing prior to collecting samples.

Note: for frozen samples, samples stored at –20˚C can also be stored at –70˚C.

Pathogen/Toxin	Sample type	Storage method
Domoic acid	Serum, urine*, feces, GI contents, amniotic fluid	Freeze vial of sample at -20°C
Saxitoxin	GI contents*, liver*, kidney	Freeze vial of sample at -20°C
Brevetoxin	Serum, urine, GI contents*, liver, kidney, lung	Freeze vial of sample at -20°C
Microcystin	Liver	Freeze vial of sample at -20°C
Ciguatoxin	Blood, liver, brain, muscle	Freeze vial of sample at -20°C
Antibodies to pathogens	Serum*, aqueous humor	Freeze vial of fluid -20°C < 1 week, -70°C > 1 week
Morbilliviruses	Swabs of nares/blowhole/lung/brain; tissue (brain, lung, lymph node)	Place swab in a plain vial, or in "RNA later" or other RNA preservative and freeze vial -20°C < 1 week, -70°C > 1 week
Influenza	Swabs of nares/brain/rectum; tissue (brain, lung, lymph node)	Place swab in a vial and freeze vial, or in "RNA later" or other RNA preservative and freeze vial -20°C < 1 week, -70°C > 1 week
Flaviviruses	Brain	Fix in formalin for histology, and 1 cm cube frozen - 70°C
Coronaviruses	Lung, swabs of nares/rectum	Place swab in a vial and freeze vial, or in "RNA later" or other RNA preservative and freeze vial -20°C < 1 week, -70°C > 1 week
Herpesviruses	Swab of oropharynx/blowhole/ conjunctiva/genitalia; abnormal tissue	Place swab or tissue in a vial and freeze -70°C; formalin-fix tissue for histology;
Leptospira spp.	Urine, kidney	Place in culture media and transport at 4 C; freeze sample – 70°C; formalin fix kidney for histology
Brucella spp.	Cerebral spinal fluid, brain, lung, lymph node, uterus, testis, spleen	Formalin fix for histology, and 1 cm cube frozen - 70°C; for culture, bacteria-specific culture media and transport at 4° C
Coliform bacteria, *Campylobacter* spp., *Vibrio* spp.	Swabs of rectum; feces	Store sample or swab at 4°C for culture (bacteria-specific culture media for swabs available from diagnostic labs), freeze -70°C for molecular typing
Klebsiella spp., *Erysipelothrix rhusiopathiae*	Swabs of abscess/lesion into transport media*; lung, spleen, liver	Store sample or swab at 4°C for culture (bacteria-specific culture media for swabs available from diagnostic labs), freeze tissue -70°C for molecular typing, formalin-fix tissue for histology
Cryptococcus spp., *Coccidiosis immitis; Paracoccidioides* spp.	Swabs of abscess/lesion into transport media*; lung, spleen, liver	Store sample or swab at 4°C for culture, freeze tissue -70°C for molecular typing, formalin-fix tissue for histology
Toxoplasma gondii, Sarcocystis spp.	Brain*, lymph node, lung, liver	Formalin fix for histology, and 1 cm cube frozen - 70°C for molecular typing; for culture protozoal-specific culture media at 4° C
Nematodes	Collect parasite whole, especially head and tail	Store in 70 % alcohol for morphological identification; freeze at - 70°C for molecular identification

Table 3. Non-infectious disease monitoring priorities

Species or taxonomic group	Primary region of concern	Health conditions to be monitored	Sampling approach
Alaska			
Pinnipeds	Alaska	Nutritional condition, molt stage, hormone levels, evidence of predation	Visual assessments, photogrammetry, capture-release health assessments, fecal sampling; necropsy
Beluga whales	All populations but particularly Cook Inlet	Nutritional condition, epigenetics, hormone levels	Photogrammetry, capture-release or opportunistic health assessments of live strandings, necropsy
Polar bears	Southern Beaufort	Nutritional condition, hormone levels	Visual assessments, hair snare and other remote sampling, capture-release health assessment; necropsy
West coast			
Gray whales	West coast	Nutritional condition, hormone levels, epigenetics, evidence of killer whale predation	Remote biopsy, photogrammetry, necropsy
Odontocetes, particularly killer whales and coastal dolphins	West coast	Nutritional condition, hormone values, epigenetics, skin lesions	Photogrammetry, remote biopsy, visual assessments, necropsy
California and Steller sea lions, fur seals	West coast	Neoplasia	Necropsy
Phocids	West coast	Nutritional condition, entanglement, hormone levels, evidence of predation	Visual assessments, photogrammetry, capture-release health assessments, fecal sampling, necropsy
Sea otters	California and southwest Alaska	Nutritional condition, evidence of shark or killer whale predation	Visual assessments, capture-release health assessments, fecal sampling, necropsy
Pacific Islands			
Hawaiian monk seals	Hawaii	Nutritional condition, entanglement, hormone levels, evidence of shark predation	Capture-release health assessments, necropsy
Northeast and mid-Atlantic			
Mysticetes, particularly NARW	Northeast and mid-Atlantic coast	Nutritional condition, skin lesions, hormone levels, epigenetics, entanglement, vessel strike	Visual assessments, remote biopsy, fecal sampling, photogrammetry, necropsy
Common, white-sided, and bottlenose dolphins; harbor porpoise	Northeast and mid-Atlantic coast	Nutritional condition, epigenetics, hormone levels	Remote biopsy, necropsy, live stranding health assessments
Pinnipeds	Northeast and mid-Atlantic coast	Nutritional condition, molt stage, hormone levels, entanglement	Visual assessments, capture-release health assessments, necropsy

Southeast			
BSE bottlenose dolphins	Southeast coast, particularly Gulf of Mexico	Skin lesions associated with freshwater exposure, inflammation markers (from blood), hormone levels	Visual assessments; capture-release health assessments; necropsy
Sperm whales, Rice's whales	Gulf of Mexico	Nutritional condition, hormone levels, epigenetics	Visual assessments, remote biopsy
Beaked whales	Southeast and mid-Atlantic	Nutritional condition, hormone levels, epigenetics	Visual assessments; remote biopsy
Manatees	Southeast coast	Nutritional condition, signs of cold stress, hormone levels, vessel strikes	Photographic assessments, comprehensive capture-release health assessments, remote skin scrape/ biopsy, necropsy

Appendix 4: Useful References

Introductory Presentations

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