Synthesizing Marine Mammal Research in the Gulf of Mexico: 
*Past, Present, and Future*

*Gulf of Mexico Marine Mammal Synthesis Workshop Report*

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ABSTRACT

Findings on the current state of the knowledge and prospective on the future marine mammal research in the Gulf of Mexico are presented. The report is based on the recommendations of the Gulf of Mexico Research Initiative sponsored workshop. The three-day workshop, which brought together 33 experts from scientific community, NOAA, BOEM, industry, and NGOs, outlined a comprehensive strategy based on ecosystem level approach for future Gulf of Mexico marine mammal research investments.

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I. Introduction: The State of Marine Mammal Research Before the 2010 Oil Spill

The Gulf of Mexico (GoM) is home to 22 commonly occurring species of marine mammals. Since the mid-1990s the assessment of marine mammal stock sizes and stock status reports have been compiled based on occasional systematic shipboard and aerial visual surveys conducted by NOAA. The most recent information is compiled in (NOAA, 2020). The most comprehensive synthesis report was recently published by Roberts et al. (2016). The report provides several marine mammal species stock density maps across the entire Gulf of Mexico based on statistical models fitted with the published multi-year visual observation data. Fig. 1 illustrates an example of the predicted density maps for beaked and sperm whales in the GoM and along the U.S. Atlantic reproduced from the publications.

![Figure 1: Predicted mean density of beaked and sperm whales (copy from Roberts et al., 2016)](image)

In the beginning of the 2000’s technological advances brought new tools to the area of experimental marine mammal research: passive acoustic monitoring (PAM) and tags. The first acoustic monitoring using ship-towed arrays and tagging of marine mammals in the GoM (sperm whales) were conducted through two NOAA- and BOEM-funded studies (SWAMP and SWSS) in 2001 and 2002-2004 (Jochens, et al., 2006). Concurrently in 2001 the Littoral Acoustic Demonstration Center (LADC) consortium, funded by ONR, deployed first autonomous monitoring buoys (EARS buoys) near the Mississippi Canyon/Valley area of the northern GoM (Newcomb et al., 2003; Ioup et al, 2005). The EARS provided three months of continuous recordings of sperm whales down the continental slope in 2001, followed by a 2002 3-month survey. In 2007 first GoM acoustic recordings of beaked whales were collected by EARS buoys (Li et al., 2020). Despite the limited use of acoustic observations for the deep-
diving marine mammal research in the Gulf, a considerable momentum in using PAM in marine mammal studies was gained in other regions of the world oceans. In 2009 Marques et al. (2009) published a seminal paper generalizing the visual-data based methodology for estimating marine mammal population density, introduced by Buckland, to an acoustic-data based one. The group also published the review paper in 2013 (Marques et al., 2013) detailing the method variations for different types of PAM.

After the 2010 oil spill more extensive PAM, tagging, and small cetacean’s health monitoring efforts were employed in the GoM to monitor the impact:

1) Five High Frequency Acoustic Recording Packages (HARPs) were deployed by Scripps (Hildebrand et al., 2012, 2015, 2019) and 10 Marine Autonomous Recording Units (MARUs) were deployed by Cornell across the Western-Southern Gulf (from the Texas border to the Dry Tortugas) as a part of an NRDA effort; the data collection and analysis using HARP buoys were later continued through funding provided by GOMRI to the C-IMAGE consortium;

2) LADC received NSF RAPID funding and Greenpeace support in 2010 for the short-term deployment of 10 EARS buoys to obtain high spatial resolution acoustic data in the vicinity of the spill where their previous monitoring efforts were conducted (Ackleh et al., 2012); the monitoring on the sites was resumed through the funding awarded to the LADC-GEMM consortium by GOMRI in 2015 (Sidorovskaia, 2019);

3) 20 advance behavior tags were embedded into sperm whales by OSU in 2011 and 2013 funded under the Natural Resource Damage Assessment (NRDA) actions;

4) Unique health assessment and monitoring studies in Louisiana’s Barataria and Florida’s Sarasota Bays were conducted since 2011 as part of the NRDA for the *Deepwater Horizon* oil spill by a team of more than 50 government, academic, and non-governmental researchers. In 2018 the CARMMHA consortium was founded and supported by GoMRI to continue these efforts in 2018-2020;

5) Several population trend forecasting models were developed to support and guide the observational methodologies and to provide input for regulatory agencies (Chiquet et al., 2013; Ackleh et al., 2017; McDonald et al., 2017).

In addition to direct studies of the oil spill impact on marine mammals, several ecosystem monitoring projects funded by GoMRI were simultaneously conducted in the region to quantify the changes in the lower trophic levels that serve as prey for marine mammals (DEEPEND, C-IMAGE). New initiatives supported by NOAA (GOMMAPPs project), BOEM, oil and gas industry are also emerging in the GoM. These efforts represent untapped opportunities to advance our understanding on food web/ecosystem connectivity in the GoM and on how past and future oil spills may impact long-lived top predators and what relevant mitigation and conservation methods should be considered.

The group of 33 participants (the full list of participants is in Appendix 1) consisted of the multi-disciplinary team of scientists actively involved in marine mammal and ecosystem research in the GoM,
regulatory/governmental agency representatives (NOAA, BOEM, ONR), NGOs (MMS), and industry representatives convened for the Marine Mammal Synthesis workshop (the agenda is in Appendix 2) on October 31-November 2, 2018 in Washington, DC to support the GoMRI Research Board broader synthesis initiative with respect to marine mammal research. Prior to the meeting, all participants were invited to attend four webinars reviewing current findings of marine mammal research projects active in the GoM. The projects included the CARMMHA consortium, the LADC-GEMM consortium, the Scripps Institution group of the C-IMAGE consortium, and the GOMMAPPS project.

The main questions the workshop aimed to address were:

- What was the state of the marine mammal research and knowledge of the baseline before the Deepwater Horizon oil spill;
- What have we learned about short-term and long-term impacts of the spill on different species of marine mammals;
- What major gaps in data and knowledge still exist;
- How can we best apply/disseminate what we have learned to inform and improve future preparedness, response, mitigation, restoration efforts in the Gulf and other regions;
- What should be priorities and methodologies of marine mammal research in the GoM for the next decade to provide the “best returns on investments.”

II. State of ecosystem/food web research

While we do not have an extensive knowledge base on the feeding habits of GoM cetaceans, generally deep-diving marine mammals prey on deep-pelagic nekton (meso- and bathypelagic cephalopods, fishes, and shrimps). Prey quality greatly affects marine mammal body conditions, distribution, health, and abundance. As an example, the primary prey of lanternfishes (Myctophidae) is zooplankton, which exhibited a large but short-term response to the spill. This fish family is often consumed by oceanic dolphins and may have greatly contributed to the poor health conditions of regional dolphin’s populations identified in current research by the CARMMHA consortium (Schwacke et al., 2017).

The workshop participants felt strongly that the link between these two research fields should be established and maintained. Limited studies of deep-water prey in the GoM were pursued before the spill, but no systematic sampling methodology was employed. Over the last decade, as part of the NRDA effort and then supported by GoMRI, the DEEPEND consortium, whose primary research focus is the ecological dynamics of deep-pelagic nekton in the GoM (Sutton et al., 2020), made an effort to design and implement systematic sampling, in spatial and temporal domains, of deep-water marine mammal prey. The effort led to the identification of 894 fish species (186 to be unknown before in the GoM) and 53 species of squid (3 unknown before). The study resulted in the conclusion that the deep-water species’ vertical migrations regularly occurred through the deep hydrocarbon plume at the meso/bathypelagic interface. Evidence was also presented showing a dramatic declines in the abundance of pelagic nekton and macrozooplankton since the 2010 oil spill, particularly in lanternfishes (considered high quality food for dolphins) and krill, consistently across all depths from 200 to 1500 m between 2011 and 2015. PAH bioaccumulation and persistence of spill-derived contaminants in fishes, shrimps, and cephalopods (particularly in their eggs) were still observed in samples collected as late as 2017 (Romero et al., 2018).
Trophic analysis using biomarkers (compound-specific stable isotope analysis) revealed close linkages between surface and deep-pelagic ecosystems (Richards et al.). To separate the long-term effects of major spills from natural variability and to characterize the drivers of such variability, it is of major importance to study the deep-water pelagic ecosystem in the context of the different water masses. Such characterization is critically important and should be considered in future designs in addition to broad geographical coverage. The main conclusion of the DEEPEND multi-year study presented at the workshop was that oil spill impact may still be ongoing in the GoM deep-water ecosystem and may very well manifest itself also in population-level marine mammal trends.

The CARMHMA consortium tested 40 bottlenose dolphins from two coastal stocks (Louisiana’s Barataria Bay and Florida’s Sarasota Bay) strongly affected by the spill to study how changes in the environment and food web affect marine mammals. The stable isotope analysis on predator and prey allows researchers to track diet changes. When correlated with fatty acid profiles used as a proxy for health conditions, these two biomarkers are promising quantifiers to describe the effects of prey on dolphins.

**Sperm Whale Telemetry**

Another fast-developing technology, which has been used to measure whale feeding success is tagging. Sperm whale tagging in the GoM started in early 2000’s with the SWSS project, with Advance Dive Behavior (ADB) tags used on 11 animals in 2011 and nine animals 2013.

Over 3,000 sperm whale dives tracked in 2013 with recoverable ADB tags showed that most whales foraged predominately near the bottom (about 1000 m) with preference for benthic feeding over midwater depths (Mate et al, 2016). The near-bottom prey is probably preferred because whales would try to come back to these depths even when the feeding success was low. This advocates for relevant synthesis using deep-water trawl data. Further, whales avoided a 4-6,000 km² area that overlapped with the main area of benthic oiling from the 2010 oil spill. Although many female sperm whales occupied relatively small and stable home ranges over long time periods along the continental slope, males moved more widely. One whale tracked in 2013 spent three days going through the "low-use" oiled area, showing a dramatic 95% reduction in foraging lunges (from 12 to 0.6 lunges/dive) during this transect. It has been hypothesized that sperm whale foraging behavior in the low-use area reflects a lower abundance of squids that cannot find their usual benthic prey in oil-affected area(s). *Monitoring sperm whale movements and foraging habits every 4-6 years would be an effective way to monitor recovery of the benthic species and habitat in the low-use area.* Tags which have been used since 2016 on blue, fin, and humpback whales allow monitoring of dive depths, durations, and foraging lunges via satellite without having to recover the ejected whale tags to download the data.

*The panel emphasized that tagging efforts are critically important to study whale’s interaction with the environment and are reasonably low-cost, so the systematic approach to tagging should be considered and funded.* Sperm whales as top predators are the key species to monitor the integrated information about deep-ocean recovery. Diving profiles and feeding lunges reflect on availability, patchiness, and movements of deep-water prey that are difficult to monitor in-situ. Tagging is a cost effective and feasible way to understand the recovery of oil-affected benthic communities and bottom
dwellling species on regional spatial scales. If large spills occur with shorter intervals than the time needed for recovery, we will be losing habitat cumulatively. The data collections on the temporal scales needed to identify and monitor recovery are important for data-supported modeling to inform mitigation policy. Tag data can also provide region and season relative parameters for density estimation models based on PAM data (e.g., changes in clicking rates when feeding in groups, daily and seasonal movement pattern) (Ackleh et al., 2012).

**Data Gaps Identified by the Panel:**

- Western and Southern Gulf and Gulf regions away from the continental slope are poorly sampled for both prey condition and marine mammal abundance.
- Noise impact on cephalopods and fishes is not known. This is a new and active research area. Spanish researchers reported that giant squids were showing up dead and stranded after active oil exploration in the area. Shallow-water cephalopod mortality due to anthropogenic noise were verified in an experimental study.
- Shallow-water prey data for coastal marine mammals are not gathered. We should also focus on data collection and the methodology to assimilate it into models to understand the connectivity between coastal and deep water ecosystems.
- Models for squid distribution in different life stages, confirmed by appropriate sampling would be helpful to understand drivers of marine mammal movements.
- There is no understanding of the nutritional value of different prey types.
- Repetitive oceanographic environment sampling and assimilation into population models is important for understanding how different oceanographic conditions influence marine mammal presence.
- Researchers need data incorporating large-scale and time-scale phenomena to understand the recovery process and forecast the Gulf ecosystem response to a next potential spill. The GoM has looked different in recent years, the separation of natural oscillations from spill impact are critical.
- The science community needs to develop protocols of assessing large marine mammal health based on body conditions.

**Synthesis Pathways and Recommendations for Future Convergence Research**

- Funding agencies should continue supporting systematic sampling for baseline characterization (spatial and temporal sequences are of critical importance).
- It would be beneficial for scientists to connect with the state management partners (commercial and recreational) to tap into data they collect. Marine mammal scientists have to get engaged early with state entities making suggestion on how prey species data are being collected. States are collecting data for different reasons, but if marine mammal science got involved earlier, both sides can benefit.
- Emphasis should be on monitoring ecosystem integrators (marine mammals) when resources are limited.
- A use of active acoustic sensing for broad spatial coverage tied with selective point net sampling for ground-proofing could be advantageous. A model to calibrate the acoustic transect data would be a helpful monitoring tool.
A quantitative spatially distributed predator-prey ecosystem models for major types of environments (coastal, deep-water etc.) should be developed.

The panel recommended that the marine mammal research community and low trophic level researchers should join their efforts to define common objectives, prioritize which data and where to collect long term, and to develop an effective infrastructure to share data and models. Such an approach would guarantee the best possible scientific value from data collection and model developments.

### III. Marine Mammal Population Monitoring/Offshore Efforts

Historically marine mammal stock assessments (population monitoring) were conducted based on data collected during annual NOAA visual observation surveys that covered the northern part of the GoM from Texas to Florida (the US exclusive economic zone). Since the early 2000’s, there have been several mostly uncoordinated Passive Acoustic Monitoring surveys to record different species of marine mammals (Newcomb et al., 2003; Ioup et al., 2005; Jochens et al., 2006; Ackleh et al., 2012). The majority of those surveys were short-term, limiting the data use to extract high-accuracy and high-precision baseline information before the spill. Workshop participants identified four ongoing studies of offshore marine mammals, which can directly and indirectly contribute to accurate abundance estimates in the northern GoM and should be taken into consideration when planning future research objectives.

i. **GOMAPPS (2017-2020).** This program is led by NOAA and employs traditional visual surveys combined with ship-towed PAMs. The planned outcome products will include spatial density maps for different species correlated with dynamic predictor variables. The density maps will be analyzed in the context of the regression analysis, enabling the prediction of the abundance dynamics based on environmental variables (temperature, salinity, currents, etc.).

ii. **Passive Acoustic Monitoring funded by GoMRI** to understand the long-term impact of the oil spill on marine mammals included the LADC-GEMM consortium (2015-2020) and the Scripps Institution group of the C-IMAGE consortium (2012-2020). Long-term bottom-moored systems (some with real-time reporting capabilities) and short-term deployments of ASV towed arrays and gliders were used to collect broad-band acoustic data for future analysis and interpretation (Dyer et al., 2015; Ziegwied et al., 2016; Sidorovskaia, 2019). Two complimentary approaches were employed in the study design. C-IMAGE surveys collected sparse spatial data across the entire northern Gulf from the West Texas Coast to the Dry Tortugas, whereas the LADC-GEMM study focused on the collection of high-spatial resolution data in the Mississippi Valley/MS Canyon region adjacent to the oil spill site.
iii. BOEM PAM Program of baseline noise measurements in the northern Gulf of Mexico

The study is led by the HDR Team and comprised several participating organizations with expertise on acoustical monitoring, big data processing, and statistical analysis: Azura Consulting, LLC, Cornell University, Marine Acoustics, Inc., Oceanwide Science Institute, Oregon State University, Southall Environmental Associates, Inc., University of Louisiana at Lafayette, University of Rhode Island, University of St. Andrews, Woods Hole Oceanographic Institution, and Proteus Technology LLC. Following the best practices of the earlier commissioned studies in the North Atlantic (ADEON project) and Europe (BIAS project), this is the first attempt to consistently monitor the GoM baseline soundscapes. The goal of the first two years of the program is to design and implement acoustic data collection and processing protocols, so measured noise levels can be directly compared with other studies in the same or other ocean regions and develop recommendations for the larger multi-year GoM PAM Program. The study is planned to focus on two northern GoM regions: Mississippi and DeSoto Canyons, representing industrially active and industrially subdued environments. The first data collection was started in May 2018 using a mix of stationary and mobile platforms. Stationary platforms included five EARS (University of Louisiana at Lafayette), five Rockhoppers (Cornell University), and two Chip Scale Atomic Clock-Several Hydrophone Recording Unit (SHRUs, WHOI). All instruments were deployed...
within an approximately 100 × 200-kilometer rectangular region in the Mississippi Canyon/Valley in the northern GoM. Individual instrument locations were chosen based on the statistical model. A mobile platform (Seaglider™) was deployed for approximately four weeks of data collection, flying between DeSoto and Mississippi Canyons. The stationary sensors will be kept two years in the Mississippi Canyon and then are planned to be moved to the DeSoto Canyon. Both canyons are populated by deep-diving marine mammals and exhibit unique acoustic propagation features, and each canyon is characterized by three separate and unique ecosystems, namely continental shelf (<200 m deep), continental slope (200 to 1,600 m deep), and the abyssal plain (>1,600 m deep). The study objectives are:

- to characterize GoM soundscapes and understand their variability over multiple temporal and spatial scales, including diel, lunar, seasonal periods, and multi-year trends.
- to describe the contribution of the physical, biological, and anthropogenic sources into the GoM soundscapes.

Methodology for Future Surveys

After reviewing the ongoing and past efforts, the expert group discussed the shortcomings of current approaches to provide accurate (nonbiased) and precise (small variance) estimates of the deep GoM species populations. PAM data, as currently collected, cannot attribute observed increase/decrease in acoustic activity to immigration/emigration to and from the monitored location due to prey availability versus actual population level shifts. Future efforts should include telemetry data to derive individual/group cue rates and their variations depending on the season, prey resources, group size, oceanographic conditions, and region. The current published density estimates also rely on the modelled detection probability to calculate the proportion of the “heard” cues. It would be desirable to include at least limited capabilities to localize the detected cues and track animals using 3-D sub-arrays. One of the strategies for limited funding resources (currently employed by the BOEM study), which was favored by the group, is to use the moving of moored sensors across different regions over time to obtain adequate spatial coverage.

The second challenge is the lack of even minimal requirements for data collection protocols to estimate populations that makes data comparison/synthesis among different platforms extremely difficult. Sampling rates, detection probability, system calibration quality, detection/classification algorithms considerably vary among groups. The PAM community has to get together and develop protocols for data collection, analysis, and sharing. If we as a community want to see individual group data to be useful in the future for synthesis and comparison, we should be very diligent about metadata formats and data archiving. There is an effort underway led by Marie Roche (Tethys schema), a metadata standards document that is ISO Compliant (developed by Shane Guam) for metadata (Rich et al., 2016). This metadata format can be used for acoustic data that will be archived to NCEI.

Existing Data Synthesis Opportunities

Existing acoustic datasets offer several opportunities for data synthesis to improve the accuracy of population density estimation models based on acoustic data.
1) The LADC-GEMM 2017 ASV survey was conducted at the same time as the GoMMAPPS vessel survey. The direct comparison between regional density estimates from different platforms can be conducted.

2) Another integration part is to provide visual confirmation of acoustic detections. Visual observations were conducted during LADC-GEMM ASV-based PAM cruises and PAM monitoring is a part of the GoMMAPPS efforts. As acoustic detectors get developed, the visual line transect survey data can be used to validate new detection/classification algorithms across different platforms.

3) The panel encouraged making limited tag data publicly available, so whales’ regional movement patterns can be linked to density estimates. The spatio-temporal scales of regional movements can provide an important input on observed variability in the density estimates.

4) The panel also noted that for initial attempts sperm whales should be chosen for comparing different methodologies, their results, and for synthesis. Beaked whales and *Kogia* spp. represent a great challenge for visual observations (i.e., only possible in ideal weather conditions) and for estimating the detectability function in acoustic methods due to high directionality of calls and the lack of algorithms and measuring protocols for localization (Guilment et al., 2020).

**Data/Information Gaps**

1) The ongoing long-term BOEM study has 10 acoustic sensors deployed in a modular approach. The survey is currently conducted in the Mississippi Canyon/Valley region of the northern GoM and is planned to be relocated to the DeSoto Canyon after two years, maintaining the same location design approach based on the statistical approach. The current design is not optimized for population studies but could be augmented with a localization array module subject to supplemental funding.

2) The community is lacking long-term deployment tags for advancing our understanding cue rate variability and regional movements. Tag data can also provide insight in feeding success and energy budget of species. Currently the long-term deployment tags do not have an acoustic module, they collect positioning data while animals are on the surface and record the dive profile. The data get transferred via satellite to a research lab. Such approach critically limits the volume of acoustic data which can be transferred. Dtags are required to be recovered to get access to acoustic recordings (Laplanche et al., 2015). A new acoustic sensor with onboard processing is under development. It will be able to report focal species detections via satellite communication. The pathways to use acoustic communication underwater with surface buoys, gliders, and Argo floats are also on the table.

3) Effective restoration/mitigation efforts and prediction of long-term population trends will require the use of a forecasting model, which rely on input data about stock structure. The knowledge of deep-water species stock structure is currently minimal. The panel recommended developing and implementing well-coordinated efforts to collect biopsies of these species. Estimation of abundances will also benefit from genetic analyses. It is important that the sampling scheme will include individuals from representative social groups. *Stenella attenuata* and sperm whales are the best candidates at this point for genetic sampling in the deep GoM. The data could serve as a
proxy for other species’ long-term changes. The focused telemetry studies could be used to inform the planning of stock-structure biopsy surveys. We can use the distribution and movements of animals determined from tagging data to design sampling schemes for stock-structure biopsy sampling to better assess stock structure. In previous studies about 90% of tagged sperm whales were also biopsied, which brought a wealth of important data about individuals and their health assessment with possible impact on the success of future acoustic identification of individuals in the stock of interest.

4) The bioacoustic community has made very limited efforts in developing a library of common processing tools with outputs suitable for abundance estimates. The Navy previously funded Scripps to produce several annotated datasets (for baleen and toothed whales) to benchmark available detection/classification algorithms. The datasets were made available for DCLDE conference participants. However very few groups made use of it. The panel felt that this effort should be sustained and hopefully expanded.

Recommendations

The panel recommended establishing a focused, working, multidisciplinary expert group of academia, regulators, Navy, and industry partners to guide effective distribution of investments into deep GoM marine mammal research. The group’s short-term efforts should include:

1) Design a comprehensive acoustic monitoring system based on mobile grid design, similar to the one used in current BOEM studies and approach different funding agencies to provide at least partial funding for long-term continuous monitoring of deep-water marine mammals in the GoM. While providing long-term temporal variability via acoustics, the Gulf-wide visual survey on a regular schedule (two consecutive years on and off) will provide data on large spatial scales. Integration across two dimensions will be an efficient way forward.

2) Conduct quantitative abundance validation studies based on the synthesis of past and on-going visual and PAM observations (e.g., GoMRI, GOMMAPPS, BOEM); such data can be later used as baseline estimates for the current post-spill state of the GoM marine mammal stocks.

3) Organize coordinated planning and implementation of biological sampling to understand the current state of several stocks in the deep Gulf. The genetic surveys should be preceded or concurrent with tagging/telemetry efforts to provide the insights on habitat use, cue rate production, and inform biopsy survey planning.

4) Develop recommendations for acoustic data collection standards, formats, and metadata amenable to integration for abundance estimates. Find long-term solutions for big data storage and public access.

5) Initiate coordinated efforts to produce and share annotated detection datasets for different species to be used for training and testing of detection and classification tools; the paradigm of big data is there but was not tackled by the community in an organized manner. This effort should also include the development of a common, validated library of tools to process acoustic data similar to the one built by the underwater acoustic community (Ocean Acoustic Library).

6) The bioacoustic community needs models/tools, validated by available data, to inform restoration planning, evaluation, and oil spill response.
There is a strong need to survey the western GoM and the southern half of the GoM in Mexican waters. Acoustic data collection would be the easier way for international collaboration. At this point we do not have a reliable understanding of spatial ranges covered by different stocks and which stocks are migrating to the southern waters seasonally.

Understudied species (endangered Bryde’s [now Rice’s] whales, *Kogia* spp.) should be monitored in systematic ways, particularly, current moored and mobile acoustic systems should have extended capabilities to capture their phonation bands.

New technologies and approaches in monitoring deep-diving marine mammals should be investigated and included (mobile autonomous vehicles equipped with acoustic systems, drones, photometry).

IV. Marine Mammal Population Monitoring/Nearshore and Inshore Efforts

Nearshore and Inshore marine mammals (dolphins) are assumed to form regionally separated stocks referred to as Bay, Sound, and Estuary (BSE) stocks and more mobile group/stock of coastal bottlenose dolphins. 31 BSE stocks are currently identified for population studies in the GoM (Fig. 3). The flow of animals between stocks and coastal water usage by the BSE stocks are not currently understood. The concern is that the impact of environmental disturbances could differ from the forecasted ones if the stock structure and exchange are different from the ones used in population modeling. The preferred study methods of coastal marine mammals are distinctively different from the deep water approaches and include direct contact testing of animals that provide data-supported quantification of injuries caused, for example, by the *Deepwater Horizon* oil spill event (DWH, 2015).

Since 1990’s the BSE stock abundances were mostly determined by collecting photo-ID data from a small boat and applying Capture Mark Recapture (CMR) models (Mullin et al., 2007). Coastal stocks are assessed using Aerial Surveys. Earlier data were of poor quality. The greatest progress in improving data quality was made for the Barataria Bay and Mississippi Sound dolphin stocks due to the
fact that intensive NRDA studies were focused in these areas following the 2010 oil spill. During the most recent Barataria Bay CMR Survey, 1,601 individuals were photographed, with projected average abundance modeled to be 2,306. The Mississippi Sound CMR Survey identified 1,908 individuals (average abundance of 3,046). The updated abundance estimates are recently reported for West Bay, TX and Galveston Bay, TX (Rosel et al., 2011; Wells et al., 2017). Two automated image identification systems finFindR and Gulf of Mexico Dolphin Identification System (GoMDIS) are currently available to researchers to share and utilize photo-ID data across the research community (Halpin et al., 2009). The quality and extension of shared databases will strongly rely on the development of protocols for data collection which are of critical importance.

A second field data collection method is satellite tagging, which provides information on habitat use and movement patterns. Tagging was implemented during the NRDA studies in Barataria Bay and Mississippi Sound in 2011-2014 (Lane et al., 2015). Since then, the new tags were placed on animals in Barataria Bay (2016-2018) and Dauphin Bay. In the last two years over 100 tags were placed on the animals with about 20% of them been recaptured. Currently tags are only put on captured animals. The tag technologies allowing remote tag placement similar to the technique used for larger, deep-diving marine mammals are under development.

The third data collection method is a collection of blubber biopsy samples, which are then analyzed for genetic connectivity, stable isotopes, hormones, persistent organic pollutants (POPs), etc. POPs, such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT), have been measured in captured animals in Barataria Bay and Mississippi Sound, identifying that the majority of Louisiana and Mississippi coastal animals were exposed to oil through breathing, skin exposure, and eating polluted prey. However, the exposure is cumulative and at this point researchers have no tools to fingerprint the source of exposure.

Themes for the Future

Three synthesis themes (common data sharing platform, offshore-inshore connectivity, and physical oceanography) were identified. These themes should sharpen future research not only for coastal but also for offshore marine mammals.

1) Data sharing with the Animal Telemetry Network and GoMDIS should be a requirement for future funded efforts. A common data repository will provide insights for understanding dolphin movements across estuaries, and connectivity from BSE to coastal to offshore.

2) A better understanding of connectivity of offshore and coastal ecosystems is needed. Studies should be ranging from comparative biopsies to understand pollutant accumulation profiles to water masses and prey movements and their effects on marine mammal mobility patterns.

3) Oceanographic studies should be incorporated into the framework of marine mammal research and shared with biologists. The Mississippi River has a large impact on the Gulf ecosystems. Its influence should be included via existing circulation models and considered as part of coastal dolphin habitat dynamics.
Data/Information Gaps

1) Valuable beaching/stranding data are an underutilized resource due to the lack of standardized reporting and survey design principles, which would allow quantification of the probability of detecting stranding animals. It would be important to establish protocols for the inclusion of opportunistic public reporting together with organized efforts. The key effort for quantifying the injury is assigning the standings to stock, so total injury could be extrapolated. The genetic assignment test method for the area around Barataria Bay was designed for the injury assessment after the oil spill (Rosel et al., 2017). A data gap exists with respect to the ability to do similar things in other regions of the GoM to collect baseline data, so we will be prepared for injury assessment for a future event.

2) Identification of the key areas, which are currently under-sampled, for collecting baseline data and the type of baseline data and collecting protocols are of urgent need prior to future industrial disasters. Baseline abundances and baseline in water survival rates extrapolated from strandings are the main metrics that can assist in identifying most vulnerable stocks and assuring their survival after future events.

Recommendations

1) Partnership with industry and utilization of their infrastructure for long-term baseline data collection could significantly increase the volume and quality of baseline data.

2) The initial injury assessment and first response should not be considered as purely governmental issues. The panel recommends the development of effective permit issue procedures, so expert research and assessment teams could mobilize quickly in the case of an environmental accident to tag and identify individual distress animals.

3) Sustainable continuous monitoring of nearshore marine mammal stocks is equally important for restoration and adaptive management since aperiodic events due to ecosystem variability and climate change; baselines are not static and needs to be regularly updated. Automated access for data input to the National Stranding Database and HealthMap Database is of critical importance.

4) The development of available passive acoustic monitoring inventory across different teams will be beneficial for quick mobilization in the case of emergency.

5) The range of reproductive studies for animals staying in highly polluted areas should be broadened to include other BSE regions; so far it has been only done in Barataria Bay.

6) Close connection and steady information exchange between researchers and industry will positively impact the preparedness and response efficiency immediately after a possible event.

V. Population Monitoring II / Nearshore and Inshore Stock Direct Contact Health Assessment

Consistently funded opportunities for studying individual marine mammal health get us closer to identifying the causes of many health issues, informing how to manage it, and providing essential data for models to predict population-level consequences. Currently PCoD and PCoMS model frameworks are open for such data fusion. The health issues observed in marine mammals could be caused by natural
stressors (such as extreme weather, HABs, disease outbreaks, persistent new effects associated with climate change) and by anthropogenic stressors (oil and other chemical pollutants, noise, marine debris).

GoM marine mammal health is mostly derived from BNDs, which include active surveillance methods (capture-release health monitoring) and passive surveillance via stranding network data collection. In active surveillance body conditions, vital rates, organ status, and immune status (via a variety of biomarkers) are assessed in captured animals. Collected data are compared with the data fairly regularly collected over long periods of time at the baseline US sites (e.g., Sarasota Bay for the GoM animals). NRDA health assessments shortly after the 2010 oil spill in Barataria Bay and Mississippi Sound and continued efforts by the GOMRI-funded CARMMHA consortium in Barataria Bay and Alabama coast clearly identified several persistent health impacts: immune alterations, lung disease, fetal distress, pregnancy failure, liver disease, mortality, reproductive failure, and low body weight (Smith et al., 2016). Ongoing CARMMHA studies also indicate lingering effects of the spill (seven + years after the incident). These effects manifest as continued reproductive failures, cardiac abnormalities, immune dysfunction mechanisms, dietary and trophic changes. These data fused into population prediction models will allow updating predicted population trajectories for key nearshore cetacean stocks and can be used as proxies for predicting population recovery for oceanic cetacean stocks.

Litz et al. (2014) provides an extensive summary of passive surveillance data for the GoM between 1990 and 2014. The GoM stranding network includes 11 agreement holders. 94% of stranding data are BSE BNDs providing established regional baselines. Near-real time stranding data can be ultimately considered as health data.

The GulfMAP database, a GoM version of HealthMAP, is a standalone platform, where all stranding and health data are required to be reported and stored. It also provides access to environmental data to assess relationships. Emerging technologies to expand health assessment data include developing new biomarkers for pollutant exposure and accumulation, collecting blow samples, and performing photogrammetry.

**Synthesis Opportunities**

1) Ongoing work with toxicologists to identify mechanisms of oil toxicity across vertebrates should help in the development of health assessment protocols for offshore animals.

2) Identification of shifts in diets via health assessment metrics is currently attempted by analyzing fatty acids compounds in nearshore animals. It could be potentially extrapolated to offshore marine mammals.

3) There were limited targeted studies on how the use of dispersants affected the overall toxicity. At this point there is no consensus on approaches to dispersant’s use in future spills. Exposure to naturally weathered oil cannot be separated from the exposure to oil processed with dispersants. However, increased bioavailability of oil constituents for marine mammal impact has been observed.

4) The success of health assessment outcome integration into studies of offshore marine mammals will heavily rely on common data collection protocols, analysis, and standards. The nearshore health assessment techniques have been standardized over the last 20 years, so the results are
fully comparable across different sites. In addition, the community has worked with NIST to
develop reference materials for specific matrices and tests (e.g., blubber, blood and feces
techniques for hormones, then compare laboratory performances against standards for each type
of tissue). As new techniques get developed and new research groups get involved, it is critically
important to maintain reporting standards (common laboratory metadata formats). The panel
emphasized that engagement of OGC, IEEE, IOOS is a key to advocate the value of such
standards for research groups.

5) The larger question is what individual health assessment data mean from the perspective of the
population-level impacts, how we can estimate changes in survival at different life stages and
fecundity which are inputs into population dynamics models. The CARMMHA VESOP project
demonstrated one way for such synthesis when individual biomarker’s assessment data were
provided to the panel of veterinary experts and a statistical model was built based on their input.
The follow-up surveys on survival and reproduction would allow to assess the accuracy of the
approach used in the VESOP project. The alternative would be to design a long-term tag which
could stay on an animal at least a year.

6) Use of stranding data to infer stock status requires estimates of detection probability and probable
breaching cause. To this extent it would be important to integrate the information from ocean
circulation models

Data Gaps

1) At this point we have no techniques/data which would allow for the understanding of cumulative
effects or chronic exposures. The panelists suggested exploring technology used in human
health monitoring (e.g., bracelets with changing colors as one gets exposed to harmful
chemicals).

2) Continuation of health assessments in the oil-spill-affected areas and at the baseline sites should
be funded to understand long-term recovery since the effects of exposure are still observed in
sampled animals 10 years after the spill. The reproductive success is still low and does not exhibit
any steady recovery.

3) We have no experience or data on the impact of the coast and marsh restoration projects on
nearshore marine mammals since the restoration projects of such magnitude were never attempted
in the GoM.

Recommendations

1) As restoration projects get underway, it would be beneficial to explore opportunistic opportunities
of leveraging restoration of other natural resources.

2) Regulatory agencies should get engaged as early as possible to ensure adequate monitoring of the
restoration activity impacts on marine mammal populations. Monitoring approaches and methods
should be standardized and integrated across different projects to increase the value and potential
usage of the collected data.

3) The oil spill response plans should be updated for cetacean responses, which are being developed
for specific regions (area contingency plans). The panel welcomes the plan to release the NRDA
guidelines on simultaneous implementation of response and injury assessment for the future.
4) Opportunities to share stranding data and to implement common monitoring protocols should be explored at least with Canada and Mexico, and ideally with other foreign countries.

5) The Joint Industry Program has provided funds for scientists and responders to develop response guidelines across different taxa.

6) Building intellectual capacity of different research and restoration teams via bringing physical oceanographers, marine mammal scientists, engineers onboard will lead to broader impact of proposed activities and provide cross-disciplinary training for students and postdoctoral researchers involved.

VI. Population Modeling

Two major approaches are used in population modeling. The first approach requires probabilities of survival and transition from year to year; the second one utilizes transition and survival probabilities from stage to stage (calves/ juveniles, reproductive female etc.) (Ackleh et al., 2017; Thomas et al., 2017). Precision and uncertainty of both methodologies rely on a priori knowledge of initial conditions (number of animals at each stage), data-supported probabilities of transitions, and impact of environmental stresses (chronic and acute) on these distributions. If a population is at its carrying capacity, the modeling parameters will be density dependent. Carrying capacities of the GoM marine mammals are currently unknown. However, the fact that resident sperm whale females in the GoM are much smaller than in other regions may be an indication that the environment is its carrying capacity.

Researchers currently do not understand the low growth rate of sperm whales (about 1% vs expected 7%) and depletion mechanisms outside whaling. Such mechanisms would be determined by prey availability, quality, and competition for the same prey with other marine mammals. The important step in population modeling of offshore animals would be a comparison of annual predicted trends against data inferred from fusion of visual, aerial, and acoustic survey which need to be conducted on a regular basis, concurrent with adequate special distribution to provide global GoM coverage, not regional trends. The panel also discussed an “expert elicitation method” to determine stress impact on parameter’s distribution when any other data are absent.

Synthesis Opportunities

1) The panel recommended to reprocess previously collected visual data based on advanced statistical assumptions and synthesize sperm whale population estimates from the last three NOAA stock assessment surveys with available acoustic data overlapping in time and space. The synthesized datasets could be used to refine the population prediction models and understand their biases and correction needs. The question of distinguishing between natural variability (e.g., due to migration between the northern and southern GoM) and oil spill impact is still open. Acoustic monitoring of high spatial resolution could inform regional trends and hopefully provide indirect information on migration connectivity between regions.

2) Cross-comparison and synthesis of acoustic data is strongly dependent on the availability of detection probability estimates for different regions and systems since detectability is one of the most critical parameters allowing conversion between acoustic activity and abundance estimates. As we plan to launch new long-term acoustic surveys, researchers should include design features.
(e.g., volumetric subarrays to obtain reliable detection rate estimates) allowing detection variability estimates. Simultaneous collection of tagged data would allow assessing an accuracy of detectability estimates.

3) The recurring disturbance methods developed for sperm whales by Ackleh et al. (2017) should be applied to other GoM populations to understand potential risks associated with multiple acute disturbances.

4) The accuracy of model-generated population trajectories heavily depends on input parameters, such as survival rates, fecundity for which the data are extremely limited for unique species and very often proxies from different species are used. The panelists saw a great opportunity in connecting to data collected on deep-water prey (DEEPEND consortium) using bioenergetic models. Energy availability and expenditure are critically important to understand the population capacity for recovery. Fast adaptability of low trophic level organisms in response to chronic and acute stressors may assist with survival and recovery of top predators, such as marine mammals. (Farmer et al., 2018)

Data Gaps

The panelists recognized multiple data gaps (more so) for offshore species that limit our abilities to reliably forecast population trajectories from the past to the current point and from the current to the future including possibilities of acute stressor re-occurrences, including the lack of:

1) Data that would advance our understanding on marine mammal density dependence on prey availability, contaminant’s distribution, and environmental variability;
2) eDNA data to answer taxonomic questions;
3) Baseline health status and species-specific stage distribution (males, females, calves);
4) Data-supported species-specific baseline probability of survivals at different stages, and fecundity, reproductive success rate;
5) Data on connectivity and migration between the northern and southern (non US waters) GoM.

Recommendations

1) Modeling indicates that survival of matured reproductive females is most critical for following population recovery, so recovery actions should take this fact into consideration when possible.
2) When funding is limited, field assessment of vital rates leading to data-supported transition probabilities should be prioritized against modeling.
3) Habitats that show evidence of impact and cumulative loss over time should be the first priority in the assessment and modeling.
4) The most recent visual observations (three GoMMAPPS surveys) indicate no shift in distribution of pantropical dolphins but decrease in abundance after the 2010 oil spill. The panel proposed shifting the emphasis to studying and modeling deep-water dolphin populations vs sperm whales. Dolphin species seem to be more vulnerable due to use of the most oil spill-impacted habitat.
5) Broad range tagging efforts with emerging technological opportunities to put tags on free ranging dolphins should be a priority and will provide critical inputs to multiple research efforts.
6) Signal processing efforts should be focused on developing broadly used tools allowing an
extraction of information from acoustic data on animal size (gender distribution, health status).
7) Synthesis of long-term abundance trends derived from acoustic data, spatial abundance trends
derived from visual observations with data on meso- and bathypelagic prey distribution is
strongly encouraged.
8) The development of a robust acoustic monitoring program allowing simultaneous monitoring
across the entire Gulf and assessment of detection variability by region is needed. The panel
recommended drafting of a white paper presenting an ideal design and then scaling it down based
on funding availability.
9) Development of an acoustic ID database for the Gulf corroborated by simultaneous visual
observations should be attempted through collaboration and synthesis among different research
teams. The availability of an open sharing platform would encourage this development.
10) The panel encouraged a discussion between population modelers and the DEEPEND consortium
on key metrics, which can be inferred from their data to inform and be directly fed into
population and ecosystem models. Information on metabolic rates and caloric content could be
improved in the framework of bioenergetic models and sensitivity analysis.
11) The panel recommended a follow-up workshop to develop a strategic approach around what
should be accessed (known) prior to the next spill and right after if a next spill would happen.
12) Researchers need to answer the question if long-term abundance monitoring provides the best
approach or if we should attempt developing protocols and measuring birth rates and mortality
and model abundances later.

VI. Future of Marine Mammal Research in the Gulf of Mexico

The expert panel recognized grand challenges that the community of stakeholders would have to
recognize and address when developing a coherent plan for research investments after closing the GoMRI
program. The decade of research showed with certainty via direct health assessments of coastal marine
mammal populations that marine mammal species were greatly impacted by the 2010 oil spill and that
effects are still broadly present ten years after the spill. During the next decade, the main post-spill efforts
will be focused on restoration projects. There are different drivers for priorities interwoven in the GoM:
regulatory agencies, the US Navy, industry, and NGOs.

NOAA, as the US regulatory agency, is responsible for administering the Marine Mammal
Protection Act (MMPA), ESA, and provides adaptive management and efficient responses to crises.
NOAA will be also actively participating in restoration, particularly of deep-water resources.

Major restoration goals:

1) Identification and efficient mitigation of key stressors that affect multiple species to support
resilient populations by collecting and using monitoring information;
2) Improvement of resilience to natural stressors and addressing direct human-caused-threats;
3) To be successful in restoration with limited resources, it is important to identify focal species (frequently observed, accessible for observations, inferred information from observations can be applied to others, broad depth and habitat span). Several key species are: Risso’s dolphins, endangered sperm and Bryde’s [Rice’s] whale, and northern Gulf coastal dolphins.

Cross-species cutting priorities:

1) Addressing critical uncertainties in habitat use, health conditions, causes of morbidity, and injury;
2) Characterizing and addressing primary stressors - what are they and how do they overlap with species, what are impacts and what can be done to mitigate;
3) Identifying priority parameters for adaptive management, developing quantitative tools to inform and evaluate restoration.

The US Navy is responsible for compliance with a set of Federal environmental regulations, including the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). “As part of the regulatory compliance process associated with these Acts, the Navy is responsible for meeting specific requirements for monitoring and reporting on military readiness activities involving active sonar and underwater detonations from explosives and explosive munitions. These military readiness activities include Fleet training events and Navy-funded research, development, test and evaluation (RDT&E) activities.” ([https://www.navymarinespeciesmonitoring.us](https://www.navymarinespeciesmonitoring.us)) Based on recommendations from the Center for Independent Experts (sponsored by the National Marine Fisheries Service), the Navy created the Navy Acoustic Effects Model (NAEMO), an advanced acoustic modeling and simulation software tool. NAEMO is used as the Navy’s quantitative model to estimate impacts of underwater acoustic sources used for training and testing on marine mammals and sea turtles. To improve the accuracy of these simulations near-term, the Navy would benefit from factoring in:

1) Region-specific seasonal occurrence and distribution data;
2) Quantitative habitat-based density model;
3) Qualitative species-specific biologically important areas;
4) Updated behavioral acoustic criteria and thresholds.

The long-term needs aim to address population-level consequences of repeated disturbances and acoustic stressors. The future development of the Population Consequences of Disturbance (PCoD) model framework is of critical interest to the Navy.

The energy industry representatives agreed with the short-term and long-term priority needs identified by the Navy. The challenges are grander because the industry stakeholders include 100’s of entities. The Joint Industry Program, or JIP, funds academic research groups to advance the understanding of the effect of sound on marine life generated by oil and gas industry exploration and production activity for future effective mitigations ([http://www.soundandmarinelife.org](http://www.soundandmarinelife.org)). There are still very few GoM-based data collection and monitoring projects despite the fact the GoM is one of the most industry-impacted regions in the world. GoM industry projects are moving into ultra-deep waters that could potentially impact north-south migration of marine mammals. Shell, the largest leaseholder in the GoM, is fostering collaboration with NASEM to support acoustic research observatories as a part of Stones, the
world’s deepest oil and gas project. The production project operates in 3 km deep water in an ultra-deep area of the US GoM. Continuous acoustic monitoring will also provide insights on marine mammal migration across the GoM. The industry is keen to use new technologies, such as gliders, to collect a broad range of data on physical (current, wind) and biological parameters in the regions exposed to smaller oil spills (such as the 2016 Brutus platform spill) and newly developed regions.

BOEM is currently committed to continue funding GoMMAPPS and long-term ambient noise baseline measurements which will be important for future understanding changes in the GoM ecosystem due to industrial expansion and climate change.

VII. Emerging Technologies Relevant to Future GoM Marine Mammal Research.

1) Environmental DNA (eDNA)

The presence of marine mammals is associated with naturally occurring genetic material left in water (from sloughed skin, dead cells, feces, blow). Such material can persist for a period of time and can be used as a non-invasive tracer to assess the presence of species, stock structure and possibly individuals (Ficetola et al., 2008, Biology Letters), and regional biodiversity. The material distribution and state will strongly depend on abiotic (e.g., temperature, currents) and biotic factors (e.g., bacteria), so synthesis with oceanographic data collection will be a key for scientific interpretation. Using autonomous vehicles (surface, gliders) for collecting eDNA should make this approach cost efficient and time-space relevant. Autonomous vehicles can simultaneously collect physical/bio-oceanographic data to understand the context of eDNA better. eDNA data processing requires rigorous standardized approaches that have to be established and agreed upon by the respective research groups. The currently recognized limitations are due to the fact that only very short pieces of DNA can be identified. That is currently considered an obstacle to using such data as relative or absolute abundance estimates. The spatial and temporal inaccuracy should be lowered with advancement of collection techniques. For example, transport rates, persistence due to bio-environment and shedding rates could be inferred when eDNA is collected simultaneously with oceanographic and acoustic data.

2) Health Evaluation in Cetaceans and Remote Sensing Methods

Direct health evaluation of deep-water cetaceans is of critical importance in developing an accurate assessment of the stock status and forecasting population trends. However, there are tremendous difficulties and high costs associated with the goal. Proven remote contact collections include biopsy, fecal samples, and the animal’s visual assessment (size, body conditions etc.). Ultrasound, radiography, and auditory evoked potential (AEP) have been tried but have not been proven to be consistently successful. Currently several methodologies are emerging, including blood collection, auscultation (simulated), breath/blow collection for hormone levels and microbiome, image characterization for weight/body condition/growth, age determination using endogenous fatty acids profiling as a proxy.

The development of autonomous vehicles and high resolution/high-definition cameras creates new opportunities for GoM marine mammal research. The cost efficiency of visual spectral methods will be increased in the near future because these cameras can be mounted on drones. Surface mapping of
Different species can be conducted with higher temporal and spatial resolution in comparison with visual surveys. High resolution satellites can detect a large whale’s presence from space. A recently published paper demonstrated the feasibility of VHR satellite technology for monitoring baleen whales (Cubaynes et al., 2019). Hannah Cubaynes and her colleagues at the British Antarctic Survey in Cambridge, UK, identified four different species of baleen whales in the WorldView-3 satellite images in waters off the coasts of Italy, Mexico, Hawaii, and Argentina. Current results come at the expense of labor-intensive manual detection/classification to generate the first results and training data. Future solutions can potentially employ machine learning and crowdsourcing. The methodology could be applied for density estimation of certain species.

Other active remote sensing technologies, such as radar, active acoustics, and thermal infrared imaging were also identified by the panel as feasible new tools in marine mammal research. They will also provide information about surface presence of species during night hours and can be correlated with passive acoustic observations.

3) Passive Acoustic Monitoring

Passive acoustic monitoring has been emerging as the most viable and cost-efficient approach in monitoring marine mammal species in open water. Current broadly used platforms include vessel-towed hydrophone arrays and autonomous bottom-moored buoys.

The first platform provides a single-time snapshot (one in several years) usually over a broad range due to be used concurrently with visual surveys. The second type of platforms cannot provide real-time data, but can, however, record continuously for many months, though they require periodic maintenance cruises and data uploads. It is also limited by individual mooring detection ranges. Moorings can become cumbersome and more difficult to maintain if animal’s localization and tracking is desired.

Several new technologies are emerging and will allow overcoming the above-mentioned limitations and drive the cost of deployment and maintenance down. Some of these technologies were developed and tested during the last decade of GoMRI research in the GoM. Several technologies are particularly relevant to the GoM region:

1) Directional vector sensors allow animal localization and separation with a single sensor configuration. Future development of robust mounting platforms should allow mounting them not only on stationary moorings but also on towed platforms.

2) Autonomous surface vehicle - towed hydrophone arrays can support missions up to 30-90 days in duration and allow programmed track-line surveys. Such surveys could provide much higher spatial and temporal resolution and be more cost-effective than ship-towed arrays (Dyer et al., 2015). Wave Glider (by Liquid Robotics) provides a similar platform but can harvest energy using solar panels providing long endurance and quieter acoustic profile for extreme sea conditions.

3) Animal borne recording tags (DTAG, ACOUSONDE) are undergoing new developments. The SMRT tag allows onboard processing for recording, detection, and noise analysis and sends data in real time via satellite with noise summary, GPS fix, detection reports. The tag mission duration
is several weeks. Another new tag (LARa tag) contains a sound emitter and recorder. It has been used to study seal’s behavioral response to sounds.

4) Real-time capability bottom moored buoys (EARS-2) were developed and tested in the GoM by the LADC-GEMM consortium. The system can be user-configured to detect several species in real-time via onboard processing and when contacted, the system uploads detection reports via an acoustic modem. Continuously recorded data are simultaneously recorded, saved on internal hard drives, and uploaded upon retrieval or during maintenance visits. Real-time acoustic observing systems (RAOS) are developed by Oregon State University.

5) C-PODs (by Chelonia Limited Co,) are inexpensive stand-alone passive systems that can be attached to the surface buoy or to the sea bottom and register the presence and activity of odontocetes. The system has been successfully used in the Baltic and North Seas to monitor harbor porpoises. The newest version, F-POD, uses new electronics and software to capture more acoustic information and to be suitable for long (over year) monitoring missions.

6) Drifting Acoustic Spar Buoy Recorders (DASBR - Jay Barlow, Scripps) records sound just below the surface and can localize animals and survey large areas in drifting regime.

7) The drifting submersible QUEphone is a new generation of autonomous acoustic profiler; it includes a built-in satellite communication electronics and GPS receiver. Once deployed it makes repetitive descents to 1000 m, drifts, records and conducts onboard detection of major acoustic events. It surfaces once per day and transmits detection reports to land laboratories for scientists to evaluate acoustic soundscapes in near real-time.

8) Underwater autonomous buoyancy-driven vehicles/gliders (SeaGlider, Slocum) have been used in the GoM by the LADC-GEMM consortium. Gliders usually carry the set of oceanographic sensors and passive acoustic recording modules and can support PAM missions lasting several months. They allow active mission control from land-based pilots via satellite communication and can provide detection reports while at the surface.

Emerging technologies will allow more effective merging marine mammal studies into broader eco-system-based research framework for more effective protection and mitigation approaches.
References


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## APPENDIX 1. List of Workshop Participants

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<tr>
<th>Last Name</th>
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<tr>
<td>Ackleh</td>
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APPENDIX 2. Workshop Agenda

Gulf of Mexico Marine Mammal Research Synthesis Workshop

Dates: October 31- November 2, 2018
Location: Consortium for Ocean Leadership Office
          Washington, DC 20005

DAY 1:
8:30 – 9:00 Welcome & Statement of Objectives (Natalia, Lori, Lance, Azmy); Introductions

MM Ecosystem Session
Session Lead: Tracey Sutton; Moderator: Vicki Cornish; Rapporteur: Brady O’Donnell

- 9:00 – 9:20 Findings of the DEEPEND (Deep-Pelagic Nekton Dynamics) program and
  their relevance to marine mammals of the Gulf – Tracey Sutton
- 9:20 – 9:30 CARMMHA research to assess changes in dolphin prey following the DWH
  oil spill and implications for dolphin population health – Ryan Takeshita
- 9:30 – 9:50 Sperm whale telemetry of foraging as an indicator of DWH benthic oil
  fouling – Bruce Mate

9:50 – 10:15 Break

- 10:15 – 11:45 Moderated discussion
  o Synthesis opportunities (30 min)
  o Data/information gaps (30 min)
  o Recommendations (30 min)

11:45 – 1:15 Lunch

1:15 – 1:30 Overview of cetacean stock structure in the Gulf of Mexico – Patty Rosel

Population Monitoring Part 1 Session – Offshore
Session Lead: Lance Garrison; Moderator: Vicki Cornish; Rapporteur: Sam Simmons

Note: preparatory material provided in webinars 1, 3, and 4

- 1:30 – 1:45 Setting the stage: recap of offshore passive acoustic monitoring, visual
  surveys, and tagging in the Gulf of Mexico – Lance Garrison
- 1:45 – 4:30 Moderated discussion
  o Methodological considerations (30-45 min)
  o Opportunities for synthesis (30-45 min)

3:00 – 3:30 Break

  o What are data/information gaps? (30 min)
  o Recommendations (30 min)
DAY 2:
8:30 – 8:45 Recap of previous day (Natalia)

Population Monitoring Part II Session – Nearshore and Inshore
Session Lead: Lance Garrison; Moderator: Laura Engleby; Rapporteur: Brady O’Donnell

- 8:45 – 9:00 Overview of nearshore/inshore (BSE, coastal) bottlenose dolphin monitoring studies, including photo-ID, remote biopsy, tagging, and GoMDIS – Lance Garrison
- 9:00 – 10:30 Moderated discussion
  - Methodological considerations (30 min)
  - Opportunities for synthesis? (30 min)
  - What are data/information gaps? (15 min)
  - Recommendations (15 min)
10:30 – 11:00 Break

Population Health Session
Session Lead: Lori Schwacke; Moderator: Laura Engleby; Rapporteur: Ryan Takeshita

Note: preparatory material provided in webinar 2

- 11:00 – 11:15 Setting the stage: overview of health related research including dolphin health assessments, stranding networks, HealthMap – Lori Schwacke
- 11:15 – 12:00 Moderated discussion
  - Opportunities for synthesis? (15 min)
  - What are data/information gaps? (30 min)
12:00 – 1:30 Lunch

- 1:30 – 2:00 Recommendations (30 min)

Population Modeling Session
Session Lead: Len Thomas; Moderator: Sam Simmons; Rapporteur: Brady O’Donnell

Note: preparatory material provided in webinars 2 and 3

- 2:00 – 2:15 Setting the stage: overview of population modeling activities, including those previously presented in webinars and bioenergetics/PCOD modeling efforts – Len Thomas
- 2:15 – 5:00 Moderated discussion
  - Opportunities for synthesis? (30 min)
2:45 – 3:15 Break
  - What are data/information gaps? (45 min)
  - Recommendations (45 min)

DAY 3
8:30 – 9:00 Brief summary from each session & linkages among sessions, including key recommendations and looking forward, what are the next steps? (Session Leads, 5 minutes each)
Tools for Future, What Will Marine Mammal Assessments Look Like in the Decades to Come?

**Session Lead: Teri Rowles; Rapporteur: Lori Schwacke**

Session lead will introduce topic, followed by a series of short presentations to present priority management needs, and to provide sampling of a few emerging technologies with particular relevance for marine mammal management.

- Overview of priority needs from agencies (10 min each)
  - NOAA – Laura Engleby
  - Navy – Joel Bell
- Short presentations of relevant future technologies:
  - eDNA – Patricia Rosel (10 min)
  - Emerging tools for health evaluations in cetaceans – Teri Rowles (10 min)
  - Remote sensing – Len Thomas (10 min)
  - Passive acoustics: fixed, towed, and gliders – Dave Mellinger (10 min)
- Discussion with group

11:45 – 12:00 Wrap-up