Report of the 2006 NOAA National Passive Acoustics Workshop

Developing a Strategic Program Plan for NOAA's Passive Acoustics Ocean Observing System (PAOOS)
Woods Hole, Massachusetts, 11–13 April 2006

March 2007

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Conveners and Workshop Co-chairs

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Contents

NOAA 2006 National Passive Acoustics Workshop: Developing a Strategic Program Plan for NOAA's Passive Acoustics Ocean Observing System (PAOOS)

Executive Summary

Sound is the primary means by which many marine organisms convey and sense information over any appreciable spatial scale. Acoustic sensing is an optimal means for detecting and characterizing physical and biological features of ocean areas. Heightened public attention on the effects of anthropogenic sound in the marine environment provides impetus for the expansion of passive acoustic observing capabilities in general and for NOAA's leadership efforts in particular, in passive acoustics deployment, data acquisition, and management.

Passive acoustics is an exceedingly powerful means of achieving many NOAA missions. Expansion of U.S. marine acoustic sensing capabilities is supported by a large variety of scientific, legislative, and policy directives, as well as number of international resolutions. Various National Research Council (NRC) reports have highlighted the wide variety of information that can be obtained through passive acoustic deployments, and have recommended that increased investments be made to realize these opportunities (*e.g.*, NRC, 2003). Passive acoustic deployments provide enhanced and unique scientific data on (a) living marine resources; (b) biotic and abiotic characteristics of marine ecosystems; and (c) the effects of anthropogenic sound on protected species and their ecosystems. For example, the U.K.'s Inter-agency Committee on Marine Science and Technology recently called for a systematic and comprehensive mapping of marine ambient noise.

In 2006, NOAA formally recognized passive acoustics as an observing requirement of the agency in the Consolidated Observing Requirements List. Passive acoustics is now also identified as an official observing system within NOAA's Ecosystem Observation Program (EOP) within the Ecosystem Goal Team (EGT). Recent collaborative interagency planning efforts (including those with academics and stakeholders) have focused on the uses of passive acoustics and integrating this tool into ocean observing systems within NOAA. These efforts culminated in the National Passive Acoustics Workshop held in April 2006 in Woods Hole, MA. The purpose of this workshop was to develop a draft strategic program plan for NOAA's Passive Acoustics Oceans Observing System (PAOOS) and to identify critical data requirements. Oral presentations were given in two sessions, by NOAA scientists and by invited experts from outside the agency to highlight the current status of research and technological capabilities in the field of passive acoustics. Each of these sessions was followed by group discussions.

The workshop recommended that NOAA's PAOOS provide data on biological, geophysical, oceanographic, meteorological, and anthropogenic ocean events. While some of these functions will be served by different elements of the PAOOS, it is critical

to note the inherently multipurpose capacity of acoustic sensors. Passive acoustic deployments will substantively augment existing observing platforms, maximize sensing capability, and generate information targeted toward meeting the following five strategic objectives:

1) ***Develop and deploy sensing capabilities to augment conventional means of detecting and assessing living marine resources***

   Passive acoustics deployed from autonomous or towed platforms provide an excellent means of detecting vocalizing marine animals that is much less compromised by sea state, visibility, or the presence of a survey vessel for detection than are existing approaches. The augmentation of conventional survey methods will enhance NOAA's mandated requirements with respect to the conservation and sustainable management of living marine resources. Passive acoustic sensors also hold significant promise in various fisheries science applications.

2) ***Quantify spatial and temporal variance in marine ambient noise***

   Baseline acoustic conditions are poorly known in various marine ecosystems, and knowledge is lacking on the respective contributions of natural and anthropogenic sound sources (ambient noise budgets). Informed assessments of how human-induced sound in marine environments may change baseline conditions must be based on a characterization of nominal conditions. Such knowledge is also critical for assessing and mitigating potential effects of acute acoustic exposures.

3) ***Provide detection capability of specific anthropogenic acoustic events***

   Passive acoustic deployments can provide an autonomous means of sensing specific anthropogenic events, such as the passage of vessels through critical habitat areas or illegal fishing activities in remote protected areas. This enhancement of NOAA's capability to remotely sense the marine environment will both provide an independent means of investigating potential effects of individual sound sources on protected marine species and serve as a powerful tool in managing large, distant areas.

4) ***Provide ecosystem information to NOAA and other geospatial sensing databases***

   As PAOOS data will be highly integrated and assimilated with those of partners in other agencies, academia, nongovernmental organizations, and industry, information can be managed, archived, and rapidly disseminated to these (and other) communities to the greatest extent possible. PAOOS will contribute to and be integrated with the Global Earth Observation System of Systems (GEOSS) Network and Integrated Ocean Observing System (IOOS).

5) ***Contribute to public education and appreciation of marine ecosystems***

A key component of PAOOS will be to promote education of the general public. Web-based information from PAOOS will be provided via various existing educational elements of NOAA line offices and will also involve collaborations between National Marine Fisheries Service (NMFS)/Office of Science and Technology (ST), NMFS/ Office of Protected Resources (PR), Oceanic and Atmospheric Research (OAR)/ Pacific Marine Environmental Laboratory (PMEL), and NOAA's Office of Education. NOAA efforts will also be directly integrated with significant ongoing Agency educational efforts.

The development of a NOAA PAOOS will be highly integrated across multiple line offices and also with academic, military, and industry partners as appropriate. The program will be coordinated nationally but integrated and executed regionally across the various marine ecosystems under NOAA's stewardship remit.

Discussion

Session 1. Internal Intra -Agency Planning Workshop on Passive Acoustics Research

INTRODUCTION

Southall (NMFS/ST) chaired this session. Southall and Van Parijs (NMFS/Northeast Fisheries Science Center) provided a brief statement of background and context for this workshop. Swartz provided background on NOAA's Planning, Programming, Budgeting and Execution System (PPBES) requirements and the mission drivers that were to form the structure of the discussion in this session.

PAOOS will be coordinated by the Ecosystem Observation Program (EOP), which is one of nine programs within NOAA's Ecosystem Goal Team (EGT; <http://ecosystems.noaa.gov/index.htm>). The EGT aims to protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management (EAM). NOAA line offices included within the EGT that support PAOOS include: NMFS, OAR, National Ocean Service (NOS) and National Environmental Satellite, Data, and Information Service (NESDIS). Descriptions of their prospective roles are given in the strategic plan presented in the conclusions section of this report. Programs within NOAA's EGT include: Coastal and Marine Resources Program (CMRP), Protected Species Program (PSP), Fisheries Management Program (FMP), Aquaculture Program, as well as two matrix programs EOP and the Ecosystem Research Program (ERP) which constitute the scientific activities that support ecosystem management within NOAA.

In early 2006, NOAA's passive acoustic program activities supported within the EOP's Protected Species Monitoring and Assessment Capability were defined as a stand-alone observing "system." The passive acoustics observing system is one of twelve observing systems that constitute the EGT's contribution to the Integrated Ocean Observing System (IOOS):

1. Fisheries Monitoring, Assessment, and Forecast (Fish Assess)
2. Protected Species Monitoring and Assessment (PSMA)
3. **Passive Acoustics Ocean Observing System (PAOOS)**
4. Ecosystem Surveys
5. Fisheries Commercial and Recreational Fish Statistics
6. Economic and Sociocultural
7. National Observer Program (NOP)
8. National Status and Trends
9. Coral Reef Ecosystem Integrated Observing System (CRIOS)
10. National Estuarine Research Reserve System–wide Monitoring Program (SWMP)
11. National Marine Sanctuaries System-wide Monitoring Program (SWIM)
12. Coastal Change Analysis Program (C-CAP)

As a result, NOAA required the development of a coherent passive acoustic program plan to allow for the initiation and implementation of a passive acoustic ocean observing system (PAOOS) within the EOP and EGT. The purpose of the Woods Hole workshop was largely to derive such a plan for NOAA. The Science Centers and Regional Offices will be responsible for implementing the defined mandates and reporting their successes or failures. While PAOOS will stand on its own, there will be a need to integrate regional level programs with this program.

Passive acoustics funding to date

Currently a small budget exists for NOAA's Ocean Acoustics Program (NMFS Office of Science and Technology) dealing with general marine acoustics and the effects of sound on marine life. This funding, which falls within the PSP, is primarily directed towards research on assessing the direct effects of sound on marine organisms. In FY06 the Administration's budget request for NOAA's Ocean Acoustics Program was $1.1M; $200,000 was appropriated. This request has been repeated in the President's Budget Request for FY07 at $1.1 and FY08 at $1.8M.

Situating the PAOOS program

PAOOS will form a separate entity to the current passive acoustics component funded within NOAA's Ocean Acoustics Program. PAOOS aims to provide baseline capabilities with which specialized questions related to NOAA's mandated requirements can be addressed. Passive acoustic techniques offer one of the most practical and economical means of undertaking large-scale, long-term monitoring, especially in challenging conditions (*e.g.*, bad weather, at night, and remote or inaccessible areas). PAOOS will form the backbone for informing three key information areas related to NOAA strategic goals (Figure 1). The system will be designed to be malleable in order to respond to and characterize ecosystem changes arising from various forces.

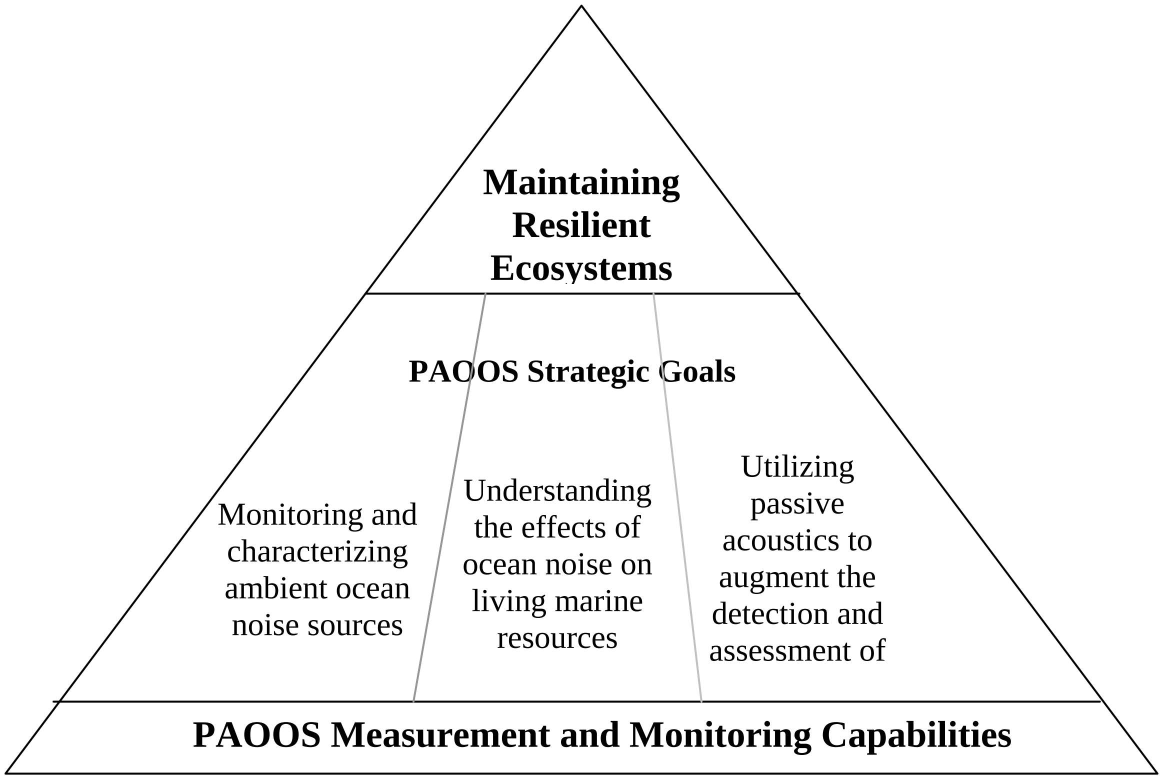

Figure 1. Schematic pyramid representing PAOOS capabilities underlying strategic goals and NOAA's commitment to maintaining resilient ecosystems.

Defining a program
Below is a detailed summary of the topics identified by the working group relating to this program. The topics were discussed in the following order:

1. Mission Drivers – why passive acoustics
2. Core Priorities - information needs, required capabilities, and applicability
3. Capital Needs – sensors, hardware, and software
4. Support Needs – platforms
5. Participating Line Offices, Collaborators, and Education
6. Current Capabilities, and Capacities
7. 100% Requirement – where we need to go
8. Planning for the future

1. MISSION DRIVERS – Why passive acoustics?

Beyond the recognition by NOAA's colleagues from across the agency that passive acoustics has numerous scientific and management benefits to the agency, there are overwhelming scientific directive, legislative authority, policy directives, and international statements and resolutions for expanding current U.S. marine acoustic sensing capabilities. Passive acoustics is an exceedingly powerful means of achieving various NOAA mission objectives by remote sensing of various aspects of the marine environment, including biotic and abiotic sources. The strategic implementation of passive acoustic sensing capabilities within various observing platforms and spatial scales has been clearly identified. The need for NOAA to design and deploy PAOOS is supported by drivers from scientific, legislative, policy, and international sectors. The *ad hoc* NOAA working group assembled here listed as many of the drivers from each sector as could be identified in a short session and tasked members of the group to provide a more complete accounting (given on pp. 26-27).

2. CORE PRIORITIES/GOALS – Information needs, required capabilities, and applicability

Workshop participants derived four NOAA-specific science priorities and objectives for PAOOS:

1) The use of passive acoustic sensors in detecting and characterizing living marine resources in high priority areas.
2) Long term monitoring and characterization of specific sound sources and site-specific ambient noise.
3) Increased capability to characterize specific anthropogenic sound sources and measure spatiotemporal variability in marine ambient noise.
4) Passive acoustic applications in augmenting conventional meteorological sensors on open-water buoy deployments.

Questions directed towards meeting these priorities and goals were identified as:

Q1. How do data on the relative anthropogenic contribution to marine ambient noise inform our understanding of human impacts on marine ecosystems?

Q2. How can passive acoustics advance our understanding and reduce the risk of potential adverse effects of anthropogenic sound sources on protected marine species?

Q3. What are the broad-scale, long-term distributions of marine organisms, especially marine mammals and fish, and how can this information be used to improve NOAA's response to mandated management obligations?

Q4. How are biological sounds linked to physical and environmental variables?

Q5. How can PAOOS be used to promote education and environmental literacy and to address misconceptions?

In order to answer the goals that have been set and the specific questions regarding PAOOS design and implementation, the following actions and capabilities are needed:

- Identify priority areas suited for asking specific comparative questions on wide ranging issues (e.g., deployments in areas of low vs. high anthropogenic sound, low vs. high species density, and variable bathymetry or ecology).
- Develop technologies to sample appropriately in these chosen areas, along with the capability to analyze, utilize, and archive data.
- Capture variability in sounds over long time scales and large spatial scales
- Concentrate on developing sampling designs that will provide the power to address the pertinent questions along with the statistical expertise to analyze these data.
- Address questions at the individual as well as the population level.
- Further explore the potential for using remote acoustic monitoring to aid species level identification and occurrence.
- Calculate noise budgets over multiple spatial, temporal, and seasonal scales to monitor long term trends in dB and frequency changes.
- Decide at which geographic and temporal scales to monitor. For the former, the options are widely dispersed acoustic sensors versus a few on each coast. For the latter, recording over short periods for a long time or continuously for a shorter period.
- How long should you monitor? Months, years or decades?
- Decide whether to focus primarily on coastal or offshore applications.
- Identify:
    1) geographic hotspots for high ambient and low noise areas;
    2) areas of biologically important marine mammal habitats and determine species' specificity;
    3) geographic variation in anthropogenic contributions to marine ambient noise levels;
    4) Key areas useful for baseline acoustic data collection which will help to monitor environmental or anthropogenic changes (*e.g.*, coral reefs and the polar areas).

3. PARTICIPATING LINE OFFICES, COLLABORATORS AND EDUCATION

Participating NOAA Line Offices

NOAA National Marine Fisheries Service (NMFS) will be responsible for the coordination and execution of the data acquisition and analyses aspects of NOAA's PAOOS. NMFS components of the system will include: fisheries and protected resources surveys, ecosystem surveys, and cooperative research including deployments conducted by NMFS science center personnel. NMFS will further ensure the scientific quality assurance of PAOOS products and collaborative linkages to other federal and state agencies, stakeholders, and the public.

National Ocean Service (NOS) will be responsible for supporting the deployment of acoustic sensors as a critical element of the PAOOS within sanctuary boundaries. This support is expected to be in-kind support in the form of deployment access and, to the extent funds are available direct support of deployments by NOS, NMFS, or outside researchers.

Office of Oceanic and Atmospheric Research (OAR) will contribute expertise and capabilities in the areas of data acquisition and processing. OAR's Pacific Marine Environmental Laboratory (PMEL) has accomplished some of the most extensive passive acoustic data collection and interpretation within NOAA to date. PMEL and other entities within OAR are expected to play a key technical role in NOAA's PAOOS.

National Environmental Satellite, Data, and Information Service (NESDIS) will be responsible for data management, archiving, and information services provided by the NOAA infrastructure to support ecosystem goal objectives. Additionally NESDIS will provide technical support and leadership in integration of information services located within ecosystem observation programs to achieve NOAA-wide objectives for IOOS, Global Earth Observation System of Systems (GEOSS) and related end-to-end data system integration efforts.

Collaboration and Integration

NOAA's PAOOS will be integrated with other ocean observing systems which are or will be deployed for other observing purposes but which could be used as PAOOS platforms, including:

- Oceans.US (IOOS)
- Ocean Research Interactive Observatory Networks (ORION)
- NOAA's National Data Buoy Center (NDBC)
- U.S. Geological Survey
- Cooperative Ecosystem Studies Units Network
- U.S. Coast Guard
- Monterey Accelerated Research System (MARS)

Education and Outreach

Numerous educational and outreach efforts will be accomplished using data obtained by the PAOOS. Metadata as well as raw acoustic recordings (as practical) will be transferred to the public in a variety of fora and media using the below and other potential mechanisms:

- NOAA's Office of Education
- National Oceans Service – National Marine Sanctuaries
- NOAA's Office of Ocean Exploration
- NMFS Line Office and Program Websites
- National Marine Educators Association
- Association of Zoos and Aquariums
- Alliance of Marine Mammal Parks and Aquariums
- URI – Discovery of Sound in the Sea
- Cornell University - MacCaulay Library of Sound

5. CURRENT CAPABILITIES & CAPACITIES

See appendices A and B for a list of participants and summaries of presentations on current research capabilities both within and outside the agency.

6. PAOOS Requirements – Personnel, Hardware, Software, and Data Management

The NOAA internal workshop identified the 100% requirement solution to meet the specific goals and answer the pointed questions above. These are discussed below in terms of people, hardware, and computing capacity.

Personnel

- 1-2 Full time equivalent (FTE) employees with skilled acoustic expertise for each NMFS Science Center and selected National Marine Sanctuaries and OAR research facilities.
- 1 FTE national team leader for passive acoustics – NMFS/ST Headquarters.
- 1 FTE acoustic propagation specialist to work with regional staff to facilitate analyses and address effects issues for discrete exposures – NMFS/ST Headquarters.
- 1 FTE statistician and acoustic software specialist – NMFS/ST Headquarters.
- 1 FTE outreach specialist.
- Resources to support temporary staff for acoustic deployments.
- Sufficient resources to support a program to promote and train students proficient in passive acoustic research (*e.g.*, via Hollings scholarship and other student programs).
- Sufficient staffing to facilitate data management.

Infrastructure and Hardware

- A range of acoustic sensors is needed with various frequency parameters, recording duration, and depth deployment capabilities. Each center and region has its own set of requirements depending on each situation and the questions asked. Current equipment options are listed in Table 1.
- Passive acoustic monitoring should be integrated into every NOAA marine mammal survey cruise, requiring each NMFS Science Center to have two towed arrays, sufficient expertise and resources to maintain and deploy them, relevant hardware and software to run programs and relevant accessories.
- Each NMFS Science Center and selected National Marine Sanctuaries and OAR research facilities should have at least 5-10 fixed passive acoustic sensors of variable deployment type (depending on requirements). The intention is to not be limited by the existence of only one NOAA sensor; instead science centers would receive internally competitive funds that would enable them to innovate, calibrate, and maintain specific acoustic devices of their choice.
- Sufficient access to ship time for surveys and deployment of acoustic recording devices will be required. Sufficient hardware and software sufficient are needed to handle massive data streams, for automated detection capabilities for multiple species, and for real time detection capabilities.
- Sonobuoys: each center wants to have the capability to deploy sonobuoys with sufficient antennae and receivers, filters/amplifiers, and data storage.
- Promoting future work with gliders in partnerships with ONR, WHOI, Scripps etc. in order to further develop the use of acoustics using this platform.

Data Analysis and Management

- Each region will require sufficient resources to establish data archives and transfer to national database (NESDIS).
- 1-3 FTE at NESDIS to handle data management and coordination with each regional PAOOS data manager as well as sufficient computing and archival capabilities.
- Promote further research and development of current software packages with the aim to increase the ability to deal with: (1) vastly larger data streams; (2) improved automated detection capabilities for multiple species; (3) more user friendly software; and (4) real time detection capabilities.

7. PLANNING FOR THE FUTURE

A PAOOS working group will be established to set priorities and guide this program. There will be a yearly rotating chair starting with Brandon Southall and semi-regular meetings that will rotate regionally. Center directors and regional administrators will be approached for advice in identifying the appropriate people to participate in this working group. An informal document will be sent to all 12 other observing programs in EOP, NESDIS, NOS headquarters and Atlantic Oceanographic and Meteorological Laboratory (AOML) to let them know of the creation of this working group along with a request for the nomination of relevant participants.

Discussion

Working group A: Requirements for passive acoustic recording devices

Facilitator: Steve Swartz; Rapporteur: Stephanie Watwood

INTRODUCTION

Swartz welcomed the group and gave brief background regarding NOAA and its organizational structure. Swartz then discussed the current aims of the workshop, the development of a clear program plan for passive acoustics within NOAA. This meeting was designed to focus NOAA's responsibilities (in session 1) and then look beyond NOAA to the expertise from outside in order to gather ideas on how the Passive Acoustics program should be designed and what the goals should be. Southall stressed the need to grow within NOAA but remain interconnected with people outside the agency. The list of participants for this session can be found on in Appendix A.

This subgroup considered a wide range of topics, centered on the following general areas:

- Passive acoustic data management and archiving (including various sensor systems)
- Research and development in autonomous versus towed passive acoustic arrays (including scaling considerations)
- Deployment and data analysis/management decisions.

1. PASSIVE ACOUSTIC DATA MANAGEMENT ISSUES

Data collection and archiving issues were discussed in terms of maximizing opportunities. Input was invited on this topic, and two different approaches were defined:

1. Onboard or "selective" processing which saves only the small amounts of data that are of interest.
2. Collection and storage of all raw data with no or little discrimination.

Problems and advantages with these approaches included:

- <u>Selective processing</u> is a useful method when a project has very specific questions; however, it is easy to miss important data when using this method. Storage is not a problem, and the personnel time needed for processing is minimal.
- <u>Collecting all data</u> is useful for a broader overarching ecosystem based approach, but it can produce so much data that it overwhelms our abilities to process and analyze the results. Although storage and personnel time are constraints, this method allows for data mining opportunities in the future.

Discussion and possible solutions included:

Swartz raised the possibility of using NESDIS (National Environmental Satellite, Data and Information Service) for data storage. The NESDIS model uses a web-portal system that is a metadata archive. It does not store anything. Data are held in individual laboratories, and NESDIS tells you where to go to get data. However this raises the problem of data holders and institutions coming and going. *What happens when data holding no longer present in NESDIS?* NESDIS only functions if individual institutions are funded to archive their own data. The Navy shares data with NASA Stennis Space Center and NOAA. The archives exist, and there is an intergovernmental agency data sharing agreement. Distributed system cannot rely on individual academics to store data; scientists are not typically responsible for data archiving. A defined data format for distributed data is needed. Distributed sites must be stable and formatted in certain ways.

As for fundamental underpinnings, individual archives must be ensured or fashioned in some way. If the government wants to maintain a distributed network, it is responsible for supporting individual data holders.

<u>*Specifications for data analysis and archive*</u>

Many readily available commercial programs exist for analysis of passive acoustic data (e.g., Ishmael <http://www.pmel.noaa.gov/vents/acoustics/whales/ishmael/>, Raven <http://www.birds.cornell.edu/brp/Raven/Raven.html>). With nominal acoustic bandwidths, it is generally not possible to hold data on a raw level. There is a need for metadata about sensors and a sampling scheme for data to be usable. Scientists must remain a clear part of this decision process. One precedent for the use of metadata is NOAA’s National Oceanographic Data Center (NODC). However, NODC may be overwhelmed by the volume of acoustic data whereas NESDIS may be more able to deal with large amounts of incoming data. However the latter requires moving beyond private ownership of the data or setting clear quality standards on incoming data. Spending time and energy in standardizing collection and data processing standards could provide a high payoff and low cost effort for NOAA at this point in time. Government committees exist for setting standards for meta and raw data, and PAOOS participants and contributors should ensure their data comply with these standards.

Possible avenues for obtaining guidance:

Census of Marine Life is also working on setting standards for metadata.

The seismic community also uses many sensors to obtain acoustic data, but they have archives, standards, etc. already in place. This could be a good model, but we would need to adopt it to a higher volume of data.

National Geophysical Data Center (NGDC) – ask them what their standards are for hardware, data, and metadata.

Federal Geospatial Data Committee (FGDC) also might give input to the question.

Future requirements and next steps:

1. Need for further developing automatic processing tools.
2. Design and set up a coherent structure for data management.
3. Define clear specifications and standards for data collection.
4. Decide upon clearly defined financial and logistical support for the data management system.
5. Promote continued development of analytical software programs.

2. RESEARCH AND DEVELOPMENT – Current status and needs

2.1 Acoustic versus visual surveys

Currently, acoustic and visual data are perceived in different ways but there is a need to think about them similarly. Correction coefficients are used in visual surveys. Passive acoustics should not be held to a higher standard than the benchmark (visual surveys). We need to be creative and develop correction coefficients for passive acoustics as well. We need distance sampling procedures for passive acoustics. However acoustic surveys should not be assumed to be a replacement for visual surveys, instead both should be utilized to complement each other. However, passive acoustic surveys have proven very reliable for some species (e.g., sperm whales).

Start using a tool kit strategically; use particular tools when they are most probable to be successful. Passive acoustics are good for estimating density of animals around a fixed listening station, because stations are not randomly placed it is difficult to extrapolate that information to other listening stations. It is important to optimize the survey pattern based on historical data. If you know more about the distribution of animals, you can improve performance.

Automated processors for dealing with real time data during surveys

Several programs exist that work well (e.g., Rainbow Click <http://www.ifaw.org/ifaw/general/default.aspx?oid=35875>). There are three main problems with acoustic data of these type; (1) high false alarms, (2) no false alarms but a high threshold; and (3) statistics – missed detection and false alarm rates are the same. Therefore, these systems still require substantial calibration of the data (i.e., visual observations and trails). The group identified matched field processing as an area of potential advancement regarding real-time data but noted some practical difficulties in application, particularly in shallow water.

3. COMPARATIVE QUESTIONS DRIVING DEPLOYMENT DECISIONS

For investigating broad scale questions (e.g., trends in marine ambient noise), long term iterative passive acoustic monitoring was deemed to be the most appropriate sampling regime.

For determining regional abundance, random sampling should occur with respect to the distribution of animals. The underlying assumption is that little is known about animals' interaction with their environment. As more becomes known, more effort can be placed where the largest variance is coming from (sample heavily in high density areas and little in low density areas).

For developing a comparative approach to assessing behavioral responses to variable marine ambient noise and/or specific sound sources, a flexible deployment scheme consisting of elements of both of the above approaches is required. The group felt that prioritizing deployments in areas with relatively high and low densities of certain anthropogenic sound sources and variable geographical features was the only way to determine whether and to what extent human-induced changes in marine ambient noise affected marine life and ecosystems

Discussion

Working group B: Integrating numerous platforms effectively

Facilitator: Sue Moore; Rapporteur: Robyn Angliss

INTRODUCTION
Sue Moore (NMFS/National Marine Mammal Laboratory (NMML)) chaired this section. Moore welcomed participants and provided a brief statement of background and context for this session. Effective PAOOS for marine mammals requires a multidisciplinary approach spanning the science spectrum from physical oceanography to animal behavior. The group was specifically charged to discuss a multidisciplinary approach with regard to three topic areas:

- Requirements of integration with oceanographic parameters
- Requirements for integration with anthropogenic conflict issues (noise, shipping, etc.)
- Requirements for integrating detection, seasonal occurrence, abundance and behavioral platforms

For each of these topic areas, specifics were discussed on: (1) data requirements and management, (2) scale of sampling, and (3) current efforts and opportunities. While it is recognized that successful PAOOS must be responsive to regional variability, there is much in the way of standard framework that can be applied to launch a successful long-term program.

1. REQUIREMENTS FOR INTEGRATION WITH OCEANOGRAPHIC PARAMETERS

Discussion on this topic focused on how to physically integrate passive acoustic equipment and data with current and future oceanographic sampling and data bases. Co-locating passive acoustic recorders on existing NOAA/PMEL moorings has been done in the Bering Sea since 2003, and expanding this practice will help forge obvious partnerships with other NOAA line offices (e.g., NOAA's NDBC and Deep-ocean Assessment and Reporting of Tsunamis (DART). The major benefit of using existing moorings is that basic oceanographic data (e.g., temperature, salinity, florescence) are collected at the same temporal and spatial scales as whale vocalizations.

1.1 Data requirements and management

Summary of main points:
a. Collect acoustic and oceanographic information on the same spatial and temporal scale.

b. Both existing and new buoys or moorings can be used to collect both acoustics and oceanographic data.

c. Forge partnerships within NOAA, with other organizations, and with state or local marine-related agencies to gain access to the buoys.

d. The National Oceanographic Data Center (NODC) list of standard oceanographic measurements outlines the types of information that should be collected and reported routinely; databases managing acoustics information should be able to accommodate the standard measurements provided in the NODC list.

The discussion was separated generally into a discussion of (1) data and equipment requirements and (2) data management needs.

Five options for instrument placement were identified and discussed:

i. On the same mooring as existing oceanographic instruments. There are significant benefits from this approach: the moorings are visited regularly for maintenance, so acoustics equipment can be deployed and collected on a regular schedule at no or a low cost. Two drawbacks are that the oceanographic moorings may not be placed in areas that are biologically interesting and sometimes the mooring itself is noisy (e.g., a chain that is part of the mooring may rattle). A good source of information on existing buoys is the NDBC; see website at www.ndbc.noaa.gov for locations of buoys. Most acoustics instruments have no moving parts. Interference with most standard oceanographic measurements is unlikely.

ii. Place passive acoustics instruments on a separate mooring adjacent to an existing oceanographic mooring. This approach also benefits from the fact that the oceanographic moorings are visited regularly for maintenance, so acoustics equipment can be deployed and collected on a regular schedule at no or a low cost. This approach may be necessary if the oceanographic researchers are uncomfortable with co-locating the passive acoustics equipment, but it is still critical to be able to collect both passive acoustics in an area where oceanographic data are already collected.

iii. Place moorings with passive acoustic recorders and oceanographic instruments in areas that are of biological interest. This approach allows the acousticians to direct the placement of the mooring and will likely be more expensive because ship time would be needed to place and maintain the instruments.

iv. Towed arrays: Towed arrays are typically used in conjunction with visual surveys for cetaceans. They enable the confirmation of species identify with acoustic recordings. Often, there are standard stations for conductivity, temperature and depth (CTD) casts; however, the full suite of oceanographic instruments may not be available on a CTD, and some vessels contracted for visual surveys do not have the capability to do CTDs.

v. Sea Gliders: These are now available from at least three organizations: Applied Physics Laboratory-University of Washington (APL-UW), Woods Hole Oceanographic Institution (WHOI), and Monterey Bay Aquarium Research Institute (MBARI). The sea gliders are already programmed to collect temperature and salinity, and hydrophones can be added. In addition, video recorders may be added to collect zooplankton data. UW-APL sea gliders have been developed to include passive acoustics. However, there is no on-board processing focused on producing interpretation of the acoustic signal.

The NODC standards should be used to decide what to collect at a mooring. Collecting data such as temperature and salinity are mandatory; collecting Acoustic Doppler Current Profiles (ADCP), fluorescence and oxygen are a bonus. A uniform acoustics protocol should be encouraged so that data from various sources will be easy to use.

1.2 Scale of sampling

To the extent possible, acoustic sampling should match the temporal and spatial scale of oceanographic sampling. Dedicated funding to support long term sampling (years to decades) is urgently needed to develop baselines of seasonal ambient noise to include natural and anthropogenic factors, and there should also be cetacean calling cycles concomitant with measures of ecosystem variability. Short term visual and acoustic sampling should be focused to address specific questions relevant to regional population assessments of behavioral changes.

Specific issues discussed included:

- Using subsurface moorings avoids problems with shaking or moving of the equipment, theft, and vandalism.
- If passive acoustic information is to be collected on a duty cycle, ensure that the duty cycle for the acoustics is synchronized with the duty cycle for the oceanographic instruments so that all instruments collect data simultaneously.
- Buoys using active acoustics are probably not good for mounting passive acoustic equipment.
- Research institutions (e.g., University of Rhode Island, Monterey Bay Aquarium Research Institute) and states or coastal commissions may also have buoys where passive acoustic instruments could be added. However, some of these buoy systems may be transitory, as smaller organizations may depend on a less-stable funding for deployment and maintenance.
- In some areas, a reusable, fully retrievable system must be used (e.g., in National Marine Sanctuaries). However, in some cases, emphasizing the use of the buoy as directly related to the mission of the organization has resulted in increased tolerance for a non retrievable anchor system.

The Macaulay Library of Sound would like feedback on the kinds of searches the acoustics community wishes to conduct in this library/database of marine mammal vocalizations. For instance, it is currently possible to search for vocalizations based on water temperature and salinity. Many participants noted that it would also be helpful to search on chlorophyll levels, water depth, and other basic oceanographic properties in order to model where vocalizations are most likely to occur. Further, databases other than the Macaulay Library of Sound, such as the Ocean Biogeographic Information System- Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) and Living Marine Resources Information System (LMRIS) should also include a set of standard, routinely-measured oceanographic parameters so that the same types of searches can be performed with these databases.

Data management needs

Although vocalizations and associated oceanographic data require a great deal of storage space (many terabytes), participants generally seemed confident that more terabytes could be easily purchased and that technology will improve storage solutions over time. A greater concern was that the available search functions and data management options would grind to a halt when trying to efficiently access huge amounts of data. One option mentioned would be to hold the vocalizations and associated data in a central archive and have familiar "front ends" such as OBIS-SEAMAP and LMRIS tap into the archive. NESDIS might be the best entity to archive and manage the acoustics data.

Whenever possible, the entire recording should be archived, even if only a portion of the recording is of primary interest. For instance, a student might be most interested in blue whale vocalizations and may ignore other interesting recorded sounds (fish, other marine mammals, vessels). The entire recording should be preserved so that it can be used for other purposes. Thorough analyses of all of the recordings might have to wait until there are better automated analyses which would allow quick overviews of the data.

Managers should work closely with acoustic experts to address specific management questions of interest. That said, it seems reasonable that some information could be readily "packaged" for easy management use (e.g., baseline information on ambient sound in a sanctuary). If each Science Center hires two acousticians, management access to acoustics information may be far easier than at present.

1.3 Current efforts and opportunities

Many current efforts were discussed earlier, such as

- Inclusion of passive acoustics instruments on existing moorings
- Coastal Ocean Observing System (COOS) buoys or other instruments that collect basic oceanography data
- Autonomous bottom mounted recorders: great for near-real-time information, but do not collect oceanographic data yet.
- Port buoy systems
- Basic, easy-to-deploy Autonomous Underwater Listening Stations (AULS) currently are deployed within each of the 14 National Marine Sanctuaries (NMS) under the supervision of the education coordinator. Of those 14 sites, seven (Gray's Reef NMS, Channel Islands NMS, Hawai'i an Island Humpback Whale NMS, Northwestern Hawai'i an Island Marine National Monument, Olympic Coast NMS, Florida Keys NMS and Cordell Bank NMS) have deployed and captured recordings from their habitats serving as a baseline for anthropogenic and natural sounds in the sanctuaries. Stellwagen Bank NMS has numerous recordings from Cornell automated recording units (ARUs) (http://stellwagen.noaa.gov/science/passive_acoustics.html).
- Piggyback on moorings made via other venues (IOOS)

- The Commonwealth of Massachusetts has been involved in integrating passive acoustics with aircraft surveys; a publication on this will be out soon.
- Seagliders. Participants noted that there is a trend towards using seagliders instead of fixed moorings. As this new equipment comes online, people should strive to collect acoustics along with all of the other oceanographic data. Seagliders with acoustic capabilities are being developed.

Meeting participants should contact the staff in their region involved in IOOS and make it clear that passive acoustics are to be integrated into the IOOS system. The following are the IOOS points of contact:

Person to talk to about IOOS – Josie Quintrell 207/798-0857

National Coordinator for National Federation of Regional Associations for IOOS (Regional Association Framework)

2. REQUIREMENTS FOR INTEGRATION WITH ANTHROPOGENIC CONFLICT ISSUES (noise, shipping, etc.)

Moore provided a brief introduction to this section of the workshop and indicated that participants should consider how sound affects marine mammals at a broad scale. To do this, researchers need to collect baseline information on sound levels and ensure that these data are collected in a way that will inform studies on local impacts of anthropogenic noise.

In this case <u>calibration of the data is critical</u>. If a researcher is simply studying calls, calibration may not be necessary, but if the researcher seeks to develop ambient noise budgets or to make other precise sound measurements, instrument calibration is necessary. Calibration is not a trivial matter, and evaluation of noise elements is impossible without it.

Reliable calibration typically involves underwater measurements using a reference hydrophone and controlled sound source. Calibration of an instrument (or an instrument design) may cost $10,000 including the facility cost and the effort expended by acoustic instrumentation specialists. A less expensive approach is to calculate the instrument response based largely on component specifications, but this approach is prone to unanticipated problems and errors. The U.S. Navy operates several calibration facilities such as the Transducer Evaluation Center (TRANSDEC) in San Diego which can be rented by the hour for such work. Even with the best facilities and personnel, calibrations are typically difficult when accuracy below 1 dB is desired or when working at frequencies below 50 Hz.

Other approaches to calibration include using wind speed measurements and known relationships of noise to wind speed in the ocean, or using ambient noise sources within an array of instruments to calibrate one to the other. The gold-standard, however, remains the reference hydrophones maintained by the U.S. Navy.

Data requirements
- When working in the noise arena well calibrated systems are essential.
- Develop a standard set of tests to verify software such as Raven, which is to be used by non-acousticians.
- Develop park/sanctuary sound budgets
- Develop a way to localize the sources of sounds

Ambient sound levels are quite variable, and everybody has a different interest. A methodology for summarizing and interpreting acoustic records should be specified.

Discussion then focused on whether monitoring of sound should be specific to certain types of vessels, which is important in monitoring and managing human use of sanctuaries. The U.S. Navy and National Park Service (NPS) already have considerable information on sounds made by ships that can be used before collecting more data.

In marine sanctuaries, measurement of sound is equivalent to the NPS mandate to monitor and value the "soundscape" in the parks; marine sanctuaries have a mandate to understand and manage the sound as it is an integral part of the marine habitat.

Participants discussed a need to better understand what features of the new ships are making them noisier; one participant suspected that it is the size and speed of the vessels that has increased the sound levels, as the number of vessels on the water has not increased substantially in recent years. Although there are devices for making ships quieter, the shipping industry is interested in a cost/benefit analysis of making equipment quieter and more efficient before they effect changes.

One major issue is that analysis of noise measurements is lagging far behind the actual collection of noise data despite the increasing availability of software to automatically analyze recordings. Validation of the software is still needed to ensure that what is being measured is what the software was intended to measure. A set of validated standards needs to be developed that can be used by anyone developing analytical software for acoustics measurements. A committee has been formed recently within the Acoustical Society of America dealing specifically with standardization of acoustic surveys of marine mammals and will likely address some of this topic.

Management of anthropogenic sound data
Participants discussed several options for management of the large extended databases being developed. There was a general feeling that it would be good to approach NESDIS in Boulder, CO as the principal place to archive and manage anthropogenic sound data. Participants noted that while data storage is cheap, data management and maintenance are expensive.

2.2 <u>Scale of sampling</u>
Clearly, depending on the source, it is important to study sound using different temporal and spatial scales. It will be important to collect information on ambient sound beyond

sanctuaries as marine mammals are not limited to these regions; in addition, there are many other special areas (e.g., critical habitat) where ambient sound measurements should be taken.

Discussion also occurred on sampling sounds from seismic explorations, and those responsible for monitoring before, during and after seismic operations. It was noted that Marine Minerals Management Service (MMS) is the first line of interaction with oil and gas companies, so MMS usually has input into how operations are monitored etc; Angliss (NOAA/NMML) noted that MMS asks NOAA for suggestions for conservation recommendations and hence we need to know how to advise MMS. There have been some differences in how seismic operations associated with oil and gas have been authorized; while incidental harassment authorizations have been issued by NMFS for work in the Arctic Ocean, they have only been issued for work in the Gulf of Mexico over the past 3-4 years. One main issue is funding: funds from a lease sale are provided to the MMS and cannot be used to address NOAA priorities for measuring impacts of sound.

NOAA is far behind in ramping up to understand anthropogenic noise. The oil and gas industry plans on 40-year timelines, yet NOAA doesn't receive this long term information. Because of these completely different time scales, it is very difficult to address issues of industry noise. The recent interest in collecting information in the Chukchi Sea highlights the need to collect ambient information throughout U.S. waters. Industry is moving so quickly to work in the Chukchi that it is very possible that baseline data may not be collected before industrial presence occurs.

2.3 Current efforts and opportunities

To date, little work has been done on the impacts of sound on fish. Very little is known about the sounds that fish produce, and even less is known about the impact of sound on fish. Passive monitoring of fisheries is likely to grow in the next few decades.

3. REQUIREMENTS FOR INTEGRATING ABUNDANCE AND BEHAVIORAL PLATFORMS

Participants identified a number of ways that passive acoustics are being used with data on abundance and behavior. Data from towed arrays have been used to augment certain cetacean abundance estimates derived from line transect sampling. Moore noted that estimates from autonomous moored recorders have not yet been attempted, but this may be possible using radial-distance sampling techniques. Advances in population estimation, statistics, and a better understanding of animal behavior will be required to make this a reality.

While passive acoustics cannot currently be used to estimate abundance, animals are detected far better than with visual surveys. The presence of blue whales off Hawaii and in the Gulf of Alaska may not have been documented without the use of passive acoustics. Visual surveys and passive acoustics should be integrated in a synergistic way. One approach might be to place long-term recorders in areas, determine what species are present during what seasons, and then use combination of acoustics and visual surveys to do more focused studies. Another way to integrate techniques is to use acoustics as a way to find animals for biopsying or tagging studies. This was done successfully in 1999 and 2005 by NMML with North Pacific right whales.

3.1 Data requirements for abundance/behavior via acoustics

Participants identified the following types of information needed to determine abundance or behavior using acoustics:

- Specific sounds need to be assigned to particular species. This can be very difficult for some delphinid species. It may be possible to identify species via clicks, but additional diagnostics will be needed. It may also be possible to use power spectra to diagnose clicks, but distinguishing species specific clicks for most mid-sized toothed whales will be challenging.
- "Strip widths" need to be estimated for standard towed arrays; these arrays provide good information on bearing but poor information on distance.
- Visual surveys need to be conducted around a passive acoustic recorder to collect recordings of animals sighted in the area.
- Always measure the full bandwidth.
- Because fish do not have to come to the surface to breathe, it is usually difficult to determine what species is making a call and what behavior is related to the call. Remotely operated vehicles cannot be used as they are too noisy. Using light on quiet buoys can work, but it can also affect fish behavior. Infrared can be used to observe fish behavior, but only for a few feet. This topic will require some focused study.
- Transmission loss needs to be evaluated in all circumstances.
- In multipath situations estimates are needed; for instance, a dolphin whistle may bounce off the surface to the receiver which presents a good opportunity for getting distance from the source to the receiver.
- Arrays of passive acoustics recorders should be deployed when possible, as these provide much better information on animal locations.
- Acoustics may be a way to augment distance sampling by providing information on different behaviors by sex and age class.
- It is critical to consider and to improve our understanding of the behavioral aspects of vocalizations.
- The possibility of translating the numbers of calls to the numbers of individuals, i.e. using acoustics to improve abundance estimates, needs to be further researched.
- Acoustics can be used to identify separate stocks, however it is important to determine which species this work for, and what species are problematic?
- Further research into the changes in vocalizations in relation to sex, age, etc needs to be pursued for all species.
- How can we get abundance via acoustics and have visual operations augment a primarily acoustic study?

NOAA is not the only agency evaluating how to best use acoustics to monitor habitat. The NPS conduct point count surveys for birds, but these have never been calibrated. There is great interest in gaining a better understanding of how sound can be used to monitor and estimate population abundance.

Data management for abundance/behavior data
At this time, there is little physical integration of visual and acoustic survey data. These data types are typically stored in separate databases but should be combined. There have also been suggestions that any point samples (e.g., biopsies) should be included in the same database.

Standardized terminology is needed to refer to behaviors observed while vocalizations are being made. Cornell University's www.ethodata.org provides a list of animal behaviors, but this list may be too exhaustive. There is a shorter list of functional behaviors that might be more useful. The list of functional behaviors should be reviewed and updated with new behaviors and definitions that are relevant to marine species.

3.2 Scale of sampling
This agenda item has been previously discussed and was not discussed further at this point in the meeting.

3.3 Current efforts and opportunities
Participants noted that it is very important to continue to study well-known populations to document fine-scale behavior. This study is important because detection probability will depend on call frequency, and call frequency depends on age, sex, and behavior, and fine scale behavior is best addressed with populations that are very well studied. Although it is not cost-intensive to "get into" acoustics, there is a paucity of systems that are inexpensive and simple; the Northwest Fisheries Science Center (NWFSC) found that starting an acoustics program, or finding people who could do acoustics work on contract, was difficult.

At this time, signal recognition software is being developed or modified by individual researchers, or their laboratories. One participant questioned whether acoustics could transition to a system where someone with a moderate amount of training can take on an acoustics project by using standardized software. The general feeling of the group was this would not be possible because even simple acoustics analysis requires substantial interpretation, and individuals without training will be unable to reliably interpret data.

NMFS staff at the workshop noted during an earlier discussion that there had been a suggestion that each NMFS Science Center should have a data manager and an analyst to handle acoustics information. In addition, NMFS HQ should have a statistician familiar with acoustics (who could assist on a nationwide basis), a coordinator for acoustics research, and a basic acoustician. There was great interest in increasing the numbers of students in acoustics because there are insufficient numbers of people trained in basic acoustics to process all the data that have been collected. The following were identified as ways to bring new students or early-career professionals into NOAA: Sea Grant fellows, National Research Council postdocs, Consortium for Oceanographic Research and Education (CORE). There was a recognition that the U.S. Navy has done a lot more to train students than has NOAA; Barlow's students at the SWFSC are supported by Navy funds.

CONCLUSIONS: *DRAFT STRATEGIC PROGRAM PLAN* for *NOAA's Passive Acoustics Ocean Observing System (PAOOS)*

I. Directives and Authority for NOAA's PAOOS

Beyond the recognition of NOAA colleagues from across the agency that passive acoustics have numerous scientific and management benefits to the agency, there is overwhelming scientific directive, legislative authority, policy directives, and international statements/resolutions for expanding current U.S. marine acoustic sensing capabilities. Passive acoustics provides an exceedingly powerful means of achieving various NOAA missions by remote sensing of various aspects of the marine environment, including biotic and abiotic sources. The development of a strategic design and implementation plan for achieving such sensing capabilities with various observing platforms has been clearly called for. The need for NOAA to implement the PAOOS is supported by certain aspects of the following drivers from scientific, legislative, policy, and international sectors.

Directives from the Scientific Community

- National Research Council (2005). "Marine mammal populations and ocean noise: Determining when noise causes biologically significant events" National Academies Press, pp.142 - http://books.nap.edu/catalog/11147.html
- Marine Technology Society (2004). "Human-generated sound and the effects on marine life" (Special Issue: Vol. 37 #4)
- National Research Council (2003). "Ocean noise and marine mammals" National Academies Press, pp. 204 - http://books.nap.edu/catalog/10564.html
- Pew Commission (2003). America's Living Oceans: Charting a Course for Sea Change - http://www.pewtrusts.org/pdf/env_pew_oceans_final_report.pdf
- National Research Council (2000). "Marine mammals and low-frequency sound: Progress since 1994" National Academies Press, pp. 160 - http://books.nap.edu/catalog/9756.html
- Richardson, W. J., Greene, Jr., C.R., Malme, C.I., and Thomson, D.H. (1995). "Marine mammals and noise" Academic Press, San Diego, CA.
- National Research Council (1994). "Low frequency sound and marine mammals: Current knowledge and research needs." National Academies Press, pp. 92 - http://books.nap.edu/catalog/4557.html

Legislative Authorities

- Marine Mammal Protection Act. http://ipl.unm.edu/cwl/fedbook/mmpa.html
- Endangered Species Act. http://www.fws.gov/endangered/esa.html
- National Environment Policy Act. http://www.nepa.gov/nepa/regs/nepa/nepaeqia.htm
- National Marine Sanctuary Act. http://www.cr.nps.gov/local-law/FHPL_NtlMarineSanct.pdf

- Marine Protected Area Executive Order. http://www.nepa.gov/nepa/regs/eos/eo13158.html
- Coral Reef Act and Executive Order. http://www.mms.gov/eppd/compliance/13089/13089.txt
- Magnuson Stevens Fishery Conservation and Management Act. http://www.nmfs.noaa.gov/sfa/magact/

Policy Directives

- U.S. Commission on Ocean Policy: An Ocean Blueprint for the 21st Century (2004) - http://www.oceancommission.gov/
- U.S. Ocean Action Plan (call for Global Earth Observation Network) - http://ocean.ceq.gov/actionplan.pdf
- OMB Circular A-16 (Coordination of Geographic Information and Related Spatial Data Activities) - http://clinton4.nara.gov/textonly/OMB/circulars/a016/a016.html
- National Spatial Data Infrastructure - http://www.fgdc.gov/nsdi/nsdi.html
- Congressional Directive to Marine Mammal Commission to convene meetings on marine acoustics - http://www.mmc.gov/sound/plenary5/pdf/plen5finalsummary.pdf

International Bodies Considering Marine Acoustics

- Arctic Council – Arctic Marine Shipping Assessment (2005-2008) - http://www.pame.is/sidur/sidur.asp?id=70
- United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea - http://www.un.org/Depts/los/doalos_publications/LOSBulletins/bulletinpdf/bulletin53e.pdf
- World Conservation Union (IUCN): Resolution on Undersea Noise (2004) - http://www.awionline.org/whales/Noise/IONC/Docs/IUCN_RES053.pdf
- Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS) - http://www.cms.int/pdf/en/summary_sheets/Accobams_Agr_Sum_Sheet.pdf
- Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) - http://www.ascobans.org/files/agreement1992.pdf
- International Whaling Commission - http://www.iwcoffice.org

Previous NOAA Workshops:

Web link to relevant reports can be found at: http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

II. PAOOS Strategic Objectives and Links to the NOAA Strategic Plan

PAOOS Strategic Objectives:

NOAA's PAOOS will provide data on biological, geophysical, oceanographic, meteorological, and anthropogenic ocean events. While some of these functions will clearly be served by different elements of the PAOOS, it is critical to note the inherently multipurpose capacity of acoustic sensors. Passive acoustic deployments will substantively augment existing observing platforms, maximizing sensing capability, and generating information targeted toward meeting the following strategic objectives:

1) *Develop and deploy sensing capabilities to augment conventional means of detecting and assessing living marine resources*
Passive acoustics from autonomous or towed platforms provide a means of detecting vocalizing marine animals that is less compromised by sea state, visibility, or the need for the immediate presence of a survey vessel for detection. The augmentation of conventional survey methods will enhance NOAA's mandated requirements in supporting the conservation and sustainable management of living marine resources (e.g. Moore *et al.* 2006 and Rountree *et al.* 2006).

2) *Quantify spatial and temporal variance in marine ambient noise*
Baseline acoustic conditions in various marine ecosystems and the respective contributions of natural and anthropogenic sound sources (ambient noise budgets) are poorly known. Any informed assessment of how human introduction of sound may change baseline conditions in which animals have evolved must be based on a characterization of nominal conditions. Such knowledge is also critical for assessing and mitigating potential effects of acute acoustic exposures.

3) *Provide detection capability of specific anthropogenic acoustic events*
Passive acoustic deployments can provide an autonomous means of sensing specific anthropogenic events, such as the passage of vessels through critical habitat areas or the presence of illegal fishing activities in remote protected areas. This enhancement of NOAA's capability to remotely sense the marine environment will not only provide an independent means of investigating potential effects of individual sound sources on protected marine species, but also a potentially powerful tool in managing large, distant areas.

4) *Provide ecosystem information to NOAA and other geospatial sensing databases*
PAOOS data will be highly integrated and assimilated with those of partners in other agencies, academia, non governmental organizations, and industry. Data will be managed, archived, and disseminated to these communities to the greatest extent possible. PAOOS will contribute to and be integrated with GEOSS Network and IOOS.

5) *Contribute to public education and appreciation of marine ecosystems*
A key component of PAOOS will be to promote education and address perceived misconceptions in the general public. Web-based information will be provided from PAOOS elements via various educational elements of NOAA line offices, including collaboration between NMFS/ST, NMFS/PR, OAR/PMEL, and NOAA's Office of Education. NOAA efforts will also be directly integrated with the significant educational effort underway in the form of the "Discovery of Sound in the Sea" project at the University of Rhode Island.

PAOOS Links to the NOAA Strategic Plan

The PAOOS contributes to NOAA's ecosystem observing activities and the ecosystem mission goal to "protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management." Contribution of the system to many of the identified outcomes, performance objectives, and strategies of the ecosystem goal are given briefly below.

- **Ecosystem Goal Outcomes**

  1) *Healthy and productive coastal and marine ecosystems that benefit society*
  The PAOOS will provide monitoring and assessment of living marine and coastal resources and their habitats (strategic objectives 1 and 2). Further, sensing capabilities will significantly enhance the capacity to assess human introduction of sound into marine environments, both acutely and chronically (objectives 2 and 3), and its role as a potential ecosystem stressor among other human impacts.

  2) *A well-informed public acting as stewards of coastal and marine ecosystems*
  As described in strategic objective 5, considerable effort will be made to ensure maximal public transfer of information from passive sensing capabilities. This will include scientific publications, input into geospatial databases (objective 4), as well as internal contributions to the education and outreach efforts of NOAA's Office of Education, NMFS Regional and Science Center efforts, and coordination with NMS educational efforts. The PAOOS design and operation will also include the transfer of information to public-access, web-based education (*e.g.*, Cornell University's Macaulay Library of Natural Sounds and the University of Rhode Island's "Discovery of Sound in the Sea").

- **Ecosystem Goal Performance Objectives**

  1) *Assess, model, and forecast ecosystem resources for management decisions*
  The activities described under Ecosystem Goal Outcomes #1, above, directly support management decisions regarding living marine and coastal resources.

2) Increase the portion of the population that is knowledgeable about coastal and marine ecosystem issues.
As described under Ecosystem Goal Objective #2, NOAA's PAOOS will generate scientific and technical publications, contribute to relevant databases, and provide outreach and education material to NOAA's internal and external constituents, including the media.

- **Ecosystem Goal Strategies**

1) Manage uses of ecosystems by applying scientifically sound observations, assessments, and research findings to ensure the sustainable use of resources and to balance competing uses of coastal and marine ecosystems
PAOOS will provide observation and assessment of specific marine species, natural environmental variables (biotic and abiotic), and anthropogenic contributions to marine ambient noise. Such baseline and applied ecosystem observations directly support the sustainable management of living marine and coastal resources.

2) Improve resource management by advancing our understanding of ecosystems through better simulation and predictive models.
Passive acoustic sensing is a powerful means of locating, identifying, and characterizing specific living marine resources and elements of their natural and affected environments. PAOOS will provide baseline measures, which may serve as a basis for predictive modeling of the effects of continued increases in anthropogenic sound input.

3) Develop coordinated regional and national outreach and education efforts to improve public understanding and involvement in stewardship of coastal and marine ecosystems.
PAOOS will have dedicated contributions to education and outreach efforts both within and outside NOAA (described above).

4) Engage in technological and scientific exchange with our domestic and international partners to protect, restore, and manage marine resources within and beyond the Nation's borders
NOAA's increased remote sensing capabilities will provide vast quantities of area-specific data to the academic and government scientific communities via geospatial data bases (e.g., OBIS-SEAMAP). Data will be obtained and archived by NESDIS in a manner that it is accessible to both domestic and international partners for research and management purposes.

III. PAOOS Design, Data Management, and Integration

Elements: Participating Line Offices

NOAA Fisheries Service (NMFS) will be responsible for the coordination and execution of the data acquisition and analyses aspects of NOAA's PAOOS. NMFS components of the system will include: fisheries and protected resources surveys, ecosystem surveys, and cooperative research including deployments conducted by NMFS science center personnel. NMFS will further ensure the scientific quality assurance of PAOOS products and collaborative linkages to other federal and state agencies, stakeholders, and the public.

National Ocean Service (NOS) will be responsible for supporting the deployment of acoustic sensors as a critical element of the PAOOS within sanctuary boundaries. This support is expected to be in-kind support in the form of deployment access and, to the extent funds are available, direct support of deployments by NOS, NMFS, or outside researchers.

Office of Oceanic and Atmospheric Research (OAR) will contribute expertise and capabilities in the areas of data acquisition and processing. OAR's Pacific Marine Environmental Laboratory (PMEL) has accomplished some of the most extensive passive acoustic data collection and interpretation within NOAA to date. PMEL and other entities within OAR are expected to play a key technical role in NOAA's PAOOS.

National Environmental Satellite Data and Information Service (NESDIS) will be responsible for data management, archiving, and information services provided by the NOAA National Data Center infrastructure to support ecosystem goal objectives. Additionally NESDIS will provide technical support and leadership in integration of information services located within ecosystem observation programs to achieve NOAA-wide objectives for IOOS, GEOSS, and related end-to-end data system integration efforts.

System Design: Personnel, Infrastructure, and Data Management Requirements

NOAA's PAOOS will be organized with overarching national goals and objectives, but integrated and implemented with a regional approach based on NOAA's identified large marine ecosystems (LME). The following personnel and infrastructure requirements exist for NMFS and NOS elements of the PAOOS to fulfill the goals and objectives for each of NOAA's LMEs:

Personnel:

- 1-2 FTEs with skilled acoustic expertise for each NMFS Science Center and selected National Marine Sanctuaries and OAR research facilities.
- 1 FTE national team leader for passive acoustics – NMFS/ST Headquarters
- 1 FTE acoustic propagation specialist to work with regional staff to facilitate

analyses and address effects issues for discrete exposures – NMFS/ST Headquarters
- 1 FTE statistician and acoustic software specialist – NMFS/ST Headquarters
- 1 FTE outreach specialist who will partner with entities identified below
- Resources to support temporary staff for acoustic deployments
- Sufficient resources to support a program to promote and train students proficient in passive acoustic research (*e.g.*, via Hollings fellowships and other student programs).
- Sufficient staffing to facilitate data management (discussed below)

Infrastructure:
- Passive acoustic monitoring should be integrated into every NOAA marine mammal survey cruise, requiring each NMFS Science Center to have two towed arrays, sufficient resources to maintain and deploy them, relevant hardware and software to run programs and relevant accessories.
- Each NMFS Science Center and selected National Marine Sanctuaries and OAR research facilities should have at least 5-10 fixed passive acoustic sensors of variable type depending on requirements.
- Sufficient access to ship time for surveys and deployment of acoustic recording devices will be required. Sufficient hardware and software are needed to handle massive data streams, automated detection capabilities for multiple species, and for real time detection capabilities.

Data management:
- Each region will require sufficient resources to establish data archives and transfer to national database (NESDIS).
- 1-3 FTE at NESDIS to handle data management and coordination with each regional PAOOS data manager as well as sufficient computing and archival capabilities.

Collaboration and Integration

NOAA's PAOOS will be integrated with other ocean observing systems which are or will be deployed for other observing purposes but which could be used as PAOOS platforms, including:

- Ocean.US (IOOS)
- ORION
- NOAA's NBDC
- U.S. Geological Survey
- Cooperative Ecosystem Studies Unit Network
- U.S. Coast Guard

PAOOS Working Group Coordination: At the April 2006 National Passive Acoustics Workshop, where years of planning and discussions regarding passive acoustics within NOAA culminated in the current concept for NOAA's PAOOS, it was agreed to form an ad hoc observing system working group. Following completion of the PAOOS strategic plan, a NOAA working group on passive acoustics will be established. Science Center directors, regional administrators, and other appropriate management will be consulted to determine the appropriate people to participate in this working group. There will be a yearly rotating chair and semi-regular meetings that will rotate regionally. An announcement will be distributed to all EOP, NESDIS, NOS, and OAR headquarters to inform them of the creation of this working group and request nomination of relevant participants.

Education and Outreach

Numerous educational and outreach efforts will be accomplished with data obtained by the PAOOS. Metadata as well as raw acoustic recordings will be transferred to the public in a variety of fora and media with the below and other potential mechanisms:

- NOAA's Office of Education
- National Oceans Service – National Marine Sanctuaries
- NOAA's Office of Ocean Exploration
- NMFS Line Office and Program Websites
- National Marine Educators Association
- Association of Zoos and Aquariums
- Alliance of Marine Parks, Zoos, and Aquariums
- URI – Discovery of Sound in the Sea
- Cornell's McCauley Library of Sounds

IV. Outcomes, End-Users and Beneficiaries

Outcomes: Short to Moderate Term

1) Provide agency scientists with increased sensing capabilities to augment existing methods to conduct timely and accurate stock assessments and forecasts for protected species.

2) Produce measures of spatial and temporal variability in marine ambient noise in areas where these factors are unknown; produce noise budgets which account for the relative contribution of natural and anthropogenic.

3) Enhance NOAA's capability to assess the potential effects of discrete noise events (*e.g.*, explosions in marine protected areas) on living marine resources.

4) Contribute information on marine animal acoustic communication and other marine environmental features to printed, classroom, and web-based education and outreach efforts.

Outcomes: Long Term

1) Fundamentally improve the ability of the agency and outside researchers to detect and characterize living marine resources.

2) Quantitatively assess temporal trends in the anthropogenic contribution to marine ambient noise.

3) Improve NOAA's capability to manage living marine resources.

4) Play a leadership role in providing scientific data on marine mammal presence and abundance as well as acoustic characteristics of marine ecosystems to geospatial databases and the general public.

End Users and Beneficiaries

NOAA**:** A successful PAOOS will provide monitoring, assessment, and forecasting information and data analysis required for NOAA to meet its science and management mandates. Within the Ecosystem Goal, PAOOS will support (at least) the missions of NOAA's Protected Species Management Program, National Marine Sanctuaries, Habitat Program, Coral Reef Conservation Program, Coastal and Marine Resources Program, Ecosystem Research Program, and Office of Law and Enforcement. Further, it is expected that PAOOS may support other goals, including NOAA's Climate and Ecosystems Program, given the potential for passive acoustic data to provide information on meteorological events.

Research Community: PAOOS will ensure delivery of data products to the research community, including high quality information on living marine resources and their environment. To the extent that NOAA's passive acoustic capabilities are integrated into the GEOSS and IOOS, those systems will benefit from PAOOS as well.

General Public**:** Science based conservation and management programs provide societal benefit and opportunities for expanding public value of marine ecosystems.

Environmental Non-government Organizations (NGOs)**:** Environmental NGOs are expected to use data provided by PAOOS to monitor the status of living marine resources and marine ecosystems.

Industry: NOAA's PAOOS will also provide critical information on presence and characteristics of marine animals and ecosystems that are essential in sustainable management and conservation of living coastal and marine resources.

APPENDIX A

Workshop Participants

The workshop was split into two separate sessions, an interagency planning session and a session involving invited experts from outside of the agency. Session two was further broken out into two separate working groups, 2a and 2b.

Session 1. Interagency planning workshop on Passive Acoustics Research

Robyn Angliss (Rapporteur Session 2a)	NMFS National Marine Mammal Laboratory
Kyle Baker (2b)	NMFS Southeast Regional Office
Jay Barlow (2a)	NMFS Southwest Fisheries Science Center
David Gouveia	NMFS Northeast Regional Office
Leila Hatch (Rapporteur Session 1, Participant 2b)	NOS Stellwagen Bank National Marine Sanctuary
Dave Johnston (2b)	NMFS Pacific Islands Fisheries Science Center
Linda Jones (2b)	NMFS Northwest Fisheries Science Center
Marc Lammers (2b)	NMFS Pacific Islands Fisheries Science Center
Tony Martinez	NMFS Southeast Fisheries Science Center
David Mellinger	Oregon State University and NOAA Pacific Marine Environmental Laboratory
Sue Moore (Facilitator Session 2a)	NMFS Alaska Fisheries Science Center @APL-University of Washington
Brandon Southall	NMFS Office of Science and Technology HQ DC
Kate Stafford	APL-University of Washington and NOAA Alaska Fisheries Science Center
Steve Swartz (Facilitator Session 2b)	NMFS Office of Science and Technology HQ DC
Sofie Van Parijs (2b)	NMFS Northeast Fisheries Science Center

Session 2. Monitoring Biological Noise Using Passive Acoustics – Integrating Platforms

Mark Baumgartner	Woods Hole Oceanographic Institution
Jack Bradbury (2b)	Cornell University
David Bradley (2a)	Pennsylvania State University
Christopher Clark (2b)	Cornell University
Roy Gaul (2a)	Blue Sea Corporation
Bob Gisner (2a)	Office of Naval Research
Clifford Goudey	Massachusetts Institute of Technology
John Hildebrand (2b)	Scripps Institution of Oceanography
Nathalie Jaquet (2b)	Center for Coastal Studies
Mark McDonald (2b)	Whale Acoustics
Jim Miller (2a)	University of Rhode Island

Dave Moretti (2b)	Naval Undersea Warfare Center
Jeff Nystuen (2b)	APL – University of Washington
Susan Parks (2a)	Cornell University
Andrew Pershing (2b)	Cornell University
Rodney Rountree (2b)	Marine Ecology and Technology Applications
Peter Tyack (2b)	Woods Hole Oceanographic Institution
Cathy Vigness (2a)	Marine Acoustics Inc.
Stephanie Watwood (Rapporteur Session 2b)	Woods Hole Oceanographic Institution
Mason Weinrich (2a)	Whale Center of New England
Lynnee Willians (2b)	Duke University
Peter Worcester (2a)	Scripps Institution of Oceanography

Observers

Ingrid Biedron (2b)	Cornell University
Nicole Mihnovets (2b)	New York State Department of Environmental Conservation
Misty Nelson (2b)	NMFS Northeast Fisheries Science Center

APPENDIX B

Presentations (Tuesday AM, 11 April)

Session 1. Interagency planning workshop on Passive Acoustics Research

SWFSC Acoustic Survey Research for Marine Mammal Assessment
Jay Barlow, Shannon Rankin, Julie Oswald, and Erin Oleson

At the Southwest Fisheries Science Center (SWFSC) we have been experimenting with the incorporation of acoustics in line-transect surveys since 1995. The Cetacean Acoustic Detection and Dive Interval Survey (CADDIS) in 1995 examined the acoustic detectability of beaked whales and found that only Baird's beaked whales made sounds that could be readily detected (Dawson *et al.,* 1998). The Shallow Water Positioning System (SWAPS) survey in 1997 was our first combined visual and acoustic survey and provided density estimates of sperm whales by using detections from both methods (Barlow and Taylor, 2005). Starting in 1998, towed hydrophone arrays were used on dolphin line-transect surveys. We have worked with others (Thode *et al.,* 2000; Mellinger, 2001) to develop software to localize dolphins from their whistles. Results showed that dolphins could be detected from their whistles at significantly greater distances using acoustics. In collaboration with Scripps, sonobuoys have been used opportunistically on our surveys to make low-noise recordings of sounds from a variety of species. Most notably, we were the first to find that Bryde's whales make stereotypical low-frequency calls similar to blue whales and that the various call types show strong geographic patterns (Oleson *et al.,* 2003). We have also made first recordings in the presence of western blue whales (Rankin et al., in press) and sei whales in the North Pacific Ocean. Recordings from sonobuoys and our towed array have been used to examine the feasibility of determining species from dolphin whistles. Using two different classification methods (DFA and CART), we have found that more than 50% of whistles from nine dolphin species can be correctly classified to species (Oswald *et al.,* 2003), compared to an 11% correct classification by chance alone; the correct classification score can be improved by recording higher frequencies (Oswald et al., 2004). We have tracked the mysterious "boing" down to its source ... the North Pacific minke whale (Rankin and Barlow 2005). Future research on acoustic survey methods will concentrate on estimating $g(0)$ for sperm whales, improving our ability to listen in a forward direction using a towed hydrophone, estimating $g(0)$ for dolphins, and estimating the density of calling minke whales from their "boings" recorded on past surveys. We also hope to expand our research into passive acoustic monitoring of ambient sound.

Listening for Large Whales in Offshore Waters of Alaska, 1999-2004.
Sue E. Moore, Kathleen M. Stafford, David K. Mellinger, John A. Hildebrand

(Based on: ***BioScience*, January 2006)**
In 1999, the first phase of a multi-year program to advance the use of passive acoustics for detection and assessment of large whales in offshore Alaskan waters was initiated at

National Oceanic and Atmospheric Administration's (NOAA) National Marine Mammal Laboratory (NMML) and Pacific Marine Environmental Laboratory (PMEL). Two types of recorders have been used: (1) long-term hydrophones developed by PMEL (http:// *www.pmel.noaa.gov/vents/acoustics/whales/bioacoustics.html*) and (2) Acoustic Recording Packages (ARPs) developed by Scripps Institution of Oceanography (SIO) (*http://cetus.ucsd.edu*). To date, autonomous recorders have been successfully deployed in the Gulf of Alaska (GOA: 1999-2001), the southeastern Bering Sea (SEBS: 2000-present) and the western Beaufort Sea (WBS: 2003-2004). Seasonal occurrences of six endangered species (blue, fin, humpback, North Pacific right, bowhead and sperm whales) have been documented based on call receptions in these remote ocean regions. In addition, eastern North Pacific gray whale calls were detected in the WBS from May through January.

In addition, and not included in the *BioScience* article, two high-frequency ARPS (HARPS) were deployed in July 2004 offshore Washington state in waters where the Navy plans to expand a training range and within the boundaries of NOAA's Olympic Coast National Marine Sanctuary. One instrument was lost, but the second has been recovered and redeployed twice. This range-monitoring study has been funded by Navy/N45, with conduct of the program transferred to SIO in October 2005. Also, with support from ONR, the Applied Physics Laboratory (APL) plans a sea trial of the Acoustic Seaglider in the Monterey Bay National Marine Sanctuary in August 2005. Six APL-type gliders will carry broadband hydrophones and operate with SIO gliders in a field including both bottom mounted and vertical acoustic arrays. This is anticipated as a proof of concept test for detection and (possibly) tracking of blue and humpback whales.

Acoustic Studies of Cetaceans in the Northwest Region

Linda Jones, Brad Hanson and Dawn Noren

The Northwest Fisheries Science Center is addressing a wide variety of acoustic related issues important to conservation of marine mammals in our region. Since 2003, the NWFSC's Marine Mammal Program has funded a variety of research projects using passive acoustic methods to directly address the distribution of cetaceans, particularly southern resident killer whales, and potential anthropogenic impacts of noise on this and other species. We have also used behavioral and energetic studies to address the potential impacts of noise on cetaceans. Studies are conducted in two areas: coastal waters off Washington, Oregon and northern California and in a highly urbanized area in the inland waters of the greater Puget Sound area. During NOAA research cruises in the coastal waters, traditional visual survey methods are combined with towed passive hydrophone arrays to study cetacean winter distribution and locate areas of importance during the winter. A hydrophone system which uses two arrays towed in parallel is being developed to track cetaceans for longer periods of time. Moored passive hydrophones (HARPS and PALS) have been placed in several coastal locations during the winter-spring period to record ocean noise and cetacean vocalizations to study winter distributions. The inland waters of Puget Sound are the primary summer and fall range for southern resident killer whales as well as a very busy shipping area with large numbers of commercial cargo ships, tugs and barges, Navy ships, fishing boats, whale watch and recreational boats. An average of over 20 boats per day now closely follow the killer whales during this period and this raises concern about the whales' ability to communicate and find prey. Navy mid-range sonar use in Puget Sound near the whales increased public concern regarding noise affects on the whales. In the inland area, studies have focused on characterizing ambient noise over different temporal scales, collecting controlled noise measurements of vessels, developing propagation models of sound in the complex acoustic environment of Haro Strait, WA, as well as collecting behavioral and energetic data to assess the affects of vessel noise on southern resident killer whales. There is evidence from recent boat-based and land-based studies that the large number of vessels may modify killer whale behavior in various ways. A final research project involved compiling a list of all available acoustic data in the Puget Sound are to identify what acoustic information is available in this region.

Passive Acoustics Preview: PIFSC Cetacean Research Program

Dave Johnston, Jeffrey Polovina & Jason Baker

More than 20 cetacean species are known to occur in the Pacific Islands Region (PIR), which encompasses the U.S. Exclusive Economic Zone, or EEZ (waters out to 200 nmi from shore) around the entire Hawaiian archipelago, Johnston Atoll, Kingman Reef and Palmyra Atoll, Baker and Howland Islands, Jarvis Island, American Samoa, Wake Island, Guam, and the Commonwealth of the Northern Mariana Islands. Many of the species present are poorly studied throughout their range, and virtually unstudied in large portions of the PIR. The Pacific Islands Fisheries Science Center (PIFSC) recently initiated a cetacean research program to begin addressing data gaps in the region, with a focus on stock assessments for poorly known species. Building on successes in other NMFS regions, passive acoustic methods are one tool being developed for stock assessment purposes in the PIR, employing both mobile and static packages. We currently have 2 bottom mounted acoustic recorders deployed in the region, one at Cross Seamount south of Oahu and another at Palmyra Atoll. Six months of data have been recovered from the Cross Seamount deployment and are currently being analyzed. A recent large vessel cetacean survey in American Samoa, the equatorial central Pacific and Johnston Atoll combined acoustic observations from a towed array and sonobouys to study cetacean vocalizations and focus visual survey efforts. Further passive deployments are planned to study cetacean distribution and fishery interactions in the Northwestern Hawaiian Islands and in the Mariana Islands in conjunction with the Southwest Fisheries Science Center.

Passive Acoustic Monitoring of Biological and Anthropogenic Activity on Coral Reefs and in Nearby Waters

Marc O. Lammers, Russell E. Brainard, Whitlow W.L. Au and Kevin Wong
lammers@hawaii.edu

Monitoring the changing state of coral reef ecosytems is a challenging task that is exacerbated when the reefs in question are in remote locations. Physical sensors provide a wide range of measurements of local environmental variables, but do not give an indication of biological activity. Since 2004, through a partnership with the Hawaii Institute of Marine Biology, PIFSC has been developing tools to monitor biological activity on remote coral reefs acoustically. Moored Ecological Acoustic Recorders (EARs) have been developed to sample the ambient sound field at pre-set intervals with a bandwidth of up to 30 kHz. Test deployments around Oahu, Hawaii are providing some preliminary results. Snapping shrimp produce the dominant acoustic energy on the reefs examined and exhibit clear diel acoustic trends. At frequencies below 2 kHz, many fish sounds occur, which also exhibit distinct temporal variability. Many sounds can be detected automatically, making the examination of the sound field an efficient means of tracking diel and seasonal variability in acoustically active species. In addition, sounds from passing vessels are also easily detected by the EAR, providing insight into anthropogenic activities near deployment sites, such as in marine protected areas. The EAR is presently in its second generation of development and has a deployment life of one year. Four units were deployed in American Samoa in February 2006 and four additional units are planned for deployment in the Northwestern Hawaiian Islands Ecosystem Reserve. The data obtained from these and future deployments will be used to examine seasonal, inter-annual and decadal trends in biological activity and to help detect significant ecological events on remote reefs, such as coral bleaching. Ongoing efforts are targeted towards improving the EAR's vessel detection capabilities, adapting the design to deep water deployments (100-300 m), increasing its deployment life and improving data processing algorithms.

Passive Acoustic Research at NOAA-PMEL / OSU

David K. Mellinger and Robert P. Dziak

The PMEL Vents Program has a passive acoustics program for research on marine mammals and seafloor hydrothermal activity. Marine mammal research is focused on measuring spatio-temporal distributions of marine mammals and the factors that affect those distributions, though we also study ocean noise, call type variation (we would like to combine this with genetic analysis), and related issues. We have studied right, blue, fin, Brydes, minke, humpback, and sperm whales. We also develop analytical tools, particularly acoustics software for detecting marine mammal sounds, visualization and measurement of acoustic features, and acoustic localization and tracking of marine mammals. Our hydrothermal research focuses on the remote detection of earthquakes associated with seafloor volcanic activity. Earthquakes in the ocean crust produce acoustic phases that propagate in the deep sound channel. Exploiting the low acoustic energy attenuation properties of the deep sound channel allows for distant detection of seafloor volcanic activity from throughout the Pacific and Atlantic Ocean basins. Our two principal methods of data collection are via the US Navy's SOSUS arrays in the Pacific (we have a classified facility for these data), and via our autonomous hydrophone instrument, the Haruphone. Autonomous hydrophone deployments have occurred or will occur in the eastern tropical Pacific, mid-Atlantic, Gulf of Alaska, Scotian Shelf, Mariana Islands, Drake Passage, Bering Sea, Davis Strait, Indian Ocean, and near Iceland.

Passive Acoustic Detection of Marine Mammals at SEFSC
Anthony Martinez and Lance Garrison

Since 2000, the NOAA Southeast Fisheries Science Center (SEFSC) has conducted several joint visual and acoustic surveys of the Gulf of Mexico, continental shelf and slope waters along the Atlantic U.S. coast and parts of the Caribbean aboard the NOAA ship *Gordon Gunter*. Acoustic operations to date have primarily employed a five-element towed hydrophone array, a shorter two-element array and surplus US Navy sonobuoys, both high frequency and directional. These passive acoustic devices were utilized simultaneously with visual survey efforts except where limited by water depths. The visual survey team operated independently of the acoustic effort and was not notified of acoustic contacts. Visual sightings were reported to the acoustics team and noted in the acoustic data logs. These datasets are currently being reviewed to match acoustic and visual detections. There have been numerous instances where acoustically detected marine mammals were not observed by the visual team.

The SEFSC has also worked through contracts with Cornell University to conduct passive acoustic monitoring utilizing anchored sub-surface autonomous recording buoys called “pop-ups”. Most recently, these devices have been deployed between Georgia and North Carolina to monitor North Atlantic right whales. Pop-ups were deployed across the bathymetry at three sites from November through April in 2004, 2005, and 2006. These buoys recorded right whale contact calls throughout the winter at all sites in each year. These data are currently being analyzed to evaluate the temporal and spatial distribution of right whales in the area and will be compared to concurrent aerial visual surveys.

The passive acoustics program at SEFSC has primarily focused on the development of methods and capability for monitoring of marine mammals. There are significant analytical challenges that remain to be addressed. The most critical programmatic needs are to increase the capacity to manage and process data, to conduct the analytical work needed to efficiently utilize acoustic tools to augment visual sightings data, and to document the spatial patterns and habitat use of marine mammals.

NEFSC Passive Acoustics Research
Sofie Van Parijs, Debbie Palka and Richard Merrick

Past work on passive acoustics within the NEFSC has involved the incorporation of acoustics in line-transect surveys in order to estimate the abundance of North Atlantic marine mammal species. Particular emphasis was placed on harbor porpoise (1999 & 2001) and offshore Atlantic marine mammal species (2004). In 1999 a specially designed porpoise box array was used which measured the amplitude of clicks detected at 50, 75 and 125 kHz. Estimated density of groups was ~2.5 times that obtained from a conventional line transect analysis of only the visual data, assuming g(0)=1. The probability of detection on the track line [g(0)] for the upper visual team was about 0.4, compared with using two visual teams g(0) = about 0.35. In 2001 a system was used that was most sensitive between the 100Hz to 22 kHz range. 133 hours were surveyed resulting in over 22 hours of recordings covering over 2500km of survey track line. 114 odontocete whistles and 24 mysticetes tonal calls and gun-shot sounds mostly in areas with low ambient noise which separated into 15 odontocetes and 16 mysticetes acoustic encounters. In 2004, Rainbow Click (a mid frequency click detector) and Whistle (a mid frequency tonal sound detector) were tried out throughout the survey. For the future a new towed array is being built that will allow access to low, mid and high frequency in order to expand our focus further in particular to sperm whales and Northern right whales. This system will be field tested in the summer of 2006.

NEFSC has funded several external passive acoustic projects in the Northeast region on large whales. Within the Center, passive acoustics ‘popup’ acoustic receiving devices (BRP, Cornell University) are being used in collaboration with Stellwagen Banks Marine Sanctuary in order to monitor the presence/absence of large whales throughout the sanctuary during a 12 month period. Firstly, we are interested in determining any activity that might occur during the winter months, seeing as the weather conditions render this time of year inaccessible to most other conventional survey methods. Secondly, we aim to develop an increased knowledge of the movements and occurrence of large whales in relation to the shipping lane passing through the sanctuary. This data will be linked with existing AIS data on ship movements. Our aim is to better inform management of the likelihood of potential conflicts between ships and whales. Future work will relate individual and group acoustic behavior of large whales with detailed oceanographic parameters, in collaboration with Mark Baumgartner (WHOI) during the May 2006 cruise. Other passive acoustic projects include the development and deployment of moored, autonomous passive acoustic buoys with real-time data processing and data uplinks, as well as continued deployment of pop-up buoys at a number of sites in the Northeast. All this work is being done cooperatively with Cornell.

APPENDIX C

Presentations (Wednesday PM, 12 April)

Session 2. Monitoring Biological Noise Using Passive Acoustics – Integrating Platforms

The Marine Animal Sound Archive at the Macaulay Library.
Jack W. Bradbury

The presentation will describe the current size and scope of the marine animal sound archive at The Macaulay Library, and outline current, imminent, and planned services that the Library can provide to those working on passive marine acoustics projects. Input from the marine bioacoustics community on how the Macaulay Library can further refine and augment these services is strongly encouraged.

Overview of Passive Acoustic Recording Devices
Brandon Southall

A brief overview by region of existing passive acoustic recording devices and discussion of the potential for future deployments.

Marine Mammal Monitoring on Navy Ranges (M3R): A Long Term Study of the Effect of Sound on Marine Mammals
David Moretti, Ronald Morrissey, Nancy DiMarzio, Jessica Ward, Susan Jarvis

To date, *in situ* studies of the effect of sound on marine mammals have centered on singular events or controlled source experiments. The ONR Marine Mammal Monitoring on Navy Ranges Program (M3R) has developed tools to detect and localize vocalizing marine mammals using the assets of the Navy's Atlantic Undersea Test and Evaluation Center (AUTEC). These facilities provide vast instrumented undersea areas each capable of acoustically monitoring over 500 nmi^2. Continual monitoring of vocalizing animals will be established. A comprehensive baseline of the effect of sonar on marine mammals as measured through the animals' movements and vocalizations over broad temporal and spatial scales will be described. The movements and vocalization patterns of the vocally active animals will be recorded. These data will provide a baseline metric of animal activity in the absence of anthropogenic sound. Vocalizing animals will also be monitored in the presence of anthropogenic sound sources. Animal movements and vocalizations during sound exposure will be recorded and compared to the baseline data.

Science Payoffs from Ambient Noise Monitoring: Results of the Warwick Workshop
David Bradley and James H. Miller

Two workshops were held on the topic of ocean ambient noise budgets, monitoring and implications for marine mammals. The attendees established a set of testable hypotheses and designed a science plan that meets the 2003 NRC recommendations for research that reveals the trends in underwater noise and consequent impact on marine mammals. The workshops were held in Warwick, Rhode Island on March 29-30, 2004 and October 25-26, 2004. This paper provides a summary of the workshops' recommendations.
The hypotheses include the following: I) low-frequency ambient noise is increasing at a rate of 3 dB per decade, dominated by shipping noise and masking mammal communications, II) high and low latitude ambient noise have differing characteristics because of the presence of the sound speed minimum at or near the surface and the speed of global climate change will stress the adaptability of the mammals to accommodate a new acoustic environment, III) the northern right whale has failed to recover from whaling due to the anthropogenic noise in those near shore areas of its habitats and IV) the acute effects of man-made sound on beaked whales from mid-frequency sonar involve a behavioral reaction rather than direct acoustic trauma. A set of experiments will be discussed to address these and other hypotheses. These experiments initially focus on the Gulf of Maine and then involve other areas.

Acoustic Monitoring of Marine Mammals and Ambient Noise
John Hildebrand

An overview of passive acoustic monitoring and ambient noise characteristics are presented. Acoustic monitoring is complimentary to visual approaches for the study of marine mammal populations. When acoustic and visual techniques are compared, they often reveal different aspects (behavioral, spatial, or temporal) of the population under study. Long-term acoustic study of baleen whales is an established technique. Acoustic Recording Packages (ARP's) have been deployed continuously for up to one year to study baleen whale calls at low frequencies (e.g. 1000 Hz). Recently, High-frequency Acoustic Recording Packages (HARPs) have allowed the study of odontocetes from their calls. Current HARP capabilities are for sampling rates up to 200 KHz, and data storage up to 1920 Gbytes, which allows for 55 days of continuous sampling. Longer deployment times are possible using intermittent sampling (e.g. 330 days at 1/6 duty cycle). HARP deployments have been conducted at four sites of interest to NOAA: (1) the Bering-Sea, (2) the Olympic Coast National Marine Sanctuary, (3) the southern California bight (including the Channel Islands National Marine Sanctuary), and (4) Cross Seamount and Palmyra Atoll in the tropical Pacific (PIFSC study areas). Long-term acoustic recordings from these HARPs reveal that odontocete clicks (impulsive calls generally at frequencies above 20 kHz), may be helpful in species identification. Examples of data from these areas of NOAA interest are presented, along with techniques for data analysis.

The characteristics of ambient noise from commercial shipping and whale watching boats are presented. Ambient noise in the North Pacific basin has increased at a rate of about 3 dB per decade for at least the past four decades. Repeat ambient noise measurements at the San Nicolas SOSUS array site (off shore southern California), reveal about 12 dB of increased noise in the low frequency band (10-80 Hz) between the early 1960's and the early 2000's. These data suggest that both more commercial ships, and increased noise from individual ships have contributed to increases in ambient noise. Noise measurements from individual whale watching vessels were made during controlled tests in the Haro Strait. These data suggest that mid- to high frequency noise (2 – 80 kHz) may be elevated in close proximity to whale watching vessels during active maneuvers.

Ocean Climate from Passive Acoustics – Sorting Out the Racket
Jeffrey Nystuen

Long-term passive acoustic measurements provide a unique description of climate in marine environments. The ambient sound filed contains quantitative information about physical, biological and anthropogenic processes and activities. Low-duty cycle passive aquatic recorders (PALs) have been used to collect data from a variety of moorings in a variety of marine environments, including deep-water, coastal and inland waterway locations. Sound budgets developed at these sites describe acoustic climate and are needed as baseline information for future decisions regarding the impact of sound-producing human activities on the marine environment.

Listening to Fish: Passive Acoustics Applied to Marine Fisheries and Ecosystems
Cliff Goudey and Rodney Rountree

Passive acoustics is a rapidly growing field that uses new technology to locate fish by listening to sounds they produce. This can be a powerful new tool for the identification of essential fish habitat (EFH). For example, spawning locations of scienanids have been mapped by listening to the courtship sounds of males in estuaries of the southeastern US. Using this approach we have successfully recorded haddock, Melanogrammus aeglefinus, spawning sounds in the Jeffreys Ledge - Stellwagen Bank region of the Gulf of Maine. In another study, Rountree and Juanes (in review) made the first field recordings of sound production in the cusk, *Brosme brosme*, in the Stellwagen Bank National Marine Sanctuary. In situ recordings of this type have not previously been made in North American continental shelf waters. As part of these efforts, we have developed novel underwater passive acoustic probes (hydrophones/recorders) for use that can be deployed by commercial fishermen. The Acoustic Underwater Listening Stations (AULS) are deployed on the seabed much like passive fishing gear and continuously record ambient sounds for up to 30 hours (at an 11 kHz sampling rate). During two field seasons we collected over 3,000 hours of recordings in 67 deployments. Preliminary results suggest that haddock soniferous activity, and presumably spawning activity, occurs primarily in the late afternoon and early evening hours. An on-going study of the spawning behavior of haddock seeks to confirm the daily pattern of spawning, and will pave the way for future passive acoustics surveys to identify haddock essential fish habitat. In other studies, we are working with all 14 of the National Marine Sanctuaries to use AULS to begin cataloguing underwater sounds in each system. More recently, we have begun sampling with a deep-water AULS capable of recording in depths of over 1000 m.

Near Real-time Passive Acoustic Monitoring, Tracking Behavior, and Movements and Defining Ocean Noise
Christopher W. Clark

Autonomous seafloor recorders have been deployed in GoM to monitor for Northern right whales since 2001. In spring 2005 and 2006 moored, auto-detection buoys that transmit data via cell phone have been deployed in Cape Cod Bay. These hardware technology efforts are tightly coupled to major software developments for automatic sound detection, recognition, and classification. A major motivation for these undertakings is to provide timely information on the presence of whales to reduce ship collisions and gear entanglements. A secondary motivation is to better understand whale acoustic behavior to interpret the distribution and population condition. Some benefits include dramatic increase in spatial and temporal coverage, higher probability of detecting presence from acoustic than from aerial survey, and an immense baseline of acoustic data including biotic, abiotic, and anthropogenic sources. Some limitations include difficulty of translating call rates into number of animals, inherent delay in obtaining results from seafloor recorders, and deployment difficulties in shallow water and areas with high noise levels from shipping traffic. Whales can be located and tracked with arrays of units to obtain minimum number of animals per unit time and to synchronize their distributions and movements relative to food resources, other whales and vessels. The auto-buoy technique provides a cost-effective mechanism for detecting species of interest while collecting marine sounds and ambient noise data. It is now totally feasible to install an integrated network of passive acoustic and oceanographic sensors to generate a near-real-time overview of the acoustic ecology in the Gulf of Maine.

Social Functions of Right Whale Sound Types – Seasonality and Implications for Passive Acoustics
Susan Parks

The social function of particular call types plays an important role in passive acoustic monitoring. Currently data is lacking on the social function of different sound types for many marine mammal species. This could have major implications for the interpretation of passive acoustic recordings for population monitoring. Differences in sound production by age, sex, or season can impact the effectiveness of passive acoustic monitoring. For example, right whales produce a variety of call types, ranging from intense broadband gunshot sounds to quieter tonal calls. These call types vary in suitability for passive acoustic detection given observed seasonal and sex differences in production. Previous studies have investigated the behavioral role of these call types in the Bay of Fundy, Canada, indicating that the gunshot sounds and tonal sounds produced in surface active groups are sex specific, with males producing gunshot sounds, and females the tonal scream calls (Parks *et al.* 2005; Parks and Tyack 2005). Both sexes produce the upcall. Analysis of recordings made in different habitat areas in different seasons indicate a difference in the relative production of different sounds types, with the upcall being the only call that is present equally in all habitats (Parks and Clark 2005). As a result, the selection of the upcall for passive acoustic monitoring provides a species specific sound that is produced by both sexes in all seasons. In species with less knowledge of the social behavior in sound production, selection of particular call types could lead to bias in sampling if, for example, calls produced only by males in the breeding season were selected for detection studies.

Vocalization Rates of North Atlantic Right Whales During Summer in the Gulf of Maine as Measured from Dtags.
Peter Tyack

One of the critical datasets required to evaluate effectiveness of passive acoustic monitoring involves the interval of time a whale will be silent without vocalizing. An ideal method for obtaining these data involves use of an acoustic recording tag on the whale. I report results of a collaboration with the IFAW RV Song of the Whale and WHOI Dtag research teams (Matthews et al. 2001) analyzing vocal rates of North Atlantic right whales in the Gulf of Maine. The data described here update the Matthews et al. paper and rely upon 160 hours of Dtag data recorded from 44 right whales tagged for more than 30 min during the summers of 1999-2005 in the Bay of Fundy, Canada and 36.1 hours of data recorded by the RV Song of the Whale during 21 encounters with right whales. Parks (2003) also estimated the Source Level of right whale calls using a hydrophone array to identify calls from whales at known ranges. Her work showed Source Levels for screams of about 170 dB re 1 µPa at 1 m when the broadband noise level averaged about 125 dB. Assuming 15 log range propagation and detection at a signal to noise ratio of 0 dB, this would suggest a detection range of about 1 km. 24 hour spectrograms from the Bay of Fundy indicate average noise levels of about 112 dB rms for the 50-200 Hz band and 95 dB rms for 200-1000 Hz. The 50-200 Hz average noise level of 112 dB is consistent with a detection range of 7 km given the same assumptions. Whale calls were clustered in time, so the average rate of calling does not provide an accurate estimate of the statistics of silent intervals. Analysis of towed hydrophone recordings estimates that the mean interval between clusters of moan vocalizations is about a minute. However, this estimate is taken from a series of moans. Four encounters recorded with towed hydrophones had no moans during intervals of 1-2 hours. Twenty-five of the tag recordings with durations up to 6.5 hours had no calls. For twelve of the other nineteen tags with recorded calls, the average interval between calls of the tagged whale was 188 s. Overall, the maximum intercall intervals (censored by start and end of recordings) had a median value of 2 hours, with an upper quartile value of 4 hours. These data suggest that acoustic detection data alone are insufficient to estimate effectiveness of passive acoustic monitoring. PAM systems must take into account unbiased estimates of intervals between detectable vocalizations along with acoustic characteristics of the calls such as Source Level, Noise Levels and Transmission Loss in the environment, and Detection Thresholds. In this case, it does appear possible to use PAM to detect right whales during intervals of many hours over spatial scales of several km, but quantitative analysis of even longer recordings of more individuals will be required to estimate the number and types of animals that would be undetected for a specific PAM application. If managers can estimate the parameters for temporal and spatial scales, and probability of detection required to meet management objectives for reducing risk of entanglement or collision, then it would be helpful to review data on visual and acoustic data from different platforms to evaluate whether any mix of existing methods can meet the requirements, and if so, what is the optimal mix.

Investigating Baleen Whale Ecology with Acoustic and Oceanographic Observations Collected from Autonomous Underwater Vehicles
Marc Baumgartner

Standard methods to investigate marine mammal ecology employ ship-based human observers and in-situ instrumentation to simultaneously characterize distribution and oceanographic conditions. Unfortunately, this approach is expensive, labor intensive and inefficient, since observers can only detect marine mammals in daylight, good visibility, and low sea state. Passive acoustics provide a means to detect the occurrence of localizing animals over long durations regardless of sea conditions, however moored recorders collect data in a fixed location only and typically lack accompanying oceanographic observations throughout the water column. Autonomous underwater vehicles are capable of continuous operation over a variety of spatial scales, and can measure many of the same oceanographic properties observed during ship-based studies. Autonomous gliders, in particular, have characteristics that make them ideal for ecological studies: high endurance (> 60 days at sea, range of hundreds of kilometers), fine horizontal and vertical measurement resolution, and relatively silent operation that permits passive acoustic measurements.

We recently demonstrated the utility of ocean gliders for studying baleen whale ecology during a pilot project conducted off Cape Cod, Massachusetts. We deployed an array of gliders to characterize the physical and biological environment near baleen whales. Each of the four gliders continuously measured temperature, conductivity, depth, chlorophyll fluorescence, and optical backscatter while profiling from the surface to 100 m once very 20 minutes. In addition, three gliders were outfitted with custom-built acoustic recorders, and the fourth carried an acoustic Doppler current profiler (ADCP). The gliders were deployed on May 6, 2005, operated flawlessly through a gale during which seas reached 17 ft, and were recovered on May 11. Downsweep whale calls in the 40-100 Hz frequency band preliminarily attributed to sei whales exhibited a diel pattern (fewer calls by night, more by day) that corresponded strongly to the diel vertical migration of zooplankton observed in the ADCP acoustic backscatter measurements. The number of calls in this frequency band did not diminish during the gale. Acoustic events were accurately time- stamped, thus the moving glider array was used to determine the position of vocalizing whales. Having demonstrated the potential of ocean gliders for baleen whale ecological research, our future efforts will focus on (1) extending the duration of the acoustic recordings to match the endurance of the vehicles, (2) developing a real-time detection and reporting capability, and (3) increasing the recording/detection frequency to monitor odontocete vocalizations.

Towards Operational Forecasts of Right Whale Distributions in the Gulf of Maine
Andy Pershing

All management actions to limit right whale mortality depend on knowing when and where right whales are likely to be found. For certain applications such as setting up seasonal area management zones, a knowledge of the right whale's climatological movement patterns are sufficient; however, other management options such as dynamic area management zones or sighting advisories require more precise information on likely whale locations. We have developed a prototype system to forecast the distribution of right whales. At the heart of this system is a model of the right whale's main prey, the copepod *Calanus finmarchicus*, and the dynamics of this model are determined by circulation forecasts and satellite data (chlorophyll and temperature). Although our experience with the prototype suggests that our approach has merit, several improvements are needed. We are currently beginning a one-year project to dramatically improve the performance and utility of this system. Improvements will include: state of the art circulation forecasts, the ability to assimilate zooplankton observations, a right whale likelihood model, and an improved web-based interface. Initially, localizations of right whales, including those from passive acoustic sensors, will be displayed on top of the satellite or modeled fields. Eventually, we hope to assimilate these observations into the right whale likelihood model.

Stellwagen Bank National Marine Sanctuary as a Model for Integrating Platforms to Characterize the Marine Acoustic Environment
Leila Hatch and David Wiley

The US National Marine Sanctuary Act directs designated sanctuaries to protect sanctuary resources while allowing compatible human uses, and to conduct, support, or coordinate research, monitoring, evaluation, and education programs. To meet these mandates, the National Marine Sanctuary Program has identified site characterizations as a priority activity. Site characterizations provide an account of a sanctuary's biodiversity, habitats, resources, ecological processes, anthropogenic impacts and, when combined with monitoring programs, provide the means for objective and informed management decisions. The Stellwagen Bank National Marine Sanctuary (SBNMS) is host to many species of protected species (e.g., critically endangered North Atlantic right whales) and is subjected to high levels of sound producing anthropogenic activity (e.g., vessel traffic). Site characterization of the SBNMS, therefore, necessitates comprehensive acoustic monitoring and the development of integrative analytical approaches to determine the relative inputs of sound sources within the sanctuary and their possible effects on the behavior of federally-protected species.

To address this goal, ten automated recording units (ARUs), developed by Cornell University's Bioacoustics Research Program, have been deployed to monitor the acoustic sound field within the boundaries of SBNMS continuously between January, 2006 and January, 2007. Through collaborations with scientists, managers and policy experts from the NOAA's Northeast Fisheries Science Center and Northeast Regional Office, Woods Hole Oceanographic Institution, Cornell University and the University of Massachusetts, Boston, these acoustic data will be analyzed to address multiple questions regarding the locations and behaviors of vocalizing whales, estimate the potential for hearing loss and masking to various species, and identify the sound contribution from large commercial vessels and specific vessel classes.

Here, we highlight ongoing and preliminary research at the sanctuary that will be further informed by this year's acoustic monitoring data, including efforts to accurately estimate reductions in whale ship strikes due to re-routing of shipping lanes, integration of ARU data with vessel data from the US Coast Guard's Automatic Identification System, and efforts to characterize received levels and behavior relative to boats for whales tagged in the sanctuary.

APPENDIX D

NOAA National Workshop on Passive Acoustics Terms of Reference

Background

In August 2003 NOAA's Ocean Acoustics Program (NMFS ST-HQ) convened a meeting in Silver Spring, MD of agency colleagues on the general subject of marine acoustics, with particular emphasis on the effects of noise on marine mammals. Ongoing efforts to enhance agency policies regarding the setting of "effects thresholds" were presented and discussed, and software for calculating sound propagation that was demonstrated and provided to regional colleagues. This was the first national forum among the various NOAA personnel working on marine acoustics.

This collaborative national effort was preceded by a workshop convened by Dr. Dave Mellinger (Oregon State University @ NOAA-PMEL) and Dr. Jay Barlow (SWFSC) in November 2002 (Mellinger and Barlow 2003) and followed by a second workshop in February 2004 convened by Dr. Jay Barlow and Dr. Roger Gentry (Ocean Acoustics Program) (Barlow and Gentry 2004). The current state of knowledge regarding anthropogenic sound and marine mammals was reviewed and discussed, with specific emphasis on research needs and the development of a national program by which NOAA would begin to address those relating most directly to our mandated responsibilities (Barlow and Gentry 2004). A national research plan was developed (NOAA Acoustics Program Research Proposal 2004) to enable NOAA to more fully meet management requirements regarding marine acoustics. Though this proposal has yet to be funded, a small portion was in the FY06 budget request.

Many issues considered in previous workshops and in the proposed national program remains of high relevance to NOAA. One of these is passive acoustics and the extensive opportunities arising from deploying hydrophones on various monitoring platforms. Recently, the NOAA Observing Systems Council (NOSC) conducted an inventory of the agency's observing requirements (Consolidated Observational Requirements List (CORL)). Thanks to the collaborative efforts of NOAA colleagues from several areas, three general passive acoustic observing capabilities (sound from both biological and other natural sources, as well as human sources of sound) were identified within the CORL. Additionally, passive acoustic sensing has been identified as a discrete observing system within NOAA's Observing Systems Architecture (NOSA) database (IOOS 2005). Arising from these distinctions and the critical importance to various agency missions of expanding NOAA's passive acoustic sensing capabilities, collaborative efforts are underway to identify and prioritize operational solutions to meet these requirements.

A NOAA-wide workshop is proposed for 11 – 13 April 2006 in Woods Hole, MA to continue internal efforts to develop the passive acoustic observing system and integrate deployments with existing and planned ocean observing systems. Following an initial internal planning session, the workshop will be expanded to include colleagues from outside the agency who have been considering the implementation of passive acoustic systems on broad spatial scales as well as a meso-scale regional approach. This second session of this workshop will focus primarily on the Gulf of Maine, with the anticipation for future workshops to concentrate on other key regions.

Workshop Goals

1. Augment observational requirements documentation for CORL and NOSA databases and EOP goal team.
2. Define clear and prioritized observing requirements as they relate to NOAA strategic goals.
3. Use Gulf of Maine as a "test bed" for discussions on various strategies for integrating passive acoustics into existing and proposed ocean observing systems, emphasizing multiple data uses (*e.g*., ambient noise budgets, marine animal detection, weather/climate issues).

Workshop Format and Goals

The workshop will be three days long and divided into two discrete sessions, each with a corresponding working group. Each section will have a chair to guide and advance discussion in a productive manner; break-out groups may be used in any or all of the sections. A rapporteur will be provided for each working group and each working group will produce a written report that will contribute to the planned final workshop report.

Session 1. Interagency planning workshop on Passive Acoustics Research

This session will comprise the first day and a half of the meeting and will be limited to invited NOAA staff. It will commence with discussion of the general structure and goals of the workshop and brief presentations from respective centers, regions, and sanctuaries, on existing passive acoustic projects. Break-out groups will assess: (1) mandates and drivers for NOAA to engage strongly in passive acoustics; (2) existing technologies for data acquisition, analysis, and archive; and (3) current NOAA capabilities and activities and prioritize specific goals on 5, 10, and 20 year timelines.

Session 2. Monitoring Biological Noise Using Passive Acoustics – Integrating Platforms

The second session will comprise the latter one and a half days. Following the internal NOAA working group on passive acoustics, colleagues from outside the agency will be invited to continue on-going discussions of global deployment of passive acoustic equipment. Two previous workshops on this issue have been convened with some of the top researchers in the world, many of whom will be invited to join NOAA colleagues and consider the role that NOAA may play in various research projects identified in previous workshops. One of the main focuses will be on a case-specific consideration of an extensively studied area of the country in terms of passive acoustics, the Gulf of Maine region. A number of reviews will be presented of what existing passive acoustic research has achieved to date within the Gulf of Maine area as well as on larger scales. Participants will consider the Gulf of Maine as a “test bed” to explore ideas regarding what acoustic techniques, deployments, and sampling regimes might answer the pertinent questions for this area.

Workshop Participants

The workshop will bring together a diverse group of scientists and managers to include:

- NOAA Acoustics staff representing Headquarters Office and at least one representative from each of the Science Centers and Regional Offices
- NOAA NOS staff including staff from Stellwagen Banks
- Scientists from academia and other government agencies

Workshop Venue, Logistics, and Attendance

The workshop will be held from 11 to 13 April 2006 at the NMFS Northeast Fisheries Science Center in Woods Hole, MA. The NEFSC conference room has been reserved for the workshop. Travel support will be provided to invited speakers from outside the agency; limited support may be available for NOAA participants lacking programmatic funds to support their involvement.

The workshop will be open to the public to the extent practical with limited space but will not include public comment sessions. Only invited speakers and participants will present or participate in discussions. This is not a consensus building workshop.

Workshop Outcomes

Observing requirements and strategies for the NOAA Passive Acoustic Observing System will be improved and expanded. A more formalized mechanism for internal NOAA collaboration on passive acoustics will be considered. A NOAA Tech Memo will be prepared containing summary of presentations, discussions, and recommendations of the full session deliberations and working groups for each section.

APPENDIX E

DRAFT AGENDA
NOAA NATIONAL WORKSHOP ON PASSIVE ACOUSTICS

11-13 APRIL 2006
WOODS HOLE, MA

DAY 1: TUESDAY, APRIL 11TH

SESSION I. INTERAGENCY PLANNING WORKSHOP ON PASSIVE ACOUSTICS RESEARCH

Meigs Room, Swope Building, Marine Biological Laboratory.

Chair: Brandon Southall, NMFS HQ – ST
Rapporteur: Leila Hatch, SBNMS

8:30 – 9:00 COFFEE BREAK

9:00 -9:15 OPENING REMARKS

9:15 – 9:45 "Building NOAA's Passive Acoustics System within the PPBES System" – Steve Swartz (NMFS HQ, Office of Science and Technology)

9:45 -10:45 SUMMARIES OF PASSIVE ACOUSTIC RESEARCH AT NMFS SCIENCE CENTERS (20 MIN)

- ***Jay Barlow, SWFSC****: Review of SWFSC*
- ***Sue Moore, AFSC@ APL-UW****: Listening for large whales in offshore waters of Alaska, 1999 - 2004*
- ***Linda Jones, NWFSC****: Review of NWFSC*

10:45 - 11:00 BREAK

11:00 – 12:30

- ***Dave Johnston/Marc Lammers, PIFSC****: Review of PIFSC*
- ***Dave Mellinger, NOAA-PMEL****: Review of NOAA-PMEL*
- ***Tony Martinez, SEFSC****: Review of SEFSC*

- ***Sofie Van Parijs, NEFSC****: Review of NEFSC*

12:30-1:30 LUNCH (ON YOUR OWN)

1:30 – 3:15 GROUP TASK I (All)

1. Identify why NOAA should develop/expand passive acoustic sensing capabilities (45 min.)
   - What relevant scientific questions NOAA is/should be addressing are met with passive acoustics?
   - What management strategies are supported by the current research?
   - Identify mandates/drivers and how passive acoustics relates to NOAA missions

2. Identify current tools and sampling regimes/data management (1 hr.)
   - What are the current and future sensors?
   - Discuss sampling bandwidth and data management.
   - Identify relevant existing or planned observing systems in which passive acoustics should be implemented.
   - Discuss spatial and temporal scaling considerations.
   - Identify uses where passive acoustics can serve multiple purposes (*e.g.* living marine resource detection and climate issues)

3:15- 3:30 BREAK

3:30 – 5:00 GROUP TASK II (All)

3. Where are we now and where do we need to go?
   - Where are we now (summaries provided from morning presentations)?
   - What are the current knowledge gaps?
   - How do we improve and integrate efforts within and across regions?

5:00 - 5:30 REVIEW/ASSESS

- Chair and rapporteur meet to discuss progress and prepare summary of tasks I and II for distribution to group for morning session

DAY 2: WEDNESDAY, APRIL 12TH

SESSION 1. CONTINUED

Meigs Room, Swope Building, Marine Biological Laboratory.

8:30 – 8:45 REVISIT PROGRESS

8: 45 – 10:30 REVIEW/MODIFY GROUP TASKS I and II (All)

10:30 – 10:45 BREAK

10:45 – 11:45 GROUP TASK III (All)

4. Develop priorities/recommendations
   - Specify 100% solution to meeting NOAA needs regarding passive acoustics
   - Identify most pressing and achievable research needs – set priorities!
   - Identify goals on 5, 10, and 20 year timelines
   - Discuss how recommendations of workshop will be used in the development of a strategic plan for NOAA passive acoustics system

11:45 – 12:00 CONCLUSION

- Establishing a formal working group
- Concluding remarks

12:00 – 1:00 LUNCH (ON YOUR OWN - LUNCHTIME SEMINAR AT 12:30!)

SESSION II. MONITORING BIOLOGICAL NOISE USING PASSIVE ACOUSTICS– INTEGRATING PLATFORMS

Meigs Room, Swope Building, Marine Biological Laboratory.

Chair: Sofie Van Parijs, NEFSC
Rapporteur: Stephanie Watwood, WHOI

12:30 – 1:00 LUNCHTIME SEMINAR

- ***Jack Bradbury, CORNELL UNIVERSITY:*** *The Marine Animal Sound Archive at the Macaulay Library.*

1:00 – 1:20 OPENING REMARKS

[1:20 – 3:30] BIG PICTURE PRESENTATIONS ON PASSIVE ACOUSTICS

1:20 – 1:35

- ***Brandon Southall, NOAA Acoustics Program (NMFS/ST):*** *Summary of existing acoustic deployments and existing/proposed potential platforms*

1:35 – 1:50

- **David Moretti, Ronald Morrissey, Nancy DiMarzio, Jessica Ward, Susan Jarvis (Naval Undersea Warfare Center)**: *Marine Mammal Monitoring on Navy Ranges (M3R): A Long Term Study of the Effect of Sound on Marine Mammals*

1:50 – 2:10

- ***David Bradley, PENN STATE and James H. Miller, URI:*** *Science Payoffs from Ambient Noise Monitoring: Results of the NOAA Warwick Workshops*

2:10 – 2:40

- ***John Hildebrand, SCRIPPS:*** *CALCOFI and CINMS monitoring*

2:40 – 3:10

- ***Jeff Nystuen, APL-UW:*** *Ocean Climate from Passive Acoustics – Sorting Out the Racket*

3:10 – 3:30

- ***Cliff Goudey, MIT, and Rodney Rountree, META***: *Listening to Fish: Passive Acoustics Applied to Marine Fisheries and Ecosystems*

3:30-3:45 BREAK

[3:45–5:15] PRESENTATIONS - PASSIVE ACOUSTICS IN THE GULF OF MAINE REGION

3:45 – 4:00

- ***Chris Clark, CORNELL UNIVERSITY:*** *Real time passive acoustic monitoring, tracking behavior and movements and defining ocean noise*

4:00 – 4:15

- ***Susan Parks, CORNELL UNIVERSITY:*** *Social functions of right whale sound types – seasonality and implications for passive acoustics*

4:15 – 4:30

- ***Peter Tyack, WHOI:*** *Integrating DTAGs with passive acoustics for studying vocalization rates of North Atlantic Right Whales.*

4:30 – 4:45

- ***Mark Baumgartner, WHOI***: *Investigating baleen whale ecology with acoustic and oceanographic observations collected from autonomous underwater vehicles*

4:45 – 5:00

- ***Andy Pershing, CORNELL UNIVERSITY:*** *Towards Operational Forecasts of Right Whale Distributions in the Gulf of Maine*

5:00 – 5:15

- ***Leila Hatch and Dave Wiley, SBNMS****: Stellwagen Bank National Marine Sanctuary as a model for integrating platforms to characterize the marine acoustic environment.*

5:15 – 5:30 SUMMARY

- Discuss format of working groups for day 3
- Co-chairs/Rapporteurs for working group meet to discuss progress

DAY 3: THURSDAY, APRIL 13TH

SESSION 2. CONTINUED

MBL Club, Marine Biological Laboratory & Candle House Room 105

8:30 – 10:30 WORKING GROUP DISCUSSIONS

Working group A [Facilitator: Steve Swartz; Rapporteur: Stephanie Watwood]

- Requirements for passive acoustic recording devices
    - Scale that each recording device addresses
    - Current use of these devices
    - Current failures in data collection i.e. patchy data collection at varying sites
    - Goals needed to cover different components of data collection
    - What is needed to address NOAA’s mandates for acoustics? Need specific recommendations and action plan
    - Advantages and problems of fixed versus towed passive acoustic arrays
    - Identify and prioritize deployment sites

Working group B [Facilitator: Sue Moore; Rapporteur: Robyn Angliss]

Integrating numerous platforms effectively:

- Requirements for integration with oceanographic parameters
  - Data requirements and management
  - Scale of sampling
  - Current efforts and opportunities

- Requirements for integration with anthropogenic conflict issues (noise, shipping etc.).
  - Data requirements and management
  - Scale of sampling
  - Current efforts and opportunities

- Requirements for integrating abundance and behavioral platforms
  - Data requirements and management
  - Scale of sampling
  - Current efforts and opportunities

10:30 – 10:45 BREAK

10:45 – 12:30 WORKING GROUP DISCUSSIONS (Cont.)

12:30-1:30 LUNCH (ON YOUR OWN)

1:30-4:30 WORKING GROUP DISCUSSIONS

3:15 – 3:30 BREAK

4:30-5:30 RECONVENE

- Discussion/Summary
- Co-chairs/Rapporteurs meet to conclude and discuss report

5:30 END OF WORKSHOP

APPENDIX F

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APPENDIX G

ACRONYM REFERRAL LIST

ADCP – Acoustic Doppler Current Profiler
AFSC – Alaska Fisheries Science Center
AIS – Automatic Identification System
APL-UW - Applied Physics Laboratory of the University of Washington
ARP – Acoustic Recording Packages
ARU – Automated Recording Units
AULS – Autonomous Underwater Listening Stations
AUTEC - Atlantic Undersea Test and Evaluation Center
BRP – Biological Reference Point
CADDIS – Cetacean Acoustic Detection and Dive Interval Studies
C-Cap – Coastal Change Analysis Program
CMRP – Coastal and Marine Resources Program
COOS - Coastal Ocean Observing System
CORE – Consortium for Oceanographic Research and Education
CORL - Consolidated Observations Requirements List
CRIOS – Coral Reef Ecosystem Integrated Observing System
CTD – Conductivity, temperature, and depth
DART - Deep-ocean Assessment and Reporting of Tsunamis
EAR – Ecological Acoustic Recorder
EOP – Ecosystem Observations Program
EFH – Essential Fish Habitat
EGT – Ecosystem Goal Team
ERP - Ecosystem Research Program
FTE – full time equivalent
GEOSS – Global Earth Observation System of Systems
HARPS – High-frequency Acoustic Recording Packages
IFAW – International Fund for Animal Welfare
IOOS - Integrated Ocean Observing System
LME – Large Marine Ecosystems
LMRIS – Living Marine Resources Information System
NDBC - National Data Buoy Center
NESDIS - National Environmental Satellite, Data, and Information Service
NGO – Non Government Organization
NODC – National Oceanographic Data Center
NOP – National Observer Program
NOS – National Ocean Service
NOSA – NOAA Observing Systems Architecture
NOSC – NOAA Observing Requirements List
NMFS/PR – National Marine Fisheries Service/Protected Resources
NMFS/ST – National Marine Fisheries Service/Science and Technology
NMML – National Marine Mammal Laboratory

NMS – National Marine Sanctuaries
NRC – National Research Council
NWFSC – Northwest Fisheries Science Center
OAR – Oceanic and Atmospheric Research
OBIS-SEAMAP – Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations
ONR – Office of Naval Research
PAM – Passive Acoustic Monitoring
PaCOOS – Pacific Coast Ocean Observing System
PAOOS – Passive Acoustics Ocean Observing Program
PIFSC – Pacific Islands Fishery Science Center
PMEL – Pacific Marine Environmental Laboratory
PPBES – Planning, Programming, Budgeting, and Execution System
PSMA - Protected Species Monitoring and Assessment
PSP – Protected Species Program
ROV – Remotely Operated Vehicles
SBNMS – Stellwagen Bank National Marine Sanctuary
SEAMAP – Southeast Area Monitoring and Assessment Program
SIO – Scripps Institution of Oceanography
SOSUS – Sound Surveillance System
SWaPS – Shallow Water Positioning System
SWFSC – Southwest Fisheries Science Center
SWiM – National Marine Sanctuaries System-Wide Monitoring Program
SWMP – National Estuarine Research Reserve System-wide Monitoring Program
TRANSDEC – Transducer Evaluation Center

	TOWED HYDROPHONE ARRAYS	DRIFTING SONOBUOYS	MOORED AUTONOMOUS HYDROPHONES	NEAR REAL TIME BUOYS	SEA BED MOUNTED HYDROPHONE ARRAYS	GLIDERS	ACOUSTIC TAGS
TYPE	Multiple units	Multiple units Onmi 57B DIFAR 53D	Multiple units; sometimes used in arrays of 3-10 units	Multiple units	Multiple hydrophones	Multiple units following programmable route	Targets individual animals
VESSEL REQUIREMENTS	Dedicated ship time	Dedicated ship time	Yearly or bi-yearly deployment and retrieval	One-time deployment; maintenance	One-time deployment; maintenance	Deployment and retrieval	Deployment and retrieval (ship+RHIB)
FREQUENCY RANGE	0.5 - 250 kHz	10 Hz – 2.5 kHz DIFAR 10 Hz – 25 kHz OMNI	10Hz – 100 kHz; this varies by type	0-50 kHz	0 – 1000 Hz	0-50 kHz	0 – 100 kHz
DURATION	Hours to months	Up to 8 hours	0.25-2 years / deployment	Years	Years to decades	Weeks to months	Hours to days
DATA STORAGE CAPACITY	Essentially unlimited	Essentially unlimited	Giga- to terabytes.	Essentially unlimited	Essentially unlimited	Gigabytes	A few gigabytes
AVAILABLE TYPES	Within NOAA: NMFS-SWFSC (Barlow) Outside of NOAA: Ecologic Ltd., many other vendors	Military surplus, usually free but somewhat unreliable	Within NOAA: Haruphone (OAR-PMEL) EAR (NMFS/PIFSC – Lammers). Outside of NOAA: Popup (Cornell Univ. - Clark), HARP, ARP (Scripps - Hildebrand), EARS buoy (UNO – Ioup), AULS (MIT – Goudey & Rountree), AURAL-M2 (MTE Inc)	Cornell Univ. – Clark	Military (e.g., SOSUS); Oceanographic (MOOS, ORION/ NEPTUNE)	SeaGlider (Univ. of Washington) Several others: SIO ALICE, WHOI	DTAG – (WHOI - Johnson); BProbe (Greenridge Sciences – Burgess)

Table 1. Summary of the passive acoustic sensors currently available for data collection.