JOINT WORKSHOP REPORT: PREDICTING SOUND FIELDS—GLOBAL SOUNDSCAPE MODELLING TO INFORM MANAGEMENT OF CETACEANS AND ANTHROPOGENIC NOISE

15-16 April 2014

TNO- Gorter Building, Wassenaarseweg 56

Leiden, Netherlands

OVERVIEW: A two-day workshop was sponsored by the International Whaling Commission (IWC), the International Quiet Ocean Experiment (IQOE), the U.S. National Oceanic and Atmospheric Administration (NOAA), Office of Naval Research Global, and the Netherlands Organisation for Applied Scientific Research (TNO) and the Netherlands Ministry of Infrastructure and the Environment. Twenty-six international experts came together from 11 countries to discuss regional and ocean-basin scale underwater sound field mapping techniques to provide support for decision makers seeking to characterize, monitor, and manage the potential impacts of chronic or cumulative anthropogenic noise on marine animals. The workshop product is a meeting report that includes recommendations directed to sponsoring international organizations and/or their science advisory groups to support the development and implementation of soundscape modelling and mapping tools needed to make informed management decisions.

RATIONALE: Over the past decade, the effects of anthropogenic noise have become a recurring agenda item for discussion within several international fora focused on the conservation and management of marine biota. Initially, concerns primarily targeted the potential effects of acute sources of sound that could lead to very near term consequences (e.g. behavioural changes, strandings). In recent years, however, there has been a distinct broadening of the focus of noise impacts to include the much larger scale, and longer term chronic effects of increases in ocean noise and changes in underwater soundscapes. An increasing number of scientific efforts (International Quiet Ocean Experiment (IQOE), U.S.'s National Oceanic & Atmospheric Administration CetSound effort) directed at this topic reflect this broader scope. In September 2011, the IQOE held an open science planning meeting[1] where research into soundscape characterization and modelling were identified as one of the four key themes to be contained in the IQOE's Science Plan. NOAA has similarly recognized the need for this work through the convening of the Cetaceans and Sound (CetSound) project in which it is developing mapping tools to produce underwater sound-field maps, along with cetacean density and distribution maps[2]. In addition, to meet the noise-related Good Environmental Status objectives of the European Marine Strategy Framework Directive, sound field modelling and mapping comprise a substantial portion of the recommended monitoring programs for noise assessment[3]. In this relatively new field of knowledge, cooperation between nations will increase advances and such cooperation is actively pursued as stated, for example, between the US, Canada and the European Union in the Galway Statement on Atlantic Cooperation[4]. The International Whaling Commission (IWC) has also exhibited an interest in the more regional effects of noise pollution. During the meeting of the IWC Scientific Committee in June 2012, the U.S. presented the CetSound project and its preliminary results. The IWC Scientific Committee strongly recommended support for further development and improvement of these sound and cetacean mapping tools, and subsequently provided support for a joint workshop (with IQOE, NOAA, and the Ministries of Infrastructure and the Environment, Netherlands) to expand these tools and their global application in order to better inform the management and conservation of marine species, including cetaceans.

TERMS OF REFERENCE:

The general terms of reference for the joint workshop were to:

- Exchange, evaluate, and analyse sound modelling and mapping methodologies at spatial, temporal and spectral scales relevant to chronic and cumulative noise assessments with a view to optimizing techniques and their transferability in order to increase the accessibility of these methodologies to a wider range of researchers, governments, industry, and organizations.
- Identify and assess information needs, within priority regions, for 1) sound field characterization at spatial, temporal and spectral scales relevant to chronic and cumulative noise assessments, including human use, and 2) sound source and propagation medium data that are necessary to model longer-term and larger-scale anthropogenic noise contributions.

- Develop scientific recommendations and priorities for an initial two-year work plan for consideration by international fora to continue to develop, improve, and apply these sound mapping tools to global locations of importance, in the context of assisting managers in addressing possible impact of chronic and cumulative anthropogenic noise on marine species of concern. While the focus is on marine mammals (specifically on large cetaceans, for which there is specific concern due to observed increases in low frequency noise levels), other marine life that is affected by the same low frequency sound is also within scope.

STEERING GROUP:

Leila Hatch, Jason Gedamke (National Oceanic and Atmospheric Administration, USA); René Dekeling (Ministry of Infrastructure and the Environment, NL); Mike Porter (Heat, Light & Sound Research, Inc.; CetSound; IQOE); Christine Erbe (Curtin University); Peter Tyack† (St Andrews; IQOE); George Frisk† (Florida Atlantic University, IQOE); Rob Williams† (IWC-SC); Michael Ainslie (TNO-Netherlands); Greg Donovan† (IWC-SC)

†unable to attend but serving in planning capacity

Workshop participants are listed in Appendix A.

INTRODUCTION

The workshop agenda (Appendix B) was developed to transfer knowledge of current management needs and sound field modelling/monitoring efforts to the international audience prior to initiating focused group discussion. A series of four short summary presentations provided the context of the workshop by describing the perspectives and needs derived from conservation or management pressures (abstracts included in Appendix C). This was followed by 12 presentations describing the current regional to ocean-basin scale sound field modelling and/or monitoring efforts. Following the presentations, there was a general discussion among the workshop participants on currently available methodologies for modelling sound fields at spatial, temporal, and spectral scales relevant to chronic and cumulative noise assessments. It was agreed upon that in order to predict and interpret regional soundscapes from discrete source types, the following general information is needed:

1. Standardized ambient sound measurements
2. Knowledge of contribution from dominant anthropogenic regional sources (vessels, pile driving, seismic exploration, explosives, land-based construction, and sonar)
3. Weather (e.g. rain, wind, lightning)
4. Surface conditions (e.g. ice, surf)
5. Seabed characteristics (e.g. composition, vertical profile)
6. Bathymetry
7. Water column sound speed and absorption profile

The workshop considered many sources as potentially significantly contributing to local and regional soundscapes, but focused on low frequency sound sources identified to be prolific across regional and basin scales (shipping, pile driving, and seismic survey activity) that may contribute to auditory masking of important biologically relevant signals for marine mammals. While additional sources may have acute effects (e.g. sonar, deterrent devices), their short duration, higher frequency content, or prevalence reduced their priority in workshop discussions.

It was recognized that there will be a mismatch between model predictions and sound field measurements unless natural sound in a regions is understood and incorporated in the models. The main natural contributors to low frequency sound levels are natural seismic (earthquakes, underwater volcanoes), wind and storms (rain/lightning), ice, and marine animals. Some of these sources are intermittent and unpredictable, while others are seasonally present and more predictable. When addressing acute exposure or impact over short time periods, natural sound patterns are largely irrelevant; however, examining the natural source contribution is necessary to understand regional dynamics over longer time periods, as they will impact regional sound levels and the interpretation of cumulative or chronic effects.

The final portion of the workshop tasked small working groups with generating recommendations in four topic areas:

1. Temporal resolution of sound measurement and modelling
2. Spatial and spectral resolution of sound measurement and modelling
3. Sources, measurements, and databases
4. Management tools

Working Groups 1 and 2 were tasked with identifying priority measurement and modelling output resolution and metrics appropriate for assessing cumulative and chronic source contributions. Minimum requirements were identified with the understanding that many measurement and modelling efforts will exceed the recommended minimum. Working Group 3 was tasked with identifying new sources/activities of regional concern, natural sources and conditions relevant to long term sound field predictions, and for assessing the quality of source data currently available in order to make recommendations for future data collection efforts. Working Group 4 focused on evaluating the current status of available assessment and prediction tools to make recommendations on future management implications and use. Information from the working groups was then used to compile recommendations for short-term research that could be executed within a two-year work plan.

RECOMMENDATIONS

With increasing interest in global soundscapes, managers desire investments that will produce products that can be used in a variety of decision making contexts, both for what is known in the present and what may potentially occur in the future. There is an immediate need to have management tools that provide information to make informed decisions quickly, recognizing that the decisions will be made in the face of a great number of unknowns and uncertainty. Uncertainty stems from the quantity and unpredictable nature of components contributing to regional soundscapes. Natural environmental conditions affecting sound propagation are dynamic and constantly changing on time scales ranging from seconds to years, and advances in technology and dynamic offshore industrialization patterns continually change the acoustic characteristics and distributions of anthropogenic sources. In addition, significant uncertainty remains in determining the environmental consequences of various noise features, which leads to uncertainty in selecting modelling and measurement output metrics. Thus, there is a need to preserve flexibility in management tools to modify input and output parameters in order to easily shift to different scenarios as new information becomes available. The following recommendations maintain a focus on preserving the flexibility to alter tools in the future and remain transparent in relaying uncertainty to the user for incorporation into management decisions. In addition, they address the need for short term tangible assets as well as articulation of long term investment needs.

The need for international standardization related to the communication, measurement, and modelling of ocean sound is a recurring theme. All of the recommendations rely on international standardization of terminology, first, to ensure effective communication, and then of measurement and modelling procedures to ensure compatibility between international partners. The International Organization for Standardization has established a sub-committee (TC 43/SC 3) dedicated to underwater sound. That sub-committee, chaired by George Frisk, is in the process of developing standards for underwater acoustical terminology generally, and procedures for measuring radiated sound from ships and from pile driving. Similar efforts are needed for lateral loss measurements and directional properties of airgun arrays, and measurements of ambient sound. Standards are also needed for modelling or prediction of underwater sound.

Recommendations are made in four topic areas: sources, soundscape measurement, sound field modelling, and management/visualization tools. Measurements provide empirical data on actual sound levels where recorders are located, and models can be used to predict sound levels in regions where no measurements exist, to fill gaps between recorder locations, and to predict sound levels in response to a range of alternate scenarios. It is critical to recognize the reciprocal relationship between measurements and models in the interpretations and implementation of the recommendations. Measurements are used to build, ground-truth, and improve models, whereas models provide information on how to best make measurements. Management systems will need to capture and reflect this adaptive cycle in order to be most effective.

A) <u>Sources</u>

a. Four priority sources were identified for which more knowledge of source signatures is needed to accurately inform status assessment and predictive modelling:

i. Shipping – While the approach for modelling shipping noise based on density and distribution of ship traffic is feasible, speed variance remains a fundamental uncertainty in estimating source levels from AIS information. AIS (e.g via Marinetraffic.com) can provide information about the presence of ships (GT>300) or shipping densities, but the Wales and Heitmeyer model[5] that is often used to estimate source levels for this traffic data does not include ship speed dependence as earlier models (e.g. the RANDI model[6]) had. For regulation purposes and for noise mapping, a new model that includes speed dependence and associated uncertainty is required. This requires coherent empirical measurements to inform model development.

ii. Pile driving – Pile driving is spatially and temporally episodic, and although the individual impulses are short in duration, they can contribute to chronic noise levels over large distances. There are still questions over how to efficiently represent a pile as a source for propagation modelling, or how accurate the predictions of piling noise propagated to larger distances are. There are some measurement data available, and models are under development for estimating the acoustic output of the piling. It is recommended that the feasibility of representing the pile as a simple source as input for long distance modelling be evaluated.

iii. Seismic exploration (including airguns, sparkers, marine vibrators, etc) – Seismic exploration sources are well characterized as an array of monopoles at frequencies up to 1 kHz. Industry has the information on the strength of these monopoles, and it can be predicted. The uncertainty in the predicted field for a generically defined array is less well known. It is recommended that information on industry exploration and production source types be provided by companies at a level of detail appropriate to incorporate into soundscape modelling.

iv. Ice – Natural sea-surface noise sources in the polar regions involve ice-free mechanisms and ice-related mechanisms. The ice-free mechanism can be handled by published wind-wave noise models. The ice related noise characteristics are less well understood; therefore, development of models of radiated noise for the various types of polar ice cover is recommended. These models should possess the flexibility to accommodate the effects of climate change in order to extrapolate the evolution of high latitude ambient noise into the future (e.g. changing nature of ice-cover in the Arctic Ocean). Focused measurements should be collected that isolate the radiated contribution of these components. A comprehensive first order ice noise model will require at a minimum the proportion of the ice cover area of each type of ice in the vicinity of the receiver, which may be available via satellite. A hierarchy of more complicated models may include the ice pack stress and temperature gradient fields.

b. It is recommended that an inventory/database of source type and activity be created and organized by geographical location. Initial efforts towards establishing a registry for loud impulsive sources are currently being implemented in EU[6].

c. In order to determine which sources should be included in regional sound field modelling, the total acoustic energy (or energy budget) should be calculated in the region of interest. This rationale was used in a study in the North Sea to select the most salient source contributions for future modelling[7].

B) <u>Soundscape Measurements</u>

a. Recognizing that flexibility in soundscape monitoring is important and that duty cycles, equipment and measurement paradigms will change on a project-by-project basis, the following minimum sampling and processing parameters are recommended:

i. Record for 1 minute at least once an hour. The 1-min duration was selected to be representative of the duration of the closest point of approach for a passing ship[9];

ii. Compute daily sound level statistics from 0 h to 24 h UTC;

iii. Compute the arithmetic mean [SPL = $10\log_{10}\frac{1}{N}\sum_{i=1}^{N}p^2(i)$] in each 1/3 octave band from 10-1000 Hz for every 24h period. This recommendation would allow estimation of the 1/3 octave band levels that are thought to be most relevant to mammalian hearing, and in addition, provide outputs relevant to the European Union-Marine Strategy Framework Directive (MSFD)[7] (1/3 octave bands centred at 63 and 125 Hz) (IEC 61260-1995; ISO 266-1997, Appendix D);

iv. Compute percentile power spectrum density levels (10th, 25th, 50th, 75th, 90th) in each 1/3 octave band from 10-1000 Hz, in 1-minute windows, for every 24-hour period.

Based on this data recorded according to the above recommendations, monthly, seasonal and annual statistics (arithmetic means and percentiles) can be computed. The recommended measurement parameters itemized above are minimum requirements. Sampling at a higher duty cycle is encouraged in order to better reconstruct the full percentile distribution and hence the arithmetic mean. The statistics should always be calculated in 1-minute windows.

b. Systems capable of measuring frequencies above the 1 kHz minimum provide valuable data beyond that prescribed above and may contribute to addressing future concerns while adding little operational data collection cost to a program. Data storage, maintenance and analysis costs, however, will scale with data quantity.

c. The number and distribution of recording devices will vary according to specific concerns and regions. It is recommended that acoustic measurements capture two aspects of the regional acoustic habitat: the dominant sound sources and the ambient environment. We endorse the MSFD TSG Report[3,7] recommendation to guide new monitoring investments.

C) <u>Soundscape Modelling</u>

a. With the general focus of this type of predictive sound field modelling on larger spatial scales, aggregating multiple sources, and assessing long term source contributions, the sound field modelling should target a high resolution in the lower portion of the frequency scale (< 1 kHz). It is recommended that modelling efforts provide “single frequency” output sound levels at 1/3-octave band centre frequencies below 1 kHz (IEC 61260-1995; ISO 266-1997; Appendix D). This will allow extrapolation to band levels for comparison to recommended soundscape measurements (section B.a.iii).

b. While predictive sound field modelling can be carried out over small scales (surrounding a particular activity), the modelling related to chronic cumulative noise assessment and predictions focus on larger scale areas (e.g. regional to ocean basin scale). Hence, the model output resolution should be scaled appropriately with the area covered. Three nominal resolutions are suggested to respectively represent ocean basin, swaths of coastal waters or seas, and more focused and localized representations surrounding areas of activities or of particular management interest: 1° x 1°, 0.1° x 0.1°, and 0.01° x 0.01° (approximately 111 km x 111 km, 11 km x 11 km, and 1.1 x 1.1 km at the equator).

c. In order to characterize the heterogeneity of the sound field in any one modelled geographic location, and allow assessment of the predicted sound fields to which marine life living at or diving to different depths might be exposed, modelling should be conducted with outputs spanning the near surface to full ocean depth. The receiver depths modelled should offer higher resolution in surface waters but include depths at well-defined intervals to the ocean bottom. To accomplish this, it is recommended that sound levels be computed at the following depth intervals where applicable: every 5 m depth interval to 30 m (5, 10, 15...), every 10 m in depth to 100 m (i.e. 30, 40, 50….), every 100 m to 1,000 m depth (200, 300, 400, 500…), at 2,000 m, 3,000 m, 4,000 m, 5,000 m, and at a contour following the bottom depth directly (i.e. 1 m) above the seabed.

d. Source depths included in models should reflect the source type according to the following recommendations:
   i. Airgun arrays: 6-8 m
   ii. Shipping/dynamic positioning systems: 6 m
   iii. Explosions: full water column (smaller regions should consider 10 depths over the full water column)
   iv. Pile driving: As noted above, the most computationally efficient and representative method of modelling sound radiated by pile driving for larger scale regions remains an important question that needs further investigation. Alternative approaches include using a phased array of point sources distributed along a vertical line[10], or using a finite element model to represent the pile[11]. It is recommended that the feasibility of representing the pile as a simple source as input for long distance modelling be evaluated.

e. The highest resolution of the modelling should match the highest resolution of the measurements, with the option of reducing the resolution to meet specific needs.

f. Model output verification or building trust in the model output and associated soundmaps via empirical measurements and hindcasting is recommended.

g. To ensure flexibility with respect to computationally intensive, large scale, propagation loss modelling, a two-stage approach is recommended for model results that will allow users to consider a variety of 'what if' scenarios (e.g. changes in resulting soundscapes from shifting shipping lanes). An alternative approach is also possible for situations where actual source positions are well defined:
    i. In the first stage, one designates a regularly spaced grid of 'virtual sources', and computes and retains the multiple sound fields (a sound pressure field, including phase information, that incorporates transmission loss) that would result from sounds produced at those locations.
    ii. In the second stage, each virtual source can be weighted in proportion to a calculated 'source level density' at each locations. The source level density represents the noise source radiant intensity per unit area, and can characterize a variety of noise sources such as shipping lanes, the trajectories of seismic airgun arrays as they survey an area, or the pile drivers at discrete locations. The resulting sound field due to any particular source level density scenario can then be calculated by summing up the ensonification resulting from each individual virtual source.
    iii. In the alternative approach, for the many cases where the actual source positions are well-defined in advance, it is not necessary to precalculate the sound field for a regular grid of virtual sources. For instance a wind farm often has specific pile locations selected in advance. Similarly, ship positions are often provided for specific waypoints. For such cases the sound field can be calculated for the specific source positions.

D) Management/Visualization Tools

a. Platforms that managers use should be interactive and accessible so that they can visualize different time frames, spatial areas, or source configurations of interest. There is a need for platforms that guide managers in evaluating alternatives quickly, with first-order or pre-computed accuracy, and at relatively low cost. More complex targeted evaluations will remain necessary and will require higher level expertise.
b. Where soundscape mapping products exist, they should be used as a tool in evaluating current environmental status and trends to consider in risk assessment.
c. Where soundscape mapping products exist, they should be used as a means to predict future conditions and evaluate scenarios (e.g. future offshore industrial activity profiles) of interest.
d. It is recommended that trends and status be determined based on the minimum (sound floor), average, and maximum (sound ceiling) level statistics. Trend statistics should reflect the minimum processing recommendations of 10%, 25%, 50%, 75%, 90%, and the arithmetic mean based on 1-minute averaging windows. This will allow managers to evaluate changes in quietest regional conditions as well as changes in average and noisiest conditions.
e. Visualizing percentile acoustic conditions of high and low sound levels (e.g. visualize 10% and 90% levels), as well as average conditions is recommended.
f. The development of a visualization tool to identify the difference in an acoustic distribution statistic between two environmental scenarios (time or condition) is recommended. These products could identify areas of increasing/decreasing sound level or areas with specific management targets.

E) Research

All Working Groups were tasked with identifying short-term research that could be initiated under a two-year work plan. Recommended research addressed two topic areas of need: 1) linking minimum requirements of measurement and modelling to the need for a statistical verification and extrapolation to fill data gaps and confirm adequate sampling resolution, and 2) increasing geographic coverage of measurements and models to address baseline needs of high priority. Grossly, these topic areas match well to next steps for regions that are currently data rich versus data poor. The following research recommendations are not prioritized on any level.

a. Case studies should be initiated in areas with longer term acoustic and source distribution data to evaluate uncertainty and model sensitivity. This could be accomplished through ensemble modelling by varying model input parameters, or alternatively by selecting a number of traverses on a pre-computed grid to 'spot-check' and incorporate variability.
b. Baseline status and trend analyses should be conducted in high priority areas. High priority areas could include regions of rapid industrial or environmental change, biologically important

areas for acoustically sensitive species, or other identified characteristics (e.g. regions designated by national/international marine resource management bodies).

c. Research is needed to identify indicators (acoustic quantities and thresholds) for significant acoustic change to inform visualization tools.
d. Research is needed to determine how acoustic quantities characterizing a soundscape in both the temporal and spatial domains can be reconstructed from subsampled measurements.
e. International measurement campaigns are needed along shipping lanes, in combination with recorded AIS data and possibly additional data from classification society registers, to better characterise the relationship between source level and ship operating or design characteristics such as its speed. This could result in additional requirements for speed and operating parameters (e.g. towing gear, dredging) to be made available in AIS data from ships.

SUMMARY

This workshop has demonstrated that the capabilities to measure and model the ocean soundscape have advanced well beyond short-term, localized efforts. This now allows management agencies to look beyond acute, temporary impacts of sound exposure on marine mammals to concerns addressing chronic and cumulative impacts related to potential auditory masking. Many different agencies, countries, and/or organizations across the globe have already established or are in the process of launching soundscape monitoring and modelling programs: LIDO (http://listentothedeep.com), QUONOPS (www.quiet-oceans.com), BIAS (http://biasproject.wordpress.com), SoundMap (cetsound.noaa.gov), SONIC (http://www.sonic-project.eu/), and AQUO (http://www.aquo.eu/). While these programs are an excellent start towards being able to predict ocean soundscapes at a global scale, they are not standardized in their measurement or modelling parameters, making it extremely difficult to compare products across regions. In addition, they are largely focused on US and European waters, while management concerns for marine organisms are far wider ranging. The recommendations stemming from this workshop identify acoustic measurement and modelling protocols that if implemented world-wide would greatly add to the value of local and regional studies by allowing data to be combined and integrated at larger scales. The development of status assessment and predictive tools that are transferable to any region will aid in visual scenario building where sound maps can be constructed and deconstructed based on source type and distribution. The identified data gaps and research represent topic areas where progress can be made to extend current modelling efforts beyond where they are today in order to better inform sound-related management and conservation of marine species.

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APPENDIX A

Participant List

Leila Hatch	NOAA	USA
Jason Gedamke	NOAA	USA
René Dekeling	Ministry of Infrastructure and the Environment, Ministry of Defence	Netherlands
Mike Porter	Heat, Light, & Sound Research, Inc.	USA
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Kevin Heaney	OASIS	USA
Mark Prior	CTBTO	United Nations
John Young	CSA & World Ocean Council	USA
Peter Dahl	University of Washington	USA
Christ de Jong	TNO-Netherlands	Netherlands
Robert Laws	Schlumberger Ltd	UK
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Brandon Southall	SEA, Inc.	USA
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Kyle Becker	Office of Naval Research	USA
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Niels Kinneging	Rijkswaterstaat (RWS)	Netherlands
Oliver Boisseau	International Fund for Animal Welfare (IFAW)	USA

APPENDIX B

AGENDA

DAY 1:

0800-0830 CONVENE

0830-0900 WELCOME from co-chairs of steering committee; overview of workshop goals and review agenda

900-1000 SHORT SUMMARY PRESENTATIONS: Context and needs derived from conservation or management (including monitoring) efforts

- 900-915 NOAA & Cetsound: Jason Gedamke
- 910-930 EU & MSFD: René Dekeling
- 930-945 IQOE: Jen Miksis-Olds
- 945-1000 Navy-ONR: Kyle Becker

1000-1050 SHORT SUMMARY PRESENTATIONS: Current regional to ocean-basin scale sound field modelling/monitoring efforts

- 1000-1025 Peter Dahl/Christ de Jong/Robert Laws: Describing sources most relevant to large scale modelling
- 1025-1050 Brief overviews of large scale monitoring efforts to inform/ground truth modelling
    - 1025-1030 Michel André
    - 1030-1035 Peter Sigray
    - 1035-1040 Rex Andrew
    - 1040-1045 Mark Prior

1050-1100 BREAK

1100-1200 SHORT SUMMARY PRESENTATIONS: Current regional to ocean-basin scale sound field modelling efforts (continued)

- 1100-1115 Mike Porter--large scale modelling techniques (propagation methods & data needs) I
- 1115-1130 Kevin Heaney--large scale modelling techniques (propagation methods & data needs) II
- 1130-1145 Thomas Folegot--large scale modelling techniques (propagation methods & data needs) III
- 1145-1200 Sergio Jesus--case study scale integration of sound field modelling and measurement

1200-1300 LUNCH

1300-1315 Michael Ainslie—National & International Standardisation of Acoustical and Bioacoustical Terminology

1315-1500 FULL GROUP DISCUSSION TOPIC: Currently available (commercial or open-source) methodologies for modelling at spatial, temporal and spectral scales relevant to chronic and cumulative noise assessments

- Identifying priority output metrics
    - Spatial (including depth) resolutions: emphasis on regional to ocean-basin scales; depth related to modelling techniques and marine animals of concern
    - Temporal resolutions: emphasis on cumulative and chronic summary durations
    - Spectral resolutions: emphasis on lower frequencies due to longer-term and larger-scale focus
- Retaining the flexibility to derive multiple output metrics from source data
    - Computing process management lessons for those engaged in building or maintaining the databases or processing systems that will support such modelling efforts in order to maximize their utility for managers

1500-1515 BREAK

1515-1700 FULL GROUP DISCUSSION TOPIC: Currently available (commercial or open-source) methodologies for modelling sound fields at spatial, temporal and spectral scales relevant to chronic and cumulative noise assessments (*continued*)

- Existing propagation modelling techniques

  - Algorithms and approaches and their performance at scales of interest
  - Enhancing computational feasibility for scales of interest
  - Determining accuracy at scales of interest
- Transferability
  - Access (open source, commercial)
  - Costs (purchase, base program, processing needs)
  - User expertise

EVENING: Group dinner (details TBD)

DAY 2:

0800-0830 CONVENE

0830-0845 OPENING COMMENTS: Co-chairs of steering committee provide notes from Day 1 and review objectives for Day 2

0845-1030 DISCUSSION TOPIC: Within regions determined to be of high interest by conservation and management-focused bodies, currently available (commercial or open-source) geospatial databases and/or sound source information to support modelling sound fields at spatial, temporal and spectral scales relevant to chronic and cumulative noise assessments

- Environmental attributes
  - Distribution and density of sound-producing activities
  - Characterization of sound sources
  - Ambient long-term sound monitoring data

1030-1045 BREAK

1045-1200 FULL GROUP SYNTHESIS OF DISCUSSIONS: Priority next steps for the development and improvement of sound field mapping tools & identification of small group topic areas for afternoon writing task

- Source data, database maintenance
- Modelling approaches and platforms
  - Scenario modelling
- Accuracy and uncertainty
  - Depicting uncertainty
  - Comparison of predicted and empirical results
    - Lessons for monitoring efforts
- Identification of opportunities and funds that would support expansion of modelling efforts to more and key global locations

1200-1300 LUNCH

1300-1430 SMALL GROUP RECOMMENDATION WRITING: Divide into topic areas identified before lunch to craft recommendation language

Group 1 Topic: Temporal resolution: Brandon Southall, Christine Erbe, Michael Ainslie, Thomas Folegot, Jennifer Miksis-Olds, Mark Prior

Group 2 Topic: Spectral and spatial resolution: René Dekeling, Jason Gedamke, Mike Porter, Kevin Heaney, Sander von Benda-Beckmann, Roberto Racca

Group 3 Topic: Sources, measurements, and databases: Robert Laws, Christ de Jong, Peter Dahl, Niels Kinneging, Sergio Jesus, Rex Andrew, Ozkan Sertlek

Group 4 Topic: Management tools and propagation tools: Leila Hatch, Michel André., Kyle Becker, Peter Sigray, John Young, Marina Melcón, Oliver Boisseau

1430-1445 BREAK

1445-1600 SMALL GROUP RECOMMENDATION WRITING: *Continued*

1600-1700 FULL GROUP REPORT DEVELOPMENT: Review of small group recommendations and additional report content

1700 CLOSING COMMENTS

APPENDIX C

Workshop Abstracts

* denotes presenter

NOAA & CetSound: Context for predictive sound field mapping workshop

*Jason Gedamke**

Sound is an integral component of the physical and biological habitat that many aquatic animals have evolved over millions of years to rely on. In just the last ~100 years, however, human activities have caused large increases in introduced noise and fundamentally altered the nature of underwater soundscapes. In the past, management of potential impacts on marine life have focused on the acute physical and behavioral effects from exposure to individual noise sources. Longer term effects of chronically increased noise arising from multiple sources are more difficult to discern. In 2011, NOAA organized two working groups, collectively called “CetSound,” to develop tools to map the density and distribution of cetaceans (“CetMap”), and the predicted contribution of human activities to underwater ocean noise (“SoundMap”) in U.S. waters. The “SoundMap” working group utilized data on the density, distribution, and acoustic signatures of dominant anthropogenic noise sources (e.g. global shipping, passenger vessels, oil and gas exploration) and environmental descriptors, to develop estimates of their temporal, spatial, and spectral contributions to background noise levels. While further development of these tools will include refining inputs on anthropogenic and natural noise sources, and ground-truthing predicted noise with empirical measurements, the maps effectively illustrate the vast extent over which man’s activities can alter the natural acoustic habitat of the ocean. These initial predicted anthropogenic soundscape maps are a necessary first step towards characterizing and assessing the potential effects of multiple, chronic anthropogenic sound sources on both the ocean's varied acoustic habitats, and the animals utilizing this habitat.

Ambient Noise Monitoring, Implementation of the EU Marine Strategy Framework Directive

*René Dekeling**

The European Marine Strategy Framework Directive requires European member states to develop strategies for their marine waters. The ultimate goal of the MSFD is to achieve Good Environmental Status (GES) in European seas by 2020. Programs of measures are currently being designed and should be operational from 2016. An essential step towards reaching GES is the establishment of monitoring programs, enabling the state of marine waters to be assessed on a regular basis. Monitoring for the MSFD should be implemented in 2014.

A register for impulsive noise generating activities is being built and data on these activities will be collected from 2014; the data will enable assessment of cumulative impacts on wide temporal and spatial scales in the future. European Member States are cooperating to in marine regions to set up monitoring programmes for ambient noise, that are needed to provide information on actual levels and trends. In the Baltic Sea, measurements have started within the BIAS-project.

The EU expert group TG Noise has published guidance for setting up monitoring programmes. This guidance addresses provides clarity on main objective and scope of the indicator. The presently chosen indicator is a pressure indicator, for future environmental targets more information is needed on the relation between pressures, state and impact. Where the Commission Decision of 2010 required EU Member States to monitor trends, TG Noise has concluded that to determine whether GES is reached information on trends is not sufficient and actual levels need to be determined. To monitor ambient noise, a combination of measurements and modeling is needed, and TG Noise has provided (initial) minimum standards for both measurement equipment and models, and considerations for planning measurement locations. The TG Noise guidance addresses averaging methods and has evaluated pros and cons of several methods (arithmetic mean, geometric mean, median and mode); and concluded that the arithmetic mean (of squared sound pressure samples) complied best with the requirements; the initial advice of TG Noise is to use the arithmetic mean to establish average ambient noise levels, noting that there is still insufficient information on effects of masking on marine life and therefore the most suitable averaging method for biological relevance is still unclear. TG Noise has advised that complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time.

In the OSPAR meeting of April 2014 it was decided that an OSPAR working group (ICG Noise) should draft a proposal for a coordinated ambient noise monitoring programme for the North Sea, based on the advice of TG

Noise, this work will be coordinated by The Netherlands; cost of ambient noise monitoring is a main concern and the proposal must pay specific attention to control of cost, showing options for ambition level and balance short term product with the ability to enable future changes/further development.

International Quiet Ocean Experiment
*Jennifer Miksis-Olds**

The International Quiet Ocean Experiment (IQOE) evolved from a series of meetings sponsored by the Alfred P. Sloan Foundation through the Scientific Committee on Oceanic Research (SCOR) and Partnership for Observation of the Global Oceans (POGO). The aim of the IQOE effort is to coordinate the international research community to quantify the ocean soundscape and examine the relationship between ocean sound and marine organisms. It is envisioned as a 10-year activity to coordinate existing and new national activities focused on 1) ocean soundscapes, 2) defining the effects of sound on marine organisms, 3) observing sound in the ocean, and 4) industry and regulation of ocean sound. An IQOE Science Plan was developed following community input at an Open Science Meeting in 2011. The Science Plan has been reviewed and is currently being revised to address review comments. The 10-year program will commence once the Science Plan is published. An International Year of the Quiet Ocean is proposed at the mid-point of the program to focus a one-year period of intensive observation and research on ocean sound.

Rendering the Undersea Soundscape
*Kyle Becker**

Acoustic systems are used extensively in Navy operations. In support of better performance prediction capabilities, the Navy invests heavily in acoustic experimentation, modeling, and environmental database building. Nevertheless, although previous measurement programs have demonstrated qualitative differences in regional ambient noise levels and characteristics, there has not been a program to address these differences in a holistic way. This brief describes a notional concept for rendering regional undersea soundscapes to predict the ambient noise state into which a sonar would be expected to operate. Progress in this area is expected to benefit both Navy and marine resource managers.

Underwater Noise from Pile Driving
*Peter Dahl**

Pile driving as used for in-water construction can produce high levels of underwater sound, with the potential to produce physiological and/or behavioral effects on fishes, invertebrates, and aquatic mammals. There are two basic pile driving methods: impact pile driving where the pile is driven by strikes from a high-energy hammer, and vibratory pile driving where the pile is effectively vibrated into the sediment. At ranges on the order of 10 m, vibratory pile driving produces sustained RMS sound pressures of order 10^3 Pa. In contrast, each impact pile strike (for which the hammer strike energy is of order 10^5 to 10^6 J) produces a transient sound with peak sound pressure on the order of 10^5 Pa.

In terms of the mapping of the underwater noise field from pile driving, a unified approach to quantifying the source level for the underwater sound generated by an individual pile remains a research question. However, progress has been made in terms of modeling the reduction, or loss, in noise intensity or energy versus range from the pile. Common drivers in determining this transmission loss include local bathymetry, dominant sediment type, and average sound speed in the water column.

Radiated Noise from Ships
*C.A.F. (Christ) de Jong**

Ships produce underwater radiated noise as an unintended byproduct of their propulsion system, other machinery and flow around the hull. The amount of noise radiated depends on the ship design as well as on operational parameters. Published radiated noise levels ships are often difficult to compare because of a lack of standardization of measurement, analysis and reporting procedures. Source level data that can be reliably used in combination with propagation models to create shipping noise maps is scarce. Individual ships often exhibit a clear trend of increasing radiated noise with increasing ship speed. However, general trends of radiated noise versus ship type, size and speed are much less clear. It is clear, however, that the radiated noise of most merchant vessels in normal cruising condition is dominated by propeller cavitation noise, which makes these vessels

orders of magnitude (~40 dB) more noisy than, for example, fishery research vessels at survey speed, with limited propeller cavitation and noise control measures applied to all relevant machinery.
Two EU research projects (http://www.sonic-project.eu/ and http://www.aquo.eu/) are currently working on tools for generating shipping noise maps for European waters. These are developing coherent ship noise data bases and models that allow estimation of ship source levels on the basis of the information available from ship tracking systems (AIS).

Marine Seismic Sources
*Robert Laws**

The sound source used for deep seismic surveying is almost always an array of airguns. Each airgun releases a bubble of compressed air into the water which pulsates and radiates sound as it does so. The oscillation period depends, inter alia, on the volume of the airgun. Arrays of airguns are used, with a mix of volumes, to obtain a flat spectrum, to increase the emitted energy and to control the directivity.

Airgun bubbles are small compared with the wavelength emitted, but the arrays are not small. An airgun array is therefore well-described as an array of monopoles with individually defined source functions. These source functions can be obtained by measurement or by modelling matched to experiment. It is not possible to calculate accurately the output energy spectrum of an airgun array where only the total volume of the array has been defined. Published estimates of the emitted acoustic energy from an array of airguns range as high as 870kJ per shot, although this may well be an overestimate. The array is fired typically every 10 seconds. Most (but not all) of the emitted energy is below 200 Hz.

There a consortium to develop a marine vibratory source. The advantage of the vibrator is environmental; for the same acoustic energy spectrum a vibrator array has less environmental impact than an airgun array.

Composing Soundscapes from Real-time Acoustic Data Stream
*Michel André**

Seven years have passed since LIDO (http://listentothedeep.com) was first launched in European waters. It now operates 24/7 worldwide and continues expanding through contracts with public administrations and industries to mitigate the effects of artificial noise associated to offshore operations. Its exclusive database as well as the data management architecture behind its software package, SONS-DCL, allows to continuously fine-tune the algorithms responsible for noise monitoring, detection, classification and localization of acoustic events. A custom alert service is also available, warning the user of the presence of acoustically sensitive species in the area of activity. The analysis is standardized, automated and performs in real time while the processed data is displayed through a user-friendly interface on the Internet. It incorporates noise measurements in 1/3-octave bands, including the EU MSFD (Marine Strategy Framework Directive) descriptors. LIDO also couples AIS (Automated Identification System) with *in situ* noise received levels allowing the monitoring of individual ship noise signatures. SONS-DCL can be implemented on cabled observatories, autonomous radio-linked buoys, moored antennas, autonomous vehicles (including gliders), towed arrays and existing data sets. It is designed to build and retrieve standard statistical analysis, including percentiles distribution, of all processed data. Through a partnership with Quiet Oceans, the software package QUONOPS has been integrated into LIDO to create close-to-real-time noise maps that are directly displayed on its web interface. This unique internet-based combination of real-time noise measurement and sound field mapping techniques is anticipating the future broad use of predictive acoustic data at any spatial and temporal scales (regional or ocean-basin) immediately providing support for decision makers to manage the potential impact of chronic or cumulative artificial noise on marine organisms.

BIAS – Baltic Sea Information on the Acoustic Soundscape
*Peter Sigray**

In September 2012 the EU supported BIAS project was started (LIFE+ program). The project has three main objectives. The first is to establish a regional implementation of Descriptor 11 of the Marine Strategy Framework Directive, which includes development of user-friendly tools for management of the Descriptor and to obtain sound levels. The second objective is to establish regional standards and methodologies that will allow for cross-border handling of data and results, which is necessary for an efficient joint management. The third objective is to model the soundscape based on measured sound levels.

The BIAS project is aimed at solving the major challenges when implementing Descriptor 11 in the Baltic Sea region. Monitoring of sound will be performed during one full year. In total 38 sensors will be deployed. The measurements will be performed by adhering to the standards that will be established in the project. Likewise will the data be analyzed using standardized signal processing routines. Results will be subjected to a quality control and finally stored in a common data-sharing platform. The goal is to establish monthly and yearly averages of sound levels in the whole of the Baltic Sea. These levels will be used to establish the long term trends.

Collecting and Curating 20+ Years of Low-Frequency Ambient Sound
*Rex Andrew**

APL has been collecting low-frequency ambient noise power spectra from multiple receiver systems located in the North central and North-East Pacific and along the Aleutian Islands for about 20 years. The value of these datasets increases as the collections grow. Maintaining the quality of these datasets has required new and persistent attention to varying hardware (hence requiring varying data calibration correction curves) and weekly attention to data collection computer uptime (to avoid prolonged collection gaps). The survivability of archival digital data media remains a challenge: I discuss some promising recent technologies.

Soundscapes from Hydrophones Stations in CTBTO's IMS Hydroacoustic Network
Mark Prior, David Brown*

The Comprehensive Nuclear-Test-Ban Treaty Organisation operates a global network of sensors that includes cabled sound-channel hydrophones in the Atlantic, Pacific and Indian Oceans. Hydrophones are deployed in groups of three, known as triads, so that the arrival times and azimuths of signals can be obtained. Data are recorded at frequencies up to 100 Hz with continuous acquisition and data relay via satellite connection to CTBTO's International Data Centre. Signals from distant earthquakes, underwater explosion, marine mammals and ice-breaking are routinely detected and an extensive archive has been built up over the last decade. To understand sensor detection performance, high-level summaries of noise properties are required to establish the 'acoustic context' for each station. These 'soundscapes' allow the identification of source types that dominate in specific frequency bands. Examples signals are illustrated and information regarding the sources of persistent signals is extracted.

Global Ocean Soundscape Modelling
Michael Porter, Laurel Henderson*

In the NOAA/Navy/BOEM CetSound effort, extensive modelling was done of sound sources in the U.S. EEZ. This included layers for different classes of ships, seismic airgun surveys, Navy sonar exercises, oil rig demolition, and pile driving for a wind farm. We review briefly this effort as background to the current effort, which is looking to do develop techniques for global soundscape modelling. We briefly describe the algorithms and present preliminary results showing the global noise pattern due to both ships and wind noise.

Basin Scale Acoustic Modelling
*Kevin Heaney**

Ocean propagation in the deep ocean is extremely efficient leading to the effective propagation across entire ocean basins. Measurements have been made of explosions, earthquakes, oceanographic acoustic experiments and seismic exploration experiments at ranges easily greater than 8000 km. Modelling of this sound has been done using ray-tracing, normal mode propagation and the Parabolic Equation (PE) model. Application of the 3-dimensional Parabolic Equation model to many of these experiments shows that 3-dimensional propagation effects can be significant for low frequency sound. These results demonstrate how high fidelity modelling can be used to estimate the long-term sound exposure on marine mammals on long range basin scales. Examples of basin scale propagation modelling for seismic surveying, as well as surface shipping were presented.

About Statistical Noise Mapping
*Thomas Folegot**

The Marine Strategy Framework Directive has officially stated as soon as 2008 the anthropogenic noise due to shipping were to be mitigated. To address this issue, the project AQUO "Achieve QUieter Oceans by shipping noise footprint reduction" (http://www.aquo.eu) started in October 2012 for 3 years in the scope of FP7

European Research Framework. It involves 13 partners from 8 European countries, mixes academic experts, industry representatives from yard, classification society and other acoustic and bio-acoustic specialized bodies.

Soundscape mapping is one of the tools used during this project to represent the noise field. The characteristic and variability of the anthropogenic noise footprints are highly dependent on the spatial and temporal distribution and variability of the traffic and of the environmental conditions, such as bathymetry, oceanography, meteorology and bottom properties.

To deal with the 4-dimensional properties of the noise field (latitude, longitude, depth and time), Quiet-Oceans recommends a statistical approach for soundscape mapping and the use of percentile to capture the stochastic nature of the noise. The percentile description of the noise can be achieved by calculating the statistics of a time series of 3-dimensional noise fields.

The production of such a series of noise fields is provided by in quasi real-time, for example, by the LIDO-QUONOPS internet-based combination of real-time noise measurement and modeling (see Michel André abstract). This platform is able to provide daily, weekly, monthly, quarterly and yearly percentile soundscape maps, combined with cetacean presence statistics to be used for management and decision aid.

Predicting Global Soundscape: Experiment, calibrate, and validate
Sergio Jesus with contribution from the SiPLAB team*

Reliable prediction of global soundscape interconnects three main aspects: one is the accuracy and extent of the environmental information globally available to feed numerical models, the other is the numerical tools and hardware for sound propagation prediction and the third aspect is the methodologies and infrastructure for experimental assessment, validation and, if necessary, calibration of the model results. Based on the experience of the SiPLAB team at the University of Algarve over the last 25 years, this presentation emphasizes the third aspect by recalling the concept of "equivalent model" as a possible technique for calibration and assimilation of actual acoustic measurements into propagation models and provides a series of real data collection examples for relevant cases. These examples include the assessment of the underwater acoustic noise produced by a wave energy plant in the Island of Pico (Azores); the calibration of propagation models offshore a fish farm plant in Portugal; and the recording of acoustic noise fluctuations due to Posidonia Oceanica prairies off the Island of Corsica (France), as a possible perturbation for experimental soundscape validation. The presentation concludes with a series of recommendations and a list of open issues regarding optimal sensor placement, sensor standardization, reconfigurability, regional to global scaling/patching and sensor cost, all of which "road-blocks" preventing the wide scale usage of current acoustic measurements.

Standardisation of Acoustical and Bioacoustical Terminology: why bother?
Michael Ainslie

Don't write so that you can be understood, write so that you can't be misunderstood. William Howard Taft (1857 - 1930), 27th President of the USA.

In 1999, a cargo flight crashed while taking off in Shanghai (China), with the loss of 8 lives, because a request to climb gently from 1400 m to 1500 m was misinterpreted as a requirement to dive to 1500 ft. In the same year, the Mars Climate Orbiter was lost due to a failure to standardise between ground-based and on-board computers, at a cost of 650 million USD. These two costly incidents demonstrate the importance of international standardisation of units and terminology.

A timeline of the standardisation in national and international acoustical terminology and reference values is presented, from the introduction of the decibel in 1928 to the publication of the latest ANSI 'Acoustical Terminology' standard in January 2014, through the completion of the International System of Quantities in 2009, including ISO 80000-8:2007 'Quantities and Units - Acoustics'. Both the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) have made progress towards international standardisation of acoustical terminology, although not all definitions are defined in the same way by the two different bodies. Particular issues discussed are various incompatible definitions of basic terms like "sound pressure", "sound pressure level" and "source level".

In order to mitigate the confusion, under the chairmanship of George Frisk, sub-committee 3 'Underwater acoustics' of ISO TC43 'Acoustics' has tasked a working group with the development of international standard for underwater acoustical terminology, due for publication in 2015. The objective of this working group is to facilitate effective communication in underwater acoustics by providing an internally consistent basis of unambiguous terminology. Also in progress is a process that will for the first time provide international standard reference values of sound pressure, sound particle velocity and related quantities for use in underwater acoustics.

APPENDIX D

1/3 Octave Centre Frequencies (IEC)

Recommended 1/3 octave centre frequencies from 25 Hz to 20 kHz based on the International Standard IEC 61260-1995 Electro-acoustics – octave band and fractional-octave-band filters.

Table A.1 — Midband frequencies for octave-band and one-third-octave-band filters in the audio range

Indice x	Base-ten exact f_m $(10^{x/10})$ (1 000) Hz	Base-two exact f_m $(2^{x/3})$ (1 000) Hz	Nominal midband frequency Hz	One-third octave	Octave
–16	25,119	24,803	25	*	
–15	31,623	31,250 †	31,5	*	*
–14	39,811	39,373	40	*	
–13	50,119	49,606	50	*	
–12	63,096	62,500 †	63	*	*
–11	79,433	78,745	80	*	
–10	100,00 †	99,213	100	*	
–9	125,89	125,00 †	125	*	*
–8	158,49	157,49	160	*	
–7	199,53	198,43	200	*	
–6	251,19	250,00 †	250	*	*
–5	316,23	314,98	315	*	
–4	398,11	396,85	400	*	
–3	501,19	500,00 †	500	*	*
–2	630,96	629,96	630	*	
–1	794,33	793,70	800	*	
0	1 000,0 †	1 000,0 †	1 000	*	*
1	1 258,9	1 259,9	1 250	*	
2	1 584,9	1 587,4	1 600	*	
3	1 995,3	2 000,0 †	2 000	*	*
4	2 511,9	2 519,8	2 500	*	
5	3 162,3	3 174,8	3 150	*	
6	3 981,1	4 000,0 †	4 000	*	*
7	5 011,9	5 039,7	5 000	*	
8	6 309,6	6 349,6	6 300	*	
9	7 943,3	8 000,0 †	8 000	*	*
10	10 000 †	10 079	10 000	*	
11	12 589	12 699	12 500	*	
12	15 849	16 000 †	16 000	*	*
13	19 953	20 159	20 000	*	

NOTE 1 Exact midband frequencies are calculated from equation (3) to five significant figures except for the exact values marked by †.

NOTE 2 See ISO 266 for other nominal midband frequencies of octave and one-third-octave-band filters.

1/3 Octave Centre Frequencies (ISO)

Recommended 1/3 octave centre frequencies from 10 to 1 kHz based on the International Standard ISO 266-1997: Acoustics—Preferred frequencies.

Nominal Centre Frequency (Hz)	Base-Ten Exact Centre Frequency (Hz)
10	10
12.5	12.589
16	15.849
20	19.953
25	25.119
31.5	31.623
40	39.811
50	50.019
63	63.096
80	79.433
100	100
125	125.89
160	158.49
200	199.53
250	251.19
315	316.23
400	398.11
500	500.19
630	630.96
800	794.33
1000	1000