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Assessing the cross platform performance of marine mammal indicators between two collocated acoustic recorders

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ABSTRACT

Equipment and deployment strategies for remote passive acoustic sensing of marine environments must balance memory capacity, power requirements, sampling rate, duty-cycle, deployment duration, instrument size, and environmental concerns. The impact of different parameters on the data and applicability of the data to the specific questions being asked should be considered before deployment. Here we explore the effect of recording and detection parameters on marine mammal acoustic data across two platforms. Daily classifications of marine mammal vocalizations from two passive acoustic monitors with different subsampling parameters, an AURAL and a Passive Aquatic Listener (PAL), collocated in the Bering Sea were compared. The AURAL subsampled on a preset schedule, whereas the PAL sampled via an adaptive protocol. Detected signals of interest were manually classified in each dataset independently. The daily classification rates of vocalizations were similar. Detections from the higher duty-cycle but lower sample rate AURAL were limited to species and vocalizations with energy below 4 kHz precluding detection of echolocation signals. Temporal coverage from the PAL audio files was limited by the adaptive sub-sampling protocol. A method for classifying ribbon (*Histriophoca fasciata*) and bearded seal (*Erignathus barbatus*) vocalizations from the sparse spectral time histories of the PAL was developed. Although application of the acoustic entropy as a rapid assessment of biodiversity was not reflective of the number of species detected, acoustic entropy was robust to changes in sample rate and window length.

1. Introduction

Determining habitat usage by marine mammals contributes to the overall understanding of the ecology of these animals. Conducting visual surveys of marine mammals is expensive and difficult. Some marine mammal species are at the surface for only a short period of time making visual detection even more difficult. Acoustic monitoring permits the surveying of vocalizing animals without relying on visual detection. Remotely deployed autonomous passive acoustic monitoring enables persistent monitoring of a region for vocalizing marine mammals over long periods of time without requiring the presence of human observers. Improvements in hardware technology now permit the collection of enormous passive acoustic data sets from remotely deployed recorders (Van Parijs et al., 2009; Wiggins and Hildebrand, 2007). The use of autonomous passive acoustic monitoring (PAM) for studies of marine mammals greatly increases our capacity for collecting information about vocalizing animals in the absence of concurrent visual observations, which is critical for acquiring information in remote, inaccessible, or hazardous areas (Mellinger et al., 2007). Increasing the amount of data collected leads to an increase in the required storage space and post-processing demands. Analysis requirements have traditionally been met by long and often tedious hours from a human classifier listening to and looking through spectrograms of the recordings. Automated detection and classification algorithms are now replacing the previously required man hours with computer hours (Mellinger et al., 2011; Roch et al., 2008). Many different recording systems are being designed and employed for various studies around the world (Moore et al., 2012; Sousa-Lima et al., 2013). The results stemming from these efforts provide information on animal distribution, behavior, and reactions to environmental change, all of which have the potential to inform resource management, research efforts, and industry. As not all recordings are the same, understanding the relative strengths, weaknesses, and impacts of sampling strategies on data interpretation and results becomes increasingly important. Comparisons of detections from different species and across different recording systems will greatly increase the inferential power from the results of the analyses of the individual units. As deployment durations are increased and PAM recorders are deployed in new and increasingly remote locations, methods are being developed to handle the collection and processing load to yield results for interpretation regardless of recording strategy

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(Wiggins and Hildebrand, 2007). This will make all data more valuable due to the wider use and applicability for short and long term studies.

There are tradeoffs in remote passive acoustic sensing between memory capacity, power requirements, sampling rate, duty-cycle, deployment duration, and instrument size. For any signal of interest, the Nyquist theorem requires that the minimum sample rate must be at least twice the highest frequency in the signal or aliasing may occur and spectral data will be compromised (Nyquist, 1932). This places a minimum constraint on the sample rate for a signal with known frequency content. For low frequency vocalizations, like those of blue whales (*Balaenoptera musculus*), the required sample rate can be below 1 kHz because the highest frequency in known blue whale vocalizations does not exceed 400 Hz (Berchok et al., 2006). With these low sample rates and modern data storage capabilities, deployments are often limited by battery power. However, for signals containing high frequency components found in many odontocete vocalizations and echolocation signals, the required bandwidth of the recording introduces data storage constraints along with limitations from battery power. Reducing the duty-cycle of the recorder, so that it is recording only part of the time, can extend the battery and memory capacity. With reduced duty-cycle, the ability of a system to capture a particular sound depends on the probability of the signal being present with substantial signal to noise ratio and the probability of the system recording at that moment (Miksis-Olds et al., 2010; Richardson et al., 1995). For species with seasonally ubiquitous vocalizations, like bearded seals (*Erignathus barbatus*) in the Bering Sea during late winter and early spring, this is not an issue because vocalizations from multiple individuals are almost continuous (Miksis-Olds et al., 2010). If the received level of the vocalizations is consistently above the background noise, the signal will be recorded when the system is active. A caveat exists for those species where vocalizations are rare, either because the species vocalizes infrequently, or the number of vocalizing individuals is low e.g. North Pacific Right whales (*Eubalaena japonica*) (Mellinger et al., 2004). A sub-sampling protocol operates under the assumption that rare vocalizations may be missed yet permits the collection of long term data sets from recorders deployed in remote locations for long durations.

Sub-sampling methods can be adequate to address many research questions such as those pertaining to the presence and absence of marine mammals in a region over time and acoustic biodiversity (Lammers et al., 2008; Sueur et al., 2012). For binary presence/absence research questions, long recordings dominated by the repeated vocalizations of a single species provide the same result as a recording of a single vocalization from that species. Research questions addressing topics such as the vocalization behavior and population density may benefit from long recordings of a single species' vocalizations. Adaptive recorders with on-board decision making algorithms permit the collection of a limited amount of data with feature triggers focusing the effort on periods containing signals of interest; thus reducing battery, memory and post-processing requirements (Miksis-Olds et al., 2010).

Describing the biodiversity of the environment is often limited to the species richness or the number of different species present (Sueur et al., 2012). Marine mammal classifications from acoustic recordings obtained using autonomous recorders provide a measure of biodiversity. An automated assessment of biodiversity comparing the temporal and spectral entropies of the acoustic signals in the terrestrial environment was presented by Sueur et al. (2008). Biodiversity assessments amongst and between varying passive acoustic monitors have not been examined. Utilizing instruments with different duty cycles and sampling rates may not provide comparable results for detection, classification and relative vocal activity for different species.

Expanded effort to monitor the marine environment with subsampling acoustic recorders equipped with increasingly complex onboard processing raises the question of how to integrate data across acoustic monitoring systems. The species level classifications or acoustic biological diversity, and a statistically based acoustic biodiversity index can be generated from each dataset. Understanding the relative performance of systems with different sub-sampling recording paradigms is useful for comparisons between the systems. Two systems currently deployed on a single mooring (subsurface buoy) in the Bering Sea implement different strategies to achieve year-long deployments: 1) semi-continuous sampling; and 2) an adaptive sub-sampling paradigm with an on-board event detector for initial processing and adaptive control. The concurrent deployment of these two systems enables a comparison between detection and classification of marine mammal vocalizations necessary to identify the strengths and weaknesses of the two different sampling methods. The daily species level classifications of the two recording systems were examined. The acoustic biodiversity index calculated for each system was compared to species detected within a single recorder and across recording platforms.

2. Materials and methods

Two autonomous passive acoustic recorders with different sampling strategies were collocated on an oceanographic mooring maintained by NOAA's Pacific Marine Environmental Laboratory as part of the Fisheries Oceanography Coordinated Investigations (Eco-FOCI) Program (Stabeno et al., 2008). The Passive Aquatic Listener (PAL) is an adaptively sub-sampling recorder developed by Jeffrey Nystuen at the University of Washington (Nystuen, 1998) and the AURAL-M2 (Multi-Electronique Inc, Quebec) is a commercially available, programmable passive acoustic recorder. The mooring was located on the 70 m isobath southeast of St. Matthew Island in the eastern Bering Sea (59° 54.285′ N, 171° 42.285′ W)(Stabeno et al., 2008). The PAL and AURAL were deployed serially in the mooring line at depths of 65 m and 67 m, respectively. The data for this work are from a single deployment, September 2008 through May 2009, as part of a multiyear study.

2.1. Passive Aquatic Listener (PAL)

The PAL consists of a wide-band (0–50 kHz), low-noise hydrophone (HTI-96-MIN), pre-amplifier, and recording computer. An internal battery pack provided power for instrument operation. On-board memory consisted of a 2 GB compact flash card. The PAL was programmed to record a 4.5 s audio clip at a sampling rate of 100 kHz every 10 min. Eight spectra were created from 10.24 ms subsamples spaced equally throughout the 4.5 s clip. The spectral values were compressed by integrating the frequency bins over 200 Hz bandwidths from 100 to 3000 Hz and 1 kHz bandwidths from 3 to 50 kHz (Nystuen, 1998). The eight individual compressed spectra, or spectra cluster, were analyzed against predetermined detection thresholds. A signal of interest was detected in the sample if one of three criteria were met: 1) matching predefined spectral patterns for rain, 2) a 12 dB amplitude threshold difference for sequential samples, or 3) peaks in frequency bins indicating tonal signals (Miksis-Olds et al., 2010). Exceeding any of the criteria resulted in a detection and the implementation of the adapted sampling protocol. If the recording was determined to contain a signal of interest, the audio clip and the spectra cluster were saved to memory, otherwise the audio clip was cleared, the spectra were averaged, and only the average spectrum was saved. Additionally, if a signal of interest was present, the PAL reduced the sampling interval from 10 to 2 min until a signal of interest was no longer detected (Fig. 1a). These two sampling intervals resulted in duty cycles of 0.75% and 3.75%, respectively. A daily quota limiting the number of saved audio clips was selected based upon the expected deployment duration to ensure adequate disk space. For this deployment, the daily quota was six audio clips. If the number of audio clips saved for any day was less than the quota, the excess allocation was made available to subsequent days up to a maximum of 21 total audio clips per day. If the daily limits were exceeded, the PAL continued to operate with the same adaptive sub-sampling protocol with the exception that no further audio clips were saved; spectra clusters continued to be saved throughout the deployment regardless of whether the daily audio clip limit was exceeded (Miksis-Olds et al., 2010). This programming paradigm