Development Of Passive Acoustic Monitoring Systems For Northern Right Whales

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ABSTRACT

Both species of northern right whale (North Atlantic, *Eubalaena glacialis* and North Pacific, *Eubalaena japonica*) are critically endangered. The overall distribution of these small, migratory populations is not well known, especially outside of summer. Passive acoustic monitoring is a tool that could provide information on locations of whales. Better distributional information will inform management efforts to reduce anthropogenic mortalities caused by both ship strikes and fisheries interactions. Recent research on passive acoustic monitoring is summarised, focusing on developments relevant to detection and classification of right whale calls. Some outstanding research requirements are outlined, including the need for the development of models to investigate the potential for risk reduction from acoustic data. Buoys capable of fully automatic whale vocalisation detection, classification and transmission to shore are currently under development.

SOMMAIRE

Les deux espèces de baleines franches nordiques (Atlantique Nord, Eubalaena glacialis et Pacifique Nord, Eubalaena japonica) sont gravement menacées d'extinction. La distribution générale de ces petites populations migratoires demeure à ce jour méconnue, plus spécifiquement en dehors de la période estivale. Le monitorage acoustique passif est un outil pouvant donner de l'information sur l'emplacement des baleines. Une meilleure indication de la distribution de ces dernières pourrait fournir des renseignements sur les efforts mis en place pour réduire les mortalités de cause anthropogénique causées à la fois par les collisions avec les bateaux et les interactions avec l'industrie de la pêche. Les recherches les plus récentes sur le monitorage acoustique passif sont ici résumées, en mettant l'accent sur les développements pertinents à la détection et la classification des vocalisations de baleines franches. Quelques lacunes tirées des conclusions de ces recherches sont soulignées, incluant le besoin de développer des modèles pour investiguer le potentiel des données acoustiques dans la réduction du risque. Des balises capables de détection, de classification et de transmission vers la côte sont présentement en développement.

1. INTRODUCTION

The purpose of this paper is to (a) provide very brief summaries of the conservation status of northern right whales (populations and threats) (b) outline potential application of passive acoustics to this problem (c) outline recent developments in passive acoustic research and development relevant to management (d) describe some outstanding research topics.

2. STATUS OF NORTHERN RIGHT WHALES

2.1 Population status

Both species of northern right whale are critically endangered. The North Atlantic right whale (Eubalaena glacialis), now regularly found only off the eastern US-Canadian seaboard, numbers about 300-350 (IWC 2001). Previous abundance estimates of the North Pacific right whale (Eubalaena japonica) are not reliable but the numbers are certainly very low. The eastern North Pacific population in particular was severely impacted by illegal whaling during the twentieth century (Brownell, 2001).

Population projections for E. glacialis have been made by Caswell et al. (1999) and Fujiwara and Caswell (2001), based on a reliable long-term photo-identification record maintained by the New England Aquarium. These analyses suggest that current levels of mortality will lead the population to extinction within 100-400 years. Collisions with ships and entanglement in fishing gear have been identified as major sources of mortality (Knowlton and Kraus 2001). Anthropogenic mortalities are a large proportion (40%) of known mortalities. Falling survival rates over the last two decades have brought this small population into decline. According to Fujiwara and Caswell (2001), 'preventing the deaths of only two female right whales per year would increase the population growth rate to replacement level'.

2.2 Management systems

On the eastern US seaboard, of 45 reliably documented deaths of right whales, 16 were confirmed to be due to ship strikes between 1970 and 1999 (Knowlton and Kraus 2001), and unreported deaths are also thought to occur (a proportion likely to be a result of collisions).

A Mandatory Ship Reporting scheme was introduced in 1999 that requires ships over 300 tonnes to report in to the US coastguard as they enter critical right whale habitats. The mariners then receive the most up-to-date information on right whale sightings in the area as well as on the characteristics of right whales, and are cautioned to keep a sharp look out for, and avoid all right whales. This system currently relies on rather patchy sightings information from research vessels, aerial surveillance and opportunistic sightings reported by mariners, fishermen, etc. As far as we are aware, there are no equivalent risk reduction or management schemes in place in the Pacific.

In the Bay of Fundy, Canada, a long-term data set documenting right whale distribution enabled the Government of Canada to propose changes to the shipping lanes away from areas of high right whale use. The Maritime Safety Committee of International Maritime Organisation approved and adopted this proposal, which came into effect in July 2003.

In the US, a series of comprehensive and region-specific recommended measures to reduce ship strikes (including speed reductions, alternative routing etc) have been developed in consultation with the industry, scientists and management authorities (Russell and Knowlton 2001). The proposed measures are currently under consideration by the relevant authorities in the US Government, with a view to incorporating them into national legislation.

The efficacy of any management scheme is reliant on the quality and quantity of data to inform it, and on effective mitigation measures being in place to deal with the conflicts between whales and human activity. Acoustic monitoring could compliment or supplement existing surveillance systems.

3. CONSERVATION APPLICATIONS OF PASSIVE ACOUSTICS

Passive acoustic monitoring is being considered as a method of detecting and locating right whales. It offers several advantages, including the ability to monitor autonomously for long periods in inhospitable conditions or in poor visibility (including at night). There is also potential for automation of the detection/classification process. Automation is a particularly useful feature when dealing with rare or widely dispersed populations such as northern right whales (Gillespie and Leaper, 2001).

However, the successful application of acoustic monitoring is dependent on a number of factors, including: sufficiently high vocalisation rates; appropriate detection ranges (source levels, propagation characteristics); detection algorithms robust to noise and capable of finding variable signals; sufficient understanding of detector efficiency and false alarm rates; and availability of technological expertise and equipment. A greater understanding of these issues has been obtained in recent years.

A workshop devoted to the subject of passive acoustics in management of right whales (Gillespie and Leaper, 2001) noted the following potential applications:

1. Detecting the presence of right whales in areas where there is little or no dedicated surveillance or other data, including poorly surveyed areas known to be used at least occasionally.
2. Assessing the predictability of right whale distribution patterns in known high use areas, including use of these areas in non-peak seasons.
3. Verifying aerial surveys.
4. Detecting a threshold number of whales in an identified high risk area that would 'trigger' some management action
5. Monitoring levels of ship traffic
6. Real-time detection systems for dynamic management

4. RIGHT WHALE ACOUSTICS

4.1 Summary

Descriptions of northern right whale acoustics (e.g. McDonald and Moore 2002, Vanderlaan et al. 2003) are more recent and more limited than the extensive study of the southern right whale (E. australis) repertoire made by Clark (1982, 1983). Tonal or pulsive sounds are typically in the 50-600 Hz range (but may reach over 1000Hz) and usually about 0.5-1 second duration. These calls are usually frequency-modulated: for example, McDonald and Moore (2002) categorised E. japonica calls as 'up', 'down-up', 'down', 'constant' and 'unclassified'. Another distinctive type of sound is the 'gunshot', described from E. australis by Clark (1982, 1983) and frequently heard from E. glacialis (e.g. Matthews et al. 2001, Laurinolli et al. 2003). As their name suggests, these are brief, broadband transients.

Various technologies are available and are being or have been in use to research and monitor right whales, including: towed arrays, acoustic tags, bottom-mounted recorders, sonobuoys and shore-cabled systems. Accounts of their use can be found in e.g. Clark et al. (2000), Matthews et al. (2001), McDonald and Moore (2002), Laurinolli et al. (2003), Nowacek et al. (2004) and ONR (1997).

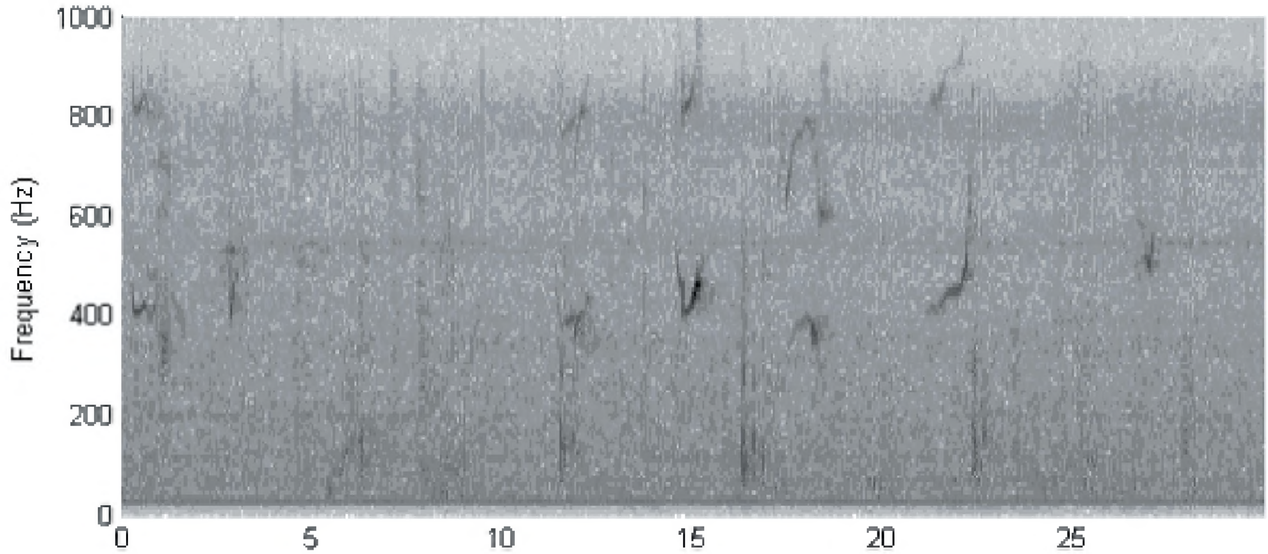

Figure 1. Spectrogram of a 30 second sequence of calls from North Atlantic right whales in the Bay of Fundy.

4.2 Recent developments relevant to passive acoustic monitoring

Characterisation of repertoire

In the early 1980s Clark (1982, 1983) found that southern right whales make common use of upsweeping calls (50-200 Hz, 0.5-1.5 seconds), and established that they are used to help animals maintain contact at a distance. Recent studies have now shown this type of call to be commonly produced by northern right whales too. The sample of E. glacialis calls illustrated in ONR (1997) from the Florida critical habitat were upsweeps. McDonald and Moore (2002) found upsweeps to be the predominant type (85%) in a sample of 511 from E. japonica. Gillespie (2004) and Matthews (2004) supply further evidence of their common occurrence in E. glacialis. In a study in the Bay of Fundy, Laurinolli et al. (2003) reported that 38 of 255 tonal sounds (15%) were low-frequency upsweeps. The relatively low proportion in this area may be due to increased use of other sounds with social or sexual functions (Parks, 2003). Although sounds corresponding to contact calls were not found in the study by Vanderlaan et al. (2003), they state that this is 'likely because we experienced high noise levels at these lower frequencies'.

Establishing the widespread use of upsweeps by northern right whales is a significant step forward for automatic detection systems. These calls are variable (see e.g. Gillespie 2004, Fig. 1) but also more-or-less invariant in shape. This means a good conceptual understanding of a common type of sound is now available when designing detectors and classifiers. These systems must nevertheless be flexible enough to respond to a degree of variation.

Vocalisation rates and patterns

A study of vocalisation rates of E. glacialis by Matthews et al. (2001) in the Bay of Fundy, Great South Channel and Cape Cod Bay, found the waiting time between vocalisations varied broadly from less than a minute to a few hours. In the Bay of Fundy, Vanderlaan et al. (2003) report waiting times of 2-700 seconds. According to McDonald and Moore (2002) after call bouts E. japonica in the Bering Sea 'commonly … became silent for an hour or more, with some animals not calling for periods of at least four hours'.

Several studies have now demonstrated that in general terms vocalisations are clustered in time. Matthews et al. (2001) reported clustering in most recordings made of E. glacialis, and Vanderlaan et al. (2003) also observed this in the Bay of Fundy. McDonald and Moore (2002) reported clustering of sounds in E. japonica.

Detection/Classification

Of significant interest is the discovery of excellent propagation characteristics in the Bering Sea, which allowed Wiggins et al. (2004) to detect right whales at long ranges of up to 50 km using bottom-mounted recording units. Unfortunately, the propagation and ambient noise conditions in many parts of the range of northern right whales are not so favourable.

Several techniques for automatic detection and/or classification were discussed in Gillespie and Leaper (2001): energy detectors, matched filtering, spectrogram correlation, neural networks, statistical pattern recognition and time sequence detection. Several studies have applied these techniques to cetacean vocalisations in general (e.g. Potter et al. 1994, Mellinger and Clark 2000). Some detectors have now been examined in more detail with respect to right whales in this volume. Mellinger (2004) examines spectrogram correlation and neural networks. Gillespie (2004) examines statistical pattern recognition using image analysis of a spectrogram. Matthews (2004) looks at a parametric detection method for frequency-modulated tones. La Cour and Linford (2004) describe a method using independent component analysis.

Localisation

Passive acoustic data can provide highly accurate information on source location, providing a sufficient number of detectors are available and properly configured (Spiesberger and Fristrup, 1990). A number of estimation methods are available and under active investigation (this volume). Localisation is a valuable tool in applications such as behavioural, source-level estimation or ground-truthing studies. For example, Clark et al. (2000) placed seafloor recorders in groups of three, in the Great South Channel in 2000 and Cape Cod Bay in 2001, which allowed sounds to be localised and the results compared with aerial survey sightings.

However, accurate localisation may be unnecessary in many management applications. Any detection is also a crude localisation of an animal to somewhere within the detection range. Large-scale monitoring programmes do not necessarily require resolution at a finer scale than this. On the other hand, localisation may be useful for management applications in restricted spaces. Laurinolli et al. (2003) looked at the feasibility of passive acoustic localisation, particularly 'to clarify the frequency and numbers of right whale incursions into the [Bay of Fundy] shipping lane …'.

An experimental real-time detection system

A real time acoustic monitoring system is currently being developed by Cornell University, Woods Hole Oceanographic Institute, and the International Fund for Animal Welfare. The goal is to implement a system of moored buoys to automatically detect and classify right whale sounds, and report this data on a daily basis. Each buoy will transmit right whale sound detections by cell phone or satellite to computers at Cornell University. Prototype buoys will be on trial off Cape Cod, USA, in 2004 and it is hoped that similar systems may be able to provide real time information on the presence and distribution of right whales in high-risk areas in the future.

5. SOME SUGGESTED TOPICS FOR FUTURE RESEARCH

5.1 Risk reduction modelling

There is a need for modeling of potential management systems, using data from passive acoustics, to assess the potential for risk reduction. Models should incorporate data on ranges of detection, reliability of detection, vocalisation rates, whale distribution and movement patterns as well as the potential hazards and possible mitigation measures. These models are likely to be area specific.

The temporal and spatial scales for any mitigation measure should be considered. The total time taken to receive vocalisations from whales, process the acoustic data, make a management decision and issue instructions to mariners needs to take place within the time frame for which the surveillance data are valid.

The research outlined in sections 5.2-5.4 will provide valuable information for this.

5.2 Detection

It is crucial to assess detection/classification systems for both their efficiency (probability of correctly detecting a sound) and their false alarm rates (probability of incorrectly detecting a sound). Any management system based on passive acoustics will require some expression of confidence in the detections/classifications made. In the context of a monitoring system for right whales, it is likely that the cost of false detections will be high, since this may lead to management actions as described in section 2.

To assess the detection performance, some means of ground-truthing is required. Matthews (2004) and Gillespie (2004) attempt to assess the performance of their detectors using the following approach. They compare the numbers of calls detected from recordings when right whales were known to be present (as verified by visual survey) with recordings when whales were thought absent (using visual surveys and human listening).

This approach allows the performance of detection algorithms to be quantitatively compared. The efficiency of detection systems cannot be determined absolutely because the actual occurrences of whale sounds are not fully known. However, the relative efficiency of detectors (including human operators) can be tested. The false detection rate can be determined absolutely. These tests are, of course, conditional on the testing environment.

More extensive investigations of the performance of detection algorithms are needed. Ground-truthing using visual observations is likely to be an important part of this process.

5.3 Classification

Current classification methods for northern right whales search for upsweeping calls in about the 50-400 Hz range. Detector/classifier efficiency could be increased significantly if the desired signals could be expanded to include more of the right whale repertoire. Particularly in social or sexual contexts, right whales can be highly vocal and will use relatively complex, higher-frequency calls in abundance (Fig. 1; Parks, 2003). However, expanding the call range of classifiers also increases the chances of confusion with humpback whales (Megaptera novaeangliae), which are highly vocal, and produce many sounds similar in frequency and duration to those of right whales. In addition to their well-known 'song', humpback whales produce other potentially confusing sounds in feeding or social contexts (Cerchio and Dahlheim 2001, Thompson et al. 1986).

Humpback whales do not restrict their singing to low-latitude wintering grounds. Singing has been documented in spring in the same regions where part of the North Atlantic right whale population regularly gathers (Mattila et al. 1987). They have also been reported singing in Alaskan waters occasionally in late summer (McSweeney et al. 1989).

5.4 Vocalisation rates

Vocalisations are a prerequisite for passive acoustic detection. Some areas where further information is desirable are listed below.

(i) No information appears to be available on vocalisation rates from right whales on migration.
(ii) The Great South Channel is an area with relatively heavy shipping traffic but rather sparse data on vocalisation rates.
(iii) Matthews et al. (2001) found higher vocalisation rates from right whales at night in the Bay of Fundy, and ONR (1997) reported higher rates between 1700 and 0500 in the southeast US. No published information is available on diurnal rates in the Great South Channel/Cape Cod, or in the North Pacific.
(iv) Information on vocalisations rates in the southeast US, the only known calving ground for E. glacialis, is poor. The only study we are aware of (ONR 1997) reported vocalisation rate results from a shore-cable system. The overall rate appeared to be relatively low (690 calls in about 300 hours or ~2.3 calls per hour), although the number of whales present is not stated. The tapes examined were 'most likely to yield vocalisations … based on … visual sightings in the vicinity of the fixed array'. It is not clear (a) whether the recordings were examined exactly when whales were within detection range (i.e. excluding periods when whales were out of range), and (b) whether tapes were selected on the basis of higher vocalisation rates (which would bias the estimated rate upwards). A fuller account of the acoustic and visual data would assist interpretation.

The statistics of the waiting times between vocalisations are crucial to understanding the efficacy of a management system based on passive acoustic detections. Detection probabilities will be more sensitive to the waiting times between clusters than the waiting times between vocalisations. The waiting time between clusters of calls relative to the period for which whales are within detection range will be a major factor affecting detection probability.

5.5 Extension of acoustic monitoring programme

It would be of interest to extend the acoustic monitoring programme to lesser-studied areas where animals may gather or pass through. Some areas e.g. Roseway Basin and Browns Bank off Nova Scotia, are known summering grounds for E. glacialis, but use of these areas varies considerably between years. Outside of summer, the whereabouts of a major part of the E. glacialis population is not known. The distribution of E. japonica outside of summer is also not well understood and no wintering grounds have been confirmed (Brownell 2001).

The US eastern seaboard forms migratory habitat for North Atlantic right whales en route between summer feeding grounds, and winter nursery and calving grounds. Shipping activity is intense in parts, and ship strikes are known to have occurred there. Passive acoustics could play a role in providing information on the whales' movements in this migratory coastal zone, including how close to shore the whales migrate, and whether they spend extended periods in certain areas.

6. CONCLUSION

The potential for passive acoustic techniques to contribute towards right whale conservation has been widely acknowledged, including by the Scientific Committee of the International Whaling Commission (IWC, 2002). In recent years there has been a substantial increase in applied studies of northern right whale acoustics, moving towards this goal. Further work is still required to determine how passive acoustic information and techniques might best be applied to practical management scenarios for risk reduction. Nevertheless, with continued research efforts, passive acoustic techniques could play an important role in reducing right whale mortality within a few years.

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