USE OF ACTIVE SONAR FOR CETACEAN CONSERVATION AND BEHAVIORAL-ECOLOGY STUDIES: A PARADOX?

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ABSTRACT - The relationship between low frequency military sonar use and some whale stranding events has attracted negative attention towards the use of active sonar in the marine environment. As a consequence, there has been only limited use of active acoustic techniques by marine mammal researchers. Instead more attention has been given to the development and use of passive acoustic methods for the detection of cetaceans. Nevertheless there is great potential for the use of active acoustic systems in ecological studies, and studies aimed at improving conservation of whales and dolphins in their natural environment: active acoustic techniques can be used for the good of cetaceans, and should not just be considered a source of disturbance. We evaluated the capability of various acoustic systems - systems that are used commonly in fisheries research - to detect and track cetaceans underwater. We collected data initially with standard scientific echosounders (SIMRAD EK500) from moving vessels and from fixed moorings (EK60) at 38 and 120 kHz. Scientific echosounders have narrow beams and therefore enable sampling from only fixed and limited volumes. To overcome these limitations we progressed to use high frequency omnidirectional sonar (SIMRAD SH80) operating at 110 kHz. During Norwegian Sea ecosystem surveys (2006-2008) we recorded the backscatter energy from three species of large whales: Fin whale (*Balaenoptera physalus*), Minke whale (*Balaenoptera acutorostrata*) and Humpback whale (*Megaptera novaeanglie*). During the observations no avoidance reactions by cetaceans were observed, even when the vessel's entire suite of active acoustic instruments were running (frequency range from 18 kHz to 200 kHz, maximum source level 210 dB re 1 µPa (at 20 and 110 kHz). Here we present a small sample of data from two Fin whales that show the animals backscatter response at broadside. In addition, we give an overview of the present status and possible future development of the use of standard active acoustic methods for cetacean studies. Omnidirectional sonar shows great potential as a tool for marine mammal detection, and could be developed to produce an automatic cetacean detector. Such a detector would be a highly valuable aid for seismic mitigation and ship strike prevention, and in addition could contribute to behavioural studies with its high definition time scale. Much work is required to understand relationships between cetacean body shape, physiology, kinematics and acoustic reflectivity, before a detector can be realized.

1 INTRODUCTION

The capability of active acoustic systems for probing oceanic life has been demonstrated clearly by the advances that such technologies have brought to fishery science (Simmonds and MacLennan 2005). However, few investigations have been on large bioacoustic targets such as whales (Lucifredi and Stein 2007; Miller 1999; Levenson 1974; Love 1973; Dunn 1969). Active acoustic detection of whales could offer an alternative approach to damage mitigation associated with seismic operations, providing real-time detection capabilities. At the moment visual observations and passive acoustic monitoring (PAM) are the standard methods used to detect cetaceans during seismic campaigns. However, visual detection is limited by visibility and sea state, and PAM is strongly dependent on whales actively vocalizing. Cetaceans are acoustically active mostly during foraging (a limited period), and their vocalizations are highly directional: vocalizations not directly in line with a passive listening array may go undetected. There are thus limitations to both presently used techniques, limitations that could fail to prevent conflict between human activities and cetaceans. Active acoustic techniques could overcome these limitations, but use of such techniques presents at first glance something of a paradox. The commonly held view is that active sonars are, at the least, a source of nuisance to cetaceans (Rendell and Gordon 1999; Richardson et al. 1995; Watkins et al. 1985) and, at worst, are sometimes (military applications) a direct cause of death (Parsons et al. 2000; Frantzis 1998; Simmonds and Lopez-Jurado 1991). However, at appropriate frequencies and source levels, active acoustic techniques could be used to protect whales. With this in mind, we embarked on a project, with the long-term goal of exploring the possibility of using fishery omnidirectional sonars to detect cetaceans during seismic operations and to use such detections as triggers to stop potentially harmful seismic shooting. Ultimately an automatic detector could help control of seismic surveys, and could perhaps reduce the incidences of whale strikes by commercial freighters. We began by using the high frequency (110 kHz) SIMRAD SH80, attempting short distance detections of animals under constant visual observation. In this short manuscript we show samples of data from two Fin whale detections at broad side. The manuscript is essentially a 'proof of concept' showing how whales can be detected by this system. We also give consideration to potential behavioural reactions by target whales to our detection system.

2 SYSTEM DESCRIPTION

Sonars have been used in the past for behavioural studies of fish, marine mammals and sea birds with good results (Nøttestad et al. 2002; Axelsen et al. 2001; Vabø and Nøttestad 1997; Oliver and Kvitek 1984). We started to evaluate the quantitative application of such instruments in 2004 using a set of data collected during a fishery survey in Namibian water. Dusky dolphins were acoustically detected, while feeding on a large school of Cape horse mackerel, using a scientific echosounder (SIMRAD EK500) with a 38 kHz splitbeam transducer. Signals obtained during some 2 hours of acoustic observations were confirmed as a) dolphin traces by the presence of dolphins at the surface and b) mackerel by trawl-sampling (Bernasconi et al. 2007a; 2007b). Other clear evidence of the possibility of using active acoustics for cetacean detections comes from fixed moorings with upward looking transducers (Godø et al. 2007): analyses revealed presence of echotraces similar to the dusky dolphin marks in the echograms from areas with high cetacean abundance. Both of these systems used narrow beams that could not be directed and, as a consequence, those results remain indicative rather than quantitative. For this reason we next evaluated the directional and radar-like characteristics of another series of instruments: fisheries sonars.

The SIMRAD SH80 system used in the present study is an omnidirectional high frequency sonar designed to be used from a range of sizes of fishing vessels. The transceiver unit performs the signal processing and the digital beamforming of 240 transmitters and 480 receiver channels. The unit is designed to be lowered from a hull hutch 1 m below the ship's hull (in our case the total depth was 6.2 m). The cylindrical transducer array enables the sonar beam to give a full 360 degrees instantaneous horizontal coverage. The sonar beam can be tilted 60 degrees from the surface. The sonar can also transmit vertically. The data output gives a vertical slice of 60 degrees aperture that can be manually aimed in the target direction. We operated the sonar at 110 kHz using pulse lengths varying from 0.8 ms to 3.8 ms with a source level of 210 dB//1µPa (RMS).

3 TARGET STRENGTH MEASUREMENTS

Our test observations were made in July 2007 in the Norwegian Sea onboard the vessel EROS M-60 HØ, a 72 m purse seiner adapted to be a scientific platform. We collected more than 8 hours of acoustic data. The samples presented in this paper come from 2 Fin whale sightings and correspond to just 10 sec of recording. A plot of an omnidirectional single ping is shown in FIG 1 for an 18 m Fin whale insonified at broad side at the surface. The vertical slice example in FIG 2

shows another animal (slightly smaller, approximately 15 m long) swimming parallel to the ship at 30 m depth: those data were obtained while we were operating the sonar manually and following the whale's dive visually from the surface. Fin whale TS measurements at broad side are summarized in Table 1. . The animals spent a long period of time (around 1 hour for each sighting) in close proximity (between 50 and 300 m) to the ship, giving ample opportunity for us to estimate length.
For quantitative TS estimates the data output from the sonar were considered with the sonar equation:

$$TS = dBl - SL + TVG + Cal \qquad (1)$$

where dBl is the received dB level; SL is the source level of the sonar; TVG is time varied gain generated for every sighting using CTD data, and corresponding to $40\log_{10}R+2\alpha R$ (with R the range and α the absorption coefficient); Cal is a correction value obtained using a tungsten carbide sphere in a dedicated calibration experiment. CTDs were also collected with the aim of running detection probability and ray tracing simulations using the software Lybin 4.0 (FIG 3).
The TS values we obtained are low as compared to the few results described in the literature (Love 1973; Miller 1999; Lucifredi and Stein 2007). However, the frequency dependence of broadside backscatter by our Fin whales may be consistent with the dependence shown in backscatter data from dolphins (Au 1996) and, as such lower TS than published values is to be expected. We are investigating this aspect further, comparing data from different species, and are planning the use of a lower frequency instrument during the second phase of the project. The sample of data presented here serves to show the feasibility of our approach and suggests the potential of our notion of using sonars for the wellbeing of the whale.

4 DISCUSSION AND CONCLUSIONS

At this stage of our project we have good indications as to the possibility to develop a dedicated active acoustic cetacean detection system using standard fishery sonar instruments. A fast MATLAB analysis tool has been generated to interrogate pings, and this enables us to extract TS values in near real time. Our next step is to analyze the received backscatter in relation to the body aspect shown to the sonar to generate and test a basic detection system for whales in any orientation. Given the widespread belief that cetaceans react adversely to any sound in the ocean, we are also analyzing the behavioral patterns observed among species during the experiments, and comparing periods when the acoustic instrument suite was turned on and turned off. However, we feel that even at this early stage it is noteworthy to report that no whale showed avoidance reactions. This allowed us to perform short range detection (minimum distance 50 m) even when all the active fishery acoustic tools were running at full power. TS values appear low if compared to other studies results, but signals stand out above background noise. The low TS values are probably due to a strong frequency dependence of TS. This hypothesis will be tested trough the analysis of the large amount of data we have already collected and will collect in summer 2009 with the new low frequency sonar SIMRAD SX90 (20-30 kHz).
Marine explorations achieved great goals in the last 60 years thanks in part to advances in acoustic instrumentation and the application thereof (e.g. fisheries research). We are now seeing the maturation of a new generation of 3D multibeam sonars such as the SIMRAD MS70 that are capable of working as an acoustic underwater camera, covering an entire school of fish. These instruments have potential for application to cetacean research, particularly if the popular view of active acoustics threatening cetaceans can be overcome.

FIGURES AND TABLES

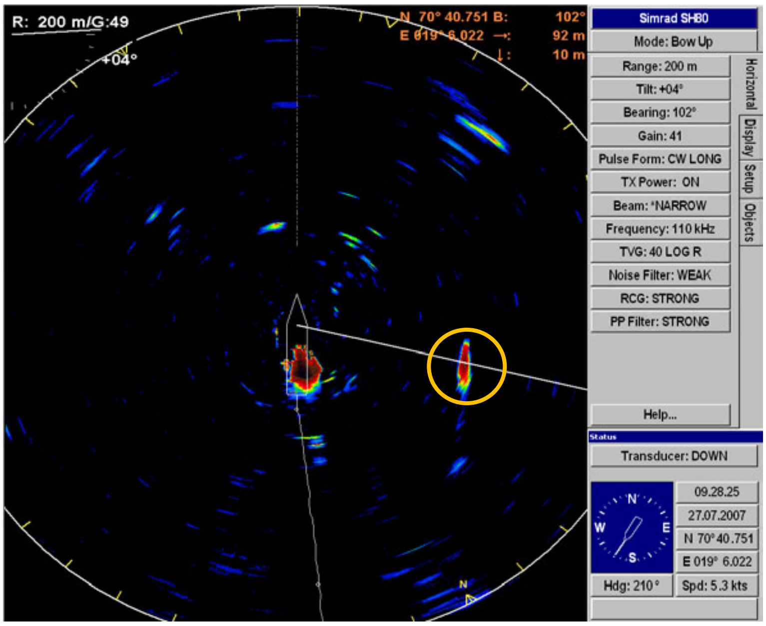

FIG 1. Screen shot sample from the SIMRAD SH80 sonar showing the surface-swimming Fin whale (orange circle) standing out clearly from the noise.

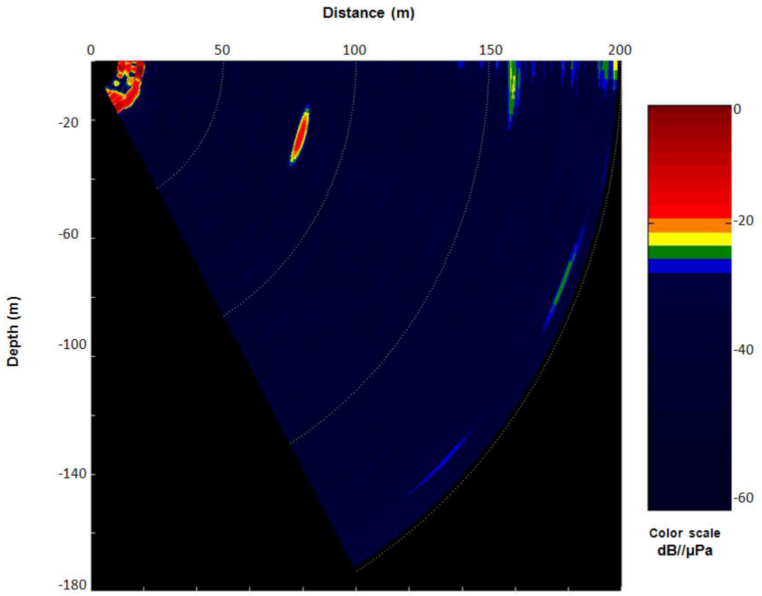

FIG 2. This ping shows a submerged Fin whale swimming parallel to the ship (range of 75 m; depth of 30 m).

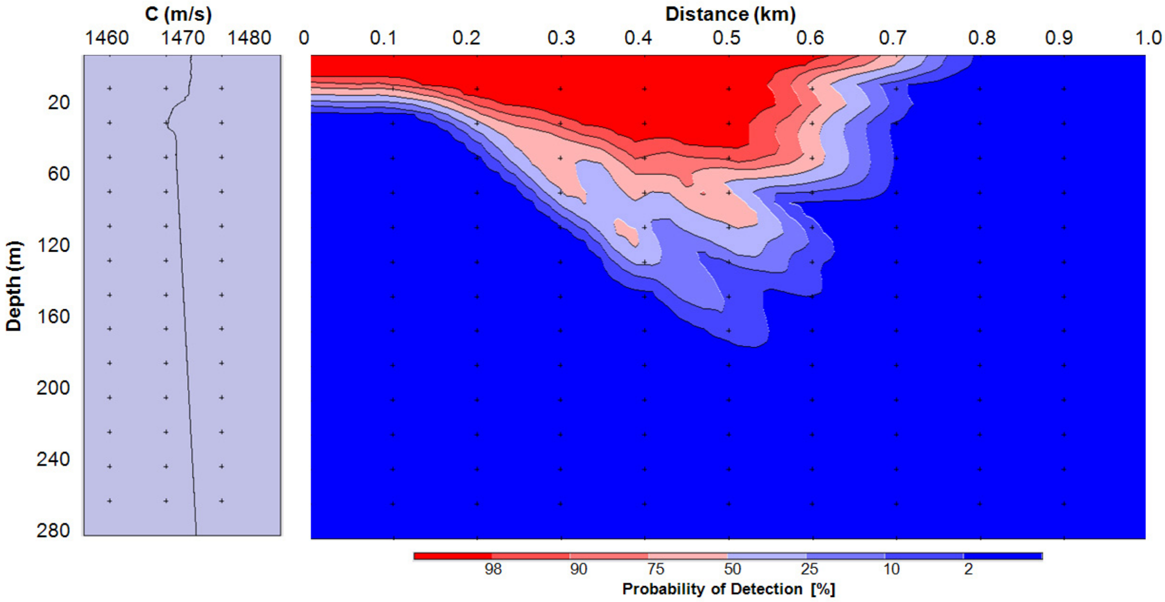

FIG 3. Sound speed profile for the area of the sightings (78°03.2937' N - 008°57.1707' E) we present in this paper, and detection probability plot generated using the software Lybin 4.0 developed by the Norwegian Royal Navy.

Whale ID	**Distance** (m)	**TS** (dB//1µPa)
1	202	-9.6
1	213	-6.6
1	211	-5.5
1	208	-8.5
1	205	-9.5
1	200	-5.9
2	349	-9.0
2	347	-9.7
2	345	-9.3
2	340	-7.3

TABLE 1: Sample Target Strength measurements for two Fin whales at broad side made during preliminary observations in the summer 2007.

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REFERENCES

1. Axelsen B.E., Anker-Nilssen T., Fossum P., Kvamme C. And Nøttestad L. Pretty patterns but a simple strategy: predator-prey interactions between juvenile herring and Atlantic puffins observed with multibeam sonar. Can.J.Zool., 79:1586-1596, 2001.

2. Au, W.W.L. Acoustic reflectivity of a dolphin. J. Acoust. Soc. Am., 99: 3844-3848, 1996.

3. Bernasconi M., Nøttestad L., Krakstad J. O. and Axelsen B.E. *In situ* target strength measurements of a small cetacean: Tracking individual dusky dolphins (Lagenorhyncus obscurus) in deep water. 17th SMM Biennial Conference Cape Town, South Africa, December 2007.

4. Bernasconi M., Nøttestad L., Krakstad J. O. and Axelsen B.E. (2008). Dusky dolphins (*Lagenorhyncus obscurus*) hunting Cape horse mackerel (*Trachurus trachurus capensis*) in the northern Benguela: active acoustic recording of predator-prey interactions. *In Review* to Mar.Ecol.Prog.Ser.

5. Dunn J. L. Airborne measurements of the Acoustic Characteristics of a Sperm Whale. J.Acoust.Soc.Am., 46: 1052-1054, 1969.

6. A. Frantzis, “Does Acoustic Testing Strand Whales?” *Nature*, 392: 29, 1998

7. Gødo O. R., Doksæter L., Olsen E., Nøttestad L. and Patel R. (2007) Monitoring of marine mammals and their prey by an active upward looking bottom mounted echosounder. 17th SMM Biennial Conference Cape Town, South Africa, December 2007.

8. Levenson J. L. Source level and bistatic target strength of the sperm whale (*Physeter catodon*) measured from an oceanographic aircraft. J.Acoust.Soc.Am., 55: 1100-1103, 1974.

9. Love, R.H. (1973). Target strengths of humpack whales Megaptera novaeangliae. J. Acoust. Soc. Am., 54, 1312-1315, 1974.

10. Lucifredi I. and Stein P. J. Gray whale target strength measurements and the analysis of the backscattered response. J.Acoust.Soc.Am. 121: 1383-1391, 2007.

11. Miller J. H., Potter D. C., Weber T. and Felix J. The target strength of the northern right whale (Eubalaena glacialis). J.Acoust.Soc.Am. 105: 992, 1999.

12. Miller P.J.O., Biassoni N., Samuels A. and Tyack P. L. “Whale Songs Lengthen in Response to Sonar,” *Nature*, v. 405 (2000): 903, 2000.

13. Oliver J. S. and Kvitek R. G. Side-Scan Sonar records and diver observations of the Gray Whale (*Eschrichtius robustus*) feeding grounds. Biol. Bull. 167:264-269, August 1984.

14. Parson E. C. M., Birks I., Evans P. G. H., Gordon J. C. D., Shrimpton J. H. And pooley S. The possible impacts of military activity on cetaceans in West Scotland. Europ.Res.Cet. 14:185-190, 2000.

15. Rendell, L.E. & Gordon, J.C.D. Vocal responses of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. *Marine Mammal Science*, **15**, 198-204, 1999.

16. Schrope M. “Whale Deaths Caused by US Navy’s Sonar,” *Nature* 415: 106, 2002.

17. Simmonds, M. & Lopez-Jurado, L.F. Whales and the military. *Nature* **337**: 448, 1991.

18. Simonds J. and MacLennan D. *In* Fisheries Acoustic Theory and Practice. Second Edition published by Blackwell Science, 2005.

19. Vabø, R., and Nøttestad L. Individual based model of fish schooling reactions: Prediction of antipredator behavior as observed in nature. Fisheries Oceanography 6:3, 155-171, 1997.