Proceedings of the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR2014), 28 April – 02 May 2014, Stornoway, Isle of Lewis, Outer Hebrides, Scotland. *www.eimr.org*

EIMR2014-943

STICKING TOGETHER: MOVEMENT OF MARINE MAMMALS AND RESPONSE TO UNDERWATER NOISE

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Abstract

Marine mammals use vocalisations for a number of purposes: in locating food and underwater obstacles, and to maintain contact with members of their family group. These sounds are loud in comparison with the ambient background, but are subject to masking due to underwater noise sources such as tidal turbines.

We developed a model of animal movement which implements simple behavioural rules to allow group cohesion. We discuss some general features of group behaviour, and approaches to validation of the model using empirical data. Including external sources of noise can lead to loss of contact between group members. However, animals can take various measures to deal with these effects, such as more frequent vocalisation or "panic" swimming in response to sounds.

Introduction

Marine mammals (and in particular, odontocete cetaceans) use sound to navigate, find prey, and communicate with con-specifics. The use of sound as a means of navigating and communicating underwater has many advantages over other sensory modalities, in particular the ability to operate in low visibility, and the ability to sense surroundings and communicate over a scale of several hundred metres to kilometres (Janik, 2000). However, dependence on sound means that marine mammals face particular challenges when confronted with human activities and infrastructure (such as boats, tidal turbines and so on), much of which either alters the ambient noise environment, or emits noise itself. Properties of the sound itself (level and frequency range) and the local conditions (water depth, salinity, bed type and so on) affect the potential magnitude of these effects (Nowacek, Thorne, Johnston, & Tyack, 2007).

The group dynamics of different marine mammals varies by species, from large groups that associate together (e.g. oceanic dolphins), to those operating alone or in smaller groups that occasionally coalesce or split to form new groups (e.g. harbour porpoise, bottlenose dolphin). This partly reflects the nature of the environment which they primarily inhabit, and their specific life history traits. Study of the group dynamics of animals is a challenging topic. The challenges associated with predicting the movements of other species (such as insects or birds) have led to the development of computer models of flocking (Reynolds, 1987) . Using this approach, it has been found that familiar group dynamics observed in nature emerge naturally from simple individual behaviours (Wood & Ackland, 2007).

We used such a model to study the dynamics of groups of marine mammals that communicate with one another by emitting (and responding to) sounds. Sensitivity analysis of biological assumptions and parameters allows the robustness of our predictions to be verified, and provides direction for future empirical studies. We then used the model to investigate the potential impacts of underwater noise on group cohesion (including behavioural approaches to mitigation of its effects), focussing on small groups and parent/calf pairing. Our findings have clear implications for the management of sources of marine noise (vessel movements, engineering operations and tidal turbine operation) in areas used regularly by marine mammals.

Methodology

The model underlying this study essentially defines individual animals with three fundamental behaviours. Firstly, they swim at a fixed speed v ms^{-1}.

Secondly, they randomly emit vocalisations ("whistles") at a fixed level L dB, each lasting α s, at a fixed rate r $minute^{-1}$. For transmission loss (in dB) of sound over distance is we follow the formulation of David (2006): $TL=10*\log(R) + 0.036*R*f^{1.5}$, where R is distance from source, and f is the sound's frequency.

Finally, with probability β, model animals orient themselves according to the whistles made by other animals in their group, and their separation d from them. In order of precedence, they orient themselves away from very short range whistles ($d<d_1$; collision avoidance), align themselves with movement of mid-distance whistles ($d_1<d<d_2$), and towards distant (quiet) whistles ($d>d_2$). Ability to align in response to medium range sounds assumes visual contact with neighbours, or that their direction of travel can be identified audibly. These orientation responses are summarised in Figure 1. In the absence of audible cues, model animals make small random changes to their direction of travel, with their new orientation being selected from $U(-\theta, \theta)$.

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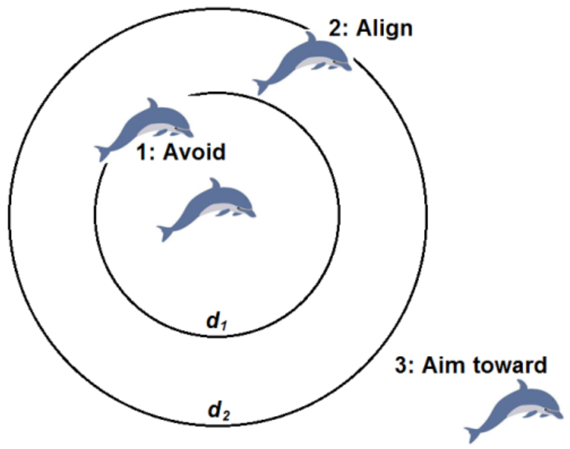

Figure 1: Orientation responses of a focal individual animal (centre of bullseye) to neighbours. In order of precedence, close neighbours are avoided, mid-range aligned with, and distant aimed towards. This means that individuals in a group avoid collisions, swim in a coherent direction, and maintain a group.

The model has a time step of *dt*=1s. At each time step, each animal has an opportunity to emit a whistle. Each animal then responds to the closest whistle that is being emitted, by altering its orientation. Finally, each animal moves *v*dt* m in its direction of orientation. The simulated time is 3600 time steps (1 hour). We ran simulations using two different group sizes: i) 2 animals (based on a parent and calf), and ii) 10 animals, based on a school of bottlenose dolphins. For all simulations, our principal metric of group cohesion was inter-individual distance.

Parameter	Symbol	Value	Units	Range
Swim speed	v	2	ms^{-1}	1-8
Turning angle	θ	π/16	radians	0-π/2
Avoidance radius	d_1	2	m	0.5-8
Alignment radius	d_2	4	m	1-20
Whistle level	L	150	dB	125-173
Ambient noise	L_{BG}	40	dB	---
Whistle rate	r	0.1	s^{-1}	0.01-0.5
Whistle duration	α	1	s	1-5
Whistle response	β	0.5	---	0.1-1
Group size	N	2, 10	indivs.	---

Table 1: Model parameters used in baseline simulations ("Value") and sensitivity analyses ("Range") (Bearzi, 2005; David, 2006; Fish, 1993; Janik, 2000; Quick & Janik, 2008).

Sensitivity analysis

We assessed sensitivity of basic model behaviour to the parameters with an additional range identified in Table 1. This enables robustness of the model to be tested with respect to the parameters.

Response to sound and environmental scenarios

We investigated the impacts of external sources of underwater noise on group dynamics, focussing on two contrasting scenarios. A first scenario is presented by two animals (for example a mother and calf travelling together) swimming through a tidal channel containing a number of tidal turbines (Figure 2; water velocity $2ms^{-1}$ left to right). The sound output of such devices is not well studied, so we tested individual device levels in the range 130-170dB, with configurations of 1, 3 and 6 turbines. A second scenario was a larger array of tidal devices situated in open water. We assessed the performance of both the mother-calf pair and the 10 animal group in this scenario.

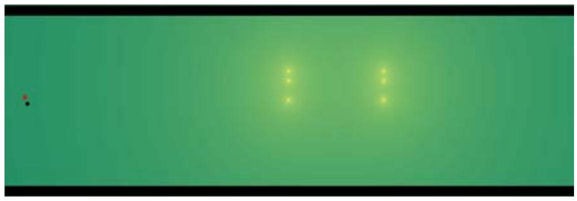

Figure 2: Turbine layout for tidal channel scenario. Background colour indicates device/ambient sound level. The points at the left are the start locations of the two animals.

We investigated ways in which groups of animals might overcome the effects of background noise in order to remain close together. This was investigated by considering changes in behaviour: i) change in whistle rate; ii) adoption of a faster swimming speed upon entering area with high ambient sound level; iii) increasing their random turning angle in the absence of being able to hear a neighbour; iv) reduction of critical radii for orientation behaviours.

Results

Model behaviour is most sensitive to the swim speed *v* and whistle rate *r* and rather insensitive to response radii or random turning angle (not shown). For brevity, we focus here on noise response and impact mitigation results for the scenario of two animals swimming in a tidal channel. For additional results please see the poster presented at EIMR 2014, or Adams et al. (in preparation).

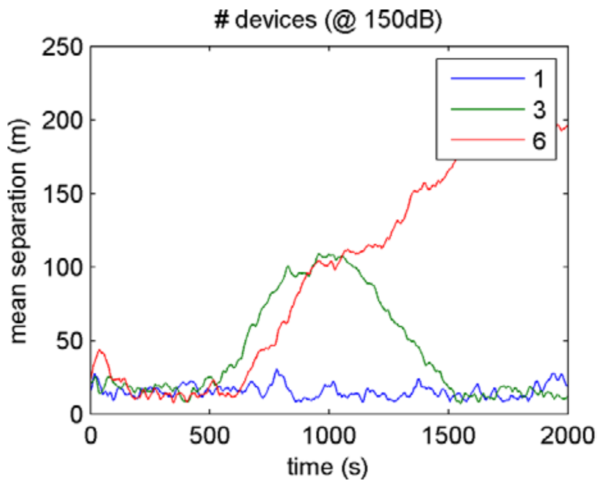

Figure 3: Mean separation of two animals swimming in a tidal channel, past 1, 3 or 6 devices each emitting either 150dB in the band of communicative whistles.

Figure 3 shows the mean separation of two animals swimming in 1km wide tidal channels, containing different numbers of devices, each emitting a fixed sound level occupying the band used for communicative whistles. With larger numbers of sound sources (or at individually higher sound levels), animals' inability to communicate in the region close to the turbines is predicted to lead to their separation, either temporarily (3 x 150dB) or permanently (more extreme cases, not shown), once animals enter a region in which device sounds mask whistles.

By changing their behaviour, animals can potentially modify the impact of sound upon their group dynamics. Figure 4 shows mean separation over the latter half of simulations in the case of 3 x 150dB sound sources. By increasing their whistle rate, or by responding to whistles more frequently, model animals are predicted to maintain acceptable separation distances. However, where source sound levels are higher it becomes more difficult to stay close together (not shown).

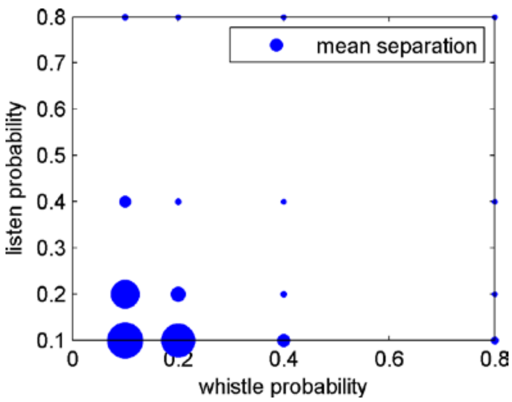

Figure 4: Impact of altering whistle rate (horizontal axis) or response probability (vertical axis) on mean separation distance between two animals swimming in a channel containing 3 x 150dB sound sources.

Another manner in which modelled animals could reduce their separation distance was by swimming quickly in the presence of loud sounds (not shown here).

Discussion

Our results have several particular implications. Firstly, sensitivity analyses in the "no-turbine" model suggest that certain parameters in the model have greater impact on its results than others, in turn suggesting that particular behavioural attributes warrant more pressing investigation. Namely, individual swimming speed and vocalisation responses to noise and other stressors might be considered the most important avenue for future empirical studies.

Secondly, sufficiently loud (or many) sources of local underwater noise clearly have the potential to disrupt communication and movement of marine animals. In extreme cases (i.e. several neighbouring turbines operating at high output) this was predicted to lead to permanent separation of animals, with clear implications for the survival chances of juveniles, or for group coordination during feeding activities. A key factor affecting this result is the sound output of devices in the critical frequency bands used for communicative whistles; authoritative information on which is rather difficult to obtain at this point in time.

Finally, the behavioural changes that allow animals to improve their chances for remaining close to one another in these simulations (increased whistling, faster swimming, etc) are similar to some of those observed in real situations where there is elevated background noise. This suggests that, to a certain degree, animals are able to adapt to new situations. However, studies such as ours could provide useful guidance as to the times when they cannot.

Acknowledgements

This work was carried out as part of the NERC funded Optimising Array Form for Energy Extraction & Environmental Benefit (EBAO) project.

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