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RESPONSES OF FREE-LIVING COASTAL PELAGIC FISH TO IMPULSIVE SOUNDS

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ABSTRACT

There are substantial gaps in our understanding of the effects of sounds upon fish. This paper describes experiments on the behaviour of wild, pelagic fish in response to sound playback, observed by means of sonar. Fish, including sprat *Sprattus sprattus* and mackerel *Scomber scombrus* were examined at a sheltered and quiet coastal location. Short bursts of repeated impulsive sounds were presented at different sound pressure levels, simulating the strikes from a pile driver. Behavioural responses included the break up of fish schools and changes in depth. The incidence of responses increased with increasing sound levels. The levels of sound to which the fish schools responded on 50% of presentations were estimated from dose response curves, in terms of the received sound pressure level and the single strike sound exposure level. Observations by means of sonar are especially valuable for examining the behavior of unrestrained fish exposed to different sound sources. The technique allows testing of the relationship between responsiveness, sound level, and sound characteristics for different types of man-made sound. It is only by examining the responses of wild fish to sound, under natural conditions, that we can fully understand how marine renewable energy and other marine or coastal developments might interact with natural populations of fish.

INTRODUCTION

There is increasing concern over the impact of man-made noise from marine renewable energy developments upon fishes [1, 2, 3]. Attention is currently strongly focussed on effects on fish behaviour – which can occur at considerable distances from sound generating activities.

There are substantial gaps in our understanding of the effects of sounds upon the behaviour of wild, free-living fish. Much of our information comes from "grey literature" reports that lack detail on experimental design and controls. Most studies have been carried out in aquarium tanks or sea pens, where the acoustical conditions are often inappropriate and the captive fish have become accustomed to sound exposure. There are almost no observations upon the behaviour of wild, free-living fish exposed to man-made sounds.

This paper describes experiments on the behaviour of wild, pelagic fish in response to sound playback. Fish, including sprat, *Sprattus sprattus,* and Atlantic mackerel, *Scomber scombrus,* were examined at a sheltered and quiet coastal location. Using made-to-order sound projectors, fish were exposed to short bursts of repeated impulsive sounds, simulating the strikes from a pile driver. The sounds were presented at different sound pressure levels. The behaviour of the fish was observed by means of sonar.

METHODS

A simple and practical procedure was adopted for the experiments. The behaviour of fish was observed by means of a sonar system (Humminbird 998c SI) deployed from a surface vessel. The sonar was able to detect fish directly beneath and on either side of the vessel and incorporated a geographic positioning system (GPS) with navigational capabilities. Data from the echo sounder and side-scan sonar were recorded on an internal SD card for analysis. The vessel was allowed to drift through areas where fish were present, with the outboard motor switched off. GPS coordinates of the track were saved and later exported to Google Earth. Echograms, displayed on the echo sounder and side-scan sonar, were recorded continuously.

Sounds were presented from an array of four underwater sound projectors (Subacoustech Type HPX15-100). The projectors were connected to a 2400 W car amplifier into which a signal was fed from a sound recorder. Each presented sound consisted of a sequence of identical low frequency pulses, repeated at regular intervals. The sound pulses had the same spectral and temporal characteristics as impulsive sounds from impact pile driving and showed a rapid onset followed by an exponential decline. Ten 'strikes' were present in each sound sequence, with a gap of 2 seconds between strikes. The maximum source level depended on the depth of the sound projectors and the water depth and was estimated to be in the region of 185 dB re: 1µPa peak to peak at 1m. Playbacks of 'silent' sound sequences (referred to as control trials) were randomly interspersed with sound exposure trials.

Sound level measurements were made by means of a calibrated hydrophone. The signal from the hydrophone was amplified, digitised using a data

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acquisition device at a sample rate of 350,000 samples per second, and stored on a laptop computer. Following sound presentations the sound pressure levels (SPLs) were measured for each level of sound playback, at different depths and hence distances from the sound projectors, measured over a bandwidth of 15Hz to 100kHz. Measurements were made as peak-to-peak sound pressure levels (expressed as dB re: 1µPa), and as Sound Exposure Levels (SEL), the time integral of the sound pressure squared, for a single pulse (expressed as dB re: $1\mu Pa^2{\cdot}s$).

RESULTS

Two experienced observers scored possible responses on the echograms (including control trials). A response was defined as a sudden change in depth, or density of a target, or movement out of the sonar beam (cut-off) occurring during the trial (Figure 1). A density change was observed as a change of the echo strength indicated by the brightness and colour on the echogram, a depth change was defined as the top of the target changing in depth. A sharp cut off to the target indicated a dispersal of individual reflectors, which often re-appeared as a combined target at a different depth shortly afterwards. Each response was described and later tabulated against the received sound level for different target categories.

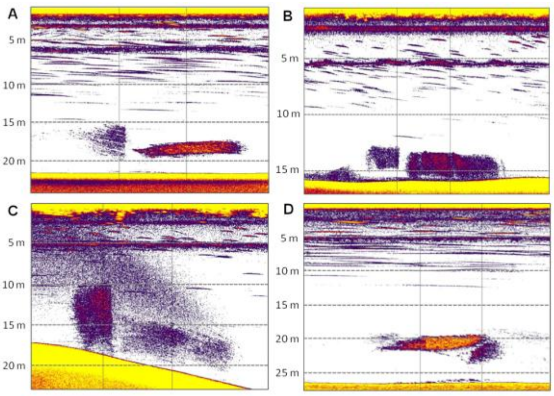

Figure 1 Responses of sprat schools to sound exposure. A: Small school, cut off abruptly after the beginning of the sound. B: Medium sized school cut off at the onset of the sound. C: Large sprat school cut off at the onset of the sound. D: Small sprat school increasing in density in response to sound exposure. A vertical line indicates the beginning and end of each sound sequence.

Different types of targets were observed and the data were split into target categories for analysis. Diffuse layers of very small reflectors (type A) consisted of zooplankton, including calanoid copepods, cladocerans, decapod larvae, gastropod larvae and bivalve larvae. Aggregations of small targets of varying density (Type B) were identified as schools of sprat. Less dense aggregations of large targets (Type C) were shown by rod and line fishing to be mackerel, with the occasional presence of other predatory fishes. Individual reflectors (Type D) were observed at a range of depths during daytime and were thought to be comb jellies (ctenophores). Other small individual reflectors, examined at night, were derived from the breakdown of Type B schools and were predominantly sprat, although some individual mackerel and other species may also have been present.

Only 8 "responses" were recorded from 99 control trials with no sound playback. Five of these responses were by type 'C' aggregations of mackerel, which changed depth quite often, even in the absence of sound playback. Zooplankton layers (A) responded to sound by showing a 'dent' in the top of the layer at the onset of the sound sequence, although the change often did not persist for the whole duration of the presentation. Sprat schools (B), most commonly responded to sound exposure with a complete cut-off of the acoustic target, resulting from lateral dispersal of the fish, taking them outside the sonar beam. The fish often then reappeared at a greater depth recombined into a school. In some cases there were also changes in the density of the fish school. Mackerel (C) responded by a complete cut off, a density change or a depth change.

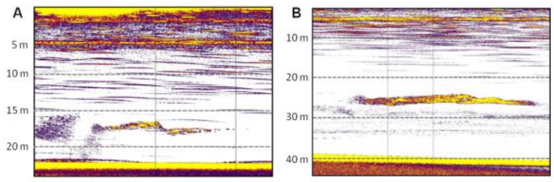

Figure 2 Responses of mackerel schools to sound exposure. A: Mackerel school diving in response to sound. B: Mackerel school exhibiting a change in density in response to sound.

The incidence of responses by the fish schools (B & C) increased with increasing sound levels. Dose response curves were prepared to estimate the levels of sound to which the fish schools responded on 50% of presentations, expressed in terms of the received sound pressure level and the single strike sound exposure level. The received sound pressure levels associated with these 50% response rates are shown in Table 1 for sprat and mackerel.

Table 1. 50% response levels for sprat and mackerel

Species	Measure	50 % Response Level
Sprat	Peak to peak sound pressure level (dB re: 1 µPa)	163.2 dB
Sprat	Single strike sound exposure level (dB re: 1 $\mu Pa^2{\cdot}s$)	135.0 dB
Mackerel	Peak to peak sound pressure level (dB re: 1 µPa)	163.3 dB
Mackerel	Single strike sound exposure level (dB re: 1 $\mu Pa^2{\cdot}s$)	142.0 dB

CONCLUSIONS

Observing wild fish by means of sonar is especially useful for examining the behavior of unrestrained fish exposed to different sound sources. The use of sonar for such playback experiments allows testing of the relationship between responsiveness, sound level, and sound characteristics for different types of man-made sound. There is now an urgent need to extend the present observations to other species of fish. It is only by examining the responses of wild fish to sound, under natural conditions, that we can fully understand how man-made noise affects natural populations of fish.

The experiments reported here were carried out in an enclosed area where the use of powered vessels was restricted. Care was also taken to avoid exposing the same schools to repeated stimulation by moving the vessel to a new position once a drift path had been completed. Neither the sprat schools nor the mackerel schools showed any evidence of a reduction in responsiveness with time. There is the possibility, however, that habituation might occur if the same school of fish was subjected to repeated stimulation.

The sprat, like its close relative the Atlantic herring, *Clupea harengus*, is thought to be especially sensitive to sounds by virtue of its specialized auditory system [4]. In contrast, the mackerel lacks a swim bladder (that in many fishes serves as an accessory hearing organ), and there is evidence that the mackerel is much less sensitive to sounds [5]. Remarkably, despite these differences in their hearing abilities the sprat and mackerel responded to similar sound levels in the playback experiments. Although mackerel may not hear as well as sprat they may be more ready to respond to any stimulus – they are perhaps more “flighty” than sprat. It is also interesting that aggregations of zooplankton responded to similar sound levels, although they showed only limited short-lived changes in depth.

In this paper data have been presented on the levels of impulsive sound to which sprat and mackerel respond. However, these data cannot yet be used to define sound exposure criteria for use in environmental impact assessments. More detailed studies of the behavior of these species are required to establish whether the responses observed are likely to result in adverse effects upon fish populations. Examination of the effects of repeated exposure of the same fish to sound is also important, as the response may wane with time.

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