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Use of baited remote underwater video (BRUV) and motion analysis for studying the impacts of underwater noise upon free ranging fish and implications for marine energy management

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ABSTRACT

Free-ranging individual fish were observed using a baited remote underwater video (BRUV) system during sound playback experiments. This paper reports on test trials exploring BRUV design parameters, image analysis and practical experimental designs. Three marine species were exposed to playback noise, provided as examples of behavioural responses to impulsive sound at 163–171 dB re 1 μPa (peak-to-peak SPL) and continuous sound of 142.7 dB re 1 μPa (RMS, SPL), exhibiting directional changes and accelerations. The methods described here indicate the efficacy of BRUV to examine behaviour of free-ranging species to noise playback, rather than using confinement. Given the increasing concern about the effects of water-borne noise, for example its inclusion within the EU Marine Strategy Framework Directive, and the lack of empirical evidence in setting thresholds, this paper discusses the use of BRUV, and short term behavioural changes, in supporting population level marine noise management.

1. Introduction

The use of seabed video systems, or, remote underwater video (RUV), baited remote underwater video (BRUV) has increased notably within the last decade (e.g. Mallet and Pelletier, 2014), due to the refinement of technology leading to a reduction in camera and video processing costs. Camera systems are typically non-destructive observation methods, used in a range of habitats and depths, provide permanent records, give potential for high replication and reduce the staff and field time required for experiments (Ellis and DeMartini, 1995; Mallet and Pelletier, 2014; Shortis et al., 2007). By using two cameras which have an overlapping field of view (stereoscopic), a perception of depth can be obtained allowing the 3D co-ordinates of a subject to be calculated, making observations particularly useful for behavioural studies (first described by Harvey and Shortis, 1995).

Stereo systems have been implemented widely, for example, from estimating abundance, assemblage composition, richness and individual fish identification (Griffin et al., 2016; Langlois et al., 2010; Unsworth et al., 2014; Watson et al., 2005; Wraith et al., 2013). These have been used in a range of depths from shallow water (Unsworth et al., 2014) and natural/artificial reefs (Kemp et al., 2008; White et al., 2013; Wraith et al., 2013) to the deep sea (Cousins et al., 2013; Priede et al., 2006). Within these, bait is commonly used to attract organisms into the field of view (King et al., 2007; Stobart et al., 2007) and it is widely accepted that bait type has a significant effect on the fish assemblage attracted (Harvey et al., 2007; Løkkeborg and Bjordal, 1992; Watson et al., 2005; Wraith et al., 2013). However despite BRUV being widely used, Mallet and Pelletier (2014) found only six studies (at depths < 100 m) that used these methods to investigate the effect of human disturbance upon behaviour, and of these only one was an acoustic study (Picciulin et al., 2010). Yet there is a need to describe the behavioural responses of fish exposed to noise on both a school and an individual level (Hawkins et al., 2012).

To process video data, motion analysis software has been used increasingly for quantifying locomotory changes in animal behaviours, for example for monitoring prey-predator interactions and schooling behaviour (Kawaguchi et al., 2010; Pohlmann et al., 2001). Depending on the experimental setup, video footage available and the parameters to be calculated, programs that can track animal movement range from frame-by-frame (Abràmoff et al., 2004) to more sophisticated automatic 3D tracking programs (discussed later). Although swimming changes have been quantified for a few fish species (Domenici et al., 2004; Fuiman et al., 2010; LeFrancois et al., 2009; Weber, 2006), such software has not been used to analyse responses to sound stimuli in field conditions. Swimming parameters obtained from motion analysis

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of free swimming fish can be translated into metrics (such as percent response, response latency, angular velocity, etc.), which could be compared across noise levels and signatures.

Typical immediate behavioural responses by fishes in tanks to underwater noise stimuli include startle responses, increased speed and positional changes in the water column (Blaxter and Hoss, 1981; Engås et al., 1995; Kastelein et al., 2008). This includes the involuntary flexion of the body resulting in a rapid change of direction and speed, the 'C start' response (Blaxter and Hoss, 1981; Zottoli, 1977). Another behaviour commonly exhibited is 'milling', an increased swimming speed with random turns (Blaxter and Hoss, 1981). However, the behaviour of captured (or hatchery reared) individuals within tanks cannot be assumed to accurately reflect wild behaviour, e.g. Benhaïma et al. (2012). Confinement in tanks is likely to induce stress, and behavioural changes such as circling the tank (Kastelein et al. (2008). The solution is to film animals in the wild, but this presents logistical challenges regarding monitoring the behaviour of highly mobile species to calibrated stimuli; For this reason, many field-based studies have used cages, nets or pens (Engås et al., 1998; Engås et al., 1995; Fernandes et al., 2000; Fewtrell and McCauley, 2012; Sara et al., 2007; Schwarz and Greer, 1984). For example, during exposure to low frequency sonar (Popper et al., 2007), vibro pile-driving (Nedwell et al., 2003) and airgun arrays (Engås et al., 1996; Hassel et al., 2004; Pearson et al., 1992) key responses exhibited in such confined conditions are directional avoidance, increased speed, and variation of group density (Engås et al., 1995; Fewtrell and McCauley, 2012; Sara et al., 2007; Schwarz and Greer, 1984), varying with acoustic and environmental context. One less restrictive method is to film animals with distinct territories or nests naturally occupied during the noise exposure, eliminating the need for confinement (Picciulin et al., 2010). Another potential solution is to use an attractant to lure fish to cameras. It is of note that in many cases the presence of a camera lander is enough to warrant the attention of 'curious' fish.

Whilst behaviours observed on camera may be short lived, these may have knock-on implications for feeding, migration, reproduction and even interrupt predator-prey interactions (Chan et al., 2010; Hawkins et al., 2014b; Simpson et al., 2014). For example, the time budgets of two reef fish have been shown to be altered in response to boat noise, with time for nest caring reduced (Picciulin et al., 2010), and mussels have been shown to close the valve in response to sediment vibration which directly reduces time spent filter feeding (Roberts et al., 2015). The extent to which noise affects migratory patterns, feeding, reproduction, communication, predator-prey interactions and navigation is relatively unknown (Hawkins et al., 2014a), leading to difficulties setting noise exposure criteria for fish species and anthropogenic sources (DEFRA, 2014; Popper et al., 2014).

It is not always possible to undertake experiments near actual anthropogenic sources. Permissions are required, there are strict experimental limitations, sound regimes are unpredictable, and experiments would need to be fitted around construction timings. Playbacks of actual recorded signatures, or synthetic versions, can overcome this problem, allowing the exposure source to be fully controlled. In laboratory tanks it is difficult to play back calibrated sound stimuli accurately due to the presence of boundaries and the creation of standing waves of differing frequencies (Parvulescu, 1964a, 1964b; Rogers, 2015), as such field experiments in the acoustic free field have strong advantages over laboratory studies.

The current study aimed to investigate the behaviour of wild, unrestrained individual fish in response to playback of calibrated noise signatures. We tested the practical use of underwater cameras fitted on a purpose-built camera frame to document live behavioural responses of fishes during control exposure experiments (CEE). The combined field approach, including the deployment of a calibrated purpose-built underwater sound projector array and other technical aspects such as working in natural marine habitats with variable environmental conditions, motion analysis tracking and the use of purpose-built projector array for example, made the current work both a challenge and innovative. With this in mind the emphasis is on the techniques and methodologies employed by the work, rather than quantitative outputs.

2. Methods

A purpose-built projector array was used, consisting of four speakers as a unit, connected to an InPhase IPX2400 amplifier (2400 W) into which a signal was fed via a Tascam model DR05 sound recorder or IBM Thinkpad laptop computer (details in Hawkins et al. (2014b); Roberts (2015). The array produced source levels in the region of 186.0 dB re 1 μPa @ 1 m. Two playback signatures were used (20 s, 6 amplitudes −6 dB steps), of recorded shipping and a synthetic impulsive sound. The ship noise consisted of a twenty second recording of a large container ship, as captured by Subacoustech Ltd. during routine noise monitoring. The synthetic pile-driving stimulus consisted of 10 sharp-onset low frequency pulses, two seconds apart, constructed from white noise (50–600 Hz) to mimic spectral characteristics of pile-driving. It is of note that particle velocity (dB re 1 m s^{-1}) was not measured, but the particle velocity capabilities of the projector array are provided in Hawkins et al. (2014b), as derived from sound pressure measurements. To avoid pseudoreplication, for example when an insufficient number of recordings are used to test for a certain response (McGregor, 1992), six versions of the sound were used. Each was created with the same characteristics (i.e. onset time and filtered frequency ranges) but with a different white noise used in each case. Overall the sounds were an accurate representation of pile-driving and shipping noise in the acoustic far field, with predominant energy in the 50–600 Hz band (Supplemental material).

Recordings of 'silence' were randomly interspersed to ensure that equipment alone did not influence subjects (that is, that activation of the playback system itself did not elicit responses without added noise) referred to as control trials. Received sound levels were recorded at the camera frame using a purpose-built subsea recording pod (Subacoustech prototype 1/2) consisting of a steel pressure housing containing a miniature battery-powered amplifier and a digital recorder (Roland R-09HR or Tascam model DR05) connected to an external calibrated hydrophone (Brüel & Kjær 8105, −205 dB re 1 V/μPa ± 2 dB, 0.1 Hz–100 kHz). For synchronization of playback noise with the video footage, an additional Aquarian Audio H2a hydrophone (uncalibrated, sensitivity −180 dB re 1 V/μPa, 10 Hz–100 kHz) was connected to the video recorders on the camera frame to alert the viewer to the playback during video analysis.

A BRUV system, purpose-built to work in changeable coastal conditions (low light levels, strong currents and unpredictable deployment conditions) consisted of a large steel frame (approximately 2 m × 1 m × 1 m) of a similar design as Langlois et al. (2010) and Cappo et al. (2007), (Fig. 1). The first BRUV system had a subsea housing with two cameras and video recorders (Mini DVR III HDVR720) and necessary power supplies, allowing the unit to record audio and video signals unattended for approximately 8 h. An Internet Protocol (IP) camera was used to relay real-time footage via a wireless local network to the observer controlling the playback system (the access point was from a water-resistant housing mounted on a surface buoy, Fig. 2). Real-time observations were necessary to ensure presence of fish prior, during and after exposure. However since deployments were shore based, or to a small vessel close by, the system was then simplified to remove the subsea housing and connect the frame to the surface video recorders via an armoured umbilical cable to provide power and to export the footage. An observer could therefore use the IP camera image or video recorders for live observations of the BRUV for extended periods of time (i.e. not limited by the duration of the batteries or distance to the access points that provide the wireless link used in the first prototype).

Dropdown (rapid deployment) inspection cameras were used prior to deployment to ascertain whether visibility and bottom conditions were suitable. The position of the BRUV was adjusted until the field of