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Behavioural responses of draughtboard sharks (*Cephaloscyllium laticeps*) to rare earth magnets: Implications for shark bycatch management within the Tasmanian southern rock lobster fishery

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ABSTRACT

Catches of draughtboard shark (*Cephaloscyllium laticeps*) in the Tasmanian Southern Rock Lobster Fishery are considered an economic and potentially ecological issue. Consequently, there is interest in developing strategies to mitigate and minimise shark bycatch within this fishery. This field study examined the behavioural responses of draughtboard sharks to neodymium-iron-boron ($Nd_2Fe_{14}B$) rare earth magnetic rods attached to baited video apparatus. Two magnetic treatments and one control were used in 12 × 1.5 h observational trials conducted in inshore waters of Tasmania, Australia. Results demonstrate that draughtboard sharks: (1) showed substantial individual variation in behaviours both between and within treatments, with no patterns of individual responses observed over time to both magnetic treatments or the control, (2) showed significant differences in initial interactions between the magnetic treatments and the control, and (3) attempted to take bait at the control significantly more often than at the 2-magnet treatment. These findings demonstrate the individualistic and highly variable response behaviours of draughtboard sharks to rare earth magnets. Understanding such behaviours may facilitate the development of effective deterrent strategies in this fishery and improve management of shark-fishery interactions globally.

1. Introduction

For over 400 million years, sharks and other chondrichthyans (cartilaginous fishes) have functioned successfully in diverse marine ecosystems (Camhi et al., 2007; Shäfer et al., 2012). Yet despite their evolutionary success, they are extremely vulnerable to, and threatened by, fishery interactions (Camhi et al., 2007; Hutchinson et al., 2012; Molina and Cook, 2012) including by directed shark fisheries, the shark fin trade, and as bycatch in multiple commercial gear types (Camhi et al., 2007; Hutchinson et al., 2012). Of these, bycatch has been recognised as the greatest threat to elasmobranch survival as well as a major nature conservation issue faced globally (Davies et al., 2009; Rigg et al., 2009). Historical data from coastal marine environments suggest the loss of large predatory fishes prompts dramatic changes in ecosystem structure and function (Jackson et al., 2001; Myers and Worm, 2003) due to their important ecological roles (Stevens et al., 2000). The direct effect of fishing operations on individual shark species can result in alterations in abundance, size structure, and life history parameters, causing biodiversity and population declines (Gilman et al., 2008; Hall et al., 2000). In addition to the resulting ecological effects, bycatch can have severe negative financial implications for commercial fisheries (Gilman et al., 2008) by reducing profitability though competition between target and non-target species for bait, reducing capture of marketable species, depredation of target species, and time and monetary losses resulting from increased handling times and gear replacement/repair (Gilman et al., 2008; Jordan et al., 2011; Kaimmer and Stoner, 2008).

Over the last two decades, various methods have been investigated to minimise line and net-based shark capture including the use of monofilament leaders (Stone and Dixon, 2001; Ward et al., 2008), hook design (Afonso et al., 2011; Kerstetter and Graves, 2006; Yokota et al., 2006), bait type (Ward and Hindmarsh, 2007), and modifications to fishing operations (Carruthers et al., 2011; Gilman et al., 2008; Kumar et al., 2015). However, due to the general consideration of pots as a target species-selective method, bycatch within commercial pot fisheries has received little attention (Brock et al., 2007; Frusher and Gibson, 1998).

The use of magnets and electromagnetic devices such as permanent magnets and rare earth metals have been examined as potential shark deterrent stimuli (O'Connell et al., 2011a; Robbins et al., 2011; Smith

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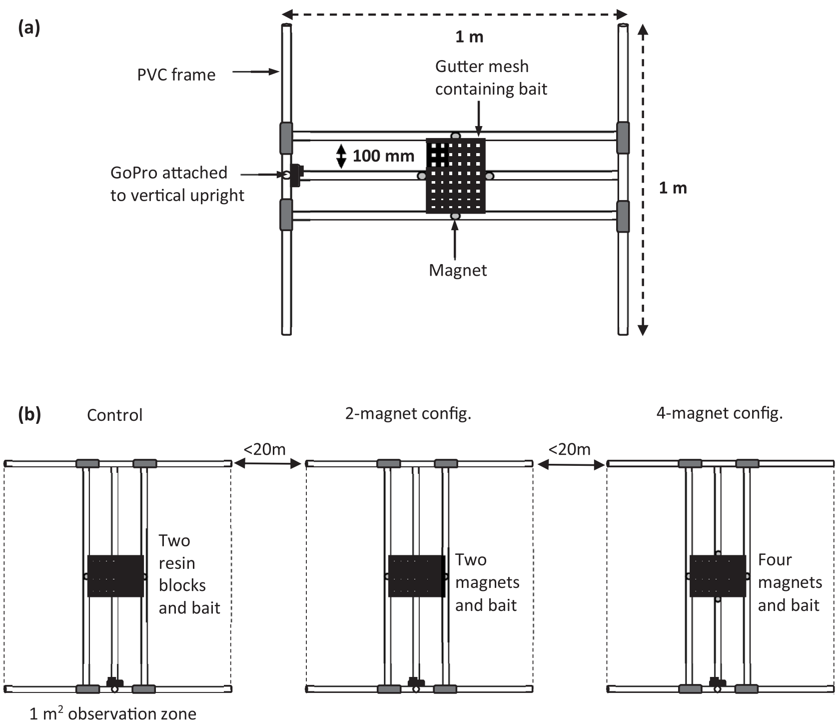

Fig. 1. Overhead view illustrating (a) key BRUV components and position of resin blocks/magnets (4-magnet configuration shown), and (b) observational trial arrangement. Dashed lines: observation zone within which behaviours were recorded and characterised.

and O'Connell, 2014), aimed to reduce elasmobranch bycatch without affecting targeted catch. Although the mechanism for detecting permanent and rare earth magnets has not yet been confirmed, the electrosensory system is likely to mediate magnetic field detection indirectly via induction of electric fields. These are detected by electroreception, a highly specialised sensory modality of elasmobranchs that allows detection of small electric signals and bioelectric potentials within the environment (Haine et al., 2001; Kalmijn, 1971; Jordan et al., 2011). The electrosensory system consists of a series of electroreceptors called the ampullae of Lorenzini (Kalmijn, 1971) that are used to detect electric field fluctuations of as little as 1 nV/cm (Kalmijn, 1971; Jordan et al., 2011). Electroreception is multifunctional, facilitating detection of prey and predators (Kalmijn, 1966; Kalmijn and Weinger, 1981; Kempster et al., 2012; Tricas, 1982), conspecific recognition (Tricas et al., 1995), and navigation and orientation (Kalmijn, 1982; Montgomery and Walker, 2001). Magnets and rare earth metals are thought to indirectly act on the electrosensory system of interacting elasmobranchs through electromagnetic induction, causing aversion or avoidance responses (Kaimmer and Stoner, 2008; O'Connell et al., 2014; Rigg et al., 2009). However, previous studies have demonstrated highly inconsistent results among species, highlighting species-specific responses. Furthermore, to our knowledge, there is a lack of published literature investigating the specific responses of individual sharks to magnets, to explain why individuals of the same species elicit different behavioural responses, and the implications that may have for the development of bycatch mitigation strategies.

Within Australia, the Tasmanian Southern Rock Lobster Fishery (TSRLF) is a major state industry, providing significant economic benefits within the commercial sector (DPIPWE, 2014). Targeting the southern rock lobster (*Jasus edwardsii*), the TSRLF inadvertently has a large elasmobranch bycatch. The draughtboard shark (*Cephaloscyllium laticeps*) comprises the third largest component of this, with an estimated total annual catch of 544,000 individuals for 2011/12 (Hartmann et al., 2013), equating to an estimated total economic loss of over AUD$12.2 million per year. Consequently, the development of strategies to mitigate and minimise draughtboard shark bycatch within the TSRLF is vital for the sustainability of shark populations, ecosystem structure and function, and fisheries management within Tasmania.

This study investigated the behavioural responses of individual wild draughtboard sharks (the main elasmobranch bycatch species of the TSRLF) to neodymium-iron-boron ($Nd_2Fe_{14}B$) rare earth magnets. Preliminary experiments by O'Connell et al. (2010) suggested that when elasmobranchs were exposed to a single magnetic lobe flux (magnetic field), approaching elasmobranchs would often accelerate through the field, while duel magnetic flux lobes would result in elasmobranchs slowing and turning before reaching the second lobe. As such, this study also examined the efficiency, configuration and feasibility of this magnet type as a possible shark-specific bycatch reduction method within commercial potting operations.

2. Materials and methods

2.1. Study area

This study was conducted in shallow inshore waters around Clarke Island, Cape Barren Island, Eddystone Point, and Maria Island, Tasmania, Australia. These areas were chosen due to known high densities of draughtboard shark (Lambert, pers. comm. 25 August 2014) and accessibility to the Australian Maritime College training vessel *Bluefin*. Study sites consisted of multiple substrate types and ranged in depth from 4.5 to 8 m. Experimental trials took place during daylight hours over 20 days between August and December 2014. All research adhered to Australian scientific animal care guidelines (National Health and Medical Research Council, 2013) and was approved by the University of Tasmania Animal Ethics Committee (Project A14282).

2.2. Apparatus and field design

Three polyvinyl chloride (PVC 25 mm diameter) baited remote underwater video (BRUV) apparatus, producing a 1 m^2 observation zone (Fig. 1a), were deployed during each trial: one control fitted with non-magnetic resin blocks, and two magnetic treatments containing