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Protected areas preserve natural behaviour of a targeted fish species on coral reefs

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ABSTRACT

Marine protected areas are increasingly being implemented to attain a variety of conservation and fisheries management objectives. Although rarely considered, protection of targeted species within these areas may also conserve behaviours (e.g. boldness) that are often the first removed by human exploitation. Here we examine fish behaviour in fished, no-take, and no-entry management zones for a highly targeted reef fish species (coral trout; *Plectropomus leopardus*) on coral reefs in two regions of the Great Barrier Reef Marine Park, Australia. Using three behavioural metrics (flight-initiation distance, pre-flight behaviour, and escape trajectories), we demonstrate how protected areas, particularly no-entry zones, can effectively conserve naïve or bold behavioural traits in fish populations. Flight-initiation distance was consistently highest in fished zones, but the effects of protection afforded by no-take and no-entry zones varied by study region. Flight-initiation distance was consistently higher for fish above the minimum legal retention size limit, except in no-entry zones of the southern region. This indicates that no-entry zones may be maintaining near-natural, pre-exploitation behaviour, which could have considerable implications for the genetic and social structures of a highly valuable commercial species. Conservation and fisheries management would therefore benefit from an increased understanding of how fish behaviour can influence population structures, and how these populations may be influenced by fishing and other human interactions.

1. Introduction

Protected areas have been used for centuries to attain a range of natural resource management outcomes, including conservation and sustainable harvest. These desired outcomes often encompass the protection of targeted or threatened species, as well as ecosystem functions or processes. Numerous studies have documented changes in animal behaviour due to human exploitation and interaction from terrestrial (de Boer et al., 2004; Thiel et al., 2007), freshwater (Sutter et al., 2012) and marine systems (Januchowski-Hartley et al., 2011), but few studies have examined what occurs in the absence of these pressures (but see Feary et al., 2011; Januchowski-Hartley et al., 2015).

In the context of marine ecosystems, it may be expected that the exclusion of extractive activities in no-take or no-entry marine reserves may lead to modifications in animal behaviour towards natural, pre-disturbance states, characterised by naïve or bold behaviour. For example, Charles Darwin documented "extreme tameness" (i.e. naïvety) for birds of the Galapagos Islands in his Journal of Researches (1845), even though they had already been subject to hunting by humans, and may not have been as tame as they naturally would be (see Darwin, 1845). The maintenance of, or shift towards natural, bold behaviour could have important management implications, considering that these behavioural changes may affect sexual selection (e.g. Biro and Post, 2008), habitat usage (e.g. Cleveland et al., 2012), or the foraging behaviour of key species (e.g. Fortin et al., 2005; Madin et al., 2010; Rizzari et al., 2014). Thus, the relative paucity of research examining fish behaviour in the absence of human pressures constitutes a critical knowledge gap for conservation biology.

Animal behaviour can be modified substantially through interaction with humans, whether non-lethal (e.g. coexistence, tourism viewing or feeding) or lethal (e.g. hunting, fishing, or collection). An extensive literature has documented these changes in many of the world's ecosystems (reviewed by Stankowich and Blumstein, 2005; Cooper and Blumstein, 2015), and documents many similarities in altered behaviour of animals in terrestrial, freshwater, and marine environments. For example, the non-lethal presence of humans in terrestrial environments often results in increased flight distance for a variety of species, including birds and large-bodied ungulates (e.g. de Boer et al., 2004; Thiel et al., 2007). This trend of increased flight distance also occurs when humans hunt animals, often inducing greater changes in behaviour compared to non-lethal interactions with humans, regardless of the species or ecosystem (Jayakody et al., 2008; Guidetti et al., 2008).

Flight-initiation distance (FID) is regularly used as a behavioural measurement or proxy of fear in animals towards predators and humans (Frid and Dill, 2002; Stankowich and Blumstein, 2005), and is defined as the distance an animal will allow a potential predator to

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approach before fleeing. FID can be influenced by numerous biological and environmental factors, including habitat complexity, visibility, trophic position of the animal affected (e.g. predator vs. herbivore), and body size (Kulbicki, 1998; Gotanda et al., 2009; Januchowski-Hartley et al., 2011). However, the effects of environmental or biological factors are typically of secondary importance compared to the effects of hunting or fishing (Thiel et al., 2007; Jayakody et al., 2008; Januchowski-Hartley et al., 2015), especially if these anthropogenic pressures are intense and/or sustained. As noted previously, studies of FID have occurred in most of the worlds' ecosystems, but the emphasis is often on terrestrial settings rather than aquatic environments. Documenting changes in fish behaviour due to fishing is inherently challenging, but recent years have seen an expansion of this topic, especially in coral reef ecosystems (e.g. Gotanda et al., 2009; Feary et al., 2011; Januchowski-Hartley et al., 2011, 2012, 2015).

Australia's Great Barrier Reef Marine Park (GBRMP) is a large multi-use marine park that generates gradients of fishing pressure and human interaction (Rizzari et al., 2015), making it an ideal system in which to investigate resultant changes in fish behaviour. The management system of the GBRMP includes areas open to fishing and permanent spatial closures, which comprise two different levels of protection from humans: no-take and no-entry zones. Fishing is prohibited in both closure types, but no-entry zones are strictly enforced human exclusion areas, whereas non-extractive activities (e.g. diving) are permitted in no-take zones. The most heavily targeted reef fish species in the GBRMP is the common coral trout (*Plectropomus leopardus*, otherwise known as leopard coral grouper), which comprises approximately 52% of spearfishers' catch (Frisch et al., 2012; Leigh et al., 2014). Coral trout are thus an ideal study species to document changes in behaviour due to fishing pressure and varying degrees of human interaction. The aim of this study was to determine the effect of fishing and human interaction on behaviour of coral trout. Specifically, we investigated two research questions: 1) How does protection from fishing influence target species behaviour; and 2) Does fish behaviour differ between no-entry and no-take zones?

2. Methods

2.1. Study site and design

This study was conducted on 18 outer-shelf coral reefs, in two regions (northern and southern) of the Great Barrier Reef, Australia, between March and May 2014; the northern region included outer-shelf reefs of the Cairns and Innisfail management regions, while the southern region included the Swains reefs, located ~140 NM offshore of Mackay (Fig. 1). We surveyed three reefs per management zone in both regions (fished, no-take, and no-entry; total per region = 9, Table S1). The two regions surveyed in this study also receive different types and amounts of human pressure. For instance, although located ~140 NM offshore, the Swains reefs in the southern region receive considerable commercial line fishing pressure, and some charter line fishing pressure, but relatively few divers or spearfishers (Mapstone et al.,

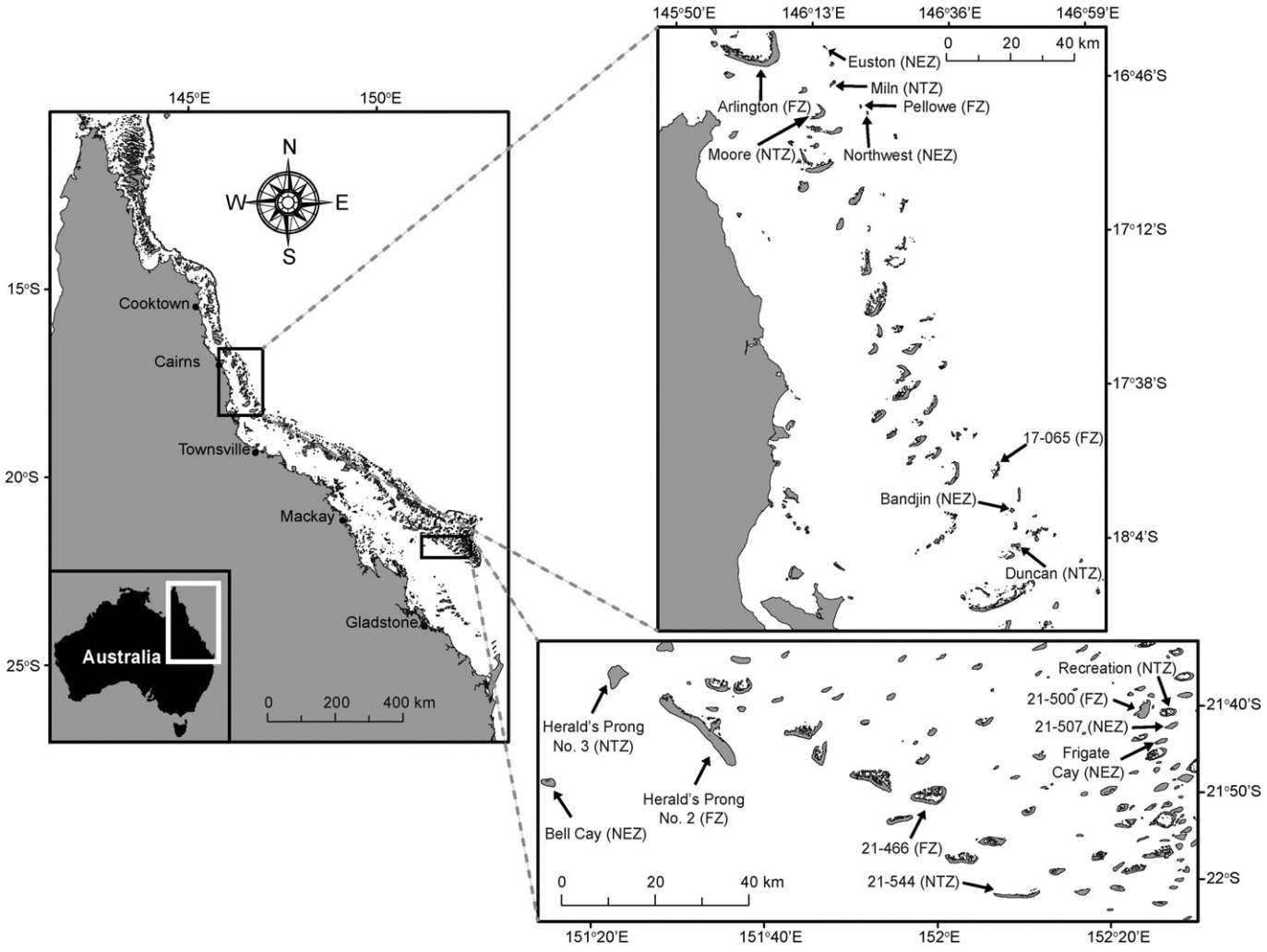

Fig. 1. Map of study sites in the Great Barrier Reef Marine Park, Australia.