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Evidence for rapid recovery of shark populations within a coral reef marine protected area

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ABSTRACT

There is limited evidence on the rate at which the shark populations of coral reefs can rebound from over-exploitation, the baselines that might signify when recovery has occurred and the role of no-take Marine Protected Areas (MPA) in aiding this process. We surveyed shark assemblages at Ashmore Reef in Western Australia using baited remote underwater video stations in 2004 prior to enforcement of MPA status and then again in 2016 after eight years of strict enforcement. We found an increase in the relative mean abundance of *Carcharhinus amblyrhynchos* from 0.16 ± 0.06 individuals h^{-1} in 2004 to 0.74 ± 0.11 individuals h^{-1} in 2016, a change that was also accompanied by a shift in the assemblage of sharks to greater proportions of apex species (from 7.1% to 11.9%) and reef sharks (from 28.6% to 57.6%), and a decrease in the proportional abundance of lower trophic level species (from 64.3% to 30.5%). Abundances and trophic assemblage of sharks at Ashmore Reef in 2004 resembled those of the Scott Reefs, where targeted fishing for sharks still occurs, whereas in 2016, abundances and trophic structures had recovered to resemble those of the Rowley Shoals, a reef system that has been a strictly enforced MPA for over 25 years. The shift in abundance and community structure coincident with strict enforcement of the MPA at Ashmore Reef has occurred at a rate greater than predicted by demographic models, implying the action of compensatory processes in recovery. Our study shows that shark communities can recover rapidly after exploitation in a well-managed no-take MPA.

1. Introduction

The k-selected life history traits of slow growth, long life spans, late sexual maturity, long gestation periods and reduced fecundity of sharks (Cortes, 2000) imply inherently slow rates of recovery (4–5% $year^{-1}$) from population declines. Coupled with high rates of exploitation (6–8% $year^{-1}$) by fishing in response to market demand (Clarke et al., 2006; Worm et al., 2013), this has resulted in many populations of sharks being depleted at a rate that exceeds their natural recovery potential (Worm et al., 2013). In tropical ecosystems, fishing has caused declines in common species of sharks in many localities worldwide. For example, there have been losses of reef sharks of 7–17% per annum on the Great Barrier Reef (Robbins et al., 2006), over a 90% decline on reefs in the Chagos Archipelago since the 70s (Graham et al., 2010), and modelled estimates of declines in abundance to 3–10% of baseline values on reefs in the central-western Pacific (Nadon et al., 2012).

Declining populations of sharks in the tropics are of concern because of increasing evidence of their important trophic role (Heithaus et al., 2010; Heupel et al., 2014; Roff et al., 2016; Ruppert et al., 2013). The presence of sharks has been shown to affect the diet, condition and morphology of their prey (Barley et al., 2017a, 2017b; Hammerschlag et al., 2018) and food chain structure (Barley et al., 2017a). There is also evidence that the absence of predators may affect the ability of reefs to recover from disturbances that remove coral cover (e.g. cyclones and bleaching) (Ruppert et al., 2013) and promote outbreaks of corallivores (e.g. crown-of-thorns starfish *Acanthaster plancii* (Dulvy et al., 2004; Ruppert et al., 2013), which is a major issue in a world facing climate change (Hughes et al., 2003). However, there is still some uncertainty around the exact functional role reef sharks play in structuring reef communities, which is due to the complex nature of ecosystem dynamics and unknown exploitation histories (Roff et al., 2016; Ruppert et al., 2016). For many coastal and island nations in the tropics, sharks are also a valuable tourism resource that support industries that provide significant benefits to regional economies (Brunnschweiler, 2010; Gallagher and Hammerschlag, 2011; Huveneers et al., 2017; Vianna et al., 2012).

An understanding of the rate at which populations of reef sharks might recover, and the management strategies that might enhance this

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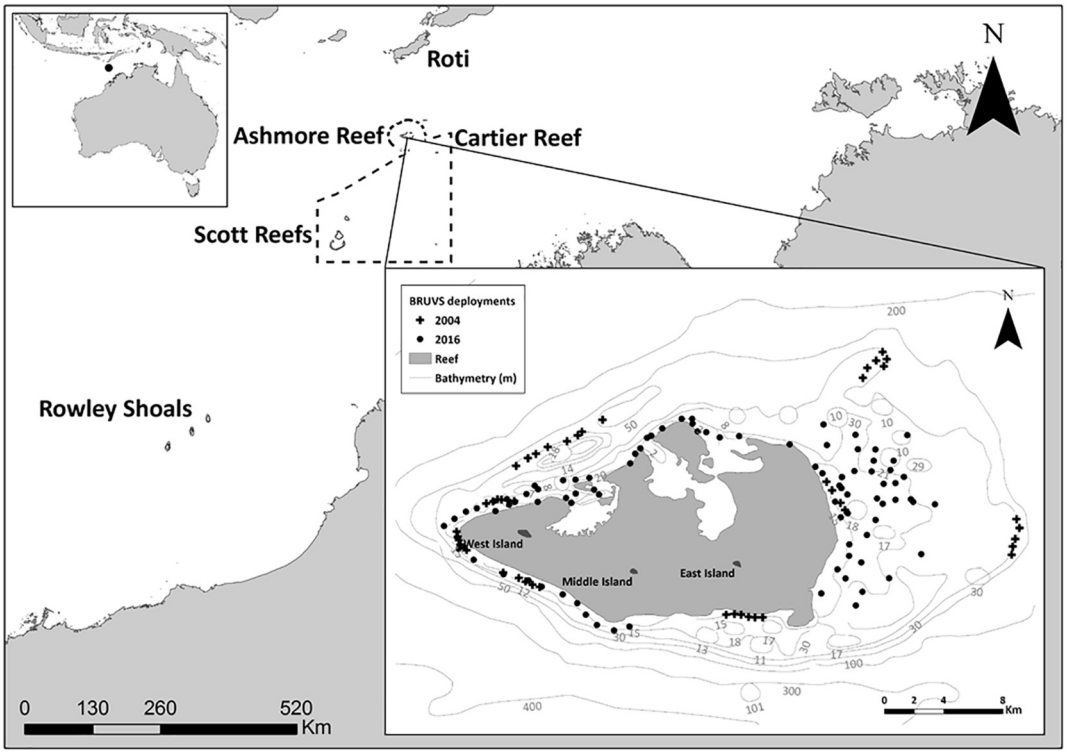

Fig. 1. North-west oceanic region of Australia including study site map of Ashmore Reef with bathymetric contours and BRUVS deployments in 2004 (n = 46) and 2016 (n = 89). Dashed line shows boundary of MOU Box within which fishing by Indonesians using traditional techniques is allowed in the Australian Exclusive Economic Zone.

goal are hampered by a lack of field observations of this process. Estimates of recovery rates are largely based on modelling of demographic rates of growth, reproduction and survivorship (Cortes, 2002; Hisano et al., 2011; Smith et al., 1998) that often do not include estimates of density-dependant factors such as competition, predation, cannibalism, immigration and emigration. Moreover, once circumstances have allowed recovery to begin, the endpoint of the process is uncertain, since there are few baselines that might indicate what a "pristine" (unfished) shark community might look like (Nadon et al., 2012). This uncertainty is largely due to the ubiquitous nature of fishing in coral reef ecosystems worldwide (Newton et al., 2007). These issues are pertinent to the establishment of management strategies such as marine protected areas (MPAs) (Bond et al., 2012; White et al., 2017) and shark sanctuaries (Ward-Paige et al., 2012) that have been promoted as a means of ensuring the conservation and recovery of shark populations. They add to other unanswered questions about this approach to management and its efficacy (Davidson, 2012), such as the optimal size and placement of MPAs, whether they are useful for all components of a shark fauna including wide-ranging apex predators (Ward-Paige et al., 2012) and mesopredators (White et al., 2017), and the level of enforcement that is required to have desired effects for shark populations (Ward-Paige, 2017). It is generally agreed that strict enforcement is paramount to the success of an MPA (Chapman et al., 2013; Dulvy, 2006; Edgar et al., 2014; Gill et al., 2017), although even well-managed parks such as the Great Barrier Reef Marine Park have seen declines in common species of reef sharks due to illegal fishing in no-take zones (Robbins et al., 2006).

Coral reef systems in the north-west of Western Australia (WA) offer a unique opportunity to examine the recovery of reef shark populations from fishing and the role of MPAs in this process, within the context of a large-scale (hundreds of km, multiple reefs) natural experiment. Three atoll-like reefs systems, Ashmore Reef, the Scott Reefs, and the Rowley Shoals occur at the edge of the continental shelf in this region. Prior to 1988, Ashmore Reef was subjected to both targeted shark fishing and subsistence fishing (both legal and illegal) by Indonesian fishermen. A no-take MPA was established at this time and enforced through occasional monitoring from 2004 and then by the continuous presence of a government vessel from 2008. The Scott Reefs to the south of Ashmore Reef have been subjected to targeted fishing for sharks by Indonesian fishermen for centuries, a phenomenon that is still ongoing today (Meekan et al., 2006; Vince, 2007). In contrast, the Rowley Shoals that lie to the south west of the Scott Reefs have been an MPA for over 25 years and are subject to very low or negligible levels of fishing pressure (Conservation, 2007). Surveys at Ashmore Reef collected in 2004 and then again 12 years later in 2016 following these changing conditions of enforcement of MPA regulations provided our study with an ideal platform to monitor the rate and outcome of the recovery of shark populations. By comparing results for Ashmore Reef with those of surveys of Scott Reefs and the Rowley Shoals, we were able to identify changes in the structure and abundance of shark communities that might indicate a return to pre-fishing levels and to examine the effectiveness of MPAs as a conservation tool for the recovery of shark populations. We focus our study on the grey reef shark, *Carcharhinus amblyrhynchos*, as an indicator species of recovery given that it is one of the most common species of reef shark in the Indo-Pacific and targeted for its fins by both legal and illegal fishing (Marshall, 2011). We compare predicted rates of recovery for this species with direct observations in order to identify the potential role and importance of density-dependant factors in the recovery process.

2. Material and methods

2.1. Study site and background

2.1.1. Ashmore Reef

Ashmore Reef (12° 14.929′S, 123° 3.319 E) is a large, lagoonal platform reef (26 km long and 14 km wide) with three low vegetated islands on the North-West Shelf of Australia, rising from the edge of the continental slope (Wilson, 2013) (Fig. 1). The reef is situated ca. 350 km from the mainland of north-west Australia; its closest reef