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Assessment of a data-limited, multi-species shark fishery in the Great Barrier Reef Marine Park and south-east Queensland

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ABSTRACT

The status of five species of commercially exploited sharks within the Great Barrier Reef Marine Park (GBRMP) and south-east Queensland was assessed using a data-limited approach. Annual harvest rate, U, estimated empirically from tagging between 2011 and 2013, was compared with an analytically-derived proxy for optimal equilibrium harvest rate, U_{MSY}^{Lim}. Median estimates of U for three principal retained species, Australian blacktip shark, *Carcharhinus tilstoni*, spot-tail shark, *Carcharhinus sorrah*, and spinner shark, *Carcharhinus brevipinna*, were 0.10, 0.06 and 0.07 year^{-1}, respectively. Median U for two retained, non-target species, pigeye shark, *Carcharhinus amboinensis* and Australian sharpnose shark, *Rhizoprionodon taylori*, were 0.27 and 0.01 year^{-1}, respectively. For all species except the Australian blacktip the median ratio of U/U_{MSY}^{Lim} was <1. The high vulnerability of this species to fishing combined with life history characteristics meant U_{MSY}^{Lim} was low (0.04–0.07 year^{-1}) and that U/U_{MSY}^{Lim} was likely to be >1. Harvest of the Australian blacktip shark above U_{MSY} could place this species at a greater risk of localised depletion in parts of the GBRMP. Results of the study indicated that much higher catches, and presumably higher U, during the early 2000s were likely unsustainable. The unexpectedly high level of U on the pigeye shark indicated that output-based management controls may not have been effective in reducing harvest levels on all species, particularly those caught incidentally by other fishing sectors including the recreational sector.

1. Introduction

North-eastern Australia's Great Barrier Reef Marine Park (GBMRP) is regarded as one of the most successful examples of large-scale marine reserve management globally (McCook et al., 2010). Implementation of the 2003 Great Barrier Reef Zoning Plan led to, notably, the protection of 33% of the GBRMP from commercial fishing activities (Fernandes et al., 2005). It has been demonstrated subsequently that re-zoning led to a range of ecological and economic benefits (reviewed in McCook et al., 2010), including improved ecosystem health and resilience (Sweatman, 2008; Emslie Michael et al., 2015), conservation of biodiversity (Pitcher et al., 2007) and more profitable tourism and commercial fishing industries (Deloitte Access Economics, 2013).

Despite the successes of the GBRMP's 2003 re-zoning, a persistent challenge for scientists and natural resource managers has been to demonstrate that management of sharks and rays is effective and that stocks are sustainable (Brodie and Waterhouse, 2012; Ceccarelli et al., 2013). Multiple studies in the GBRMP have now documented lower relative abundances of grey reef sharks, *Carcharhinus amblyrhynchos*, and white-tip reef sharks, *Triaenodon obesus*, on fished reefs compared with unfished reefs (Ayling and Choat, 2008; Espinoza et al., 2014; Rizzari et al., 2014), with some studies suggesting that population declines of up to 97% have occurred (Robbins et al., 2006; Hisano et al., 2011). Evidence from the Queensland Shark Control Program has also shown large declines in the abundances of wide-ranging species such as tiger sharks, *Galeocerdo cuvier*, (Holmes et al., 2012) and hammerheads, *Sphyrna* spp., (de Jong, 2009). Coastal development and fishing have also resulted in the likely disappearance of sawfishes, *Pristis* spp., south of Cairns between the 1970s and 1990s (Giles et al., 2004).

While the commercial catch of vulnerable, reef-associated sharks by the Coral Reef Finfish Fishery (CRFF) has been a focal issue

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within the GBRMP (Robbins et al., 2006; Ayling and Choat, 2008; Heupel et al., 2009; Rizzari et al., 2014), line fishing including that of the CRFF has historically only been a minor component of total shark and ray catch (Gribble et al., 2005). Other sources of mortality in Queensland waters and the GBRMP include penaeid trawl fisheries (Kyne, 2008), recreational fishing (Lynch et al., 2010), and the Queensland Shark Control Program (Sumpton et al., 2011). However, by far the largest sources of past and present landings – accounting for around 94% of all sharks – have been the gillnet fisheries that comprise the East Coast Inshore Finfish Fishery (ECIFF) (Gribble et al., 2005). The large catch by this fishery of non reef-associated sharks from the inshore regions of the GBRMP has proven particularly difficult to quantify and manage, with the catch composition only recently defined (Harry et al., 2011).

One of difficulties in managing shark catch by the ECIFF is the nebulous nature of the fishery; it is effectively a collective of many distinctly different small-scale fisheries aggregated for management convenience. Although sharks have historically been a dominant component of the catch, they are generally not the target species, rather, a low-value by-product that is caught when targeting teleosts. Targeted shark fishing occurs, but is generally not a full-time activity. Nonetheless, the capacity has existed to target sharks within the fishery, and between 1994 and 2003 commercial landings of sharks on the east coast of Queensland increased markedly from 462 to 1480 t. Much of this increase was in the GBRMP where total catch of predominantly whaler (family Carcharhinidae) and hammerhead (family Sphyrnidae) sharks quadrupled from 319 to 1252 t, raising concern from fishery and marine park managers (Gribble et al., 2005; GBRMPA, 2007).

Over the following decade, a range of major management changes, as well as a number of specific measures to address concerns about shark sustainability, were introduced into the region (Queensland Department of Agriculture Fisheries and Forrestry, 2011). The re-zoning of the GBRMP restricted commercial fishing in ∼33% of the total area of the Marine Park, and was accompanied by the buyout of 56 gillnet licences (which had accounted for 14.5% of total catch) to prevent displacement of fishing effort. The capacity of the ECIFF was further restricted through a 40% reduction in latent gillnet effort and the introduction of a limit reference point on nominal effort. Shark-specific measures implemented by fishery managers included a range of input and output controls. Retention of sharks was restricted to 154 licence holders, and possession limits (10 sharks per trip) imposed for non shark-licence holders. Additionally, a 600 t annual fishery-wide catch limit (480 t in the GBMRP, 120 t in southeast Queensland [SEQ]) was introduced, and a maximum size limit of 150 cm set for line-caught sharks to protect large, breeding females. Since 2003 the catch of sharks by the ECIFF has fallen steadily, and was 309 t in 2014 (Queensland Department of Agriculture Fisheries and Forrestry, 2011).

A relatively large number of direct and indirect management measures now exist to protect sharks in the GBRMP, and Queensland more generally. However, evaluating the efficacy of these measures, and assessing the status of inshore shark stocks is still problematic. Despite recent attempts to increase the resolution of the reported shark catch, the high diversity of morphologically similar species makes species-specific reporting impractical (Harry et al., 2011, 2012), and the low economic value of shark products has resulted in little routine monitoring. Assessment of data-poor multi-species fisheries in Australia has most commonly been done using ecological risk assessment (ERA) involving productivity and susceptibility indices (Stobutzki et al., 2002; Tobin et al., 2010). While ERA provides a framework for identifying high-risk species within a fishery, it still does not provide information on current stock status.

One approach for assessing stock status that has been used in similar data-limited shark fisheries has been to combine a traditional tagging study with demographic analysis (McAuley et al., 2007; Bradshaw et al., 2013). This involves estimating exploitation levels from tagging, and comparing these with biological reference points from demographic models, namely the intrinsic rate of population increase, *r*, from a life-table or Leslie matrix model (Gedamke et al., 2007). A limitation of simple demographic methods is that they do not account for density-dependence. While this is generally acknowledged, *r* is frequently still interpreted in a similar way to *r* from the logistic (Schaefer) model, despite not being equivalent (Xiao, 2002). In recent years, this issue has been addressed by the development of methods that incorporate density-dependence into demographic methods, extending their utility beyond simple density-independent methods and linking them to more conventionally used reference points (Forrest and Walters, 2009; Brooks et al., 2010; Braccini et al., 2015).

This study builds on previous data-limited shark assessments by combining a traditional tagging study with density-dependent demographic methods to assess the status of inshore sharks from the GBRMP and SEQ. Harvest rate, U, estimated from tagging was compared to a proxy for optimal (or maximum sustainable) harvest rate, ${U_{MSY}}^{Lim}$ (Forrest and Walters, 2009). ${U_{MSY}}^{Lim}$ is an analytically derived equilibrium quantity corresponding to the theoretical upper limit to U_{MSY} of a stock given its life history and selectivity parameters. Although attaining MSY is unlikely to be a goal for this particular fishery, values of $U > U_{MSY}$ indicate that it is unlikely that the stock is being maintained at its highest level of productivity, a standard reference point for acceptable performance (Department of Agriculture Fisheries and Forrestry, 2007).

Five species were identified for inclusion in the study. These included three of the most commonly harvested sharks in GBRMP and SEQ; the Australian blacktip shark, *Carcharhinus tilstoni,* the spot-tail shark, *Carcharhinus sorrah,* and the spinner shark, *Carcharhinus brevipinna*. Two commonly retained non-target species from the region, the pigeye shark, *Carcharhinus amboinensis,* and the Australian Sharpnose shark, *Rhizoprionodon taylori,* were also included to serve as indicators of harvest levels on large (>2 m total length [TL]) and small (<1 m TL) coastal sharks, respectively. Collectively these are among the most commonly caught sharks by the ECIFF, and also span many of the of life history strategies of the species caught by this diverse, multi-species shark fishery (Harry et al., 2011). All species occur throughout Queensland inshore waters in varying levels of abundance, and their distributions likely extend beyond the boundaries of the ECIFF. Each species is highly mobile and, with the exception of spinner sharks, presumed to be a single genetic stock on the east coast of Queensland (Stevens et al., 2000; Welch et al., 2010; Munroe et al., 2015). The population of spinner sharks in SEQ appears to be separate to that in the GBRMP (Geraghty et al., 2013b).

The ultimate aim of this study was to assess the stock status of all five species and evaluate the efficacy of management changes during the past decade. While the commercial sector was the focus of the study, results from the recreational sector are also included.

2. Methods

2.1. Tagging study

Tagging of sharks in the GBRMP and SEQ initially occurred opportunistically from 2008 to 2010 as part of several student research projects (Kinney, 2011; Knip, 2011; Chin, 2013). Subsequently, dedicated tagging to estimate harvest levels occurred from 2010 to 2013. Dedicated tagging was carried out using contracted commercial gillnet fishers assisted by a trained fisheries observer. Fishers used modified techniques (e.g. shorter net setting times) to minimise post-release mortality, which was assumed to be negli-