Short communication

Local fishing influences coral reef fish behavior inside protected areas of the Indo-Pacific

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ABSTRACT

Fishing is altering aquatic ecosystems through changes in the abundance, species composition and behavior of target species. Changes in fish behavior have received relatively little attention, despite significant evidence of behavioral change driven by human impacts mediating function and processes in terrestrial ecosystems, and emerging evidence that the same is true in marine systems even within marine reserves. Here, we measured the wariness of two families of coral reef fishes in both fished areas and marine reserves embedded within a fished seascape along an exploitation gradient ranging from wilderness sites (Chagos) to heavily fished areas (the Philippines). We used linear mixed effect models to identify relationships between fish flight initiation distance (FID) and fishing pressure, fish size, habitat complexity and life-history stage. Critically, fish FID increased with fishing pressure both in fished areas and inside marine reserves. These results imply that as fishing pressure increases in adjacent areas, progressively greater fish wariness may reduce the magnitude of some ecosystem functions within small marine reserves.

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1. Introduction

Fishing shapes the structure and function of fish communities globally, influencing trophic composition, biomass, abundance, and diversity (Estes et al., 2011; Mora et al., 2011). There are documented evolutionary consequences of fishing, particularly on fish size and reproduction (Enberg et al., 2009). Multiple experimental studies have confirmed that preferential capture of particular genotypes (e.g., bold or faster growing), can have impacts on the average fitness of fishes in the population (Sutter et al., 2013) and on productivity of a fishery (Biro and Post, 2008). Overfishing of important functional groups has also been implicated in cascading effects on benthic ecosystems through removal of herbivores (Hughes et al., 2010), or indirectly through predation release of keystone species such as urchins (Guidetti, 2006). In contrast, the effects that fishing has on fish behavior (Gotanda et al., 2009; Januchowski-Hartley et al., 2011) and the resulting implications

for conservation and fisheries management have been largely overlooked. For example, the importance of Acanthuridae (surgeonfish) and Scaridae (parrotfish) in cropping algae, both reducing mechanical damage to corals and creating space for coral recruits, thus facilitating coral dominance is now well established (Hughes et al., 2010; Rasher et al., 2013). However, evidence is accruing that increases in wary behavior of fishes within these families, such as spending more time near shelter or fleeing from predators earlier, reduces the intensity and spatial area over which they graze and control algal growth (Madin et al., 2010, 2011).

Substantial research has shown the potential for marine reserves to help rebuild fish assemblages (Babcock et al., 2010), and there is mounting evidence that fishes that have spent a period of time under protection exhibit less wary behavior in response to fishers than fishes permanently exposed to fishing (Gotanda et al., 2009; Feary et al., 2011; Januchowski-Hartley et al., 2014). Similarly, fishes are less wary in waters immediately adjacent to permanent marine reserves, likely due to the export of naive behavior (Januchowski-Hartley et al., 2013). If marine reserves can export behavioral effects through the movement of fishes (Abesamis et al., 2006; Januchowski-Hartley et al., 2013), it is also possible that the intensity of fishing in areas surrounding reserves may influence behavior within reserves, similar to how intense fishing effort at the boundary of marine reserves ("fishing the

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line") is associated with reductions in the abundance of fishes immediately inside the boundary (Kellner et al., 2007).

Other attributes of both fishes and the environment (e.g., body size, refuge availability) can also influence how fishes respond to predation risk (Gotanda et al., 2009; Sutter et al., 2013). Knowing how fish wariness responds to protection, fishing pressure and other factors has important implications for fisheries sustainability and the ability of fishes to perform key ecological functions that help sustain ecosystem health (such as herbivory). Here, we present the results of surveys of flight initiation distance (FID – how close an observer can get to an animal before it flees: Stankowich and Blumstein, 2005) on fishery targeted families inside and outside marine reserves on coral reefs across a wide gradient of fishing intensity. We ask the following questions: (1) what are the relative influences of environmental and ontogenetic factors on fish wariness? (2) Does fish wariness outside marine reserves change with increasing fishing pressure? (3) Does fishing pressure in the surrounding seascape impact fish wariness inside marine reserves?

2. Methods

We estimated FID for species of Acanthuridae (surgeonfish) and Scaridae (parrotfish) at 23 sites between 2009 and 2011, spanning four countries (Chagos, Papua New Guinea, Philippines, and Vanuatu), ~96° of longitude and ~27° of latitude in the Indo-Pacific (see Tables A1 and A2 for details). Thirteen sites were protected from fishing through permanent no-take reserves or traditional management closures, and 10 sites were openly fished areas (none in Chagos). Protected areas were either remote, or compliance was considered to be high by the local communities. Tourist presence was high in reserves in the Philippines, and occasional in one reserve in Vanuatu.

2.1. Fish behavior

We estimated FID by measuring how closely we could approach individual fishes before they fled (see Januchowski-Hartley et al., 2011 for details). Fish species were selected based on local abundance, and only individual fishes >10 cm total length were approached. In the Philippines, Papua New Guinea (PNG) and Vanuatu, all locally abundant surgeonfish and parrotfish species are targeted by fishers (Abesamis et al., 2006; McClanahan and Cinner, 2008; Januchowski-Hartley, unpublished data). In Chagos, we specifically approached fishes of species present in the other locations, or closely related species (e.g. *Chlorurus strongylocephalus* instead of *Chlorurus microrhinos*). We recorded fish size to the nearest centimeter, life history stage (parrotfish only) and reef complexity as predictor variables. The visual complexity method we used correlates with the number of refuge holes >10 cm (Wilson et al., 2007), which are likely refugia for fishes within our target size range. In total we measured FID and associated predictor variables of 1039 parrotfishes and 758 surgeonfishes, ranging in size from 10 to 57 cm total length (see Tables A1 & A2 for species lists).

2.2. Fishing pressure

We estimated fishing pressure for each area by dividing the linear extent of fringing reef open to fishing by the number of fishers in the associated fishing community. Fisher numbers were obtained through either household interviews (PNG) or through interviews with the chairmen of local fisher organizations or the local chief (Philippines, Vanuatu). Where possible, we validated our results either through comparison with the number of fishers obtained by previous studies or with scientists and managers working independently in the same areas. For all sites we

considered a person a regular fisher if they conducted at least one fishing trip per week to the fringing coral reef. Spearguns were used at all fished areas, as were 'drive-in nets' in the Philippines and PNG, a gear where swimmers attempt to startle fish to swim into a set net. Hook and line, gill nets and traps were used in the Philippines and PNG, but not on the fished sites in Vanuatu. Because active gears that involved fishers being present in the water were common at all areas, the density of fishers is likely to be a good proxy for encounters between fish and fishers. The resulting fishing pressure gradient spanned 0 fishers/km in Chagos, to over 80 fishers/km in PNG.

2.3. Data analysis

We used linear mixed effect models to assess relationships between fish FID and the following explanatory variables: fish size, fishing pressure (for protected areas this was the fishing pressure in the remainder of the community fishing ground that was not protected), substrate complexity and life-history stage (initial or terminal stage – parrotfishes only). FIDs from fished and protected sites were analyzed separately for two reasons; (1) because the Chagos region only has protected areas; and (2) in order to distinguish if variables differed in their influence under protection. We examined co-plots to determine likely interactions between these factors and included any significant and ecologically meaningful interactions in the model selection process. Country and genus (surgeonfishes: *Acanthurus*, *Ctenochaetus* and *Naso*; parrotfishes: *Chlorurus* and *Scarus*) were included as random effects, and we examined the random effect structure for a model with all explanatory variables prior to testing fixed factors (Zuur et al., 2009). We used genera to group the species because this appropriately captures the different ecological and behavioral characteristics of each group. For example among surgeonfishes, species of the genus *Naso* are vagile, large bodied planktivores, whereas species of the genus *Ctenochaetus* have very small home ranges and occur in small groups. We selected the random effect structure from the models with the lowest Akaike Information Criterion adjusted for small sample size (AICc): country for parrotfish, and country and genus for surgeonfish.

The optimal fixed structures for explanatory variables were found using likelihood ratio tests of a set of nested models, each of which excluded one explanatory variable from the full model. Statistical significance was evaluated by testing $-2\log_e$ (likelihood) against the χ^2 distribution with 1 df between each nested model and the full model (Zuur et al., 2009). We then repeated this procedure with the best nested model until no further improvement in model performance was found. If we retained an interaction term in the model, all individual variables associated with that interaction were retained. We considered the 'best' set of models for each family/protection group as all models within 2 AIC_c units of the model with the lowest AIC_c score. These models were averaged to identify the standardized effects of each explanatory variable on FID. All analyses were performed within the lmer and model.avg functions of the lme4 and MuMIn packages in R (R Development Core Team, 2013). Variances of the full models (all explanatory variables) were found to be homogenous, and residuals normally distributed.

3. Results

There was strong evidence for a relationship between fish FID and our explanatory variables, with the null model never being within 5 AICc values of the best performing model (Table B1). When we averaged the best performing models, it was evident that fishing pressure consistently had the largest effect on fish FID (Fig. 1). As fishing pressure in the local seascape increased, FID also