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Conservation challenges for small-scale fisheries: Bycatch and habitat impacts of traps and gillnets

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ABSTRACT

Small-scale fisheries provide over half the world's wild-caught seafood, employ over 99% of its fishers, and are frequently promoted as a sustainable alternative to large-scale industrial fisheries. However, few studies have quantitatively examined how possible habitat impacts and non-target species composition vary across gears used in small-scale fisheries, as data are sparse and conservation efforts are largely focused on more iconic species. Here, we quantify and compare the ecosystem impacts of four fishing gears (lobster traps, fish traps, set gillnets, drift gillnets) used in small-scale fisheries of Baja California, Mexico, using at-sea observations and field experiments. Set gillnets had the highest overall impact on both non-target species and habitat, with discard rates higher than most industrial fisheries (34.3% by weight), and an estimated 19.2% of *Eisenia arborea* kelp and 16.8% of gorgonian corals damaged or removed within 1 m of the net path. Fish traps had the lowest discard rates (0.11%) while lobster traps and drift gillnets had intermediate discard rates (15.1% and 18.5% respectively). In contrast with gillnets, traps caused minimal immediate damage to gorgonian corals and rarely interacted with kelp. Results indicate that ecological impacts depend more on fishing gear type and habitat characteristics than the size of fishing vessels, calling into question broad generalizations that small-scale fisheries are inherently more sustainable than industrial fisheries. Our findings highlight the ecological impacts of artisanal gillnet fisheries as priorities for research, management, and conservation efforts in Baja California and other coastal areas.

1. Introduction

Most of what we know about the ecological impacts of specific fishing gears has come from studies of large-scale fishing operations from industrialized countries. Primary direct impacts include overexploitation of target species, incidentally caught bycatch, and impacts to benthic habitats (Dayton et al., 1995; Dulvy et al., 2003; Kappel, 2005). While there have been several studies worldwide on the impacts of artisanal fisheries particularly on marine turtles (e.g., Koch et al., 2006), seabirds (e.g., Morenoa et al., 2006), and mammals (e.g., Amir et al., 2002; Lopez et al., 2003), studies remain sparse that compare bycatch compositions and habitat impacts of small-scale fishing gears used in the same habitat type. Small-scale fisheries (defined by vessels under 15 m long, mechanized or manual fishing gears, low relative catch per vessel, and dispersed, local ownership), provide over half of total global fisheries production and employ over 99% of the world's 51 million fishers (Berkes et al., 2001; Chuenpagdee et al., 2006). These fisheries often suffer from competition with large-scale fisheries and lack of resources and infrastructure to monitoring and manage of exploited populations and ecosystems. Despite these shortcomings, some of the characteristics of small-scale fisheries, including the relatively low technology used for extraction, limited aerial extent of fishing, and capability for effective local governance (e.g., Jacquet and Pauly, 2008) are expected to lead to low ecological impacts, making small-scale fisheries 'our best hope for sustainable utilization of coastal marine resources' (Pauly, 2006).

A major documented ecological impact of fisheries occurs through bycatch. Bycatch, or the incidental catch and discarding of undesired organisms in a fishery, occurs when fishing gear catches unwanted species whose retention is either not economical or prohibited by law (Dayton et al., 1995). Bycatch in commercial fisheries can cause severe impacts to marine populations including sea turtles (Spotila et al., 2000; Lewison et al., 2004; Peckham et al., 2007), marine mammals (Mangel, 1993), seabirds (Zydelis et al., 2009), skates (Brander, 1981; Casey and Myers, 1998), corals (Anderson and Clark, 2003), and entire marine ecosystems (Dayton et al., 1995; ICES, 1995). For fisheries where discard reporting exists, discard rate estimates vary widely by gear type (Kelleher, 2005). While some fisheries have negligible levels of discards, other fisheries discard more than they retain

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(e.g. Mexican Pacific shrimp trawl fishery discards 76.4%, (Bojorquez, 1998).

In addition to discards, some fishing gears can remove or damage benthic structures that form habitat for marine life. The impacts of bottom trawling on seafloor habitats are well studied (Johnson, 2002) and found to reduce the complexity, diversity, and productivity of benthic habitats (Watling and Norse, 1998; NRC, 2002). Biogenic structures in the marine environment, including algae, seagrass, corals, and sponges, are among the most sensitive habitats to fishing gear impacts. Cold-water corals in particular have come to the attention of policymakers because of their sensitivity to human impacts, long lifespan, and ecological importance (Krieger and Wing, 2002; Freiwald et al., 2004; Roberts and Hirshfield, 2004; Love et al., 2007). Impacts to gorgonian corals are a focus of this study because they are found throughout the world's oceans from the tropics to the poles, and their three-dimensional structure makes them widely indicative of fisheries impacts across a broad range of habitat types.

Small-scale fisheries are generally assumed to have a low or negligible discard rate (3.7% of total catch in aggregate) (Kelleher, 2005), but recent studies suggest that wide variation in bycatch rates may exist, with some small-scale fisheries having levels of discards that have the potential to extirpate some populations of megafauna (D'agrosa et al., 2000; Voges, 2005; Peckham et al., 2007). Similarly, studies on the habitat effects of artisanal fishing gears, particularly traps and gillnets, have been sparse and results have been mixed (Breen, 1989; ICES, 1995; Erzini et al., 1997; Quandt, 1999; Appeldoorn et al., 2000; Stephan et al., 2000; Eno et al., 2001) creating uncertainty regarding how to manage these activities.

Small-scale fisheries employ a wide variety of gear types, including traps, set gillnets, and drift gillnets, which vary in the way they interact with marine ecosystems (e.g., Morgan and Chuenpagdee, 2003). Comparing the impacts across different fishing gears used by the same fishing community is important because it can help communities make decisions about the "portfolio" of activities they choose to engage in. In addition, such comparisons may highlight potential negative interactions among fisheries, either directly through bycatch of commercial species targeted in another fishery or indirectly through damage to habitats used by species targeted in another fishery.

In this study, we quantify and compare for the first time the potential impacts of four artisanal fishing gear types (lobster traps, fish traps, set gillnets, and drift gillnets) in terms of their bycatch and impacts to benthic habitats. The lobster fisheries of this region use only traps and are managed through effort control, size limits, area-based concessions, and seasonal closures. These fisheries were the first small-scale fisheries from a developing country to be certified as sustainable by the Marine Stewardship Council, which assess the stock status of target species, ecosystem effects, and management regime of commercial fisheries (Lopuch, 2008; Phillips et al., 2008). As a condition of certification, the fisheries were required to collect data on the bycatch and habitat impacts of the lobster traps. In contrast, no management plan or concession exists for the finfish fisheries. We conducted fisheries observations and field experiments in two fishing cooperatives located within the Vizcaino Desert Biosphere Reserve in the Pacific region of Baja California Sur, Mexico, characterized by a temperate to sub-tropical kelp forests and rocky reefs. We asked: (1) if bycatch and habitat impacts of lobster fishing are negligible, as assumed in the spiny lobster fishery certification assessment (SCS, 2004); (2) whether finfish fisheries have significant ecological impacts, how these might vary depending on the gear used, and how they compare with possible impacts of the certified lobster fisheries; and (3) if interactions among these fisheries occur through bycatch or impacts on benthic habitat used by the target species.

2. Methods

2.1. Bycatch quantification

To quantify the amount and composition of bycatch in each fishery we observed 106 distinct fishing trips between January and November 2006 allocated across the four fisheries (Table 1; see Appendix A). We adopt the definition of bycatch of the US National Marine Fisheries Service (MSA, 1996) to include all organisms that are caught in fishing gear, but not kept for sale or personal consumption. With the exception of some lobster fishing trips observed in Bahía Tortugas, all observations took place in the Punta Abreojos Fishing Cooperative.

On each fishing trip, we recorded the size, species, and fate of all organisms caught, then estimated their biomass from known size-weight conversions based on the equation: $Biomass = a \cdot Length^b$. For fish, we used total length–weight conversions (a and b constants) from Froese and Pauly (2008) to convert length to biomass, and used available estimates from the literature for invertebrates, rocks, and algae (see Appendix B).

We quantified discard rates for each gear type in three different ways: (1) as the percent discarded by number of individuals; (2) as the percent of total biomass caught; and (3) as bycatch biomass per unit revenue from the sale of market species. For bycatch per unit revenue, we used our observed discards and all reported landings to the cooperative on each trip, which we received from the cooperative production manager. To calculate revenue, we used prices the cooperative received for each species in July 2006 and the exchange rate at the time of 11.13 pesos/USD. Discarded species were not counted toward revenue.

For trap fisheries, we analyzed discard rates excluding sub-legal target species as these are discarded live as mandated by fishing regulations (Kelleher, 2005). We divided discards into seven categories: finfish, elasmobranchs, bait species, habitat-formers, other invertebrates, seabirds, and marine mammals (Table 2). Estimates of bycatch were compared among gear types using one-way ANOVAs, with gear type as the fixed factor and fishing trips as replicate observations. To assess the potential vulnerability of different finfish and elasmobranch populations to mortality associated with bycatch, we used the relative vulnerability estimates provided by Cheung et al. (2005). Cheung et al. (2005) combined several life history and ecological characteristics of species (i.e. fecundity, lifespan, and geographic range) into a relative index (on an arbitrary scale of 1–100) of intrinsic extinction vulnerability to fishing that correlates well with observed declines of some species. We quantified the composition of the fish catch in each of four vulnerability categories: low, medium, high, and very high as assigned by Cheung et al. (2005) and report bycatch by biomass and number of individuals per unit revenue in each of these categories.

2.2. Habitat impact assessment: field experiments

To examine the possible impacts of lobster traps and set gillnets on benthic habitat, we conducted field experiments in two rocky

Table 1
Total fishing effort observed by onboard researchers in this study to obtain bycatch rates, broken down by the four gear types in terms of quantity of gear use and number of fishing trips.

Gear type	Gear use observed	Trips observed
Lobster traps	4940 Traps set ~24 h each	56
Fish traps	502 Traps set ~30 min each	16
Set gillnets	83 Daily net deployments and retrievals (total 13,600 m of net)	30
Drift gillnets	4 Overnight net deployments and retrievals (1400 m each)	4