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Trophic flow structure of the Danajon ecosystem (Central Philippines) and impacts of illegal and destructive fishing practices

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ABSTRACT

A trophic model of the shallow Danajon Bank, in the Central Visayas, Philippines was developed using a mass-balance approach (Ecopath) to describe the system characteristics and fisheries interactions. The Ecopath model is composed of 37 functional groups and 17 fishing fleet types reflecting the high diversity of catches and fishing operations in the Danajon Bank. Collectively, the catch is dominated by lower trophic level fish and invertebrates as reflected in the mean trophic level of the fishery (2.95). The low biomass and high exploitation levels for many upper trophic level groups and the little evidence for strong natural physical disturbances suggest that top-down fishery is the main driver of system dynamics. The mixed trophic impacts (MTI) analysis reveals the role of the illegal and destructive fishing operations in influencing the ecosystem structure and dynamics. Furthermore, the illegal fisheries' estimated collective annual harvest is equivalent to nearly a quarter of the entire municipal fisheries catch in the area. Improved fisheries law enforcement by the local government units to curb these illegal and destructive fishing operations could substantially increase the potential gains of the legal fisheries.

1. Introduction

Past studies on the specific effects of destructive fishing practices customarily focused on the direct impacts either on the physical structure of the habitat or on the target organisms (Cervino et al., 2003; Christian, 1973; McManus et al., 1997; National Research Council, 2002; Riegl and Luke, 1998; Saila et al., 1993). However, fishing not only affects the target organisms and their associated habitats directly through harvest mortality and gear effects, respectively, but it also indirectly affects the biological interactions in the system via disrupted predator–prey or trophic relations (Essington et al., 2006; Jennings et al., 1998; Pauly et al., 1998). These ecosystem impacts of fishing may lead to shifts in overall species composition, reduced species richness, and shifts in overall ecosystem structure and function that may subsequently result in the decline in quantity, quality, and economic value of fisheries catches, as demonstrated in highly exploited fishing grounds in the Philippines (Armada, 2004a, 2004c; Silvestre and Hilomen, 2004; Silvestre et al., 1991) and several other fished systems worldwide (see for example Albaret and Laë, 2003; Armada, 2004c; Blaber et al., 2000; Coll et al., 2008; Ebil et al., 2013; Garrison and Link, 2000; Jennings et al., 1995).

Trophic modeling of aquatic systems using Ecopath (Christensen and Pauly, 1992; Walters et al., 1997) has enabled fisheries managers to explore the trophic interactions among the exploited and non-exploited functional groups of an ecosystem, thus allowing for the investigation of both the direct and indirect impacts of the fisheries to all biological components of the system and the resulting system productivity (Christensen and Walters, 2004; Pauly et al., 2002). A more in depth examination of the capabilities and limitations of the Ecopath modeling approach is provided in Plaganyi and Butterworth (2004) and Christensen and Walters (2004). Overall, the relative simplicity of Ecopath modeling, its fewer key data requirements, and flexibility to accommodate future updates in inputs make it a very useful ecosystem modeling tool to generate information on the overall structure and functioning of a variety of marine ecosystems, especially in data-limited areas where the resources to conduct very rigorous and extensive fisheries data collection may be inadequate. In the Philippine fisheries setting, several trophic models of aquatic ecosystems are available (Aliño et al., 1993; Armada and Bacalso, 2004; Bundy, 2004; Bundy and Pauly, 2001; Campos, 2003; Delos Reyes, 1993; Guarin, 1991). However, only a few are dedicated specifically to examining the impacts of fisheries activities and exploring the potential long term effects of fisheries management policies (Armada and Bacalso, 2004; Bundy, 2004; Bundy and Pauly, 2001).

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In the Philippine context, the marine waters are classified into commercial and municipal waters. The Philippine Fisheries Code of 1998, which is a comprehensive national policy on fisheries and fisheries-related activities, defines "municipal waters" as all bodies of water within 15 km from the coastline, and delineates them for the priority use of municipal fishing activities. Subsequently, "municipal fishing" is defined as fishing using vessels not more than three (3) gross tons, or fishing not requiring the use of fishing vessels. In this regard, the municipal fisheries in the Danajon Bank and in the Philippines in general is largely artisanal and subsistence in nature. The Danajon Bank (Fig. 1, box A) is a typical municipal fishery setting in the Philippines that is characterized by multiple types of small-scale fishing gears and operations exploiting a variety of fish and invertebrate species (Armada et al., 2009; Christie et al., 2006; Fragillano, 2010). Importantly, the Danajon Bank forms part of the region that has been identified as the center of marine shorefish biodiversity in the Indo-Malay-Philippines Archipelago (IMPA) (Allen, 2008; Carpenter and Springer, 2005). It is a shallow bank with an average depth of only 5 m and a maximum depth of 28 m with characteristically muddy and sandy substrates. Its prominent feature is a double-barrier reef that measures 130 km long and covers an estimated area of 463.8 km^2. This very unusual geological formation is a product of over 6000 years of coral growth, and is one of the only 3 documented double barrier reefs in the Indo-Pacific Region (Pichon, 1977). Thus, the Danajon Bank has gained increasing attention not only for its contributions to marine biodiversity and fisheries production, but also, as a heritage area.

A survey of the municipal capture fisheries of Central Visayas, Philippines (Armada et al., 2004) revealed that the north-western Bohol section of the Danajon Bank supports over 50% of the municipal fishers and fishing boats of the entire province, thus implying the vital contributions of the Danajon Bank fisheries to supporting local livelihoods and economies in the area. Unfortunately, like in many other fishing grounds in the Philippines, anthropogenic stressors threaten the sustainability of the Danajon Bank fisheries resources and overall marine biodiversity. Nañola et al. (2011) found in their recent surveys that the Central Visayas region to which the Danajon Bank is part of has a reef fish species richness that is already among the lowest in the Philippines, which is contrary to the high shorefish biodiversity estimates reported in past studies for the region (Carpenter and Springer, 2005). A more localized study by Campos et al. (2010) in the Danajon Bank reported an overall mean live hard coral (LHC) cover of 34.9%, which borders on the "poor to fair" level of standard reef health classification (Gomez et al., 1994). The same study likewise showed a trend of decreased LHC cover and increased algal concentrations in reefs that are located near highly populated fishing communities. Thus, the decline in marine fish biodiversity and the overall degradation of marine and coastal habitats are primarily attributed to the increasing livelihood demands of the coastal communities who are greatly dependent on the natural resources. Increased competition for access and use of these resources have led many fishers in the Danajon Bank to resort more and more to unsustainable resource use practices, including destructive fishing (ADB et al., 2003; Christie et al., 2006). Major examples include bottom trawling, use of fine mesh nets, blast or dynamite fishing, and toxic (e.g. cyanide) fishing operations that destroy benthic habitats and result in indiscriminate fishing mortality (Aliño et al., 2004; McManus et al., 1997). The history and evolution of destructive fishing operations in the Philippines and in the Asia-Pacific are discussed in depth by Alcala and Gomez (1987), Johannes and Riepen (1995), and Pauly et al. (1989), from the use of munition remnants after World War II, the expansion of the aquarium fish and live reef food fish trade in the region, the introduction of highly efficient seining techniques from developed countries, and the progressive increase of fisher populations. The Philippine Fisheries Code of 1998 prohibits the conduct of these destructive fishing operations.

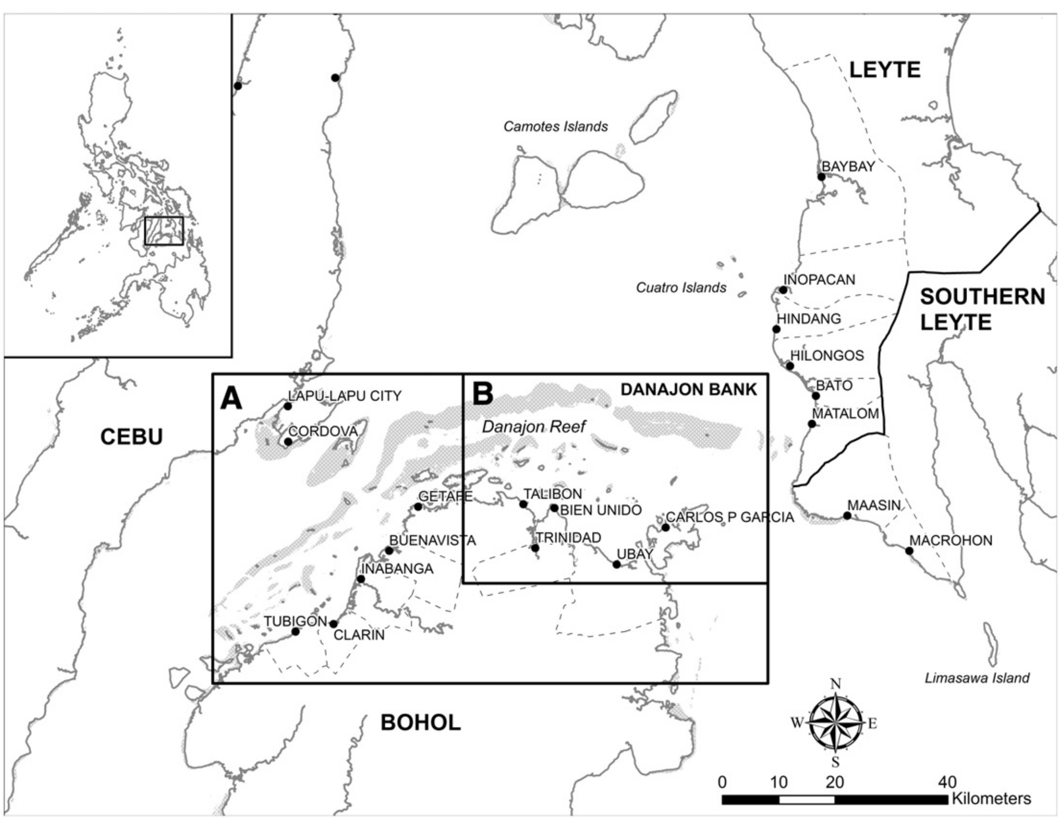

Fig. 1. The greater Danajon Bank (box A) and vicinity. The delineated area for the study's system model (box B) corresponds to the focal area of the Fisheries Improved for Sustainable Harvest (FISH) Project in northern Bohol, Philippines.