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Cascade effects and sea-urchin overgrazing: An analysis of drivers behind the exploitation of sea urchin predators for management improvement

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ABSTRACT

Marine ecosystems generate a wide variety of goods and services, but are globally deteriorating due to multiple drivers associated with anthropogenic activities. Intense fishing pressure can lead to changes in structure and function of marine food webs. Particularly overfishing of predatory species at high trophic levels can cause cascading effects leading to ecosystem degradation, affecting both marine organisms and people dependent on them. In the Western Indian Ocean region, intensive fishing takes place and degradation of coral reefs and seagrass beds has been documented. One reason behind this degradation is overgrazing by increasing numbers of sea urchins. An essential step towards better management is to thoroughly understand the drivers leading to such changes in ecosystems. Against this background, the general aim of this study was to gain understanding about whether sea urchin predators in the WIO region are fished, and to identify the drivers behind the fishing of these species. The study had four objectives: (i) to document if and how predatory fish eating sea urchins are caught in smallscale fisheries, (ii) to assess if, and if so why, sea urchin predators are targeted species, (iii) to assess if and to what degree local ecological knowledge (LEK) on ecological complexity involving sea urchins and their predators (e.g. trophic cascades) is present among local fishers, and (iv) to identify fishers' suggestions for management that can reduce problems linked to sea urchin overgrazing. The results show that all investigated species of sea urchin predators are fished by local small-scale fishers. Most sea urchin predators are not actively targeted, are not popular local food fish, and have minor use and economic importance for fishers. This stands in sharp contrast to their ecological keystone role by controlling sea urchin populations. The fishers' awareness and LEK were weak and partly lacking. Management suggestions targeted mostly the symptoms of food web changes rather than the drivers behind them.

Based on the results we suggest that management of degraded ecosystems, as a result of food web changes, should encompass a wide variety of strategies and scales. Specific suggestions for sea urchin predator management are education of local stakeholders on destructive gear effects and food web complexity, further investigations of catch- and release fishing as well as the use of selective gears.

1. Introduction

Anthropogenic disturbances cause increasingly negative changes to marine ecosystems around the globe, threatening the livelihoods of people depending on their goods and services (Halpern et al., 2008; Jackson et al., 2001; Lotze et al., 2006; MEA, 2003). One such disturbance is intense fishing pressure, which may lead to considerable changes in structure and functioning of marine ecosystems, like alterations of marine food webs (Jackson et al., 2001; Pauly et al., 1998). The drivers behind human

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activities leading to ecosystem changes are highly diverse. An essential first step to counteract or prevent negative changes is to understand the underlying drivers (MEA, 2003), such as those behind overfishing. A high fishing pressure on predatory species at the top of food webs can cause community-wide changes and cascading effects, which may potentially affect other levels of the food web (Menge, 1995; Pace et al., 1999; Pinnegar et al., 2000). Such trophic cascades are likely to develop in simple food webs (Pauly and Watson, 2005) involving keystone predators, which often are few in numbers and are specialized to prey on morphologically well-defended organisms such as sea urchins (Terborgh and Estes, 2010; Pinnegar et al., 2000).

Over the past four decades, increasing densities of sea urchins leading to overgrazing of seagrasses and bioerosion of corals have been documented more frequently (Alcoverro and Mariani, 2002; Eklöf et al., 2008; Heck and Valentine, 1995; McClanahan and Muthiga, 1988). One factor leading to such high sea urchin abundances and destructive grazing in seagrass beds and on coral reefs is the loss of top-down control due to intense fishing of sea urchin predators (Eklöf et al., 2009; McClanahan, 1992; McClanahan and Muthiga, 1989; McClanahan and Shafir, 1990). Alarmingly, coral reefs and seagrass beds are globally declining due to human disturbances (Bellwood et al., 2004; Duarte et al., 2008; Pandolfi et al., 2003; Waycott et al., 2009), and additional food web alterations could have further devastating effects (Baden et al., 2010; Duarte, 2002; Jackson et al., 2001; Moksnes et al., 2008). These shallow-water habitats provide a broad range of ecosystem services, which makes them indispensable for the everyday lives of people in many coastal areas, primarily as valuable fishing grounds in small-scale fisheries (de la Torre-Castro et al., 2014; Moberg and Folke, 1999; Unsworth and Cullen, 2010). In the Western Indian Ocean region (WIO), seagrass- and coral-associated fish contribute to a large part of the economy as well as the protein intake of coastal communities (de la Torre-Castro et al., 2014; de la Torre-Castro and Rönnbäck, 2004; Gullström et al., 2002; McClanahan, 2010; Thyresson et al., 2011). However, the use of destructive fishing methods like beach seines (used as drag-nets) leads to physical damage to seagrasses and corals, while gears with very small mesh sizes catch high proportions of juvenile fish and by-catch (Jiddawi and Öhman, 2002; Mangi and Roberts, 2006; Ochiewo, 2004). The use of such destructive gears, the open access character of the fishery, insufficient management, increasing tourism and a lack of livelihood alternatives has led to overexploitation and depletion of fish stocks throughout the WIO region, including both the Kenyan coast and Zanzibar (Jiddawi, 2012; Jiddawi and Öhman, 2002; McClanahan and Mangi, 2001; Ochiewo, 2004).

In the WIO in general, and along the Kenyan coast in particular, several events of seagrass overgrazing by dense sea urchin populations have been documented (Alcoverro and Mariani, 2002; Crona, 2006; Eklöf et al., 2009). Previous studies have shown that fishing of sea urchin predators (particularly finfish like the red-lined triggerfish *Balistapus undulatus*) has led to increased urchin densities on coral reefs and seagrass beds (McClanahan, 1992, 2000; McClanahan and Muthiga, 1989; McClanahan and Shafir, 1990). McClanahan (2000) found densities of sea urchin predators to be higher and sea urchin densities to be lower in protected areas, compared to fished ones, and McClanahan and Shafir (1990) suggested that the fishing of sea urchin predators is thought to have "disproportionate consequences" in the food web.

Examples from other parts of the world show comparable trophic cascades from overfishing, but that the drivers behind sea urchin predator overharvest can vary between ecosystems. For example, the overfishing of lobster on rocky reefs in Northeastern New Zealand was driven by its high commercial value and led to an ecological release of sea-urchins and overgrazing of kelp (Shears and Babcock, 2002). Along the Pacific coast of North America, overhunting of fur seals offshore forced their main predator – the killer whale *Orca orca* – to move inshore and switch to feeding on sea otters. This led to a trophic cascade where sea urchins – the main prey of sea otters – increased greatly in abundance, and subsequently overgrazed giant kelp, the habitat-forming species in the system (Estes et al., 1998). Understanding the drivers behind the exploitation of species with crucial ecological functions, such as sea urchin predators, is especially important for adequate management design. Although the drivers of overfishing in general in the WIO are well documented (McClanahan et al., 2008, 2005; McClanahan and Mangi, 2004), the specific drivers behind the exploitation of sea urchin predators are poorly understood. Therefore it is important to gain a better understanding of the factors contributing to the fishing of these species, to be able to design management that leads to well-functioning marine ecosystems.

Before designing management measures, it is further important to assess the local ecological knowledge (LEK) and awareness of local fishers about ecological complexity such as interactions between sea urchins and their predators. This is important as such assessments can provide a basis to address resource users' and stakeholders' knowledge gaps (Crona, 2006). It has further been shown that including LEK besides scientific knowledge can add valuable information when designing management schemes (Moller et al., 2004; Olsson and Folke, 2001), and that the inclusion of LEK can benefit managers when designing awareness programs aimed at enhancing compliance with management measures.

Against this background, the overall aim of this study was to gain understanding about whether sea urchin predators in the WIO region are fished, and to identify the drivers behind the fishing of these species. The study had four specific objectives: (i) to document if and how sea urchin fish predator species are caught in smallscale fisheries; (ii) to assess if, and if so why, sea urchin predators are target species; (iii) to assess if and to what degree local ecological knowledge (LEK) is present among local fishers (on ecological complexity involving sea urchins and their predators, e.g. trophic cascades); and (iv) to identify the fishers' suggestions for management strategies that can reduce problems with sea urchin overgrazing.

2. Material and methods

2.1. Theoretical framework

In this study, we used the term "drivers" as defined by the Millennium Ecosystem Assessment (MEA): "natural or anthropogenic factors causing changes in ecosystems" (MEA, 2003). Drivers can have direct impacts on ecosystem processes (e.g. physical, biological or chemical factors), as well as influence their wider scope (e.g. demographic, economic, sociopolitical, scientific, technological, cultural and religious factors). Many major ecosystem alterations are known to originate from multiple drivers on local, regional and/or global scales (MEA, 2003).

2.2. Study sites

The study was carried out in two areas of the WIO region: (1) the larger Mombasa area in the Coast province of Kenya, and (2) the coast of Unguja Island in the Zanzibar archipelago, Tanzania (from here on referred to as "Zanzibar") (Fig. 1). Typical features for these areas are intertidal lagoons characterized by seagrass beds, patch- and fringing coral reefs, and also mangroves. The fisheries are small-scale, artisanal and generate lowincome. Fishers targeting finfish are predominantly male, and use a variety of traditional and