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Editorial

Social-ecological traps in reef fisheries

There is a long history of research on social traps, which are situations where individuals or even whole societies "get started in some direction or some set of relationships that later prove to be unpleasant or lethal and that they see no easy way to back out or to avoid" (Platt, 1973, p. 641). Although the idea of social traps are prevalent in debates about the governance of natural resources (e.g. Hardin, 1968; Costanza, 1987), they have rarely been discussed using the resilience lens of linked social-ecological systems, which emphasizes feedbacks between social and ecological domains and the potential for phase shifts to alternative, less socially desirable, stable states (e.g. Hughes, 1994). Here, I discuss the idea of 'social-ecological traps' (sensu Steneck, 2009), which refer to situations when feedbacks between social and ecological systems lead toward an undesirable state that may be difficult or impossible to reverse. I synthesize recent research conducted on coral reef social-ecological systems in east Africa as a focal context for this discussion.

1. Potential feedbacks between social and ecological systems: missing or weak institutions, poverty traps and gear use ratchet down the fishery

There is an emerging literature on the ecological feedbacks that can lead to phase shifts (Nystrom et al., unpublished data; Steneck, 2009). Phase shifts are when ecosystems shift, sometimes rapidly and unexpectedly, from one stable state to another (e.g. Hughes, 1994; Hughes et al., 2007). For example, Steneck (2009) notes that removal of herbivorous fishes that graze coral reefs can result in algal overgrowth that makes the system hostile to recruiting corals. Consequently, fewer corals will persist resulting in an eventual collapse of the structural complexity of the reef that is critical for habitat and settlement of some key herbivores (Graham et al., 2007). These interactions create an alternate stable state that sustains fewer fish. As the resilience of a coral dominated system erodes, resilience builds for alternate configurations such as algal or urchin dominated systems (Bellwood et al., 2004). An important concept related to phase shifts is that returning to the original state may be difficult or impossible because there are non-linear relationships between drivers and responses, often described as thresholds (Hughes et al., 2010). The nature of these relationships means that once a system has been pushed beyond a threshold, it can "lock" in an undesirable state, at least in terms of timescale relevant to management and human use.

There are also social dynamics that often reinforce these ecological feedbacks, but these interactions between social and ecological domains that can lead to traps are poorly understood. One example of where these social-ecological linkages are beginning to be uncovered is the coral reef fishery in the western Indian Ocean (Cinner et al., 2009a,b, 2011). This emerging research suggests that there seem to be several key feedbacks between social and ecological domains that drive the system toward an undesirable social-ecological trap. These include: missing or weak institutions, interactions between poverty and resource use, and the use of specific technologies (Fig. 1).

Many developing countries lack adequate investment in research and management institutions that are thought to be critical for natural resource governance. In some cases, in place of the more formal governance organizations are informal institutions (Johannes, 1978, 2002). Research from both east Africa and the Pacific has found that certain informal institutions, such as taboos, can be effective at improving or maintaining ecological conditions in marine systems, even though the goals of such institutions tend to be social (i.e. equity, conflict reduction, providing fish for a feast) rather than conservation oriented (McClanahan et al., 1997, 2006). In places like Madagascar, these types of social controls have been shown to limit the use of specific gears and the closure of certain patches of fishing ground (Cinner and Aswani, 2007; Cinner, 2007). However these customary systems seem to break down when societies experience certain types of social and economic changes (Ruddle, 1994). For example, Cinner et al. (2007) found that customary management systems were absent in Papua New Guinean communities that were over 1000 people and closer than 16.5 km to provincial markets. These findings are broadly supported by research in forest systems that found the capacity of communities to employ or maintain monitoring (a critical component of making common property systems function) decreases when the size of the group gets too large (Agrawal and Goyal, 2001).

Another potential social-ecological feedback stems from interactions between poverty and resource use. Across five western Indian Ocean countries (Madagascar, Tanzania, Kenya, Mauritius, and Seychelles), the heaviest overfishing on coral reefs occurred in places with intermediate levels of development (Cinner et al., 2009b). Places with either very low or high levels of development (sites in Madagascar had the lowest and sites in Seychelles had the highest) tended to have reefs with about four times the reef fish biomass of the intermediate development sites. This depletion, particularly in the intermediate development sites may be reinforced by the ways in which people there respond to diminishing goods and services resulting from overexploitation. In Tanzania, fishers had heterogeneous responses to scenarios of decline, but on aggregate said they would respond to a 50% decline in catch by increasing fishing effort (Cinner et al., 2011). In Kenya, poorer fishers with fewer livelihood options were the least likely to be able to exit the fishery when resources decline severely (Cinner et al., 2009a). This is consistent with a broad body of literature on

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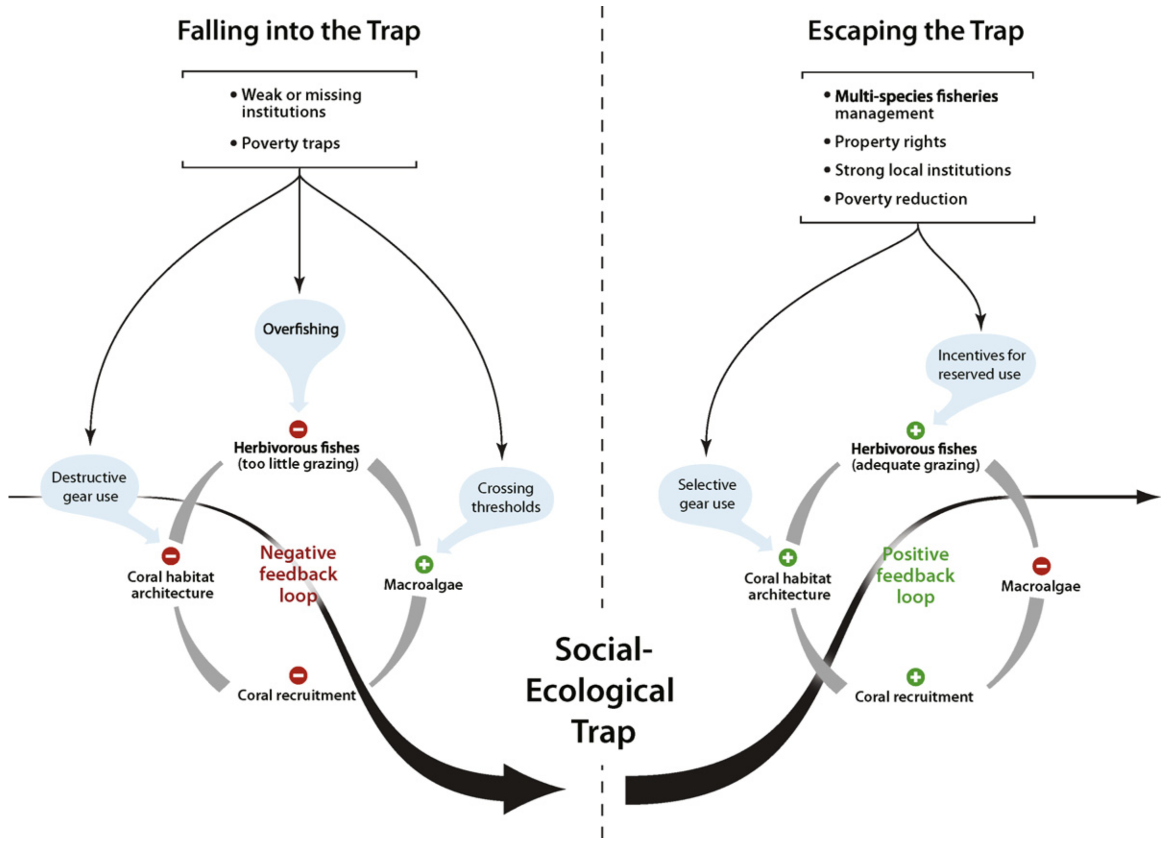

Fig. 1. Heuristic model of a social-ecological trap in coral reef fisheries. Drivers into social-ecological traps include poverty and weak (or missing) institutions, which can drive overfishing, destructive gear use and ultimately push social-ecological systems beyond key thresholds. These can reinforce ecological feedbacks in ways that drive the system toward less desirable states. Alternatively, multi-species fisheries management, property rights, strong local institutions, and poverty reduction can help to change the directionality of these feedbacks, for example by creating incentives for reserved use of the commons. The positive and negative labels for the feedback loops are normative, relating to what is generally considered desirable.

poverty traps, which are situations in which poor people are unable to mobilize the necessary resources to overcome either shocks or chronic low-income situations and are trapped in stable or increasing poverty (Adato et al., 2006; Carter and Barrett, 2006; Dasgupta, 1997). Often exacerbated by social exclusion, a lack of access to cash and credit can prevent the poor from accessing higher risk (and resultant potential income) livelihood strategies. Consequently, in a poverty trap situation, the poor need to protect their few assets and consequently choose livelihood strategies with low and short-term returns (Barrett et al., 2006b; Dasgupta, 1997).

Poverty and missing or weak institutions can set the stage for the use of technologies that are more damaging to the environment and reduce ecological resilience of the system (Walker et al., 2009). Importantly, the characteristics of the specific fishing activities associated with these sites have implications for the resilience of the system. Artisanal coral reef fishers use a range of gears, each of which target specific sizes and species of fishes. Critically, the gears predominantly used in the early and intermediate stages of socioeconomic development (gillnets and spear guns, respectively) target a very high proportion of key species that have feeding activities thought to be critical to the resilience of coral reefs, such as herbivory (Cinner et al., 2009b,c). Fishing activities in these places are likely to severely erode the resilience of coral reefs. Furthermore, poorer fishers in Kenya and Tanzania were more likely to use beach seine nets (Cinner, 2010) that can severely damage habitat and capture a high proportion of juvenile fish, diminishing reproductive potential (Mangi and Roberts, 2007). This, of course, further damages the fishery and has the potential to create a cycle of poverty and reef destruction. Thus, these locations may have a poverty trap that is likely to result in reef degradation.

Social drivers such as gear use, missing or weak institutions, and poverty traps act as strong attractors toward a social-ecological trap (Fig. 1). These ‘undesirable’ social drivers can intensify as the flows of goods and services diminish. In some situations, the associated scarcity of resources may create incentives for more intensive resource extraction which, in turn, can diminish both resources and the ecological capacity to maintain them, creating further scarcity (Pauly, 1990; Steneck, 2009). It is the reinforcing nature of these feedbacks between social and ecological domains that make the process a social-ecological trap that ‘ratchets down’ (sensu Birkeland, 2004) the fishery and leads toward an alternate ecosystem configuration that may be difficult to return from. These social and ecological interactions may result in a highly resilient, but extremely undesirable social-ecological system.

2. Avoiding social-ecological traps

Conceptualizing overfishing as linked social-ecological processes with critical feedbacks may help re-contextualize how it needs to be confronted in places such as east Africa. So far, marine conservation has largely relied on a model from developed countries that says that the number of people is the biggest threat to reefs. Consequently, conservation actions have largely focused on creating large marine parks to keep people out. This approach has produced significant results in places like Australia (McCook et al., 2010), but has not produced the tangible results we would like to see in many other places where poverty reinforces constant or increased resource extraction (McClanahan et al., 2006). Rather than largely focusing on goals of designating *x* or *y* percent of the oceans to be locked out of human use (Mora et al., 2006), we also need to be concerned with the likelihood of entrapment and the characteristics which predispose social-ecological systems to entrapment. Avoiding or escaping these traps will require creative solutions to address the underlying conditions that create undesirable interactions. Examples include multi-species fisheries management to maintain critical ecological functions throughout the seascape, the development of property rights and hybrid management to change incentives for resource exploitation, and policies to avoid or escape poverty traps (Fig. 1).

3. Multi-species fisheries management in the broader seascape

Even in multi-species reef fisheries, gear-based management has the potential to reduce fishing effort on specific species of interest while maintaining or even improving profits for fishers. For example, McClanahan et al. (2008a) note how in Kenya, heavy exploitation had caused fishers' catches to decrease by 40% between 1996 and 2000. In 2001, some communities began enforcing regulations banning destructive beach seine nets, resulting in a dramatic 30% increase in catch. However, in control sites that did not enforce these regulations, catch remained much lower, even dropping to ~$1/day. Importantly, experience in east Africa suggests that gear-based management that limits the use of spear guns and destructive beach seine nets has considerable support from coastal communities (McClanahan et al., 2005, 2008b) – a stark contrast to the intense conflicts that accompanied attempts to expand Kenya's national marine protected area network in the mid-1990s (Evans, 2009). Additionally, investments in modifying artisanal fishing technology, such as adding escape slots to basket traps, can reduce the capture of functionally important herbivores by over 55%, while still maintaining similar levels of profitability (Johnson, 2010). In places that can afford to fish conservatively, reproductive and ecological function can be maintained by 'slot' fisheries that only harvest intermediate sized fish (Steneck et al., 2009). Importantly, these fisheries management tools can help to maintain key ecosystem functions throughout the broader seascape.

4. Property rights and strong local institutions

Another part of the solution to escaping (or avoiding) social-ecological traps in marine fisheries may be the development (or maintenance) of property rights. Under the right conditions, property rights can provide incentive for sustainable use and reduce the prevalence of 'roving bandits' that can sequentially exploit species, particularly in open-access situations (Berkes et al., 2006; Gelcich et al., 2010). Perhaps the most vivid example of successful property rights establishment comes from Chile. In the mid-1990s the Chilean government developed delineated property rights for artisanal fisher organizations, resulting in 547 areas covering ~1000 km^2 (Gelcich et al., 2008, 2010). Designed primarily for the management of export-based benthic resources (e.g. *Concholepas concholepas*), these systems have significantly increased the abundance of nearshore fishes (Gelcich et al., 2008) and resulted in a phase shift back from an undesirable mussel dominated state, to a more desirable state dominated by gastropods, urchins, and algae (Gelcich et al., 2010). Promisingly, we are starting to see the emergence of property rights systems for coral reef fisheries in the Indian Ocean, particularly with Kenya's recent Beach Management Unit legislation that allows local communities to create by-laws regarding the use of local marine resources, and charge levies to, or exclude, fishers who are not local members (Cinner et al., 2009d).

Another emerging trend that may help communities avoid or escape social-ecological traps is the combining of local knowledge with contemporary science to develop 'hybrid' management systems (Aswani et al., 2007; Cinner and Aswani, 2007). In places such as Vanuatu and Solomon Islands, communities and scientists are working together to develop conservation programs that are based on local customs and designed to meet community needs. For example, emerging science on reef connectivity and Geographic Information System technology are being combined with local knowledge to determine where fishery closures should be placed (Aswani and Hamilton, 2004; Aswani and Lauer, 2006). In some cases, communities will harvest fish from these areas to provide food for culturally important occasions (Bartlett et al., 2009). Empirical studies suggest that these 'hybrid' systems are having tangible conservation benefits; when compared to nearby areas open to fishing, they have more than three times the biomass of fish vulnerable to overfishing inside periodically harvested areas in Vanuatu and two times the amount of herbivorous parrotfish in some community-based closures in Solomon Islands (Aswani and Sabetain, 2010; Bartlett et al., 2009). Importantly, the rules-in-use developed by these 'hybrid' systems are more likely to reflect local social, economic, and cultural conditions than those devised by technocrats in far away capital cities. This may help to garner the support required for local compliance in places where national enforcement capacities are lacking (McClanahan et al., 2006). At the same time, because the capacity to enforce is often very local, community-based management are often unable to deal with transgressions committed by 'outsiders' and in some cases break down rapidly when exposed to poaching (Cudney-Bueno and Basurto, 2009). Thus, one of the important properties of 'hybrid' management systems is their connections to resources and processes operating at larger scales (what is referred to as nested enterprises, Ostrom, 1990), which is expected to help provide support for dealing with encroachments by 'outsiders'.

5. Escaping or avoiding poverty traps

Importantly, studies have found that transitions into and out of poverty are quite dynamic, but that there are threshold levels of poverty that influence the types of livelihood strategies people pursue (Barrett et al., 2006a,b; Carter and Barrett, 2006; Krishna, 2006; Krishna et al., 2004). At the local level, efforts to avoid poverty traps for people on the edge will likely involve investing in 'social protection' programs that prevent a decline into poverty. These may include healthcare, family planning, and access to information and fair loans through social networks and mentoring (Barrett and Carter, 2001; Krishna, 2006; Krishna et al., 2004). Escaping poverty traps will require helping the poor build assets beyond the poverty trap threshold by: (1) improving the productivity of existing asset bases; (2) accessing new sources of productivity through diversified livelihoods; (3) increasing opportunities to access capital, credit, and insurance (which can help people develop and protect assets) (Adato et al., 2006; Badjeck et al., 2010; Barrett and Carter, 2001; Barrett et al., 2006a). However, to enable escape from a social-ecological trap, policies and incentives will be required to facilitate investments that do not amplify negative trends in the ecosystem, such as increased fishing capacity (Bene et al., 2010; Cinner et al., 2011). Social dimensions of poverty, such as marginalization, also need to be addressed.

6. Conclusion

Critically, the solutions necessary to avoid or escape social-ecological traps will be a substantial departure from the traditional expertise of many fisheries and park managers. Management will increasingly need to 'think outside the box', which will include: (i) developing novel partnerships with scientists (both social and natural), NGOs, and donors to address poverty reduction and institutional capacity building; (ii) engaging in active adaptive management experiments to determine whether and how management can actively reverse phase shift and break detrimental feedbacks in social-ecological systems; and (iii) focusing management actions at the scales relevant to key social and ecosystem processes and drivers (as opposed to small no-take reserves) (Hughes et al., 2005; Steneck et al., 2009; Wilson, 2006).

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