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ORIGINAL ARTICLE

To cope or to sustain? Eroding long-term sustainability in an Indonesian coral reef fishery

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Abstract Small-scale fisheries in coral reef areas support the livelihoods of millions of people worldwide. Anthropogenic impacts such as overfishing and climate change increasingly threaten both the reef ecosystem and the livelihood security of the people that depend on the reefs. Adaptive management strategies are needed to adequately deal with these threats, but they require an understanding of the underlying drivers, which often originate and act on multiple levels. Using a social-ecological system approach, the coral reef fishery of the Spermonde Archipelago in South Sulawesi/Indonesia is assessed to identify key drivers and strategic leverage points for management. Under the influence of international markets and technological changes, several export-oriented fisheries have developed in the area that led to distinct subsequent peaks in fishing activity in a pattern of sequential marine resource exploitation. In response to stressors such as seasonality and overfishing of individual locations or species, a number of coping strategies have developed locally. These include extensive borrowing from fishing patrons, diversification of fishing methods, fishing migrations, and the crafting of local institutions to regulate fishing activity. However, the coping strategies hinder, and even decrease, the capacity of the system to adapt to future stressors and undermine the sustainability of the fishery. Potential strategies that target different levels of the fishery system in order to strengthen adaptive management are identified.

Keywords Adaptive capacity · Coping strategies · Indonesia · Precious corals · Sea cucumbers · Spermonde Archipelago

Introduction

Small-scale marine fisheries employ the vast majority of fishers worldwide. Over 90 % of them are located in developing countries, where they contribute significantly to food security and livelihood strategies among the coastal population (Berkes et al. 2001). Coral reefs in particular are important fishing grounds for tropical coastal communities, and it has been estimated that hundreds of million people depend on fish catches from reef areas for their livelihood (Whittingham et al. 2003). As coral reefs are becoming increasingly threatened by anthropogenic influences such as habitat degradation and changes in ocean chemistry, so are the livelihoods of the people associated with these ecosystems (Burke et al. 2011). At the same time, coastal and fisheries management in tropical countries still often is inadequate to sustain coral reef resources and their use (Mora et al. 2006, 2009). A sound understanding of coral reef fisheries and their underlying drivers is thus needed in order to steer coral reef fisheries toward more sustainable paths.

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Among the defining features and potential drivers for these fisheries are natural factors and drivers such as ecosystem configuration and climate, as well as social and economic factors and drivers such as demand for resources and products, technological innovation, knowledge, supply of equipment, policies, and formal as well as informal institutions including social networks. Ecosystem configuration determines resource diversity and has a decisive role in the development of particular fisheries. Systems with a high abundance and biomass of a specific species, a situation often encountered in temperate regions, can contribute to the development of specialized fisheries, which may lead to a high dependency vulnerable to breakdown. One of the most famous examples is the collapse of the Northern cod fishery in Canada in the 1990s. As a result of overfishing, thousands of fishermen and plant workers were left unemployed. In tropical areas (with the exception of upwelling regions), ecosystems are generally more diverse, and the associated fisheries thus tend to be more diversified in terms of target species and gears (Pauly and Murphy 1982). Climate is another factor which has a considerable influence on fisheries systems. Regions under monsoon influence are hotspots of climatic variability. Fisherfolk in these areas respond to wind and precipitation changes, for example, by changing fishing effort, target species, or fishing grounds (van Oostenbrugge et al. 2001; Teh et al. 2007). Social factors can also crucially affect the characteristics of a fisheries system. Social networks play an important role for the choice of target species and fishing techniques (e.g., Crona et al. 2010; Merlijn 1989). In many fishing communities throughout the world, traditional management systems still define ownership of and access to marine resources (Whittingham et al. 2003).

The Spermonde Archipelago hosts one of the largest coral reef fisheries of Indonesia. For centuries, the region has been known for its enormous abundance in marine resources. Historical narratives from Dutch colonial times illustrate the importance of Spermonde for the trade in valuable marine commodities, especially sea cucumbers (also known as *trepang*; Schwerdtner Máñez and Ferse 2010). As sea cucumbers were not consumed by the local fishing communities, the demand for these goods came solely from distant markets and led to the development of large trading networks. In this way, Spermonde's inhabitants became connected to traders and consumers in other parts of the world, mainly China. Political, social, and cultural developments in such distant markets affect preferences for specific commodities and thus impact fishing activities until today. This is because Spermonde islanders strongly depend on marine resources, both for subsistence and for sale as part of their livelihood strategies. Bio-geographical conditions of the tiny coral atolls hardly provide possibilities for land-based alternatives. The proximity of Makassar, which has been a major trading hub for marine commodities at least since the seventeenth century, certainly strengthens the importance of trade (Schwerdtner Máñez and Ferse 2010).

Chinese sea cucumber traders began visiting Makassar in the seventeenth century, when the increasing demand in China exceeded the supply from proximate waters. Spermonde soon became an important collection ground, and the supplier of the highest quality of sea cucumbers, in particular of *Holothuria scabra* and *H. nobilis* (Sutherland 2000). In contrast to sea cucumbers, up until the twentieth century, fish catch in Spermonde was predominantly consumed locally. Part of the catch was sold on the fish market in Makassar and contributed to its vast diversity (Weber-van Bosse 1904). Commercial fishing increased with the use of explosives during World War II. Following independence in 1949, a period of political instability ensued, and fighting caused many islanders to flee from Spermonde, leading to a decline in fishing activities. Many inhabitants returned after 1968 when the political situation became more stable. Since the 1970s, a combination of technical developments and new preferences for specific marine products has caused the development of consecutive waves of marine resource exploitation. For centuries, the biodiversity-rich marine waters of Spermonde seemed to offer unlimited options for commercial use. But what was thought to be an almost inexhaustible abundance of marine resources is now increasingly showing signs of overexploitation. High-value species such as the sea cucumbers *Holothuria nobilis* and *H. scabra* or the humphead wrasse *Cheilinus undulatus* have virtually disappeared from many reefs in Spermonde (Johannes and Riepen 1995; Massin 1999).

Each of the specific fisheries in Spermonde developed under the influence of a number of distinct factors, taking effect on different spatial and temporal levels. Analyzing such a system requires an approach which considers both its ecological and social dimensions, as well as its drivers at the local, regional or global scale. Social-ecological system analysis offers a possibility to analyze complex systems as what they are: the product of multi-level and cross-scale dynamics. Utilizing an explicitly problem-focussed definition, a social-ecological system (SES) is comprised of three elements: (1) a bio-geo-physical system such as the Spermonde Archipelago, (2) its associated social agents with their institutions which are not necessarily situated within the bio-geographical system, and (3) a specific problem-context, such as the depletion of a specified (set of) resource(s) (Glaser et al. 2010b).

This paper analyses the Spermonde coral reef fishery as a social-ecological system beset by resource overexploitation, trying to identify the major drivers behind the exploitation of selected marine resources of particular economic importance. In an explicitly cross-scale and multi-level analysis, we examine the rise and fall of specific forms of exploitation as a result of influential local, regional, and global drivers.

With this thematic focus, we aim to identify strategic points of management leverage to help move Spermonde reef fisheries onto more sustainable trajectories of change. Our explicitly multi-level social-ecological system definition sets the stage for this scale-sensitive analysis.

Materials and methods

The region of study, the Spermonde Archipelago off the coast of South Sulawesi, Indonesia, consists of some 70 islands on a shallow shelf extending up to 80 km offshore (Fig. 1a), about 50 of which are inhabited. The majority of the islands belong to two administrative units, the municipality of Makassar and Pangkep regency.

This analysis is based on investigations conducted by an Indonesian-German research team under the umbrella of the Science for the Protection of Indonesian Coastal Ecosystems (SPICE) program in Cluster 6 (Governance and Management of Coastal Social-Ecological Systems). SPICE is a cooperation between the Center for Coral Reef Research (PPTK) of Hasanuddin University (UNHAS) and the Leibniz Center for Tropical Marine Ecology (ZMT) in Bremen, Germany. SPICE Cluster 6 researchers and students have been undertaking research in the Spermonde Archipelago since 2007. The work included three 10-day research excursions to the Spermonde islands in 2009 and 2010, each with over 20 members from natural and social science disciplines. Employed methods included focus group discussions with elder and young women, fishers, and middlemen (Glaser et al. 2010c), as well as classical survey and anthropological work, in 18[1] of the inhabited islands of the Spermonde Coral Reef Archipelago (Fig. 1a).

A range of open-ended key informant interviews was conducted between 2005 and 2008 with traders, fishers, company owners, and village elders, to elicit qualitative information, for example, on major fishing methods, trade structures, major challenges faced by the island communities, and ways in which the communities cope with these challenges. Respondents were selected in a convenience sampling approach. This information was used for a qualitative assessment of the major drivers behind selected fisheries, stressors facing the Spermonde reef fishery, and coping strategies adopted by the island communities. In addition, questionnaire-based interviews ($n = 54$) were conducted with fishermen and middlemen involved in the ornamental coral fishery on Barrang Lompo and Karanrang, selected by convenience sampling, to obtain quantitative information on the fishery, livelihoods of ornamental fishers, and the roles of middlemen in the fishery (Ferse et al. 2012). In the second half of 2008, a questionnaire-based survey of every second household ($n = 180$) was conducted on Badi island in relation to the introduction of mariculture activities on the island. The head of each household was interviewed. Where the (male) household head was absent, a surrogate was interviewed (usually the wife). Each respondent's main occupation was recorded. The guidelines for the focus groups and interviews as well as the questionnaires used are provided as Electronic Supplementary Material.

For our assessment, we define *driver* broadly as 'any factor that changes an aspect of' the social-ecological system (MA 2003:15). Following Kolasa and Pickett (1992:12), we define *stressors* as those factors that impair the function of SES components, which 'may or may not be associated with the loss of components'. We adopt the IPCC definition of *coping responses* as 'the use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions' (IPCC 2012:33), while *adaptive responses* are the 'adjustment to actual or expected' impacts in order to 'moderate harm or exploit beneficial opportunities' in an 'ongoing process that encompasses responses to many factors, including evolving experiences with both vulnerabilities and vulnerability reduction planning and actions, as well as risk perception' (IPCC 2012:443). Coping thus refers to short-term responses, while adaptive responses generally involve long-term processes. While data collection included various aspects of the life of island communities and the environment of Spermonde, the present assessment focuses on those factors related to fisheries.

In addition to field research, data were collected from the literature. Available government documents and statistics on the capture and trade of marine organisms were compiled from visits to the South Sulawesi Department of Fisheries and Marine Affairs (DKP) and the Department of Industry and Trade as well as from the webpages of the Ministry of Marine Affairs and Fisheries (http://statistik.kkp.go.id/) and the South Sulawesi Department of Industry and Trade (http://www.disperindagsulsel.go.id/).

This paper draws on and reviews findings from these various pieces of research for a social-ecological assessment of the Spermonde fishery.

Results and discussion

Marine resources in island livelihoods

Marine resources in the Spermonde Archipelago are the mainstay and, for the majority of households, the only natural capital to support their livelihood. Considering the

[1] The islands of Badi, Bangko Bangkoang, Barrang Caddi, Barrang Lompo, Bone Tambung, Gondongbali, Kapoposang, Karanrang, Kodingareng Lompo, Langkai, Lanyukang, Polewali, Sabangko, Sabutung, Sagara, Sarappo Lompo and Saugi, which are permanently settled, and the island of Jangang-Jangangang on which fishing camps regularly take place.

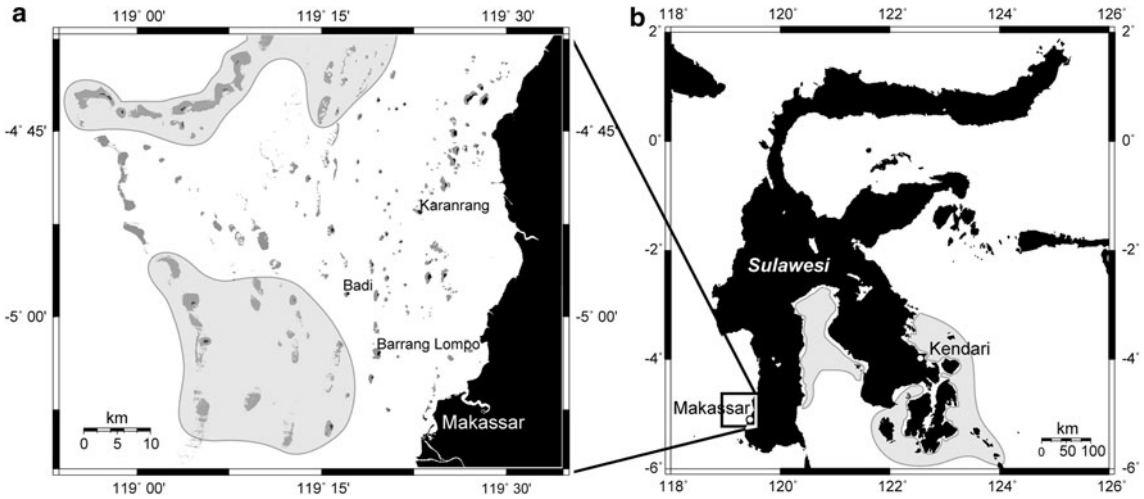

Fig. 1 Map of the study area (**a**), showing the location of the three major research sites (Badi, Karanrang and Barrang Lompo). The location in relation to the island of Sulawesi is indicated by the inset in **b**. During the southeast monsoon, the major fishing grounds of Spermonde fishermen are within the Spermonde shelf area (indicated by the two *shaded areas* in **a**), while fishing activity shifts to more protected areas in the Bay of Bone and Southeast Sulawesi during the northwest monsoon, when weather conditions in Spermonde are rougher (**b**)

geo-physical contexts including low per capita land availability, poor soil conditions, and an extremely limited freshwater supply (Schwerdtner Máñez et al. 2012), fisheries are the only income source for most Spermonde islanders. The household survey on Badi Island revealed that a high proportion of occupations directly depend on marine resources (Fig. 2). Over 70 % of the male respondents were fishermen. More than half of the female respondents were housewives, the majority apparently with husbands in fishing. One old widow constituted the only female fisher. Other female occupations comprised sellers of various items (29 % of women) and other small jobs. Within fishing households, there was little occupational diversity: men, in most cases from several generations, fished, while women worked in the house or in petty trade. When family connections between households are considered, at least 80 % of all households on Badi Island are directly or indirectly dependent on marine resources. On other islands in Spermonde, household dependence on marine resources is equally high (Deswandi 2012).

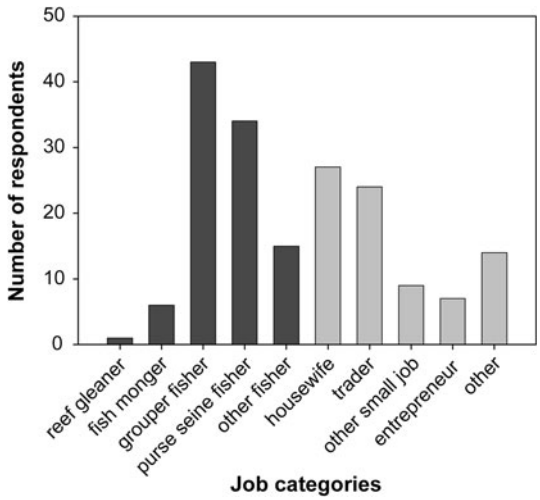

Fig. 2 Job categories of representatives of 180 households on Badi Island. While major types of fishing usually differ from island to island, the level of reliance on marine resources is similar. *Dark shaded bars* indicate jobs directly dependent on marine resources. In addition, respondents who rely on other household members for income generation (e.g., housewives, part-time workers) may depend on marine resources indirectly

Current status of the Spermonde reef fishery

The reef fishery in Spermonde displays a high degree of spatial and temporal variability, as well as a diversity of fishing methods and target species.

A wide array of different fishing methods currently operate within Spermonde (Table 1). Some of these are used in combination by the same fishermen (e.g., line fishing in combination with fish attracting devices, or cyanide fishing in combination with compressor diving). Islands usually differ in terms of the predominant fishing methods employed by residents. For instance, while the small island of Bonetambung is known for the predominant use of bamboo fish traps, other islands are notorious for the widespread use of bomb- and cyanide fishing. Others, located more inshore in areas with high sediment input and less reef development, specialize in the use of crab traps and mini trawls. Several of the closely reef-associated fisheries are best defined via the method used, rather than by target species. Instead of being specific grouper, sea

Table 1 List of different fishing methods used in the Spermonde Archipelago. Modified and expanded after Pet-Soede et al. (2001)

Category	Gear type	Local name	Target species	Main market	Legal status
Hook and line	Horizontal longline	Rawe	Lutjanidae, Carangidae, Serranidae, Nemipteridae	Local	Legal
	Vertical longline	Rinta	Clupaeidae, pelagic bait fish	Local	Legal
	Trolling for piscivores	Kedo-kedo	Serranidae, Scombridae	Local/ export	Legal
	Trolling for squid	Doang-doang	Teuthida	Local	Legal
	Octopus bait	Pocong-pocong	Octopoda	Local/ export	Legal
	Shark bait	Tomba	Carcharhiniformes, Batoidea	Local/ export	Legal
Net	Gill net	Lanra	Clupeidae, Carangidae	Local	Legal
	Crab and shrimp gill net	Lanra	Crustacea	Local	Legal
	Scoop net	Sero	Pomacentridae, other small ornamentals	Export	Legal
	Purse seine	Gae/Rengge	Clupeidae, Engraulidae, Carangidae	Local	Legal
	Danish seine	Gae/Rengge	Leiognatidae, Synodontidae	Local	Legal
	Mobile lift net	Bagang Lopi	Carangidae, Clupeidae, Engraulidae, Teuthida	Local	Legal
	Stationary lift net	Bagang Tancap	Clupeidae, Leiognatidae, Teuthida	Local	Legal
	Beach seine	Jaring (mairo)	Miscellaneous	Local	Legal
	Mini trawl	Rere/Renreng	Miscellaneous	Local/ export	Illegal
Traps	Fish trap	Bubu	Lethrinidae, Lutjanidae, Serranidae	Local/ export	Legal
	Crab trap	Rakkang	Crustacea	Local/ export	Legal
	Flying fish trap	Buaro/Bale-bale	Exocoetidae	Export	Legal
Others	Compressor diving	Penyalam/ Hookah	Holothuridae, Gastropoda, Nephropidae, Anthozoa	Export	Legal
	Spear gun	Patte'	Lutjanidae, Scombridae, Serranidae, Scaridae, Siganidae, Acanthuridae	Local	Legal
	Reef gleaning	?	Gastropoda, Bivalvia	Local	Legal
	Fish Attracting Device	Rumpon	Various pelagic fishes	Local/ export	Legal
	Blast fishing	Pembom/ Panges	Various fishes	Local	Illegal
	Cyanide fishing	Pembius/ Paselang	Live ornamental and food reef fishes, Nephropidae	Export	Illegal

cucumber, or ornamental coral fishers, for example, there are hookah divers, collecting a range of different organisms, versus fishermen using lines or nets to catch various reef-associated fish species (see also Ferse et al. 2012).

In terms of environmental impact and local consumption, a few practices, such as blast fishing, are particularly prominent. Pet-Soede and Erdmann (1998a) estimate that 10–40 % of the fish on local markets are caught using blast fishing and that around 15 % of the fishers on Barrang Lompo, one of the centers of this activity, derive their income predominantly from blast fishing. Besides the fisheries producing predominantly for local consumption, a few fisheries cater almost exclusively to international markets (Table 1). These export-oriented fisheries are of major importance for a number of reasons: First, they usually generate substantially more income than fisheries for local markets. For example, fishers in the live food fish trade can earn 3–10 times the average salary of other artisanal fishers (Erdmann and Pet-Soede 1996). Second, as the target markets are vast, demand often does not cease until the resources are depleted, with considerable environmental consequences. Third, export-oriented fisheries

require management strategies that go beyond the level of local and regional actors and institutions, where current management approaches are focused.

The technology and infrastructure for several fisheries is often similar. For instance, compressor diving and holding tanks or cages are used by the live reef food fish and the marine ornamental fisheries. The same boat types are used in a range of fisheries, such as trolling, compressor diving, or the setting and collection of traps and gill nets. This facilitates the addition of new target species to a fisher's portfolio once market opportunities arise.

Within Spermonde, a wide range of patch reefs are targeted, with fishermen choosing their fishing grounds based on target species, equipment being used, and weather conditions. During the southeast monsoon, which usually lasts from May to October, submerged reefs and outershelf islands in the south- and northwest of the archipelago are the major fishing grounds (Fig. 1a). During the northwest monsoon, between November and April, weather conditions in Spermonde make fishing trips to the outershelf regions unsafe. In response to this seasonality, fishing migrations (*Sawakung*) take place that lead fishers from Spermonde to the protected waters of Bone Bay and the islands off southeast Sulawesi (Fig. 1b). During this time, entire fishing crews and captains may leave their houses in Spermonde for several months and move to the regional capital Kendari, from where they operate.

The high diversity of fishing grounds, fishermen, and fishing methods that occur and often compete in Spermonde has led to the emergence of a variety of informal institutions on fishing activity in the area. They consist of highly context-dependent rules, which often refer to particular fishing gears, and may differ from island to island (Deswandi 2012; Glaser et al. 2010a). Fishing activity in waters around inhabited islands usually is more regulated than around submerged reefs or islands without inhabitants. As these institutions have developed throughout the past few decades without central coordination (Deswandi 2012), the result is a diverse and sometimes conflicting mosaic of island-specific rules, supported by a range of perceptions, norms, and values regarding marine resources and fishing activities throughout Spermonde.

Trends in the reef fishery over time

Most of the fisheries for local markets have existed in the area for many decades. Blast fishing has been practiced at least since World War II (Pet-Soede and Erdmann 1998a). The most recent innovations include the use of artificial bait (*pocong–pocong*) to catch octopus, which has spread among fishers on the islands within the past few years. For export-oriented fisheries, the response to new market opportunities has resulted in the successive adoption of at least four distinct fisheries since hookah diving was introduced to the area in the 1970s (Fig. 3).

Sea cucumbers have been collected in the area and exported to China since at least 300 years (Schwerdtner Máñez and Ferse 2010). When compressors where introduced in the 1980s, the collection of sea cucumbers reached unprecedented volumes (Tuwo and Nessa 1991; Tuwo 2004; DKP 2011; Fig. 3a), but the amount of animals in Spermonde has declined rapidly as a result (Hoeksema 2004). Nowadays, sea cucumber landings in Spermonde consist mostly of specimens collected off the coast of Kalimantan and in eastern Indonesia.

In combination with cyanide, compressor diving was used to gather live groupers for export predominantly to Hong Kong. Accurate data on the collection of live groupers are notoriously difficult to obtain, as monitoring by the regional fisheries department is often incomplete due to lack of personnel, funds, field access, and training. Nonetheless, landings data for Pangkep regency and Makassar municipality indicate a peak in grouper capture during the mid-1990s (DKP 1975-2009; Fig. 3b). These data agree with a catch estimate of 45 tons per month for the late 1990s (Pet-Soede and Erdmann 1998b). During the 1990s, about half of the total grouper production in Makassar consisted of live specimens (Erdmann and Pet-Soede 1996), and based on personal observations, this proportion appears to have increased in recent years.

In the late 1990s, the infrastructure that had been developed within the live reef fish fishery (boats, compressors, holding facilities, and links to exporters in Makassar), and the rapid devaluation of the Indonesian Rupiah during the Asian Financial Crisis of 1997/1998, spurred the adoption of another export-oriented activity: the collection of living corals and fishes for the marine ornamentals trade. Most of the fishermen involved in the coral fishery took up coral collection around the year 2000 (Ferse et al. 2012; Fig. 3c). Similarly, the export of ornamental fish from South Sulawesi peaked in 2005 (DISPERINDAG 2006, 2007, 2008, 2009; Fig. 3c).

The fourth and most recent trend was the collection of Bamboo Coral (*Isis hippuris*), a slow-growing gorgonian species. Export data at the provincial level indicate an initial peak in 2006, followed by a surge in export that coincides with the major collection activity in Spermonde, and reveal China as the major export destination (DISPERINDAG 2006, 2007, 2008, 2009; Fig. 3d). The fishery for bamboo coral reportedly began in the Bay of Bone in early 2005, but had been banned there by the regional fisheries department in 2006. In 2008, fishermen began to collect Bamboo Coral in Spermonde, probably a substitute for the stopped activities in Bone Bay. Whether the ban was effectively enforced, or the resource was simply exhausted in Bone, is unclear. At any rate, the amount

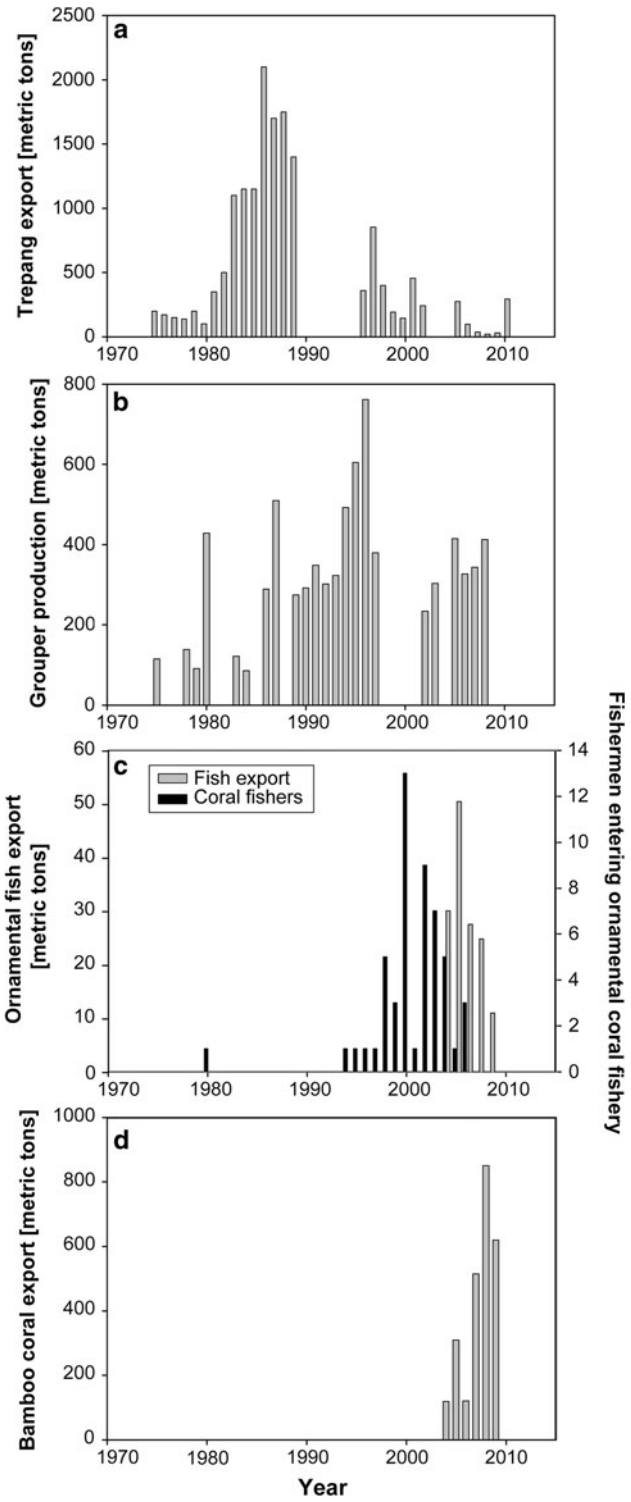

Fig. 3 Consecutive peaks in sea cucumber (**a**), live grouper (**b**), ornamental (**c**), and bamboo coral (**d**) fishery activities in Spermonde. Note that the data are compiled from various sources and that **c** comprises data from the collection of ornamental corals and fishes (see details in text)

exported rose dramatically beyond the levels previously collected in Bone. A possible reason for this may have been a policy change in China (G. Tsounis, pers. comm. 2010). In 2008, China added four species of precious Red Coral to CITES Appendix III following national legislation on its protection (CITES 2008). The CITES listing restricted the international trade in the Red Coral species, which seems to have resulted in the use of Bamboo Coral as a surrogate in the production of coral jewelry in China. The collection of Bamboo Coral in Spermonde was also short-lived. By 2010, no more collection was observed in the area. It is not entirely clear whether this is due to changes in the market, enforcement of regulations on the fishery, or an overharvesting of the coral in the archipelago.

The consecutive peaks in fishing activities appear to become shorter with each new activity. While this observation has to be treated with caution because of the differences in data used, there appears to be a trend of shifting from abundant resources, which are targeted first, to less and less common species. While the appearance of new fisheries is largely caused by new market opportunities and technological changes, it is somewhat difficult to ascertain whether the consecutive declines are due to new market opportunities, overfishing, or enforcement of regulations. All factors are likely to play a certain role, but several lines of evidence point to overfishing as the most important aspect: first, demand on international markets has not decreased for any of the resources considered, and collection of each of them continues on a low scale. Second, a number of ecological studies have reported dramatically declining abundances and unsustainable levels of harvest (e.g., Hoeksema 2004; Bruckner and Borneman 2006). And third, there are either no regulations for these fisheries (in the case of sea cucumbers), or legal enforcement is highly ineffective (in the case of cyanide and ornamental fishing; see Erdmann and Pet-Soede 1996; Ferse et al. 2012). Although distinct peaks in the different fisheries are discernible from trade and capture data, permanent declines in marine resources are not readily acknowledged by fishermen. Many attribute perceived changes in abundance to natural fluctuations, stating that fishes have 'moved elsewhere'. Furthermore, there is a widespread perception that 'there is a *punggawa* [patron]' for anything that fishers collect and that there always will be another marine resource to be targeted in case a particular species should become scarce.

Patron–client relations and social security

The social and economic dynamics of the Spermonde region is centrally affected by the roles and actions of local patrons (*punggawas*) and other middlemen. Following the definition of Ferse et al. (2012), there are three major types of middlemen in the Spermonde coral reef fishery. These are small and big patrons, and transport middlemen. Patrons provide fishing gear and credit to fishers, while

transporters do not provide loans but are responsible for bringing catches from the islands to Makassar. Small patrons usually focus on one particular fishing activity and often fish themselves or act as boat captains. They are also characterized by providing a kind of social security or displaying strong reciprocal social ties with fishers and are often called upon to provide finances or personal support for family affairs such as weddings. With big patrons, who diversify their economic activities beyond single fisheries and individual boats, such social ties are increasingly less prominent. As fishing is an almost exclusively male activity in Spermonde, the clients are usually male only. Patrons on the one hand initiate and enable the ongoing destructive and unsustainable trajectory of fisheries by providing gear, access to markets (via contacts, licenses and transport facilities) and by providing credits for investment in fisheries equipment (Ferse et al. 2012). In order to repay these loans, fishermen are required to sell their catch to the patrons at prices below current market prices. By gaining access to markets for additional marine products or new fishing gear through the patron networks, fishers have been able to cope with crowding or overfishing in individual fisheries. Furthermore, patrons often provide fishermen with illicit fishing gear and protect them from prosecution, using links to the military and law enforcement agencies. Thus, they are instrumental in driving the ongoing and often destructive fishing activities in Spermonde. However, this is not to say that the blame for unsustainable fishing practices is to be placed exclusively on patrons. Lack of enforcement on behalf of government institutions, international consumers with limited concern for the sustainability of marine products, and limited ecological literacy of fishers contribute to the current fishery situation. The clearly (ecological) sustainability-reducing aspect of the role of patrons contrasts with their role in providing social security to those most vulnerable in the fisheries system, to the fishing laborers and their families. Thus, women in client (*sawi*) fishing households habitually borrow from patrons if husbands are out for a long time or cannot fish. In local off-seasons, patrons provide extended family networks beyond the home islands of their respective *sawis* which enable spatially more dispersed year-round fishing activities to cope with seasonality and sustain household livelihoods.

Flows of marine resources and information

Sea cucumbers, live corals and fishes, crabs, fish roe, and precious coral skeletons are gathered from local reefs, collected in the houses of traders on certain islands, and transported to Makassar, from where they are exported, either directly or via Bali, Surabaya and Jakarta, to East Asia, Europe and the United States. Along this chain, the price of the commodities increases considerably. The price that fishers fetch for sea cucumbers ranges from about 6–32 USD kg^{-1} for salted animals, while middlemen in Makassar sell dried specimens from 6 to >200 USD (Dumestre 2010). For ornamental corals, fishermen receive from about 0.2–1.7 USD per piece, while the trading companies in Makassar sell them for about 1–5 USD. Retailers in the US or Europe sell corals for 35–80 USD (Ferse et al. 2012). Live grouper fetch around 5–18 USD kg^{-1} for fishers, 25–50 USD for exporters, and 70–180 USD at wholesalers and restaurants in Singapore and Hongkong (Erdmann and Pet-Soede 1996; Deswandi 2012). Figure 4 shows that the major flows of marine products and information on the social side of the multi-level Spermonde reef fishery system are between the local and the international levels of this SES. Market information is passed down to individual fishermen via the chain of exporters, transport middlemen and patrons. Along this chain, information becomes distorted and modified according to the interests of actors at each level. For example, in group discussions on the islands with fishers and patrons, the latter would often express views such as 'there will always be fish in the sea, as long as there are leaves on the trees'. Conversely, patrons receive catches from a number of associated fishermen. Thus, experiences of diminishing resources or catch failure that may be felt by individual fishermen may be masked as long as other fishers are still able to return catches to the island. This aspect is reinforced even more in a society where social hierarchies do not encourage opinions to be voiced by those on a lower social level (Glaser et al. 2010c). As a consequence, the perception of ecological change by patrons who do not fish themselves may be altered so that environmental warning signals are not passed up the trade chain.

Currently, fisheries management takes place primarily at the regional level. Quotas for collection and export of restricted species such as corals and certain threatened fish are set by the Department for Environmental Conservation and Forest Protection (BKSDA). Patrolling of fishing grounds and enforcement of formal rules is carried out by the provincial Department of Fisheries and Marine Affairs (DKP), and the navy and water police in Makassar. Actual collection of fishery data at the fishing grounds or upon landing on the islands is limited by the available financial and personnel resources. Data on fishery catches are thus predominantly collected from traders and at major fish landing sites in Makassar.

Important drivers and stressors in the fishery

From discussions and interviews with fishers and middlemen and an analysis of fishery production, the factors

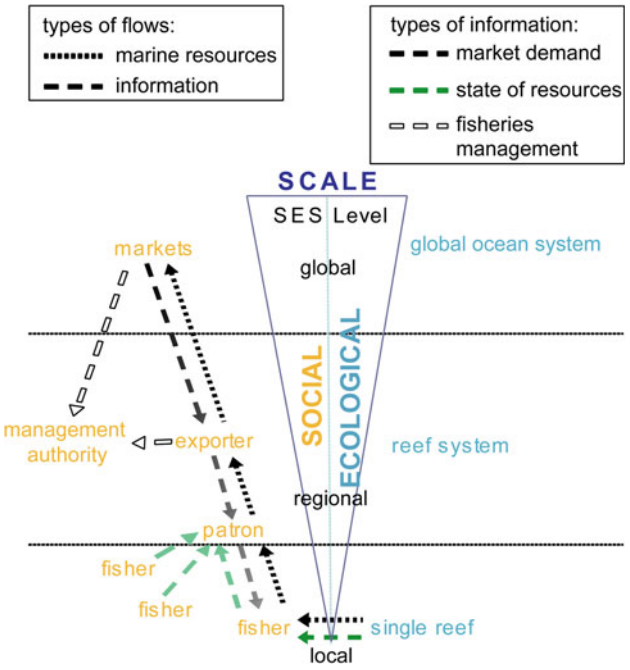

Fig. 4 Flows of major marine resources and information between actors on multiple spatial levels in the Spermonde reef fishery. Marine resources are supplied to international markets via a chain of fishermen, patrons and exporters. Information on market demand is supplied to fishermen via the same chain in reverse order and is filtered along the way. Patrons receive information on the state of resources from a multitude of fishermen supplying catch to them. State regulation of the fishery takes place at various levels within the region and relies on data derived from exporters and information from international markets

demand, technological innovation, knowledge, indebtedness, and fisheries policy emerged as important drivers of the fishery in Spermonde. As marine resources are the only available natural capital for most households in Spermonde, the need of local inhabitants to generate an income is the most ubiquitous proximate driver in the fishery. Demand for marine resources stems both from local demand for marine products (which is mostly from Makassar and other cities in Indonesia, as well as some local consumption on the islands, consisting for the most part of lower-value fish species and invertebrates) and of international markets. The latter are behind several of the highest-value fisheries in Spermonde, such as those for groupers, tuna, sharks, crabs, ornamental fish and corals, sea cucumbers, and flying fish roe (Table 1). As the prices for export commodities such as grouper are calculated in dollars, the depreciation of the Indonesian Rupiah in the late 1990s has further spurred the intensity of these export-oriented fisheries. Technological innovation in many cases has led to the adoption of unsustainable practices. Introduction of the use of explosives or potassium cyanide has resulted in the spread of the most destructive fishing practices in the region. As described above, the spread of compressor diving has facilitated the adoption and intensification of several fisheries. In other cases, such as the adoption of artificial octopus bait, it has simply enabled fishers to specifically target certain resources and broaden their spectrum of fishing activity. Another important consideration, particularly for fishers, is their perception on the inexhaustibility of marine resources and on their patrons' willingness to buy any marine resource that the fishers could find in the sea (see Ferse et al. (2012) for a further discussion of this point). Together with the need to repay loans from patrons, these perceptions led to the continuation and intensification even of highly destructive fishing methods. Fisheries development was also influenced by some of the Indonesian five-year-plans, called REPELITA. REPELITA II (1974–1979) induced the establishment of a central fish market in Makassar with a government employee to supervise transactions, which greatly improved selling possibilities for local fishermen. REPELITA III (1979–1983) allowed foreign vessels to fish in Indonesian waters. Hong Kong fishermen introduced new trends and techniques such as capture of live reef fish, or cyanide fishing, which were then taken over by the locals. REPELITA VI (1994–1999) aimed explicitly at the development of fisheries in eastern Indonesia and provided subsidies for new boats and engines. This was based on a common assumption that Indonesian marine resources were underutilized.

Key stressors of the Spermonde reef fishery have evolved over time and are projected to increase in their extent in the future (Fig. 5). From early on, fishers were faced with seasonality, extreme weather events, and often limited financial or physical resources. An arbitrary and ineffective judicial and executive system plagued by corruption and exclusion from decision-making has impaired the function of formal institutions in regulating the fishery. In the past few decades, an increase in the number of fishers and conflicting fishing gears began to influence the fishery, eventually leading to the emergence of new, informal institutions (Deswandi 2012). At the same time, overexploitation of several key species and detrimental effects from pollution are increasingly apparent, resulting in ecological responses such as physiological and life history changes of species and changes in biological communities (e.g., Madduppa 2012; Fig. 5a).

Different responses of the Spermonde SES to stressors

The coral reef fishery of Spermonde can be described as a complex social-ecological system with strong links to international markets and global-level actors. Besides technological change, demand from international markets led to successive peaks in export-oriented fisheries, as 'waves' of demand, described by Berkes et al. (2006) as

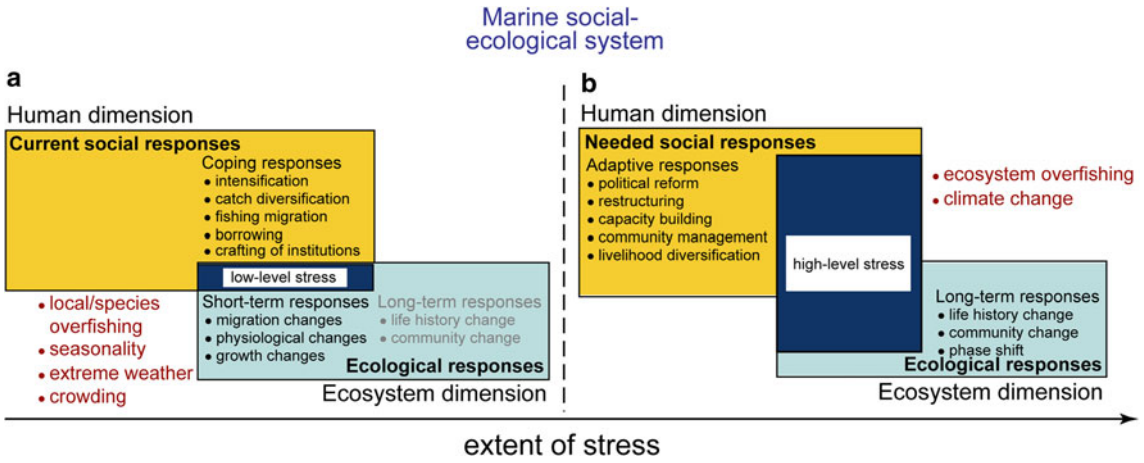

Fig. 5 Responses of the social-ecological Spermonde fishery system to different types of stress. While the system has developed a number of responses to cope with low-level stress such as natural fluctuations, localized overfishing, seasonality, crowding at fishing grounds, or extreme weather events, there currently is limited adaptive capacity to deal with higher-level stress such as ecosystem overfishing or climate change. High-level stress requires system adaptation instead of coping strategies. Modified after Perry et al. (2011)

symptoms of 'roving banditry', reached the archipelago. An analysis of the underlying drivers of the system yields a number of responses by the local fishers that can be characterized as coping strategies to deal with the low-level stressors which they have been exposed to in previous decades. Fishers and their households have responded by seasonal migrations to other fishing grounds, by borrowing from patrons to meet daily household needs, by intensifying their fishing efforts and employing more effective fishing gear (often with the help of loans from patrons), by targeting novel marine resources, and by crafting new local institutions to regulate fishing activity (Fig. 5a).

The appearance of the current institutional environment in Spermonde reef fisheries is one of different, uncoordinated, and partially conflicting local rules (Deswandi 2012). These have developed in response to population growth and technological change on the islands and political reform at the national and provincial level and, in their present form, may act as a barrier to regional institutional integration. For governance and management to be able to develop approaches which work with, rather than against, the self-organizational forces of this highly complex adaptive fisheries system, further research efforts are needed to distinguish the diversity of different origins from the shared elements of past and ongoing institutional dynamics.

The social network in form of a patron–client system is central for Spermonde's fisheries. Patrons have a key position in the local society and are well connected to external traders and buyers. This allows them to obtain information on demands for resources and products, which they then pass on to their clients. Local fishermen profit from this system because patrons act as information brokers for knowledge which would otherwise not reach the local level, or at least be difficult to get. In addition, patrons fill existing gaps in social security and provide some insurance against arbitrariness and uncertainty in the legal apparatus. While patrons decrease transaction costs for their clients, they also filter information in accordance with their own interests. This creates information asymmetries, so that fishermen do not fish according to the real market demand, but in response to information given by their patrons (see also Crona and Bodin 2010).

In the foreseeable future, stressors on the coral reef fishery system will increase in terms of extent, duration, and impact. The population on the Spermonde islands is increasing continuously, and there are already indications that the natural resource base to support them has reached its limits (Schwerdtner Máñez et al. 2012). There are increasing signs that overfishing in Spermonde is eroding ecosystem functioning and resilience by exterminating entire functional groups. For example, rather than indicating a concern for the environment, the use of bamboo traps and line fishing to catch live grouper may reflect a state of overfishing of large reef-associated piscivores where the previously common capital-intensive cyanide fishing operations are becoming economically less viable (Pet-Soede and Erdmann 1998b). The sequential exploitation of marine resources, together with the lack of ecological feedback to the main agents in the fishery, reinforces a 'pathology of resource use' (Huitric 2005: 3) that hampers adequate responses to overfishing. Once critical thresholds are reached, there is a looming danger of the ecosystem shifting into a different phase, for example, to the reefs becoming dominated by algae instead of stony corals (Mumby et al. 2007; Hughes et al. 2003). Furthermore, the anticipated effects of anthropogenic climate change are predicted to seriously impair the functioning and resilience

of coral reef ecosystems, with stark consequences for the human societies that depend on them (Wild et al. 2011; Hoegh-Guldberg and Bruno 2010). Currently, island households have few options to diversify their livelihoods beyond the use of marine resources (Ferse et al. 2012). Leaving the islands for the mainland is hindered by a lack of financial resources, low formal education, and lack of land on the mainland. In order to be able to adapt to the predicted high-level stress, societal responses on multiple levels are needed (Fig. 5b).

From a broader perspective, the current system configuration does not support sustainable adaptive development, and several of its coping strategies appear maladaptive for sustainability. The patron–client system, developed in response to environmental and social uncertainty, contributes to the introduction and maintenance of unsustainable fishing behavior and techniques. It also suppresses the ecological feedback needed for adaptive fisheries management, hinders the enforcement of fishing regulations, and reinforces a lack of environmental awareness among the main actors in the fisheries. The effective exchange of information among actors in the fishery, a prerequisite for adaptive management, is constrained by the presence of patron–client networks in the fishery that impair communication. Under the influence of international markets and technological innovation, fishing migrations lead to the export of fishing pressure and the overfishing of distant fishing grounds (Berkes et al. 2006). Thus, while patron–client networks in the short term contribute the coping capacity of fishers by offering new opportunities and credit to them, in the system's current configuration they hinder sustainability in the long run. However, responsibilities for overexploitation are largely shared at different levels of the SES and should not be sought exclusively with individual actors.

Management approaches to target the different levels of the fishery

The assessment of the coral reef fishery in Spermonde shows that a social-ecological system may well be able to cope with low-level stress while at the same time lacking the capacity to adapt to higher-level types of stress. In this context, coping strategies developed in the past to respond to shocks and stressors actually impair long-term sustainability and undermine the future persistence of the system.

In order to bring the system onto a path toward sustainability, multi-level governance and management approaches are needed. As a first step, gaps between system elements (the 'missing links') that restrict feedback and hinder adaptive management need to be addressed. Management approaches might target strategic leverage points at the local, regional, and international levels of the system as follows.

Local level

The central role of the patrons in the fishery has to be acknowledged. Alternative forms of a social security system or local organizations such as fishermen associations are needed to decrease the dependency of fishermen on patrons. At the same time, and particularly where such social security alternatives are not feasible, patrons need to be constructively integrated in the development of sustainability-oriented management approaches, as they are powerful players that cannot be ignored.

Provincial/regional level

The current patchwork of sometimes conflicting, local institutions among the islands in Spermonde needs to be harmonized and integrated into a coherent co-management framework that acknowledges individual differences between islands. The options for such management reform are provided in the 2007 Indonesian law on Coastal and Small Island Management (Government of Indonesia 2007). Regional fisheries management needs to integrate ecological information from the local level. To collect such information, monitoring staff should be deployed within the local community (e.g., 'beach recorders', see de la Torre-Castro 2006).

National level

The export of marine products needs to be better monitored, and information has to be gathered, evaluated and exchanged with the help of a central organization. This requires both financial support and well-trained personnel.

International level

The majority of the marine products exported from Spermonde are destined to international markets such as Europe, the US, and China. The role and responsibility of these markets in driving destructive fishing activities needs to be better acknowledged. Changes in the trade can only be effected if stricter import controls are coupled with campaigns to raise consumer awareness. This requires serious commitments from all countries involved.

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