– CHAPTER 5 –

Seagrass Meadows in Chwaka Bay:
Socio-ecological and Management Aspects

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INTRODUCTION

The shallow-water seascape of Chwaka Bay consists of diverse habitats including coral reefs, sand/mud flats, algal belts and mangrove forests, but the embayment is primarily characterized by its widespread and highly productive seagrass beds. The Bay is a unique seagrass diversity "hotspot", with eleven species observed, from small, fast-growing and thin-leaved "pioneer" species like *Halophila ovalis* and *H. stipulacea* to large, slower-growing "climax species" with thick and long leaves like *Thalassodendron ciliatum* and *Enhalus acoroides*. Consequently, it is not surprising that the small-scale subsistence fishery of Chwaka Bay can be seen as a seagrass fishery, with catches consisting primarily of species intimately associated with the seagrass meadows (de la Torre-Castro and Rönnbäck 2004; de la Torre-Castro 2006).

Seagrasses are a polyphyletic group of marine vascular, rhizomal plants (den Hartog 1970, 12-13), which form stands of varying sizes usually called "beds" or "meadows" in intertidal and subtidal coastal waters across the globe. Seagrass meadows typically occur on nearshore soft bottoms (although some species are found on rocky bottoms) in single- or mixed-species assemblages, with the typical wide range from tropical to boreal margins of coastal waters (Green and Short 2003, 21-22). They form one of the most productive aquatic ecosystems on Earth (Duarte and Chiscano 1999) and in most areas occur intermixed with other large primary producers like macroalgae. Seagrass ecosystems support multiple ecological functions, including nursery grounds, food and refuge for many benthic,

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demersal and pelagic organisms (Kikuchi and Pérès 1977; Jackson et al. 2001). Fish and invertebrates utilize the complex three-dimensional plant structure to hide from predators and take advantage of high food supply, especially during early life stages prior to migrating to habitats where they spend their adult stages (Orth et al. 1984; Edgar and Shaw 1995). Even though their role as nurseries has been debated (Beck et al. 2001; Heck et al. 2003), the abundance and diversity of organisms are typically greater in seagrass meadows than in adjacent unvegetated habitats (see e.g. reviews by Pollard 1984; Bell and Pollard 1989). In addition, seagrass meadows alter the physical environment by, for instance, reducing water energy and current flow (Fonseca and Fisher 1986), thereby enhancing particle deposition and stabilising bottom sediment (Terrados and Duarte 2000), preventing coastal erosion (Almasi et al. 1987) and influencing nutrient dynamics (Romero et al. 2006).

There is strong and growing evidence that seagrasses are declining in distribution on a global scale, and that these declines are primarily caused by anthropogenic factors (Short and Wyllie-Echeverria 1996; Duarte 2002; Orth et al. 2006; Waycott et al. 2009). Rain runoff and high fluxes of nutrients and sediments that reduce water transparency are today the greatest anthropogenic threats to seagrass meadows (Green and Short 2003, 1-3; Orth et al. 2006). Other stressors include chemical pollution, mechanical damages from boating activities, coastal construction (for example, of boat marinas), dredging and landfill activities, destructive fishing practices, and indirect effects of overfishing and aquaculture (Orth et al. 2006; Ralph et al. 2006). Natural disturbances such as storms and floods can also have adverse effects. Potential threats from climate change include rising sea levels, changing tidal regimes, UV radiation damage, low oxygen concentration in the water column and sediment, increased sea water temperatures and increased storm and flooding events (Björk et al. 2008). However, the actual effects are difficult to predict and model; in the short-term an increase in atmospheric CO_2 concentrations could actually benefit seagrass primary production.

During the last two decades, the extent of seagrass research in Chwaka Bay has increased dramatically, a pattern that reflects a global increase in the number of seagrass studies. Within the Bay, studies have been conducted within many subdisciplines, including physiology, ecology, ecotoxicology, and more applied areas such as impacts of aquaculture and fisheries. Furthermore, the social-ecological importance of the meadows have been addressed in management studies and detailed investigations of the role of seagrasses for the local population (in terms of provision of ecosystems goods and services). With reference to these studies, this chapter aims to (1) describe the basic characteristics of seagrasses reported, the seagrass beds and their associated floral and faunal communities, (2) assess the use of seagrass-associated ecosystem services, (3) discuss current and potential threats to the meadows, and (4) identify some research gaps.



The high abundance and productivity of seagrasses in the Bay, together with the tidal and current movement produce high abundance of seagrass "beach wrack" in the shorelines which in turn provides organic matter to the system. Photo: Maricela de la Torre-Castro.

BASIC FEATURES AND DISTRIBUTION OF SEAGRASS MEADOWS

Seagrasses are distributed throughout Chwaka Bay, interspersed with macroalgae (primarily *Halimeda* spp.), and are found both as large continuous meadows and as heterogeneous patchworks (Gullström et al. 2006; see chap. 8). The meadows are mainly mixed assemblages of different seagrass and macroalgae species. Eleven seagrass species have been found in the embayment (Mohammed and Jiddawi 1999), of which *Enhalus acoroides* (L.*f.*) Royle, *Thalassia hemprichii* (Ehrenberg) Ascherson, *Cymodocea rotundata* Ehrenberg and Hemprich ex Ascherson, *Cymodocea serrulata* (R. Brown) Ascherson and *Thalassodendron ciliatum* (Forsskål) den Hartog are the dominant species. *Syringodium isoetifolium* (Ascherson) Dandy, *Halodule uninervis* (Forsskål) Ascherson, *Halodule wrighthii* Ascherson and *Halophila ovalis* (R. Brown) Hooker *f.* are also relatively common in the Bay, while *Halophila stipulacea* (Forsskål) Ascherson and *Nanozostera capensis* Setchell are sparsely distributed. From a global point of view, this high number of species in a relatively small area like Chwaka Bay is exceptional and occurs only in some specific localities within the Western Indian Ocean (WIO) and Southeast Asian regions. Taxonomically, seagrasses comprise between 50 and 60 species (Hemminga and Duarte 2000, 1-4; den Hartog and Kuo 2006), and the coastal zones of the WIO region encompass 14 known species (Gullström et al. 2002 ; Duarte et al. 2012). Hence, Chwaka Bay contains almost all seagrass species found in the region.

Seagrass/seaweed assemblages in Chwaka Bay are distributed in an extraordinarily complex manner (Hammar 2005; Gullström et al. 2006). In intertidal areas close to the highest shoreline at high tide, the seagrass assemblage is dominated by small species like *H. ovalis*, *H. uninervis* and *H. wrigthii*. The central and western parts of the embayment comprise continuous intertidal meadows, typically dominated by *T. hemprichii* and *Cymodocea* spp. interspersed with the calcareous green algae *Halimeda discoidea*, *H. macroloba* and *H. opuntia* and to a less extent with other macroalgae. At the subtidal and low intertidal areas near and towards the Bay entrance, the slightly deeper meadows, dominated by *E. acoroides*, are adjacent a patchy mix of other seagrasses, e.g. *T. ciliatum* and *T. hemprichii*. Irregular meadows dominated by *T. hemprichii* and *Halimeda* spp. characterize the eastern and south-eastern parts, while the south-western part of the Bay is characterized by wide continuous seagrass meadows (dominated by *T. hemprichii* and *Cymodocea* spp.) interspersed with extensive belts of the brown macroalgae *Sargassum* spp. Sporadic cover of "pioneering" seagrass species and macroalgae fringe the mangrove forests in the south, whereas dense monospecific *T. ciliatum* meadows directly border the patchy coral reefs found at the bay mouth. The Bay has numerous channels with a bottom substrate generally covered by an irregular mix of seagrass (primarily *T. ciliatum* and *E. acoroides*), macroalgae and bare sediment.

SPATIAL DYNAMICS OF SEAGRASS

Accurate assessments of seagrass distribution patterns and changes over time (seasonal and inter-annual) are imperative to manage the resources of seagrass systems. To date, no comprehensive conventional *in situ* mapping of seagrass has been conducted in Chwaka Bay. However, in a satellite remote sensing study by Gullström et al. (2006), the long-term dynamics of submerged aquatic vegetation (SAV) were assessed in combination with testing the potential of the technique for change detection. The methodological component of the study verified the use of satellite image analysis to map large-scale changes in SAV coverage. By comparing five different years during a period of almost two decades (1986-2003), the distribution of SAV was found to vary locally (with both losses and gains), but at the Bay-scale, it was fairly stable. Overall, the SAV coverage decreased 11.7% throughout the study period; a result rather similar to those found in other shallow areas of the WIO region during an equivalent time frame (e.g. at Inhaca Island in southern Mozambique and in the northern part of Zanzibar, Gullström and Lundén unpublished data). Considering seasonal within-year variation, an even more stable pattern was found when comparing SAV coverage at four different seasons during 2000/2001. On average, the Bay was covered by 24.4% seagrass, 16.0% *Halimeda* spp., 5.3% other macroalgae and the remaining part (54.3%) of bare sediment, with very little seasonal variation. With respect to seagrass areas, estimations within homogeneous meadows showed a mean seagrass coverage of 69.5% for meadows dominated by *T. hemprichii*, 51.6% for *Enhalus*-dominated meadows and 53.8% for a mixed meadow. Within the WIO region, comprehensive seagrass mapping and monitoring studies are still relatively scarce (but see for example Coppejans et al. 1992; Dahdouh-Guebas et al. 1999; Bandeira 2002; Gullström et al. 2006), but much needed to improve resource management and conservation of seagrass habitats.

SEAGRASS CHARACTERISTICS

Spatial and temporal variation in seagrass biomass and primary productivity have been assessed in various studies in Chwaka Bay (de la Torre-Castro and Rönnbäck 2004; Gullström et al. 2006; Lyimo et al. 2006; Lyimo et al. 2008). Lyimo et al. (2008) showed that the seagrass biomass and growth parameters remain relatively stable over different seasons, whereas spatial variability is large and depends on meadow type and location. In terms of detailed seagrass characteristics, Lyimo et al. (2006) reported a mean canopy height in areas dominated by *T. hemprichii* to range from 9 to 16 cm while in meadows of *E. acoroides*, the mean canopy height ranged from 26 cm to 47 cm. The shoot density of *T. hemprichii* ranged from a mean value of 380 to 1,090 shoots m^{-2} while for *E. acoroides* the shoot density ranged from a mean value of 128 to 148 shoots m^{-2} recorded close to Chwaka village and at Marumbi, respectively. Furthermore, Gullström et al. (2006) examined spatial variability in seagrass meadows dominated by *T. hemprichii* or *E. acoroides*



Seagrasses in Chwaka Bay normally co-exist with the macroalga *Halimeda* spp. Photo: Mats Björk.

(three sites each) and one mixed meadow mainly composed of *T. hemprichii*, *E. acoroides* and *T. ciliatum*. Similar to what was found by Lyimo et al. (2006), the canopy height and shoot density demonstrated a high spatial variability. However, estimations in Gullström et al. (2006) partly showed greater ranges and higher values than Lyimo et al. (2006), differences which could be caused by choice of sampling sites and season. Mean canopy height ranged from 9 to 21 cm for *T. hemprichii* and from 28 to 49 cm for *E. acoroides*, whereas the mean shoot density was 768 – 1,353 shoots m^{-2} for *T. hemprichii* and 274 – 439 shoots m^{-2} for *E. acoroides*. The mixed meadow showed a mean canopy height of 423 shoots m^{-2} and a mean shoot density of 34 cm. In term of seagrass biomass, Lyimo et al. (2008) reported a total seagrass biomass ranging from 393 to 3,063 g dw m^{-2}. The above-ground biomass in their study was noticeably higher (mean: 175 – 609 g dw m^{-2}) than what was reported by Gullström et al. (2006) (mean: 62 – 105 g dw m^{-2}). Overall, the values of seagrass plant variables reported in Chwaka Bay fall within the reported ranges in the region (e.g. Martins and Bandeira 2001; de la Torre-Castro and Rönnbäck 2004; Uku and Björk 2005).

Measurements of productivity (some growth variables) have also been conducted for both *T. hemprichii* and *E. acoroides* in Chwaka Bay. In their studies, Lyimo et al. (2006) estimated growth characteristics of *T. hemprichii* in different meadows as follows (in brackets): mean total leaf growth rate (13 to 18 mm $shoot^{-1}$ day^{-1}), leaf production (0.004 – 0.01 g dw $shoot^{-1}$ day^{-1}), relative growth rate (0.07 – 0.10 g g^{-1} dw day^{-1}), aerial production (1.7 – 2.2 g dw m^{-2} day^{-1}) and leaf turnover time (16 – 17 days). For *E. acoroides* values were: mean total leaf growth rate (18 to 25 mm $shoot^{-1}$ day^{-1}), leaf production (0.02 g dw $shoot^{-1}$ day^{-1}), relative growth rate (0.02 – 0.03 g g^{-1} dw day^{-1}), aerial production (2.1 – 2.8 g dw m^{-2} day^{-1}) and leaf turnover time (39 – 51 days). The observed values in Chwaka Bay are comparable to those reported elsewhere (e.g. Erftemeijer et al. 1993; Uku and Björk 2005).

BIOTA ASSOCIATED WITH SEAGRASS MEADOWS

Generally, seagrasses are found living in association with a wide array of organisms from many phyla. Seagrasses can function as habitat for a variety of organisms, including epiphytes such as microalgae, macroalgae, bacteria and a number of invertebrates such as echinoderms, crustaceans, molluscs, nematodes and polychaetes (Uku and Björk 2001; de la Torre-Castro et al. 2008). The associated organisms within seagrass beds can affect seagrass ecosystem productivity and structure (Eklöf et al. 2008a).

Macroalgal Communities

Both calcareous and fleshy macroalgae are commonly found among the seagrass meadows of Chwaka Bay. Yet there are no extensive studies that document their distribution and diversity. Of the few studies carried out, the most prominent is

on the green calcareous alga *Halimeda* spp. (including *H. discoidea*, *H. macroloba* and *H. opuntia*). *Halimeda* species are normally found living in association with seagrasses, and owing to the benefits calcareous algae obtain from seagrasses, the latter tend to increase pH of their surrounding water, especially during the low tide, which boosts the calcification processes within these algae (see Semesi et al. 2009). This genus of calcareous green algae is a major contributor of the sediments in the Bay as they are made of fragile $CaCO_3$ flakes that easily disintegrate into sand when the algae die (Muzuka et al. 2001). High densities of *Halimeda* spp. are found within the western part of the Bay, greatly contributing to the sediments in these locations (Muzuka et al. 2001). Additional important calcareous algae genera found within the Bay are the red algae *Hydrolithon* sp. found mostly in the southern part, and *Mesophyllum* sp. found close to the reefs (Semesi et al. 2009).

Other macroalgae growing within or in close association with seagrass meadows of the Bay include representative genera from green (Chlorophyta), brown (Phaeophyta) and red (Rhodophyta) algae. The green algae include *Ulva reticulata*, *U. fasciata*, *Phyllodictyon anastomosan*, *Cladophoropsis vaucheriiformis*, *C. (Boodlea) composite*, *C. sundanensis*, *Cladophora vagabunda*, and *Dictyosphaeria cavernosa*. The brown algae include *Turbinaria tanzaniensis, Padina sp.,Sargassum sp.* and *Cystoseira myrica,* while the red algae include among others, *Gracilaria salicornia, Laurencia sp.,* and *Eucheuma sp.* (Leliaert et al. 2001; Buriyo and Kivaisi 2003; Leliaert 2004; Msuya 2007). Some of these, and other macroalgal species within seagrass beds, exist as epiphytes on seagrass leaves and/or stems. Leliaert et al. (2001) gives a description of 49 epiphytic macroalgal taxa on seagrass leaves and stems within Chwaka Bay, which is less compared to other parts of the world. For example, leaves and stems of *Thalassia testudinum* beds in South Florida were recorded to have 113 species of epiphytic macroalgae. Examples of macroalgal seagrass epiphytes that were recorded in Chwaka Bay include representatives from Rhodophyta (*Acrochaetium caespitiforme*, *Amphiroa rigida*, *Caulacanthus ustulatus, Ceramium flaccidum, C. mazatlanense*, *Chondria pygmaea*, *Gelidiella acerosa*, *G. lubrica*, *Gelidiopsis intricate*, *Laurencia papillosa*, *Gracilaria corticata* and *Jania pumila*), Phaeophyta (*Dictyota humifusa*) and Chlorophyta (*Boergesenia forbesii*, *Boodlea composite*, *Bryopsis pennata*, *Caulerpa verticillata* and *Ulva reticulata*). The study by Leliaert et al. (2001) revealed that Rhodophyta comprises the majority of macroalgal epiphytes, both in species number and abundance within seagrass beds, represented by around 27 species that contribute 83% of the epiphyte cover, with the majority being of the crustose type, belonging to Corallinaceae. In Chwaka Bay, Corallinaceae represents up to 65% of epiphytic macroalgae within seagrasses, especially on *Thalassodendron ciliatum,* while the Phaeophyta epiphytes contribute 14% and the green algal epiphytes 1% (Leliaert et al. 2001).

Apart from the ecological role, the presence of macroalgae also contributes to small-scale fisheries of the Bay, which are of crucial economic significance (see chap. 11). Some macroalgae and seagrasses are used as fish bait, in special basket traps locally referred to as *dema*. Such traps specifically provide highly valued her-

bivorous fish, e.g. the seagrass rabbitfish *Siganus sutor* and the seagrass parrotfish *Leptoscarus vaigiensis*. A study by de la Torre-Castro et al. (2008) that investigated the bait types used in these *dema* traps at Chwaka Bay had indicated that the fishers use a bait mixture of a macroalga, in particular the red macroalga *Laurencia papillosa*, seagrasses and a sponge (Porifera) from the family Halichondriidae, which forms a symbiosis with cyanobacteria (locally referred to as "gozi"). This kind of bait is particularly efficient in catching *Siganus* spp. and *L. vaigiensis*.

Microorganisms

Few studies have investigated microorganisms in seagrass meadows of Chwaka Bay. The sole study on microbial processes is the one carried out by Lyimo and Hamisi (2008), who assessed microalgal biomass and cyanobacteria diversity and their nitrogen fixation rates comparing areas with and without seaweed farms (see chap. 7). In another study, Leliaert et al. (2001) described seagrass epiphytes (including cyanobacteria) on different sites of Unguja Island, including Chwaka Bay.

Generally, seagrasses are hosts to many epiphytic organisms such as microalgae, macroalgae, bacteria and a number of invertebrate species (Uku and Björk 2001). Various studies focusing on seagrass meadows have shown a close association between microorganisms and seagrass species (e.g. Hamisi 2010). Microbes may contribute significantly to nutrient cycling through processes such as photosynthesis, nitrogen fixation, de-nitrification and sulphate reduction (Harris 1999; Hansen et al. 2000). For example, it has been estimated that the epiphytic communities may contribute up to 56% of the total production (carbon fixation) in seagrass beds (Morgan and Kitting 1984; Moncreiff et al. 1992). Epiphytic microalgae are also known to be an important food source for herbivorous organisms, the abundance of which may influence the meiofaunal abundance in seagrass meadows (Pinckney and Micheli 1998; Yamamuro 1999).

Benthic Infauna

Infauna consists of invertebrates that live within sediments. They constitute a common and important component of seagrass communities and food webs; they consume and break down organic material (e.g. plants, detritus and other animals), and thereby link seagrass production to higher trophic levels when they are consumed by other invertebrates, fish and birds. Few studies have been conducted to investigate benthic communities in Chwaka Bay. Eklöf et al. (2005) studied seagrass infauna (there defined as organisms retained on a 0.5 mm sieve), as a part of a study on environmental effects of open-water seaweed farming (see chap. 13). In total, 53 different taxa (families, sub-orders, orders and classes) were found in three different habitat types: seagrass beds, seaweed farms and a sandy, vegetation-free area. In the three sampled seagrass beds (one monospecific *Thalassia hemprichii* bed, one mixed *T. hemprichii* and *Cymodocea serrulata* bed,

and one monospecific *Enhalus acorodies* bed), the numerically dominant groups were gammarid amphipods, isopods, and more than 15 families of free-living polychaetes. In terms of biomass, mussels from the family Lucunidae completely dominated, which is interesting as species in this family have been suggested to indirectly benefit seagrasses by reducing levels of toxic sediment-bound sulphides (Reynolds et al. 2007). The total density of macrofauna in the seagrass beds ranged from 23,000 to 41,000 individuals per m^2, whereas the density in the vegetation-free reference area was ca. 1,100 individuals per m^2; i.e. 20-40 times lower. As much as 99.6% of variation in the macrofauna community composition across the six sites was explained by (a) percent cover of benthic vegetation (seagrasses and *Halimeda* spp.), and (b) sediment organic matter content, in the seagrass beds (Eklöf et al. 2005). This pattern is quite typical for seagrass areas on a global scale, because of the concentration of food (e.g. bacteria, protozoans, plants, algae and other animals), shelter from predators (provided by the seagrass shoots and rhizome/root mat) and stable micro-conditions (e.g. reduced wave action and current strength) in seagrass beds compared to unvegetated bottoms (Hemminga and Duarte 2000, 199-247).

Epibenthic Invertebrates

Invertebrates of epibenthic communities represent an important group of organisms in seagrass meadows as they do in most marine benthic systems. In Chwaka Bay, only a few studies have investigated epibenthic invertebrates. Subramaniam (1980; 1990) studied the nursery role of various habitats for penaeid shrimp, and showed that the commercially important *Penaeus latisulcatus* dominated shrimp assemblages (75% in total) and was tightly linked to seagrass beds in its juvenile life stage (see also chap.10). Eklöf et al. (2006) studied the diversity and density of large (>2 cm) slow-moving or sessile epifauna in a mixed *Thalassia hemprichii*/*Enhalus acoroides* bed, as part of an experiment assessing the effects of seaweed farming on seagrasses and associated fauna (see chap. 13). Out of the 16 species of large macrofauna encountered, the soft coral *Heteroxenia fuscescens* (Actinaria), the sponge *Spongia ceylonencis* (Porifera) and the sea urchin *Echinometra mathaei* (Echinoidea) constituted 41, 23 and 20% of total abundance, respectively.

One particular group of epifauna that has been the focus of several recent studies is sea urchins. This is partly because they constitute one of the dominant groups in terms of density, and partly because seagrass loss in the WIO region has been linked to intense grazing ("overgrazing") by dense sea urchin aggregations (Eklöf et al. 2008b). In a recent field survey by Hammar (2009), the importance of sea urchin grazing was studied in *T. ciliatum* meadows, including two sites in Chwaka Bay. Results showed higher grazing pressure at the edges of the meadows than in the centre, but that grazing pressure did not differ among the spatial scales tested. Furthermore, an experimental field study by Asplund et al. (unpublished data), focusing on effects of sea urchin (*Tripneustes gratilla*) grazing in mixed seagrass meadows, indicates that a low number of sea urchins may positively affect the

shoot biomass of seagrasses, whereas a high number can diminish this positive effect. Grazing was more intense on *T. ciliatum* than on the other seagrass species (*E. acoroides* and *T. hemprichii*) tested. Moreover, Freiburghaus (2009) experimentally investigated the relative effects of sea urchin grazing ("top-down" control) and resource supply ("bottom-up" control) on *T. ciliatum*. Seagrass biomass, leaf production and shoot density were all negatively affected by sea urchin presence (at densities of eight individuals per m^2). Interestingly, addition of nutrients seemed to exacerbate some of the grazing-induced losses in seagrass biomass. Similar interactive effects between high densities of sea urchins and nutrient enrichment have been observed in, for example, the Caribbean (Tewfik et al. 2007), and indicate that previously observed sea urchin overgrazing events in the WIO region (e.g. Alcoverro and Mariani 2002; Eklöf et al. 2008b) could be caused by locally interacting effects of increased urchin densities and coastal eutrophication.

In a study by Håkansson (2005), the harvest of invertebrates in seagrass meadows in Chwaka Bay was highlighted and assessed from different perspectives, including socio-ecological importance and effects of exploitation. Håkansson (2005) identified a large number of harvested epibenthic species of which the bivalves *Modiolus philippinarum*, *Atrina vexillum* and *Pinna muricata*, the gastropods *Strombus gibberulus* and *Chicoreus ramosus*, and Chitonidae were important for subsistence, while the gastropods *Cypraea tigris* and *S. gibberulus* were important for cash income (see chap. 12).

Fish

The fish communities of the embayment are highly diverse, most likely because the Bay is a mangrove-seagrass-coral reef continuum, typical for tropical seascapes (see chap.10). Since the seagrass meadows are so widespread, diverse and heterogeneous, the seagrass-associated fish community also shows a high diversity. A number of studies have examined and compared fish assemblages in different shallow-water habitats of Chwaka Bay (including seagrass meadows), most of which have focused on coral reef species and the contribution of nursery habitats to adult populations on the reef (e.g. Dorenbosch et al. 2005a; b: 2006; see also chap. 10). However, few studies have explicitly focused on fish associated with seagrass meadows. Gullström et al. (2008) examined spatial patterns and variability of seagrass fish assemblages and the relative importance of explanatory factors at different scales. Overall, 79 taxa (of which 71 were identified to species level) from 35 families (predominantly juvenile specimens) were identified in meadows dominated by *T. hemprichii* or *E. acoroides* (three sites each) and one mixed meadow (*T. hemprichii*, *E. acoroides* and *T. ciliatum*). Labridae (wrasses) was the most species-rich family (17 taxa of which 14 were identified to species), while the most abundant fish species was the seagrass parrotfish *Leptoscarus vaigiensis*, which made up 32% of all fish specimens caught during the study (excluding the abundant but very sporadically occurring shoaling species eeltail catfish *Plotosus lineatus*; see Gullström et al. 2008). The abundance and distribution of these seagrass-associated fish assemblages appear

to be determined by multiple factors operating at various scales; in particular seagrass structural complexity (canopy height and to lesser extent shoot density) and the position of a seagrass habitat within the seascape context. In another field survey, Lugendo et al. (2005) studied habitat use by 13 commercial fish species in five shallow-water habitats – including two seagrass sites (one close to mangrove and the other farther out in the Bay). They found that the seagrass habitat close to mangrove comprised the highest number of species, a result which was explained by the function of seagrass beds as a corridor between mangroves and deeper parts of the embayment.

Two studies have investigated food items for a number of seagrass-associated fish species in Chwaka Bay via stomach content analysis. First, Lugendo et al. (2006) found that crustaceans (mainly copepods, crabs and shrimps) were the primary source of food for zoobenthivores and omnivores, whereas not surprisingly piscivores preferred fish and herbivores preferred algae. Furthermore, stable isotope analysis indicated connectivity between Bay habitats (principally mangrove and seagrass habitats), which was suggested to be a result of either daily migration or recent ontogenetic migration. In the second study, de la Torre-Castro et al. (2008) studied food items from 13 commercially important fish species, and found a clear coupling between food provision from seagrass meadows and the bait traditionally used in the artisanal fishery.

A number of recent studies have explored the ecology of the seagrass parrotfish *Leptoscarus vaigiensis*, primarily focusing on seagrass herbivory (Dahlgren 2006; Berkström 2007; Pongolini 2009; Gullström et al. 2011). Besides being a highly abundant fish species in seagrass meadows of Chwaka Bay (see Gullström et al. 2008), *L. vaigiensis* is also an efficient seagrass grazer (Berkström 2007; de la Torre-Castro et al. 2008; Gullström et al. 2011) and one of the dominating food species sold for local consumption (de la Torre-Castro, unpublished data). In terms of feeding mode, results from Dahlgren (2006) and Gullström et al. (unpublished data) indicate that leaves of *T. hemprichii* are a preferred food item, even though meadows dominated by *E. acoroides* hold a much higher abundance of fish specimens, likely utilising the sheltering capacity of the long leaves of *E. acoroides*. In general, information of spatial variability, feeding behaviour and patterns of herbivory focusing on seagrass fish assemblages is of high importance for future spatial planning and selection of marine protected areas around Zanzibar, including Chwaka Bay.

THE PRESENT AND FUTURE ROLE OF SEAGRASS MEADOWS - A SOCIO-ECOLOGICAL PERSPECTIVE

Rapid development is taking place around Zanzibar, and Chwaka Bay is no exemption. In less than one decade, the west coast of the Bay has suffered from rapid tourism development and changes in land use (see chap.1). Still, the conditions

in the Bay can be considered relatively pristine. There are currently two crucial human activities which are negatively affecting the seagrass meadows: seaweed farming and drag-net fisheries (de la Torre-Castro and Rönnbäck 2004; de la Torre-Castro and Lindström 2010). Seaweed farming in the Bay is limited to only a few areas (de la Torre-Castro 2006; chap. 13), but where farms are located seagrass shoot density, shoot biomass, growth and canopy height are known to be reduced (Eklöf et al. 2005; 2006). The majority (70%) of seaweed farmers in Chwaka village confirmed these negative effects on seagrasses, partly caused by manual uprooting to simplify farming (de la Torre-Castro and Rönnbäck 2004). If the seaweed cultivation areas would expand drastically in the Bay, the consequences could be severe for the seagrasses as well as the general productivity of the Bay.

Regarding small-scale fisheries, the number of fishermen is increasing and the dominant damaging gear, comprised of drag-nets pulled over the substrate cause severe damage to the meadows (for example, through sediment re-suspension, uprooting of seagrasses and fragmentation of meadows) (de la Torre-Castro and Lindström 2010; see chap. 11). Other damaging gears such as gill nets and beach seines are still being used actively. A more intense fishery might first of all reduce the individual and population sizes of commercial species, which in turn would impact the fisheries directly (as reduced catch per unit effort, CPUE). Along the Kenyan coast, long-term studies in fished and non-fished areas show that effects of small-scale artisanal fisheries have devastating impacts on the fishery as well as on by-catch species (Eklöf et al. 2009). By reducing the density and/or biomass of functionally important species, the resulting fisheries could also indirectly impact the ecosystem. During recent years, local communities have observed local, but rapid aggregations and increases in the number of sea urchins (de la Torre-Castro and Jiddawi 2005). Many sea urchins feed on seagrasses, and can thus negatively affect seagrass distribution (Alcoverro et al. 2002) and growth (Eklöf et al. 2008a). The specific reasons for such sea urchin "outbreaks" are not known, but have been linked to overfishing of large predatory fish, e.g. triggerfish that feed on sea urchins in the WIO region (McClanahan and Muthiga 1989; McClanahan and Shafir 1990; Eklöf et al. 2008b; 2009). Interviews with fishers during 2009 in Chwaka and Uroa villages showed that important sea urchin predators regularly form part of the by-catch in most fishing trips (de la Torre-Castro, unpublished data). This potential link between fisheries on urchin predators and overgrazing of seagrass beds was identified as one of the priority issues for research during a workshop in Chwaka, where scientists and local fishermen met to discuss the social-ecological history and future of the Bay (de la Torre-Castro and Jiddawi 2005).

The impact of drag-net fishing on seagrasses themselves has so far not been investigated, but damages reported by fishers themselves and personal observations confirm the potential adverse effects. A study from neighbouring Kenya shows that this method clearly impact benthic communities, including coral reefs (Mangi and Roberts 2006). Since the seagrass meadows are the main fishing grounds (de la Torre-Castro and Rönnbäck 2004), there is a risk that the fishing pressure within

seagrass meadows may become so intense that reduced seagrass biomass and/or cover could indirectly affect the fishery, through loss of fish habitats.

A major threat to seagrass meadows globally is eutrophication, usually coupled to an increased coastal population and/or development of tourist sites, followed by increasing volumes of domestic sewage being discharged into coastal waters. The capacity of tropical seagrass systems to tolerate increased nutrient levels is, however, high, and in Kenya for example, it has been shown that quite high levels of nutrients can be absorbed by seagrass meadows and even increase the growth of the seagrasses (Uku and Björk 2005). At the same time, the growth of epiphytic macro- and microalgae also increases, and as many herbivorous fishes in seagrass meadows prefer these algae to the seagrasses, this has been suggested to increase the number of herbivorous fish, many of which are of great commercial value (de la Torre Castro et al. 2008). This also means that these fish will feed on the algae, reducing their cover. However, if the nutrient levels in the water are very high, and elevated over an extended period this will cause massive growth of algae, covering the seagrasses. The algae will then shade the seagrass leaves, lowering their productivity and at the end possibly causing their death. Another effect of eutrophication is the increased loading of organic materials (e.g. dead algae) to the sediment, which in turn increases its biological oxygen demand (BOD) and potentially causes excessive hypoxia, thus first asphyxiating the seagrass roots, leading to death of the whole plant.

Social-Ecological Importance and Management of Seagrass Meadows of Chwaka Bay

Apart from their ecological role, seagrass meadows in the Bay are of vital importance for the local communities of the surrounding villages. The social-ecological aspects of the ecosystem in the Bay have been investigated in different studies including the goods and services they provide for the local population (e.g. de la Torre-Castro and Rönnbäck 2004). The most important goods and services were provision of fishing and collecting grounds for finfish, shellfish, bait, medicines and fertilizers and "good" substrate for seaweed farming. In addition, religious, aesthetic and spiritual values were associated with the meadows.

The influence of seaweed farming in the surrounding environment has also been investigated (Chap. 13). Negative changes in the benthic environment were identified (Eklöf et al. 2005) as well as changes in fish catches (Eklöf et al. 2006). The biomass of catches in areas with and without seaweed farms was of the same order of magnitude, but species composition differed and diversity was lower in catches from areas with farms. The collection of invertebrates from the meadows in relation to food security and cash income generation was investigated by Håkansson (2005) and is presented in chapter 13.

Seagrass meadows have been identified as favourite fishing grounds by the local fishers in the Bay so that heavy fishing pressure is currently taking place in the seagrass-dominated areas (de la Torre-Castro and Rönnbäck 2004). Due to the huge dependence on fish from the seagrass meadows, conflicts among fishers coming from other villages and using different gears have been reported (especially between Chwaka and Marumbi). This illustrates the social value and importance of the meadows to the local people (de la Torre-Castro and Lindström 2010). De la Torre-Castro (2006) provides a comprehensive review of the societal and management importance of the seagrasses in Chwaka Bay. While there are many examples of the societal importance of coral reefs and mangrove forests, this kind of research is uncommon for seagrass ecosystems. Therefore, Chwaka Bay is a good example of the potential importance of seagrass meadows on a global scale. From a management perspective the identification of the social values of the meadows, together with knowledge on physiological, biological and ecological aspects provide a solid basis for planning and setting of priorities. Since the meadows play such an important role for the livelihoods of villages in the Bay, sound management is needed. A plausible management strategy should consider Chwaka Bay as an integrated system of people and ecosystems. The seascape approach is much needed due to the complex variety of ecosystems and habitats present in the Bay (see chap. 10,14 and 15).

Key issues and gaps for future research

If the seagrass meadows of Chwaka Bay are to be preserved in the future, accompanied by intensified human pressure in the form of increasing fishing effort, tourist activities and coastal constructions, it will be of crucial importance that effective management is in place, focusing on the sustainable use and preservation of the primary conditions for promoting seagrass health. Here, a summary of key issues to achieve the above is given (see also chap. 15).

- Comprehensive studies providing the extent and distribution of the meadows are needed and have to be carried out systematically and repeatedly. Satellite image analysis and conventional mapping/monitoring using random transect technique are tools that managers can use to address the lack of information.
- Regular assessments of the social-ecological sustainability of different human activities taking place in the Bay are needed.
- A holistic and integrated approach for management is imperative. Seagrass meadows in Chwaka Bay are inextricably linked to human activities such as small-scale fisheries and seaweed farming from the meadows. Monitoring and zoning with the participation of the local people is an option to promote co-management.
- A general arena for discussion is needed at the Bay level to resolve conflicts and zoning issues.

From the natural science perspective, while seagrass meadows vary across the Bay, there is a growing consensus on some common key environmental variables that are needed to preserve the health of seagrass systems (e.g. Björk et al. 2008). In short, these are:

– A high water quality, allowing enough light for the plants. The water must not be allowed to become too turbid by suspended matter. Eutrophication increases turbidity by growth of plankton in the water column or reduces the light reaching seagrasses by inducing overgrowth of the seagrasses by algal epiphytes. Therefore, construction in shallow water (including of beach bungalows and piers), sewage effluents or agricultural run-off into the Bay should be monitored and kept within the limits of what the natural systems can absorb. Water must be kept in constant movement. This is very important for the supply of nutrients and inorganic carbon to the photosynthesising seagrass leaves. However, very high water movement can damage the plants. Therefore, it is important to allow the tidal current to flow unhindered and design coastal constructions, dykes, etc. in such a way that seagrasses are not left in stagnant waters, where they will die. At the same time, reefs and other natural barriers that protect the meadows from destructive water motion, like large ocean swells, must be protected. Likewise, the integrity of the mangrove forests that fringe the Bay (e.g. in the Chwaka Bay-Jozani Conservation Area) will reduce erosion (and thereby sediment input from land) and could reduce the rate of freshwater floods reaching the Bay.

– Favourable sediment conditions. The roots and rhizomes of seagrasses need an undisturbed environment to remain healthy. An increased organic load in the sediment can cause increased bacterial BOD in the sediment, causing both hypoxia and the danger of sulphide formation. Also mechanical disturbances of sediments can destroy seagrass meadows by uprooting. Hence, it is important to monitor activities within the Bay so that the negative effect from e.g. sewage on the sediment does not reach levels where hypoxia might occur. Boat anchoring and fishing activities such as bottom trawling should not be allowed where they cause drastic uprooting of seagrasses. The critical issue of the extensive use of drag-nets, potentially disturbing the sediments, must be solved together with the fishing community.

– Diversity should be maintained. A high genetic diversity of the plants has been proven to be important for seagrass to withstand temperature stress (e.g. Ehlers, Worm and Reusch 2008). It is possible to help preserve genetic diversity by also allowing for genetic exchanges between meadows and neighbouring lagoons. Resilience can thus be strengthened in Chwaka if diverse and isolated seagrass areas are preserved, hence allowing for genetic connectivity.

– An ecosystem perspective is needed. To insure the integrity of the ecosystem, we need to ensure that the harvest of organisms (invertebrates, sea urchin predators, herbivorous fish, etc.) are kept at environmentally sustainable levels. Otherwise, these ecosystems might experience cascading effects of food-web changes similar

to those in overexploited seagrass ecosystems along the Kenyan coast (Eklöf et al. 2009). Aspects of biodiversity, ecosystem functioning and food-web interactions should hence be seriously considered in conservation efforts of seagrass meadows in Chwaka Bay.

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