Seaweed farming and artisanal fisheries in an Indonesian seagrass bed

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Complementary or competitive usages?

Sven Uli Blankenhorn

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Alfred Wegener Institute for Polar- and Marine Research
Wadden Sea Station Sylt

Seaweed farming and artisanal fisheries in an Indonesian seagrass bed – Complementary or competitive usages?

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Sven Uli Blankenhorn
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Gutachter der Dissertation: Prof. Dr. W. Arntz, AWI Bremerhaven / Universität Bremen
Dr. H. Asmus, AWI Wattenmeerstation Sylt

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„Kalau tidak ada rumput laut Puntondo mati."
"Without seaweed Puntondo would be dead."

Daeng Laga, village chief of Puntondo

previous page: Satellite image of the western part of Laikang Bay, South Sulawesi, Indonesia. Puntondo on the small peninsula extending into the bay. Source: GoogleEarth

Disclaimer

Herewith I assure that I wrote this thesis independently and that I did not use any additional help except to the extend and the manner stated. References are cited in compliance with guidelines on safeguarding good scientific practice.

Bremen, June 4th 2007

Sven Blankenhorn

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Summary

In Indonesia, coastal villages traditionally strongly depend on artisanal fisheries. With increasing population density (and hence fishing pressure), alternative sources of income become more important. One possible economic activity is seaweed farming, which has been introduced in many communities since the 1980's. There, algae farming is restricted to shallow coastal waters and their natural ecosystems, e. g. seagrass beds. Seagrass beds themselves are important habitats for many species of fish, shrimp and crab which are the basis for traditional fisheries. Therefore, if seaweed farming causes the seagrass ecosystem to change, its economical benefits might be outbalanced by losses in the fisheries sector. The field research for this thesis included investigations of seaweed farming and its economic importance, its influence seagrass flora, the economic importance of artisanal fishery's practices and implications for management, and the variation of fish stock and gill net fishery in the seagrass bed off Puntondo, a small village in district Takalar, South Sulawesi, Indonesia.

In chapter 1, a study of economical activities and the effort allocated to each of them in Puntondo is presented. Problems as well in seaweed culture and marketing as well as in fisheries as perceived by the villagers were evaluated. Seaweed farming was practiced by nearly all villagers and contributed a very high percentage to average household income. Both seaweed farming and fisheries were believed to have high future prospects and wanted to be developed by the villagers. The results are discussed in detail in chapter 1 and it is concluded, that, based on economical considerations, efforts to increase production in the area should mainly focus on increasing productivity by improving post-harvest processing. Further development of seaweed farming in other areas should not only take environmental suitability of proposed sites into account, but also consider market access as a viable factor for continuous and predictable income. In community development plans, other sources of alternative income should be included, as seaweed prices can oscillate significantly.

Chapter 2 deals with the effects of shading, trampling, a combination of both factors, and actual seaweed farming in different intensities on seagrass. High shading intensities reduced the performance of small seagrass species, whereas trampling was only effective in combination with shading. Compared to small seagrasses, the big species *Enhalus acoroides* was much less influenced by any treatment. Farming itself however had less influence than could be expected from shading / trampling manipulations. The results are discussed in detail in chapter 2 and a seedling density of approximately 185.000 seedlings ha^{-1} is estimated to be environmentally sustainable. Current farming densities were below this threshold level but still, based on ecological considerations, production should be increased by establishing farms in deeper waters, away from fragile benthic communities like seagrasses and corals. In deeper waters production can be expected to be higher than on reef flats, thus compensating the comparatively high initial investments needed for suitable farming schemes.

In chapter 3, local Puntondo fishing methods, habitats, target species and their biology are the focus of study. Fish landings were dominated by only a few fishing methods and habitats, which most of were used unsustainably. Fishes depending directly on seagrass resources were not an important source of income and neither were seagrass beds important fishing grounds. In chapter 3 it is recommended that economically unimportant, but unsustainable methods and sensible habitats should no longer be used. Gill nets were the most important gear and mesh size restrictions could help to improve their sustainability. Fishes from coral habitats were sensitive to overfishing and therefore seasonal closures and / or gear restrictions are recommended for these habitats. Generally, line fishing yielded the most adult fish and is recommended over all methods. Lift nets could also be operated environmentally friendly, provided that sub-adults were released immediately after catch.

In chapter 4 a study of gill net fishery in the seagrass bed and its fluctuations is presented. Fish catches were dominated by generally small fish from a few families. Relative maturity of the catch did not differ between mesh sizes and a high abundance of predatory species questions the role of the seagrass bed as a nursery habitat. There were indications of predators entering the seagrass bed during the day, more adult specimens being caught around full moon, and relatively more adult fish using the seagrass area during the dry season. Small specimens and fishes however were not sampled and predator-prey induced migrations could not be determined as exclusive factor. The results of this study do not support the seasonal closure of fisheries or mesh size restrictions in the seagrass bed as a management tool. In chapter 4 it is recommended, that rather the biology of economically important and sensitive species should be used as the basis for management decisions.

The current uses – seaweed farming and artisanal fisheries – coexist without influencing each other significantly. With current culture methods, seaweed farming does not interfere with the seagrass flora and a reduction of habitat quality for the associated fauna is minimal. With respect to the little contribution of fisheries in seagrass beds to the economy and the low percentage of valuable and seagrass dependent fish species, respectively, minor changes in the ecosystem will not affect artisanal fisheries. If however, seaweed farming is to be intensified in the future, care should be taken not to stress the seagrass ecosystem over its threshold level. This would be reached soon, if farming methods are not adjusted. Off-shore seaweed farming might be the solution for this and might create synergistic effects with fisheries: Schooling pelagic fishes are known to aggregate under floating structures and could be harvested there. Many artisanal fishing methods clearly over exploit fish stocks and most habitats are fished to intensively. Therefore, artisanal fisheries productivity can not be increased by higher effort. There are experimental fish farms (open water cages) in the area, and their development into a local applicable scale would be beneficial, provided that their environmental impact is assessed.

Zusammenfassung

Küstendörfer in Indonesien waren schon immer stark auf traditionelle Fischerei angewiesen. Mit zunehmender Bevölkerungsdichte und Befischungsdruck werden alternative Einkommensquellen immer wichtiger, wovon eine, Algenanbau, seit den 1980ern in vielen Gemeinden eingeführt wurde. Algenanbau ist auf Flachwasser und seine Ökosysteme, z.B. Seegraswiesen, beschränkt, welche selbst ein wichtiger Lebensraum für viele Fisch-, Garnelen- und Krebsarten sind. Diese sind eine Grundlage der traditionellen Fischerei, und wenn Algenanbau Veränderungen im Seegrasökosystem verursacht, könnten seine ökonomischen Vorteile durch Einbußen in der Fischerei egalisiert werden. Die Feldforschung für diese Doktorarbeit umfasste Untersuchungen zur Algenzucht, ihrer ökonomischen Bedeutung und Auswirkungen auf die Vegetation, zur Bedeutung traditioneller Fischereimethoden und deren Management und zur Varianz der Fischpopulation und der Kiemennetzfischerei im Seegras vor Puntondo, einem kleinen Dorf im Kreis Takalar, Süd Sulawesi, Indonesien.

Kapitel 1 umfasst eine Studie zu ökonomischen Aktivitäten und dem für sie betriebenen Aufwand. Es wurden sowohl Probleme im Algenanbau und der Vermarktung der Ernte als auch im Fischereisektor bewertet. Beinahe alle Dorfbewohner bauten Algen an und ihr Haushalteinkommen basierte zu einem Grossteil darauf. Sowohl Algenzucht als auch Fischerei wurde ein hohes Entwicklungspotential zugeschrieben und die Bewohner wollten beides ausbauen. Die Ergebnisse werden in Kapitel 1 detailliert diskutiert und aus ökonomischen Überlegungen heraus wird gefolgert, dass eine Intensivierung sich darauf konzentrieren sollte, die Produktivität durch eine bessere Ernteaufbereitung zu steigern. Eine Ausweitung in neue Gebiete sollte neben Überlegungen zu Standortfaktoren für die eigentliche Produktion auch den Zugang zu Märkten berücksichtigen, um den Dörfern ein kontinuierliches und vorhersagbares Einkommen zu ermöglichen. Darüber hinaus sollten auch andere Einkommensquellen bedacht werden, da der Preis für Algen sehr stark schwanken kann.

In Kapitel 2 wird der Einfluss von Schattierung, Tritt, einer Kombination aus beidem und von Algenfarmen auf Seegras betrachtet. Starke Beschattung verminderte die Wüchsigkeit von kleinen Seegrasarten, wohingegen Tritt nur in Verbindung mit Beschattung Auswirkungen hatte. Im Vergleich dazu wurde die große Art *Enhalus acoroides* weit weniger beeinflusst. Die Auswirkungen von Algenanbau selbst waren geringer als aufgrund der Beschattungs- und Trittmanipulationen erwartet werden konnte. Die Ergebnisse werden in Kapitel 2 ausführlich besprochen und eine Algendichte von ungefähr 185.000 Pflanzen ha^{-1} wird als nachhaltig abgeschätzt. Tatsächliche Anbaudichten auf Farmen waren unter diesem Grenzwert. Dennoch sollte eine Produktionssteigerung aus ökologischer Sicht durch neue Farmen in tieferem Wasser mit Abstand zu fragilen Systemen (Korallenriffe und Seegraswiesen) er-

folgen. Dort ist eine höhere Produktion als auf Riffdächern zu erwarten und die Mehreinnahmen könnten die hohen Investitionen für geeignete Anbaumethoden ausgleichen.

In Kapitel 3 sind lokale Fischereimethoden, Fischgründe, Zielarten und deren Biologie der Schwerpunkt. Fischanlandungen wurden von einigen wenigen Methoden und Fischgründen dominiert, von denen die meisten nicht nachhaltig genutzt wurden. Seegraswiesen waren weder bedeutendes Habitat für wichtige Fischarten noch bedeutende Fischgründe. In Kapitel 3 wird angeraten, dass ökonomisch unbedeutende, aber nicht nachhaltige Methoden in sensitiven Fischgründen eingestellt werden sollten. Kiemennetze waren das wichtigste Fanggerät und Beschränkungen der Maschenweite könnten ihre Umweltverträglichkeit verbessern. Fischarten aus dem Riffbereich waren tendenziell überfischt und daher wird dort zu generellen Schonzeiten und / oder Beschränkungen der Methoden geraten. Im Allgemeinen waren mit Handangeln gefangene Fische relativ adult und diese Methode wird daher besonders empfohlen. Senknetze können ebenfalls umweltfreundlich angewandt werden, wenn untermassige Fische unmittelbar nach dem Fang wieder freigelassen werden.

In Kapitel 4 werden die Kiemennetzfischerei in der Seegraswiese und ihre Schwankungen behandelt. Generell wurden hauptsächlich kleine Fische aus nur wenigen Familien gefangen. Der Anteil adulter Tiere am Fang unterschied sich nicht zwischen verschiedenen Maschenweiten. Ein hoher Anteil von Räubern stellt die Funktion des Seegrases als Kinderstube in Frage. Räuber schwammen tagsüber in die Wiese ein, und in den Tagen um Vollmond und während der Trockenzeit war der Anteil adulter Tiere höher. Kleine Individuen wurden nicht gefangen und eine Räuber-Beute Beziehung konnte nicht als entscheidend für diese Schwankungen festgestellt werden. Die Ergebnisse lassen nicht auf eine Nützlichkeit von generellen Schonzeiten oder Beschränkungen von Maschenweiten zum Bestandsschutz der Fische im Seegras schließen. In Kapitel 4 wird angeraten, dass stattdessen die Biologie ökonomisch wichtiger und sensitiver Arten die Grundlage für eine Bewirtschaftung sein sollte.

Die gegenwärtigen Nutzungen – Algenanbau und Fischerei – beeinflussen sich gegenseitig nicht nennenswert. Die praktizierten Anbaumethoden schädigen die Vegetation kaum und die Qualität des Lebensraumes Seegraswiese wird nur minimal beeinträchtigt. In Hinsicht auf die geringe Bedeutung der Fischerei im Seegras bzw. auf Arten, die von ihm abhängig sind, werden schwache Veränderungen im Seegras die traditionelle Fischerei als Ganzes nicht beeinflussen. Beim Ausbau des Algenanbaus in Zukunft sollte jedoch darauf geachtet werden, das Seegrassystem nicht über seine Toleranzschwelle hinaus zu belasten. Ohne angepasste Methoden wäre diese bald erreicht. Off-shore Algenfarmen könnten eine Lösung mit Synergieeffekt mit der Fischerei sein. Pelagische Schwarmfische sammeln sich unter schwimmenden Strukturen an und können dort gezielt befischt werden. Viele traditionelle Fangmethoden überfischen die Bestände eindeutig und die meisten Habitate sind überfischt. Die Produktivität kann nicht mit einem höheren Aufwand gesteigert werden. Es gibt experimentelle Fischfarmen im Dorf und ihre Weiterentwicklung in Hinsicht auf lokale Anwendbarkeit wäre nützlich, vorausgesetzt dass ihr Einfluss auf die Umwelt abgeschätzt wird.

Ringkasan

Di Indonesia, keberadaan desa[2] pesisir sangat bergantung pada perikanan tradisional. Dengan bertambahnya populasi penduduk dan meningkatnya aktivitas penangkapan ikan sumber pendapatan alternatif menjadi lebih penting. Salah satu usaha tersebut adalah kegiatan budidaya rumput laut (BRL) yang sejak tahun 1980-an diperkenalkan di banyak daerah. BRL ini umumnya dilakukan di daerah perairan / ekosistem yang dangkal, misalnya padang lamun. Lamun merupakan habitat penting bagi banyak spesies ikan, udang dan kepiting yang menjadi dasar bagi perikanan tradisional. Dengan demikian, jika BRL menyebabkan ekosistem lamun terganggu, maka keuntungan ekonomis yang diperoleh dari BRL bisa menjadi tidak berarti karena hal tersebut menyebabkan hilangnya pendapatan dari perikanan. Penelitian untuk tesis ini meliputi studi[2] tentang BRL dan peran ekonomisnya, pengaruhnya terhadap flora lamun, kepentingan metode[2] perikanan lokal dan dampak[2] untuk pengelolaannya dan variasi populasi ikan dan penangkapan jaring insang pada padang lamun di pantai Puntondo, sebuah dusun kecil di kabupaten Takalar, Sulawesi Selatan, Indonesia.

Pada bab 1 diuraikan sebuah studi tentang aktivitas ekonomi dan masalah yang berkaitan dengan BRL dan perikanan didiskusikan dan dievaluasi. BRL dilakukan oleh sebagian besar nelayan dan rata[2] memberikan kontribusi yang sangat tinggi bagi pendapatan rumah tangga. BRL laut dan perikanan dipercaya memiliki prospek yang sangat cerah di masa depan dan mau dikembangkan oleh penduduk. Hasil[2] penelitian tersebut didiskusikan secara rinci pada bab 1 dan disimpulkan bahwa, berdasarkan pertimbangan ekonomi, peningkatan produktivitas wilayah itu sebaiknya difokuskan kepada perbaikan pengolahan pasca panen. Perkembangan BRL di wilayah[2] lain sebaiknya bukan hanya mempertimbangkan kesesuaian lingkungan setempat tetapi juga mempertimbangkan akses pasar sebagai faktor kunci untuk pendapatan seterus yang bisa diprediksikan. Di dalam rancangan[2] perkembangan sebaiknya sumber[2] pendapatan lain dimasukkan karena fluktuasi[2] signifikan harga pasar rumput laut.

Bab 2 membahas tentang efek[2] bayangan, peninjakan, kombinasi dari keduanya dan BRL yang nyata dengan intensitas[2] berbeda terhadap lamun. Bayangan dengan intensitas tinggi menurunkan kesuburan spesies lamun kecil dan sebaliknya peninjakan hanya efektif jika dikombinasikan dengan bayangan. Spesies lamun *Enhalus acoroides* yang besar kurang dipengaruhi oleh manipulasi tersebut dibandingkan dengan spesies lamun lain. Pengaruh BRL yang nyata lebih kecil daripada diprediksi dari manipulasi bayangan / peninjakan. Hasil[2] penelitian itu didiskusikan secara rinci pada bab 2 dan kepadatan bibit rumput laut sebanyak 185.000 bibit ha^{-1} diperkirakan dapat berkelanjutan. Dalam praktek BRL kepadatan bibit lebih rendah tetapi tetap berdasarkan pertimbangan ekologis produksi rumput laut sebaiknya ditingkatkan dengan tempat[2] budidaya di perairan yang lebih dalam dan jauh dari

komunitas[2] dasar laut yang agak sensitif. Di perairan dalam produktivitas dapat diharapkan lebih tinggi dan dapat mengembalikan modal yang relatif tinggi untuk metode[2] yang sesuai.

Pada bab 3 penelitian difokuskan pada metode[2] perikanan lokal, habitat, spesies target beserta aspek biologisnya. Hasil penangkapan didominasi oleh beberapa metode penangkapan dan habitat saja, yang kebanyakan tidak berkelanjutan. Ikan[2] yang tergantung pada sumber daya lamun secara langsung tidak penting bagi pendapatan rumah tangga dan padang lamun sendiri tidak merupakan habitat penangkapan ikan yang penting. Pada bab 3 direkomendasikan bahwa metode[2] yang tidak penting tetapi merusak lingkungan sebaiknya ditinggalkan. Jaring insang adalah alat yang terpenting dan regulasi ukuran mata jaring dapat memungkinkan pemanfaatan berkelanjutan. Ikan[2] berhabitat karang sensitif terhadap penangkapan berlebihan dan karena itu direkomendasikan penutupan musiman dan / atau regulasi alat di daerah tersebut. Jaring[2] angkat bisa juga dioperasikan secara ramah lingkungan asalkan ikan[2] yang belum dewasa langsung dilepaskan.

Pada bab 4 diuraikan sebuah studi tentang penangkapan ikan dengan jaring insang dan fluktuasinya. Penangkapan pada umumnya didominasi oleh ikan kecil dari hanya beberapa famili. Kematangan relatif tidak berbeda antara ukuran mata jaring dan kelimpahan ikan[2] pemangsa meragukan fungsi daerah lamun sebagai habitat bagi pemijahan dan pembesaran ikan. Ada indikasi bahwa ikan[2] pemangsa memasuki padang lamun pada siang hari, ikan[2] yang lebih dewasa pada hari[2] bulan terang dan pada musim kemarau. Ikan[2] kecil tidak tertangkap dengan jaring insang dan interaksi pemangsa-mangsa tidak dapat ditentukan sebagai faktor penyebab variasi tersebut. Hasil[2] studi ini tidak mendukung penutupan musiman atau pelarangan penggunaan ukuran mata jaring tertentu sebagai alat pengelolaan sumber daya ikan. Pada bab 4 direkomendasikan bahwa sebaiknya biologi jenis[2] ikan penting yang bernilai ekonomi dan ikan[2] yang sensitif dijadikan dasar untuk upaya pengelolaan.

Pemanfaatan[2] sekarang – BRL dan perikanan tradisional – berjalan bersamaan dan tidak saling mempengaruhi secara signifkan. Dengan metode[2] yang ada sekarang BRL tidak mengganggu lamun di bawahnya dan kekurangan kualitas habitat untuk fauna hanya minimal. Berdasarkan kontribusi kecil perikanan pada padang lamun untuk ekonomi lokal dan persentase kecil ikan[2] yang tergantung dari sumber daya lamun perubahan minimal pada lamun tidak akan menyebabkan perubahan pada sektor perikanan secara umum. Tetapi kalau BRL ingin dikembangkan seharusnya diperhatikan kebatasan daya dukung ekosistem alami. Kalau metode[2] tidak dicocokkan batas tersebut itu cepat dilewati. Budidaya rumput laut di perairan lebih dalam barangkali adalah solusinya dan bisa menimbulkan efek[2] sinergetis dengan perikanan juga. Ikan[2] kecil mengumpul dibawah benda[2] terapung dan bisa ditangkap lebih mudah. Banyak metode penangkapan ikan menangkap berlebihan dan kebanyakan habitat mengalami overfishing. Karena itu produktivitas sektor perikanan tidak mungkin ditingkatkan dengan perusahan lebih keras. Di Puntondo terdapat karamba ikan di tingkat percobaan dan pengembangannya sampai bisa dilakukan lokal akan menguntungkan asalkan pengaruhnya terhadap lingkungan sekitarnya dievaluasi terlebih dahulu.

General introduction

Humans in coastal zones have ever been living with and from natural ecosystems. In Indonesia, a very long stretch of coast (> 80.000km, second in the world only to Canada) scattered over more than 17.500 islands has to accommodate a high population (more than 220Mio people, 4th in the world after China, India, and the USA). Today virtually no marine resource remains unaffected and traditional use of marine ecosystems (e. g. artisanal fisheries) is confronted with advances in technique and globalisation. In Indonesia, large areas of mangrove forests in Java, Kalimantan, Sulawesi, and Sumatra have been transformed to fish ponds; coral reefs are heavily, and very often unsustainably, fished. Changes in those two ecosystems and the reasons for it have been well documented. Compared to those systems, knowledge of seagrass beds, their use, and their entire changes due to recent human activities is very poor.

The seagrass environment

Seagrasses are flowering plants inhabiting inter- and subtidal zones around the globe except the Antarctic (den Hartog 1970). Though different in their species composition, their communities can be characterized by prevailing growth forms and their ecological needs and capabilities (den Hartog 1973).

Pioneer communities are typically formed by comparatively small species (*Halodule*, *Halophila*, and *Zostera* subgen. *Zosterella*) which can tolerate oscillating environmental conditions. Usually, their plant communities consist of up to two seagrass species without significant abundance of rhizophytic algae (e. g. *Caulerpa, Halimeda,* and *Penicillus*).

In later stages of succession, and especially in the subtidal, they are replaced by larger species (*Cymodocea, Thalassia*, *Syringodium*, and *Zostera* subgen. *Zostera*) which are less tolerant to changing habitat conditions. Their communities usually consist of several seagrass species (Figure 1) and often rhizophytic algae can be found within their beds.

The climax state within a succession is formed by large and competitive species that show narrow limits of tolerance for environmental parameters (*Amphibolis*, *Enhalus*, *Heterozostera*, *Phyllospadix*, *Posidonia*, and *Thalassodendron*). Their communities very o en consist of only one seagrass species in very dense stands, repressing the growth of rhizophytic algae (den Hartog 1973, Figure 2).

Natural disturbances, e. g. erosion, sedimentation, and bioturbation however often set back the succession in small (less than one square meter) to large (several hectares) areas, thus creating a patchwork of seagrass succession communities within a seagrass bed (e.g. Birch 1984, Jensen & Bell 2001, Fourqurean & Rutten 2004, Rasheed 2004, Sintes et al. 2005)

Together with tropical rain forests and coral reefs, seagrass beds are among the most productive ecosystems (McRoy & McMillan 1973). Their high net primary production is not only the result of high seagrass growth rates. Small epiphytic algae, mainly Rhodophyta and diatoms profit from additionally available settling substratum due to the surfaces of leaves and the better light climate on top of the seagrass leaves compared to that at the bottom.

Figure 1. A *Cymodocea / Thalassia* community growing on coral rubble, Spermonde Archipelago, Indonesia

Figure 2. *Enhalus acoroides* growing in a monospecific community, Spermonde Archipelago, Indonesia

Mediation of oceanographic parameters

Seagrasses stabilise the sediment with their web of rhizomes and roots (Stoddard 1963, Glynn et al. 1964, Orth 1977). The energy of waves is decreased due to the high roughness of the benthos and hence, the water becomes much calmer towards the shore (Burrell & Schubel 1977, also see Sheppard et al. 2005). In calm water, suspended particles sink to the bottom and accumulate between the plants (e.g. Scoffin 1970, McRoy & Helfferich 1980, Asmus & Asmus 2000b, Kennedy et al. 2004). Seagrasses absorb significant amounts of dissolved nutrients from the water column via their leaves and immobilize them by fixation as biomass (e.g. Ziemann 1975, McRoy & Helfferich 1980, Moriarty & Boon 1989, Stapel & Hemminga 1997, Evrard et al. 2005). Both sedimentation of fine particles and removal of nutrients keep the water turbidity low (Moore 2004) – essential to coral reefs, which are most often associated with tropical seagrass beds. Additionally, low nutrient loads inhibit the growth of macroalgae (e.g. Caulerpales), which compete with and harm corals (McCook 2001, Lapointe et al. 2005).

Enrichment of coastal biodiversity

Seagrass beds are an integral part in the mosaic of coastal ecosystems. They provide critical services for other systems and depend on neighbouring biotopes themselves (reviewed by Boström et al. 2006). Most seagrass beds which have been studied have a higher faunal biomass and biodiversity than unvegetated neighbouring habitats (e.g. O'Gower & Wacasey 1967, Morton & Miller 1968, Homziak et al. 1982, Wells et al. 1985, Carpenter & Lodge 1986, Nakamura & Sano 2005). After Kikuchi & Pérès (1973, also see Howard et al. 1989) the fauna can be classified into six groups:

- sessile animals
- macrofauna between the epiphytes
- creeping and walking organisms
- benthic organisms
- swimming animals resting on seagrass leaves and
- animals swimming below the leaf canopy

All of them profit from increased surface area, organic enrichment and stabilization of sediments, higher food resources, lower predation risk and reduced hydrodynamic forces (Lewis 1984, Orth 1992). The last group mainly consists of fishes, but invertebrates, e.g. Cephalopoda and vertebrates (sea turtles and manatees / dugongs) are included. Fish migrations between seagrass beds and other coastal habitats are well documented and underline the importance of seagrass areas among the coastal habitats (e.g. Weinstein & Heck 1979, Heck & Orth 1980, Baelde 1990, Hindell et al. 2000, Scott et al. 2000, Guest et al. 2003, McArthur et al. 2003, Chittaro et al. 2005, Dorenbosch et al. 2005a, Unsworth et al. 2006). Fishes can be further classified (Kikuchi 1966):

- "Permanent residents" can be found throughout the year with all life stages in seagrass beds. Many Blenniidae, benthic and pelagic Gobiidae, Syngnathidae, and other fishes are in this group (Figure 3). Based on family dominances, differences between seagrass beds within this group are minimal (Heck & Orth 1980, Pollard 1984).
- "Seasonal residents" are species which inhabit seagrass beds during certain seasons of the year or during certain life stages. In the tropics, this is the case for a wide range of fishes which are reef-associated as adults (Kochzius 1999, Figure 4). Most of these species are pelagic spawners and their larvae are not capable of actively migrating into seagrass beds (Victor 1986a, b, Bell & Pollard 1989). Rather they are carried with currents and are settling in seagrass areas due to sheltered conditions.
- Fishes migrating form neighbouring habitats (e.g. coral reefs or sand flats) into seagrass beds are classified as "temporary residents". Most of them are relatively large and forage on plant (e.g. Acanthuridae, Scaridae, Siganidae) and animal (e.g. Lutjanidae, Serrani-

dae, Sphyraenidae) resources. Especially during the night those species enter seagrass beds, whilst resting in other habitats during daytime (Ogden 1980).

- „Occasional migrants"are species which are only exceptionally encountered. They are not linked by a feeding or spawning habitat to seagrass beds.

The role of seagrass beds as nursery and feeding habitat for fishes, crabs, and shrimps from other habitats like mangroves and coral reefs has been a major focus of study (e.g. Pollard 1984, Bell & Westoby 1986, Kenyon et al. 1999, Heck et al. 2003, Smith & Sinerchiab 2004, Chittaro et al. 2005, Dorenbosch et al. 2005a, 2005b, Lugendo et al. 2005). However, the reasons and mechanisms behind the patterns observed in the field are diverse and no common consensus has been reached yet.

Human influences

As virtually all ecosystems on earth, seagrass beds are exposed to varying degrees of disturbance by humans (Thia-Eng & Garces 1994). Seagrasses depend on sunlight and therefore, anthropogenic increases in turbidity are probably the most important factor for survival of seagrass beds (e.g. Neverauskas 1988, Vermaat et al. 1996, Bach et al. 1998, Longstaff et al. 1999, Fokeera-Wahedally & Bhikajee 2005, Gacia et al. 2005, Kelble et al. 2005, Kiswara et al. 2005, Waycott et al. 2005). Many human activities reduce underwater visibility, e.g. increased sediment load in rivers, dredge fishing, or marine sand-mining and coastal development (e.g. Odum 1963, Long et al. 1996, Vermaat et al. 1996, Asmus & Asmus 2000a, Sealey 2004, Sheridan 2004, Gonzalez-Correa et al. 2005). If the vegetation is destroyed physically, recovery is often slow due to changed bio-chemical substrate conditions (Ziemann 1975, 1976, Clarke & Kirkman 1989, Marbà & Duarte 1994, Gacia et al. 2003, Kaldy et al. 2004, Neckles et al. 2005, Waycott et al. 2005).

Eutrophication initially leads to increa-

Figure 3. *Parapercis cylindrica* (Pinguipedidae) is a permanent resident in seagrass beds, Puntondo, Indonesia

Figure 4. Juveniles of *Plotosus lineatus* (Plotosidae) in a seagrass bed, Spermonde Archipelago, Indonesia

sed growth of the plants (e.g. Ziemann 1975, Hillman et al. 1989). High nutrient loads lead to blooms of pelagic and benthic algae, which reduce light levels at seagrass canopy height and overgrow the plants, respectively (Dong et al. 1972, Ziemann 1975, Shepherd et al. 1989, Asmus & Asmus 2000a). The reactions of pioneer and climax seagrass species differ significantly (McNulthy 1970, Barada 1973, Armitage et al. 2005, Waycott et al. 2005).

In rural areas, agriculture is the main contributor to eutrophication. Additionally, significant amounts of pesticides can be washed into coastal ecosystems, where they cause diebacks in seagrass and other ecosystems (Asmus & Asmus 2000a, Bester 2000, Macinnis-Ng & Ralph 2004, Duke et al. 2005, McMahon et al. 2005, Schaffelke et al. 2005, Waycott et al. 2005). In South-East Asia, shrimp and fish farms cover large areas of coastal plains. Their effluents have exceptional high nutrient loads and are often polluted with aquacultural chemicals (Trott & Alongi 2000, McKinnon et al. 2002, Islam et al. 2004, Trott et al. 2004).

Seaweed farming

Marine brown (Phaeophyta), green (Chlorophyta) and red algae (Rhodophyta) have been used by humans since prehistoric times, predominantly for direct consumption and medicinal applications (Anggadiredja 1992, Anggadiredja et al. 2006). Today, industrial usages, e.g. as source of thicking / gelling substances are far more important on a global scale (Figure 5). In Indonesia, only *Eucheuma* spp. and *Kappaphycus* spp. (commonly referred to as eucheumatoid species or carrageenophytes, Figure 6) and *Gracilaria* spp. are cultivated commercially. Latter one is usually grown in brackish water ponds, the former ones are grown in open marine environments.

Culture of carrageenophytes in South-East Asia

Until the 1960s industry demand for Rhodophyta was largely covered by wild stocks (Trono 1999) and cold water species collected in North America and Europe dominated the market (Neish 2003). In SE-Asia, Indonesia exported the largest quantities of red seaweeds, however, due to political unrest this supply to the world market collapsed. This and increasing production costs for cold water seaweeds in the 1960s encouraged cultivation trials for warm water species in the Philippines (Delmendo et al. 1992, Trono 1999). Today, 99 % of the market demand for carrageenophytes is met by tropical species farmed in the Philippines (70 %), Indonesia (24 %), Malaysia (Sabah, 4 %), and Tanzania (1 %, Neish 2003).

Since the 1980s, there has been a high effort in Indonesia to repeat the commercial success of seaweed farming in the Philippines (Adnan & Porse 1987, Sievanen et al. 2005, Anggadiredja et al. 2006). Starting in the province of Bali and on Lombok Island, commercial farming has since spread all over the archipelago. Today, the main production centres are the islands stated above and South Sulawesi, especially Jeneponto and Takalar districts.

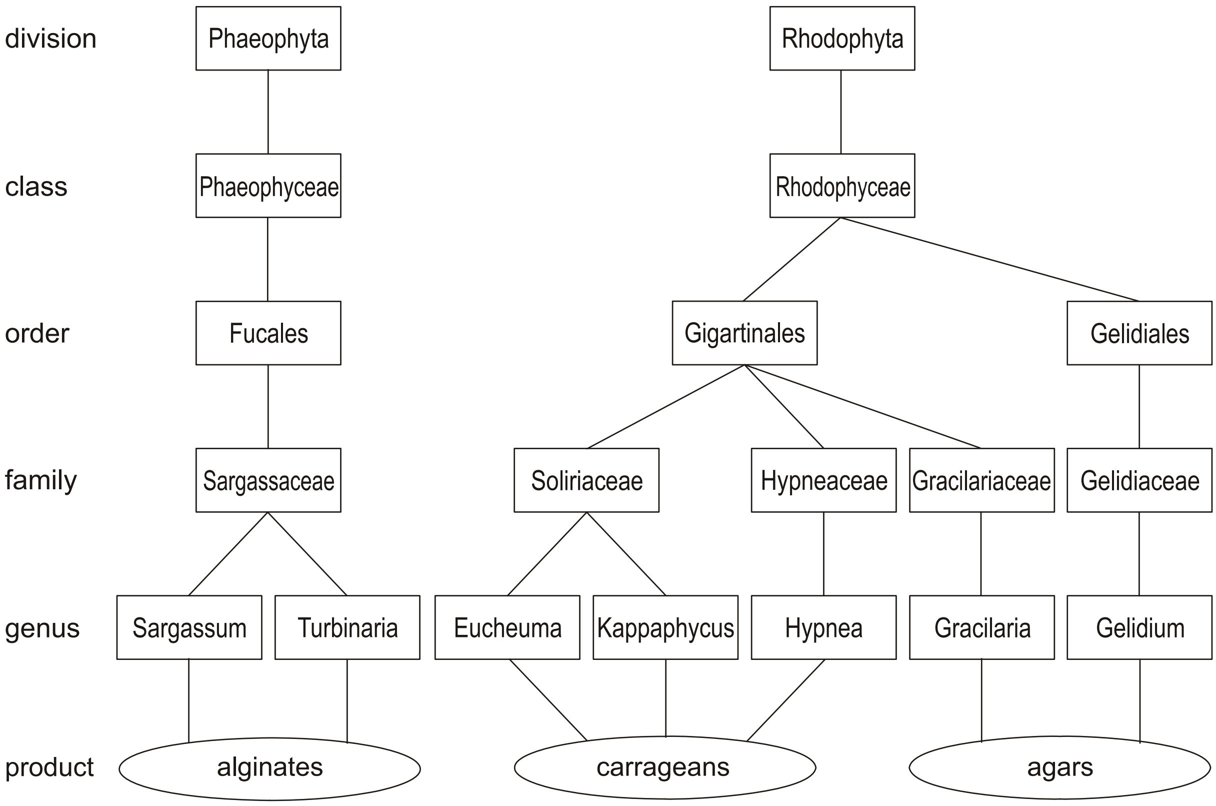

Figure 5. A simplified classification of commercially used brown and red algae and their products (after Anggadiredja et al. 2006)

The culture of marine algae is widely seen as a valuable source of additional income for poor coastal communities (Figure 7), especially as the need for initial investment and human resources is small compared to other forms of sea ranching / farming (Luxton & Luxton 1999, Anonymous 2000b, Crawford 2002, Sievanen et al. 2005). In South Sulawesi, coastal shallow areas and seagrass beds are preferred locations for seaweed farming (Aslan 1998, Anonymous 2000a, 2000b).

Farming methods

The natural habitat of *Eucheuma* and *Kappaphycus* species is the reef environment, were they grow attached to hard substrates (Trono 1999). In very early farming trials, the seedlings were tied to stones and then "sown" on the farming site. This changed significantly after it was discovered that the algae could thrive without attachment to hard substrate but rather tied to lines. With lines, seaweed culture was no longer restricted to the benthos and the more favourable environmental conditions of the water column above could be used:

- less competition with other benthic flora (seagrasses and macroalgae)
- less predation by benthic herbivores (e.g. the sea urchin *Diadema setosum*)

- o better water circulation around the plants
- o better crop control and
- o overall better plant growth

Figure 6. *Kappaphycus alvarezii* harvested in Puntondo, South Sulawesi, Indonesia

Figure 7. Typical houses in Puntondo, South Sulawesi, Indonesia

Today, practically all open water seaweed farms use lines as growth "substrate". In the Philippines, initially large-mesh fishing nets were fixed horizontally over the seafloor with poles. The algae seedlings were then tied to the knots of the mesh. This practice however was very labour intensive as the net could not be prepared on land and the seedlings had to be tied to it on location. Furthermore, it was discovered that the spacing of the plants could be much closer than practiced until then. From this findings, the "off-bottom method", like it is still in use today, evolved (Neish 2003).

The off-bottom method (Figure 8) consists of relatively small (2,5m · 5m) individual plots. Head ropes are tightened between poles at a distance of around 40–50cm above the seafloor. Between those head lines the culture ropes are spaced at approximately 20–25cm. Average planting distance on these ropes is 20–25cm (Anggadiredja et al. 2006). Between the individual plots, small paths are left open for maintenance and harvest of the algae. With this method a very high farming, intensity (in terms of seedlings per area unit) can be achieved (Figure 9). The shortcoming however is the relatively close distance to the sea bottom and benthic herbivores still might reach the plants, e.g. by climbing up the poles or benthic structures below farms. Furthermore, the defined distance from the seafloor limits usable areas: Water depth at average low tide has to be less than 1,20–1,50m so that harvest and maintenance can be done during this time without uneconomical SCUBA equipment. Additionally, this method is not suitable for turbid waters, as the plants growing close to the sea bottom do not receive optimum light levels during high tide and times of turbidity spills. The very shallow waters are also the natural habitat of herbivorous fishes (mainly of the families Acanthuridae, Scaridae, and Siganidae), which can cause total crop loss (Uy et al. 1998, Tomas et al. 2005). Because of these disadvantages, several other methods have been developed.

The "floating raft method" (Figure 10) consists of frames approximately the same size as individual plots of the off-bottom method (2,5m · 5m). In calm waters however, the rafts may be up to 10m · 10m. The frames are made of floating material, usually bamboo as it is sturdy and relatively cheap (Anggadiredja et al. 2006). Within the frames, the culture ropes with a seedling density similar to the off-bottom method are tightened. The rafts are held in place with ropes tied to large stones or anchors. The length of these ropes depends on water depth, tidal amplitude and wave exposure. Due to the additional weight of the crop, the frames float just below the water surface during all tidal stages. With growth of the plants (i.e. with increasing weight of the frames), additional floaters might be necessary to prevent them from sinking. The algae receive maximum light, and turbid water is much less a problem than with benthic methods (Zuberi 2001). Farming intensity per unit area is lower than with the off-bottom method, as the rafts cannot be spaced tightly in order to accommodate their movement with waves and currents. However, the farming area is not restricted to a certain water depth (Hurtado & Agbayani 2002), and the total area under farming can be much higher than with shallow-water methods (Zuberi 2001). Benthic herbivores are excluded from the plots due to the distance from the seafloor. Reef-dwelling fishes feeding on the crop are much less abundant in deeper water. Additionally, seasonal parameters (e.g. water temperature and salinity) are more stable off-shore and therefore seaweed growth with the floating raft method is better than with the off-bottom method (Zuberi 2001, Hurtado & Agbayani 2002). The rafts can be towed on-shore to facilitate easy crop handling. Disadvantages of this method are that it requires a minimum water depth. If the water is too shallow, waves

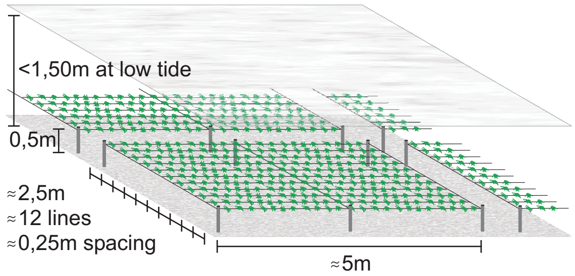

Figure 8. Schematic drawing of the off-bottom method

Figure 9. A reef flat densely covered by off-bottom seaweed farms. Note small boats on upper right corner, Nusa Lembongan, Indonesia (source: GoogleEarth)

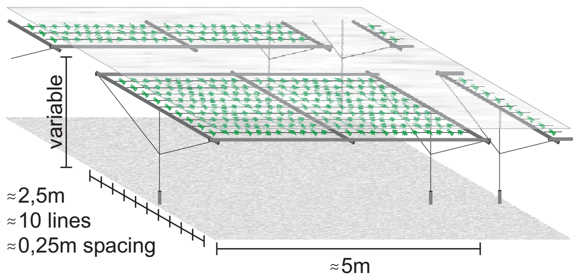

Figure 10. Schematic drawing of the floating raft method

can crash the floats on the sea bottom and destroy them (Hurtado & Agbayani 2002). Initial investment is much higher than for the off-bottom method, especially in areas where bamboo is not readily available (Zuberi 2001). If rocks are difficult to find in the area, concrete blocks or iron anchors have to be used. Ropes and lines are usually priced per kg and the sturdy lines needed for anchoring add significantly to the costs (Neish 2003). However, economical analysis show that the floating raft method can be operated with profit (Hurtado & Agbayani 2002).

The „floating long-line method“ (Figure 11, Figure 12) evolved parallel to the raft method in order to overcome the problems of the off-bottom technique. With this farming method, the seaweed is cultivated on long lines (up to 100m), which are kept in place with individual anchor ropes. The cultivation lines are kept close to the surface by floaters, which can be commercially available Styrofoam buoys, or, much more common, used PE water bottles. Seedling distance on the lines is similar to both methods mentioned above; however, individual ropes are spaced much further apart. Usually, a spacing of 1m is necessary between the ropes to prevent them from tangling. However, in calm waters, the cultivation lines can be spaced much closer, but seedling densities as high as with the off-bottom method cannot be achieved. The floating long-lines have no restrictions of minimum or maximum water depth or soil structure and can be used in most situations. Only in areas with very high wave action, the off-bottom method is still preferred by farmers, though they admit that higher yields are possible when the plants are kept at a constant distance to the water surface (pers. communication with seaweed farmers on Lembongan Island, Bali, Indonesia). Initial investment is significantly lower than for the floating raft method without compromising its benefits. Cultivation lines can be prepared and the harvest can be handled conveniently on land, which adds to the popularity of the method. From this basic cultivation scheme local variations have evolved as a response to differing environmental conditions and availability of construction materials. In very clear waters, cultivation lines of the floating raft as well as floating long-line method, might be installed hanging vertically from headlines with bottom weights,

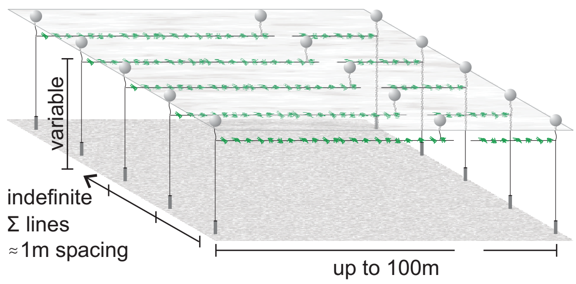

Figure 11. Schematic drawing of the floating long-line method

Figure 12. A seaweed farm using the floating long-line technique, Puntondo, Indonesia

effectively increasing the total length of culture rope per plot and hence, harvest (Mandagi & White 2005).

Effects on the environment

Though seaweed farming does not change the physical environment directly (Johnstone & Ólafsson 1995, Bryceson 2002), it has been documented to alter natural, complex processes, as well in the flora as in the fauna (Olafsson et al. 1995, Bergman et al. 2001, Semesi 2002, Eklöf et al. 2005, 2006a, 2006b). The reasons for this are manifold: less sunlight on the seafloor and increased siltation due to the algae above (Vermaat et al. 1996, Bach et al. 1998, Enriquez 2005, Gacia et al. 2005), physical disturbance by trampling on or clipping of leaves, increased amount of detritus and changing sediment parameters (Rasheed 2004, Cruz-Palacios & van Tussenbroek 2005), poisonous secrets of the seaweeds (Collén et al. 1995), and competition for nutrients. Often complex interactions of the factors mentioned above are responsible for changes in seagrass beds where cultivation areas have been installed (Livingston et al. 1998, Eldridge et al. 2004, Ibarra-Obando et al. 2004). However, the actual effect on benthic communities below seaweed farms surely differs between farming methods. In an extensive review Zemke-White & Smith (2006) describe the environmental impacts of seaweed farming in the tropics.

Artisanal fisheries

Artisanal fisheries involve skilled but non-industrialized operators. This type of fishery typically represents a small-scale, decentralized operation. Normally it is subsistence fishery although sometimes the catch may be sold. Usually fishing trips are short and inshore and fishing vessels are small (Figure 13). In Indonesia, where 75 % of fishing vessels are not motor-driven (Anonymous 1977–1995), the majority of fishermen depend on coastal resources close to the beach. These places are mostly covered by seagrass beds providing food and habitat resources for a wide range of economically important species and representing important fishing grounds. They are easily fishable, keeping financial investment and human resources to a minimum level. Most often, their fisheries has an open-access character. Under this conditions, the seagrass ecosystem

Figure 13. Unmotorized small vessels are still common in Indonesia

and its associated fauna are vulnerable to overfishing (Amar et al. 1996, McManus 1997, Kramer et al. 2002, van Oostenbrugge et al. 2004).

Rapid population growth and the general desire to develop coastal regions lead to an increasing fishing effort and changing techniques in Indonesia, putting local fish stocks under heavy pressure (Johannes 1998, Mous et al. 2005). Unsustainable methods and overfishing interfere with natural processes (Jennings 1998, Pet-Soede et al. 2001, Valentine & Heck 2005) and disturb the food web of the system (e.g Sumaila et al. 2000, Arreguín-Sánchez et al. 2004, Aubone 2004, Campbell & Pardede 2006). To prevent the disastrous effects of chronic overfishing improved management and community development plans have to be developed (e.g. Fernández et al. 1999, Pollnac et al. 2001, DeVantier et al. 2004, Barker 2005, Butler 2005, Mous et al. 2005).

Fisheries management

After the decentralization of coastal management in Indonesia (Satria & Matsuda 2004), evaluation of local fish stocks has improved (see Pet-Soede et al. 1999). However data gathering and management needed for a traditional western fisheries management is still underdeveloped (Pet-Soede et al. 2001). Tropical fisheries typically target hundreds of species with dozens of methods, changing regionally, even between villages (Chan 2002). The extensive data sets needed for maximum-sustainable-yield (MSY) models are virtually impossible to gather for Indonesia (Johannes 1998, Pet-Soede et al. 1999, Pet-Soede et al. 2001, Mous et al. 2005). Even in developed countries the MSY model has not prevented the decline and even collapse of many once abundant target fish species. To overcome the general shortcomings of the MSY model, the ”precautionary approach” and ”ecosystem based management” have been developed. Both theories however still strongly depend on extensive data from natural-sciences and do not explicitely include the needs of local fishermen. Hence, for developing countries several authors (e.g. Hegarty 1997, Johannes 1998, Cannon & Surjadh 2004) have proposed to abandon the idea of western fisheries management.

Marine protected areas and alternative livelihoods

The establishment of marine protected areas (MPAs) is an integral tool in the ecosystem precautionary approach to coastal zone and fisheries management. If their establishment is merely based on environmental evaluations without consideration of the needs of local residents, their success is doubtful (Elliott et al. 2001). Community based management approaches have been successful (Christie 2005), but there are indications that co-management of resources might be a more favourable option (Clifton 2003, Crawford et al. 2004, Satria et al. 2006). In South Sulawesi with its high population density and chronically overfishing (Pet-Soede et al. 2001) the implementation of large MPAs is not possible and a network of small protection zones is preferred (Jompa et al. 2004).

Alternative livelihood approaches (e.g. mariculture and seaweed farming, land-based activities and tourism), are crucial to implementing sustainable ecosystem management (Alder et al. 1994, Kuhlmann 2002). However, the success of introduced alternative incomes depends on their cultural acceptance in the community, on market access, and on market prices. Latter factors can oscillate, and are out of the control of managers. Therefore, to minimize the vulnerability of local economics several activities should be promoted simultaneously. For seaweed farming (see e.g. Sievanen et al. 2005) it has been hypothesized that a sense of stewardship of the coastal sea is created. However, there are no empirical data supporting this theory.

Traditional knowledge

Hegarty (1997), Johannes (1998), Cannon & Surjadh (2004), and other authors have suggested to use traditional knowledge and rapid assessment methods to gather basic data on fish stocks and other living resources (see e.g. Johannes 1998, Ruddle 1998, Evans & Birchenough 2001, Chan 2002, Bergmann et al. 2004). These data then, together with generalized data from other, but similar areas, could form the basis for an ecosystems-approach management. Amongst others, Amar et al. (1996), Jennings & Polunin (1997), Russ & Alcala (1998), Friedlander et al. (2003), and McClanahan & Mangi (2004) have explicitly analysed the influence of fishing gear and pressure on coral reef fish stocks and biodiversity in South-East Asia and made management suggestions. Methods and theories of the livelihood approach can be integrated, as even assessment of ecological data partly relies on perceptions of local resource users.

Aims of the thesis

In South Sulawesi, Indonesia, both seaweed farming and artisanal fisheries in most locations where they co-occur depend on shallow waters and seagrass beds in particular. Research on the influence of seaweed farming on traditional fisheries or the interaction between those sectors is rare.

Socio-economic aspects of seaweed farming

Seaweed farming is a very common coastal activity in Indonesia. Amongst other reasons, it has been promoted by state agencies and NGOs to reduce stress on other coastal resources, e.g. fish stocks. Seaweed farming provides fishers with a steady income, requiring comparatively little financial and time resources. This makes seaweed farming a very popular activity and farming areas are spreading continuously. The need for management is most urgent in areas, where intensive seaweed farming is present or in areas, where it contributes a high percentage to household income. There, a collapse of algal farming due to e.g. diseases or decreasing market demand / prices can have devastating consequences for local economies. In the sub-village of Puntondo (village Laikang, district Takalar, South Sulawesi, Indonesia), where the field research for this thesis was carried out, the contribution of seaweed farming to household income was investigated and compared to other sources of income, fisheries in particular. The results of this study have been submitted to Ocean & Coastal Management and are presented in chapter 1.

Long-term effects of seaweed farming on seagrass beds

Seagrass beds are common in Puntondo and are intensively used for seaweed farming. Besides socio-economic aspects, ecological impacts of algae farms have to be considered for management decisions also. Changes of the seagrass community induced by seaweed farming reduce not only the ability of the vegetation to prevent erosion, but also habitat quality for associated fauna. Under given oceanographic and geophysical conditions, seagrass species composition and performance (i.e. shoot density and biomass) are the most crucial factors structuring fish communities. Therefore, in Puntondo the effects of different seaweed farming intensities on seagrasses below the farms were investigated in field experiments. The results of this study have been submitted to Marine Ecology Progress Series and are presented in chapter 2.

Economically important fish species, methods and fishing habitats

In most coastal communities in Indonesia where seaweed farming was introduced, artisanal fishing still exists. This fishery uses a wide range of gear and fishing grounds and, in consequence, targets a very broad spectrum of fish species. Seagrass beds are an important habitat for (juveniles of) economically important fish species and therefore, changes in this ecosystem have the potential to alter catch composition and abundance of artisanal fishers. This however is under the premise that seagrass-dependent fish species contribute a high percentage to overall catch or that seagrass beds themselves are important fishing grounds. Traditional knowledge on fished species, used gear and fishing grounds were surveyed in Puntondo and analyzed in context with literature data. The results of this study have been submitted to Ocean & Coastal Management and are presented in chapter 3.

Fish stocks and gill net fishery in seagrass beds

Unselective, passive fishing methods, e.g. gill nets, are a preferred fishing gear in seagrass beds. They catch a wide range of fishes, small species can be harvested, they require little knowledge of fish behaviour, and they have little opportunity costs. Altogether, they have a high catch per effort ratio compared to other methods. If (small) mesh sizes however are used in nursery habitats or during spawning seasons, their high catch efficiency can easily over harvest fish stocks. Fishes migrating into seagrass beds from other ecosystems (e.g. coral reefs) on a daily or seasonal basis are therefore exceptionally prone to overfishing. Gill net catch efficiency and catch diversity was investigated for two years in the field. The results of this study have been submitted to Fisheries Management and Ecology and are presented in chapter 4.

Seagrass beds as a common resource for seaweed farming and fisheries

The research for this thesis comprised not only ecological empirical studies (chapters 2 and 4) but also socio-economic issues (chapter 1) and a transdisciplinary approach between local knowledge and empirical ecology-data (chapter 3). The success of management plans for Indonesian coastal regions, which are faced with serious problems, is questionable without incorporation of socio-economic issues and local knowledge. The results of the field research for this thesis are therefore discussed in context and management suggestions for a co-existence of both activities are made in the general discussion section of this thesis.

Results of the thesis

Socio-economic aspects of seaweed farming

Seaweed farming was introduced in Puntondo in 1996 and ten years later, 94% of the households were farming seaweed (*Kappaphycus alvarezii* and *Eucheuma denticulatum*). From data collected during community surveys it was calculated that a total area of about 22 ha was under seaweed farming. Average yield on a farm was 228 kgDW after 40 days of culture, resulting in approximately 1,8 $tDWfarm^{-1}a^{-1}$ (≈ 9,5 $tDWha^{-1}a^{-1}$). Land-based work (i.e. preparation of culture ropes, seedling and harvest processing) was mainly done by women and children. 17% and 48% of the farmers tried to use other seaweed species and farming methods, respectively. Floating rafts were reported to be too cost intensive and were not used any more. All but one of the interviewed households which were farming seaweed also fished on a daily basis. The vast majority (94%) of fishers used gill nets and only a few used hook and line also. Around 34% of the households had additional sources of income, e.g. small stores. The main problems on the seaweed farms were correlated with weather conditions. For fisheries, low abundance of fish (89% of respondents) and high fuel costs (29%) were the dominant problems. Some fishers reported area conflicts with seaweed farming. Owners of small stores reported low turnover. Seaweed farming contributed 81% to average household income. An average seaweed farm in Puntondo was estimated to create at least IDR 680.000 (USD 74,59) per harvest of *K. alvarezii* and IDR 390.000 (USD 42,52) per harvest of *E. denticulatum*. Most farmers were satisfied with the income created by seaweed farming, however, many of them reported that the prices were unstable. Though the contribution of fisheries to net household income was comparatively low, most fishers were satisfied with the income it created. The low but frequent income from fisheries was used to cover the daily needs, whereas the much higher, but infrequent income from seaweed farming was used to send the children to school and to buy more expensive goods. Because of this, 93% of the villagers wanted to extend seaweed farming activities and 89% wanted to develop fisheries.

Long-term effects of seaweed farming on seagrass beds

Shading by the algae on the farms and trampling by the farmers during maintenance and harvest were supposed to be the main factors influencing the seagrasses below. These two factors and their impact were tested in field experiments for two years. Generally, high shading levels reduced shoot density on experimental plots, whereas trampling was effective in combination with medium and high shading only. The effect of manipulations on seagrass performance varied between seasons and there was no cumulative effect over time. Regression analysis indicated shading to be the main factor for shoot density changes of small seagrass species (*Cymodocea* spp. and *Thalassia hemprichii*). The much larger species *Enhalus acoroides*, however, was less influenced by shading; its shoot density tended to increase with shading intensity. This might be due the comparatively high tolerance of *E. acoroides* towards low light levels. Under experimental conditions in this study, the shade cloth of the manipulations might have provided protection from excess solar radiation during low tide air exposure. Biomass development closely followed shoot density changes. Weight of single plant fractions of small species was more dependent on species-specific ratios than on any of the applied treatments. The positive effect of shading on *E. acoroides* shoot density was mirrored in the biomass development of this species. Experimental data were used to estimate threshold levels for shading and farming intensities, beyond which seagrass performance would decrease. Based on data from shading manipulations, the maximum sustainable standing crop of algae was estimated to be approximately 185.000 and 205.000 seedlings ha^{-1} for the community of smaller species and *E. acoroides*, respectively. Using data from seaweed farms, this estimate was significantly lower (small species: 135.000 seedlings ha^{-1}; *E. acoroides*: 200.000 seedlings ha^{-1}). Based on this estimate, the commonly used farming density in Puntondo (110.000 seedlings ha^{-1}) might damage plants of *Cymodocea* spp. and *T. hemprichii*. However, as seaweed farming plots in Puntondo are not used year-round the commonly used farming can be considered environmentally sustainable. Though, further development of algal culture in the area should focus on methods which can be applied in deeper water. Current seaweed farming is restricted to shallow waters and the reef flats are (seasonally) packed with farms. There, productivity could only be increased by higher algal densities and longer periods with continuous operation of the farms. Thus, the calculated threshold levels might be reached soon.

Economically important fish species, methods and fishing habitats

In community surveys of fishers, 208 fish species of 65 families were identified in Puntondo, of which 70 % did not depend directly on plant resources. The 10 most species-rich families contributed 52 % to the total number of fished species. About 97 % of the species were consumed locally and 85 % of the species were sold on the market. Nets and lines were the most important fishing methods; "rocks", "beach" and "coral" were the most important fishing habitats. The number of fished species was determined by fishing method and not by habitat. Cumulative catch decline was highest for net and line catches without regard of habitat. Fishes caught in Puntondo were small in average; with lines (method) and offshore (habitat) yielding the biggest fishes. Average price of fishes was determined by habitat: fishes from reefs (categories "rock" and "coral") were more expensive than from seagrass and mangrove areas. Nets were the preferred fishing method, and the resulting high fish landings resulted in the highest cumulative price of catches of all methods. 10 of 51 marketed fish families contributed 61 % to overall income from fisheries. "Economic importance" (calculated from data on abundance, seasonality and market price) of 80 species was low and very low, 36 species were of medium importance, and 57 were of high and very high value. Average economic importance did not differ significantly between fishing methods or habitats. Nets used on reefs, however, targeted the most valuable species. Cumulative economic importance was highest for the methods "net" and "line". Species from beach and off-shore catches had very low, from seagrass intermediate and from rubble, coral and mangrove high average trophic levels. Fishes caught with nets had a lower position in the food chain than catches with lines. Cumulative abundance change and trophic level were negatively correlated, indicating substantial fishing pressure in the area. More than half of the species were caught before first maturity. Lines tended to catch more adult individuals than any other method. Over corals the percentage of juveniles was very high. For all fishing methods there were indicators for an unsustainable use of fish resources. Therefore, it is recommended that especially economically unimportant methods, i. e. spear gunning and catch with bare hand, which were severely depleting natural stocks, should be stopped. For gill nets, only larger mesh sizes could increase the percentage of adult individuals in the catch. For lift-net methods the release of immature specimens is recommended. Provided that the coral reefs are not damaged physically by boats, anchors or by trampling on them, lines are the most preferable fishing method. Fishing pressure on reefs and close to the beach should be decreased by either (seasonally) closings or gear restriction. In nursery areas (i. e. seagrass beds and mangroves) species rather than size selective methods should be used. Lift nets could operate both species and size selective and are therefore recommended.

Fish stocks and gill net fishery in seagrass beds

A few fish families in terms of biomass and individual numbers dominated fish catches with gill nets during two years in the seagrass bed of Puntondo. Small individuals below 100gWW represented many families. Omnivores were present with high individual numbers but low biomass compared to predators. Individual relative maturity did not differ between mesh sizes. Catches with 4" nets had significantly higher trophic levels than from the other mesh sizes. For 1" nets, which had the highest catch per effort ratio (CPE), fish length was positively correlated to trophic level. This was due to the high percentage of slender predatory species of the families Belonidae, Hemiramphidae, and Sphyraenidae in the catch. Fish sizes differ and L/ L_m ratios are the same between mesh sizes, indicating that different spectra of species were targeted. The high abundance of the families stated above questions the role of the seagrass bed in Puntondo as a nursery habitat. During the day, average relative maturity of the catch did not change. For all mesh sizes, fishes with average trophic levels had lowest abundance around noon and highest around midnight. CPE for 1" nets was highest in the hours before noon and lowest in the afternoon. However, due to shortages in the methology it could not be concluded that there were diurnal migrations into or out of the seagrass bed. During a lunar cycle, the L/L_m ratio of catches with 1" nets was highest at full moon. For other mesh sizes, however, there were no significant differences within the lunar cycle. Changes of trophic levels and CPE for different mesh sizes were most evident for 1" nets. Maximum and minimum values occurred during the days following new moon and full moon, respectively. This was due to the predatory species mentioned above. Though, the reasons for their abundance changes remain unclear, as potential small prey species could not be sampled with gill nets. Year-to-year variation in catch characteristics was high. For 1" nets (pooled data of two years), L/L_m ratio was highest in April and lowest in January (peak of the rainy season). 2" nets had maximum L/L_m ratios during September and minimum ratios during December. For 4" nets, there were no significant differences. Trophic levels of fishes caught with 1" and 2" nets did not differ between months. Fish assemblages caught with 4" nets, however, had maximum trophic levels in November and minimum levels in December. Highest CPE with 1" nets occurred during the peak of the rainy season. 2" nets showed no clear seasonality and 4" nets none at all. The variation in catch characteristics was likely not due to changes in wave exposure or seagrass performance but rather due to changing water temperature and salinity. For management purposes, the general ban of small mesh sizes for gill nets or the closure of fisheries during certain times of the year cannot be supported by the results of this study. Management of seagrass fisheries should be based on single (valuable) species' ecology. Further studies are necessary to evaluate the importance of local seagrass beds as nursery and feeding habitat for those species.

General discussion

The four studies conducted within the frame of this thesis revealed an intensive use of seagrass beds in Puntondo by both seaweed farmers and artisanal fishers. The individual aspects covered by the field research are discussed in detail in the corresponding chapters 1 to 4. In the following, the results are evaluated in context and general conclusions are drawn.

Sustainability of seaweed farming

In Puntondo, a very important economical activity does not change the natural ecosystem significantly and current farming methods seem sustainable. Future economic growth in the area will most likely be based on seaweed farming by intensifying and / or extending it into new areas. Without adequate impact assessment this will have socio-economic and ecological consequences.

The use of seagrass beds in Puntondo for algal farming differed significantly from other areas and the results presented in chapter 2 should be generalized carefully. The off-bottom method is the most intensive farming scheme and was applied in the studies by Eklöf et al. (2005, 2006a, 2006b). A very high seedling density and stationary plots close to the sea bottom contrast with the attributes of seaweed farming in Puntondo: Comparatively low farming densities, the migrating character of the farms and the distance of the crop from the seagrass below minimized effects on the environment. The former two attributes however are likely to change when seaweed farming is to be intensified due to e.g. population growth or economic pressure. Additionally, an effort to extend seaweed farming is also likely to push the used area towards and over the reef. There, changes in light climate and physical stress during establishment, maintenance, and harvest of the plots would cause severe damage. There have been no empirical studies quantifying the impact of seaweed farming on coral reefs, however. Surely, a threshold level for sustainable seaweed farming intensity could be determined, though the general sensitivity of corals towards external stresses most probably would push this level below any economically feasible intensity.

Within the framework of this thesis, benthic fauna below seaweed farms was not investigated. Eklöf et al. (2005) and Olafsson et al. (1995) have shown that macrozoobenthos abundance is reduced under seaweed farms. In these studies, however the farming intensities were much higher than in Puntondo. This and the ephemeral character of farms in South Sulawesi might minimize such effects. As for coral reefs, a farming intensity threshold for benthic fauna remains to be estimated.

Sustainability of artisanal fisheries

Compared to seaweed farming, the contribution of fisheries to household income was very low, but still played an important part in local economy. In contrast to seaweed farming however, there are strong indicators of an unsustainable use of this natural resource. A minor contributor to local economy that damages the environment over proportionally obviously should be managed. Fishers in Puntondo felt a general decline in fish catches but could not pinpoint the species which were most affected. In Puntondo gillnet fishery dominates and a wide spectrum of species is targeted with this method. Fishers who often use more selective hook and lines, therefore should have been able to much better pinpoint species which have declined. In the interviews however it was not distinguished which gear was preferred. Furthermore, it was not evaluated if hook and line was more common in the past and if its catch decline had triggered the widespread use of gill nets. If so, the general recommendation of hook and line had to be reviewed, as it proved unsustainable in the past.

Within the frame of this thesis only fishery for fishes has been included. Gleaning of invertebrates on the reef flat is a regular activity and fishing for crabs (*Portunus pelagicus*, Portunidae) contributes significantly to fisheries income. Intensive gleaning surely affects the food web within the system, as target species (e.g. *Holothuria* spp.) are removed very efficiently. To what extend their ecological function is taken over by other faunal groups is unclear and a vast area of research waits there. Fisheries for crabs is close to collapse, and even in seagrass beds, where crabs are usually not fished, their numbers were rapidly declining during the research period (Blankenhorn, unpublished data). Their harvesting could be example for the urgent need of an effective community based fisheries management that is easily to understand for the local people: Though they know the basics of stock protection (i.e. release of egg-carrying females), the high revenues, open access character of the fishery and neglectance of government agencies lead to a "what can we do!?" attitude.

Seagrass beds as a common resource for seaweed farming and fisheries

Seaweed farming and artisanal fisheries did not interfere negatively in Puntondo. Seagrass beds and their fishes were not important fishing grounds and target species, respectively. Hence, changes in the seagrass ecosystem due to seaweed farming were very unlikely to have a direct impact on fishermen's catches. However, and this was not studied in the frame of this thesis, indirect effects of seagrass loss on fish communities might occur. Diminishing seagrass resources alter the bio-chemical processes in the sediment and water column, eventually altering the food web within and around seagrass beds. These effects can be quite severe, leading to significantly reduced fisheries production.

Some of the fishers complained about the limited access to areas under seaweed farming. Indeed, this was not because of legal, but merely because of technical restrictions as the most common fishing gear, gill nets, could not be used within farms. Therefore, attributes that are commonly associated with marine protected areas (MPAs), i.e. restrictions of fishing gear and general access, respectively, were effectively "enforced" for fishing within farms. MPAs need a certain minimum size to protect marine resources effectively. This size depends on the home range and ecological needs of fish species which are to be managed. An ecosystem approach to management should include sub-systems like mangroves, seagrass beds and coral reefs. When seaweed farms are to be established over seagrass beds, neither of these factors has to be considered and therefore, their role as micro-MPAs might be rather limited. Usually, small fishes have smaller home ranges than bigger ones and hence, the habitat of small species is more likely to be covered by seaweed farming areas. Those species however are not commonly targeted and probably do not need protection. Bigger (and migrating) fishes can still be fished outside farming areas and are therefore not protected by seaweed farms. For benthic animals, seaweed farms are also very unlikely to act as MPAs. Gleaning is carried out during spring low tides, when only tidal pools and water pockets remain on the reef flat. In contrast to fisheries, restrictions in gear and access, respectively, are not "enforced" as cleansers easily access seaweed farms and cultivation lines do not restrict their activity.

Seaweed farming as an alternative livelihood

A careful evaluation of suitable farming methods and areas is inevitable if environmental and socio-economic sustainability are to be maintained. Advanced farming schemes require higher investments for and running costs of the farms, reducing their economic profitability. Therefore, acceptance of such methods among villagers should be increased by a parallel development of post-harvest processing and marketing, thus yielding an overall higher net profit from their farms. It was hypothesized (see Sievanen et al. 2005) that seaweed farming can create a stewardship over marine shallow water resources. The usability of seaweed farming as a tool to stop overfishing and the use of destructive fishing methods, however, is doubtful (see Sievanen et al. 2005) and overharvesting of marine resources prevails. However, in contrast to artisanal fisheries, where merely the end product of the system is skimmed off, seaweed farming can help to building a better general environmental awareness. The whole production cycle, pests and diseases depend on and are influenced by environmental conditions. Very simple monitoring of such parameters and their contribution to farming success can contribute significantly to a better understanding of and identification with the marine environment. Government agencies therefore should not only promote seaweed farming, but also combine this effort with programmes to built general awareness. The impact of local NGOs, which are active in coastal communities in Indonesia, is probably much more significant than that of official programmes.

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Chapter 1
Seaweed farming in traditional fishing villages: An example from South Sulawesi, Indonesia

Sven Uli Blankenhorn and Harald Asmus
submitted to Ocean & Coastal Management

Abstract

Seaweed farming has been introduced in many coastal communities in Indonesia as a means of improving local livelihood. In this study, its impact on the economy of a small village in South Sulawesi, Indonesia, was investigated. Similar to experiences from other areas, seaweed farming was the main source of income for most families in the village, though artisanal fisheries still played an important role. Locals had high hopes for the future for all economic activities, though problems may arise in the future. Especially area conflicts between seaweed farming and fisheries, though not rated important during the study, have the potential to limit sustainable development.

Keywords

seaweed farming, alternative livelihood, Sulawesi, Indonesia

Introduction

Seaweeds have been harvested by humans since ancient times (Trono 1999). Today, carageenans extracted from several species of red algae (Rhodophyta) are essential in many industries, e.g. food, pharmaceutical, or cosmetics (Trono 1999, McHugh 2003, Anggadiredja et al. 2006, Poncomulyo et al. 2006). Until the 1960's, supply to the industry was met mainly from natural stocks in Canada, France, and Indonesia (Neish 2003). After the collapse of the Indonesian supply due to political unrest, open water farming of carrageenophytes, i.e. *Eucheuma denticulatum* (Burman) Collins et Harvey, *Kappaphycus alvarezii* (Doty) Doty, and *K. striatum* Schmitz was developed in the Philippines to meet the steadily rising market demand (Doty & Alvarez 1973, Adnan & Porse 1987, Lovatelli & Bueno 1988, Trono 1999, Ask & Azanza 2002). After several years, production reached commercial significance in the 1970's (Doty & Alvarez 1973, Lim & Porse 1980, Doty 1983). Since then, farming of eucheumatoid algae has been introduced in many tropical countries (reviewed by Ask & Azanza 2002, Anggadiredja et al. 2006) but with more than 98 % SE-Asia still is the centre of carrageenophyte production (Neish 2003). In Indonesia, commercial seaweed farming had a difficult start (Adnan & Porse 1987) but after initial problems were overcome, it had been introduced in many costal communities (Anggadiredja et al. 2006).

The culture of marine algae is widely seen as a valuable source of additional income for poor coastal communities, especially as the need for initial investment and human resources is small compared to other forms of sea ranching / farming (e.g. Msuya 1993, Luxton & Luxton 1999, Trono 1999, Anonymous 2000, Crawford 2002, Sievanen et al. 2005). Indeed, in many villages the standard of living has improved since the introduction of seaweed farming (e.g. Msuya 1993, Crawford 2002, Hurtado & Agbayani 2002, Sievanen et al. 2005). However, information on the actual contribution of this new activity to household income and its interaction with other economical sectors is scarce for Indonesia. Most studies focused on Bali and Lombok (e.g. Firdausy & Tisdell 1991, Hatta & Dahoklory 1996), and North Sulawesi (see Crawford 2002, Mandagi & White 2005, see Sievanen et al. 2005) but vast stretches of coast remain poorly covered. Smart (2005) evaluated the economical importance of seaweed farming on a small Island in South-East Sulawesi. His experiences were very similar to reports from other provinces in Indonesia. The aim of this study was to investigate the importance of seaweed farming in a small village in South Sulawesi, Indonesia and to evaluate the possibility to generalize conclusions drawn from other studies. The results of this study provided valuable background-information for other research dealing with seaweed farming and its impact on the environment (Blankenhorn & Asmus submitted-a, submitted-b, submitted-c).

Methods

In the village of Puntondo (5°35,330'S, 119°29,050'E, village Laikang, district Takalar, South Sulawesi, Indonesia, Figure 1) 31 out of approx. 125 households were selected randomly and semi-structured interviews were held in October 2006. It was asked for the respondent's age, formal education and that of his wife, and the number of children living in the household.

For seaweed farming, data on the start of the participant's farming activities, source of money for initial investments, and initial training were collected. The size of the individual farming plots, distance from the village, the usage of motorized boats for maintenance and harvest, cultivated seaweeds and methods, and experiences with other species and / or methods was also asked for. Monthly harvest and its marketing as well as main problems associated with both were assessed. Furthermore, the farmers were asked for their time allocated for seaweed farming each month and the contribution to household income. Initial motivations to start seaweed faming, satisfaction with the present situation and hopes for the future were also evaluated. For fisheries and other activities a similar set of questions was asked.

The answers were then categorized from 0 (= lowest values, i.e. no contribution to household income, or total disappointment) to 4 (= highest values, e.g. 100% contribution to household income, or very high satisfaction). Correlations between the factors were analysed with Spearman rank order Correlations (SROC, significance level set to p=0,05). Additionally, from October 2002 to May 2005 key informant interviews were held, oral histories were collected and seaweed farming activities were observed in the field.

Results

Average age of the respondents was 33,2 a (± 10,71 a), 13% of men (27% of women) did not receive any formal education. 65% of men and 69% of women attended elementary school for at least some years; 22% of men and 3% of women received at least junior high school education. In average, a household had 2,45 (± 1,34) children and consisted of 4,48 (± 1,50) persons, including other relatives. Age of the husband was negatively correlated with the education of his wife (p = 0,036, R = –0,392) and positively with the number of household members (p = 0,006, R = 0,483). Two of the interview participants were widowed and living without children, though one of them was living with one of his grandchildren.

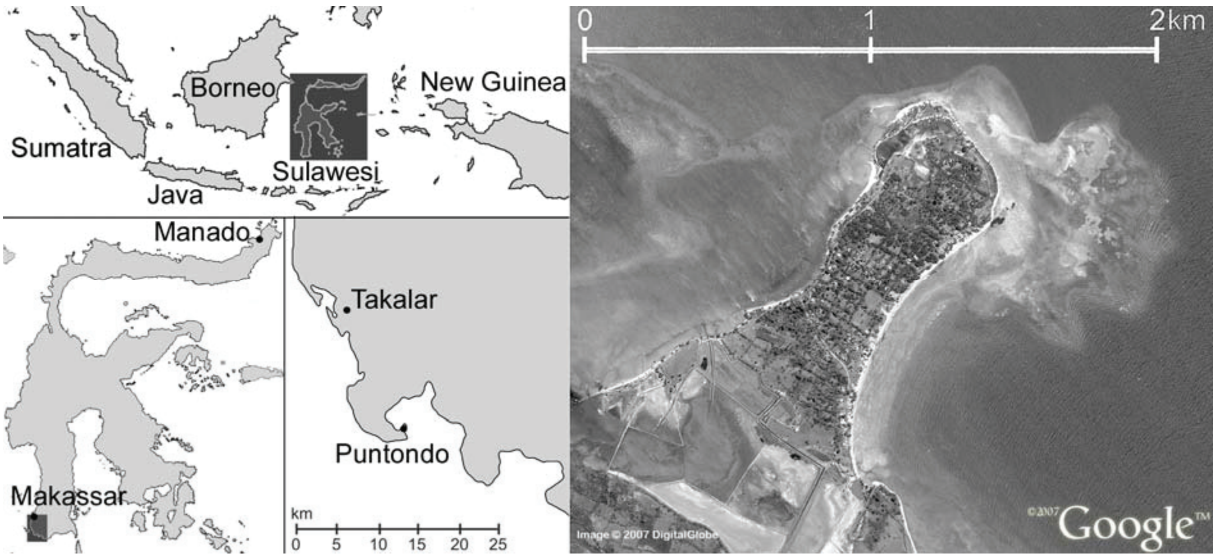

Figure 1. Map of Indonesia, Sulawesi and the costal zone of Takalar district (left), satellite image of Puntondo (right, source: GoogleEarth)

Economic activities and effort

94 % of the households were farming the seaweed species *Kappaphycus alvarezii* (syn. *Eucheuma cottonii*) in various strains and *Eucheuma denticulatum*. Seaweed farmers experienced problems with *K. alvarezii* due to the ice-ice disease (see e.g. Ask & Azanza 2002) especially during the dry season (April to November), and therefore during this time *E. denticulatum* was cultivated alternatively. 45 % of all interviewed villagers begun farming in 1996, and another 45 % between 1997 and 2000 (Figure 2). 67 % of the farmers used own savings for initial investments, 17 % needed additional loans (from friends: 7 %, from seaweed dealers: 10 %) and 17 % were fully dependent on loans (3 % from friends and 14 % from dealers, Figure 2). 79 % of the farmers reported not to have received initial training rather than learning from and together with friends. 10 % reported to have been trained by state programmes and friends with seaweed farming experience from the outside, respectively.

An average seaweed farm in Puntondo had 151 ropes (± 71,9 ropes), each approx. 25 m long. With a rope spacing of 0,5 m, an average farm covered approximately 1900 m^2. Seedlings were tied to cultivation lines with an average spacing of 0,18 m (i.e. 11 seedlings m^{-2} = 110.000 seedlings ha^{-1}, also see Blankenhorn & Asmus submitted-a). The prevailing farming scheme (Figure 3) was a mixture of the off-bottom and floating long line method described e.g. by Neish (2003) and Anggadiredja et al. (2006). The cultivation lines were kept afloat by empty water bottles and did not have individual anchors but were fixed to perpendicular ropes at both ends instead. These ropes themselves were tightly fixed to wooden poles harvested from *Lannea coromandelica* (Anacardiaceae) trees. Sometimes, additional ropes were used along the cultivation lines to maintain equal distances (also see Hurtado & Agbayani 2002).

With an average rope spacing of 0,5 m, a total area of ± 22 ha was calculated to be under seaweed farming, whereof 72 % (16 ha) were in Puntondo waters all year and 28 % (6 ha) were moved to areas further away especially during the dry season. The algae were harvested after ± 40 days of growth, equalling approx. 9 harvests per

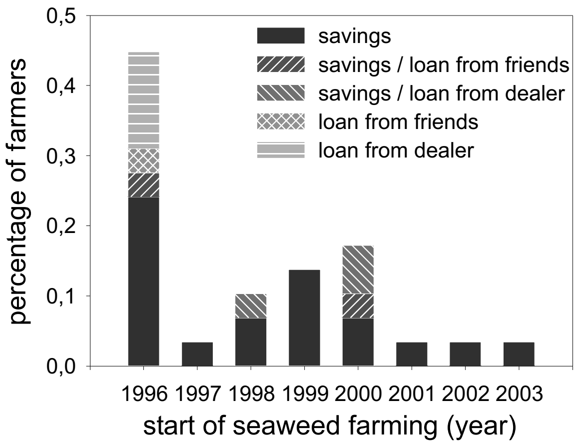

Figure 2. Start of seaweed farming and money sources for initial investment

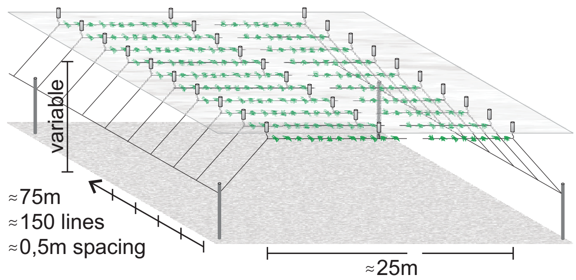

Figure 3. Commonly used farming method in Puntondo, cultivation lines are kept afloat by empty water bottles

year. Average yield on a farm was 228 kg (± 113,9 kg) dried algae per harvest, and therefore 1,8 tDW (± 0,45 tDW)/ farm a^{-1} and 9,5 tDW (± 2,38 tDW) $ha^{-1}a^{-1}$, respectively. Average yield was not correlated with the type of training the farmer had received initially ($p >> 0,05$).

Preparation of culture ropes, seeding and harvest processing required 4,4 d (± 0,9d) per farm and harvest. This land-based work was mainly done by women and children. Often members of several households gathered under a traditional house on stilts and processed the crop together. Men were doing the work on the farms (i. e. establishment and maintenance, harvest of culture lines and restocking). The number of household members was statistically not relevant for the number of ropes in a farm ($p > 0,05$). The number of ropes was closely related to harvest ($p < 0,001$, $R = 0,746$) and was determining the time spent for land-based activities ($p < 0,001$, $R = 0,678$, Figure 4). For farms further away from the village, relatively more effort was necessary ($p = 0,023$, $R = 0,421$) though they had similar rope numbers as farms close by ($p >> 0,05$). 66 % of the farmers used motorized boats exclusively. For farms close to the village, 17 % and 14 % additionally used row boats and walked, respectively. Only 3 % of the respondents did not use any boat but rather walk. Distance of the farms to the village was correlated to the usage of motorized vessels ($p = 0,018$, $R = 0,437$).

17 % and 48 % of the farmers had tried other algae species and farming methods, respectively. The latter ones, floating rafts, were too cost intensive and were not used any more. There had been seaweed seeds imported from Bali, but the local conditions were not unsuitable their culture hence was discontinued. The training the farmers had received influenced the readiness to try new methods ($p = 0,004$, $R = 0,525$) and seaweeds ($p < 0,05$, $R = 0,371$), farmers with distant farms were more ready to try alternative methods ($p = 0,008$, $R = 0,484$).

All but one of the interviewed households which were active in seaweed farming also fished on a daily basis (Figure 5). 68 % of the fishers only caught fish around Puntondo, 29 % and 4 % in neighbouring water also and only, respectively. Location of seaweed farms was correlated with preferred fishing area ($p < 0,001$, $R = 0,702$). 86 % of the villagers used motorized vessels for fishing.

In average, 4 h (± 1h) were spent on fishing and gear maintenance each day. The further the distance of the fishing ground the more time was spent for fishing ($p < 0,001$, $R = 0,706$). Fishers with a motorized boat tended to spend more time on the sea ($p = 0,021$, $R = 0,434$). The vast majority (94 %) of fishers used gill nets and only a few used hook and line also (also see Blankenhorn & Asmus submitted-b).

About 34 % of the households had additional sources of income (Figure 5). 40 % of those households had small stores, commonly integrated into the main house. 20 % of were employed on or owned fish ponds, farms, and the local NGO PPLH-Puntondo, respectively. One of the interviewed villagers was a seaweed dealer, and one had a seasonal job in the main village Laikang. If present, 39 % of time was allocated for other activities; however, little shops practically did not consume additional time.

Seaweed culture and fishing problems

Asked for main problems occurring on the seaweed farms, 59 % of the responses stated "seasonality" as the most important factor (Figure 6). 38 % and 31 % of the farmers considered diseases and herbivorous fishes, respectively, a serious problem. 10 % of the villagers reported difficulties in choosing appropriate farming locations. Generally, shallow areas close to the reef were not used for seaweed farming. Difficulties to drive-in wood poles to the ground were one reason, but more important was herbivory by fishes, which the farmers perceived to be intolerably high close to corals.

For fisheries, the main complaints were low abundance of fish (89 % of fishing respondents) and high fuel costs (29 %). Some fishers remarked area conflicts with seaweed farming. Owners of small stores reported low turnover but this was not regarded a serious problem as no perishable goods were sold. Workers on shrimp farms reported diseases to be the main problem, farmers complained about the weather conditions (long dry period and very high precipitation during January).

Market problems and income

Seaweed farming contributed 81 % (± 23 %) to average household income (Figure 7). The percentage depended on the time spent for preparation and post-harvest processing ($p = 0{,}010$, $R = 0{,}452$). In October 2006, the price for dried seaweed *Kappaphycus alvarezii* was Indonesian Rupiah (IDR) 3.000–3.500 (USD 0,33–0,38) per kg, depending on the buyer and the quality of

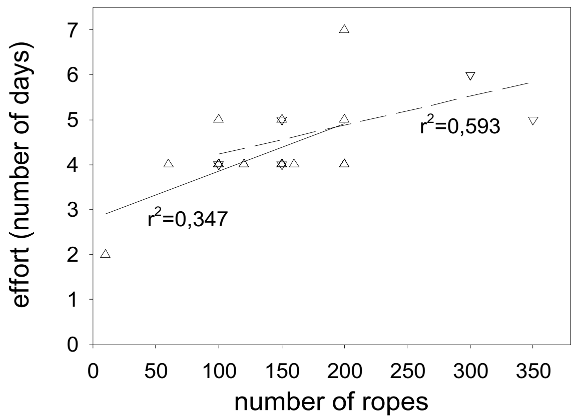

Figure 4. Regressions of effort for seaweed farming in relation to number of ropes and distance from the village (near: left, far: right)

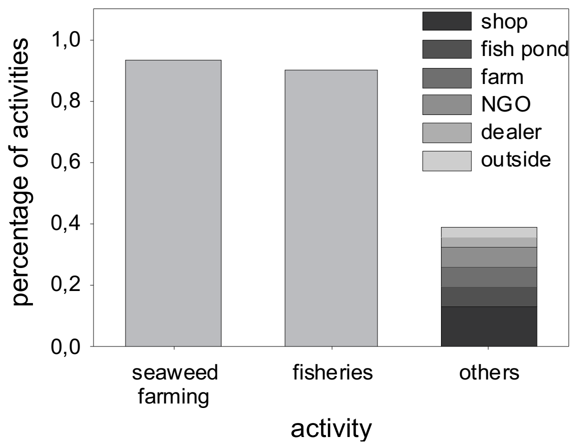

Figure 5. Percentages of households involved in several activities

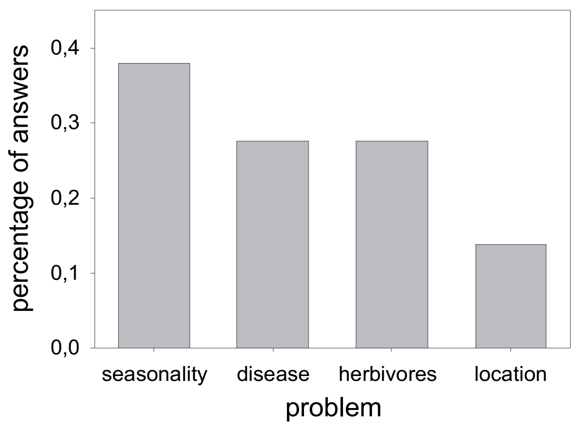

Figure 6. Main problems on seaweed farms

the crop. For *Eucheuma denticulatum* prices were much lower, IDR 1.700 (USD 0,19). Based on these numbers, an average seaweed farm in Puntondo was estimated to create IDR 684.000 ± 342.000 (USD 74,59 ± 37,44) per harvest of *K. alvarezii* and IDR 388.000 ± 194.000 (USD 42,52 ± 21,26) per harvest of *E. denticulatum*. Farms were harvested nine times per year, with five crops of *K. alvarezii* and four crops of *E. denticulatum*, respectively, ≈ 5 Mio IDR (USD 540) would be earned yearly. Initial investment for small shops often originated from seaweed farming, loans were never used.

45 % of the farmers had no complaints about the marketing of their crop. 21 % and 17 % reported prices to be cheap sometimes and buyers from outside the village to pay better, respectively. Another 17 % complained about the dependence from the seaweed dealer they bought the seed stock from. 89 % of the respondents were satisfied with the income created by fishing and 11 % complained about varying prices for their catch. The income from fisheries and other activities contributed 23 % (± 8 %) and 16 % (± 30 %), respectively, to average household income (Figure 7). Villagers working for larger employees complained about low and / or fluctuating wages and farmers about low prices for their crops on local markets.

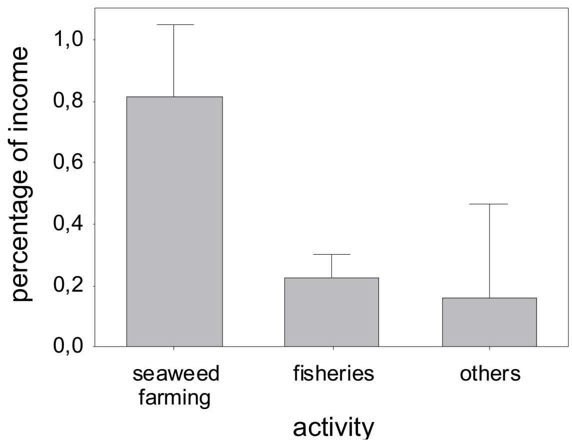

Figure 7. Relative contribution of several sectors to average household income, summarized percentage > 1 due to categorized answers

Satisfaction with seaweed farming and fisheries, hopes for the future

76 % of the interviewed farmers were very satisfied with seaweed farming and 17 % had only minor complains. 7 % (2 respondents) did not answer the question. Farmers who had tried other seaweeds in the past tended to be less satisfied with their current situation ($p = 0{,}007$, $R = -0{,}509$). 93 % of the villagers want to develop seaweed farming, and only 3 % each want to develop it slowly or look for other possibilities (if available), respectively (Figure 8). Only one farmer thought seaweed farming to have little negative impact on the environment. Several others remarked that in areas with coral cover it might be dama-

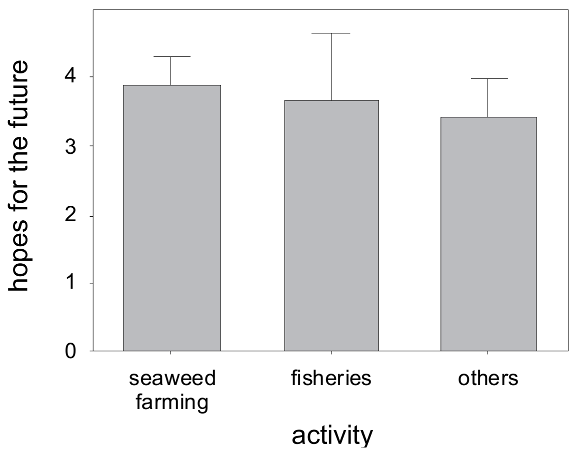

Figure 8. Hopes for future development laid in different activities in categories from 0 (no hopes) to 4 (very high hopes)

ging due to trampling on the reef surface. 89 % of the fishers want to further develop this activity, only 4 % think that this will be difficult and 8 % want to abandon fisheries if other sources of income are available. All respondents wanted to further develop "other" activities.

Discussion

Economic activities and effort

The seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* are by far the most widespread species under cultivation in Indonesia and SE-Asia in general (Trono 1999, Neish 2003, Sievanen et al. 2005). Alterations in the preferred species also occur in other areas, e. g. Lembongan Island, Bali (pers. observation). There, the abundance of green algae (Ulva spp.) during the dry season caused this shift: The more delicate branches of *E. denticulatum* are very difficult to clean off debris and hence the less and thicker branched *K. alvarezii* is farmed (pers. com. with seaweed farmers).

Only in the first year of seaweed farming in Puntondo many farmers got loans from seaweed dealers. In the following years, a higher percentage of them was able to rely on own savings and borrow money from friends, respectively. Interestingly, none of the interviewed villagers had borrowed money from a bank. In Indonesia, small fishermen, but also farmers generally are reluctant to borrow money from a banks because of high interest rates, the lack of qualifying collateral and the unfamiliar bureaucratic process (Hurtado & Agbayani 2002).

A very high percentage of village households were farming seaweed, and most operations started in the mid 1990's. In North Sulawesi a very similar development took place (NRMP 1996, Pollnac et al. 1997, Merrill 1998, Dimpudus 1999), where during a phase of sharply increasing prices for dried seaweed the majority of households adapted seaweed farming.

The farming method used in Puntondo is not described in any available seaweed cultivation manuals (e. g. Aslan 1998, Neish 2003, Anggadiredja et al. 2006, Poncomulyo et al. 2006), but resembles the method described by Hurtado & Agbayani (2002). Most likely, villagers had learnt it from farmers from Tanakeke Island nearby, where also initial brood stock originated from. However, how the farming method evolved there and whether their algae originated from Bali or directly from the Philippines was not investigated. Poles needed for seaweed farms are often extracted from mangrove forest, which lead to a significant loss in them (Merrill 1998, Mandagi & White 2005). In Puntondo such practices were never observed, instead, poles from Lannea coromandelica trees were used.

The actual area influenced by seaweed farming was larger than 22 ha calculated from average farms size and numbers. Most of the farms were moved according to the season (e. g. from the western to the eastern side of the peninsula) and additionally, individual farming plots were typically spaced 10 to 15 m apart. Therefore, a cultivation area of at least 60 ha (though not farmed year-round) is a more realistic estimation. Seasonality of seaweed growth is a common problem (e.g. Buriyo et al. 2001, Ask & Azanza 2002) and the relocation of farms in Puntondo a very simple answer to it.

Accurate and complete information on farming methods and intensity (i.e. number of lines, line and seedling spacing and hence, algae seedlings per unit area) is scarce. Resulting harvests reported in other studies (Firdausy & Tisdell 1991, Samonte et al. 1993, Hurtado et al. 2001, Hurtado & Agbayani 2002, Mandagi & White 2005, Smart 2005) are varying widely and difficult to compare. However, production per farming area in Puntondo was in the lower range of production in the reports stated above.

The observed gender distribution between the different tasks associated with seaweed farming has also been described by Hurtado et al. (2001) for southern Mindanao, Philippines and Crawford (2002) for North Sulawesi, Indonesia. Crawford stresses the differences which can occur in gender distribution even between villages within a region. On Lembongan Island, Bali, for example, women can be observed harvesting and landing the crop (pers. observation), a sight which is not imaginable for Puntondo. Besides cultural and religious differences between those regions of Indonesia, the used farming method might determine if women work on seaweed plots or not: Gleaning of reef tops is usually done by women whereas fishing, especially from boats and in deeper water, is a work done by men. Activities on farms using the off-bottom method much more resemble gleaning activities, whereas the skills and movements required to work on floating long-line farms are similar to fishing with gill nets.

Alternative farming methods, e.g. the floating raft and long-line method require considerably higher investments than the off-bottom method (Zuberi 2001, Hurtado & Agbayani 2002, Neish 2003, Anggadiredja et al. 2006, Poncomulyo et al. 2006) and the modification thereof, respectively, as it is applied in Puntondo. Especially bamboo, which is not commonly grown in the village and has to be bought in neighbouring communities, increases the costs for the floating raft method above a limit which would be acceptable for the farmers. In this context, the farming method can be seen as a variation of the multiple raft long-line method described by Hurtado & Agbayani (2002), where bamboo poles for tying the culture ropes to were replaced by ropes.

Initial training the farmers had received did not influence the success of operations. Many seaweed farmers learned from and together with others and it can be assumed that they also shared their experiences with other, more inexperienced villagers. Therefore, it is likely that formal training on seaweed farming spread through the whole community though only relatively view individuals had actually received it. Experience with alternative methods and algae species, however, was higher among fishermen who received formal training. Apparently those alternative practices were introduced during the training but must have failed during the very first crop cycles. Otherwise, villagers outside the training program would have adapted the more promising farming schemes.

Nearly all households involved in seaweed farming in Puntondo were also fishing. It has been described by many authors (e.g. Pomeroy 1992, Crawford 2002, Pollnac et al. 2002, Sievanen et al. 2005) that introduction of seaweed farming not necessarily leads to a decreased fishing effort. In this sense, seaweed farming should not be referred to as alternative, but rather supplementary source of income (Crawford 2002, Sievanen et al. 2005). In Puntondo, fishing does not increase opportunity costs for seaweed farming. Gill nets are set during the night, whereas all seaweed farming activities take place during day hours. Furthermore, the time consuming harvest processing and preparation of the lines for the following crop is mainly done by women and children, which allow the men to rest from fishing trips during the night.

The distance of farms was correlated with preferred fishing grounds. Though not investigated in detail in the interviews, fishers / farmers obviously try to minimize their fuel costs by splitting it between both activities.

Seaweed culture and fishing problems

Most of the problems the villagers experienced on their farms are the result of significantly different environmental conditions between the dry and wet season. Changing and / or varying growth parameters cause stress in the seaweeds and increases their vulnerability towards pathogens causing the ice-ice disease (e.g. Largo et al. 1999, Ask & Azanza 2002). Additionally, especially during the rainy season waves can cause a high percentage of the algae branches to break of and being lost for the farmer. Villagers in Puntondo tried to overcome those problems by seasonal migrations to the most suitable farming locations. There however, available space was not enough for all farmers, indicated by answers stating "difficulties to choose farming location" and "herbivory by fishes", respectively, as farming problem. If the number of villagers who farm seaweed should further increase, farms can be expected to expand into coral areas where herbivorous fishes are abundant. Additionally, environmental damage to the reef ecosystem can be expected to be higher than in seagrass beds (Eklöf et al. 2006, Zemke-White & Smith 2006, Blankenhorn & Asmus submitted-a), where farms were preferably placed in Puntondo.

Low fish abundance and average sizes are common problems small-scale fishers are faced with in South Sulawesi (Pet-Soede et al. 1999, Pet-Soede et al. 2001, Blankenhorn & Asmus submitted-b). In the latter study influences of fishing ground and gear on abundance and average size of individual species in Puntondo was the main focus. Results however do not indicate decreased catch abundances on the same level as perceived by fishers in this study. A possible explanation is that fishers were not able to pin-point species which became rare but rather felt a general decrease in their catch.

Merrill (1998) reported area conflicts between farmers due to the high profitability of the activity in North Sulawesi. In Puntondo such conflicts were not reported in the interviews and witnessed by the authors during three years, respectively. This does however not mean that no such conflicts exist. Rather, emerging conflicts are mediated and solved with the help of the head of the village before they are perceived as such.

Some villagers felt area conflicts with their fishing activities. Within farming plots gill nets are virtually impossible to set; only small gaps between the plots are left open where fishing is possible. Seagrass beds and rubble areas in Puntondo are of very low importance as fishing grounds compared to reefs (Blankenhorn & Asmus submitted-b). Considering this and the low relative contribution of fisheries to average household income, area conflicts between those activities can not be rated a major problem for the whole community of Puntondo. However, very poor, young, and old fishermen who can not afford a boat to fish rely on shallow waters for fishing. This group also is the most vulnerable to problems occurring on their seaweed farms, as they lack financial resources, experience, and manpower, respectively, to quickly adapt to changing conditions.

Market problems and income

The potential income from an average seaweed farms in Puntondo was about USD 40–75 (depending on the seaweed species) per harvest, equalling USD 540 per year. In this study expenditures and revenues of seaweed farming practices were not calculated explicitly, and those earnings are gross values. However these gross earnings seem realistic, though in the lower range of data presented by Smart (2005). Reports on household earnings from seaweed farming vary greatly in the literature, from maxima of about USD 3.600–5.400 a^{-1} (e.g. Hurtado & Agbayani 2002) down to minimum of 400–600 a^{-1} (e.g. Pollnac et al. 2002). Latter numbers can be compared to the situation in Puntondo, as seaweed price, general inflation as well as IDR / PhP (Philippine Peso) – USD exchange rate was relatively stable between 2002 and 2006. Older data presented by NRMP (1996, IDR 7,8 Mio per year) are difficult to evaluate; especially inflation and exchange rate have dramatically increased since then and an analysis of this topic would have been beyond the aim of this study. Anggadiredja et al. (2006) calculated a yearly income of IDR 33.600.000 (USD 3380) per 0,2 ha plot and a yearly benefit of IDR 24.000.000 (USD 2.640) per household. These numbers seem too high, especially if seen in context with average wages in Indonesia (e.g. civil servants in 2006: minimal IDR 1.000.000 per month).

Virtually all villagers in Puntondo rely on seaweed farming as main and fisheries as secondary source of income. This is probably similar to many, if not to most Indonesian communities which have allocated parts of their effort to seaweed farming. Sievanen et al. (2005) discussed studies from the Philippines and Indonesia and in most of the communities the importance of seaweed farming has increased since its introduction and became the dominant source of income. But still, fishing contributes significantly and has not been reduced as could have been expected from the "alternative income" paradigm. This might also be true in more developed areas where also other sources of income are potentially available. On Lembongan island (Bali province, Indonesia) most families have adapted seaweed farming as the main source of income (pers. communication with villagers). Fishing still plays an important role, especially during the rainy season when pelagic fishes migrate through the strait separating the island from Bali. Tourism is a major source of income for only a few, who occasionally work as guides, drivers, have small stores or are employed in the hotels.

Nevertheless income from fisheries was much smaller than from seaweed farming and varied on a daily basis, it was still was evaluated important by the villagers in Puntondo. Basically, income from it was used to cover daily needs, whereas the periodical, but high revenues from seaweed farming were used to school the children, for major investments, or was saved. Not surprisingly, several villagers expressed the importance of seaweed farming for their community with the words "without seaweed farming Puntondo would long have been a ghost village".

Satisfaction with seaweed farming and fisheries, hopes for the future

Not surprisingly, in all main sources of income high expectation for the future are laid in. A parallel development of all current sectors seems possible, as they do not interfere with each other in terms of time and workforce allocation. However, young families who want to establish themselves in the community there might face serious economical problems in the near future. As discussed above, suitable farming sites are more or less occupied and fish resources are overexploited. Hence, alternative farming methods, though economically less promising, and an effective fisheries management seem inevitable to sustained development and social stability in the village. The local NGO PPLH-Puntondo (Environmental Education Center Puntondo) is intensively working with villagers to improve their farming and post-harvest processing, fisheries management, and general environmental awareness.

Conclusion

Training in seaweed farming probably would be more successful if programmes would more thoroughly survey their target areas before implementation, so that impracticable methods and unsuited algae species and strains, respectively, are not included. However, the common practice to focus on relatively small groups is applicable, as success stories spread fast within the community and superior farming schemes are adapted. It is the opinion of the authors that, starting with basic methods, the capability of seaweed farmers to adapt their farms to local conditions should not be underestimated. Besides that, more effort should be put in training programmes aiming at increased productivity, as proposed by Ask & Azanza (2002). In many households in Puntondo post harvest processing was still poor; the algae were often dried on the ground and contamination with sand was high. Due to the low quality in average, seaweed dealers usually paid low prices regardless of the actual quality of the farmer's product. This has also been reported by Hurtado & Agbayani (2002). Therefore, improvements of post harvest processing and, hence, increase of the quality standard of the crop on a broad basis will significantly increase local market price for dried seaweed.

Official Indonesian reports (Anonymous 2006) estimated 1,2 Mio ha of coastal waters to be suitable for seaweed farming. In the authors' opinion this number should be handled carefully. Access to seaweed markets is crucial to maintain profitability of farms (Ask & Azanza 2002), and in most parts of eastern Indonesia, this is not the case. Environmental and socio-economic suitability of farming locations should rather be evaluated individually (Sievanen et al. 2005). Some locations within the range of a farming community to be developed should be set aside to allow for relocation of farming plots during unfavourable seasons.

International prices for seaweed and its products were high during the first half of the 2000's and virtually all market analyses indicate a steadily growing demand (e.g. Neish 2003, Anggadiredja et al. 2006, Poncomulyo et al. 2006). This might well be the case, but variations of the exchange rate between IDR and USD however are unpredictable in the long term. Seaweed is traded in USD, and a low IDR would make seaweed operations unprofitable. Diversification of crops to cushion market price oscillations (Delmendo et al. 1992) and a general promotion of land-based activities should be included in community development plans.

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Chapter 2
Long-term effects of floating long-line seaweed farming on seagrass shoot density and biomass

Sven Uli Blankenhorn and Harald Asmus
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Abstract

In a seagrass bed at the coast of South Sulawesi (Indonesia), the impact of seaweed farming has been investigated by simulating special processes occurring in cultivation plots where macroalgae are cultivated on floating ropes. Among the different possible influences, shading and trampling were assumed to have the most significant effects on natural seagrass beds. The combination of different levels of both impacts was used to simulate different farming intensities on experimental plots. Additionally, on seaweed farms different algae seedling densities were applied. On all test fields, changes of seagrass shoot density and biomass were recorded over a period of two years. Shading has proved to be the strongest effect on seagrass shoot density and biomass development. Although seasonal species-specific dynamics determined density and biomass patterns of seagrasses, high shading levels reduced shoot density and biomass generally, whereas trampling was effective in combination with medium and high shading only. Actual farming was less damaging than could be expected from shading and trampling manipulations. The results of the study were used to estimate threshold levels for a maximum sustainable standing crop of seaweeds. At approximately 205.000 and 185.000 seedlings ha^{-1} for the community of smaller species (mainly *Cymodocea serrulata* and *Thalassia hemprichii*) and *Enhalus acoroides*, respectively, a rotating farming scheme does not influence seagrass significantly. Other functional groups of the seagrass ecosystem (e.g. macrozoobenthos and fishes) were not included in this study and their tolerance levels towards seaweed farming might be lower.

Keywords

seaweed farming, seagrass, shoot density, biomass, threshold, sustainable management, Sulawesi, Indonesia

Introduction

Seaweed farming is a common type of aquaculture in tropical countries and is mostly practiced in shallow areas and on reef flats, where rather sensitive ecosystems, e.g. seagrass beds, occur naturally. Environmental conditions like currents and wave action are moderate in those places compared to more exposed open sea conditions (Aslan 1998, Anonymous 2000a, 2000b). First implemented on a large scale in the Philippines, seaweed farming has since spread throughout the tropics (Bergschmidt 1997), especially in SE Asia and Indonesia (Adnan & Porse 1987). Negative effects of seaweed farming on seagrass systems have been documented, but no long term studies have yet provided reliable quantitative data for sustainable management purposes.

Natural communities, such as seagrass beds, are likely to be disturbed by seaweed farming; however, the possible risks for the living environment are largely unknown or neglected due to economical pressure. Especially ecosystem services of the natural communities are often underestimated compared to the expected economic yield of farming (de la Torre-Castro & Ronnback 2004, Sievanen et al. 2005).

Several single factors have been proposed to influence the flora and fauna of seagrass beds, e.g. sediment disturbance (Rasheed 2004, Cruz-Palacios & van Tussenbroek 2005) or light and siltation (Vermaat et al. 1996, Bach et al. 1998, Enriquez 2005, Gacia et al. 2005). Combinations of several factors (Livingston et al. 1998, Eldridge et al. 2004, Ibarra-Obando et al. 2004) as well as catastrophic events (Campbell & McKenzie 2004, Fourqurean & Rutten 2004, Cruz-Palacios & van Tussenbroek 2005) have been investigated also.

Most studies on seaweed farming in seagrass areas have focused on differences in water column parameters (e.g. Collén et al. 1995), seagrass species composition and growth parameters (e.g. Eklöf et al. 2005, Eklöf et al. 2006b), associated macrophytes (Semesi 2002), microbial stocks and activity (Johnstone & Ólafsson 1995), meio- and macrofauna (e.g. Olafsson et al. 1995, Eklöf et al. 2005), and fish assemblages (e.g. Bergman et al. 2001, Eklöf et al. 2006a) between sites with and without seaweed culture.

The studies cited above used short-term experiments to assess impacts of seaweed farming on seagrass beds; long term decrease of seagrass density and associated fauna was reported but not explicitly examined. Hence, the aim of this study was to investigate medium to long term changes of seagrass beds located under algae farms. The main stresses for the seagrasses underneath the ropes covered with cultivated algae were postulated to be shading by the algae and walking on the seagrass by the farmers during maintenance and harvest. Focus was not the response of single species but rather changes in the seagrass landscape due to external disturbance by seaweed farming activities.

Methods

Study area

The study was carried out in a shallow bay, close to the peninsula with the small village of Puntondo, District Takalar, South Sulawesi province, Indonesia (5°35,330'S, 119°29,050'E, Figure 1). The climate of the area is characterized by a distinct and prolonged dry season from April to October. The shallow waters (5–15 m) around the peninsula are relatively calm; muddy sediments prevail in the inner parts of the bay and get intermixed with corraligenous sands towards outer areas. Especially during periods with high wind intensity (September to March), the fine sediment is resuspended and the water is turbid.

The seagrass bed northwest of the peninsula is dominated by a *Cymodocea serrulata* (R. Br.) Aschers. et Magnus / *Enhalus acoroides* (L. f.) Royle / *Thalassia hemprichii* (Ehrenb.) Aschers. community, occasionally intermixed with *Cymodocea rotundata* Ehrenb. & Hempr. et Aschers., *Halodule uninervis* (Forsk.) Aschers., *Halophila ovata* Gaud., *H. ovalis* (R. Br.) Hook.f., *H. spinulosa* (R. Br.) Aschers. and *Syringodium isoetifolium* (Aschers.) Dandy (Blankenhorn, unpublished work, Schauerte, unpublished work). Due to the tidal regime in the South Sulawesi area the seagrass beds experience strong seasonal environmental changes leading to periodical die-off and recovery (Erftemeijer & Herman 1994, Stapel et al. 1997).

Since its introduction in the mid 1990's, most of local fishermen have adapted farming of *Kappaphycus alvarezii* (commonly referred to as *Eucheuma cottonii*) and *Eucheuma denticulatum* with a modified floating long-line method (Blankenhorn & Asmus submitted).

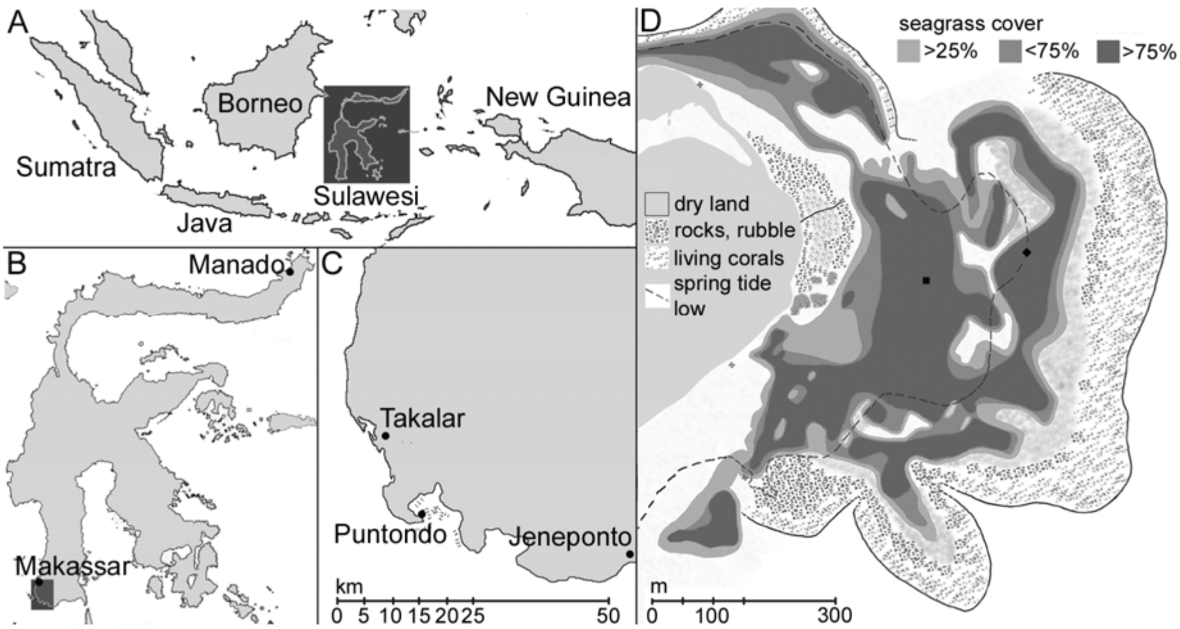

Figure 1. Map of (A) Indonesia, (B) Sulawesi, (C) Takalar and Jeneponto districts, and (D) the seagrass bed off the eastern tip of Puntondo peninsula. Research plots: experimental plots ▪; farming plots ♦

Farming areas are chosen and changed within the bay according to the season (i.e. prevailing winds and currents, freshwater run-off from the hinterland, and water turbidity (pers. communication with villagers), so that no area in the bay has seaweed farming plots year-round. However, algae cultivation is restricted to intertidal reef tops and sand flats which are then farmed very intensively during certain times. Deeper areas (> 5 m) are not used, mainly because set-up and maintenance of suitable farming methods (i.e. floating rafts) are comparatively expensive (Blankenhorn & Asmus submitted).

Experimental design

On a relatively homogenous seagrass bed in the lower intertidal area (see Figure 1) with *Enhalus acoroides*, *Cymodocea serrulata* and *Thalassia hemprichii*, experimental plots (explot) were installed. 19 patches, each 1 m^2 in size, were manipulated with different levels of shading (sh) and trampling (tr, Figure 2). For all treatments a common rope grid, fixed on top of wooden 1,5 m- poles driven into the ground, was used. Without a common grid, each treatment would have needed individual poles, which would have disturbed sediment characteristics. Within this grid, all manipulated plots (n = 15) as well as controls (n = 4) were distributed. The pattern shown in Figure 2 was chosen in so that no treatment was surrounded completely by other manipulated plots.

For shading, one, two, and three layers of black shade-cloth (mesh size 3 mm) were fixed 1m above the seafloor. The shading nets were cleaned off debris and algae regularly. During average high tide, below these treatments the light level at seagrass canopy height was reduced to approx. 72 %, 52 %, and 37 %, respectively, of ambient levels (approx. 1500 µmol photons at the surface and cloudless sky). Photosynthetic active radiation (PAR) was measured with a Licor LI–250 and Licor LI–193SA spherical sensor, respectively.

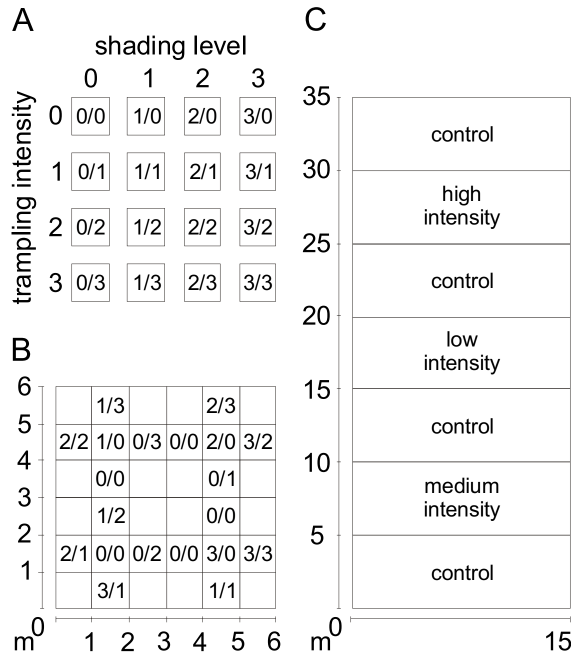

Figure 2. (A) Experimental plots (explot): Combinations of shading and trampling and (B) distribution of manipulations, 3 replicate samples per plot (C) Farming plots: Distribution of controls and manipulations, 6 replicate samples per plot

In trampling manipulations (also see Brown & Taylor 1999), the plants were trampled on with 20 steps m^{-2} once in a month (intensity 1), 20 steps m^{-2} in two weeks (intensity 2) and 20 steps m^{-2} for three continuous days every two weeks (intensity 3). The trampler wore rubber boots and weighed approximately 65 kg.

Table 1. Rope spacing, knot distance and resulting seedling densities on 75m² and 1ha for low, medium and high farming intensity

intensity	spacing		seedlings	
	ropes	knots	$75m^{-2}$	ha^{-1}
low	0,7m	0,25m	430	57500
medium	0,5m	0,18m	820	109300
high	0,25m	0,13m	2360	315000

Additionally to these treatments, experimental seaweed farms (farm) were installed in the upper subtidal area (see Figure 1), using the same techniques and materials as local farmers. Three different farming intensities (in terms of algae seedling density) were chosen, of which the medium density is most commonly applied by farmers in the area (Figure 2, Table 1). During average high tide, below these strips the light level at seagrass canopy height was approx. 92 %, 77 %, and 55 % of ambient PAR at the surface for low, medium and high faming intensity, respectively. Water temperature on average was 29,3° C (28° C – 32,1° C), pH 8,21 (7,60 – 8,76), and salinity 29,1 (25,8 – 30,5) psu.

Field sampling and laboratory analysis

Sampling was conducted from March 2003 to March 2005. Shoot density was measured every three months within each manipulation by using three randomly placed frames (0,0625 m^2, n = 3). *E. acoroides* was distinguished from other species, which were pooled and treated as "others". This was done with respect to the aim of the study and the similar responses of *T. hemprichii* and *Cymodocea* spp. to environmental forces (Agawin et al. 2001).

Seagrass biomass was sampled twice (March 2003 and March 2005) with PVC-tube cores (8,6 cm inside diameter, 15 cm deep) placed randomly within each manipulation for three times. The seagrass samples were roughly washed with sea water to remove sand, mud, benthic animals, and macro algae. Frozen samples were transported to the lab on ice and were thoroughly cleaned from sand and epiphytes with freshwater. *E. acoroides* and "others" were separated each into the fractions "roots and rhizomes", "leaves", and "dead material" (i. e. photosynthetic inactive leaf sheaths, leaf bases, and fibres). The fractions were then dried at 80° C for 48 h to constant weight and weighted afterwards. For root / shoot ratio calculation, both fractions "leaves" and "dead material" were summed up and treated as "shoot material".

Statistical analysis

After testing for consistency, data for two consecutive times within a season (i. e. dry and wet, starting with the sampling in June 2003) were pooled, resulting in n = 30 and n = 6 replicates for controls and each treatment, respectively, on the experimental plots. On the farming plots, n = 48 replicates for controls and n = 12 replicates for each farming intensity were used for further analysis.

Differences between the four seasons (dry and wet 2003 and 2004) covered in this study were checked for with a one-way analysis of variance (ANOVA) followed by a post-hoc multiple comparisons versus control group Holm-Sidak test (HS) to determine the differing set; the significance level was set to p = 0,05. Additionally, for the controls and each manipulation a one way repeated measures (RM) ANOVA over all sampling times followed by a HS comparison were executed to include plot-specific dynamics in the analysis.

To meet equal variance criteria necessary for a two way (TW) ANOVA (critical p = 0,05) with the factors shading and trampling, the pooled shoot density data were √√ transformed (n = 120). For significant differences, a multiple linear regression procedure (MLR) was performed. As current shoot density depends on shoot density in the past also, shoot density at the previous sampling period (t_{-1}) was also considered a factor in MLR. Significance level for factors was set to p = 0,05, R^2 > 0,55 was considered to indicate a significant correlation.

A TW-ANOVA was run on log(x+1) transformed shading / trampling / farming manipulations' biomass data (n = 20) and a MLR was executed on untransformed biomass data. Intensities of the factors shading (n = 20), trampling (n = 20) and farming (n = 14) as well as fractions' biomass of the sampling two years before were used as factors. Significance levels were set to p = 0,05 and R^2 > 0,55 for factors and regressions. For root / shoot ratio calculation, if no above but below ground biomass was present, the ratio was set to 100 by default.

Results

Shoot density

For any manipulation shoot density development of *Enhalus acoroides* over time was not distinctively different from controls (Figure 3). For most single manipulations, development of "others" was not different from the controls also. For high shading intensities however, "others" decreased significantly with time, for medium shading only a decreasing trend was visible. For all trampling intensities, shoot density development was very similar between manipulations and control. Differences between farming intensities were not detectable. In general, seasonal effects were more visible on farming plots (indicated by a higher undulation of the regressions) compared to single or combined treatments on the experimental plots.

Shading manipulations caused significant differences (p = 0,001) for *E. acoroides* in the wet season 2004 with shading intensities 1 and 2 resulting in higher shoot densities (Table A1). Trampling as single factor never was effective. Shoot density of "others" was never influenced by low shading. Medium level shading reduced shoot density in the wet season 2004 (p < 0,001), high level in the wet seasons 2003 (p = 0,002) and 2004 (p < 0,001) as well as in the dry season 2003 (p < 0,001). As for *E. acoroides*, trampling of any intensity as single factor never resulted in significant differences from controls.

Low farming intensity reduced shoot density of *E. acoroides* in the dry season 2004 (p = 0,01), medium intensity in the dry season 2003 (p = 0,025) and high intensity in the wet season 2003 (p = 0,008). For "others", low farming levels resulted in reduced shoot densities

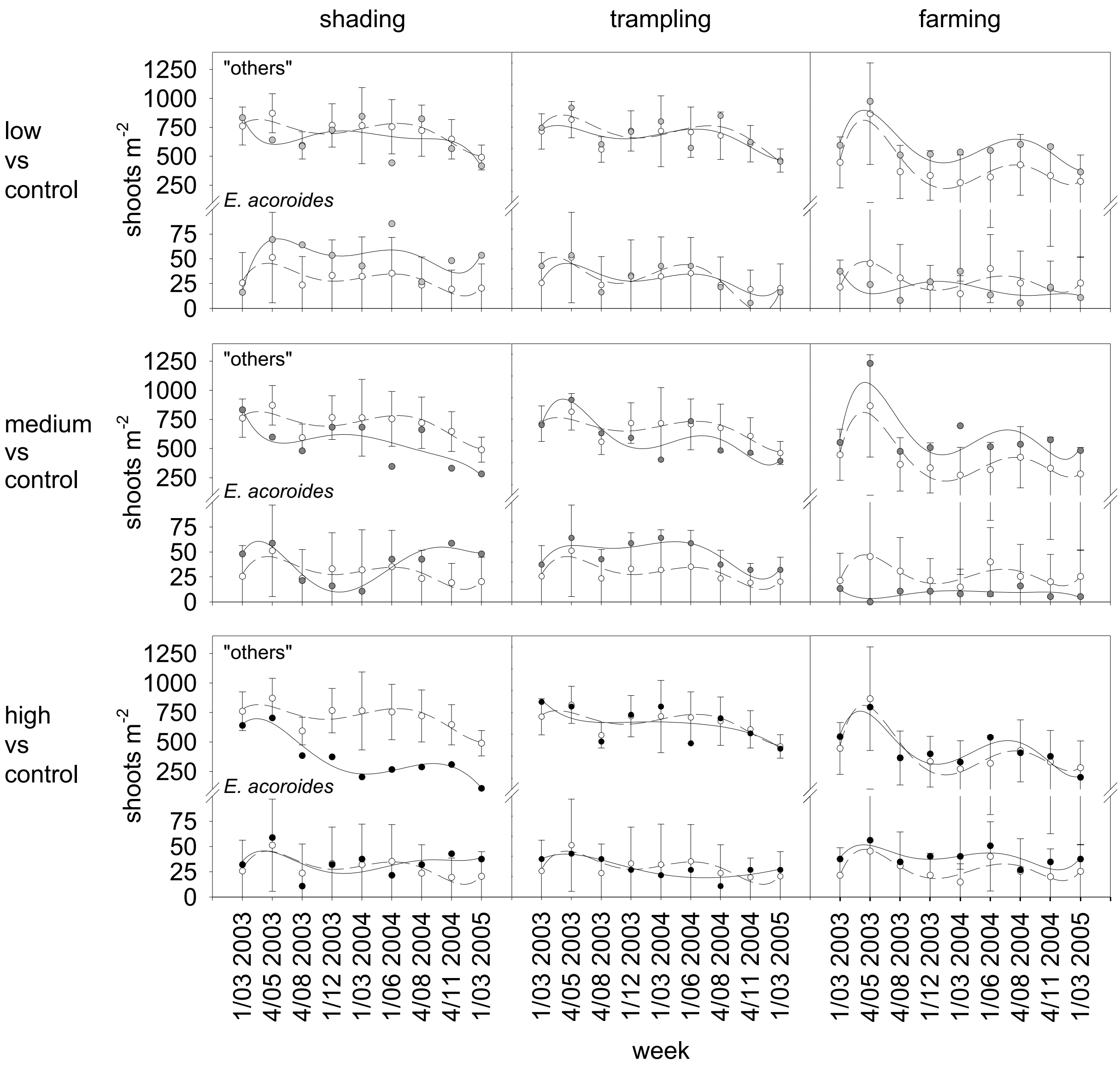

Figure 3. Shoot density (shoots m^{-2}) development of *Enhalus acoroides* (lower graphs) and "others" (upper graphs) for shading and trampling on the experimental plots (explot, left and middle) and farming (right) on the algae farms for different single treatment intensities. Controls (explot n = 15; farm n = 24) with dotted, treatments (explot n = 3; farm n = 6) with solid regression lines (linear regression 5. order). Error bars represent standard deviation of controls

in the wet seasons 2003 ($p < 0{,}001$) and 2004 ($p = 0{,}003$) as well as in the dry season 2004 ($p = 0{,}011$). Medium farming level was effective in the wet season 2004 ($p = 0{,}003$); high farming level did never change the performance of "others" significantly.

RM-ANOVA of shoot density data of *E. acoroides* on the experimental plots revealed decreased shoot density on plots under medium shading between the wet season 2003 and 2004 ($p = 0{,}038$). Shoot density of "others" was reduced on plots with medium shading between March 2003 and the wet season 2004 ($p = 0{,}01$). On plots with medium trampling shoot density decreased significantly ($p = 0{,}004$) between the dry and wet season 2004. On explot controls, shoot density of small seagrasses decreased between the dry and wet season 2004 ($p = 0{,}002$). On farming plots, *E. acoroides* was less abundant on controls in the wet season 2004 compared to the dry season of the same year ($p = 0{,}004$). Shoot density of small species was lower on controls in the both seasons 2004 compared to March 2003 ($p = 0{,}001$ each). It also decreased between the dry and the wet season 2004 on plots with low ($p = 0{,}006$) and high ($p = 0{,}002$) farming levels, respectively.

In TW-ANOVA, all shading manipulations influenced shoot density of *E. acoroides* in the wet season 2004 (Table A2). Significance was highest for a combination of medium and high levels of both treatments ($p \leq 0{,}003$). In MLR, all factors significantly contributed to the regression with shoot density in the dry season 2004 having the lowest error probability ($p < 0{,}001$), shading increasing and trampling decreasing shoot density. A high shade level in combination with trampling was effective in the dry seasons 2003 ($p \leq 0{,}004$) and 2004 ($p < 0{,}001$), however, in MLR none of the factors could sufficiently describe current shoot density. "Others" were influenced by all shading levels in combination with various intensities of trampling in the wet seasons 2003 ($p \leq 0{,}007$) and 2004 ($p \leq 0{,}015$) as well as in the dry season 2004 ($p = 0{,}002$). Especially combinations of high shading levels with any trampling intensity were significant ($p \leq 0{,}014$). In MLR for the data of the wet season 2003, none of the factors was able to predict shoot density, whereas for the dry and wet season 2004, shoots at t_{-1} ($p \leq 0{,}016$) and shading level ($p \leq 0{,}002$) were of significant importance. In contrast to *E. acoroides*, shading was negatively correlated with shoot density whereas trampling was not of significant importance. In the dry season 2003, only medium shading combined with trampling intensity 0 ($p = 0{,}023$) and 2 ($p = 0{,}007$) and high shading in combination with trampling intensity 0 ($p = 0{,}012$) and 3 ($p = 0{,}002$) were effective. MLR revealed shading level to be able to predict shoot density ($p = 0{,}001$). However, none of the MLRs for shoot density prediction of *E. acoroides* and "others" fitted the data well ($R^2 << 0{,}55$).

Biomass

During the research period, overall biomass of *E. acoroides* was significantly higher on the experimental plots than on the seaweed farms (Figure 4). On all controls, biomass was lower in March 2005 compared to 2003. Weight of *E. acoroides* plant fractions on shading plots was similar between 2003 and 2005, whereas on trampling and farming plots it was considerably lower in 2005. Overall biomass of “others” was slightly lower on the farms than on the experimental plots. On controls, trampling, and farming plots it was constant but considerably lower on shaded plots.

In 2003, MLR for single plant fractions of *E. acoroides* as well as “others” resulted in significant regressions ($R^2 > 0{,}6$) for all fractions (Table A3). However, overall biomass and root / shoot ratio at the beginning of the experiment could not be described well ($R^2 < 0{,}136$). In 2004, TW-ANOVA for manipulation intensities and biomass produced non-significant results for the parameters shading and trampling. MLR, including biomass at t_{-1} as factor, however, resulted in (minor) significant positive correlations for shading levels on *E. acoroides* “dead”, roots, and overall biomass. For small seagrass species, only the fraction “dead” was negatively influenced, but the significance was low (p = 0,069). For both *E. acoroides* and “others” trampling was not significant in the regressions and correlations between single plants fractions were fewer than in 2003. Also, the overall fit of the equations was worse than in 2003 (low R^2 values).

Farming was a significant positive factor in MLR for “dead” (p = 0,047) and overall bio-

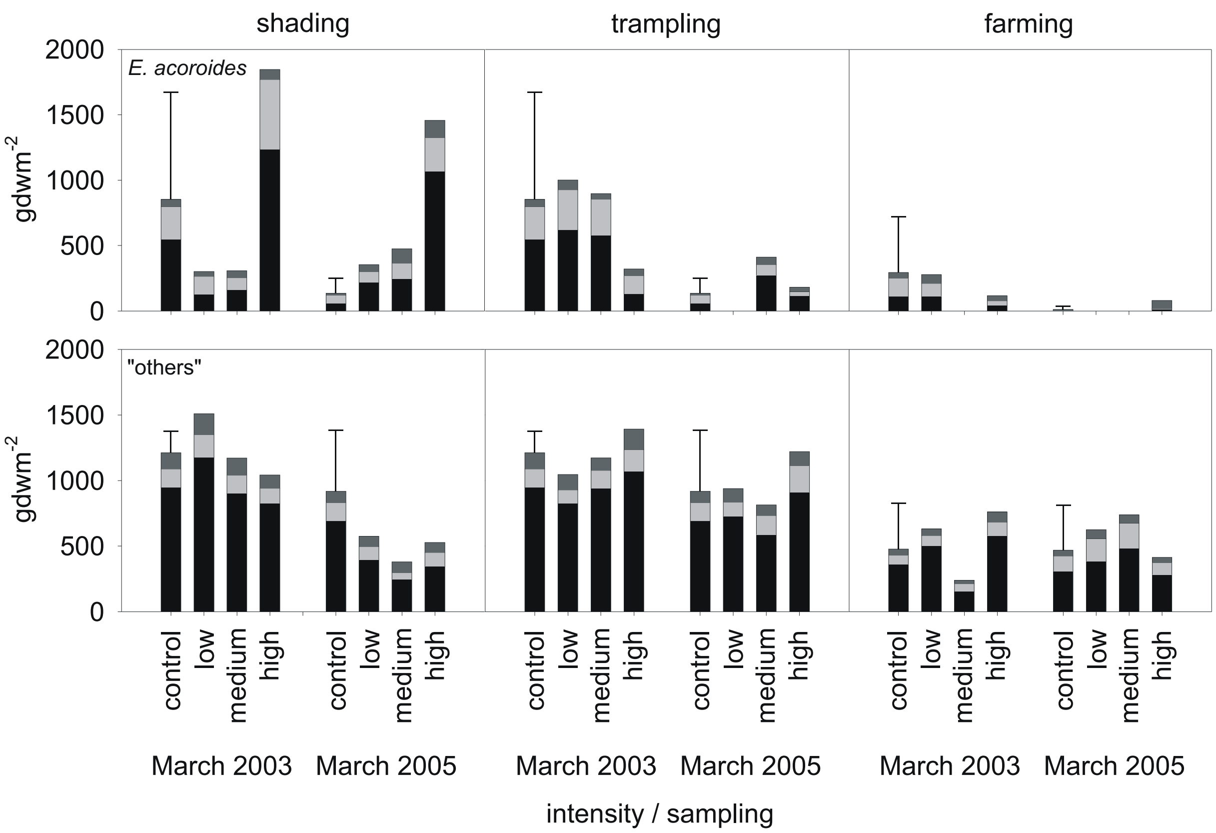

Figure 4. Biomass of *Enhalus acoroides* (top) and "others" (bottom) for March 2003 and March 2005 and shading (n = 3), trampling (n = 3), and farming (n = 6). Black: roots and rhizomes, light grey: photosynthetic inactive above ground, dark grey: leaves. Error bars represent standard deviation of total biomass of controls (explot n = 15, farm n = 24)

mass (p = 0,039) of *E. acoroides* in 2004. Leaves and overall biomass also depended on weight of dead parts and roots in 2003 and only their MLRs were significant ($R^2 > 0,832$). For others, farming was not a significant factor in MLR and the fit of the regressions was bad.

Discussion

Shoot density

Shoot density of *Enhalus acoroides* in Puntondo was within the range reported for comparable areas (Brouns 1985, Erftemeijer & Herman 1994, Bach et al. 1998, Agawin et al. 2001), whereas "others" were at the lower range of reported densities. The observed seasonal pattern was also reported by Erftemeijer & Herman (1994).

The effect of shading and trampling on shoot densities of *E. acoroides* and "others" was not consistent for single and combined manipulations. For single treatments high shading intensity resulted in significant differences for "others", whereas *E. acoroides* was already influenced by low and medium intensities. Trampling did never result in differences. Assuming that shading intensity is analogous to farming intensity, however, high farming intensity did not result in significant differences for "others". *E. acoroides* shoots were influenced by all farming intensities, but only one single intensity at a time gave significant ANOVA results. This might partly be explained by internal dynamics of the seagrass patches, as (especially "others") controls as well as many manipulations exhibited variations not directly correlated with manipulation quality or quantity. Furthermore, the patchy distribution of *E. acoroides* (see den Hartog 1970) caused a high standard variation in shoot numbers, thus decreasing the possibility of finding differences between the treatments.

The dominating importance of shading (and shoot density at t_{-1}) was also reflected in the results of TW-ANOVA and MLR analysis. Shoot density of "others" was mainly affected by medium or high shading and, eventually, in combination with trampling of all intensities. *E. acoroides* was also influenced by low shading intensities and in the wet season 2004 by trampling, too. Again, species and patch specific dynamics as well as sampling errors due to patchy seagrass distribution might explain the comparatively low R^2 values of the regressions. Their plots visualize the mainly positive and negative effect shading and trampling, respectively had on *E. acoroides* shoot density. Interestingly, not only shading but also trampling had an opposite effect on the shoot density of "others". Positive effects of trampling on shoot density might be explained by removal of silt from the sediment and old leaves from the plants, leading to better sediment climate and less competition for light respectively (see Bach et al. 1998).

Biomass

Biomass of leaves, roots, and sheaths of *Enhalus acoroides* and "others" were well within the reported range for other SE Asian mixed seagrass beds (e.g. (Erftemeijer & Herman 1994, Agawin et al. 2001). For March 2003, MLR gave highly significant and easily understandable results for correlations between compartments (e.g. roots and "dead"). These correlations disappeared for regressions in March 2005, and often "shading" or "farming" was the most important variable. However, the R^2 values of the regressions were generally very low except for *E. acoroides* on the farming plots. Root / shoot ratio of *E. acoroides* increasing with shading intensity can be explained by root biomass being much more affected by shading than other parts of the plant.

The positive effect of shading on *E. acoroides* shoot density and biomass on the experimental plots can be explained by a reduction of irradiance during spring low tides when large die-offs occur (Erftemeijer & Herman 1994). Under shading the plants were protected from excessive heat and radiation, and losses of shoots and / or biomass were less severe. "Others" in contrast might be naturally protected from excessive radiation. In water pockets, also reported by Erftemeijer & Herman (1994), the short leaves of e.g. *Cymodocea* spp. and *Thalassia hemprichii* are exposed to the sun for a much briefer period. In this aspect shading would not improve their survival. *E. acoroides* has a lower respiration and thus a lower light compensation point than "others", which have been reported to be much more prone to siltation and reduced light availability (Vermaat et al. 1996, Bach et al. 1998). Under reduced light levels those species show self-thinning of shoots and less allocation of photosynthetic products to below-ground biomass (Madsen & Sand-Jensen 1994). Though, for short periods of shading the plants use internal carbon resources (Gacia et al. 2005), and substantial changes occur after prolonged periods of altered environmental conditions (Ziemann et al. 1989, Bach et al. 1998).

Eklöf et al. (2006b) found *E. acoroides* to perform worse and smaller seagrasses similar under seaweed farms compared to control plots. Principally, they concluded that most probably this was due to the difference in leaf length between the two growth forms and the exposure to air during low tides. In their study area (Chwaka Bay, Zanzibar, Tanzania) farming intensity was much higher than in Puntondo and the off-bottom method was commonly used. There, the long leaves of *E. acoroides* were often entangled in and damaged by seaweed farming lines which was never observed in Puntondo. The authors linked this reduced leaf length and density to a comparatively better light climate for small species, which are normally shaded by *E. acoroides*. Thus, the expected negative effects of shading by seaweed farms on small seagrasses were outbalanced. In Puntondo, both seaweed farms and *E. acoroides* shaded small species, and hence, their performance was decreased.

In this study, seagrass biomass closely followed shoot density development. To estimate threshold levels for seaweed farming beyond which seagrass performance would decrease, the general equation for the shoot density MLR

$$z = k + n_1 a + n_2 x + n_3 y \qquad \text{was transformed to} \qquad x = \frac{k + n_1 a + n_3 y - z}{-n_2}$$

with z = shoot density at time t, k = equation constant, n_1 = factor for shoots at t_{-1}, a = shoots at t_{-1}, n_2 factor for shading or farming, x = shading / farming intensity, n_3 = factor for trampling, and y = trampling intensity. For the farming plots, the term n_3y was set to 0. For all significant observations for combinations of shading and trampling (n = 160 and 128 for "others" and *E. acoroides* respectively) and farming intensity (n = 32 for "others" and 24 for *E. acoroides*) the equation was run and the averaged results plotted (Figure 5). Calculated threshold levels for shading on the experimental plots were 1,4 and 1,7 for "others" and *E. acoroides*, respectively.

When projected on the PAR regression of the farming plots, these values and their standard deviation resulted in approx. 220.000 (185.000 – 250.000) seedlings ha^{-1} and 260.000 (205.000 – 340.000) seedlings ha^{-1} for "others" and *E. acoroides*, respectively, as approximate threshold level (Figure 5). If "trampling" was not included in the equations (n_3y = 0) threshold levels were estimated considerably higher. For management decisions, seedling densities

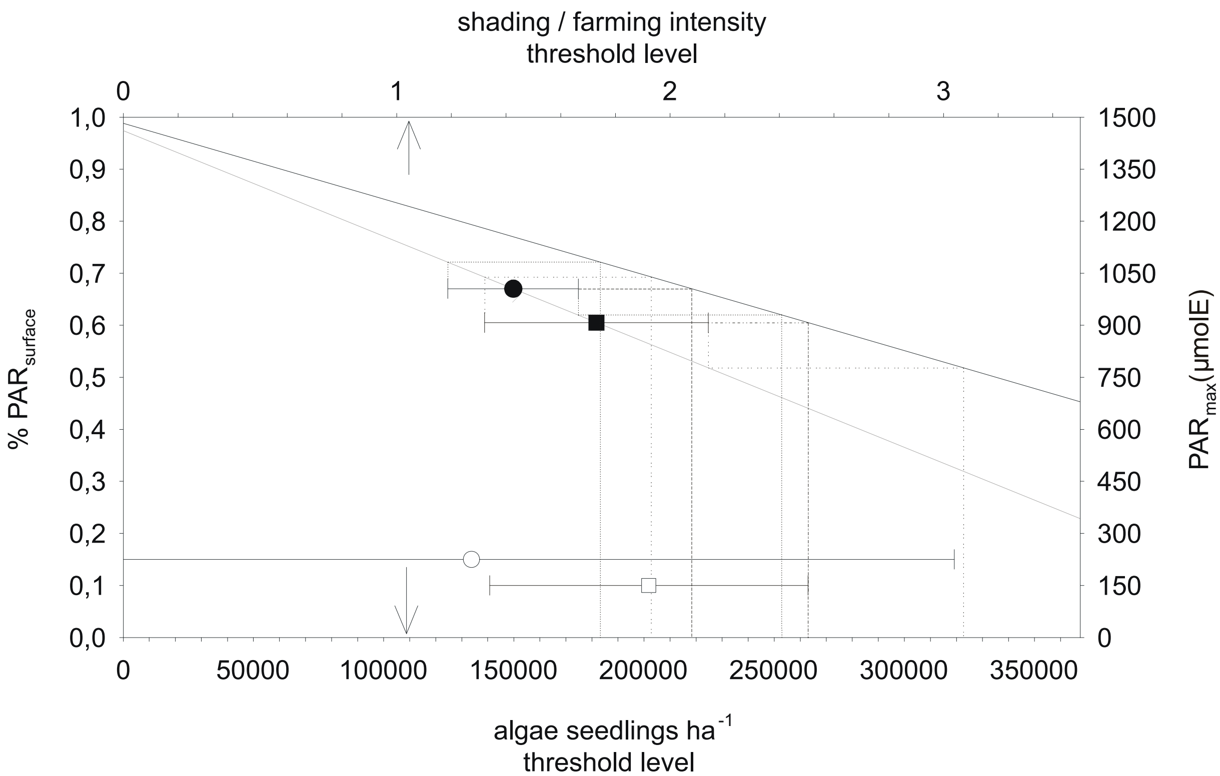

Figure 5. Threshold levels and their standard deviation (extreme values excluded) of *Enhalus acoroides* (■,□) and "others" (●,○) for shading on experimental plots (grey regression) and farming plots (black regression, white symbols). Threshold levels for farming plots not in scale with PAR, but giving reference for drop lines (grey: *E. acoroides*, black: "others") indicating corresponding light and shoot density levels on farming plots. Arrows indicating commonly practiced farming level

for the lower range of the standard deviations can be considered as "safe", because those levels are below the actual threshold level without compromising maximum sustainable yield to much. However, threshold levels calculated with data from the farming plots were even below the low standard deviations (135.000 seedlings ha^{-1} for "others", 200.000 seedlings ha^{-1} for *E. acoroides*), and standard deviation of "others" was much higher than on the experimental plots. This might be due to plot specific dynamics in the farming area or due to other factors present in the farming, but not in the shading and trampling manipulations. For shading manipulations, sterile materials were used, whereas on the farming plots living plants altered environmental conditions. The plants themselves act as additional habitat and food for a wide range of animals (see Hay 1997) which also might influence the seagrass beneath. Gacia et al. (2005) estimated threshold levels for metabolic community balance of a mixed seagrass bed in the Philippines. Their calculated values (80 % of PAR_{max}) are extremely high compared to other studies (e.g. Erftemeijer et al. 1993), and it is very likely that in fact their estimation of minimal PAR to sustain ecosystem quality is on the uppermost limit. Calculated and projected PAR threshold levels from this study are slightly lower than (or for "others" on the farming plots equal with) 80 % of surface PAR. Though the scope of the study by Gacia et al. (2005) was not the same as in this study, their results support the proposed threshold levels for seaweed farming. Further analysis of seagrass C / N ratios and pore water chemistry in correlation with shading, trampling and farming manipulations may help to validate the findings presented in this paper.

The commonly used farming density in the Puntondo area (approx. 110.000 seedlings ha^{-1} with a rotating farming scheme) is well below densities reported or recommended in literature for permanent farming operations, e.g. Adnan & Porse (1987): 320.000 seedlings ha^{-1}; Anonymous (2000a & b): 200.000 – 240.000 seedlings ha^{-1}. Nevertheless, the results presented in this study indicate that even the low local seedling densities are close to or even over the carrying capacity if applied year-round. For eastern Africa, shoot densities as low as 5.000 seedlings ha^{-1} (e.g. Johnstone & Ólafsson 1995) have been reported to decrease habitat diversity, a standing crop 20 times less than currently applied in the Puntondo area. Therefore, it seems obvious that those high recommendations have to be reconsidered with respect not only to the highest possible yield, but also to environmental issues.

Conclusion and recommendation

The farming methods and seedling densities presently applied in the area (floating line method, ≈ 110.000 seedlings ha^{-1}) do not seem to harm the seagrass below, especially if farming plots are rotated seasonally and the seagrass is not torn out prior to farming. Other factors like sediment movement and species-specific dynamics are more important for seagrass performance. However, associated fauna (e.g. macrozoobenthos, fishes) might well be affected by current farming standards, and threshold levels for ecosystem integrity might be different from the ones presented above. The estimated threshold levels should be further on discussed and validated for different biota and at other locations. The results of Eklöf et al. (2006b), though at first sight contradicting the results presented in this study, underline the necessity to discriminate between farming schemes and their impact on seagrass ecosystems for the development and management of seaweed farming.

In the future, open water seaweed farming is very likely to be intensified and surely farming techniques and harvest processing will be improved. Available space on the reef tops is already more or less divided between farmers, therefore the algal harvest for the whole area can be increased by (A) using all areas even in unfavourable seasons, (B) increasing seedling densities, (C) extending farming activities both to the reefs and (D) the open water. Possibility (C) has to be rejected as the fragile coral community surely will suffer from farming activities (e.g. installation and maintenance of the plots, shading by the algae, and debris). The possibilities (A) and (B) seem to have some potential, though the carrying capacity of the system might be reached soon. Therefore, possibility (D), the extension of seaweed culture to areas outside the reef system, seems most reasonable with respect to seagrass and reef top management. Initial investments will be higher than for farms on reef flats, but many problems occurring on the reef tops (e.g. extreme range of water temperature and salinity, tidal exposure of the algae, insufficient water exchange, grazing pressure by herbivorous fishes) could probably be minimized in more open areas (Santelices 1999, Anonymous 2000b). But still, individual risk assessments will be necessary, as potential farming sites will differ greatly in their oceanographic, geological, and biological environments.

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Appendix

Table A1. One-Way ANOVA and post-hoc test results for pooled shoot density data of *Enhalus acoroides* (E) and "others" (o) for different single treatments, + indicating significance (p < 0,05)

One-Way ANOVA			significance for		Multiple Comparison versus Control Group (Holm-Sidak Method) test results			
season	treatment	intensity	*E. acoroides*	others	Difference of means	t	unadjusted P	critical level
1/03 2003	shading	1	-	-				
		2	-	-				
		3	-	-				
	trampling	1	-	-				
		2	-	-				
		3	-	-				
	farming	1	-	-				
		2	-	-				
		3	-	-				
dry 2003	shading	1	-	-				
		2	-	-				
		3	-	-				
	trampling	1	-	-				
		2	-	-				
		3	-	-				
	farming	1	-	-				
		2	+	-	32,667	2,557	0,012	0,017
		3	-	-				
wet 2003	shading	1	-	-				
		2	-	-				
		3	-	+	476,800	4,131	<0,001	0,017
	trampling	1	-	-				
		2	-	-				
		3	-	-				
	farming	1	-	+	240,667	3,388	0,001	0,025
		2	-	+	322,000	4,533	<0,001	0,017
		3	+	-	22,000	2,756	0,007	0,017
dry 2004	shading	1	-	-				
		2	-	-				
		3	-	+	460,267	4,681	<0,001	0,017
	trampling	1	-	-				
		2	-	-				
		3	-	-				
	farming	1	+	+	E 3,333	2,556	0,013	0,017
					o 219,000	2,937	0,004	0,017
		2	-	-				
		3	-	-				
wet 2004	shading	1	+	-	30,933	3,074	0,004	0,025
		2	+	+	E 3,600	3,339	0,002	0,017
					o 261,333	3,769	<0,001	0,025
		3	-	+	360,000	5,192	<0,001	0,017
	trampling	1	-	-				
		2	-	-				
		3	-	-				
	farming	1	-	+	178,667	2,418	0,018	0,025
		2	-	+	238,667	3,231	0,002	0,017
		3	-	-				

Table A2. Significances of TWO-WAY ANOVA for shoot densities of *Enhalus acoroides* and "others" with the factors shading (sh) and trampling (tr) and differing groups (post-hoc Holm-Sidak). For significant differences (p = 0,05) multiple linear regression results are given; significance level for factors set to p = 0,05 and p = 0,10 (in brackets), $R^2 > 0,55$. Not significant results grey

two-way ANOVA			multiple comparison versus control group (Holm-Sidak method) test results						multiple linear regression				
sampling	species	signifi-cance	comparison of levels sh	tr	Difference of means	t	unadjusted P	critical level	constant p coefficient	shoots t_{-1} p coefficient	shading p coefficient	trampling p coefficient	R^2
1/03 2003	*E. acoroides*	-											
	others	-											
dry 2003	*E. acoroides*	+	3	all	0,597	2,936	0,004	0,017	<0,001 50,028	0,402 0,194	0,839 -1,167	0,920 -0,575	0,015
			3	2	1,631	3,808	<0,001	0,017					
	others	+	2	all	0,098	4,187	<0,001	0,017	<0,001 1051,250	0,185 0,205	<0,001 -109.762	0,259 -24,321	0,366
			3	all	0,097	4,107	<0,001	0,025					
			2	0	0,089	2,314	0,023	0,025					
			2	2	0,137	2,761	0,007	0,017					
			3	0	0,098	2,545	0,012	0,017					
			3	3	0,154	3,116	0,002	0,017					
wet 2003	*E. acoroides*	-											
	others	+	all	1	0,160	2,785	0,006	0,017	<0,001 717,062	0,682 0,0534	0,230 29,964	0,802 5,834	0,019
			all	2	0,158	2,746	0,007	0,025					
			3	all	0,157	2,729	0,007	0,017					
			3	0	0,570	6,080	<0,001	0,017					
			3	1	0,577	4,764	<0,001	0,025					
			3	2	0,686	5,668	<0,001	0,017					
			3	3	0,345	2,847	0,005	0,005					

Table A2. continued

two-way ANOVA			multiple comparison versus control group (Holm-Sidak method) test results						multiple linear regression				
sampling	species	significance	comparison of levels sh	comparison of levels tr	Difference of means	t	unadjusted P	critical level	constant p coefficient	shoots t_{-1} p coefficient	shading p coefficient	trampling p coefficient	R^2
dry 2004	*E. acoroides*	+	3	2	1,349	3,566	0,001	0,017	<0,001 29,302	0,106 0,139	0,828 -0,508	0,332 -2,263	0,032
	others	+	all	1	0,096	3,223	0,002	0,017					
			2	all	0,109	3,668	<0,001	0,017					
			2	0	0,134	2,763	0,007	0,025					
			3	all	0,109	3,666	<0,001	0,025	<0,001 582,074	0,005 0,194	<0,001 -74,778	0,588 -9,213	0,229
			3	0	0,271	5,612	<0,001	0,017					
			3	1	0,283	4,540	<0,001	0,017					
			3	2	0,180	2,877	0,005	0,025					
wet 2004	*E. acoroides*	+	all	1	0,403	2,360	0,020	0,025					
			all	2	0,640	3,749	<0,001	0,017					
			1	1	0,882	2,449	0,016	0,016	<0,001 16,799	<0,001 0,235	(0,076) (3,022)	0,041 -3,497	0,141
			2	1	0,985	2,737	0,007	0,017					
			2	2	0,857	2,380	0,019	0,025					
			2	3	1,106	3,072	0,003	0,017					
			3	2	1,337	3,714	<0,001	0,017					
	others	+	all	1	0,138	5,097	<0,001	0,017					
			all	2	0,091	3,351	0,001	0,025					
			all	3	0,067	2,475	0,015	0,050					
			2	all	0,071	2,608	0,011	0,025					
			2	0	0,164	3,709	<0,001	0,025					
			2	1	0,140	2,458	0,016	0,017	<0,001 431,310	0,016 0,179	0,002 -47,523	0,270 15,301	0,185
			3	all	0,117	4,330	<0,001	0,017					
			3	0	0,310	7,003	<0,001	0,017					
			3	1	0,343	6,004	<0,001	0,017					
			3	2	0,217	3,792	<0,001	0,025					
			3	3	0,142	2,491	0,014	0,050					

Table A3. Results of multiple linear regression for biomass data of *Enhalus acoroides*, "others", and different treatments. Significance level set to p=0,05 and p=0,10 (in brackets), R2>0,55. Not significant results grey; -: not relevant

					manipulation			March 2003 fractions				
sampling	plot	species	fraction	constant p coefficient	shading p coefficient	trampling p coefficient	farming p coefficient	leaves p coefficient	dead p coefficient	roots p coefficient	r/s p coefficient	R^2
March 2003	explot	*E. acoroides*	leaves	0,001 19,701	0,415 -1,663	0,814 -0,532	-	-	0,210 0,104	0,922 -0,003	-	0,627
			dead	0,932 -1,905	0,944 -0,441	0,141 9,854	-	0,210 0,984	-	<0,001 0,369	-	0,943
			roots	0,754 -17,387	0,751 5,021	(0,086) (-28,391)	-	0,922 -0,198	<0,001 2,310	-	-	0,940
			all	0,002 553,855	0,970 -3,037	0,292 -87,727	-	-	-	-	-	0,071
			root / shoot	<0,001 14,255	0,881 0,239	0,314 -1,632	-	-	-	-	-	0,060
		others	leaves	0,513 -18,130	0,332 -3,123	0,870 0,523	-	-	0,795 0,110	(0,098) (0,144)	-	0,602
			dead	0,421 -13,774	0,635 0,959	0,140 2,820	-	0,795 0,042	-	<0,001 0,163	-	0,778
			roots	0,003 206,011	0,607 -4,840	0,265 -10,061	-	(0,098) (1,198)	<0,001 3,535	-	-	0,821
			all	<0,001 815,569	0,121 -38,129	0,621 10,422	-	-	-	-	-	0,136
			root / shoot	<0,001 8,960	0,146 0,658	0,775 -0,125	-	-	-	-	-	0,121
	farm	*E. acoroides*	leaves	0,523 6,109	-	-	0,448 4,282	-	0,609 -0,711	0,036 0,429	-	0,830
			dead	0,875 -3,502	-	-	0,844 -2,601	0,609 -0,381	-	0,001 1,394	-	0,932
			roots	0,825 3,022	-	-	0,691 -3,204	0,036 0,859	<0,001 0,521	-	-	0,955
			all	0,022 293,394	-	-	0,327 -81,086	-	-	-	-	0,283
			root / shoot	0,028 0,300	-	-	0,820 -0,020	-	-	-	-	0,004

Table A3. continued

sampling	plot	species	fraction	constant p coefficient	manipulation shading p coefficient	 trampling p coefficient	 farming p coefficient	March 2003 fractions leaves p coefficient	 dead p coefficient	 roots p coefficient	 r/s p coefficient	R^2
March 2003		others	leaves	0,381 7,144	-	-	0,725 1,271	-	0,424 0,123	0,021 0,082	-	0,803
			dead	0,791 4,534	-	-	0,838 1,534	0,424 0,525	-	0,153 0,113	-	0,719
			roots	0,946 4,534	-	-	0,805 -7,913	0,021 5,263	0,153 1,710	-	-	0,827
			all	0,001 471,734	-	-	0,612 40,277	-	-	-	-	0,022
			root / shoot	<0,001 2,409	-	-	0,877 0,058	-	-	-	-	0,002
March 2005	explot	*E. acoroides*	leaves	0,329 26,331	0,151 11,246	0,170 -11,755	-	0,908 0,110	0,608 0,161	0,559 -0,074	-	0,203
			dead	0,369 42,638	0,040 29,618	0,463 -10,828	-	0,507 1,134	0,567 -0,318	0,702 0,085	-	0,292
			roots	0,660 77,518	(0,080) (92,513)	0,686 -22,194	-	0,861 -1,115	0,835 -0,431	0,622 0,410	-	0,266
			all	0,535 146,486	(0,062) (133,377)	0,544 -44,776	-	0,988 0,129	0,832 -0,588	0,704 0,421	-	0,269
			root / shoot	0,734 3,985	0,585 2,247	0,870 0,691	-	-	-	-	0,488 0,440	0,052
		others	leaves	0,171 57,964	0,184 -6,586	0,442 3,643	-	0,039 0,863	0,700 -0,240	0,806 -0,033	-	0,492
			dead	0,489 52,965	(0,069) (-17,206)	0,356 8,139	-	0,380 -0,635	0,248 -1,362	0,114 0,410	-	0,375
			roots	0,530 303,806	0,129 -89,208	0,169 78,387	-	0,850 -0,855	0,529 -4,618	0,408 1,311	-	0,284
			all	0,475 414,734	0,110 -113,000	0,185 90,169	-	0,908 -0,627	0,480 -6,220	0,375 1,688	-	0,308
			root / shoot	0,189 -6,508	0,880 -0,145	0,858 0,161	-	-	-	-	0,003 1,704	0,449

Table A3. continued

sampling	plot	species	fraction	constant p coefficient	manipulation shading p coefficient	 trampling p coefficient	 farming p coefficient	March 2003 fractions leaves p coefficient	 dead p coefficient	 roots p coefficient	 r/s p coefficient	R^2
March 2005	farm	*E. acoroides*	leaves	0,784 -0,335	-	-	0,113 1,232	0,115 -0,069	<0,001 0,251	<0,001 -0,202	-	0,981
			dead	0,977 -0,043	-	-	0,047 1,956	0,268 -0,057	0,164 0,032	0,714 -0,013	-	0,478
			roots	0,677 1,153	-	-	0,109 2,827	0,394 -0,080	0,692 0,016	0,982 0,002	-	0,326
			all	0,933 0,376	-	-	0,039 6,256	0,160 -0,224	0,001 0,293	(0,086) (-0,199)		0,832
			root / shoot	(0,070) (0,445)	-	-	0,810 0,032	-	-	-	0,136 -0,696	0,198
		others	leaves	0,024 45,713	-	-	0,872 1,215	0,884 -0,099	0,829 0,071	0,935 0,007	-	0,018
			dead	0,028 143,211	-	-	0,779 6,869	0,905 -0,262	0,619 -0,530	0,734 0,093	-	0,044
			roots	(0,059) (277,897)	-	-	0,848 11,069	0,667 2,234	0,919 0,253	0,761 -0,196	-	0,046
			all	0,042 466,821	-	-	0,829 19,154	0,813 1,873	0,957 -0,206	0,922 -0,096	-	0,017
			root / shoot	0,008 1,152	-	-	0,334 0,154	-	-	-	0,151 0,184	0,244

Chapter 3
Fishermen's perception of artisanal fisheries and implications for management in a bay in South Sulawesi, Indonesia

Sven Uli Blankenhorn and Harald Asmus
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Abstract

Fishermen in Puntondo, a small village in South Sulawesi, Indonesia, were interviewed about their perception of current fisheries status and its development in recent years. They were asked for target species, individual size of fishes as well as abundance and its change. Also information on fishing habitats, on fishing methods, such as used gear, and market prices were collected. From literature, the data-set was completed with information on trophic levels, maximum sizes and sizes at first maturity of the fishes. Nets and lines were the most important fishing methods. Nets were more efficient to catch smaller size classes of fish compared to lines and tended to over-exploit fish stocks whereas lines caught relatively large fish. Coral reefs and beaches were the most important fishing grounds. On both, catch abundance had decreased and fishes were comparatively small. For the whole bay however, overall fish abundance had not decreased significantly. Abundance change of individual species was negatively correlated with trophic level, indicating substantial fishing pressure in the area. Based on the status of fisheries perceived by the local people different methods and fishing habitats are evaluated in respect to improving fisheries management.

Keywords

artisanal fisheries, fishing gear, fishing ground, management, Indonesia

Introduction

In costal areas in developing countries artisanal fishery is an important source of income, often intermixed with agricultural activities (Cesar et al. 1997, Allison & Ellis 2001, van Oostenbrugge et al. 2004). In Indonesia, 5 % of the fishing vessels have inboard engines, 20 % are equipped with outboard engines and 75 % of the boats are not motor-driven (Anonymous 1977–1995). Hence, most fishermen depend on coastal fish stocks and access to offshore fishing grounds is restricted by their equipment. Rapid population growth and increasing need for protein rich food leads to increasing fishing pressure on local stocks (Johannes 1998, Mous et al. 2005). This has to be addressed by improved management (Butler 2005) and community development plans (Fernández et al. 1999, Pollnac et al. 2001, Barker 2005).

Ecosystem health and services are prone to change with increasing fishing effort or techniques. Unsustainable methods directly damage the environment by altering physical conditions of the habitat (Öhman et al. 1997). Additionally, such methods, as well as overfishing (e.g. Jennings 1998, Pet-Soede et al. 2001, Valentine & Heck 2005), interfere with biological factors and hence disturb the food web of the ecosystem (Sumaila et al. 2000, Arreguín-Sánchez et al. 2004, Aubone 2004, Campbell & Pardede 2006). This can have dramatic effects which, in contrast to direct physical damage, might not be visible immediately.

In Indonesia, decentralisation processes (Satria & Matsuda 2004) have led to increased concern of local authorities about their marine resources. Evaluation of local fish stocks, like recommended by (Pet-Soede et al. 1999) is much more common today, though interest of local fishermen are not necessarily fully addressed (Elliott et al. 2001). Still, there the problems of lacking fisheries data and insufficient data management as described by Pet-Soede et al. (2001) remain unsolved.

Local fishers provide a valuable source of information on fish stocks and catch habitats (Johannes 1998, Ruddle 1998, Evans & Birchenough 2001, Bergmann et al. 2004). Most often their voice is heard in designing marine protected areas (e.g. Hegarty 1997, Crawford et al. 2004, Armitage 2005) and managing local fish stocks (Baticados 2004, Nielsen et al. 2004, Blaber et al. 2005). Amar et al. (1996), Russ & Alcala (1998), Jennings & Polunin (1997), Friedlander et al. (2003), and McClanahan & Mangi (2004) have explicitly analysed the influence of fishing gear and pressure on coral reef fish stocks and biodiversity in South-East Asia and made management suggestions. This paper seeks to evaluate local fishermen's perception of artisanal fisheries and the possibility of implementing the findings into management decisions (see Hegarty 1997, Johannes 1998, Cannon & Surjadh 2004).

There are strong efforts to extend seaweed farming activities in the area (Sievanen et al. 2005, Blankenhorn & Asmus submitted-b). Common farming methods use shallow waters, preferably on subtidal reef tops. This is the natural habitat of seagrass beds which host a unique fish fauna. The vegetation provides food for many reef dwelling species and shelter for larvae and juveniles of commercially important fishes. Seaweed farming can damage seagrass communities below (Eklöf et al. 2005, Eklöf et al. 2006b, Blankenhorn & Asmus submitted-a) and fishes depending more or less on plant (especially seagrass) resources might suffer from changes in this habitat (Eklöf et al. 2006a). In this article, these fish species are given special reference.

Methods

Study area

The study was carried out in the village of Puntondo, District Takalar, South Sulawesi province, Indonesia (5°35,330'S, 119°29,050'E, Figure 1). The village has approximately 800 inhabitants and the area is generally not very densely populated. The south of Takalar district is characterized by a distinct and prolonged dry season from April to October. The shallow waters (5–15 m) of the Laikang bay surrounding the peninsula are relatively calm throughout the year; the sediment is muddy in inner parts of the bay and intermixed with corraligenous sediments towards the open sea. Especially during periods with high wind intensity (September to March), fine sediment is resuspended and hence the waters are turbid.

The fringing coral reefs in the bay are in relatively good condition compared to other coastal reefs in the region (pers. observation) and only locally degraded. Towards inner parts of the bay hard corals are replaced by soft corals and later by hydrozoan and sponge communities in very turbid waters. Reef tops are vegetated by dense seagrass beds, mainly consisting of *Enhalus acoroides*, *Cymodocea serrulata* and *Thalassia hemprichii* (Blankenhorn, unpublished data). In the inner parts of the bay there is a small rest of once extensive mangrove forests which have been cleared since the 1970's for the construction of fish and shrimp ponds (personal communication with villagers).

Most common fishing methods are gill nets, lines, and the stationary lift-net devices "bandung" and "bagang". A bandung is typically constructed on the beach or on the shallow reef top. It consists of a wooden pole tower (approx. 5 m high) and a lift net (approx. 25 m^2) which is operated from top of the tower. The net is positioned on the sea bottom and when the fisher sees sufficient fish above it, it is li ed. A bagang operates in deeper water (up to 7 m). Below a platform on bamboo stilts a lift net is lowered to the sea bottom during the night. Strong lamps are used to aggregate fish and the net is li ed periodically. Most fishing vessels are driven by outboard engines and a crew of one or two, though non-motorized small canoes are still common. In addition, in shallow waters on the reef crests nets are often set without a boat and lines are also used standing on the reef crest. There are no large local vessels suitable for fishing trips of several days; there-

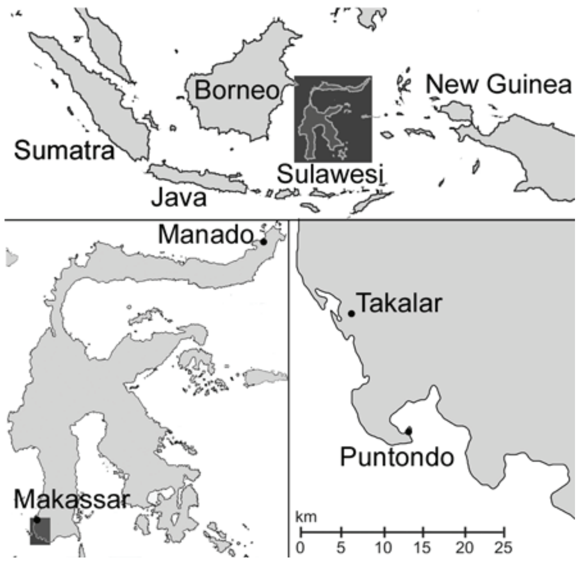

Figure 1. Map of Indonesia (top), Sulawesi (left) and the Puntondo area (right)

fore the area fished by local residents is mainly restricted to the bay and its neighbouring coastal waters.

Community surveys

Five groups of fishermen were interviewed in December 2002 and January 2003. Pictures of fishes (Allen 2000) were presented and fishermen were asked which fish species they had ever caught in the waters around Puntondo. Local names (Makassar language) of the fishes were noted. In a second run the fishermen were asked for details on fishery techniques as well as on fishes, such as used gear, fished area, seasonality (rainy vs. dry season) of the targeted species, past (5 years ago and "when he was a child") and ongoing abundance, average and maximum body length, and market prices. Questions for abundance and prices were asked to be answered in the categories "very low", "low", "medium", "high", and "very high", these categories were ranked from 1 to 5. It was not possible to separate answers of single individuals because the interviews were attended by several fishermen engaging in discussion. Within those groups the people were free to comment at any time and often they agreed on responses to questions. However, guidelines for semi-structured interviews (Bunce et al. 2000) were followed as close as possible.

Literature data

Information on the fishes maximum sizes (L_{max}) and sizes at first maturity (L_m) was obtained from Froese & Pauly (2000). Additionally, data on the species' preferred food and the resulting trophic levels, as well as on preferred habitats was gathered.

Statistical analysis

The different sets of variables from the interviews were analysed with a Two-Way (TW) ANOVA procedure with the factors "habitat" and "method". In order to determine the differing sets an All Pairwise Multiple Comparison (PMC, Student-Newman-Keuls Method) was performed. Fishermen reported that many of the 208 fish species could be caught with different methods and within different habitats. In those cases, the species was accounted for in each possible combination of method and habitat leading to a cumulative n of 624. To visualize the importance of method / habitat comparisons, relative values for each pairing were plotted in matrices. To detect general shifts in abundance, categories for "present", "5 years ago" and "in the past" were analysed with a Repeated Measurement (RM) ANOVA on Ranks Procedure (n = 208) followed by an PMC (Student-Newman-Keuls Method).

Average and maximum size of fished species in Puntondo (P_{av} and P_{max}, respectively) were divided by their maximum sizes (L_{max}) and sizes at first maturity (L_m) obtained from literature (Froese & Pauly 2000). The resulting ratios P_{av}/L_{max} and P_{max}/L_{max} indicated relative sizes of the species in respect to its growth potential. The ratios P_{av}/L_m, and P_{max}/L_m were used to evaluate the relative maturity of the catch, i.e. values below 1 indicated immature catch. Those ratios were then analysed with a TW-ANOVA procedure as described above.

Species' economical value was calculated by multiplying abundance with the root of the market price index. This was done in order to give catch abundance a higher weight in the calculation. Catches of non-migratory fishes lead to more reliable income, and therefore the abundance of seasonal and slightly seasonal species was multiplied with 0,5 and 0,75, respectively. The data then was analysed as described above for differences between habitat and fishing method. Additionally, an analysis based on averaged values for method / habitat combinations, cumulative values were calculated for each method and habitat. Data of relevant species were added up, leading to n = 35 combinations (5 methods, 7 habitats) which were compared in a TW-ANOVA.

Species using seagrass beds neither as habitat nor as feeding ground were given the (seagrass index" i = 1. Species only feeding on plant material or only inhabiting vegetation were given the index i = 2, fishes using plants both for food and shelter the index 4. Those indices as well as the species' reported trophic level ware analysed with TW-ANOVA procedures (see above) as well. For all statistical analysis the SigmaStat 3.0 software package was used.

Results

Fished species and local names

208 fish species of 65 families were identified by the villagers in Puntondo (Table 1). Ranked after number of species, the families Lutjanidae (13), Mullidae, Serranidae and Siganidae (12 each), Lethrinidae and Nemipteridae (11 each), Labridae (10) and Haemulidae (9) were most common.

Used gear, catch habitat and abundance

10 fish families (of a total of 65) contributed 51,8% to overall species number landed in the village (Figure 2). Lutjanidae and Lethrinidae were the most dominant families (7,5% of all fished species each), followed by Nemipteridae (5,8%), Labridae (5,7%), Serranidae (5,4%), Haemulidae and Siganidae (4,9% each), Mullidae (4,5%), Carangidae (3,0%), and Gerreidae (2,7%). Nets were the most common fishing gear in Puntondo, and 93,8% of all fish species were (at least occasionally) caught using this method. 52,4% of the fishes could be fished using lines (Figure 3). The stationary fishing devices bagang and bandung caught 17,8% and 13,0% of species, respectively. "Other methods", i.e. spearing, fish traps, and catching with bare hand (e.g. seahorses) could be used for 2,9% of the species. Most fishes (52,4%) could be caught in rocky habitats, followed by beach, corals and offshore with 43,3%, 27,4% and 26,0%, respectively.

Table 1. Fish species caught in Puntondo and their local names (Bahasa Makassar)

family	genus	species	local name
Acanthuridae	*Acanthurus*	sp.	andangan
		xanthopterus Valenciennes, 1835	andangan
	Ctenochaetus	*tominiensis* Randall, 1955	andangan
	Naso	*annulatus* (Quoy & Gaimard, 1825)	tawasang
Apogonidae	*Apogon*	*pallidofasciatus* Allen, 1987	lua lua karang
		savayensis Günther, 1872	lua lua
Atherinidae	*Atherininomorus*	sp. aff. *duodecimalis* (Valenciennes, 1835)	balumbung
Balistidae	*Abalistes*	*stellaris* (Bloch & Schneider, 1801)	lepis
	Balistoides	*viridescens* (Bloch & Schneider, 1801)	papakulu
	Pseudobalistes	*flavimarginatus* (Rüppell, 1829)	papakulu
	Rhinecanthus	cf. *verrucosus* (Linnaeus, 1758)	papakulu
Belonidae	*Tylosurus*	*crocodilus crocodilus* (Péron & Lesueur, 1821)	tendro
Bothidae	*Asterrhombus*	*intermedius* (Bleeker, 1866)	galarang
	Engyprosopon	*grandisquama* (Temmink & Schlegel, 1866)	galarang
	Pseudorhombus	*arsius* (Hamilton, 1822)	galarang
		diplospilus Norman, 1926	galarang
Callionymidae	*Dactylopus*	*dactylopus* (Valenciennes, 1837)	coronai
Carangidae	*Alectis*	*ciliaris* (Bloch, 1788)	rambo rambo /cuku kebo
		indicus (Rüppell, 1828)	rambo rambo
	Carangoides	*fulvoguttatus* (Forsskål, 1775)	longoran
	Caranx	*ignobilis* (Forsskål, 1775)	masidung
	Parastromateus	*niger* (Bloch, 1795)	kapasa
	Ulua	*mentalis* (Cuvier, 1833)	cepa
Centropomidae	*Lates*	*calcarifer* (Bloch, 1790)	kanja
	Psammoperca	*waigiensis* (Cuvier, 1828)	pica pica
Chaetodontidae	gen.	sp.	jangan jangan
Chirocentridae	*Chirocentrus*	*dorab* (Forsskål, 1775)	bale bale
Clupeidae	*Sardinella*	cf. *melanura* (Cuvier, 1829)	temban java
Cynoglossidae	*Paraplagusia*	*bilineata* (Bloch, 1787)	lila lila
Dasyatidae	*Dasyatis*	*kuhlii* (Müller & Henle, 1841)	toka toka biru
	Himantura	*undulata* Whitley, 1939	lambaru bati
	Pastinachus	*sephen* (Forsskål, 1775)	lambaru sawala
	Taeniura	*lymna* (Forsskål, 1775)	toka toka biru
Diodontidae	*Diodon*	*holocanthus* (Linnaeus, 1758)	buntala durian
		liturosus Shaw, 1804	buntala durian
Engraulidae	*Stolephorus*	sp. aff. *commersonnii* Lacepède, 1803	temban java
Ephippidae	*Platax*	*teira* (Forsskål, 1775)	tapi tapi
Exocoetidae	*Cypselurus*	sp.	tuing tuing
Fistulariidae	*Fistularia*	*commersonii* Rüppell, 1838	bum bum
Gerreidae	*Gerres*	*erythrourus* (Bloch, 1791)	birang kasa
		filamentosa Cuvier, 1829	birang kasa buku
		oyena (Forsskål, 1775)	birang kasa lumu
		subfasciatus Cuvier, 1830	birang kasa
Glaucosomidae	*Glaucosoma*	*burgeri* Richardson, 1845	bakukung
Gobiidae	*Cryptocentrus*	sp.	laba laba
	Valencienna	*longipinnis* (Lay & Bennett, 1839)	bogolo
		muralis (Valensciennes, 1837)	bogolo

family	genus	species	local name
Haemulidae	*Diagramma*	*labiosum* Macleay, 1883	kaneke
		pictum (Thunberg, 1792)	kaneke puro
	Plectorhinchus	*chaetodontoides* Lacepède, 1800	kaneke
		chrysotaenia (Bleeker, 1855)	kaneke
		gibbosus (Lacepède, 1802)	kapalibibere
		lineatus (Linnaeus, 1758)	kaneke
		orientalis (Bloch, 1793)	kaneke cura
		picus (Cuvier, 1830)	kaneke
		unicolor (Maclay, 1883)	kaneke
Harpodontidae	*Harpodon*	*translucens* Saville-Kent, 1889	sangiri
	Saurida	*gracilis* (Quoy & Gaimard, 1824)	babalagandrang
		tumbil (Bloch, 1795)	babalagandrang
		undosquamis (Richardson, 1848)	babalagandrang
Hemiramphidae	*Hemiramphus*	*robustus* Günther, 1866	tendro
Holocentridae	*Myripristis*	sp.	sulo sulo
	Plectrypops	*lima* (Valenciennes, 1831)	sulo sulo eja
	Sargocentron	sp.	sulo sulo
Labridae	*Cheilinius*	*undulatus* Rüppell, 1835	bacu dongo
	Cheilio	*inermis* (Forsskål, 1775)	bacu pama
	Choerodon	*anchorago* (Bloch, 1791)	bacu tarangigi
		rubescens (Günther, 1862)	bacu tarangigi
	Cirrhilabrus	sp.	bacu
	Coris	*pictoides* Randall & Kuiter, 1982	rambing
	Hologymnosus	*doliatus* (Lacepède, 1801)	bacu teleng
	Paracheilinus	*maccoskeri* Randall & Harmelin-Vivian, 1977	bacu
	Pseudocheilinus	*octotaenia* Jenkins, 1900	bacu papa
	Thalassoma	*lunare* (Linnaeus, 1758)	bacu pare
Leiognathidae	*Leiognathus*	cf. *equulus* (Forsskål, 1775)	oco oco
	Secutor	*ruconius* (Hamilton, 1822)	oco oco tumbera
Lethrinidae	*Gymnocranius*	*elongatus* Senta, 1973	katamba
		grandoculus (Valenciennes, 1830)	birangkasa
		griseus (Schlegel, 1844)	(katamba) bogo
	Lethrinus	*harak* (Forsskål, 1775)	katamba
		laticaudis Alleye & Mcleay, 1877	katamba
		lentjan (Lacepède, 1802)	katamba
		miniatus (Schneider, 1801)	katamba
		olivaceus Valenciennes, 1830	(katamba) cidu
		sp.	katamba
		sp. / *Gymnocranius* sp.	katamba
		variegatus Valenciennes, 1830	katamba
Lobotidae	*Lobotes*	*surinamensis* (Bloch, 1790)	balang balang
Lutjanidae	*Lutjanus*	*bohar* (Forsskål, 1775)	ara biasa
		carponotatus (Richardson, 1842)	pakantulusu
		decussatus (Cuvier, 1828)	pakantulusu
		fulviflamma (Forsskål, 1775)	bate bate
		fulvus (Schneider, 1801)	samu samu
		gibbus (Forsskål, 1775)	dapa
		lutjanus Bloch, 1790	gandrang eja
		rivulatus (Cuvier, 1828)	bunga baru
		russelli (Bleeker, 1849)	ara bateang
		vitta (Quoy & Gaimard, 1824)	sindrisindrili
		xanthura (Bleeker, 1896)	bara bara
	Pinjalo	*pinjalo* (Bleeker, 1850)	bara bara
	Symphorichthys	*spilurus* (Günther, 1874)	kaneke

family	genus	species	local name
Menidae	*Mene*	*maculata* (Bloch & Schneider, 1801)	oco oco bakato
Monacanthidae	*Acreichthys*	*tomentosus* (Linnaeus, 1758)	sukang
	Chaetoderma	*penicilligera* (Cuvier, 1817)	sukang
	Monacanthus	*chinensis* (Osbeck, 1765)	sukang
Monodactylidae	*Monodactylus*	*argenteus* (Linnaeus, 1758)	kapa kapasa
Mugilidae	*Valamugil*	*buchanani* (Bleeker, 1853)	balana
Mullidae	*Mulloidichthys*	*flavolineatus* (Lacepède, 1801)	ciko ciko /cambang cambang
		vanicolensis (Valenciennes, 1831)	ciko ciko /cambang cambang
	Parupeneus	*barberinoides* (Bleeker, 1801)	ciko ciko /cambang cambang
		barberinus (Lacepède, 1801)	ciko ciko /cambang cambang
		cyclostoma (Lacepède, 1801)	ciko ciko /cambang cambang
		indicus (Shaw, 1903)	ciko ciko /cambang cambang
		macronema (Lacepède, 1801)	ciko ciko /cambang cambang
		multifasciatus (Quoy & Gaimard, 1825)	ciko ciko /cambang cambang
		spilurus (Bleeker, 1854)	ciko ciko /cambang cambang
	Upeneus	*moluccensis* (Bleeker, 1855)	ciko ciko /cambang cambang
		tragula Richardson, 1846	ciko ciko /cambang cambang
		vittatus (Forsskål, 1775)	ciko ciko /cambang cambang
Muraenidae	*Gymnothorax*	sp.	kumpa
Myliobatidae	*Aetobatus*	*narinari* (Euphrasen, 1790)	lambaru jangan
Nemipteridae	*Nemipterus*	*celebicus* (Bleeker, 1854)	cuku eja
	Parascolopsis	*eriomma* Jordan & Richardson, 1909	sulo sulo
	Pentapodus	*bifasciatus* (Bleeker, 1848)	cura cura
		porosus (Valenciennes, 1830)	bara bara
		trivittatus (Bloch, 1791)	katamba
		vitta Quoy & Gaimard, 1824	cura cura
	Scolopis	*bilineatus* (Bloch, 1793)	cilala
		lineata Quoy & Gaimard, 1824	kaneke cura bateang
		margaritifer (Cuvier, 1830)	kaneke cura
		trilineatus Kner, 1868	kaneke cura
		vosmeri (Bloch, 1792)	cilala eja
Ophichthidae	*Ophichthus*	*rutiodermatoides* (Bleeker, 1853)	kumpa oser
	Phyllophichthus	*xenodontus* Gosline, 1951	kumpa oser
Opistognathidae	*Opistognathus*	*inornatus* Ramsay & Ogilby, 1887	dare dare
		latitabundus (Whitley, 1937)	dare dare
Ostraciidae	*Lactoria*	*cornuta* (Linnaeus, 1758)	tedong tedong
		diaphana (Bloch & Schneider, 1801)	kudu kudu
Platycephalidae	*Onigocia*	*spinosa* (Temminck & Schlegel, 1844)	para para batu
	Platycephalus	*endrachtensis* Quoy & Gemard, 1825	para para jampaga
Plotosidae	*Paraplotosus*	*albilabris* (Valenciennes, 1840)	samelang
		butleri Allen, 1998	samelang
	Plotosus	*lineatus* (Thünberg, 1791)	ote ote
Pomacentridae	*Abudefduf*	*bengalensis* (Bloch, 1787)	nreto nreto
	Dischistodus	*darwiniensis* (Whitley, 1928)	balang balang kasi
		fasciatus (Cuvier, 1830)	balang balang kasi
		perspicillatus (Cuvier, 1830)	balang balang kasi
		prosopotaenia (Bleeker, 1852)	balang balang kasi
Priacanthidae	*Priacanthus*	*macracanthus*Cuvier, 1829	pakatok
Psettodidae	*Psettodes*	*erumei* (Bloch & Schneider, 1801)	potikoli
Rachycentridae	*Rachycentron*	*canadus* (Linnaeus, 1766)	mondo
Scaridae	*Bolbometopon*	*muricatim* (Valenciennes, 1840)	bacu teleng
	Scarus	*ghobban* Forsskål, 1775	bacu gau / eja
Scatophagidae	*Scatophagus*	*argus* (Linnaeus, 1766)	kitang
Scianidae	*Johnius*	*coitor* (Hamilton, 1822)	bojolo
	Protonibea	*diacanthus* (Lacepède, 1802)	gulama

family	genus	species	local name
Scombridae	*Euthynnus*	*affinis* (Cantor, 1849)	cakalang
	gen.	sp.	tinumbu
Serranidae	*Anyperodon*	*leucogrammicus* (Valenciennes, 1828)	sunu langa
	Cephalopholis	*argus* Bloch & Schneider, 1801	sunu java java
		miniata (Forsskål, 1775)	sunu para pepe
	Cromileptes	*altivelis* (Valenciennes, 1828)	tikus
	Diploprion	*bifasciatum* Kuhl & Van Hasselt, 1928	lua lua
	Epinephelus	*corallicola* (Valenciennes, 1828)	sunu kerapu
		fuscoguttatus (Forsskål, 1775)	sunu kerapu
		quoyanus (Valenciennes, 1830)	sunu bencong
	Grammistes	*sexlineatus* (Thunberg, 1792)	boborang
	Plectropomus	*leopardus* (Lacepède, 1802)	sunu bone
		maculatus (Bloch, 1790)	sunu bone
		oligocanthus (Bleeker, 1854)	sunu bone
Siganidae	*Siganus*	*canaliculatus* (Park, 1797)	biauwasa
		corallinus (Valenciennes, 1835)	baronang didih
		fuscescens (Houttyn, 1782)	biauwasa
		guttatus (Bloch, 1787)	baronang biasa
		javus (Linnaeus, 1766)	baronang biauwasa
		lineatus (Valenciennes, 1835)	baronang kurang
		puellus Schlegel, 1852	baronang didih
		punctatus (Forster, 1801)	baronang eja
		trispilos Woodland & Allen, 1977	baronang didih
		vermiculatus (Valenciennes, 1835)	baronang kurang
		virgatus (Valenciennes, 1835)	baronang didih
		vulpinus (Schlegel & Muller, 1845)	sepakulu
Sillaginidae	*Sillago*	cf. *burrus* Richardson, 1842	kalatodok
Soleidae	*Dexillichthys*	*muelleri* (Steindachner, 1879)	galarang kasi
Sphyraenidae	*Sphyraena*	*barracuda* (Walbaum, 1792)	pangalasan
		jello Cuvier, 1829	pangalasan
		obtusata Cuvier, 1829	limbang
		qenie Klunzinger, 1870	pangalasan
Syngnathidae	*Syngnathoides*	*biaculeatus* (Bloch, 1785)	pasalibuaja
	Hippocampus	sp.	dundu
Synodontidae	*Synodus*	cf. *variegatus* (Lacepède, 1803)	babalagandrang
		sageneus Waite, 1905	babalagandrang
	Trachinocephalops	*myops* (1801)	babalagandrang
Terapontidae	*Pelates*	*quadrilineatus* (Bloch, 1790)	kerung kerung
	Terapon	sp.	kerung kerung
Tetraodontidae	*Arothron*	*reticularis* (Bloch & Schneider, 1801)	buntala
		sp.	buntala
	Chelonodon	*patoca* (Hamilton-Buchanan, 1822)	buntala tumbera
Triacanthidae	*Halimochirurgus*	*centriscoides* Alcock, 1899	sukang
	Pseudotriacanthus	*strigilifer* (Cantor, 1850)	sukang
	Triacanthus	*biaculeatus* (Bloch, 1786)	sukang
		nieuhofi Bleeker, 1852	sukang
	Trixiphichthys	*weberi* (Chadhuri, 1910)	sukang
Triodontidae	*Triodon*	*macropterus* Lesson, 1829	sukang tumbera
Uranoscopidae	*Ichthyscopus*	*fasciatus* Haysom, 1957	kokok
		inspiratus Mees, 1960	kokok
	Uranoscopus	*bicinctus* Temminck & Schlegel, 1850	kokok
Urolophidae	*Urolophus*	*mitosis* Last & Gomon, 1987	toka toka
Σ = 65	Σ = 127	Σ = 208	

Over seagrass and coral rubble each 4,3 % and in mangrove areas 3,9 % of the species could be fished. The fishing method was significantly (TW-ANOVA, $p = 0{,}001$) determining the number of catchable species, whereas the habitat was not of significant importance ($p = 0{,}136$).

The decline in catch abundance of single species (averaged values) as perceived by the fishers did not differ significantly ($p > 0{,}4$) between fishing methods and habitats, respectively (Figure 4). However, total catch with bandung increased slightly, which was significantly different from decreasing catch with net and line ($p = 0{,}005$ and $0{,}019$, respectively). Cumulative yield from other methods decreased less than catch with net and line ($p = 0{,}01$ and $0{,}03$, respectively) and bagang catch were more stable than net landings ($p = 0{,}036$). Differences in total catch decline between habitats were not significant ($p > 0{,}05$).

Categorized catch abundance was relatively stable over time. Species with very high catch abundance in the past decreased, especially since the last 5 years, though not significantly (RM ANOVA on Ranks $p > 0{,}05$, Figure 5). The percentages of species with low and very low abundances increased slightly. Overall fish abundance (ranging from 1 = "very low" to 5 = "very high") had decreased, especially during the last 5 years.

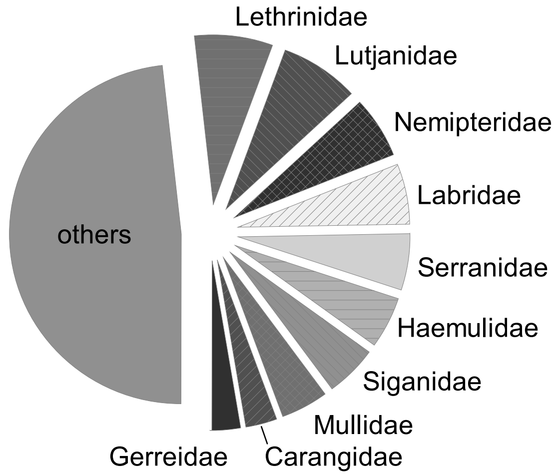

Figure 2. Contribution of the ten most diverse families to overall number of fished species

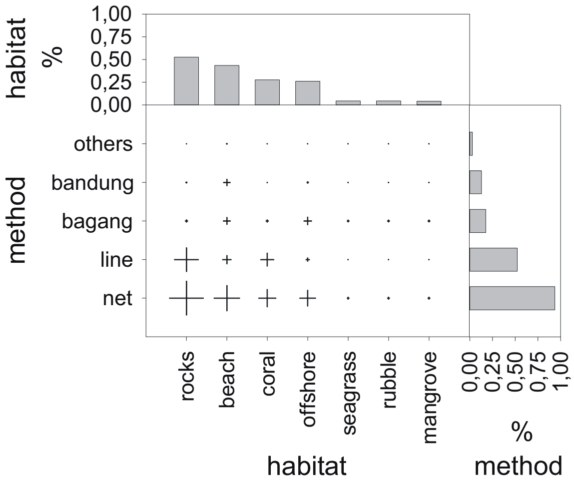

Figure 3. Relative numbers of species for different fishing habitats and methods in Puntondo. Size of crosses indicating relative values for different combinations. Overall percentage in >1 due to species inhabiting more than one habitat

145 fish species (69,7 %) could be caught in both the dry and the rainy season, 9 species (4,3 %) showed a slight seasonality with increased abundance during the wet season. 53 species (25,5 %) were only caught during the rainy season, only one species (Exocoetidae: *Cypselurus* sp.; 0,5 %) was abundant during the dry months only.

Fish sizes

Fishers in Puntondo reported average size of their catch being in 90,3 % of all cases below 30 cm body length, the majority of species (47,1 %) only reaching up to 20 cm. The few very large species (91–100 cm body length) were morays (Muraenidae) and the pelagic cobia (Rachycentridae: *Rachycentron canadus*). Average size of fishes caught with lines was significantly ($p < 0,005$) bigger than for any other method (Figure 6). Size of fishes targeted with nets was second and higher than for fishes from bandung and other methods ($p = 0,001$ each). Catch size from bagang was similar to net catch, but significantly larger than landings from bandung and other methods ($p < 0,001$).

Without consideration of methods, catch size in the various habitats was not significantly different. However, average size of fishes caught with line was much higher off-shore than in any other habitat (TW ANOVA $p < 0,001$). Differences in maximum sizes for methods and habitats were very similar to average size differences. Additionally, maximum sizes of fishes caught with nets in mangrove areas and off-shore were higher than those of fishes caught at the beach and over rocky ground ($p < 0,05$ each). Over rubble and seagrass, maximum size of catches with nets was significantly higher than at the beach and over rocks ($p < 0,03$ each).

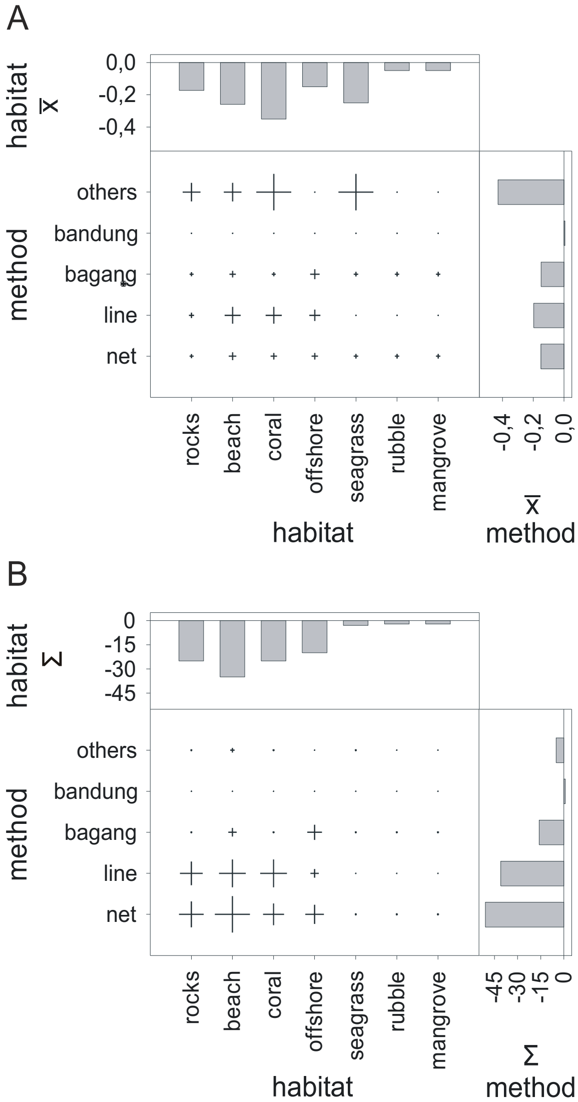

Figure 4. Average (A) and cumulative (B) catch decline for different fishing habitats and methods in Puntondo. Size of crosses indicating relative values for different combinations

Average and maximum length at site compared to literature data

The ratio of the locally reported average length in Puntondo (P_{av}) to the maximum length reported from literature (L_{max}) did not vary significantly between different fished habitats (TW-ANOVA). P_{av} / L_{max} ratios for net catches were significantly lower than for bandung landings (p = 0,029) but higher than for other methods (p = 0,025). The ratio for fishes caught with nets set in coral areas was significantly lower than for off-shore (p = 0,021); there, the ratio for line catches was higher than for any other method (p < 0,02 each).

Significances (TW-ANOVA) for the ratio of the maximum species length in Puntondo (P_{max}) to L_{max} were similar to the P_{av} / L_{max} ratio except for the comparison of bagang with "other methods" and bandung. Ratios for bagang-catches were higher than for others methods (p = 0,019) but lower than for bandung (p = 0,024).

The ratio P_{av} to length at first maturity (L_m) was in 54 % of all cases below the range of $0,9 \le x \le 1,1$ (i.e. average catch < L_m ± 10 %). 14 % of all species were caught at L_m ± 10 % and 32 % well above this size (x > 1,1). For line catches, P_{av} / L_m ratio was highest and significantly different from all other methods (p < 0,05 each) except bandung (p = 0,576, Figure 7). Ratios for catches with bagang were higher than ratios for catches with "others methods" (p = 0,013), but lower than for catches with bandung (p=0,010). In off-shore areas, catches with lines had significantly higher P_{av} / L_m ratios than all other methods (p < 0,05).

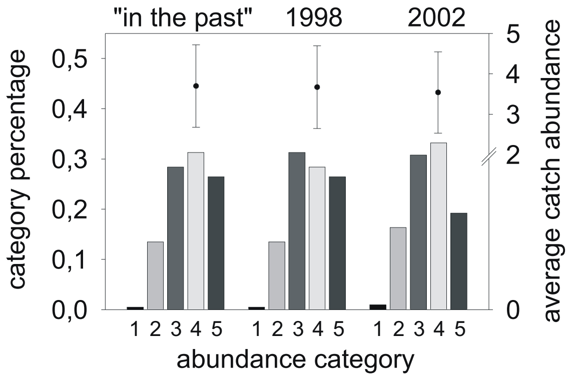

Figure 5. Changes of percentages of fishes in abundance categories over time (bars) and overall fish abundance over time (scatter plot, with standard error). Abundance categories 1 = very low, 2 = low, 3 = intermediate, 4 = high, 5 = very high

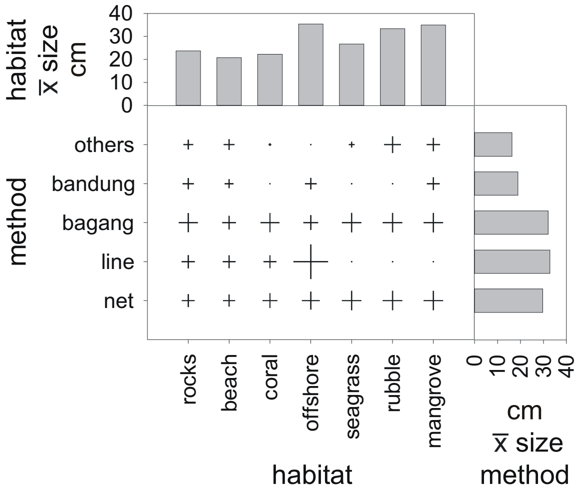

Figure 6. Average sizes of fishes caught with different gear and in different habitats in Puntondo. Size of crosses indicating relative values for different combinations

Significances for P_{max} / L_m ratios were similar to significances for P_{av} / L_m ratios except for the comparisons line vs. net and bagang, respectively, which were not significant. Additionally, net catches over corals had significantly (p = 0,047) lower ratios than catches from off-shore.

Market prices and economical value

202 fish species (97,1 % of all fishes caught) were consumed in the village, 176 species (84,6 %) were sold. 12,4 % of the fishes (25 species) eaten were not marketed. One species

(Syngnathidae: Hippocampus sp.) was marketed but not consumed locally. Four fish species (1,9 %) were not used at all. 17 species (9,7 %) of sold fishes were very cheap, 26 species (14,8 %) cheap, 89 species (50,6 %) of intermediate value, 43 species (24,4 %) expensive, and only one species (0,6 %; *Chromileptes altivelis*, Serranidae) was very expensive.

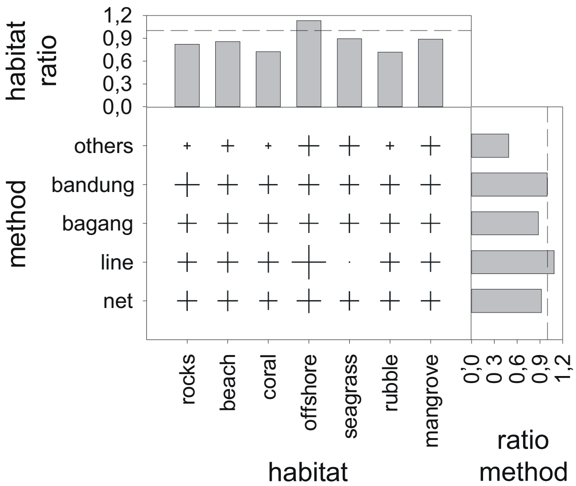

Figure 7. Ratio of Average length in Puntondo (P_{av}) to length at maturity (L_m) for different fishing habitats and methods in Puntondo. Ratio of $P_{av} / L_m = 1$ indicated with dashed references. Size of crosses indicating relative values for different combinations

Average market prices of the catch did not differ significantly (p > 0,05) between fishing methods (Figure 8). Comparison between habitats revealed that catches from rocky areas were sold more expensive than catches from rubble, mangrove and seagrass areas (p = 0,001, 0,001, and 0,045, respectively). Fishes from rubble or mangrove areas were cheaper than species from coral habitats (p = 0,047 and 0,033, respectively), off-shore (p = 0,032 and 0,020, respectively), and the beach (p = 0,019 and 0,01, respectively). Average price of fishes caught with nets was significantly higher in coral and rock habitats (p < 0,01 and p = 0,035, respectively) compared to net landings from other fishing grounds. Over corals, average prices of fishes caught with bagang were significantly lower than for line catches (p < 0,001). In off-shore habitats, average prices for fishes caught with bandung were higher than for other methods (p < 0,05) except for lines (p = 0,228).

Cumulative prices of catches with nets were significantly higher than of catches with "other methods" (p = 0,007) and bandung (p = 0,013, Figure 8). Overall catch price from rocky areas was higher than from any other habitat (p < 0,05 each).

10 of 51 marketed fish families dominated the overall income with 61,3 % (Figure 9). Lethrinidae (10,4 %), Lutjanidae (8,7 %), Haemulidae and Nemipteridae (7,9 % each) were the most important families, followed by Labridae (6,6 %), Mullidae (6,3 %), Siganidae (5,7 %), Gerreidae (3,1 %), Carangidae (2,4 %) and Holocentridae (2,2 %).

19 species (10,8 %) of the marketed fishes had a very low economical value index below 1,8, 61 species (34,7 %) were in the "low" category (1,8 ≤ x ≤ 3,6), 39 species (22,2 %) were of medium value (3,6 ≤ x ≤ 5,4), 36 species (20,5 %) were of high value 5,4 ≤ x ≤ 7,2), and 21 species (11,9 %) were of very high value (x > 7,2).

Species' average economic importance did not differ significantly for single factor comparisons between habitats or between used gears (TW-ANOVA, Figure 10). However, nets used on coral and rock habitats yielded species with significantly higher economic value than from net catches in all other habitats (p < 0,001 each). Between rocks and coral habitats themselves there were no significant differences (p = 0,213). In coral habitats, species fished with lines had higher economical value than those caught with bagang (p < 0,001).

Overall economic importance of net catches was significantly higher than bandung (p = 0,027), bagang (p = 0,018), and "other methods" (p = 0,018). There was no significant difference for cumulative economical value between habitats, differences were due to the usage of nets in certain habitats. Abundance change was negatively correlated to species economical value (p = 0,002), though the fit of the correlation was rather loose (R = 0,235).

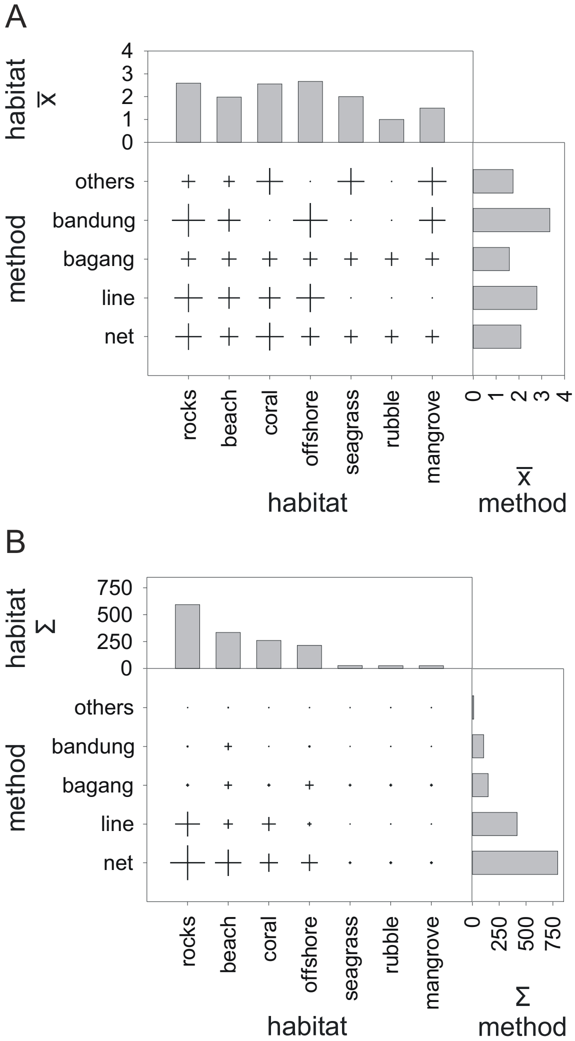

Figure 8. Average (A) and cumulative (B) price of marketed species for different fishing habitats and methods in Puntondo. Size of crosses indicating relative values for different combinations

Assessment of food items, trophic levels, and habitats

Most of the species caught by the fishermen in Puntondo reportedly (Froese & Pauly 2000) feed on zoobenthos (152 species, i.e. 73,1 % of all species). 96 species (46,2 %) feed on nekton (mainly finfish and cephalopods), 32 species feed on zooplankton and 28 on plants (15,4 % and 13,5 %, respectively). Only a small number feeds on detritus (15 species, 7,2 %), and just five species (2,4 %) reportedly forage on phytoplankton. 17,3 % of the fishes (36 species)

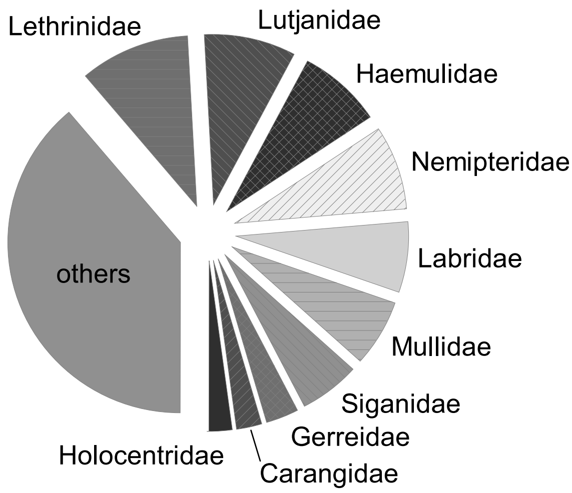

Figure 9. Contribution of the ten most important families to overall economic importance

had a trophic level between 2,1 and 2,99, 21,6 % (45 species) between 3,0 and 3,49. 40,4 % (84 species) were ranged between 3,5 and 3,99 and 20,7 % of the fishes (43 species) above 4,0.

The main habitats (as reported in literature) of fishes caught in Puntondo are “reef” and “sand” with 64,4 % (134 species) and 42,8 % (89 species), respectively. 50 species (24 %) inhabit estuaries, 46 species (22,1 %) can be found in vegetation (i.e. seagrass and algae). “Trawling grounds” and “rubble” are used by 11,5 % (24 species) and 11,1 % (23 species), respectively. Mangrove forests are the main habitat of 7,2 % of the fishes (15 species) only.

Trophic levels of fishes differed significantly between fishing grounds in Puntondo (TW-ANOVA, Figure 11). Species from beach and off-shore catches had the lowest trophic levels which were significantly different from all other habitats ($p < 0,02$ each). Fishes from rocks had higher trophic levels than species from seagrass areas ($p = 0,028$), but lower levels than species from rubble ($p = 0,032$), mangrove ($p = 0,037$), and coral ($p = 0,026$). Trophic levels of bandung landings were lowest and significantly different from all other methods ($p < 0,001$).

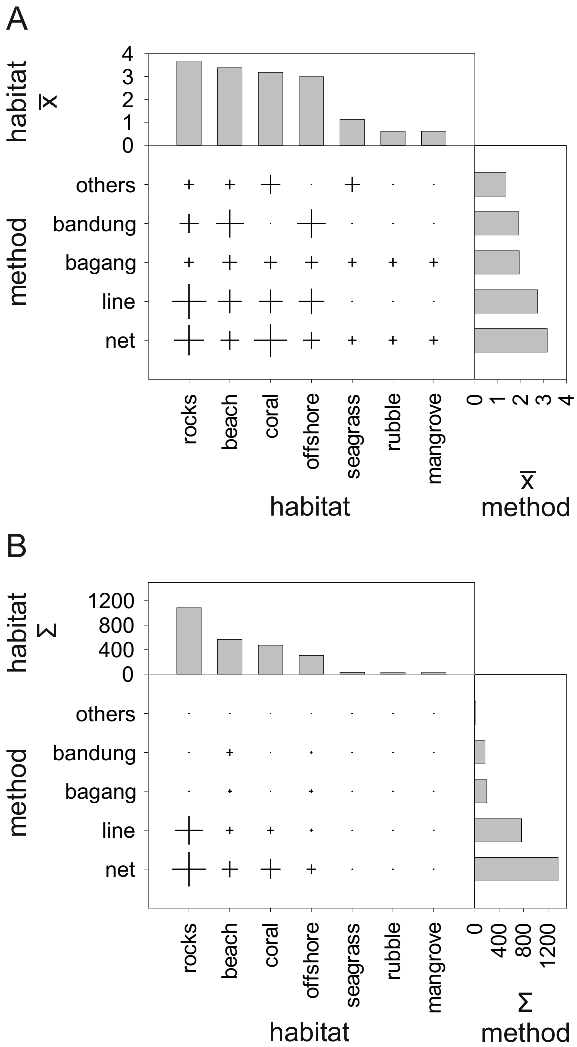

Figure 10. Average (A) and cumulative (B) economical value for different fishing habitats and methods in Puntondo. Size of crosses indicating relative values for different combinations

”Other methods” (e.g. spearing) caught species with the highest trophic levels ($p < 0,05$). Net catches had lower trophic levels than catches with lines ($p = 0,019$) but higher levels than catches with bagang ($p = 0,003$).

Linear regression between abundance change and trophic levels revealed a significant correlation ($p > 0,01$); high trophic levels were correlated to high abundance decline ($y = 0,918 - 0,304\,x$).

Fishes which could be found in mangrove habitats were the most expensive in the markets around Puntondo (average price index 3,3). Also, the prices for reef fishes (3,1) and those inhabiting vegetation (3,0) were above the average for all habitats combined (2,93). Estuarine fishes had average prices (index 2,9), sand and rubble fishes were relatively cheap (indices 2,8 and 2,6, respectively). Fishes inhabiting trawling grounds were very cheap (2,3). Fishes not sold but consumed locally are mainly sand inhabitants (68 %) and very seldom depend on mangrove habitats (8 %).

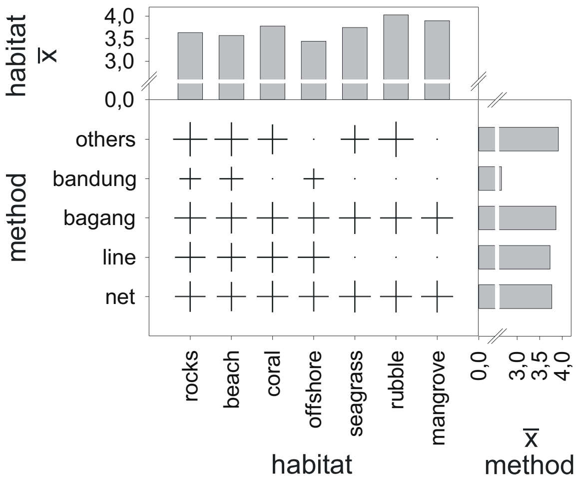

Figure 11. Trophic levels for different fishing habitats and methods in Puntondo. Size of crosses indicating relative values for combinations

35 % (16,8 %) of the fishes caught in Puntondo used weedy areas as preferred habitat but did not feed on plant material. 8,2 % (17 species) of the fishes used plants as food resources but inhabited other areas, 5,3 % (11 species) used weedy areas both for food and for shelter. However, 69,7 % (145 species) of landed fish species did not depend directly on plant resources. By calculating the average of their species, the families Mullidae and Siganidae were most dependent on weeds, followed by the Lethrinidae, Labridae, and Pomacentridae. The families Gobiidae, Acanthuridae, Syngnathidae, Scaridae and Monacanthidae also depended on this resource to a certain extend.

Discussion

Fished species and local names

Fish families in the area were typical for reef fish communities in SE Asia (Amar et al. 1996, Russ & Alcala 1998). The diversity of fishes (208 species from 65 families) caught by fishermen in Puntondo is high compared to other studies (McClanahan & Mangi 2004), especially when considering that reported catch abundance of ornamental reef fish families, especially Apogonidae, Chaetodontidae, Labridae, and Pomacentridae was much less than their actual abundance on the reefs (pers. observation).

Used gear, catch habitat and abundance

Fishermen in Puntondo often did not distinguish between the habitats “rock” and “coral”. Both structures can be found at different places in the area but they are both restricted to reef crests and slopes. Therefore, fishes caught in rocky and coral habitats can be treated as “reef” species. Similarly, the habitats “beach” and “seagrass” were sometimes used as synonyms as in some parts of the bay the seagrass beds start immediately at the shore line.

Some fishing methods were used more universally than others. Nets or lines for example were used in nearly all habitats. As their replacement or repair is rather inexpensive and can be done within the fishermen's families they were also used in unfavourable habitats (e.g. over corals, see Smith et al. 1980). On the other side, some methods were restricted to certain areas. Bagangs and bandungs for example can only be used in areas with a flat and uniform sea bottom so that their nets do not get entangled and can be lifted rapidly. TW-ANOVA results have to be seen in this context.

The methods "net" and "line" were by far the most universal gear in the area, especially over reefs and on the beach. There, they also contributed to overall fish landings with highest proportions. For certain species, those methods most certainly contributed nearly 100% to their overall catch. It is not unlikely that for those species small contributions from other methods were not mentioned during the interviews with the fishermen. The same is valid for fished habitats, i.e. very rare catches outside the usual habitats might have remained unmentioned. However, given the very high relative importance of the combinations net / line / reef / beach for fished species numbers and overall catch abundance these errors would not change the general image of main fishing gears and habitats.

Average species abundance change was not significantly influenced by any method. Increasing cumulative catches with bandung (in relative shallow water) are the result of a higher perceived abundance of Gerreidae (four species) in shallow water. Catch abundance with "other methods" was more stable than catch abundance with nets or lines. Latter two methods catch the most fish species, and as cumulative abundance change was calculated by summing up individual species' changes they also contribute most to overall abundance change. Though some species might have declined, many other species which abundances were stable over time outbalanced extreme changes.

Generally, low fish abundance is the main fishery problem in Puntondo (Blankenhorn & Asmus submitted-b). The results of this study however do not reflect this in the same magnitude as perceived by the fishers. They feel a general decrease in catch, but seem unable to pinpoint fish species with an above-average decline.

In the interviews price change of single species over time was not asked for. Therefore, changes of fish abundance within a given price category might also have been the result of single species being assorted to other categories.

Catch diversity was higher during the wet months (November to March). Though not surveyed, it is assumed that during this time fishing effort is increased as it can be observed e.g. in the Philippines (Amar et al. 1996). At least there is a shift in preferred fishing gear and habitat, as especially estuarine fishes (Mugilidae and *Chanos chanos*) are targeted with gill nets very close to the shore (pers. observation).

Fish sizes

The two methods using lift nets, i.e. bagang and bandung, differed in their average catch sizes. As bandungs operate in deeper water during night compared to bandungs on the reef top and on the beach during the day, latter method is likely to catch juveniles (Nakamura & Sano 2004) ad schooling small pelagics only. Most commonly used mesh sizes in the area are 5 cm (2", stretched mesh) in shallow water and 10 cm (4") in deeper waters. Mesh size is strongly correlated with fishes' body height and length (Hamley 1975, Reis & Pawson 1999) and hence those nets catch fishes of approximately 17 cm and 24 cm length, respectively (Blankenhorn & Asmus submitted-c). Lines are commonly targeting larger predators and hence their average catches' length is the highest of all methods. Maximum sizes of fish caught with nets were highest in mangrove areas, followed by rubble and seagrass areas, off-shore, and over rocks and at the beach in decreasing order. Mangrove areas very much restrict the use of nets and therefore species commonly targeted with nets can grow bigger in those areas. Additionally it is possible, though it was not asked for in the interviews, that big fish are predominantly caught during the night when they enter shallow areas to forage. This would also explain high maximum lengths of fishes caught over rubble and seagrass.

Average and maximum length at site compared to literature data

Fishes caught with bandung were most likely to reach their potential maximum length, as their P_{av} / L_{max} and P_{max} / L_{max} ratio ratios were higher than for all other methods. In contrast, nets selectively caught size-classes witch were, especially in reef areas, well below the potential of the target species. Off-shore, lines proofed to catch relatively old fishes, as their P_{av} / L_{max} ratios were very high.

Many species (59 %) are caught well before their first maturity at P_{av} / L_m and P_{max} / L_m ratios below 0,9. Especially "other methods" (e.g. spearing and catching with bare hands) catch immature fish. In average, species from the habitats "coral" and "rubble" are also caught before maturity.

Assessment of food items, trophic levels, and habitats

Relatively few fishes caught in Puntondo feed on zooplankton, most species have high trophic levels of 3,5 and above. The fishers preferably target large species which, especially if caught with lines, are predators and hence, have high trophic levels. The trophic levels of fish landings in Puntondo do not describe overall fish population trophic structure but are rather an image of fishermen's preferences.

Habitats reported in literature (Froese & Pauly 2000) for the fishes in Puntondo were similar to actual fishing grounds. Differences between the home habitats described in Froese & Pauly (2000) and the actual fishing grounds might be explained by fishing gear preferences on different fishing grounds. If the most effective gear was not used in the home habitat of the species than the fish might have been not reported for the habitat.

Based on habitat descriptions in Froese & Pauly (2000), highest prices should be achieved for fishes from mangrove areas, whereas actual catches from those areas were sold relatively cheap. This means that either high value species are not targeted or catchable in mangroves or that in fact the remaining small mangrove areas in the bay are not large enough to attract and accommodate populations of those species. Only 16,8 % of the fishes in Puntondo depend on vegetated areas as habitat. This number is very close to the findings of Nakamura & Sano (2004) with 15 % of fish species of a reef system to use seagrass areas as juvenile habitat.

Fishes from off-shore and the beach had the lowest trophic levels, i. e. especially planctivores and herbivores were caught there. In contrast, in reef areas ("coral", "rubble") and mangrove mainly predators on higher taxa were caught. Especially with the lift-net methods bagang and bandung which preferably operate in this area, small planctivores are targeted, whereas lines and "other methods" (e. g. spearing) are very selective for larger predators of high trophic level. In the study of McClanahan & Mangi {, 2004 #1910} lines caught also species with the highest trophic levels, but there, spear fishing did not differ from other methods. The fishers in Kenya were not selectively spear-gunning fishes, hence the average trophic level of their catch was relatively low. Therefore it seems that fishers in Puntondo target piscivore species when using spear guns. Abundance decline of fish species was correlated with trophic levels, indicating a substantial fishing pressure in the area (Jennings & Lock 1996, Pauly et al. 1998, Pauly et al. 2002).

Market prices and economical value

Fishes targeted in reef habitats, e. g. the families Haemulidae, Lutjanidae, and Serranidae were amongst the most valued fish species and hence average prices of catches (especially with nets and lines) in those areas was the highest of all habitats. In off-shore and beach habitats a high proportion of low-value or not marketable species (e. g. from the families Leiognathidae and Monacanthidae, pers. observation) contributed to low average fish price. Furthermore, as a large proportion of fishes were caught in reef habitats and/ or with nets, these habitats/ gears had also highest cumulative catch prices. For economical value comparisons between habitats and gears, seasonality (which was included in the equation to calculate species' economical value) this overall picture did not change. Seasonality of fish catches seems to be evenly distributed over all habitats and for all gears, though actual catch compositions might be different.

The most abundant families (Lethrinidae and Lutjanidae) in fishermen's landings also dominated the overall economic importance. Haemulidae were relatively low in abundance but important for local economics, whereas the abundant Serranidae where not among the 10 most valuable families.

Conclusion and recommendation

Fishery landings in the village of Puntondo were dominated by a few fishing methods (nets and lines) and fishing grounds (coral reefs and beaches). Predatory fish species, e. g. from the families Lethrinidae and Lutjanidae, were most important for local economy.

For some fishing methods (i. e. bagang, spear-gunning, and gill nets) and fishing grounds (coral reefs and beaches) there are strong indicators for an unsustainable use of fish resources (Table 2). "Other methods", i. e. spear gunning and catch with bare hand, are economically not important but can severely deplete natural stocks. Therefore, those practices should be stopped. Fishing with nets also seems to over-harvest the population, but is a very effective, cheap and hence economically important method. Nets are not species but size selective and removal and release of small specimens leads to a high mortality (Chopin & Arimoto 1995). Therefore, only larger mesh sizes can increase the low P_{av} / L_{max} and P_{av}/ L_m ratios. For the lift-net methods bandung and especially bagang, those ratios are even lower, but there the fishes are not entangled or under stress for prolonged periods. Release of immature specimens presumably would not increase mortality significantly and is therefore recommended for lift nets. Fishing with lines is the only method yielding catches with a P_{av}/ L_m ratio > 1 and is also economically very important. Provided that coral reefs are not damaged physically by boats, anchors or by trampling on them, this method is therefore recommended above all others.

Catch abundance decreased especially over reefs (habitats "rock" and "coral") and close to the beach. As these are also the preferred fishing grounds (in terms of cumulative fish land-

Table 2. Relative values for fishing methods and habitats compared for relevant economical and sustainability factors. Values corresponding to bar heights in Figures 4, 7, and 8

	economy					sustainability					total
	$\bar{x}$ price	Σ price	$\bar{x}$ econ. value	Σ econ. value	sum	$\bar{x}$ abund. change	Σ abund. change	ratio P_{av}/L_{max}	ratio P_{av}/L_m	sum	
method											
net	0,62	1,00	1,00	1,00	3,62	-0,35	-1,00	-0,68	-0,15	-2,18	1,44
line	0,83	0,52	0,87	0,56	2,78	-0,46	-0,80	-0,50	0,17	-1,60	1,19
bagang	0,47	0,18	0,61	0,14	1,41	-0,35	-0,31	-0,73	-0,23	-1,62	-0,21
bandung	1,00	0,13	0,61	0,12	1,86	0,02	0,02	-0,58	0,00	-0,55	1,31
others	0,52	0,02	0,43	0,01	0,98	-1,00	-0,10	-1,00	-1,00	-3,10	-2,12
habitat											
rocks	0,97	1,00	1,00	1,00	3,97	-0,49	-0,71	-0,84	-0,65	-2,70	1,27
beach	0,74	0,56	0,92	0,52	2,75	-0,74	-1,00	-0,80	-0,52	-3,06	-0,31
coral	0,96	0,44	0,86	0,44	2,70	-1,00	-0,71	-0,95	-1,00	-3,66	-0,96
offshore	1,00	0,36	0,81	0,28	2,45	-0,43	-0,57	-0,55	0,47	-1,08	1,37
seagrass	0,75	0,05	0,31	0,02	1,13	-0,71	-0,09	-0,84	-0,38	-2,02	-0,89
rubble	0,38	0,04	0,16	0,02	0,60	-0,14	-0,06	-1,00	-1,03	-2,23	-1,63
mangrove	0,56	0,04	0,16	0,02	0,79	-0,14	-0,06	-0,86	-0,41	-1,47	-0,68

ings) fishing pressure in those areas should be decreased by either (seasonally) closing them or gear restrictions, e.g. for nets below a critical mesh size. Fishes from other shallow water habitats (i.e. seagrass, rubble, and mangrove) contributed very little to overall fish landings in the village and were mainly sub adults (P_{av}/L_m ratios < 1). Seagrass beds and mangroves are nursery habitats for reef fishes (e.g. Nakamura & Sano 2004, Dorenbosch et al. 2005) and species rather than size selective methods should be used there. Lift nets can be operated both species and size selective and are therefore recommended.

In this study fisheries for squid and crabs (*Portunus pelagicus*, Portunidae) was not evaluated though economically important. Especially crabs have sharply decreased in size and abundance (pers. communication with fishers) and should also be considered when deciding on gear and fishing ground restrictions. Furthermore, since the interviews with the fishers in Puntondo more and more big fish traps have been built on the reef tops. The catch per effort of these devices is high, but they can be operated species and size selectively.

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Chapter 4
Variations in fish stocks and artisanal gill net fishery in an Indonesian seagrass bed

Sven Uli Blankenhorn and Harald Asmus
submitted to Fisheries Management and Ecology

Abstract

Seagrass beds are widely exploited by fishers in an Indonesian village in South Sulawesi, Indonesia, commonly using gill nets. This technique was also used to catch fishes to estimate the seasonality of abundance and species composition, and the influence of gill net fishery on local fish stocks. The results of this study indicate that gill net fishery covers a wide spectrum of species that is dominated by piscivorous fish families. Small mesh sizes were most effective. Seasonal variations were more dominant than diurnal or lunar variations, but year-to-year variation was high.

Keywords

gill nets, artisanal fisheries, fish abundance, community structure, seagrass bed, South Sulawesi, Indonesia

Introduction

Seagrass beds are being discussed as important nursery habitats for reef-associated fishes (reviewed by Pollard 1984, Heck et al. 2003). Pelagic larvae of many valuable reef fishes have been reported to settle in seagrass areas (Bell & Westoby 1986, Kenyon et al. 1999), (Smith & Sinerchiab 2004) and spent their first months there before migrating to the more hostile reef environment (Chittaro et al. 2005, Dorenbosch et al. 2005a, Dorenbosch et al. 2005b, Lugendo et al. 2005). Larger piscivorous and herbivorous fishes are known to leave coral reef areas and enter seagrass beds especially during night (Hindell et al. 2000, Guest et al. 2003), (Weinstein & Heck 1979, Baelde 1990), where they prey upon small and / or juvenile fish and graze the abundant plant biomass, respectively. Additionally, a distinct fish community of resident species, which spend their entire life cycle in seagrass beds can be found (Kikuchi 1966, Hemminga et al. 2000). Ultimately, seagrass areas enrich the reef environment (Chittaro et al. 2005, Dorenbosch et al. 2005a), resulting in higher catches for local fishers (Heck & Orth 1980, Scott et al. 2000, McArthur et al. 2003).

Fish communities in tropical seagrass beds experience natural temporal fluctuations in fish biomass and species composition. Besides daily migrations or lunar spawning and larvae settling events external physical factors like wave action and exposure, salinity, water temperature, and tidal regime (Edgar & Shaw 1995, Moran et al. 2003, Dorenbosch et al. 2004, Unsworth et al. 2006) contribute to temporal patterns of fish density. Those factors also influence the fish community indirectly via modification of biological factors, e.g. seagrass biomass, performance (Erftemeijer & Herman 1994, Stapel et al. 1997, Eldridge et al. 2004, Frankovich & Zieman 2005, Torquemada et al. 2005) and food availability for fish (Edgar & Shaw 1995, Kwak & Klumpp 2004, Rios-Jara 2005, Unsworth et al. 2006). Except the lunar cycle, those environmental parameters are changing with the monsoon seasons, but as the responses of individual organisms (i.e. seagrasses, fishes, and their prey) to the changes vary and interact with each other, a complex temporal mosaic is created (Agawin et al. 2001).

Gill nets are a preferred gear by artisanal fishermen due to their low initial cost and easy maintenance (Kramer et al. 2002). In shallow waters (e.g. in seagrass beds and mangrove areas), the use of other methods like hook and line is less practical and a boat is not necessarily required to set nets. In those areas, nets are the only fishing gear which can be used by virtually everyone. Additionally, gill nets are rather size than species selective and therefore a wide spectrum of species is targeted (reviewed by Hamley 1975, Reis & Pawson 1999). If many nets are set simultaneously by the same fisherman, the catch per unit effort (CPUE) can be expected to be higher than for other low-cost methods (e.g. hook and lines). Gill nets can be left in the water unattended and the "waiting time" may be used for other economic activities, thus decreasing opportunity costs (McManus 1997).

Due to the size selectivity of gill nets the minimum size of the catch can be controlled easily by mesh size restrictions (Hamley 1975). Unfortunately, this is difficult to enforce and control in Indonesia's and other developing countries' artisanal fishery (Mous et al. 2005). In already heavily used areas fishers tend to decrease mesh size and increase their effort, which might lead to Malthusian overfishing (Pauly 1988, Pauly et al. 1989, McManus 1997).

After the monetary crisis in SE Asia in the late 1990's, economic recovery in Indonesia has been slow, especially in more remote areas outside industrial development centres. A steadily increasing population density, shortage of economic opportunities outside the fisheries sector and the open access character of shallow coastal waters are very likely to increase the pressure on shallow water fish resources (Amar et al. 1996, McManus 1997, Kramer et al. 2002, van Oostenbrugge et al. 2004). Unfortunately, very little is known about artisanal fisheries in Indonesian seagrass beds and its influence on fisheries on a larger scale. Therefore, the aim of this study was to investigate the current status of the fish community and its fishery in a seagrass area in South Sulawesi. The focus was rather on the community of targeted fish species than on quantitative sampling of the fish community itself.

Methods

Study site

The study was carried out in the village of Puntondo, District Takalar, South Sulawesi province, Indonesia (5°35,330'S, 119°29,050'E) from May 2003 to May 2005 (Figure 1). The area is characterized by a distinct and prolonged dry season from April to October. The shallow waters (5–15 m) around the peninsula are relatively calm throughout the year; the sediment is muddy in inner parts of the bay and intermixed with corraligenous sediments towards outer areas. Especially during periods with high wind intensity (September to March), the fine sediment is resuspended and the water is turbid. The seagrass bed northwest of the peninsula is dominated by a *Cymodocea serrulata* (R. Br.) Aschers. & Magnus 1870 / *Enhalus acoroides* (L. f.) Royle 1840 / *Thalassia hemprichii* (Ehrenb.) Aschers. (1871) community, occasionally intermixed with *Cymodocea rotundata* Ehrenb. & Hempr. ex Aschers. 1870, *Halodule uninervis* (Forssk.) Aschers. 1882, *Halophila ovata* Gaud (1827), *H. ovalis* (R.Brown) J.D. Hooker 1858, *Syringodium isoetifolium* (Aschers.) Dandy 1939, and *Halophila*

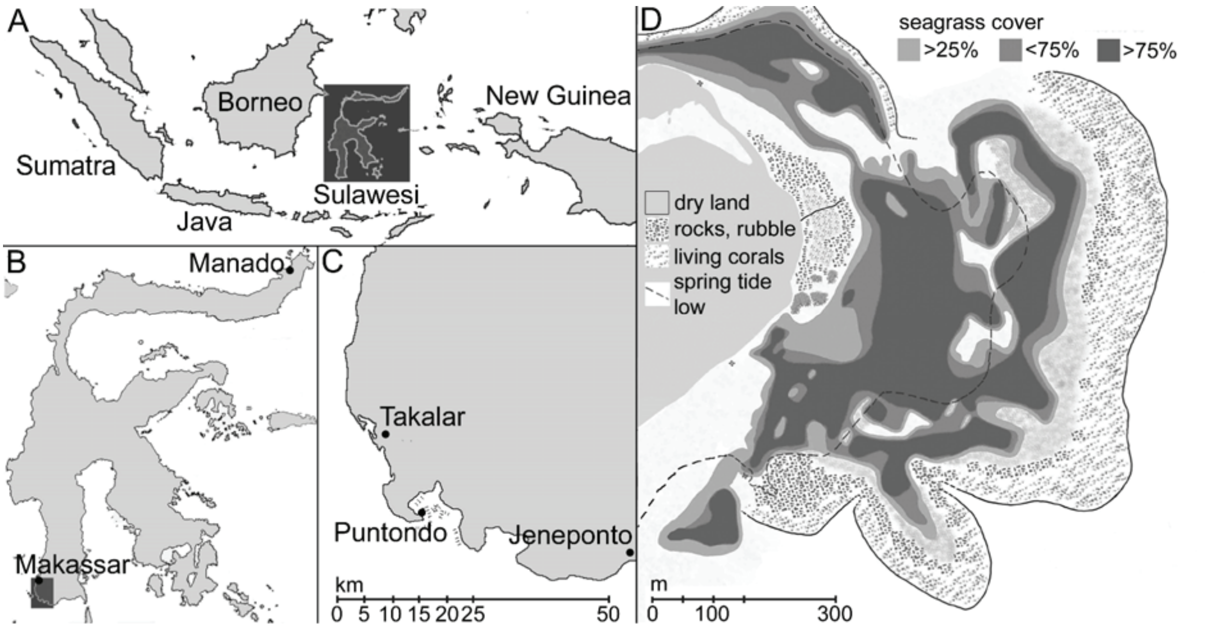

Figure 1. Map of (A) Indonesia, (B) Sulawesi, (C) Takalar and Jeneponto districts, and (D) the seagrass bed off the eastern tip of Puntondo peninsula

spinulosa (R. Brown) Ascherson (Blankenhorn, unpublished data, Schauerte, unpublished data). Due to the tidal regime in the South Sulawesi area, the seagrass beds experience strong seasonal environmental changes, leading to periodical die-off and recovery (Erftemeijer & Herman 1994, Stapel et al. 1997).

The seagrass beds in Puntondo are used for artisanal fisheries (set and drive-in gill-nets, lift nets) and seaweed farming in the sublittoral (Blankenhorn & Asmus submitted-a, submitted-b, submitted-c). Lift nets commonly operate at the borders of the seagrass bed (i.e. directly on the beach line and adjacent to coral areas). Drive-in gill nets are mainly set during day hours, targeting pelagic species of the families Atherinidae and Engraulidae, in water depths less than 1m (pers. observation). For these operations, usually small mesh sizes (1“ ≈ 2,54 cm stretched mesh) were used. Stationary gill nets were mainly set during night hours throughout the seagrass bed and the catch was collected at dawn. Most common mesh sizes for this purpose were 2“ (≈ 5,08 cm) and 4” (≈ 10,16 cm). During the rainy season many nets were set throughout the day very close to the beach (pers. observation) in order to catch milkfish (*Chanos chanos*), which had escaped from fish ponds and mullets (Mugilidae). During the rainy season, in the seagrass bed each night approx. 8–10 nets were set by local fishers. This number was lower during the dry season, when a lower fish abundance was expected (pers. communication with fishers, Blankenhorn & Asmus submitted-a).

Sampling strategy and measured parameters

In accordance to mesh sizes commonly used by local fishers, 1”, 2” and 4” stationary gill nets were set during the study period. In total, 250 1”nets, 380 2” nets, and 390 4” nets were fished. Due to higher maintenance effort for 1” nets their total number was lower than for the other two mesh sizes. The nets were made of monofilamentous nylon; 1” nets were 31,5 m long, 0,75 m high and surface set, i.e. in deeper water the bottom part of the water column remained unfished. 2” (74 m and 54 m long, 0,8 m high) and 4” nets (74 m and 53 m long, 0,8 m high), respectively, were bottom set.

At least twice each month nets were randomly distributed in the seagrass bed during all tidal stages (except very low tide, when the seagrass bed felt dry), different moon phases, and daytimes. The position of a net was fixed with a stake or anchor and stretched perpendicular to the prevailing current in order to prevent excess accumulation of drift material (algae and seagrass litter). The next net (of different mesh size) was attached to the free end of the first net with a spacing of approx. 10 m and this setting was continued until the beach was reached or 6 nets (two of each mesh size) were set in one row. The nets stayed in position for 24 h and were controlled every 3 h during the day and at dawn for catches during the previous night (i.e. 12 h). In some calm nights with relative low water nets were controlled every 3 h also. Mucus and debris (mainly macroalgae and seagrass leaves) were removed and entangled fish were collected. The fish were identified according to Allen (2000) and Froese & Pauly (2000), weighted and total length (TL) and maximum girth were measured. Data on the species' length at maturity (L_m) and their trophic levels were obtained from FishBase (Froese & Pauly 2000).

Statistical analysis

The data were analysed both for mesh size selectivity and variations in catch over different time scales. To detect general trends in mesh size selectivity, cumulative data of total length (TL), maximum girth, trophic level and used mesh sizes for all catches were compared and correlated to each other with a Pearson Product Moment Correlation. After verification of normality and homogeneity of variances of the data, differences between mesh sizes were analysed with one-way ANOVA-procedures followed by Tuckey post-hoc tests.

For ANOVA analysis of catch variation between different times of the day, catches were grouped in 8 classes of 3 h each (beginning at 0–3 am). The lunar cycle was broken up into 8 classes and indices were given ranging from –0,75 (decaying full moon) to + / –1 (full moon, Figure 2). For analysis of seasonal variation, catches were grouped for each month during the two years of the study. Additionally, catches were further aggregated by pooling data for single months from both years. Months in the dry season (May to October) were given a "relative rain index" of 0, months at the start (November) and end (March and April) of the rainy season the index 1, months within the rain season (December to February) the index 2 except for January (index 3), when the peak of annual rainfall occurs in the area. In addition to the factors used to detect differences in general catch characteristics, the individual length of fishes was divided by their L_m, i. e. ratios of $L / L_m < 1$ were indicating immature fishes.

The catch per effort (CPE) of single nets was defined by their catch wet weight per m^2 net and hour spent ($gWWm^{-2}h^{-1}$). Due to the variability in the number of nets set simultaneously by a single fisherman this definition was preferred over the traditional concept of relating catch to boat- or man-hours. In this context, CPE is equivalent to catch abundance and therefore was used (rather than a head count) as the basis for the calculation of average trophic level of individual nets. After verification of the normality of the data and homogeneity of variances, differences between mesh sizes were analysed with one-way ANOVA-procedures followed by Tuckey all Pairwise Comparisons.

Figure 2. Classes of the lunar cycle and corresponding indices

Results

General catch characteristics

42 fish families (89 species) were caught in Puntondo, with the families Sphyraenidae, Lutjanidae, Gerreidae, Nemipteridae, Belonidae and Hemiramphidae being most abundant in terms of biomass (Figure 3). Together, they contributed 51,7 % to overall catch biomass (63.515,5 gWW) and 47,8 % to all caught individuals. By far the most individuals (488 of 2.193) were from the species *Gerres oyena* (Gerreidae).

Most families' average individual weight was below 50 g, the species *Chanos chanos*

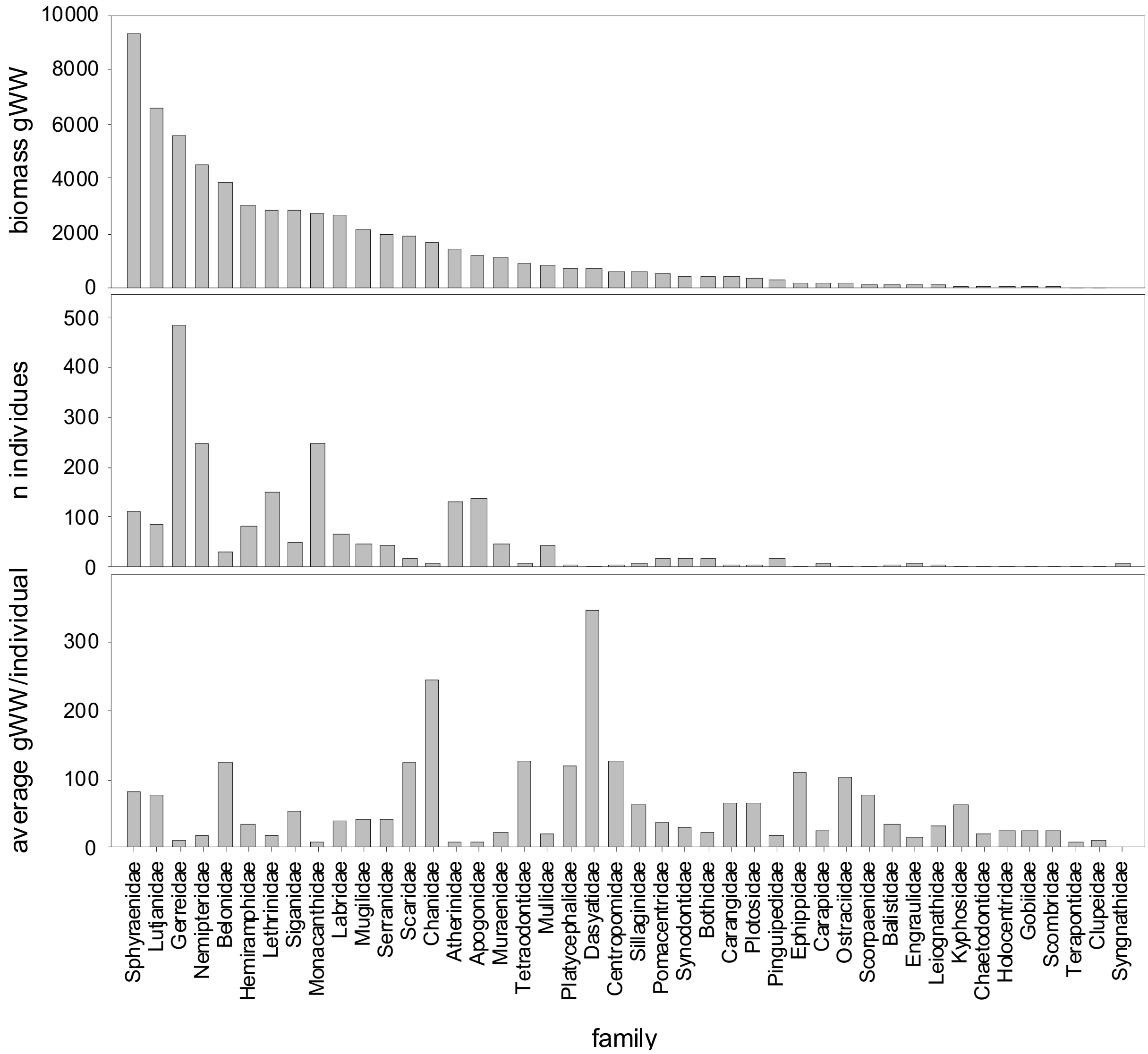

Figure 3. Biomass, number of individuals, and average weight (top to bottom) of fish families caught in the seagrass bed of Puntondo

(Chanidae) and *Taeniura lymna* (Dasyatidae) were exceptionally heavy. 1” nets contributed 51,6 % to overall biomass and 75,6 % to overall head count. 2” and 4” nets caught 40,5 % and 7,9 % biomass, respectively, and 21,6 % and 2,9 % of individuals.

The lowest trophic guild (trophic levels > 2,49; feeding on algae, phytoplankton, seagrass, and detritus) was represented by only 82 individuals (biomass 6.519 gWW, Figure 4). Omnivores (trophic level between 2,5 and 3,49) were high in number (1.137 individuals) but low in biomass (20.510,5 gWW) compared to predators on larger animals (trophic level > 3,5; 962 individuals, 35.847 gWW).

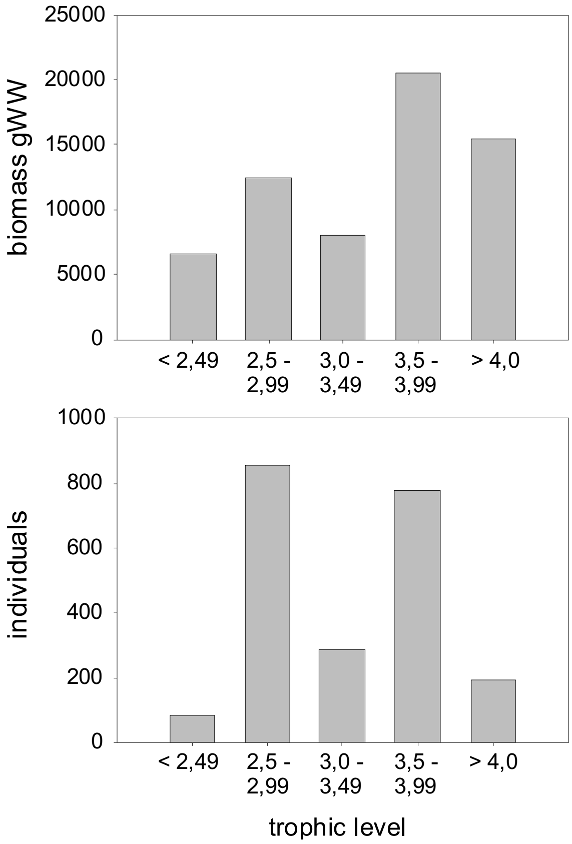

Figure 4. Trophic composition of catches based on biomass (top) and individual numbers (bottom)

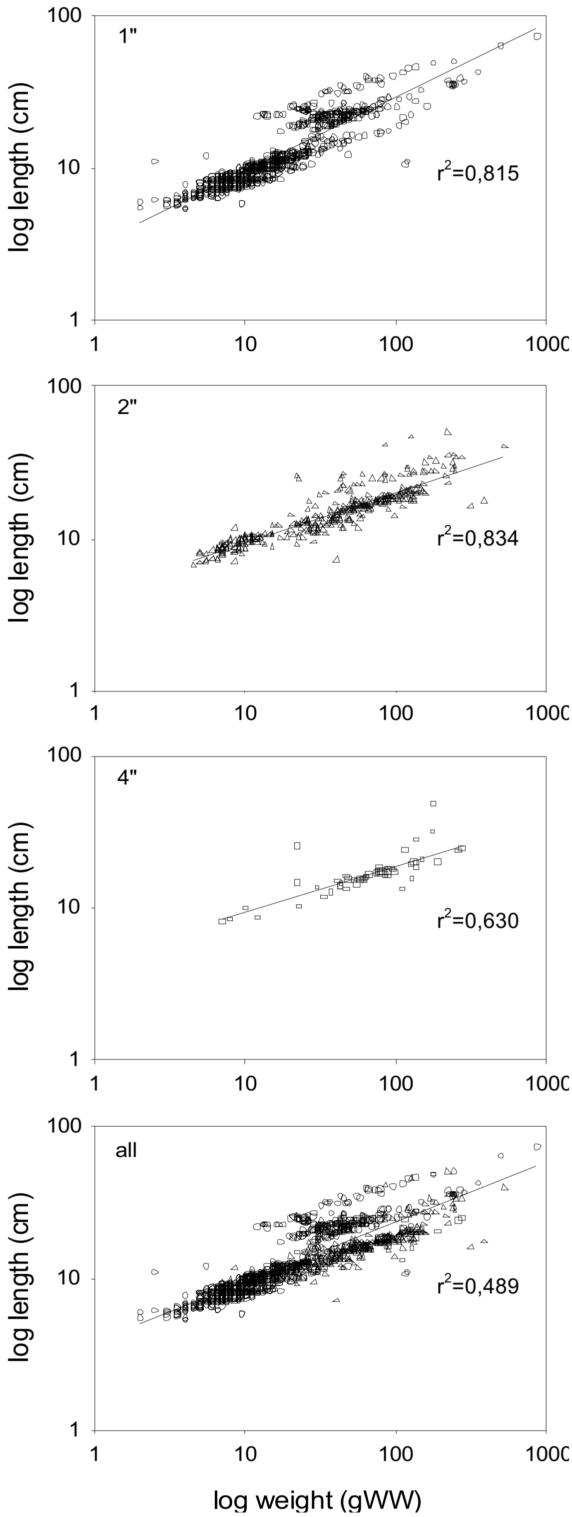

Figure 5. Regressions of log-transformed fish lengths vs. log-transformed fish weights for all mesh sizes

Mesh size was correlated to individual fish length and weight (Person Product Moment Correlation $p < 0,001$, linear regression, Figure 5) and closest with girth ($p < 0,001$, $r = 0,568$). Individual fish length was correlated with weight ($p < 0,001$, $r = 0,750$), girth ($p < 0,001$, $r = 0,311$) and trophic level ($p < 0,001$, $r = 0,441$). Catches from 1” nets differed from this overall pattern as fish length was not closely correlated with girth ($p < 0,001$, $r = 0,184$) but closer with trophic level ($p < 0,001$, $r = 0,508$).

Average length, girth and weight of catches differed between all mesh sizes (ANOVA $p < 0,005$, Figure 6). 4” nets were catching larger fish (length (L): 17,42 ± 5,84 cm, girth (G): 4,73 ± 1,73 cm, weight (W): 80,90 ± 53,12 gWW) than 2” (L: 14,74 ± 6,24 cm, G: 3,76 ± 1,46 cm, W: 54,0 ± 57,47 gWW) and 1” nets (L: 11,95 ± 6,71 cm, G: 2,43 ± 0,52 cm, W: 19,91 ± 36,34 gWW), respectively. Individual ratio of L vs. length at maturity (L_m) did not differ between mesh sizes (ANOVA $p > 0,05$).

Trophic levels of catches with 4” nets (3,434 ± 0,602) were significantly ($p = 0,024$) higher than for catches with 2” nets (3,23 ± 0,66). There was no difference between catches with 1” (3,26 ± 0,56) and 2” nets or between 4” and 1” nets. Catch per effort (CPE) was significantly

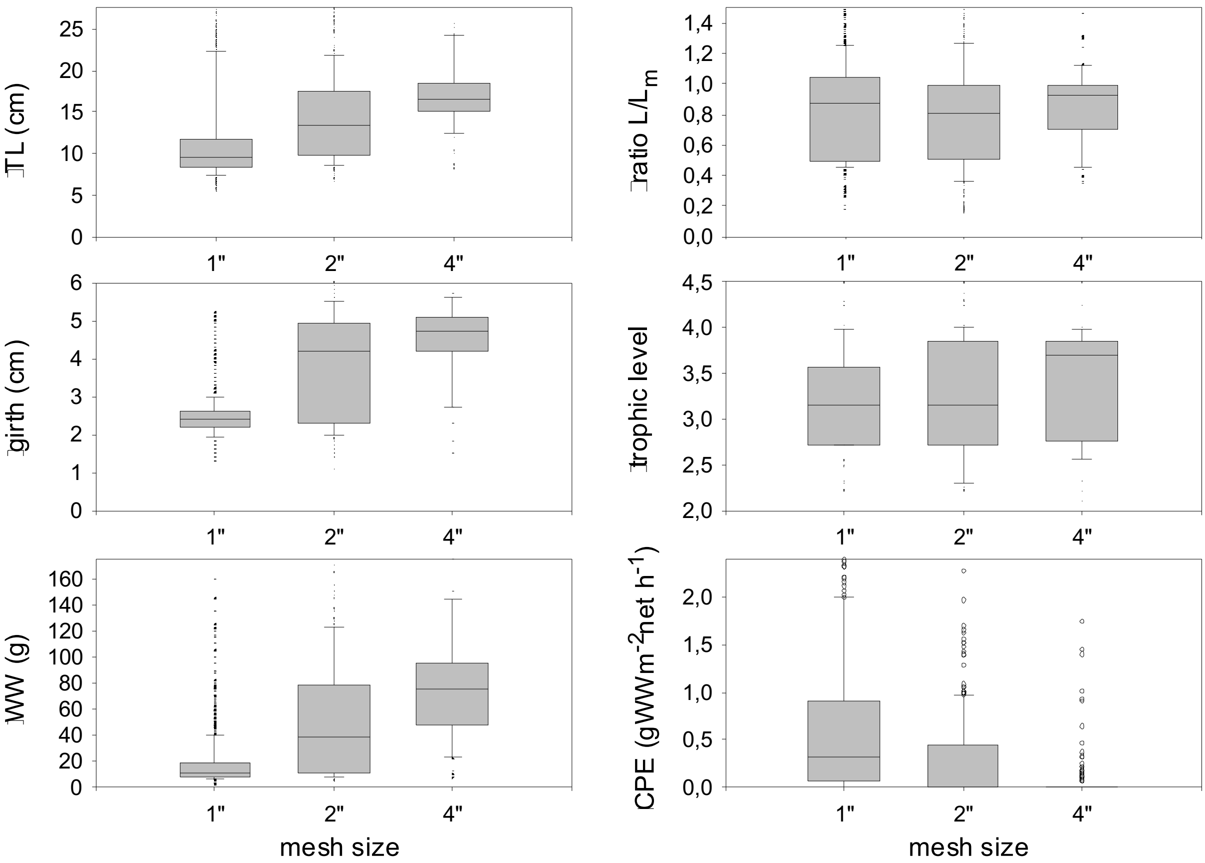

Figure 6. Comparison of catch characteristics for different mesh sizes: average total length (TL), average maximum girth, average biomass (left, top to bottom); average ratio of L / L_m, average trophic level, and average catch per effort (CPE; right, top to bottom)

($p > 0{,}001$) higher for 1” nets (0,77 ± 1,42 gWWm^{-2}h^{-1}) than for 2” (0,306 ± 0,52 gWWm^{-2}h^{-1}), and 4” nets (0,04 ± 0,24 gWWm^{-2}h^{-1}), respectively. 22,4 %, 50,8 %, and 92,6 % of 1”, 2”, and 4” nets, respectively, did not catch any fish.

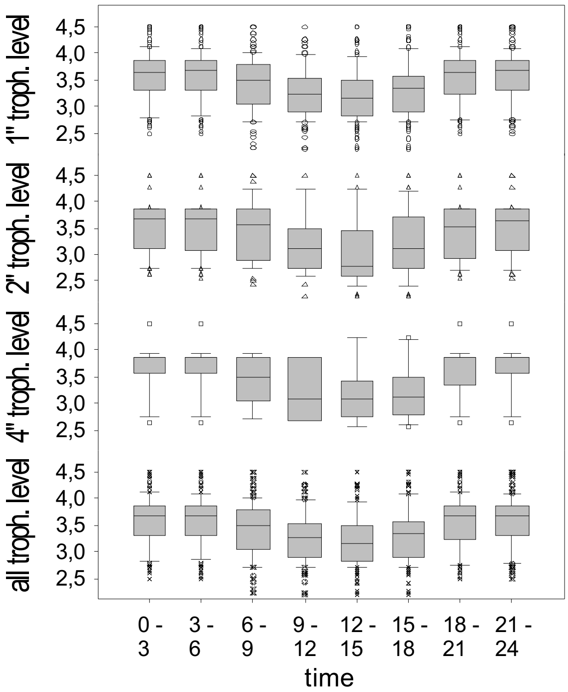

Figure 7. Variations of average trophic levels (based on biomass) for different mesh sizes and overall catch during the day

Diurnal fluctuations

Average relative maturity, indicated by L / L_m of catches, did not change significantly for any mesh size during the day ($p >> 0{,}05$). Average trophic levels of 1” nets were lower during day hours compared to night hours ($p < 0{,}01$, Figure 7).

Catches from 12–15 pm had the lowest average trophic level (3,22 ± 0,49); from 0–3 am the trophic levels were highest (3,59 ± 0,47). Catches with 2” and 4” nets showed a similar periodicity, though the differences between day and night were less distinct due to higher variations. Their average trophic levels were also lowest from 12–15 pm (3,01 ± 0,607 and 3,15 ± 0,509) and highest from 0–3 am (3,51 ± 0,475 and 3,68 ± 0,42, respectively). Variation in cumulative trophic levels for all mesh sizes between its minimum (12–15 pm: 3,22 ± 0,49) and maximum (0–3 am: 3,59 ± 0,47) was very similar to the variation in 1” nets due to the high contribution of these nets.

CPE for 1” nets was lowest from 9–12 am (0,55 ± 0,838gWWm^{-2}h^{-1}) and significantly ($p = 0{,}035$) different from catches from 12–15 pm (1,10 ± 2,03 gWWm^{-2}h^{-1}). For other mesh sizes there were no relevant changes of CPE during the day. Variation of cumulative CPE for all nets was very similar to CPE for 1” nets with the minimum also occurring from 9–12 am (0,27 ± 0,60 gWWm^{-2}h^{-1}) and the maximum at 12–15 pm (0,50 ± 1,34 gWWm^{-2}h^{-1}).

Lunar fluctuations

L / L_m ratio for 1” nets was highest at full moon (index $i = 1$; 0,91 ± 0,26) and the following days ($i = -0{,}75$; 0,91 ± 0,32, Figure 8). The ratios at increasing full moon ($i = 0{,}75$; 0,76 ± 0,23) were lowest and significantly ($p < 0{,}05$) different from the maxima and the levels at increasing half moon (0,91 ± 0,28). For 2” and 4” nets however there were no significant differences in L / L_m ratio for different phases of the moon cycle. Fluctuations of average L / L_m ratio for combined catches from all mesh sizes were similar to those from 1” nets with their minimum and maximum at lunar index 0,75 (0,76 ± 0,23) and −0,75 (0,92 ± 0,32), respectively.

Trophic levels for catches with 1” nets were highest at increasing new moon (3,71 ± 0,55) and significantly different from catches at decreasing full moon (3,24 ± 0,40) when lowest values were measured. For other mesh sizes there were no differences during the moon cycle. For cumulative catches from all mesh sizes there was no significant difference in trophic levels between different moon phases.

CPE for 1” nets was lowest at decreasing full moon (0,34 ± 0,58 $gWWm^{-2}h^{-1}$) and significantly different ($p < 0,005$) from maximum CPE at increasing new moon (1,77 ± 4,01 $gWWm^{-2}h^{-1}$). For 2” and 4” nets there were no differences of CPE during the moon cycle. However, analysis of combined data for all mesh sizes revealed that catch abundance was significantly ($p < 0,05$) lower for all stages of decreasing full moon than for catches immediately after new moon.

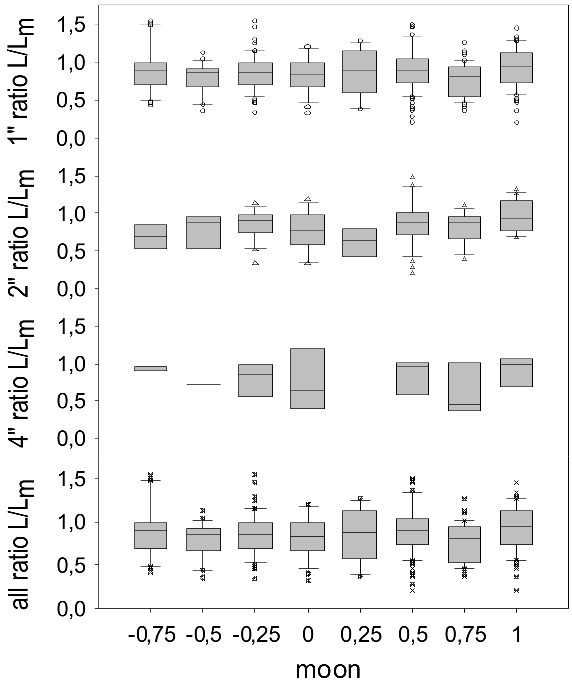

Figure 8. Variations of average L / L_m for different mesh sizes and overall catch during a lunar cycle

Seasonal fluctuations

For 1” nets, variation in monthly L / L_m ratio (Figure 9) was not significant ($p > 0,05$). However, for pooled data from two years, L / L_m ratio of catches during April was highest (1,06 ± 0,37) and statistically different ($p < 0,05$) from January (minimum values, 0,72 ± 0,21), February (0,78 ± 0,23), June (0,85 ± 0,24), and September (0,92 ± 0,25). There was a difference for the comparison of October (0,97 ± 0,28) to January, also. In terms of relative rainfall, catches during the peak of the rainy season (0,72 ± 0,21) differed from those during the dry season (0,94 ± 0,31) and the transition months (0,89 ± 0,25). For 2” nets, there were no differences detectable for single months, also. Pooled monthly data revealed a difference in L / L_m for catches during September (maximum values, 1,15 ± 0,32) and during November (0,69 ± 0,28) and December (minimum values, 0,67 ± 0,31), respectively. Those differences however disappeared after pooling into classes of relative amount of rainfall. For 4” nets there were no significant changes between months detectable in all degrees of pooling.

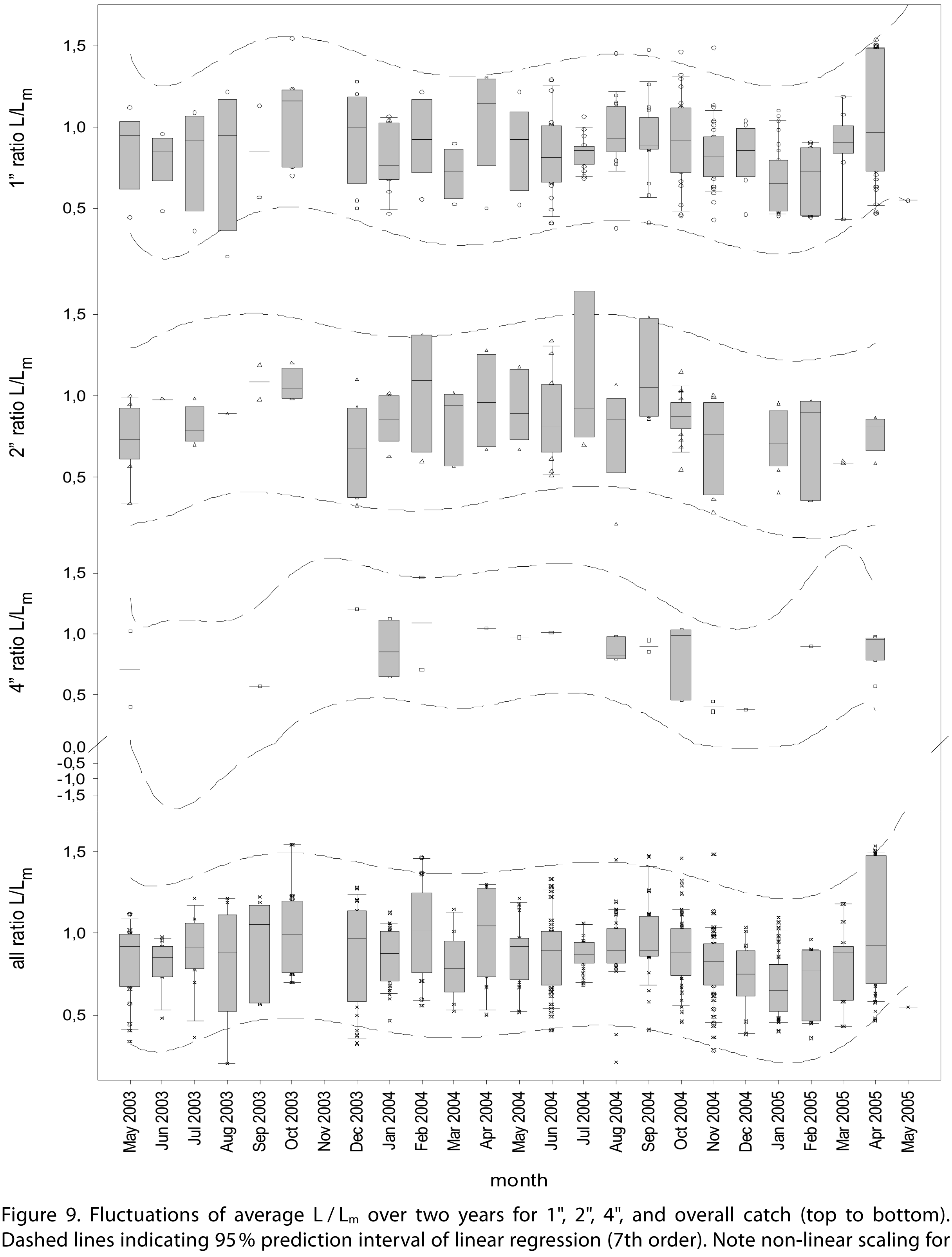

Figure 9. Fluctuations of average L / L_m over two years for 1", 2", 4", and overall catch (top to bottom). Dashed lines indicating 95 % prediction interval of linear regression (7th order). Note non-linear scaling for 4" nets

Cumulative catches from all nets had their maximum L / L_m ratio in April (1,01 ± 0,35). This month differed from January (minimum values, 0,74 ± 0,21), March, November, and December. During the peak of the rainy season catches were significantly more immature (0,74 ± 0,21) than for any other time of the year, i.e. dry season (0,90 ± 0,24), transition months (0,89 ± 0,31), and rainy season (0,85 ± 0,29).

Variation of trophic levels of catches from 1” and 2” nets was not significant. For 4” nets, trophic levels were highest during November (3,95 ± 0,59) and different from May (2,97 ± 0,45) and December (minimum values, 2,90 ± 0,59), respectively. During the rainy season (excluding its peak) trophic levels were lower (3,01 ± 0,58) than during transition months (3,60 ± 0,56). For cumulative catches from all mesh sizes there were no seasonal differences in trophic levels for all degrees of pooling.

CPE of 1” nets (Figure 10) did not change significantly over the year when data were pooled for single months. However, for pooling in relative rain classes, during the peak of the rainy season CPE was considerably higher (1,34 ± 1,17 $gWWm^{-2}h^{-1}$) than during transition months (0,52 ± 0,70 $gWWm^{-2}h^{-1}$). CPE for 2” nets was highly variable during the study period, ranging from minima of 0 and 0,04 ± 0,09 $gWWm^{-2}h^{-1}$ in December 2004 and March 2005, respectively, to maxima in May 2003 (1,13 ± 1,14 $gWWm^{-2}h^{-1}$) and February 2004 (0,84 ± 0,82 $gWWm^{-2}h^{-1}$). For 4” nets, there were no statistical differences in CPE between months due to high variation within data pools.

Pooled data for monthly catches from all years revealed a maximum of catch abundance during May (0,86 ± 0,95 $gWWm^{-2}h^{-1}$) which was significantly higher than catches during March, April (minimum values, 0,12 ± 0,23 $gWWm^{-2}h^{-1}$), June, July, and November. During the rainy season (except for its peak) CPE was higher (0,50 ± 0,67 $gWWm^{-2}h^{-1}$) than during the transition months (0,16 ± 0,35 $gWWm^{-2}h^{-1}$). Cumulative catch per effort for all mesh sizes was considerably higher during the peak of the rainy season (0,51 ± 0,92 $gWWm^{-2}h^{-1}$) compared to its minimum during transition months (0,24 ± 0,51 $gWWm^{-2}h^{-1}$).

Variation of trophic levels of catches from 1” and 2” nets was not significant. For 4” nets, trophic levels were highest during November (3,95 ± 0,59) and different from May (2,97 ± 0,45) and December (minimum values, 2,90 ± 0,59), respectively. During the rainy season (excluding its peak) trophic levels were lower (3,01 ± 0,58) than during transition months (3,60 ± 0,56). For cumulative catches from all mesh sizes there were no seasonal differences in trophic levels for all degrees of pooling.

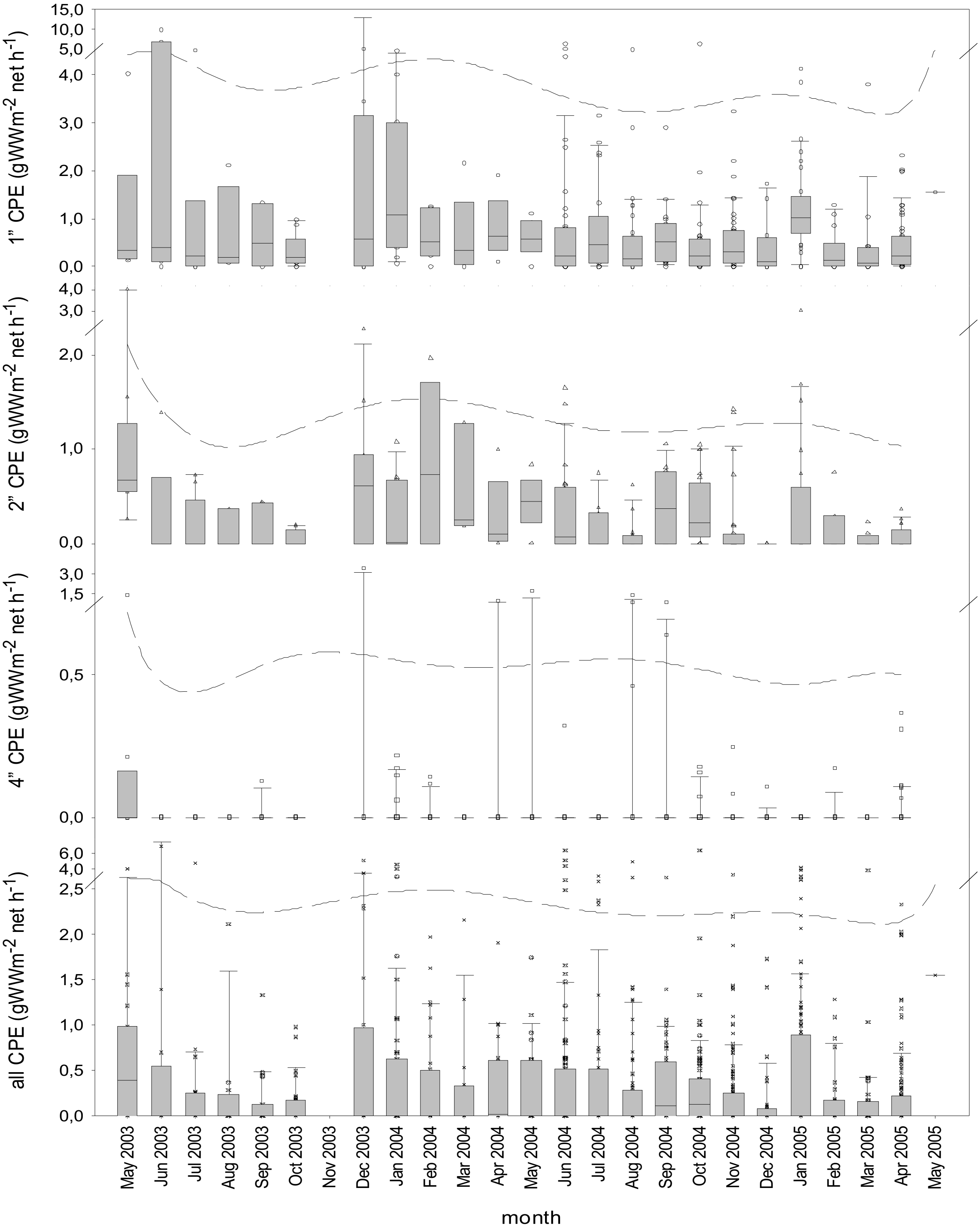

Figure 10. Fluctuations of average catch per effort (CPE) over two years for 1", 2", 4", and overall catch (top to bottom). Dashed lines indicating 95% prediction interval of linear regression (7th order). Note non-linear and different scaling for different mesh sizes

Discussion

General catch characteristics

The number of fish species (89) found in the area is comparable to the number found by Unsworth et al. (2006), but still low compared to other findings (Campos et al. 1994, Amar et al. 1996, Gell & Whittington 2002). However, the number of families (42) was similar to these studies. The number of fishes reported for a given area strongly depends on the sampling method and effort allocated to it, i.e. the time frame of the study. In the studies reporting high species numbers, fish samples were collected from fishermen who were using several different gears, including highly effective (Gilmore et al. 1990) beach seines which also catch smaller individuals than other methods (McClanahan & Mangi 2004). Unsworth et al. (2006) also used beach seines, but within a relatively short timeframe of only two months in the dry season. Most probably, repeated sampling during the wet season would have increased their number of species significantly. Compared to seines, gill nets are less effective and more selective in sampling fish communities. Fishes smaller than approx. 8 cm were not caught with the smallest mesh size in this study, and the abundant families Apogonidae, Blenniidae and Gobiidae (Blankenhorn, unpublished data) were underrepresented in the catches (also see Unsworth et al. 2006). If these unpublished data were taken into account, a total of 158 species (54 families) could be reported for the seagrass beds of Puntondo.

Gell & Whittington (2002) found that a few fish families (Lethrinidae, Siganidae, and Scaridae) were contributing a high percentage to overall fish numbers and biomass. However, in this study these families were not very important whereas piscivorous species, especially from the families Belonidae, Hemiramphidae, and Sphyraenidae contributed significantly to catch biomass and trophic structure. Gell & Whittington (2002) did not sample during the night, and in their study herbivorous and residential species might be overrepresented due the generally low abundance of pisci- and invertivores during the day (Weinstein & Heck 1979, Baelde 1990, Hindell et al. 2000, Guest et al. 2003, Unsworth et al. 2006).

Herbivores, especially Siganidae (e.g. *Siganus canaliculatus*) had a low abundance in Puntondo which was unexpected (see Tomascik et al. 1997, Salita et al. 2003, Kochzius, pers. communication). Not only were larger individuals rare in Puntondo, but also were schools of juveniles (Blankenhorn, unpublished data) which were a regular sight in seagrass beds in the close-by Spermonde archipelago (Asmus et al, unpublished data). Unsworth et al. (2006) also found Siganidae with comparatively low abundance and discussed this in context with distance from mangroves and a general low epiphyte density on seagrass leaves in their area. In the Islands of the Spermonde archipelago however, there are no mangroves and the water is meso- to oligotroph, whereas in Puntondo some mangroves are left close to seagrass beds and epiphytes were generally abundant. Siganidae are prone to be entangled in gill nets with their spiny fins, and though *S. canaliculatus* is not particularly sought after (pers. communication with villagers); frequent fishing with gill nets in seagrass obviously has reduced its population. On the islands of the Spermonde archipelago, shallow waters are left nearly unfished and at least juveniles can still be found there.

The differences in length, girth, and weight were significantly different between all mesh sizes), which could be expected (Hamley 1975). Length and girth were correlated for all mesh sizes). With 1" nets however, many long but slender species of the families Belonidae, Hemiramphidae, and Sphyraenidae were caught, often entangled with their teeth. Their contribution caused the length vs. girth regression results for 1" nets to be less evident, but in general, individual fish length was correlated with trophic level. Analysis of differences in trophic levels between mesh sizes was based on catch biomass; hence the high abundance of the families mentioned above resulted in a relative high average trophic level for 1" nets. As mesh sizes were shown to catch specific fish sizes, they therefore were catching a different spectrum of species, also. This is supported by the finding that L / L_m ratio) was not different between the used mesh sizes, indicating that different fishes rather than size cohorts of the same species were caught.

Considering very high and low catch abundance with 1" and 4" nets, respectively, it can be concluded that the fish fauna in the seagrass bed of this study site is dominated by a) a few very abundant, small omnivorous fish families and b) predatory families with slender species. Blaber et al. (2005) and Morton (1990) suggested that habitats with high densities of piscivores could not be referred to as nursery habitats, because of a high natural mortality due to predation. The latter one was not examined in this study, and therefore the high abundance of predators (especially from the families Sphyraenidae and Belonidae) can not be evaluated as an indicator of the limited nursery value of the seagrass bed of this study. To what extend they themselves use the seagrass bed as spawning area was not part of this study.

Diurnal fluctuations

From catches with gill nets in this study it could not be concluded that there were diurnal migrations of juvenile or adult fishes to or out of the seagrass bed, as L / L_m ratio was constant over the day. Trophic levels changed periodically over 24 h and were significantly higher for all mesh sizes during the night as described by Unsworth et al. (2006) Catch per effort (CPE) for 1" nets had its minimum and maximum, respectively, following each other immediately around noon when average trophic levels were low. Though gill nets are a passive gear, they only catch active fish. Locomotoric inactive species therefore are underrepresented and very active, i. e. long-range swimming species are overrepresented in the catches. Additionally, it is very probably that (active) fishes are more aware of the net during the day, especially if some mucus has accumulated on the meshes, turning them greenish. Therefore it is unclear to what extend an most certainly existing variation in trophic levels and CPE was masked by changing efficiency of the nets during the day (see Weinstein & Heck 1979, Baelde 1990, Hindell et al. 2000, Guest et al. 2003).

Lunar fluctuations

Differences of catch characteristics for different mesh sizes were most evident for 1” nets. Cumulative catches from all mesh sizes were dominated by this highly effective small mesh size, and hence, their variation was principally the same as for 1” nets. Here, maximum and minimum values of trophic level and CPE occurred during the days following new moon (index 0,25) and full moon (index –0,75), respectively, indicating that predators were less dominant in the days after full moon. This is supported by the finding that L / L_m ratio was highest during the same time: A shortage of juveniles of large-growing predators, especially from the families Belonidae and Sphyraenidae, raised the average L / L_m ratio due to the higher relative abundance of adults of small-growing omnivorous species. However, the days with the minimum of L / L_m (just before full moon) did not coincide with the maximum values of trophic level and CPE (after new moon). As small juveniles were not sampled (see above), it is not possible to conclude that there were spawning and larvae settling events around new moon (see Hoque et al. 1999), which attracted predators in the days thereafter.

Seasonal fluctuations

The comparison of L / L_m ratio between single months did not yield significant or coherent results, however, pooling of data (monthly and in respect to rainfall) revealed differences. This indicates a high year-to-year variation between corresponding months. In general, the smallest individuals (in terms of L / L_m) were caught in the rainy season, during December and January, respectively. This coincided with the highest average CPE during the wet months, when fishers also put the highest effort into fishing operations (pers. communication with fishers, Blankenhorn & Asmus submitted-a)

In Australia, Kwak & Klumpp (2004) found fish abundance changes to be closely positively related to seagrass seasonality. In the Philippines, Amar et al. (1996) reported highest CPE during the rainy season when seagrass abundance was also highest (Agawin et al. 2001).In Puntondo however, seagrass shoot density (and hence biomass) was generally higher during the dry season (Blankenhorn & Asmus submitted-b) whereas fish abundance was highest during the wet months. Edgar & Shaw (1995) documented that high wave exposure leads to lower fish biomass in seagrass beds, which, according to Moran et al. (2003), is due to lower abundance of common species. In southern South Sulawesi, wind speed is generally high throughout the year and in Puntondo, corresponding wave action is at a maximum during the peak of the rainy season (pers. observation). However, this did not result in decreased fish abundance and hence, the cyclic factors “seagrass performance” and “wave action” seem less important than e. g. variations in water salinity and temperature.

Changing wind direction and, in consequence, wave action and current during transition months (March / April and November, respectively) caused large amounts of algae and seagrass leaves being drifted away from formerly calm areas. This material got entangled in the nets and very probably led to a lower CPE, as fishes were more likely to avoid the meshes.

Conclusion

Gulland (1983) stated that CPE can be compared between sites or seasons only if the catchability is comparable, i.e. the differences of CPE between daytimes and months in this study do not necessarily reflect differences in total fish abundance. During day hours and during times with a high load of drifting material in the water nets are more visible for fishes and hence less effective.

Local fishers prefer to set nets during the night and usually avoid the use of gill nets in the seagrass bed during the transition months (pers. communication with fishers), as low catches do not justify the high effort to clean and repair the nets. Though 1" nets were very effective, the catch was sold relatively cheap on the markets (Blankenhorn & Asmus submitted-a) and the repair of the nets was very time consuming. Therefore, fishermen in Puntondo preferred 2" nets, which in their perception were most efficient in seagrass beds.

For management purposes, the results of this study do not support the general rejection of small mesh sizes or the closure of fisheries during certain times of the year. In general, species of high value are under fishing pressure in the bay (Blankenhorn & Asmus submitted-a) and the management of seagrass fisheries should be based on their ecology. Further studies are necessary to evaluate the importance of seagrass beds as nursery and feeding habitat for those species.

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