Mangrove forest decline: consequences for livelihoods and environment in South Sulawesi

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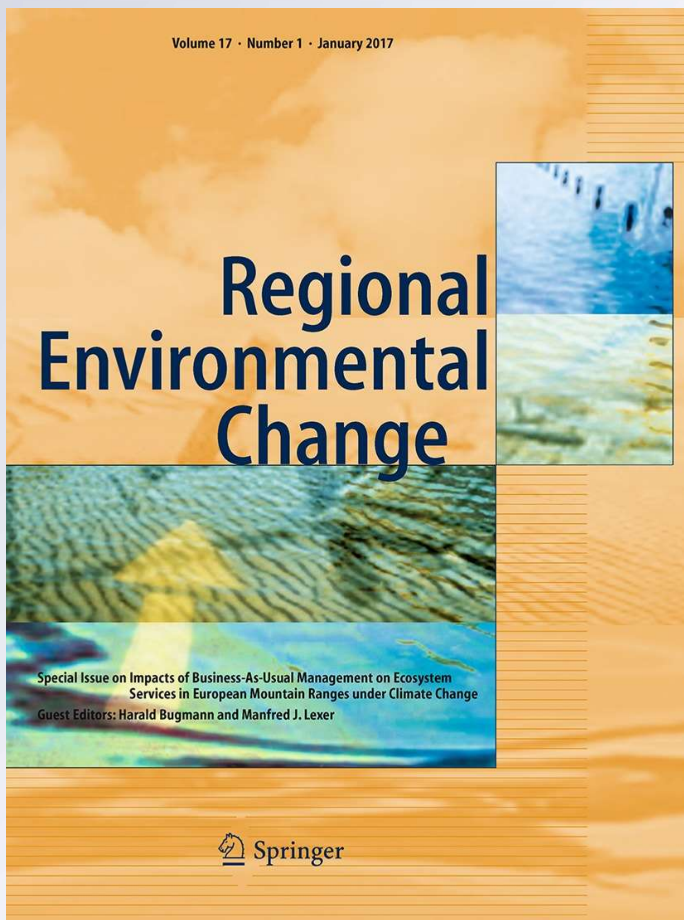

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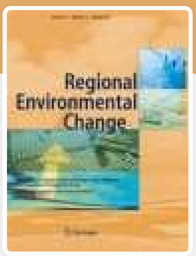

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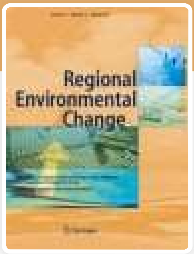

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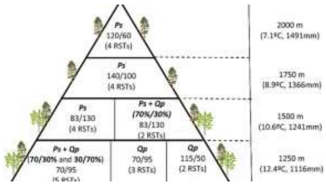

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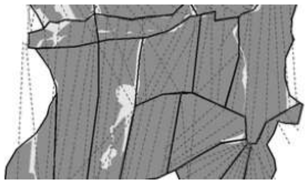

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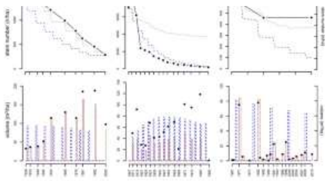

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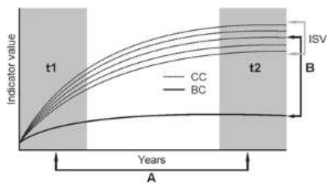

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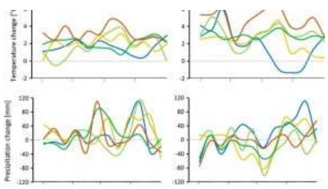

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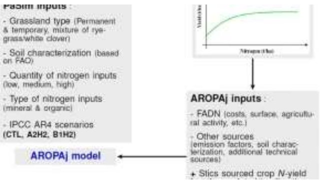

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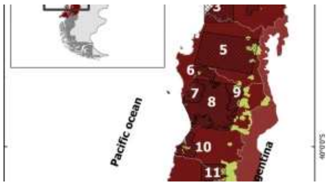

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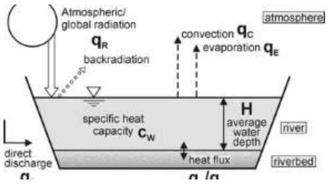

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ORIGINAL ARTICLE

Mangrove forest decline: consequences for livelihoods and environment in South Sulawesi

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Abstract Mangrove forests in the tropics and subtropics grow in saline sediments in coastal and estuarine environments. Preservation of mangrove forests is important for many reasons, including the prevention of coastal erosion and seawater intrusion; the provision of spawning, nursery, and feeding grounds of diverse marine biota; and for direct use (such as firewood, charcoal, and construction material)—all of which benefit the sustainability of local communities. However, for many mangrove areas of the world, unsustainable resource utilization and the profit orientation of communities have often led to rapid and severe mangrove loss with serious consequences. The mangrove forests of the Takalar District, South Sulawesi, are studied here as a case area that has suffered from degradation and declining spatial extent during recent decades. On the basis of a post-classification comparison of change detection from satellite imagery and a survey of households, we provide an estimate of the mangrove change in the Takalar District during 1979–2011 and the consequences of those changes. Mangrove forest areas were reduced by 66.05 % (3344 hectares) during the 33-year period of analysis, and the biggest annual negative change in dense mangrove forest cover (8.37 %) occurred during the period 2006–2011. The changes were caused mainly by the mangrove clearing and conversion to aquaculture, and consequences have been increasing forest degradation, coastal abrasion, seawater intrusion, a decline in fish capture, a reduction in juvenile shrimp and milkfish, and outbreaks of shrimp disease. On the other hand, the clearing and impoundment of mangrove forests for shrimp and seaweed culture have provided a source of foreign exchange and new opportunities for employment in the study area.

Keywords Mangrove forest · Forest degradation · Livelihoods · Remote sensing

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Introduction

Mangrove forests are found in tropical and subtropical climates, along the coast and river estuaries affected by tides. Mangrove forests are essential for protecting coastal areas from wave impact (Dahuri 2003), and their functions can be characterized in physical, biological, and economic terms. Physical functions include prevention of coastal erosion and seawater intrusion and the retention of sediments and nutrients, whereas biological functions include the ability to stabilize or balance the ecosystem by being the source of nutrients and acting as the nursery, feeding, and spawning grounds for fish, crabs, and shrimps. Mangrove forests have economic relevance for agriculture, tourism, fisheries, and timber resources and produce basic materials for household and industrial purposes, such as firewood, charcoal, and paper, of high commercial value for local communities (Giesen et al. 2007; Ghufran 2012).

Almost half of the total mangrove forest cover in the world has disappeared since 1980 (Millennium Ecosystem Assessment 2005) due to an increase in commercial logging, fuel wood collection, charcoal production, mining, conversion to agriculture (mainly rice paddies and coconut), housing, and aquaculture ponds (Giesen et al. 2007). However, the conversion of mangrove areas to shrimp ponds has been the most important development (Murdiyarso et al. 2015). The loss rate of mangrove forests is reported to be 1–2 % per year (Duke et al. 2007), and according to available data from FAO (2007), 3.6 million hectares of mangrove forest disappeared during 1980–2005, with Asia being the region with the largest loss (more than 1.9 million hectares since 1980). In the Philippines, the total mangrove cover was around 256,185 hectares in 2000, which is roughly a 50 % decrease from an estimate of 500,000 hectares in 1918 (Long and Giri 2011). In Southern Thailand, about 50 % of the total mangrove area has been converted to shrimp aquaculture and other forms of coastal development during 1975–2005 with less than 10 % left on the east coast (Thampanya et al. 2006). In the Mui Cau Mau, Vietnam, mangrove forests have decreased drastically from 71,345 hectares to 33,083 hectares during the period 1953–1992, but in 2011, an increase to 46,712 hectares was reported due to replanting as part of integrated mangrove–aquaculture system (Van et al. 2015).

The degradation and decline of mangrove areas have many potential environmental and socioeconomic consequences for coastal communities. The conservation of mangrove forests, which are among the most carbon-rich forests in the tropics, could contribute to climate change mitigation through programs such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation; Murdiyarso et al. 2010). Yet, deforestation of mangrove has been estimated to lead to massive carbon stock emissions (0.08–0.48 PgC per year; Donato et al. 2011). Moreover, the conversion of mangrove forests to aquaculture ponds has caused a decrease in nursery habitat of marine shrimp (*Penaeus* sp.), mud crabs (*Skylla* sp.), and other shellfish and fish species that spawn in coastal and offshore waters (Phan and Quan 2004). The aquaculture (e.g., shrimp farming) itself also causes environmental problems due to uncontrolled use of chemical fertilizers and pesticides and has in many places been unsustainable due to water pollution and disease outbreaks (Phan and Quan 2004). However, the expansion of aquaculture has also had positive consequences for food security and the provision of labor. In 2008, the combination of capture fisheries and aquaculture supplied 142 million tons of fish, of which 115 million tons was used for human food (FAO 2011). Fisheries and aquaculture also contributed to improving household livelihoods (Valderrama et al. 2010) and increased national income due to shrimp export providing foreign exchange (Bailey 1988).

Indonesia has the most extensive mangrove forests in the world, but they were reduced from 4.25 million hectares in 1980 to 3.16 million hectares in 2003, (Table 1; FAO 2007; Noor et al. 2006) with an annual deforestation rate of 1.24 % between 1980 and 2005 (Murdiyarso et al. 2015).

There are multiple pressures on mangrove areas including the collection of firewood, housing material, charcoal production, and material for handicrafts as well as conversion to aquaculture, agriculture, and settlement (Noor et al. 2006). However, the main factor behind the deforestation and degradation of mangrove in Borneo, Sumatra, Java, and Sulawesi is conversion to shrimp farming (Sidik 2008; Onrizal 2010; Suryono 2006; Nurkin 1994), as is also the case in other Asian countries (Barbier and Cox 2002).

Noor et al. (2006) show that aquaculture expansion led to deforestation of about 481,000 hectares of mangrove between 1991 and 2003 (Table 1). Furthermore, Onrizal (2010) reported a loss of mangroves of about 61,715 hectares during the period 1977–2006, which caused a decrease in fish species in North Sumatra. Sidik (2008) stated that 63 % of the mangrove in Mahakam Delta, East Kalimantan, had disappeared by 2001 and the peak degradation was found to occur during the period 1996–2000. In Segara Anakan, Central Java, the largest mangrove area in Java, mangroves have decreased from 35,000 hectares in 1930 to 12,000 hectares in 1996, causing a decrease in species diversity and changes in the distribution pattern of mangroves (Suryono 2006). In South Sulawesi, mangroves covered an area of approximately 110,000 hectares in the early 1950s (Giesen et al. 1991), whereas by 2003, about 75 % of the mangrove was lost, leaving only 27,000 hectares (Table 1), of which most areas were affected by the expansion of aquaculture (Noor et al. 2006). Tangko and Pantjara (2007) reported that areas with shrimp ponds in South Sulawesi had increased dramatically during the period from 1990 to 2005 (by 25,295 hectares), mainly at the expense of mangrove forests.

Exact and updated information on the density and spatial distribution pattern of mangrove forests and the consequences of decades of deforestation are, so far, poorly documented. The data provided by FAO (2007), which related to changes up to the year 2005, are still being used as a reference for the current status, which complicates decision making on the management and conservation of mangrove forests.

Timely and accurate inventory and monitoring of mangrove forests are necessary for decision making. Remote sensing technologies enable quick, inexpensive, and accurate land cover mapping, monitoring, and change detection. In some countries, remote sensing for inventory, change detection, and management of mangrove forest has been

Table 1 Mangrove change and areas converted to aquaculture by province in Indonesia

Province	Mangrove change (ha)			Area converted to aquaculture (ha)		
	1982	2003	Change	1991	2003	Change
Nanggroe Aceh Darussalam	54,335	18,000	−36,335	39,476	73,000	+33,524
North Sumatera	60,000	25,000	−35,000	1826	34,000	+32,174
West Sumatera	0	17,000	+17,000	0	0	0
Riau	276,000	235,000	−41,000	192	3	−189
Jambi	65,000	5,000	−60,000	40	2000	+1960
South Sumatera	195,000	128,000	−67,000	325	58,000	+57,675
Bangka Belitung	0	63,000	+63,000	0	1000	+1000
Bengkulu	0	2000	−2000	94	0	−94
Lampung	17,000	0	−17,000	2939	34,000	+31,061
West Java and Jakarta	28,608	2000	−26,608	50,330	4000	−46,330
Banten	0	3000	+3000	0	15,000	+15,000
Middle Java and Yogyakarta	13,577	9000	−4577	30,497	53,000	+22,503
East Java	7750	26,000	+18,250	47,913	91,000	+43,087
Bali	1950	3000	+1050	626	0	−626
West Nusa Tenggara	3678	13,000	+9322	4996	13,000	+8004
East Nusa Tenggara	1830	19,000	+17,170	550	1000	+450
West Kalimantan	40,000	137,000	+97,000	32	5000	+4968
Middle Kalimantan	10,000	38,000	+28,000	0	2000	+2000
South Kalimantan	66,650	99,000	+32,350	1405	19,000	+17,595
East Kalimantan	266,800	367,000	+100,200	6107	208,000	+201,893
Middle Sulawesi	0	44,000	+44,000	861	8,000	+7139
Southeast Sulawesi	29,000	64,000	+35,000	6636	16,000	+9364
North Sulawesi	4833	12,000	+7167	590	0	−590
Gorontalo	0	15,000	+15,000	0	3000	+3000
South Sulawesi	66,000	27,000	−39,000	73,088	109,000	+35,912
Maluku	100,000	128,000	+28,000	65	1000	+935
North Maluku	0	42,000	+42,000	0	0	0
Papua	2,943,000	1,622,000	−1321,000	95	0	−95
Total	4,251,011	3,163,000	−1088,011	268,683	750,003	+481,320

conducted using images from Landsat and SPOT and very high spatial resolution multispectral and SIR-C radar data (Wang et al. 2003). Timely, accurate socioeconomic data, on the other hand, are needed to assess the consequences of these uses on individual households and communities.

The objective of this paper is to characterize the areal extent and socioeconomic consequences of mangrove forest losses in Sulawesi during the 33-year period, 1979–2011. The Takalar District in South Sulawesi is used as a case study for highlighting changes that are occurring in many parts of Indonesia and elsewhere in Southeast Asia.

Study area

Takalar District is located in the southern part of South Sulawesi Province (between latitude 5°12′–5°38′ and longitude 119°10′–119°39′, see Fig. 1). The district covers 566.51 km^2, divided into nine sub-districts (Galesong, South Galesong, North Galesong, Mangarabombang, Mappakasunggu, Pattallassang, South Polombangkeng, North Polombangkeng, and Sanrobone). Mappakasunggu consists of a mainland part and some small islands (Tanakeke, Lantangpeo, Bauluang, Satangnga and Dayang dayangan; BPS-Kab. Takalar 2012).

The district has a coastline of about ±74 km (Ukkas 2001) and several rivers (Cikoang in Mangarabombang, Pappa in Pattallassang, Biringkassi in Sanrobone, Sabala in South Galesong, Saro and Galesong in Galesong, and Beba in North Galesong). The population is 272,316, and the population density is 481 people per km^2 (BPS-Kab. Takalar 2012).

Mangrove forests in this area primarily consist of 10 species (*Avicennia alba*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Excoecaria agallocha*, *Lumnitzera racemosa*, *Nypa fruticans*, *Rhizophora apiculata*, *Rhizophora mucronata*,

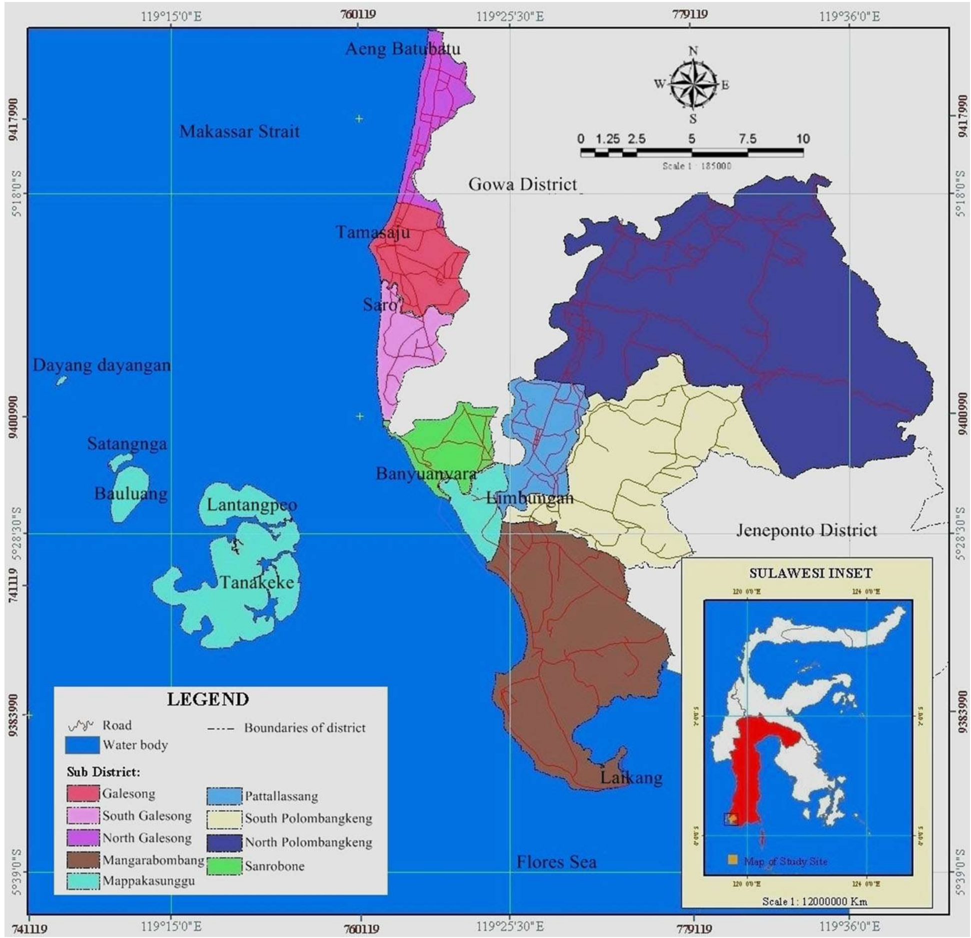


Fig. 1 Case study area; Takalar district, South Sulawesi province, Indonesia

Rhizophora stylosa, and *Sonneratia alba*). *Rhizophora mucronata* is the most dominant species, followed by *Sonneratia alba* in 2012 (Malik et al. 2015b).

Materials and methods

Digital image processing

In this study, we used images from two different sources: Landsat and SPOT 4. The images were from January 3, 1979 (Landsat MSS), from May 21, 1996, to February 24, 2006 (Landsat TM), and from August 7, 2011 (SPOT 4). We also used a 1:50,000 digital topographical maps from 1999 (Bakosurtanal 1999). The images and digital topographical maps were geo-referenced to WGS 84/UTM zone 50S.

The steps in image processing included both preprocessing and image analysis. Geometric corrections of the four images were done using the digital topography map, and false color composite (FCC) maps were created to facilitate the interpretation process. The normalized difference vegetation index (NDVI) was calculated as an indicator of vegetation density in mangrove forests (Seto and Fragkias 2007; Emch and Peterson 2006). Image classification was conducted using a supervised maximum likelihood classification (Sremongkontip et al. 2000; Manassrisuksi et al. 2001) including a separation between mangrove forest (five different density classes), aquaculture, water, and other surfaces. An accuracy assessment of the 2011 image classification was done using the confusion matrix method (Lillesand et al. 2008; Wang et al. 2003) on the basis of ground truth data collected in August 2012. In the absence of historical ground truth information, the accuracy of the historical images was established using independent (of the training areas) test areas in the satellite imagery. Hence, the test pixels for these images only partly fulfill the conditions of valid ground truth (Foody 2002), but this approach is often used as a work-around to assess the accuracy of older Landsat images for areas where no independent validation information is available (Congalton 1991). Finally, the GIS overlay technique was used to conduct a post-classification comparison change detection analysis to detect the changes in the four images classified (Manassrisuksi et al. 2001).

Household survey

A household survey was undertaken in ten areas (including seven sub-districts) covering the islands of Lantangpeo, Tanakeke, Bauluang, and Satangnga (sub-district of Mappakasunggu), and the villages of Laikang (sub-district of Mangarabombang), Limbungan (sub-district of Pattallassang), Banyuanyara (sub-district of Sanrobone), Saro' (sub-district of South Galesong), Tamasaju (sub-district of Galesong), and Aeng Batubatu (sub-district of North Galesong).

The selection of these areas was based on the criteria that mangrove forests should be present and that there should be some element of pressure on the forest for conversion to shrimp ponds, commercial logging, charcoal production, fuel wood collection, and nipa palm production.[1]

Questionnaires were administered to 100 respondents, who were selected by a purposive sampling method (Patton 1990). Thus, the respondents all had a direct relation to and dependence on mangrove forests, such as fishermen, seaweed and shrimp farmers, firewood collectors, charcoal producers, and nipa palm crafters. Heads of household were interviewed by the first author and trained enumerators, and the information obtained included basic household information such as age, number of dependents, education, livelihood, and income source. Moreover, information was collected on the respondents' understanding of mangrove functions and benefits, as well as their use of mangrove forests.

Accuracy assessment

The results of the remote sensing analyses showed that the levels of overall accuracy on Landsat MSS 1979, Landsat TM 1996 and 2006, and SPOT 4 2011 were 92.52, 95.82, 97.26, and 96.28 %. Overall accuracy (including all land use/cover classes) was assessed from pixel samples collected (3021, 2703, 2664, and 2741, respectively, covering all classes). For the mangrove class, the user's and producer's accuracies were found to be 85.90, 85.68 % ($n = 329$); 85.71, 86.19 % ($n = 156$); 84.03 85.21 % ($n = 121$); and 87.83, 83.47 % ($n = 101$), respectively. An accuracy of $\geq$85 % is considered acceptable when image classification is used for post-classification comparison change detection (Anderson 1976) to determine mangrove changes overtime (Giri et al. 2007).

[1] *Nypa fruticans*, a common component of mangrove forests, is valued primarily for its fruit and sap production, medicinal purposes, and leaves, which are crafted for various purposes.

Results

Mangrove forest change

The satellite image-based post-classification comparison change detection analysis showed that over the 33 years studied, the total areas of mangrove forest in Takalar District decreased by 66.05 % or 3344 hectares (Table 2; Fig. 2). The largest average annual negative change (2.97 %) in mangrove forests was found to occur during the period 1979–1996, followed by the period 1996–2006 (2.82 %); a slower average annual decrease rate was found during the period 2006–2011 (0.89 %).

When analyzing changes on the basis of different classes of mangrove forest density (distinguishing between three classes: high/highest, moderate, and low/lowest density of mangrove forest, Table 3; Fig. 2a), it becomes clear that the general decline in mangrove forests is not equally distributed among different density classes. The most pronounced decrease (in total ha) was found for the high/highest density classes of mangrove, with a loss of approximately 1, 812 hectares during the period 1979–2011. The greatest annual change in high/highest density mangrove occurred during the period 2006–2011 (8.37 %). For moderate, as well as for the low/lowest density mangrove classes, a decrease from 1979 to 2006 changes into an increase for the most recent period of analysis (2006–2011). This increase is, however, not large enough to counterbalance the rapid decrease in dense mangrove forest during this period.

Distribution of mangrove

In 1979, mangrove forest was found in the sub-districts of Mappakasunggu, Mangarabombang, Pattallassang, Sanrobone, and South Galesong. The largest area was found in Mappakasunggu, particularly on Tanakeke Island. Smaller mangrove areas were found in Lantangpeo, Bauluang, and Satangnga islands, and along the coast and river of Cikoang in Mangarabombang sub-district, the rivers of Pappa in Pattallassang sub-district, Biringkassi in Sanrobone sub-district, and Sabala in South Galesong sub-district. In 1996, the mangrove forests located on Tanakeke and Lantangpeo islands had degraded and declined, whereas seaside mangrove forest was retained. On the islands of Bauluang and Satangnga, mangrove forest area was unchanged. Mangrove forests located along the coasts of Mangarabombang, Sanrobone, and South Galesong sub-districts also degraded until they were only present around the rivers of Cikoang, Pappa, Biringkassi, and Sabala. In Pappa River area, the mangrove area increased. In 2006, mangrove forests located on Tanakeke Island declined even further, as was the case along the coasts of Mangarabombang, Sanrobone, and

Table 2 Mangrove forest change and conversion to aquaculture

Year	Mangrove change				Conversion to aquaculture			
	Area (ha)	Change in area from previous period (ha)	Annual change (ha)	(%)	Area (ha)	Change in area from previous period (ha)	Annual change (ha)	(%)
1979	5063	–	–	–	1989.29	–	–	–
1996	2507	−2556	−150.35	−2.97	3672.39	+1683.1	+99.01	+4.98
2006	1799	−708	−70.8	−2.82	3913.27	+240.88	+24.09	+0.66
2011	1719	−80	−16	−0.89	4582.35	+669.08	+133.82	+3.42
Total		−3344				+2593.06		

South Galesong and the rivers of Cikoang, Pappa, Biringkassi, and Sabala. On Lantangpeo Island, mangrove cover increased moderately due to reforestation and in 2011, mangrove forest cover declined further in Tanakeke, Lantangpeo, Bauluang, and Satangnga islands and around the rivers of Pappa and Biringkassi, but at a slower rate compared to the earlier periods. Along the coast and Cikoang River in Mangarabombang, areas of increased mangrove cover were associated with replanting (Fig. 2b).

Fig. 2 Mangrove forest change in the Takalar District, South Sulawesi province, 1979, 1996, 2006, and 2011 (**a**). Overlay of mangrove forest cover change. Legend colors represent different combinations of mangrove forest cover history for the 4 images analyzed (1979, 1996, 2006, and 2011) (**b**)

Mangrove conversion to aquaculture

The total area loss of mangrove forests in the Takalar District associated with aquaculture development between 1979 and 2011 was 77.54 % (2593 hectares; Table 2). The largest annual change rate of converting mangrove to aquaculture (4.98 %) occurred during the period 1979–1996, followed by an annual decrease of 3.42 % during the period 2006–2011 and a 0.06 % increase during the period 1996–2006. The most aquaculture pond development is found on Tanakake Island, Mappakasunggu subdistrict, and in Banyuanyara Village, Sanrobone sub-district (Fig. 2).

Utilization of mangrove forest by households

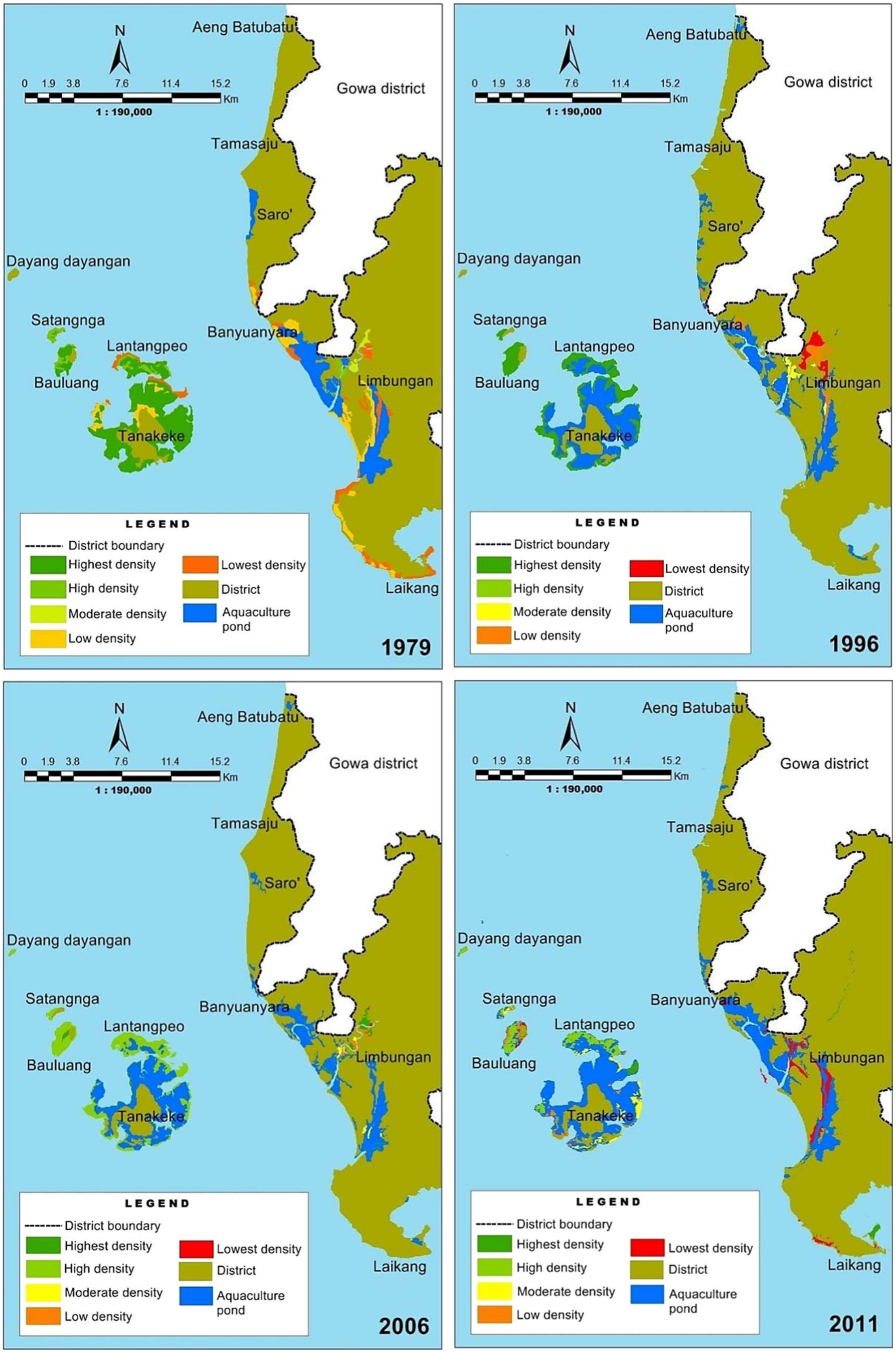
Mangrove forests provide essential natural resources that support household livelihoods in the Takalar District. Over the recent decades, households in this area have been highly dependent upon mangroves for their production of wood and fiber products (e.g., firewood, charcoal, and nipa palm leaves) and capture fisheries and aquaculture products (e.g., fish, crabs, shrimp, and seaweed; Fig. 3). However, fishing is the main livelihood of household heads (Fig. 3).

Fish capture takes place between February and September when sea conditions are good. October to January, when there are large waves and strong wind, are used as periods to rest, repair boats and fishing gear, or engage in alternative work. The income per month from fishing is generally very low, earning less than USD 53. Thus, many of the fishermen engage themselves in a variety of income-producing activities such as commercial logging and seaweed farming.

Commercial selective logging of specific species and sizes of mangrove trees is common. *Rhizophora* sp. wood with a stem height of about 4 m and a diameter of 4–8 cm is favored because it is stronger and provides better quality firewood and charcoal than other species. Monthly production is on average five bundles per harvester, and with a price per bundle of USD 8.4, the average monthly income is USD 42. Charcoal products are also mostly from *Rhizophora* sp. The production process lasts about 10 days (6 days for burning and 4 days for cooling), and each burning session can produce 500 kg of charcoal, which is packaged in 25 kg bags that are sold for USD 5.3 per bag providing an average monthly income of USD 316. Nipa palm leaves are used to build roofs and walls, as well as to make hats, floor mats, and baskets. Hat production was the most common among surveyed respondents and was mostly conducted by women, whereas men collected the leaves with up to 100 bundles per operation (1–2 times per month). Hats were sold to traders for USD 0.3 to USD 0.5 per hat, depending on the size, and the monthly income could reach USD 316.

Aquaculture (e.g., shrimp farming) is widely practiced in the mangrove areas of Indonesia, and areas of intensive shrimp farming cover Java, Sumatra, Kalimantan, and South Sulawesi (including the Takalar District studied here; Bengen and Dutton 2004). The average extent of a shrimp pond is three hectares and applied mainly as a traditional system of aquaculture that is dominated by polyculture with shrimp and milkfish (*Chanos chanos*) or milkfish and seaweed (*Gracilaria*). However, monoculture of shrimp or milkfish is also common. Two annual harvests per stocking season yield shrimp production from monoculture of 200–300 kg/ha and milkfish production of

A


1979
1996
2006
2011
N
1 : 190,000
Km
Aeng Batubatu
Gowa district
Tamasaju
Saro'
Dayang dayangan
Satangnga
Banyuanyara
Lantangpeo
Bauluang
Limbungan
Tanakeke
Laikang
LEGEND
District boundary
Highest density
High density
Moderate density
Low density
Lowest density
District
Aquaculture pond

B

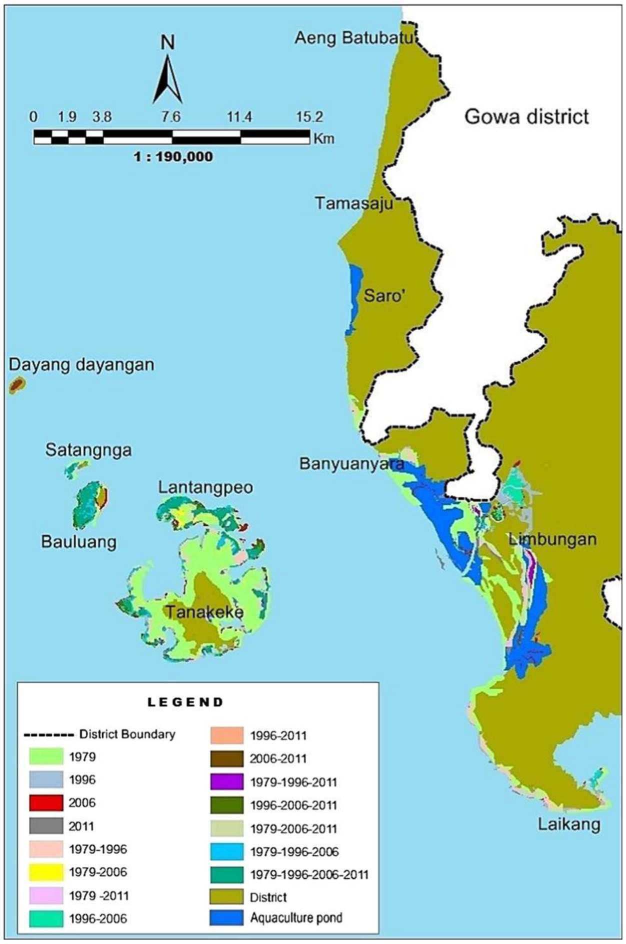


Fig. 2 continued

1700–2500 kg/ha. The production from polyculture (shrimp and milkfish) was between 600 and 800 kg/ha (of which 70 % is from milkfish), whereas milkfish and seaweed produced between 6000 and 7000 kg/ha of which about 65 % is from seaweed. The total income per production cycle is between USD 1053 and 2526. In addition, statistical data from Takalar District (BPS-Kab. Takalar 2007–2012) showed that during the period 2006–2011, the annual average income of shrimp farmers increased from USD 3368 to USD 5053 with an annual average increase of 11 %.

Many households are also engaged in seaweed farming either as single activity or as an alternative. The species cultivated is mainly *Eucheuma Cottonii* using the 'long line floating method' (by using mangrove wood as stakes) where seaweed seedlings are collected from the sea. The number of lines depends on the extent of the farming area, but on average, the survey respondents had 300 lines (one line is 20 m long and lines are placed 1 m apart), providing a potential income per crop cycle of up to USD 758. In addition, statistical data from Takalar District (BPS-Kab. Takalar 2007–2012) show that during the period 2006–2011, the annual average income of seaweed farmers increased from USD 4042 to USD 9095, with an annual average increase of 18 %.

Discussion

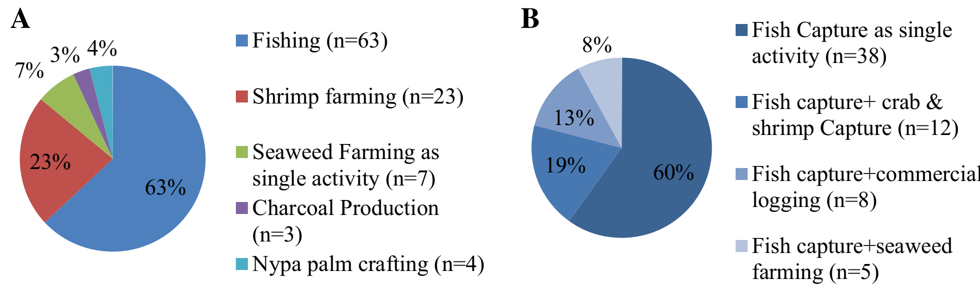
Mangrove forest change

Mangrove forest areas in Takalar, South Sulawesi, have over the past 33 years declined by more than half of their previous extent. The traditional activities of communities, who live in mangrove areas, play a fairly small role in this decline as they mainly use mangrove resources for domestic purposes such as firewood, house materials, and fish traps. However, in the early 1970s, commercial logging of mangrove began to supply the Gowa paper factory in South Sulawesi (Nurkin 1979), but currently this has stopped due to the limited remaining mangrove forests. Nonetheless, commercial logging of firewood and charcoal

Table 3 Mangrove forest density change

No.	Criteria of density	Year	Extent	Period change (ha)	Total (ha)	Annual change (ha)	(%)
1	High and highest	1979	2738.97	–		–	–
		1996	1608.88	−1130.09		66.48	−2.43
		2006	1594.64	−14.24		1.42	−0.09
		2011	927	−667.64	−1811.97	133.53	−8.37
2	Moderate	1979	452.57	–		–	–
		1996	281.9	−170.67		10.04	−2.22
		2006	59.91	−221.99		22.20	−7.87
		2011	235	+175.09	−217.57	35.02	58.45
3	Low and lowest	1979	1871.45	–		–	–
		1996	598.63	−1272.82		74.87	−4.00
		2006	144.45	−454.18		45.42	−7.58
		2011	556	+411.55	−1315.45	82.31	56.98

Fig. 3 Percentage distribution of livelihood among households (**a**) and activities among fishermen (**b**)



for food stalls in Makassar, the capital of South Sulawesi Province and elsewhere, remains and has caused continued degradation and declining stocks of mangroves. Moreover, there is a high demand for the wood of several mangrove tree species, especially *Rhizophora* sp., which is preferred for firewood and charcoal production because it is hard and dense and has a high calorific value (Aksornkoae 1993; Nurkin 1994). In addition, firewood from *Rhizophora* sp. generally produces a superior flavor of food and burns slowly (Nurkin 1994). Nipa palm leaves have also been used for centuries as material for roofing and wall webbing as well as hats, floor mats, and baskets.

The most important driver of mangrove decline, however, has been the introduction of tiger shrimp and aquaculture in the early 1980s. With an increasing international demand, cultured shrimp have become the main fisheries commodity in South Sulawesi, as is also the case in other areas of Indonesia and Southeast Asia (Purnomo 1992; Béland et al. 2006). Indonesia, Thailand, China, and India have become the major exporting countries (Rönnbäck 2001), and the international demand can be met either by catching tiger shrimp at sea or through aquaculture. However, because Indonesia has prohibited trawling operations in the marine territory since 1980 to preserve marine biological resources, the only way that tiger shrimp production can be increased is through expansion and intensification of aquaculture (Purnomo 1992). In Takalar District, the total area of mangrove forests being converted into shrimp ponds (77.54 %) occurred during the period 1979–2011 and a large-scale expansion of aquaculture during this period also took place in Tanakeke Island and Banyuanyara village. Over the period 1979–2011, the loss of mangrove forests in Takalar District constitutes 8.37 % of the losses in South Sulawesi and 0.30 % of total Indonesian losses, whereas the loss through conversion to aquaculture has contributed about 5.36 % for South Sulawesi and about 0.40 % for Indonesia.

The increase in aquaculture is mainly due to local fishermen changing their livelihoods to shrimp farming, which generates high revenue and is an export commodity that has not experienced steep declines in prices (BPS-Prop. Sulawesi Selatan 2007–2012). In addition, government support in the form of credit and subsidies to farmers to expand shrimp ponds has also been an important driver (Nurkin 1994).

Although mangrove forest destruction due to shrimp pond expansion increased during 1980 and 1990s, the rate of deforestation has decreased since the early 2000s due to an outbreak of White Spot Disease (WSD) in the 2000s, which is caused by a pathogen (white spot syndrome virus) that rapidly infects crustacean populations and results in high shrimp mortality (Crockford 2008; Alifuddin et al. 2003).

Over the past 5 years, the annual expansion of shrimp ponds has returned to previous high rates, but the expansion is less focused on monoculture of tiger shrimp, as farmers have been traumatized by several harvest failures and heavy losses due to WSD outbreaks. Households in the Takalar District were found to focus more on polyculture of shrimp and milkfish or milkfish and seaweed. This transition from monoculture toward a more resilient polyculture has also been observed in Philippines, Thailand, and Taiwan (Fast 1992). Farmers have also changed to farming white leg shrimp (*Penaeus vannamei*), which can be stocked in high densities and is relatively more resistant to disease (Tangko and Pantjara 2007).

Consequences of mangrove change

While the present study has mainly documented change in mangrove areas and household-based perceptions of consequences, several other studies document the impacts of mangrove loss on the physical and ecological functions of the ecosystem. The diversity of species has declined, and today mangrove forests mostly consist of seedlings and saplings (Malik et al. 2015b). Coastal erosion has occurred in several places in the sub-districts of Takalar (Fig. 1) which have retracted 20–100 m per year between 2003 and 2008 (Hajramurni 2010). Low density of mangrove vegetation due to timber harvesting and collection of firewood for charcoal production (Malik et al. 2015b) has been reported to cause coastal erosion (Masda et al. 2002). Furthermore, development of aquaculture ponds by clearing mangrove forests has caused coastal erosion due to wave attacks and tidal forces (Masda et al. 2002). The local communities are seriously concerned that big waves, strong winds, and flooding of the road with seawater will leave them isolated in their residential areas. Coastal erosion has also destroyed aquaculture ponds, contributing to an increasing abandonment of aquaculture that was initiated when shrimp diseases caused the production to decline. A similar development has been reported in Thailand (Sathirathai and Barbier 2001).

Salt water intrusion into cropland is another problem that has made banana cultivation difficult (Halim 2012) due to a low tolerance to salt (Palacios et al. 2000). Such consequences are also observed elsewhere, for example, in the Mahakam Delta, East Kalimantan, where dry season saltwater intrusion reached the city of Samarinda and contaminated the drinking water (Sidik 2008), and in the Mekong Delta in Vietnam, where the freshwater supply for 300,000 hectares of agricultural land was disrupted by salt water (Clayton and Brennan 1999).

Tropical marine ecosystems (e.g., mangroves and seagrass beds) are interconnected, and optimal provisioning of marine resources and fishing grounds are dependent on the well functioning of all components of the ecosystem (Unsworth et al. 2008, 2014). Seagrass beds are an important habitat for juveniles and adult fish (Unsworth et al. 2008) and carry a significant proportion of fish catch (Unsworth et al. 2014). The degradation and deforestation of mangroves are likely to have indirect consequences to reduce fish, crab, and shrimp catches due to a decline in seagrass beds caused by a subsequent increase in water turbidity (from increased land surface runoff) and wave action (Kirkman and Kirkman 2002).

Consequently, household survey respondents report that most fishing has to be conducted further away as there are fewer fish in coastal areas, and this in turn leads to higher capital investment in equipment and operational costs. Over the past years, crab species of high economic value [e.g., giant mud crab (*Scylla serrata*) and blue swimmer crab (*Portunus pelagicus*)] were reported to be increasingly difficult to find and consequently many households have stopped catching crabs (Taslim 2006). KKP-Indonesia (Ministry of Marine and Fisheries of Indonesia) (2012) reported that the volume of fish capture in South Sulawesi decreased from 354,399 to 158,138 tons (55.4 %) from 2003 to 2011. A similar decline in fish capture also occurred in North Sumatra and was attributed to degrading mangrove forests by local communities (Onrizal et al. 2009). In contrast, in the Mahakam Delta, there is no evidence that the productivity of fisheries has decreased due to the loss of mangrove (Sidik 2008).

Finally, household survey respondents report that the availability of shrimp and milkfish juvenile has declined, as has the stock of a number of fish species that depend on mangrove forests in South Sulawesi (Ilman et al. 2011). Unsworth et al. (2008, 2009) found seagrass meadows and mangroves to be important habitats for juvenile fish of some reef fish species by increasing the availability of shelter and food services. Hamilton and Snedaker (1984) reported that 80 % of the commercial marine biota in Florida, USA, is dependent on mangrove forests. Moreover, almost 100 % of shrimp and 49 % of demersal fish caught in the Strait of Malacca depend on mangrove areas (Macintosh 1982). Moreover, the availability of natural shrimp or milkfish juvenile declines as mangroves disappears. Shrimp farmers reported that it is very difficult to find enough juvenile of shrimp or milkfish in nature to meet their needs for farming and they are therefore dependent on hatcheries. While the hatcheries produce shrimp and milkfish juvenile of high quality and have become a source income and employment in many coastal regions (Rönnbäck 2002), they also lead to increased pressure on wild brood stock or spawn and cause large amounts of bycatch that is usually discharged in the sea (Rönnbäck 2001, 2002; Primavera 2006).

Furthermore, farmers have used shrimp feed that does not meet the requirements of environmentally friendly aquaculture, and this has led to outbreaks of shrimp diseases. Farmers have tried to increase production volumes using high stocking densities of juvenile shrimp and excessive feed, chemical fertilizers, and pesticides. However, this can reduce the water quality and cause the growth of microorganisms, leading to shrimp disease and directly contaminate soils, rivers, and coastal habitats (Sutrisno 2011; Lan 2013). In addition, excessive use of chemicals may cause toxicity to non-target populations (cultured species, the human consumer, and wild biota), development of antibiotic resistance, and accumulation of residues (Primavera 1998; Rönnbäck 2001). KKP-Indonesia (2012) reported increasing supplies from 2007 to 2012 of feed (2298–10,749 kg), inorganic fertilizer (17,899–43,844 kg), and pesticides (45,200–298,763 kg) for the intensification of shrimp farming in South Sulawesi. In addition, Tangko and Pantjara (2007) stated that the outbreaks of WSD have not been fully overcome; 12.648 hectares of mangrove in South Sulawesi, including 210 ha in Takalar District, are still infected by the disease, and the losses amount to more than IDR 9 billion (936,663 USD) in 2005. Such WSD outbreaks have caused production losses in other countries as well. In the Philippines, shrimp production dropped from 88,850 tons in 1995 to 36,859 tons in 1998; in Ecuador, from 129,600 tons in 1998 to 50,110 in 2000; and in Taiwan, from 16,715 tons in 1985 to 2495 tons in 2001 (Fukano 2004). The disease also affected Thailand, Indonesia, Vietnam, and Mexico (Fukano 2004).

In addition to the environmental impact, mangrove forest losses have also had socioeconomic consequences, both positive and negative. A cost–benefit analysis (CBA) over a 10-year period showed that the ecological functions of mangrove that include nursery grounds, protection from abrasion, prevention of seawater intrusion, and carbon sequestration gave far higher net present value (NPV) than aquaculture production that even had a negative NPV when environmental costs such as water pollution, forest rehabilitation, and social cost were included (Malik et al. 2015a). Furthermore, during 2003–2011 the loss of mangroves caused an average loss of fish catch in South Sulawesi of 1211 tons per year (KKP-Indonesia 2012).

This low income from fish capture and the period of rest due to unfavorable weather conditions for several months in this area have forced many fishermen to seek alternative livelihoods such as engaging in commercial logging and/or becoming shrimp or seaweed farmers. Statistical data from Takalar District gathered by the BPS-Kab. Takalar 2007–2012, the use of laborers in shrimp farming and seaweed farming increased by 1585 people (from 4515 people to 6100 people corresponding to an annual average growth of 8.7 %) and 5541 people (from 3352 people to 8893 people corresponding to an annual average growth of 31 %), respectively. The majority of shrimp and seaweed laborers only have an elementary school education, and they have limited knowledge of the environment and aquaculture techniques. Knowledge about running an aquaculture business is obtained by copying other businesses as laborers often work in a business only until they have enough experience to open their own business (Restoring Coastal Livelihoods 2011). The new livelihood strategies (shrimp and seaweed farmers) have increased the average income per month compared to that of fishermen (based on the household survey), but with the shrimp diseases and a fragile coastal environment caused by aquaculture, the new livelihoods could be a risky strategy compared to the lower, but more stable income from mangrove resources.

Change back to the traditional system is not likely to occur as the expansion of shrimp ponds and the widespread culture of seaweed provide important export commodities for the economy of South Sulawesi. Between 2006 and 2011, the production of shrimp increased by about 7510 tons (annual average growth of 11.24 %) despite slight decreases in 2009 and 2011 due to WSD, and seaweed production increased by 1073,084 tons (an annual average growth of 30 %). Despite production increases, the volume of shrimp exports decreased by about 1267 tons, but the value increased by USD 9085,000 (from USD 33,322,000 to USD 42,407,000) as market prices increased. The volume of seaweed export increased by about 46,895 tons between 2009 and 2011 with an increase in export value of USD 22,934,000 (from USD 56,953,000 to USD 79,887,000; BPS-Prop. Sulawesi Selatan 2007–2012). This makes South Sulawesi the third largest shrimp producer in Indonesia after Lampung and South Sumatra, and the largest seaweed producer in the country (BPS-Prop. Sulawesi Selatan 2007–2012; KKP-Indonesia 2012). Consequently, the South Sulawesi authorities are not likely to discourage further expansion of aquaculture as it remains crucial for the provincial economy.

Conclusions

This case study describes mangrove forest losses and related environmental and socioeconomic consequences in the Takalar District, South Sulawesi. Coastal communities in this region utilized mangrove forests as source of firewood, charcoal production, commercial logging, and nipa palm (which is used as a roofing material and the crafting of hats and other handmade items). Mangrove forests have also been cleared and impounded for aquaculture, principally shrimp and seaweed farming. High dependency on and unsustainable utilization of mangrove forests, coupled with the profit orientation of communities, has led to rapid mangrove losses. Government shrimp production targets and credit extended by governments to farmers to expand shrimp ponds and intensify farming have also played role in mangrove change and associated impacts.

An analysis based on satellite images covering the Takalar District reveals that two-thirds (3344 hectares) of the mangrove biome in the region was deforested or severely degraded during 1979–2011, mainly due to conversion to shrimp ponds. The largest annual change was found to occur during the period from 1979 to 1996 and took place primarily in Tanakeke Island and Banyuanyara Village. The rate of expansion of shrimp ponds, however, has decreased since 2000 due to WSD, which has caused several shrimp pond harvest failures and economic losses. Captive fisheries production (fish, crab, and shrimp) has declined concomitant with mangrove degradation and loss. Mangrove losses have been associated with coastal erosion and saltwater intrusion and also caused a decline in the annual production of fisheries in some regions. Declining stocks of shrimps and milkfish juvenile force shrimp farmers to buy these from hatcheries, and water pollution and outbreaks of shrimp disease threaten shrimp production.

Household surveys conducted in the study area indicate that the expansion of shrimp and seaweed farming has created new alternative employment possibilities and the shift in fishermen's livelihood to shrimp and seaweed farming has brought a significant increase in income, although the sustainability of this income is uncertain.

This study should contribute to the understanding of mangrove changes globally and, in particular, in Indonesia, which has the largest area of mangrove forest in the world. More information is needed to assess the long-term ecological and socioeconomic consequences of mangrove forest conversion to aquaculture.

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