



Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Early increases in artisanal shore-based fisheries in a Nature-based Solutions mangrove rehabilitation project on the north coast of Java

Adolphe O. Debrot^{a,b,*}, Anouk Plas^c, Herry Boesono^d, Kukuh Prihantoko^d, Martin J. Baptist^{a,e}, Albertinka J. Murk^b, Femke H. Tonneijck^f

^a Wageningen Marine Research, Wageningen University and Research, P.O. Box 57, 1780, AB, Den Helder, the Netherlands

^b Marine and Animal Ecology Group, Wageningen University and Research, P.O. Box 338, 6700, AH, Wageningen, the Netherlands

^c Inholland University of Applied Sciences, Rotterdamseweg 141, 2628, AL, Delft, the Netherlands

^d Fisheries Department, Faculty of Fisheries and Marine Sciences, Diponegoro University, Jl. Prof. H. Soedarto S.H, Tembalang, Semarang, Jawa Tengah, 50275, Indonesia

^e Aquatic Ecology and Water Quality Management, Wageningen University and Research, P.O. Box 47, 6700, AA Wageningen, the Netherlands

^f Wetlands International, P.O. Box 471, 6700, AL, Wageningen, the Netherlands

ARTICLE INFO

Keywords:

Mangrove rehabilitation
Mangrove fisheries
Fisheries rehabilitation
Livelihood restoration
Ecosystem services

ABSTRACT

We studied nearshore diurnal fish catches and fisheries development in the early stages of mangrove rehabilitation around the village of Timbulsloko on the central north coast of Java, Indonesia. Mangrove rehabilitation was part of a Nature-based Solutions project to re-establish ecological and economic resilience by combining coastal engineering measures with ecological recovery in conjunction with sustainable land and resource use. Creel surveys were conducted during the onset of the monsoon season October–December 2017 to document yields of the three main fishing gears targeting mangrove finfish in a 419 ha mangrove backwater basin. These were accompanied by structured interviews to obtain fisher views on developments in these fisheries. Analysis of satellite images and GIS-mapping were used to follow developments in mangrove coverage and effort in the estuarine lift-net fishery. Mangrove recovery between 2005 and 2018 achieved 8.5% of its maximum possible (historic) cover potential in the basin and followed an exponential growth curve. The increase in lift-net installations targeting finfish lagged in comparison to mangrove increase, remaining virtually zero till 2014, after which it rapidly increased. A baseline study in 2015 found no mangrove-associated finfish fisheries occurring in our study area. The 51 fishers surveyed in 2017, indicated that fishing activity in the area had strongly increased since 2015, with 45% of fishers stating to having started fishing this area a year earlier or even more recently. A significant majority of 87% of respondents with more than one year of experience at this location, stated that their catches had changed in terms of either fish size, quantity or composition since they started fishing, while 86% indicated improvement in terms of either size or quantity. Fishing generated about 1.05 ± 1.11 (SD) USD/hr worth of catch to professional fishers using either of the two net-types studied. As per 2017, fishing had become profitable in our study area, whereas this kind of fishery practically did not exist prior to 2014. We suggest that higher profitability may partially explain the rapid growth seen in fishing activity in the mangrove rehabilitation area. However, for 12 of the 18 larger species caught, the mean size in the catch was lower than mean size of maturation, indicating that these fisheries were principally targeted towards immature nursery fish. The results highlight the need to manage this currently developing fishery, otherwise any benefits to the local community might be nullified by overfishing.

1. Introduction

Mangroves are important for sustaining nearshore fisheries in tropical regions due to their nursery function and high productivity (Manson

et al., 2005). Up to recently, their positive effects on fishery revenues were mostly based on studies using a correlative approach and ecosystem modelling (e.g. Aburto-Oropeza et al., 2008; Anneboina & Kumar 2017; Das, 2017) and information on whether and how

* Corresponding author. Wageningen Marine Research, Wageningen University and Research, P.O. Box 57, 1780 AB, Den Helder, the Netherlands.

E-mail address: dolfi.debrot@wur.nl (A.O. Debrot).

<https://doi.org/10.1016/j.ecss.2022.107761>

Received 28 July 2021; Received in revised form 29 December 2021; Accepted 21 January 2022

Available online 31 January 2022

0272-7714/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

mangrove rehabilitation can improve fisheries production remains scant (e.g. Walton et al., 2006). In the Philippines, Walton et al. (2007) found that natural and planted mangroves had comparable mud crab (*Scylla olivacea*) densities, and hence successfully demonstrated that planting could help in restoring an economically important crab species to levels expected from natural mangrove stands. Anneboina & Kumar (2017) demonstrated a strong correlation between mangrove presence in India and fisheries productivity and calculated a net contribution per hectare of mangroves of 1.9 tons of fish catch per year, amounting to a total of 23% of the annual fisheries production. One questionnaire-based study in the Philippines suggested that replanted mangroves were benefiting local incomes to the extent of USD 564–2316/ha/y (Walton et al., 2006). Major problems remain in terms of assessing the effectiveness of mangrove rehabilitation programs (Ismadi and Yamindago, 2015), and in general, the functionality and recovery of ecosystem services have been too rarely quantified in mangrove rehabilitation projects (Duncan et al., 2016). In a recent meta-analysis of 70 wetlands that were restored 5–15 years earlier, it was found that compared to reference sites, restored wetlands (including several mangrove sites), typically provided 16% lower supporting services and 22% lower regulating services than natural sites, even though they were able to match desired levels of provisioning and cultural services (Meli et al., 2014). Still, almost no studies have been carried out to directly assess any relationship between

mangrove recovery and either fish abundance or fishing yields as indicators of ecosystem service recovery. Therefore, it is not known to what extent and how fast mangrove rehabilitation can actually lead to restored ecosystem functioning and economic vitality for coastal fishing communities.

Along the central north coast of Java mangrove loss has been particularly severe due to high human population densities and the demand for agricultural land and aquaculture (Kusmana, 2014). This has contributed to coastal erosion and flooding, loss of land and infrastructure, and emigration due to loss of livelihoods (Abidin et al., 2013; Chaussard et al., 2013; Joseph et al., 2013). This has also been the case in the coastal zone of Demak Regency, about 10 km north of the city of Semarang which has been suffering from coastal erosion and flooding fuelled by mangrove conversion to aquaculture ponds, and subsidence (Abidin et al., 2013; Chaussard et al., 2013, Fig. 1). Until the mid-20th century the main occupation was the culture of dry-land crops and rice. In the 1960s, canals for irrigation and drainage were built, and some rivers were dredged and straightened. In the 1980s, the growing international demand for shrimp fuelled the transformation of mangroves and rice fields to ponds for shrimp (Ariyati et al., 2016). This then led to seawater intrusion and rice had to be abandoned, further forcing the clearance of more mangroves. In response to socio-economic decline caused by loss of land and sinking villages, mangrove planting and

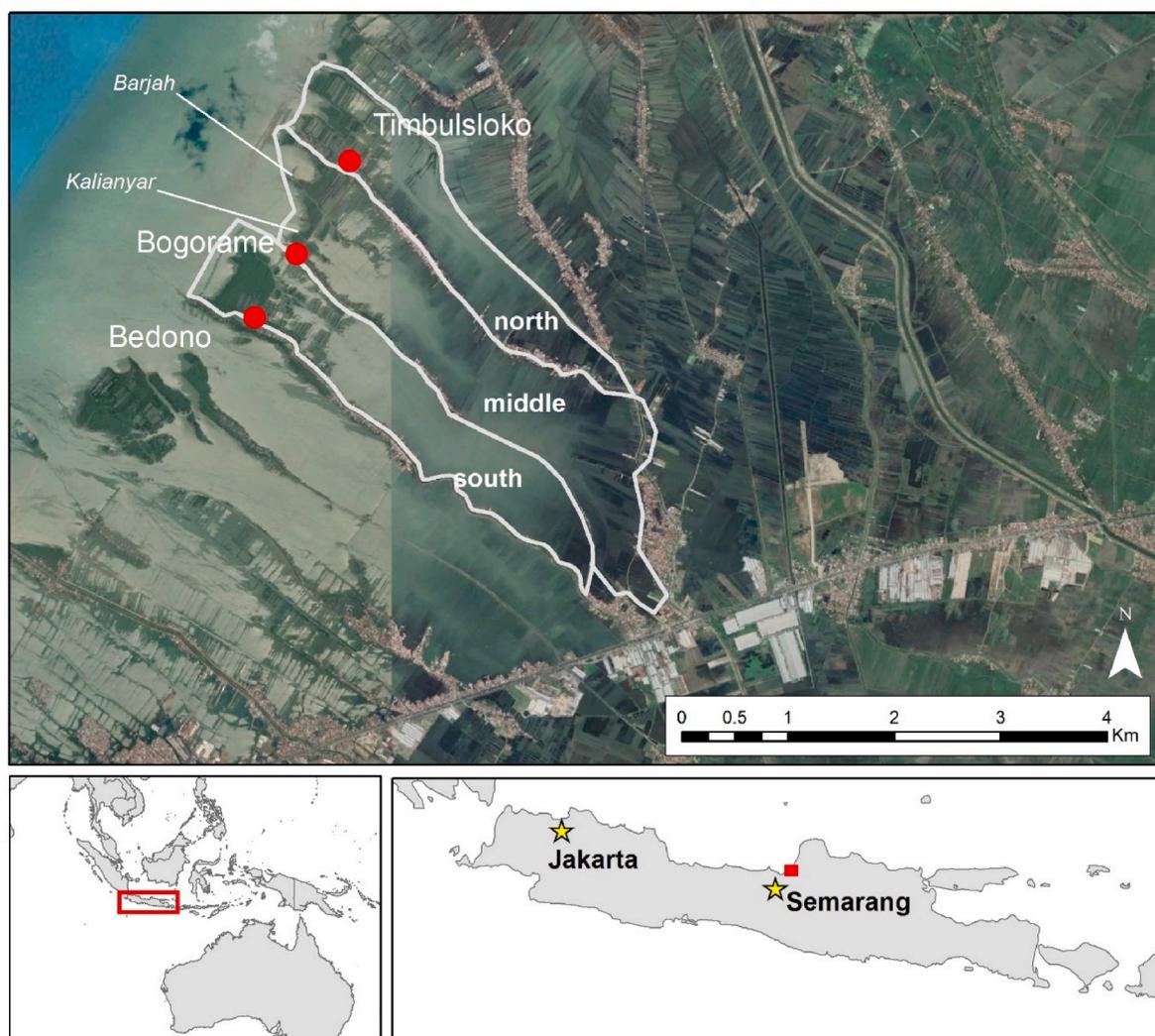


Fig. 1. Map of the study area showing the two tidal rivers (Barjah and Kalianyar) draining through the middle basin where the fishing activity was documented via interviews and satellite net counts. The two flanking basins were used as control basins for mangrove development trends. Red dots indicate the three villages as referred to in the methods. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

rehabilitation activities by the villagers have been underway since 2001 (Damastuti and De Groot, 2017) as supported and urged on by government (e.g. Demak Environmental Office) and international NGOs such as OISCA (Organization for Industrial, Spiritual, and Cultural Advancement, Japan). Most of the planted mangroves were *Rhizophora mucronata* and to a much lesser extent *Avicennia marina*. Even though by 2014 more than 5.7 million mangrove seedlings had been planted in the surrounding villages (Damastuti and De Groot, 2017), in 2013 two communities needed to be evacuated (Damastuti and De Groot, 2018).

A large-scale mangrove rehabilitation project was initiated in Demak Regency in 2015 by a Dutch-Indonesian consortium consisting of the Ecoshape Foundation, the Netherlands, Wetlands International, the Indonesian Ministry of Marine Affairs and Fisheries (MMAF), the Indonesian Ministry of Public Works and Housing (PU) and associated partners. The goal of the initiative was to halt and ultimately reverse coastal erosion and support sustainable aquaculture revitalization along a 20-km section of coast that had suffered serious ecological and socio-economic decline (Tonnejck et al., 2015; Bosma et al., 2020; Rejeki et al., 2021). The average household size in the villages of Demak, in 2015 was 5-persons and the household income from shrimp and fish farming activities were estimated at 1400 USD/yr (Ariyati et al., 2016). The average total household cumulative income was 2137 USD/yr, which lay well below the poverty standard (Ariyati et al., 2016). In this project, our Nature-based Solutions (NbS) approach (Cohen-Shacham et al., 2016, 2019) aimed at integrated coastal zone management to re-establish ecological and economic resilience by combining smart engineering and ecological rehabilitation, in conjunction with sustainable land and resource use (De Vriend et al., 2015). Implementation began with the construction of permeable dams made from bamboo poles with brushwood packed in between and placed parallel to the coast to trap sediment to support semi-natural mangrove recovery (Winterwerp et al., 2020). It involved no tree-planting. Implementation was integrated into community development plans, and supported by training programs and the intensive involvement of local stakeholders (Wilms et al., 2017).

The objective of this study was to evaluate whether mangrove rehabilitation increases local finfish fisheries production and contributes to economic vitality of coastal fishing communities along the north coast of Java. For this we assessed the nearshore fisheries taking place in and directly surrounding the channels of the associated mangrove system. Nearshore areas and mangrove channels are particularly interesting to finfish fisheries as they serve as conduits for predatory fish (e.g. Blaber, 1986; Blaber et al., 1989; Sheaves, 1995; Leh et al., 2012) that are not only at the top of the food web but also high-value target species. Increased or renewed fishing activity or increased catches of these fishes could serve as an early indication of changes in the status of mangrove ecosystem health and possible economic benefits from mangrove rehabilitation.

2. Study area and methods

2.1. Study area

The study area lies in the coastal zone of Demak Regency, about 10 km north of the city of Semarang (Fig. 1). We assessed mangrove fishing activity targeting finfish in two tidal mangrove rivers draining a 419 ha backwater area. The rivers were conveniently located along a small section of coastal road connecting the village of Timbulloko to the smaller villages of Bogorame and Bedono. This area was chosen for three reasons. Firstly, the area was in the centre of the NbS project, secondly, it was flanked on both sides by drainage basins comparable in both size and mangrove recovery and thirdly, in contrast to other nearby areas, it had maintained the same riverine structure since at least 2005. Hence, any potential changes in fishing activity or catches could not be influenced by local changes in the riverine landscape. The four enveloping main villages, namely Timbulloko, Bedono, and Sriwulan and Surodadi

(the latter two lying outside our map) amount to about 1,250 households per village and were the subject of several recent socio-economic livelihood studies (Joseph et al., 2013; Ariyati et al., 2016; Damastuti and De Groot, 2017). Based on a sample of 500 household representatives, Damastuti and De Groot (2017) determined that 64.8% of households had aquaculture, labour, trading, entrepreneurialism or civil service as the primary source of income, while 10.2% of households depended on mangrove-related fishing as the primary source of income, and 24.8% depended on other mangrove usage (for materials, fishing gears, foods, fuel, medicines, seedlings for mangrove nurseries) for their income. The most valuable mangrove-related fishing product was the mud crab, *Scylla serrata*, which amounted to 44% of the fishers' household income in Timbulloko (Damastuti and De Groot, 2017). Many different types of fishing methods are applied in the surrounding areas, including trawling for shrimp and blood clam (*Anadara granosa*) using either vessels or hand dredges, spearing or shooting fish from the shore, cast-netting, and even extracting fish from burrows by hand. However, in and around the mangrove system we studied, the three main shore-based types of fishing methods targeting finfish were: hook-and-line ("pancing"), lift net ("branjang") and drift net ("bondet") fishing. Most of such fishing activity in this area is centred around two main mangrove tidal rivers of Sungai Barjah and Sungai Kalianyar which we studied (Fig. 1). The large, shallow (<1 m) mangrove backwater basin area of roughly 419 ha (middle basin) drained by these two rivers is used for semi-extensive shrimp and milkfish culture which account for roughly 65% of the household income for the resident villagers (Ariyati et al., 2016). The backwaters are non-estuarine in nature due to extensive up-stream water diversion and extraction (Taufani et al., 2018). Salinity in the tidal rivers averages 32–34 ppt during most of the year, but drops annually to an average of just above 28 ppt during the rainy season (November–February) due to seasonal discharge (Rejeki et al., 2012, 2021).

2.2. Creel surveys

We conducted diurnal creel surveys on 16 days from 6 a.m. to 16 p.m. during the period 18 October–10 December 2017, during the first half of the rainy season. A total of 51 fishers were interviewed and 42 catches were documented. It was estimated that about 130 mangrove fishers reside in Timbulloko, almost all of whom were mangrove crab fishers and did not target finfish (Damastuti and De Groot, 2017). Therefore, our sample size of 51 fishers targeting this up-coming fishery for finfish was adequate.

A short questionnaire was designed, reviewed and translated to the main language of Bahasa Indonesia to document the socio-economic background of the fishers, their current fishing activities and experience with fishing in the study area (e.g. Debrot and Nagelkerken, 2000). The questionnaire-based interviews were conducted by Indonesian students from the Diponegoro University of Semarang (for questionnaire, see Appendix A). Other types of mangrove fishing are conducted (Damastuti and De Groot, 2017), and most village fishing takes place offshore (Hapsari et al., 2017). Therefore, and in contrast to other studies cited, all interviews were conducted on the fishing grounds to make sure that only active mangrove fishers were included. Individual fishers were interviewed only once. We used Chi-square Goodness-of-Fit tests to evaluate for deviations from expected proportions (Walpole and Myers, 1978). Because not all fishers answered all questions, tests were based on differing sample sizes for each question examined.

2.3. Characterization of fish catches

For field sampling efficiency and to save the fishers' time, we documented catches photographically by laying the catch in a rectangular tray with a cm-grid on the bottom. Thus size estimation in terms of Total Length (TL) and identification could be done later so as to minimize the time spent in the field and the hinder caused to the fishers.

Catch composition was identified using online resources, such as fishbase.org and talkaboutfish.com and local experts. Almost all species could be distinguished and reliably identified except the Mugilidae and Ariidae. We used fish size and length-weight relationships from FISH-BASE (Froese and Pauly, 2018) to estimate weight of each fish and hence species weight contribution and total weight of all catches. By recording the duration of time fished we calculated catch per unit effort (CPUE) for each fishing trip and each gear type used. Only six recorded catches had a zero fish catch (zero success). In cases of zero catch, the fishing trip was typically very short and the fisher returned home early. The zero catches were included in the calculation of average catch rate per hour.

2.4. Developments in lift net deployment

We quantified the multiannual development in lift net deployment in the two tidal rivers studied by counting the number of lift-net installations visible in a single, Google Earth satellite image each year from 2009 to 2018. These square nets were 6.75 by 6.75 m in size, permanently hung from little fishing sheds or “lift-net installations” constructed at vantage points along the river banks and could be clearly distinguished from good-quality Google Earth satellite images. However, prior to 2009, the resolution available on Google Earth images was insufficient to allow discernment of lift-net installations. When not in the water the nets hung directly above the water and could be distinguished as large white squares (Fig. 2). The dates of the Google Earth images used were as follows: 18 October 2009, 27 September 2010, 7 September 2012, 1 August 2013, 1 June 2015, 1 February 2016, 18 September 2017 and a field count conducted on 1 April 2018. These dates were spread across different seasons of the year, spanning eight months in total, because of the limited availability of high resolution daytime and cloudless Google Earth images that allowed distinction of the nets. This spread was still not a problem because the lift-net installations remain standing and the nets very visible even in case of not being in active use due to weekends, illness, holidays, tides or other (pers. observ. 2015–2019, AOD). Also, if differences in season had made a big difference then we would expect a “messy” graph of lift-net deployment but the graph instead shows a very tight and stable

pattern of change in the deployment of lift-net installations. Statistical analysis for significance of trends in lift-net deployment were done using simple linear regression analysis (Walpole and Myers, 1978).

2.5. Developments in mangrove cover

Changes in tree cover at a landscape level are typically gradual and long-term, and therefore monitoring tree cover change at annual or longer intervals is the rule (e.g., Potapov et al., 2017; Altamirano et al., 2020). To assess mangrove development in our study basin we mapped mangrove cover once a year based on Google Earth satellite images. We started with a consecutive annual assessment for all more-recent years from 2018 through 2012, a single intermediate assessment in 2010, and an early assessment in 2005 when there were hardly any mangroves present as yet. Mapping tree cover was a labour-intensive activity but in the earlier years mangrove cover was consistently low and showed little fluctuation year to year. In studies examining the relationship between habitat improvement and fish abundance, a key question is whether any increase in fish abundance is primarily due to locally enhanced production or simply due to attraction of fish from (and at the expense of) adjacent areas which lack such habitat (i.e., the long-standing “production” versus “attraction” debate surrounding artificial reef initiatives, e.g., Roa-Ureta et al., 2019; Hylkema et al., 2020; Da Costa et al., 2021; Hylkema et al., 2021). To help address this complicating issue, we collected data on mangrove cover not only from our direct 419 ha study area but also from similarly-sized flanking areas, so as to be able to verify that any fish abundance we might document was not being artificially inflated because surrounding areas might have been devoid of mangroves. Statistical analysis for significance of trends in mangrove cover were done using simple linear regression analysis (Walpole and Myers, 1978) using log-transformed data.

3. Results

3.1. Socio-economic survey

The principal results from our questionnaire-based interviews are



Fig. 2. Sample Google Earth image showing four lift net installations in the Barjah tidal river on 18 September 2017. One net appears to be submerged (2nd from right, only shed and pole visible) and three were not submerged at the time of photography (poles and net hanging visibly above the water). Google Earth Pro V 7.3.4.8248. (July 16, 2021). Demak, Java, Indonesia. 6° 53' 58.38"S, 110° 30' 35.73"E, Eye alt 264 m. CNES/Airbus 2021. <https://earth.google.com/web/>[December 21, 2021].

given in Table 1. Eighty percent of the 51 fishers surveyed were 25–50 years of age, while 10% were 18–25 years and 10% were older than 50 years. Forty-nine percent were residents from Timbulsloko (25), 23% from the city of Demak (14 km away) and 11% from the city of Semarang (6 km away), while 17% came from elsewhere to fish (Table 1). Fifty-seven percent characterised themselves as professional fishers, 24% as principally farmers, 9% as entrepreneurs and 4% as working in the private sector, while 6% gave no clear answer. None of the interviewed indicated to be either students or unemployed. Most respondents (47%) fished four times or more each week, 26% fished 2–3 times a week while 27% fished one time or less per week. Typical fishing duration of interviewees was predominantly more than 4 h as opposed to 2–4 h or 1–2 h ($X^2 = 13.27, df = 2, p = 0.000$). Clearly, the results showed that our study design targeted the more active fishers. Forty percent fished to sell their catch, 29% partly for their own consumption and partly to sell, 20% strictly for their own consumption and 11% for recreational purposes (Table 1). Sixty-nine percent of fishers had spent more than 4 h fishing when interviewed. The largest number of fishers (33%) had fished at this location for more than 2 years but 22% had only started fishing 1–2 years earlier, while 45% had started fishing in the area less than or equal to one year ago. This suggests a large influx of fishing activity. Of the 51 fishers interviewed (plus three only observed), 48% used fishing rods, 33% drift nets, 17% lift nets and 2% cast nets as their principal gear (Table 1). Fishing rods typically used 30-lbs-test nylon monofilament with a leader and were the key gear used by recreational fishers. The drift nets varied in dimensions but were typically 35 m long, 1.5 m wide and a mesh grid of 1.3×1.3 cm. Square lift nets, as explained above, were 6.75 by 6.75 m in size and were semi-permanently deployed. The fishers stated that their target species were (in declining order of importance; see Table 2 for Indonesian local names)

the Greenback Mullet (cf *Planiliza subviridis*), snappers (*Lutjanus* spp.), the Barramundi (*Lates calcarifer*), the Milkfish (*Chanos chanos*) and Gray Eel-catfish (*Plotosus caninus*), and a significant majority of fishers stated to actively target certain species ($X^2 = 12.25, df = 1, p = 0.000$). The fishers that had fished in this area for six months or more indicated that previously their dominant (78%) fishing method ($X^2 = 5.56, df = 1, p = 0.016$) was using a scoop net (to catch shrimp). A significant majority of them (87%) ($X^2 = 13.76, df = 1, p = 0.000$) indicated a change in their catches at this location since starting to fish here. According to them, this was in terms of either fish size (19%), quantity (40%), or species composition (41%). A statistically significant majority of them (86%) ($X^2 = 225.00, df = 1, p = 0.000$) further indicated that their catch amount and/or composition at this location had greatly improved since they started fishing here. Fifty-nine percent indicated to also fish in other locations and of those a significant majority 80% ($X^2 = 12.5, df = 1, p = 0.000$) indicated to be aware of site-specific differences in fish availability between the locations they fish.

3.2. Catch characteristics

The 42 individual catches documented, amounted to 359 fishes to be identified and measured, and weighed a total of 65.3 kg. The three most numerous species were the Greenback Mullet (62%), the Milkfish (9%) and Spotted Scat (7%). By weight the three most dominant species were the Greenback Mullet (46%), the Milkfish (27%) and the Barramundi (13%). Overall, at least 25 species were recorded in the combined catches (Table 2). Some difficult-to-differentiate species groups were composed of more than one species. This was especially the case for Mugilids and for Ariidae. For the purpose of analysis, all Mugilidae and Ariidae were considered as being the most-common expected species but

Table 1
Key responses of fishers at Timbulsloko to the questionnaire-based interviews (see questionnaire, Appendix A).

Question/Number of respondents (n)	Categories of response/Percent responses for each category						
1	Age	<18	18–25	25–35	35–50	>50	
51		0	10	39	39	12	
2	Residence	Timbulsloko	Semarang	Demak	other		
51		49	11	23	17		
3	Profession	farmer	fisherman	employee	entrepreneur	other	
51		24	57	4	9	6	
4	Time spent fishing now (h)	<0.5	0.5–1	1–2	2–4	>4	
29		7	7	17	0	69	
5	Typical time spent fishing (h)	1–2	2–4	>4			
50		12	15	58			
6	Frequency of fishing per week	<1	2	3	≥4		
51		27	18	8	47		
7	Purpose of fishing	recreation	food	sell	combination		
52		11	20	40	29		
8	Gear of preference	rod	gill net	lift net	cast net		
54		48	33	17	2		
9	Actively target selected species	yes	no				
51		75	25				
10	What target species	mulletts	Baramundi	snappers	Milkfish	Eel-catfish	other
65		31	19	22	12	6	11
11	Other fishing locations in use	yes	no				
51		59	41				
12	Differences between sites	yes	no				
30		80	20				
13	Experience at location (months)	<6	1–6	6–12	12–24	>24	
49		10	27	8	22	33	
14a	Other gear used here in the past	yes	no				
40		38	62				
14b	If so, gear type used then	rod	scoop net	lift net	other		
18		12	78	5	5		
15a	Did fish catch change	yes	no				
40		87	13				
15b	If so, how did fish catch change	more fish	less fish	smaller fish	bigger fish	different fish	
37		32	8	0	19	41	

Table 2

Percentage catch contribution (by weight) for all species/species groups documented from three different gears used in artisanal nearshore fisheries in Timbulsloko. Principal species adding up to 94% or more of total catch for each gear have been underlined.

Species	Family	English name	Local name	Lift net	Hook and line	Drift gillnet
<i>Acanthopagrus berda</i>	Sparidae	Gold silk Seabream	Katombal	0.00	<u>12.31</u>	0.00
<i>Acentrogobius cf. nebulosus</i>	Gobiidae	Shadowy Goby	Bilir	0.00	0.00	0.25
<i>Ambassis sp.</i>	Ambassidae	Glassfish	–	0.16	0.00	0.00
<i>Arius cf. maculatus</i>	Ariidae	Spotted Catfish	Lundu	0.00	0.00	1.72
<i>Chanos chanos</i>	Chanidae	Milkfish	Bandeng	<u>11.20</u>	0.00	<u>31.54</u>
<i>Eleutheronema tetradactylum</i>	Polynemidae	Fourfinger Threadfin	Kurau	0.00	0.00	<u>2.58</u>
<i>Elops machnata</i>	Elopidae	Tenpounder	–	0.00	0.00	0.36
<i>Epinephelus coioides</i>	Serranidae	Orange-spotted Grouper	Gerape kuneng	1.70	<u>7.34</u>	0.00
<i>Gerres erythrorus</i>	Gerridae	Deep-bodied Mojarra	Kapas-kapas	0.00	0.00	0.05
<i>Johnius belangerii</i>	Sciaenidae	Belanger's Croaker	Kekemek	0.00	0.00	<u>2.27</u>
<i>Lates calcarifer</i>	Latidae	Barramundi	Kakap putih	0.00	<u>38.01</u>	<u>8.62</u>
<i>Eubleekeria sp.</i>	Leiognathidae	Ponyfish	–	0.01	0.00	0.00
<i>Lutjanus fuscescens</i>	Lutjanidae	Freshwater Snapper	Kakap	0.00	1.02	0.00
<i>Lutjanus johnii</i>	Lutjanidae	John's Snapper	Tambangan	0.06	3.87	0.00
<i>Lutjanus russelli</i>	Lutjanidae	Russell's Snapper	Aba	0.00	0.30	0.16
<i>cf. Planiliza subviridis</i>	Mugilidae	Greenback Mullet	Belanak	<u>84.43</u>	0.00	<u>46.89</u>
Mullid sp.	Mullidae	Goatfish	–	0.00	0.00	0.31
<i>Oreochromis mossambicus</i>	Cichlidae	Mozambique Tilapia	Mujahir	0.00	0.00	0.65
Mudskipper spp.	Oxudercinae	Mudskippers	Blodok	0.17	0.00	0.19
<i>Parapocryptes cf. serperaster</i>	Gobiidae	Goby	–	0.65	0.00	0.00
<i>Plotosus canius</i>	Plotosidae	Gray Eel-catfish	Sembilang	0.00	<u>31.29</u>	0.00
<i>Scatophagus argus</i>	Scatophagidae	Spotted Scat	Kiper	1.62	0.00	<u>2.47</u>
<i>Siganus javus</i>	Siganidae	Streaked Spinefoot	Beronang	0.00	0.00	0.63
<i>Sphyræna cf. jello</i>	Sphyrænidae	Pickhandle Barracuda	Alu-alu	0.00	<u>5.87</u>	0.00
<i>Strongylura strongylura</i>	Belonidae	Spottail Needlefish	Longkong	0.00	0.00	0.96
<i>Terapon jarbua</i>	Terapontidae	Jarbua Terapon	Ikan kerong	0.00	0.00	0.33
				100.00	100.00	100.00

additional species cannot be ruled out and are even likely to co-occur. In the case of the Mugilidae, the most common one in the catches appeared to be the Greenback Mullet which is common and of commercial interest in mangrove habitat throughout south-east Asia, including Indonesia (Sasekumar 1978; Chong et al. 2004; Sukardjo, 2004). All Ariidae specimens were listed and analysed as though they were Spotted Catfish, *Arius maculatus*, a commonly occurring, important, medium-priced commercial fish, throughout south-east Asia (Sumaila et al., 2007; Mazlan et al., 2008).

The species targeted and caught by the three different gears differed greatly (Table 2). For lift nets, 95% of the catches realized were composed of only two species, the Greenback Mullet (84%) and Milkfish. Fishing rods targeted especially bottom-dwelling predators. These catches were dominated by Barramundi (38%) Gray Eel-catfish (31%) and Goldsilk Seabream (12%) followed by Orange-spotted Grouper (7%), Pickhandle Barracuda (6%) and several snappers (5%). Finally drift gill nets caught principally Greenback Mullet (47%), Milkfish (31%) and Barramundi (9%) and a wider variety of other fishes.

In addition to different species compositions, the different gears also demonstrated different catch efficiencies (Table 3). Drift gillnets had the highest catch per unit of effort (CPUE) of all three gears and averaged 1.00 kg of fish per hour spent. Next was the lift net which yielded an average of 0.42 kg of fish per hour. The lowest catch rates were found in hook and line fishing, which averaged 0.26 kg/h, albeit with a large standard deviation. The fish species caught differed significantly in market value. The 2017 market prices per kilogram were as follows:

Table 3

Average catch (kg), time spent (min) and catch per unit effort (CPUE) for three different gears used in artisanal fisheries in Timbulsloko.

Gear type	N	Average catch		Average time spent		CPUE	
		kg	(±SD)	min	(±SD)	kg/hr	(±SD)
Lift net	8	1.16	1.15	165.00	64.14	0.42	0.57
Hook and line	13	0.65	1.17	152.31	128.01	0.26	1.16
Drift gillnet	17	2.39	2.05	142.94	85.20	1.00	0.76

Spotted Scat: 16,000 IDR (1.10 USD); mullets: 20,000 IDR (1.38 USD); barracudas: 24,000 IDR (1.65 USD); Milkfish and Gray Eel-catfish: 30,000 IDR (2.06 USD) (exchange rate used: 1 USD = 14,539 IDR). We calculated the approximate market value for 12 individual catches for which full pricing of the catch was possible (and including one zero catch), expressed as value caught per hour spent fishing (Table 4). All these were for drift- and gill nets as used by professional fishers (i.e. excluding handlines). Based on average fish market prices, and documented fish catches, fishing with drift nets or lift nets can generate a rough market retail value of 1.50 ± 1.11 USD/hr. Assuming that (as reported for Aceh province) the fisher earns 70% of the retail value when selling to the market retailer (Wisibono and Sualia, 2008) this implies 1.05 ± 0.82 USD/hr worth of catch in Timbulsloko.

Table 5 compares the measured mean size in the fish catches with the mean size at maturity as reported in the literature. For 12 of the 25 species documented, the mean size in the catch was found to be lower than the average or minimum size of maturation. This was particularly the case for large predatory species such as the Barramundi, snappers, Orange-spotted Grouper, and also for the single important sparid species, the Goldsilk Seabream. Only one principal predatory target species, the Gray Eel-catfish, was caught at an average size above its size of maturation. Also two non-target species were mainly caught at sizes below the size of maturation (Spotted Scat and Jarbua Terapon). Neither of these are high value food fish but, nevertheless, Jarbua Terapon is considered to be overfished in Indonesia (Srikandace et al., 2017).

3.3. Temporal trends in mangrove development and lift net fishing

The increase in mangrove cover from 2005 through 2017 in the middle basin area of our study was exponential, large and highly significant ($F = 98.87$, $df = 7$, $p = 0.0000$). In addition, total mangrove covers were quite similar in all three basins with peaks being reached in 2017 (Fig. 4). The middle basin, in which we collected our fisheries data, was the basin with the lowest total mangrove cover, peaking at just below 35 ha in 2017 (Fig. 3), which represented less than 10% of the total mangrove cover potential (assuming that mangroves would be

Table 4

Approximate (2017) market value revenue in IDR (1 USD = 14,539 IDR) per unit of fishing time spent for twelve net-based catches for which full market-price valuation was possible, including (a single) zero catch.

Nr	Gear	Species	Caught	Market price	Market value	Time	Revenue
			kg	IDR/kg	IDR	min	IDR/hr
1	Lift net	Mugilidae	3.5	20,000	69,472	120	36,736
2	Lift net	Mugilidae	0.9	20,000	18,418	150	18,996
3	Lift net	<i>Chanos chanos</i>	1	30,000	29,072	240	7,180
		Mugilidae	1.4	20,000	27,297		
4	Lift net	<i>Scatophagus argus</i>	0.1	16,000	1,421	840	2,003
		Mugilidae	1.4	20,000	28,046		
5	Lift net	<i>Chanos chanos</i>	0.3	30,000	7,689	30	15,379
6	Lift net	None	0			120	0
7	Drift gillnet	<i>Chanos chanos</i>	3.1	30,000	91,842	180	30,614
8	Drift gillnet	Mugilidae	7.1	20,000	142,900	240	46,536
		<i>Scatophagus argus</i>	0.3	16,000	4,773		
		<i>Chanos chanos</i>	1.3	30,000	38,469		
9	Drift gillnet	<i>Scatophagus argus</i>	0.1	16,000	2,132	120	9,731
		<i>Chanos chanos</i>	0.4	30,000	12,823		
		Mugilidae	0.2	20,000	4,507		
10	Drift gillnet	<i>Chanos chanos</i>	4	30,000	120,066	210	45,231
		Mugilidae	1.9	20,000	38,243		
11	Drift gillnet	Mugilidae	0.7	20,000	13,521	240	18,241
		<i>Chanos chanos</i>	2	30,000	59,443		
12	Drift gillnet	Mugilidae	0.7	20,000	13,521	60	33,372
		<i>Chanos chanos</i>	0.7	30,000	19,851		
Average revenue IDR/hr							22,002

allowed a full 100% recovery in this basin).

With exception of the two lift-net installations present in 2012, there was no significant development in lift-net fishing directed at juvenile mullets until 2015 beyond the zero level. Thereafter, this type of fishing, however, developed very rapidly (Fig. 3; $F = 85.22$, $df = 4$, $p = 0.0027$). The number of lift-net installations counted from satellite images of the two tidal rivers increased markedly from 8 in June 2015, to 14 in February 2016, 32 in September 2017 and 38 in April 2018. The increase in lift-net fishing did not closely follow mangrove recovery but only started after mangrove recovery was well underway and increased in a constant linear fashion instead of at an increasing exponential rate (Fig. 3). Damastuti and De Groot (2017) studied mangrove-associated fisheries up to 2014 in the same area but made no mention of any significant fishing activity targeting finfish. They spoke only of two types of mangrove-associated fisheries which they termed “crab fishers” and “mudskipper fishers”. In addition to what the fishers had indicated in the interviews, this provided independent corroboration of our results that lift-net fishing in the tidal rivers was practically non-existent prior to 2014.

4. Discussion

Mangrove forests support livelihoods by providing food, timber, charcoal materials for local art and handicrafts as well as ecotourism possibilities (Armitage, 2002; Debrot et al., 2020). In addition, and more importantly, they provide coastal protection, fulfil essential ecological functions such as that of entrapping pollutants, nutrients and sediments and provide nursery and spawning habitat for important coastal fishery resources (Nagelkerken et al., 2008; Kimirei et al., 2013; Hutchison et al., 2014). Indonesia has lost about 40% of its mangroves since the 1980s (FAO 2007) but total losses for Java are around 70% (Ilman et al., 2016). Thanks to internationally increasing awareness regarding their ecological and socioeconomic significance, mangroves are seen as a NbS for ensuring coastal protection of tropical muddy coastlines (Lewis and Brown, 2014; Primavera et al., 2014; Winterwerp et al., 2020; Dey et al., 2021). Several recent studies show that the economic value of mangroves can far exceed the economic value of the same land used for aquaculture (Carandang et al., 2013; Malik et al., 2015) and that the

economic benefits of rehabilitation (in the Philippines) also exceed the investment costs (Agaton and Collera, 2022). Even so, acquiring support and finances for mangrove rehabilitation remains challenging and the need for support and in-kind input from those coastal communities most affected by mangrove loss is essential. This requires a demonstrable causal link between mangrove recovery and the recovery of livelihoods. In this study we use a combination of several independent methods and datasets (questionnaire-based interviews, assessments of developments in mangrove cover, catch assessments, lift net counts and a comparison with a published socio-economic reference study for the same area) to describe and assess the relationship between mangrove restoration and recovery of mangrove fishing as a local livelihood alternative.

The actual ecosystem contribution of habitat restoration (or recovery) in terms of on-site “production” are often confounded by “attraction” from adjacent areas (Da Costa et al., 2021; Hylkema et al., 2021). However, our results strongly suggest that the documented local increase in fishing productivity was most likely due to a local increase in habitat “productivity” resulting from mangrove rehabilitation and not due to “attraction”, which effectively would have meant depletion of fish resources from adjacent areas. Not only were the (mainly) juvenile fishes caught likely to have originated locally (as opposed to having swum in from farther away as adult fishes might), the basin also was not a unique or “isolated” mangrove area. Both flanking mangrove basins (one to the north and another to the south) showed highly significant exponential increases in mangrove coverage over the same study period (Fig. 4). As mangroves were thus well-represented in the flanking basins, the middle basin in which we documented fish catches should not have exerted any special “extra” attraction to fish to “artificially inflate” apparent fish abundance compared to the adjacent basins. Finally, if the documented increase in fishing had simply been based on more (adult) fish being attracted from the wider surroundings to the mangroves and not due to actual local productivity, then, fishing activity would have likely tracked mangrove development more closely. Adult fish are able to respond very rapidly to (new) habitat availability. Hence, as ecological processes of recovery necessarily involve time, the significant time lag we documented between mangrove recovery and actual fisheries recovery is further evidence of an actual ecological process having taken place. So while several studies already demonstrate a positive

Table 5Mean size in catch, mean size at maturity and asymptotic maximum size (L_∞) for fish species caught in artisanal nearshore fisheries in Timbulsloko.

Species	Mean size in catch		Mean size at maturity	L _∞	Source
	cm	(±SD)	cm	cm	
<i>Acanthopagrus berda</i> ^a	16.4	3.8	20–22	90	Fishbase ^b
<i>Acentrogobius cf. nebulosus</i>	22	–	–	18	Fishbase
<i>Ambassis</i> spp.	7	0	–	–	
<i>Arius cf. maculatus</i> ^a	21.3	3.2	>38	80	Fishbase
<i>Chanos chanos</i> ^a	32.2	7	68–70	180	Fishbase
<i>Eleutheronema tetradactylum</i>	22	0	20	200	Pember (2006)
<i>Elops machnata</i> ^a	42	7.1	50	118	Adams et al. (2014)
<i>Epinephelus coioides</i> ^a	22	4.1	25–30	120	Fishbase
<i>Eubleekeria</i> spp.	3	–	–	–	
<i>Gerres erythrorus</i>	12	–	<10	30	Sivashanthini et al. (2008)
<i>Johnius belangerii</i>	20	7.58	>9	30	Fishbase
<i>Lates calcarifer</i> ^a	38.9	13.3	60–70	200	fao.org/fishery/
<i>Lutjanus fuscescens</i> ^a	17	–	38.7	90	Allen, 1985/Jose et al., (2016)
<i>Lutjanus johnii</i> ^a	17	14.1	41.9	97	Allen (1985)
<i>Lutjanus russelli</i> ^a	14.5	3.5	21.5	50	Allen (1985)
<i>cf. Planiliza subviridis</i>	20.4	7.2	>14	40	Coad (2016)
<i>Oreochromis mossambicus</i>	22	–	15.4	39	Fishbase
Mudskippers	13.25	2.5	–	–	
<i>Parapocryptes cf. serperaster</i>	14.5	3.5	–	23	Fishbase
<i>Plotosus canius</i>	44.6	11.3	36.5	150	Khan et al. (2002)
<i>Scatophagus argus</i> ^a	12.4	1	>14	38	Fishbase
<i>Siganus javus</i>	14.5	5	–	53	Fishbase
<i>Sphyrnaea cf. jello/barracuda</i> ^a	42	–	>36.5/72	150/200	Hosseini et al., 2009/Kadison et al., (2010)
<i>Strongylura strongylura</i>	51	12.7	–	51.8	Karna et al. (2017)
<i>Terapon jarbua</i> ^a	12	0	21	36	Nandikeswari (2016)

^a indicates species being caught with a smaller mean size than their mean size at maturity.

^b <http://www.fishbase.org/>.

correlation between fish abundance and mangroves (e.g. Anneboina & Kumar 2017; Das, 2017), our “landscape-level” experiment approach to mangrove restorations has gone one small step further towards establishing a causal connection between mangroves and fisheries production.

Many studies on artisanal fisheries rely heavily on answers volunteered by fishers and these may be unreliable, especially if fishers fear that their answers could result in increased tax or management restrictions (e.g., Johnson, 2011). In our case, response rates to individual questions varied considerably from very high (96%) to relatively low (29%). This suggests that our 51 respondents felt little pressure to answer questions they could not or did not wish to answer and that the results of our questionnaire-based interviews provided an accurate assessment of fisher characteristics and views at the time of the survey. Clearly, mangrove recovery in our study area was still in the early stages as by 2018 less than 10% of its ultimate potential in the 419 ha backwater basin considered had been attained. Our study thus documents mangrove and mangrove-associated fisheries recovery trends and fisher views in the early stages of mangrove recovery. At the point in time of our creel survey (three last months of 2017), catch rates for the two most important mangrove net fisheries compared favourably to shrimp pond culture in terms of income per hour of effort, and thus served as a profitable alternative income source for the local community. However, only roughly half of the fishers were from the immediate surroundings while the other half came from far away. It was also clearly a “new” type of fishery, as not only indicated by the fishers themselves but also as corroborated by the study of Damastuti and De Groot (2017). In their study, which was conducted in 2014–2015 with 500 respondents from Timbulsloko and surrounding villages, only three individuals partially targeted mudskippers as the only mentioned finfish caught in mangrove areas (Damastuti and De Groot, 2017). Thus mangrove-associated fishing that targeted finfish had increased from practically zero in 2014–2015 (Damastuti and De Groot, 2017) to being a profitable livelihood option at the time of our survey at the end of 2017. Even though actual fish stock abundance was not measured, we interpret the increase

in lift-net fishing activity, and what the fishers themselves had indicated, to also mean that that the underlying fish stock abundance had likely also increased. This might explain how this “new” fishery option could have become interesting enough to attract many fishers from far beyond the local villages.

The results further showed that the linear increase in lift-net fishing initially lagged significantly behind compared to exponential mangrove recovery. Mangrove recovery was in fact already well-underway (Fig. 3) before lift-net fishing activity took off after 2014. If the increase in fishing had been due to more large fish being attracted from the surroundings to the mangroves and not due to local productivity, then, fishing activity would have likely tracked mangrove development more directly. However, it cannot be excluded that the lag in lift-net fishing might also have been due the time it took fishers to discover this new opportunity. We do not think the latter is a likely explanation because fishers in need of income would probably be very keen to key into any such new opportunities and the use of lift nets is widely practiced and well known to all. Moreover, for the inhabitants of our study area, financial reasons have been consistently found to be the strongest driver of occupational transitioning (Joseph et al., 2013).

While our results thus support the likely causal link between mangrove rehabilitation and ecosystem services relating to fisheries production, a few qualifications are important. Mangrove recovery in the study area involved many different initiatives. Therefore, any patterns detected in mangrove or associated fisheries recovery can clearly not be ascribed to any specific mangrove initiative but only to the cumulative efforts, as also even influenced by partial natural recovery. Our study was a landscape-level assessment for which statistical replication is generally problematic (Cunningham and Lindenmayer, 2017). Hence this work does not hold up to the standards of a carefully designed and replicated experiment that can formally prove or disprove cause and effect relationships between the observed increases in mangrove and fishing activity and the assumed underlying increase in fish abundance. Our data collection was further limited to the onset of the rainy-season and only considered diurnal fishing, whereas some nocturnal and/or

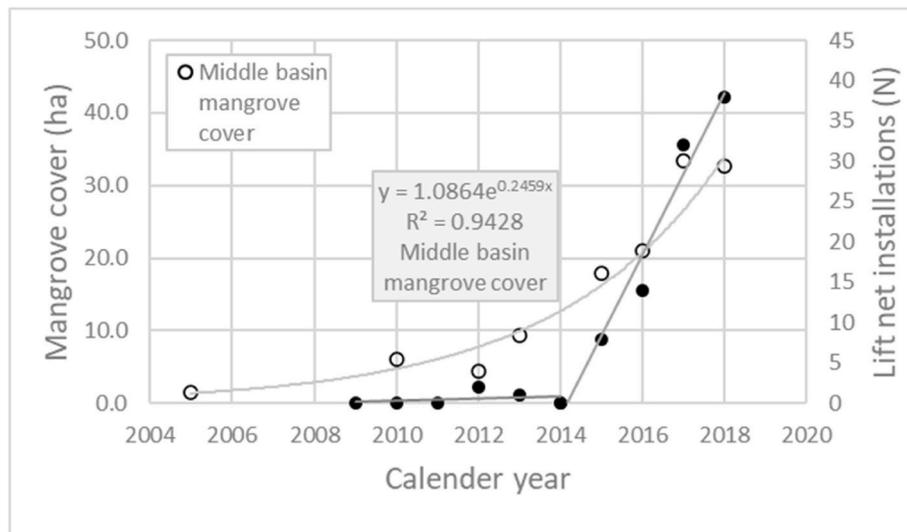


Fig. 3. Exponential increase in mangrove cover in the 419 ha middle basin since 2005, with a zero lift-net trend till 2014, followed by a strong linear increase in lift net fishing targeting finfish after 2014. Exponential fit: y is mangrove cover (ha) and x is year with 2005 as year 1.

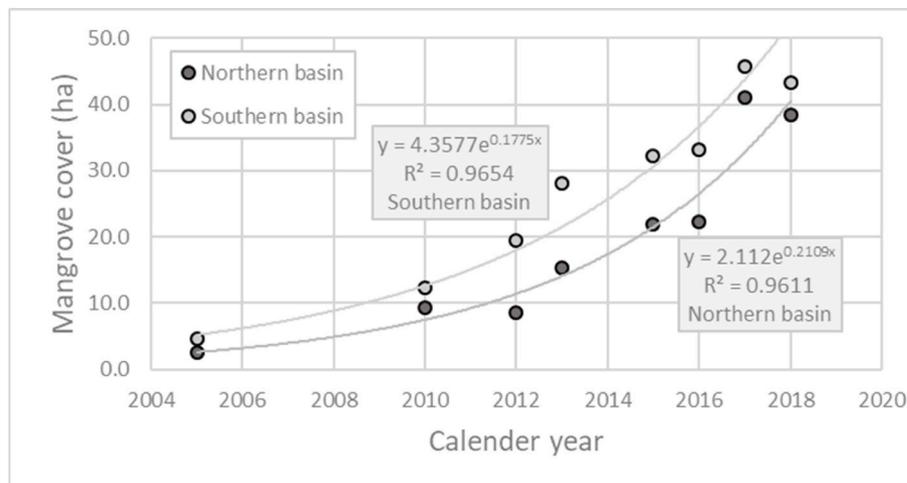


Fig. 4. Exponential increases in mangrove cover in northern and southern adjacent basins mirror the mangrove increase seen in the middle basin. Exponential fits: y is mangrove cover (ha) and x is year with 2005 as year 1.

crepuscular hook and line fishing also occurs but was not included. Finally, the study area is likely also subject to varying degrees of land subsidence caused by one or more of a combination of natural consolidation of soil layers, building loads or groundwater extraction, similar to the situation in the nearby city of Semarang (Abidin et al., 2013; Chaussard et al., 2013). If such is the case, then any recovery of fisheries might also be partly due the increase of water quality and water exchange due the increase in water depth. Hence, alternative explanations for the increase in fishing activity can clearly not be ruled out. It is good to point out that several other types of fishery take place in and around the mangroves or offshore of the study area and may have also experienced positive feedback from mangrove recovery (Sarwanto et al., 2016; Damastuti and De Groot, 2017; Hapsari et al., 2017). As our study focussed on only finfish catches closely associated with mangroves, it is certain that our study only documented a small part of the total potential positive effects that mangrove recovery likely had on the fisheries of importance to the villages. In fact, Carandang et al. (2013) showed that in different mangrove forest settings in the Philippines, the marketable value of fish associated with mangroves were well-superseded by the value of crabs, molluscs and shrimp, in that order.

Tropical coastal communities reliant on small-scale fisheries are

among the most vulnerable to climate change (Cinner et al., 2018). Such fisheries dominate the fisheries sector in Indonesia (Sularso, 2008) and in some areas more than 90% of fishing activity is conducted without boats (Sarwanto et al., 2016). However, very few studies give insight into such near-coastal fisheries. Dudley and Tampubulon (1987) provide baseline information on seine- and lift-net fisheries of the north coast of Java but give no information on fisheries that take place in direct association with mangroves. Therefore, a few comments are certainly in place regarding the species documented in the catches. Sukardjo (2004), Kusmana (2014) and Sihombing et al. (2017) reviewed the status of Indonesian mangroves and resources and conclude that, depending on the location, the most important species of commercial interest from mangrove areas were Mugilidae spp., Milkfish, tilapia (Cichlidae spp.), snappers (Lutjanidae spp.) and Barramundi. Our results largely corroborated these general findings. Greenback mullet (84%) and Milkfish were the principal species caught in lift nets. In the surrounding areas, Milkfish are cultured in the backwater pond areas so it remains a question whether the Milkfish documented in the coastal catches represent true natural production or whether they might represent spill-over from culture in the backwater areas. In our case tilapia (Mozambique tilapia) was caught only once. We ascribe the low

abundance of tilapia spp. in our documented catches to the generally high salinity of the areas where the fishing in this study took place.

The principal species caught by hook-and-line were Barramundi, Gray Eel-catfish and the Goldsilk Seabream followed by Orange-spotted Grouper, Pickhandle Barracuda and several snappers. These are generally high-value predatory species. Gray Eel-catfish was stated as the most cherished target species by the fishers and was the second-most important species (by weight) in the catches. This species is also very important elsewhere in southeast Asia such as nearby Malaysia where it comprises 21% of the commercial landings along the west coast and where hook-and-line accounts for 20% of the total landings of the species (Leh et al., 2012).

Drift gill nets caught principally Greenback Mullet (47%), Milkfish (31%) and Barramundi (9%) as well as a wider variety of other fishes. Interesting among these were especially: Belanger's Croaker, listed as important in small scale fisheries by Chong et al. (1990), Simanjuntak and Rahardjo (2001), Sukardjo (2004) and Sitorus et al. (2017) and the Fourfinger Threadfin, mentioned elsewhere also by Salini et al. (1998), Pember (2006) and Nesarul et al. (2014). According to the fishers, the gear they used in this area had dramatically changed since 2014 from mainly scoop net fishing (for shrimps) to hook-and-line, lift-net and drift gillnet fishing. This is corroborated by the fact that this kind of fishing was not (yet) recorded from mangrove areas in the 2014–2015 study by Damastuti and De Groot (2017). Shrimp and other crustaceans have remained abundant in the mangrove rehabilitation area but are also a key food source for many of the large predatory fish that visit these areas such as snappers (Kiso and Mahyam, 2003; Nuraini et al., 2007), Barramundi, Fourfinger Threadfin (Salini et al., 1998), and Belanger's Croaker (Simanjuntak and Rahardjo, 2001). All these species were documented in the catches. Now that the latter species have begun to recover in abundance, fishing activity in the mangrove channels appears to have quickly redirected itself to these larger more valuable commercial species instead of the small shrimp.

Based on average fish market prices, and documented fish catches, fishing with drift nets or lift nets generates about 1.05 ± 0.82 USD/hr worth of catch in Timbulsloko. This compares favourably to restored mud crab fisheries thanks to mangrove rehabilitation in Aceh province, which generated 5.16 USD/fishing night (Wisibono and Sualia, 2008) two years after replanting took place. In Aceh, fishing was recorded to generate an income of 4.82 USD (70,000 IDR) per fishing day, or 0.54 USD/hr (8,750 IDR), assuming 8 h of fishing effort per day (Wisibono and Sualia, 2008). With our estimated catch rates of 1.05 ± 0.82 USD/hr, fishing (with lift and or gill nets and excluding handlines) as an income-generating activity compared favourably to aquaculture in terms of (net) income yield (0.67 ± 0.53 USD/hr, assuming a 40-hr work week) as currently generated by aquaculture activities in Timbulsloko (Ariyati et al., 2016).

5. Conclusions

By means of several independent lines of evidence (questionnaire-based interviews, measurement of catch characteristics, lift net counts, measurement of developments in mangrove cover and comparison to a published baseline socio-economic and fisheries assessment) we show that in our study area, proven mangrove recovery was accompanied by a large and rapid increase of mangrove-associated fishing activity targeting finfish.

Fishing generated about 1.05 ± 1.11 (SD) USD/hr worth of catch to professional fishers. As per 2017, fishing had become a profitable alternative source of income in our study area, whereas this kind of fishery practically did not exist prior to 2014 (Damastuti and De Groot, 2017). At the time of our study, mangrove cover was less than 10% of its ultimate cover potential and the rate of increase was exponential, as is to be expected in an early stage of recovery. If mangrove recovery is allowed to continue successfully in the area, and as long as overfishing does not become excessive, a similar survey as ours in the near future

should be able to document a further increase in yields and size-structure for mangrove-associated fish species. Therefore, we can strongly recommend a follow-up study to be conducted in a few years as well as in different seasons to assess if recovery will indeed continue on course.

Our findings are of significant socio-economic value. Many muddy coastal areas have been deforested and overexploited in the past, resulting in serious coastal erosion, increased environmental vulnerability and loss of livelihoods (Abidin et al., 2013; Chaussard et al., 2013; Joseph et al., 2013; Tonnejck et al., 2015; Akber et al., 2018). The need to restore mangroves is urgent but a parallel development of sustainable and mangrove-friendly livelihood alternatives (e.g., Rejeki et al., 2012; Alam et al., 2021; Islam et al., 2021) is essential for mangrove restoration to be successful in the long-term. Without alternatives the inhabitants will have little other option than to revert to their old unsustainable practices of mangrove removal (Debrot et al., 2020). In this regard, the development of profitable mangrove-associated fisheries in our study area is particularly encouraging.

Our results finally also highlight two major management challenges for rehabilitation projects. First we point to the lag between mangrove recovery and the ensuing development of mangrove finfish fisheries as found in this study. While mangrove restoration activities and mangrove recovery in our area had begun as early as 2001 (Damastuti and De Groot, 2017), significant fisheries development only started after 2014 (Fig. 3). Hence, patience and a long-term perspective with mangrove restoration are essential in order to witness ultimate fisheries effects. Secondly we note that fishers from wider surrounding areas responded quickly to the ability to obtain better catches in the rehabilitation area and were largely catching immature fish. Intensified fishing directed towards juvenile fish can be counter-productive and possibly result in both recruitment overfishing and growth-overfishing (*sensu* Ben-Hasan et al., 2021) and concomitant lower fishery yields. In addition, endangering the recruitment of the targeted (large, predatory) species could cause a number of additional unforeseen environmental disruptions of the coastal ecosystem. Thus our findings strongly support the need to actively manage fisheries in mangrove rehabilitation areas to avoid rapid fisheries overexploitation that could result in depletion and possible cascading negative effects for the whole coastal ecosystem. While at our site there was considerable community management of mangrove restoration, there was yet no management of mangrove fisheries. Overexploitation by fishers flocking in from elsewhere and causing local residents to miss the hard-earned benefits from the mangrove rehabilitation they supported could discourage the latter from continuing to support vitally-needed mangrove rehabilitation.

Author statement

Adolphe O Debrot: Conceptualization; Data curation; Formal analysis; Funding acquisition; Methodology; Project administration; Supervision; Visualization; Writing - original draft; Writing - review & editing. Anouk Plas: Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing - original draft. Herry Boesono: Funding acquisition; Investigation; Methodology; Resources; Supervision; Validation; Writing - review & editing. Kukul Prihantoko: Funding acquisition; Investigation; Methodology; Resources; Supervision; Validation; Writing - review & editing. Martin J. Baptist: Conceptualization; Formal analysis; Funding acquisition; Methodology; Visualization; Writing - review & editing. Albertinka J. Murk: Formal analysis; Funding acquisition; Methodology; Writing - review & editing. Femke H. Tonnejck: Funding acquisition; Methodology; Project administration; Resources; Validation; Writing - review & editing.

Acknowledgments

This research made use of the framework set up by Building with Nature Indonesia, which is a programme by Ecoshape, Wetlands

International, the Indonesian Ministry of Marine Affairs and Fisheries (MMAF), the Indonesian Ministry of Public Works and Housing (PU) and associated partners. The Netherlands Sustainable Water Fund provided core funding for this work through project number FDW14R14. Additional co-funding was provided to Wageningen University and Research by the Netherlands Ministry of Agriculture, Nature and Food Quality through grant KB36 #4318300114. The authors wish to thank Olav Dobber and the students from Diponegoro University for their able assistance to Anouk Plas while collecting data in the field. Pak Slamet, Pak Muis are thanked for providing a place to stay and for their all-around hospitality during the fieldwork period. Pak Yus Rusila Noor of Wetlands International, Bogor, is thanked for providing many pieces of missing local information. Jenny Cremer, Jessica Schop and Jan-Tjalling van der Wal mapped and calculated mangrove covers and assisted with our figures. The local Wetlands field team, led by Pak Eko Has is thanked for logistical support and advice, and Apri Susanto Astra, the Wetlands Coastal Safety Manager is thanked for setting up initial contacts and arrangements. We are very grateful to Associate Editor Dr. K. Krauss and two anonymous reviewers for providing helpful suggestions and critiques on which basis major improvement were made to our manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecss.2022.107761>.

References

- Abidin, H.Z., Andreas, H., Gumilar, I., Sidiq, T.P., Fukuda, Y., 2013. Land subsidence in coastal city of Semarang (Indonesia): characteristics, impacts and causes. *Geomatics, Nat. Hazards Risk* 4, 226–240.
- Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J., Sala, E., 2008. Mangroves in the Gulf of California increase fishery yields. *Proc. Natl. Acad. Sci. Unit. States Am.* 105 (30), 10456–10459.
- Adams, A.J., Horodysky, A.Z., McBride, R.S., Guindon, K., Shenker, J., MacDonald, T.C., Harwell, H.D., Ward, R., Carpenter, K., 2014. Global conservation status and research needs for tarpons (Megalopidae), ladyfishes (Elopidae) and bonefishes (Albulidae). *Fish Fish.* 15 (2), 280–311.
- Agaton, C.B., Collera, A.A., 2022. Now or later? Optimal timing of mangrove rehabilitation under climate change uncertainty. *For. Ecol. Manag.* 503, 119739.
- Akber, M.A., Patwary, M.M., Islam, M.A., Rahman, M.R., 2018. Storm protection service of the Sundarbans mangrove forest, Bangladesh. *Nat. Hazards* 94 (1), 405–418.
- Alam, M.I., Debrot, A.O., Ahmed, M.U., Ahsan, M.N., Verdegem, M.C.J., 2021. Synergistic effects of mangrove litter and supplemental feed on water quality, growth and survival of shrimp (*Penaeus monodon*, Fabricius, 1798) post larvae. *Aquaculture* 545, 737237.
- Allen, G.R., 1985. Snappers of the world. In: An Annotated and Illustrated Catalogue of Lutjanid Species Known to Date. FAO Species Catalogue. Vol. 6. FAO: Rome.
- Altamirano, A., Miranda, A., Aplin, P., Carrasco, J., Catalán, G., Cayuela, L., Fuentes-Castillo, T., Hernández, A., Martínez-Harms, M.J., Peluso, F., Prado, M., Reyes-Riveros, R., Van Holt, T., Vergara, C., Zamorano-Elgueta, C., Di Bella, C., 2020. Natural forests loss and tree plantations: large-scale tree cover loss differentiation in a threatened biodiversity hotspot. *Environ. Res. Lett.* 15 (12), 124055.
- Anneboina, L.R., Kumar, K.K., 2017. Economic analysis of mangrove and marine fishery linkages in India. *Ecosys. Serv.* 24, 114–123.
- Ariyati, R.W., Widowati, L.L., Bosma, R.H., 2016. Socio-economic and Ecological Characteristics of Aquaculture in the Villages Threatened by the Sea in Demak District, North Java. *Asian-Pacific Aquaculture, APA-2016* (Surabaya, Indonesia).
- Armitage, D., 2002. Socio-institutional dynamics and political ecology of mangrove forest conservation in Central Sulawesi, Indonesia. *Global Environ. Change* 12 (3), 203–217.
- Ben-Hasan, A., Walters, C., Hordyk, A., Christensen, V., Al-Husaini, M., 2021. Alleviating growth and recruitment overfishing through simple management changes: insights from an overexploited long-lived fish. *Mar. Coast. Fisheries* 13 (2), 87–98.
- Blaber, S.J.M., 1986. Feeding selectivity of a guild of piscivorous fish in mangrove areas of north-west Australia. *Mar. Freshw. Res.* 37 (3), 329–336.
- Blaber, S.J.M., Brewer, D.T., Salini, J.P., 1989. Species composition and biomasses of fishes in different habitats of a tropical northern Australian estuary: their occurrence in the adjoining sea and estuarine dependence. *Estuar. Coast Shelf Sci.* 29, 509–531.
- Bosma, R.H., Debrot, D., Rejeki, S., Tonneijck, F., Yuniati, A.W., Sihombing, W., 2020. Associated Mangrove Aquaculture Farms; Building with Nature to Restore Eroding Tropical Muddy Coasts. *Ecoshape technical report*, Dordrecht, The Netherlands.
- Carandang, A.P., Camacho, L.D., Gevaña, D.T., Dizon, J.T., Camacho, S.C., de Luna, C.C., Rebugio, L.L., 2013. Economic valuation for sustainable mangrove ecosystems management in Bohol and Palawan, Philippines. *For. Sci. Technol.* 9 (3), 118–125.
- Chaussard, E., Amelung, F., Abidin, H., Hong, S.H., 2013. Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction. *Rem. Sens. Environ.* 128, 150–161.
- Chong, V.C., Sasekumar, A., Leh, M.U.C., D’Cruz, R., 1990. The fish and prawn communities of a Malaysian coastal mangrove system, with comparisons to adjacent mud flats and inshore waters. *Estuar. Coast Shelf Sci.* 31 (5), 703–722.
- Cinner, J.E., Adger, W.N., Allison, E.H., Barnes, M.L., Brown, K., Cohen, P.J., Gelcich, S., Hicks, C.C., Hughes, T.P., Lau, J., Marshall, N.A., Morrison, T.H., 2018. Building adaptive capacity to climate change in tropical coastal communities. *Nat. Clim. Change* 8 (2), 117–123.
- Coad, B.W., 2016. Review of the freshwater mullets of Iran (family Mugilidae). *Iranian J. Ichthyol.* 4 (2), 75–130.
- Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C.R., Renaud, F.G., Welling, R., Walters, G., 2019. Core principles for successfully implementing and upscaling Nature-based Solutions. *Environ. Sci. Pol.* 98, 20–29.
- Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based Solutions to Address Global Societal Challenges. IUCN, Gland, Switzerland, p. 97 xiii +.
- Cunningham, R.B., Lindenmayer, D.B., 2017. Approaches to landscape scale inference and study design. *Curr. Landsc. Ecol. Rep.* 2 (1), 42–50.
- Da Costa, I.D., Da Silva Santos, J.L., Costa, L.L., Lima, J.S., Zalmon, I.R., 2021. Reproductive potential and production role of artificial reefs-Southeastern Brazil. *Estuar. Coast Shelf Sci.*, 107710.
- Das, S., 2017. Ecological restoration and livelihood: contribution of planted mangroves as nursery and habitat for artisanal and commercial fishery. *World Dev.* 94, 492–502.
- Damastuti, E., De Groot, R., 2017. Effectiveness of community-based mangrove management for sustainable resource use and livelihood support: a case study of four villages in Central Java, Indonesia. *J. Environ. Manag.* 203, 510–521.
- Damastuti, E., De Groot, R., 2018. Participatory ecosystem service mapping to enhance community-based mangrove rehabilitation and management in Demak, Indonesia. *Reg. Environ. Change* 19 (1), 65–78.
- Debrot, A.O., Nagelkerken, I., 2000. User perceptions on coastal resource state and management options in Curaçao. *Rev. Biol. Trop.* 48 (1), 95–106.
- Debrot, A.O., Veldhuizen, A., Van Den Burg, S.W., Klapwijk, C.J., Islam, M., Alam, M., Ahsan, M.N., Ahmed, M.U., Hasan, S.R., Fadilah, R., Noor, Y.R., Pribadi, R., Rejeki, S., Damastuti, E., Koopmanschap, E., Reinhard, S., Terwisscha van Scheltinga, C., Verburg, C., Poelman, M., 2020. Non-timber forest product livelihood-focused interventions in support of mangrove restoration: a call to action. *Forests* 11 (11), 1224.
- De Vriend, H.J., Van Koningsveld, M., Aarninkhof, S.G.J., De Vries, M.B., Baptist, M.J., 2015. Sustainable hydraulic engineering through building with nature. *J. Hydro-environ. Res.* 9 (2), 159–171.
- Dey, A., Alfred, J.R.B., Chowdhury, B.R., Censkowsky, U., 2021. Mangroves, as shore engineers, are nature-based solutions for ensuring coastal protection. In: Prasad (Ed.), *Handbook of Ecological and Ecosystem Engineering*. John Wiley & Sons, Ltd., Sussex, U.K. pp. 317–331.
- Dudley, R.G., Tampubolon, G., 1987. The artisanal seine- and lift-net fisheries of the north coast of Java. *Aquacult. Fish. Manag.* 17, 167–184.
- Duncan, C., Primavera, J.H., Petteorelli, N., Thompson, J.R., Loma, R.J.A., Koldewey, H. J., 2016. Rehabilitating mangrove ecosystem services: a case study on the relative benefits of abandoned pond reversion from Panay Island, Philippines. *Mar. Pollut. Bull.* 109 (2), 772–782.
- Froese, R., Pauly, D., 2018. *FishBase*. <http://www.fishbase.org>. (Accessed 21 January 2018).
- Hapsari, T.D., Jayanto, B.B., Fitri, A.D., Triarso, I., 2017. Business profile of boat lift net and stationary lift net fishing gear in Morodemak Waters Central Java. In: IOP Conf. Series: Earth and Environmental Science, vol. 116, pp. 1–9.
- Hosseini, A., Kochanian, P., Marammazi, J., Yavari, V., Savari, A., Salari-Aliabadi, M.A., 2009. Length-weight relationship and spawning season of *Sphyrna jello* C., from Persian Gulf. *Pakistan J. Sociol. Sci.* 12 (3), 296–300.
- Hutchison, J., Spalding, M., Zu Ermgassen, P., 2014. The role of mangroves in fisheries enhancement. In: *The Nature Conservancy and Wetlands International*, p. 54.
- Hylkema, A., Debrot, A.O., Osinga, R., Bron, P.S., Heesink, D.B., Izioka, A.K., Reid, C.B., Rippen, J.C., Treibitz, T., Yuval, M., Murk, A.J., 2020. Fish assemblages of three common artificial reef designs during early colonization. *Ecol. Eng.* 157, 105994.
- Hylkema, A., Hakkaart, Q.C., Reid, C.B., Osinga, R., Murk, A.J., Debrot, A.O., 2021. Artificial reefs in the Caribbean: a need for comprehensive monitoring and integration into marine management plans. *Ocean Coast Manag.* 209, 105672.
- Ilman, M., Dargusch, P., Dart, P., 2016. A historical analysis of the drivers of loss and degradation of Indonesia’s mangroves. *Land Use Pol.* 54, 448–459.
- Islam, M.N., Rahman, F., Papri, S.A., Faruk, M.O., Das, A.K., Adhikary, N., Debrot, A.O., Ahsan, M.N., 2021. Water hyacinth (*Eichhornia crassipes* (Mart.) Solms.) as an alternative raw material for the production of bio-compost and handmade paper. *J. Environ. Manag.* 294, 113036.
- Ismadi, R., Yamindago, A., 2015. Restoring coastal ecosystems - a case study Malang and Gresik regency, Indonesia. *J. Coast Conserv.* 19, 119–130.
- Johnson, T.R., 2011. Fishermen, scientists, and boundary spanners: cooperative research in the US *Illex* squid fishery. *Soc. Nat. Resour.* 24 (3), 242–255.
- Jose, E.D., van Beijnen, J., Calago, S., 2016. First record of the elusive freshwater snapper *Lutjanus fuscus* (valenciennes, 1830) in palawan, Philippines. In: *The Palawan Scientist*, 8, pp. 62–65.
- Joseph, V., Thornton, A., Pearson, S., Paull, D., 2013. Occupational transitions in three coastal villages in Central Java, Indonesia, in the context of sea level rise: a case study. *Nat. Hazards* 69 (1), 675–694.

- Kadison, E., D'alessandro, E.K., Davis, G.O., Hood, P.B., 2010. Age, growth, and reproductive patterns of the great barracuda, *Sphyraena barracuda*, from the Florida Keys. *Bull. Mar. Sci.* 86 (4), 773–784.
- Karna, S.K., Mukherjee, M., Suresh, V.R., Manna, R.K., Manas, H.M., Raman, R.K., 2017. Length-weight and length-length relationship of *Strongylura strongylura* (van Hasselt, 1823) and *Hyporhamphus limbatus* (Valenciennes, 1847) from Chilika Lake, India. *J. Appl. Ichthyol.* 33 (3), 640–641.
- Khan, M.S.A., Alam, M.J., Rheman, S., Mondal, S., Rahman, M.M., 2002. Study on fecundity and GSI of Brackish water catfish *Plotosus canius* (Hamilton-Buchanan). *Biol. Sci.* 2, 232–234.
- Kimirei, I.A., Nagelkerken, I., Mgaya, Y.D., Huijbers, C.M., 2013. The mangrove nursery paradigm revisited: otolith stable isotopes support nursery-to-reef movements by Indo-Pacific fishes. *PLoS One* 8 (6), e66320.
- Kiso, K., Mahyam, M.I., 2003. Distribution and feeding habits of juvenile and young John's snapper *Lutjanus johnii* in the Matang mangrove estuary, west coast of Peninsular Malaysia. *Fish. Sci.* 69 (3), 563–568.
- Kusmana, C., 2014. Distribution and current status of mangrove forests in Indonesia. In: Faridah-Hanum, et al. (Eds.), *Mangrove Ecosystems of Asia*. Springer, New York, NY, pp. 37–60.
- Leh, M.U.C., Sasekumar, A., Chew, L.L., 2012. Feeding biology of eel catfish *Plotosus caninus* Hamilton in a Malaysian mangrove estuary and mudflat. *Raffles Bull. Zool.* 60 (2), 551–557.
- Lewis, R.R., Brown, B., 2014. *Ecological Mangrove Rehabilitation: a field manual for practitioners*. In: *Restoring Coastal Livelihoods Program*. www.rcl.or.id.
- Malik, A., Fensholt, R., Mertz, O., 2015. Economic valuation of mangroves for comparison with commercial aquaculture in South Sulawesi, Indonesia. *Forests* 6 (9), 3028–3044.
- Manson, F.J., Loneragan, N.R., Skilleter, G.A., Phinn, S.R., 2005. An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions. *Oceanogr. Mar. Biol.* 2005, 493–524.
- Mazlan, A.G., Abdullah, S., Shariman, M.G., Arshad, A., 2008. On the biology and bioacoustic characteristic of spotted catfish *Arius maculatus* (Thunberg 1792) from the Malaysian Estuary. *Res. J. Fish. Hydrobiol.* 3, 63–70.
- Meli, P., Rey Benayas, J.M., Balvanera, P., Martinez Ramos, M., 2014. Restoration enhances wetland biodiversity and ecosystem service supply, but results are context-dependent: a meta-analysis. *PLoS One* 9 (4), e93507.
- Nandikeswari, R., 2016. Size at first maturity and maturity stages of *Terapon jarbua* (Forsskal, 1775) from Pondicherry Coast, India. *J. Fish* 4 (2), 385–389.
- Nagelkerken, I.S.J.M., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Meynecke, J.-O., Pawlik, J., Penrose, H.M., Sasekumar, A., Somerfield, P.J., 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. *Aquat. Bot.* 89 (2), 155–185.
- Nesarul, H.M., Hena, M.A., Saifullah, S.M., Idris, M.H., 2014. Breeding biology of *Eleutheronema tetradactylum* (Shaw, 1804) from the Bay of Bengal, Indian ocean. *World Appl. Sci. J.* 30 (2), 240–244.
- Nuraini, S., Carballo, E.C., Van Densen, W.L., Machiels, M.A., Lindeboom, H.J., Nagelkerke, L.A., 2007. Utilization of seagrass habitats by juvenile groupers and snappers in Banten Bay, Banten Province, Indonesia. *Hydrobiologia* 591 (1), 85–98.
- Pember, M.B., 2006. Characteristics of Fish Communities in Coastal Waters of North-Western Australia, Including the Biology of the Threadfin Species *Eleutheronema Tetradactylum* and *Polydactylus Macrochir*. Doctoral dissertation. Murdoch University, p. 286.
- Potapov, P., Siddiqui, B.N., Iqbal, Z., Aziz, T., Zzaman, B., Islam, A., Pickens, A., Y Talero, Y., Tyukavina, A., Turubanova, S., Hansen, M.C., 2017. Comprehensive monitoring of Bangladesh tree cover inside and outside of forests, 2000–2014. *Environ. Res. Lett.* 12 (10), 104015.
- Primavera, J.H., Yap, W.G., Savaris, J.P., Loma, R.J.A., Moscoso, A.D.E., Coching, J.D., Montilijao, C.L., Poingan, R.P., Tayo, I.D., 2014. *Manual on Mangrove Reversion of Abandoned and Illegal Brackish Water Fishponds – Mangrove Manual Series No. 2*. London, UK.
- Rejeki, S., Debrot, A.O., van den Brink, A.M., Ariyati, R.W., Lakshmi Widowati, L., 2021. Increased production of green mussels (*Perna viridis*) using longline culture and an economic comparison with stake culture on the north coast of Java, Indonesia. *Aquacult. Res.* 52 (1), 373–380.
- Rejeki, S., Suryanto, A., Hutabarat, J., Ruswahyuni, S.A., 2012. Evaluation of idle eroded coastal water for mariculture based on trophic saprobic index analysis (Case Study: coast of Sayung Distric Demak, Central Java Indonesia). *J. Coast Dev.* 15 (3), 324–333.
- Roa-Ureta, R.H., Santos, M.N., Leitão, F., 2019. Modelling long-term fisheries data to resolve the attraction versus production dilemma of artificial reefs. *Ecol. Model.* 407, 108727.
- Salini, J.P., Brewer, D.T., Blaber, S.J.M., 1998. Dietary studies on the predatory fishes of the Norman River Estuary, with particular reference to penaeid prawns. *Estuar. Coast Shelf Sci.* 46 (6), 837–847.
- Sarwanto, C., Wiyono, E.S., Nurani, T.W., Haluan, J., 2016. Characterization of small scale fisheries in southern coast of Java, Indonesia. *Indian J. Fish.* 63 (1), 102–106.
- Sasekumar, A., 1978. The value of the mangrove ecosystem and its pollution problems. In: *Lectures Presented at the Fifth FAO/SIDS Workshop on Aquatic Pollution in Relation to Protection of Living Resources*, 17 Jan.- 7 Feb. 1977. Manila, Philippines. FAO, Rome, Italy, 332–342.
- Sheaves, M., 1995. Large lutjanid and serranid fishes in tropical estuaries: are they adults or juveniles? *Mar. Ecol. Prog. Ser.* 129, 31–40.
- Sihombing, V.S., Gunawan, H., Sawitri, R., 2017. Diversity and community structure of fish, plankton and benthos in Karangsong mangrove conservation areas, indramayu, west Java, Indonesia. *Biodiversitas* 18 (2), 601–608.
- Simanjuntak, C.P.H., Rahardjo, M.R., 2001. Food habits of Belanger's croaker, *Johnius belangerii* in mangrove waters, Mayangan coast, west Java. *J. Ikhtiologi Indonesia* 1 (2), 11–17.
- Sitorus, H., Lesmana, I., Tarigan, R., 2017. Relationship of mangrove density with fish diversity in the waters of mangrove area at lubuk Kertang village, langkat district of north Sumatera. *Inter. J. Fish. Aquatic Stud.* 5 (5), 266–271.
- Sivashanthini, K., Charles, G.A., Shutharshan, S., 2008. Fecundity studies of *Gerres abbreviatus* (Bleeker, 1850) from the Jafina lagoon, Sri Lanka. *J. Fish. Aquat. Sci.* 3 (5), 320–327.
- Srikandace, Y., Priatni, S., Pudjiraharti, S., Kosasih, W., Indrarti, L., 2017. Kerong fish (*Terapon jarbua*) peptone production using papain enzyme as nitrogen source in bacterial media. In: *IOP Conference Series: Earth and Environmental Science*, vol. 60, 12–05, 1.
- Sukardjo, S., 2004. Fisheries associated with mangrove ecosystem in Indonesia: a view from a mangrove ecologist. *Biotropia-The Southeast Asian J. Tropical Biol.* 23, 13–39.
- Sularso, A., 2008. *Artisanal Fisheries in Indonesia*. Directorate General of Surveillance and Controlling on Marine Fisheries. Ministry of Marine Affairs and Fisheries, Indonesia.
- Sumaila, U.R., Marsden, A.D., Watson, R., Pauly, D., 2007. A global ex-vessel fish price database: construction and applications. *J. Bioecon.* 9, 39–51.
- Taufani, A., de Lucas Pardo, M., Van Wesenbeeck, B., 2018. Exploratory integrated water resources management (IWRM) study in Demak coastal area: water availability and water Users. Ecosystem-based adaptation at scale through Building with Nature: towards Resilient Coasts in Indonesia 41. *Deltares report 1220476-000-ZKS-0006*.
- Tonneijck, F., Winterwerp, H., Van Wesenbeeck, B., Bosma, R., Debrot, A.O., Rusila Noor, Y., Wilms, T., 2015. Building with Nature Indonesia Securing Eroding Delta Coastlines: Design and Engineering Plan. *Ecoshape Foundation, Dordrecht, The Netherlands*, p. 65.
- Walpole, R.E., Myers, R.H., 1978. *Probability and Statistics for Scientists and Engineers*, second ed. MacMillan Publ. Co, New York, p. 580.
- Walton, M.E., Le Vay, L., Lebata, J.H., Binas, J., Primavera, J.H., 2007. Assessment of the effectiveness of mangrove rehabilitation using exploited and non-exploited indicator species. *Biol. Conserv.* 138 (1–2), 180–188.
- Walton, M.E.M., Samonte-Tan, G., Primavera, J.H., Edwards-Jones, G., Le Vay, L., 2006. Are mangroves worth replanting? The direct economic benefits of a community-based reforestation project. *Environ. Conserv.* 33, 335–343.
- Wilms, T., Van Der Goot, F., Debrot, A.O., 2017. Building with Nature - an integrated approach for coastal zone solutions using natural, socio-economic and institutional processes. In: *Coasts & Ports Conference, Cairns*, 21-23 June 2017, p. 7.
- Winterwerp, J.C., Albers, T., Anthony, E.J., Friess, D.A., Mancheño, A.G., Moseley, K., Muhari, A., Naipal, S., Noordermeer, J., Oost, A., Saengsupavanich, C., Tas, S.A.J., Tonneijck, F.H., Wilms, T., Van Bijsterveldt, C., Van Eijk, P., Van Lavieren, E., Van Wesenbeeck, B.K., 2020. Managing erosion of mangrove-mud coasts with permeable dams—lessons learned. *Ecol. Eng.* 158, 106078.
- Wisibono, I.T.C., Sualia, I., 2008. An Assessment of Lessons Learnt from the “Green Coast Project” in Nanggroe Aceh Darussalam (NAD) Province and Nias Island, Indonesia (Period 2005-2008). *Wetlands International – Indonesia Programme, Bogor, Java*.