Ambio 2022, 51:1963–1977
https://doi.org/10.1007/s13280-022-01720-4

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RESEARCH ARTICLE

Economic incentives drive the conversion of agriculture to aquaculture in the Indian Sundarbans: Livelihood and environmental implications of different aquaculture types

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Received: 18 August 2021 / Revised: 27 November 2021 / Accepted: 16 February 2022 / Published online: 18 March 2022

Abstract Expansion of aquaculture in the Sundarbans Biosphere Reserve (SBR) is irreversibly replacing agricultural land and the drivers of this change are disputed. Based on in-depth interviews with 67 aquaculture farmers, this paper characterizes major aquaculture types in the SBR, their impacts, and identifies drivers of conversion from agricultural land. Aquaculture types included *traditional*, *improved-traditional*, *modified-extensive,* and *semi-intensive* systems. Extensive capture of wild shrimp larvae is environmentally harmful but constitutes an important livelihood. Semi-intensive aquaculture of exotic shrimp (*Litopenaeus vannamei*) has much higher unit-area profitability than other types but involves greater financial risk. Profitability is the main driver for the transition from agriculture, but environmental factors such as lowered crop yields and cyclone impacts also contributed. Many conversions from agriculture to aquaculture are illegal according to the stakeholders. Existing legislation, if enforced, could halt the loss of agriculture, while the promotion of improved-traditional aquaculture could reduce the demand for wild seed.

Keywords Agriculture · Aquaculture types · Drivers · Farmers' perception · Indian Sundarbans Biosphere Reserve · Sustainability

INTRODUCTION

Aquaculture is a rapidly expanding sector in the Sundarbans Biosphere Reserve (SBR), West Bengal, India, as in many other tropical coastal areas of the world. The state of West Bengal is the highest producer of tiger shrimp (*Penaeus monodon*) in India producing 50 000 tonnes from an area of 51 000 ha (Handbook on Fisheries Statistics 2018) of which the major portion comes from the transitional (i.e., inhabited area) zone of the Indian SBR. There is a dearth of data that demarcates the area under freshwater and brackish water aquaculture, nor different aquaculture styles. Chopra et al. (2009) reported that brackish water aquaculture constitutes the major portion of the total aquaculture area. Brackish water aquaculture in this region started expanding in 2001 (Hazra et al. 2010) and at present, there is a trend of transition from agriculture to aquaculture and especially to brackishwater aquaculture (Ghosal et al. 2019). The conversion of agricultural land in this region has been ongoing for a few decades, drawing the attention of both researchers and policymakers (Chopra et al. 2009; Sánchez-Triana et al. 2014; DasGupta et al. 2019). Remote sensing shows that the aquaculture area has increased 2–3% annually in the last two decades (DasGupta et al. 2019; Giri et al. 2021) of which 98% (average 821.9 ha year^{-1}) have originated from the conversion of agricultural land. Different reasons behind this proliferation of aquaculture and land-use conversion from agriculture have been reported in earlier studies, including higher profitability, high market demand, reduced agricultural productivity, and detrimental effects on agriculture production from natural hazards like cyclones (Chopra et al. 2009; Sánchez-Triana et al. 2014, 2018; Dubey et al. 2017; DasGupta et al. 2019). Increased soil salinization making the land unsuitable for agriculture has also pushed farmers to transition into brackish water aquaculture (DasGupta et al. 2019).

The emergence and rapid expansion of brackishwater aquaculture in Sundarbans threaten to cause different long-term consequences such as loss of biodiversity and socio-economic impacts (Chopra et al. 2009). A major portion of the brackish water aquaculture in Sundarbans depends on

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the wild post-larvae and broodstock of shrimps and fishes. For this purpose, many marginal villagers in Sundarbans, especially women, are dependent on income generated from the post-larvae collection of tiger shrimp (*P. monodon*). In these juvenile stages (seeds) they are either directly procured by the aquaculture farmers or supplied by seed sellers. The collection of shrimp seeds is common in India and Bangladesh and has been shown to result in large by-catch (Das et al. 2016). Santhakumar et al. (2005) estimated that around 400 different species are caught as bycatch, including 318 other prawns, 8 fishes, 60 crabs, 1 mollusk, and 13 unidentified. Aquaculture expansion in the delta has come at the cost of other land-use types such as agriculture, mudflats, and fringe mangroves (Chopra et al. 2009; Knowler et al. 2009; Philcox et al. 2010; Bhattacharya and Ninan 2011; Sánchez-Triana et al. 2014). The socio-economic impact of brackish water aquaculture can be conspicuous when contributing to economic inequality relative to agriculture. The considerable higher returns (compared to agriculture) from aquaculture accumulates within a limited number of individuals (Chopra et al. 2009). Moreover, as aquaculture is less labor-intensive than agriculture, land conversion reduces employment opportunities for landless local people and successively reduces the scope of dissipating the profit inflow among the local community (Choudhury et al. 1994; Chopra et al. 2009). Apart from this, the risk of seepage or leaching of saltwater from the brackish water aquaculture farms into the adjacent agriculture farms often results in social conflicts (Chopra et al. 2009).

As the diverse types of aquaculture practices in Sundarbans have different economic, social, and environmental impacts, there is an urgency for increasing our understanding of the present land-use transformation, environmental and social performance of different aquaculture types, farmers perceptions, and the key drivers behind the transition. Therefore, the main aims of this study were to: (1) characterize the different types of aquacultures currently found in SBR, including their practices, labor demands, and profitability, and (2) identify the different drivers behind the conversion of agricultural lands to aquaculture.

MATERIALS AND METHODS

Study area: Sundarbans Biosphere Reserve

Indian Sundarbans Biosphere Reserve (SBR) (21° 32′ N–22° 40′ N and 88° 05′ N–89° 51′ E), a unique mangrove forest with high population density is located in the southern end of the state of West Bengal (Fig. 1). It comprises an area of 9630 km^2 including core, buffer, and transition zones (Ghosh 2015). The core of the reserve forest area is fully protected and no human activities are allowed except research with the prior permission of the forest department. In the buffer zone, fishing and honey collection are allowed with permits from the forest department. The core and buffer area together constitute the Reserve Forest part of the SBR, covering an area of 4263 km^2. Out of the total Reserve Forest area, core and buffer areas cover 1700 km^2 and 2563 km^2, respectively. The Reserve Forest area includes the Sundarbans Tiger Reserve (STR), which covers an area of 2585 km^2. In the transition zone only (an area of 5367 km^2, adjacent to the uninhabited core zone with a contiguous mangrove forest) there is human habitation of around 4.43 million people (as per the 2011 census) (Samanta 2018) and all kinds of human activities are allowed in this zone. The SBR encompasses 19 of the 51 administrative blocks of the two coastal districts of North and South 24-Parganas. The transitional zone of the SBR has an estimated aquaculture area of about 519.13 km^2 (Thakur et al. 2021). The SBR region was declared as a National Park in 1984, and in 1987 it was inscribed to the list of UNESCO World Heritage Sites. The SBR has 102 low-lying islands of which 54 are inhabited by humans. The islands of the entire Sundarbans including both India and Bangladesh are formed by the intricate network of tributaries and distributaries of the river Ganges, Brahmaputra, and Meghna (Rahman et al. 2020). The Indian part is demarcated by river Ichamati-Kalindi-Raimongal on the east, by the river Hugli on the west, by Dampier-Hodges line on the north, and the Bay of Bengal on the south.

Sundarbans has a rich and diverse flora and fauna and has the highest natural production of fish, prawns, and shrimps of West Bengal. Around 172 species of fishes, 20 species of prawns and shrimps, and 44 species of crabs are found in Sundarbans which supports the aquaculture and fisheries activity in the SBR (Chand et al. 2012). Historically Sundarbans was reclaimed from pristine mangrove forest for agriculture and settlement. In recent times, the area consists of different types of land use classes like mangrove forests, agricultural lands, aquaculture farms, tidal rivers and creeks, rural and semi-urban settlements, and mudflats (DasGupta et al. 2019). The region is physically isolated from the mainland leading to a high dependency of the population on natural resources. Primarily, the livelihood of this rural population was agriculture followed by artisanal fishing, and forest goods collection (DasGupta et al. 2019).

The climate across the SBR is monsoonal, predominated by the southwest monsoonal wind. Usually, the middle of June is considered as the onset of the southwest monsoon that continues up to the first or second week of October with the highest rainfall during August. The average annual

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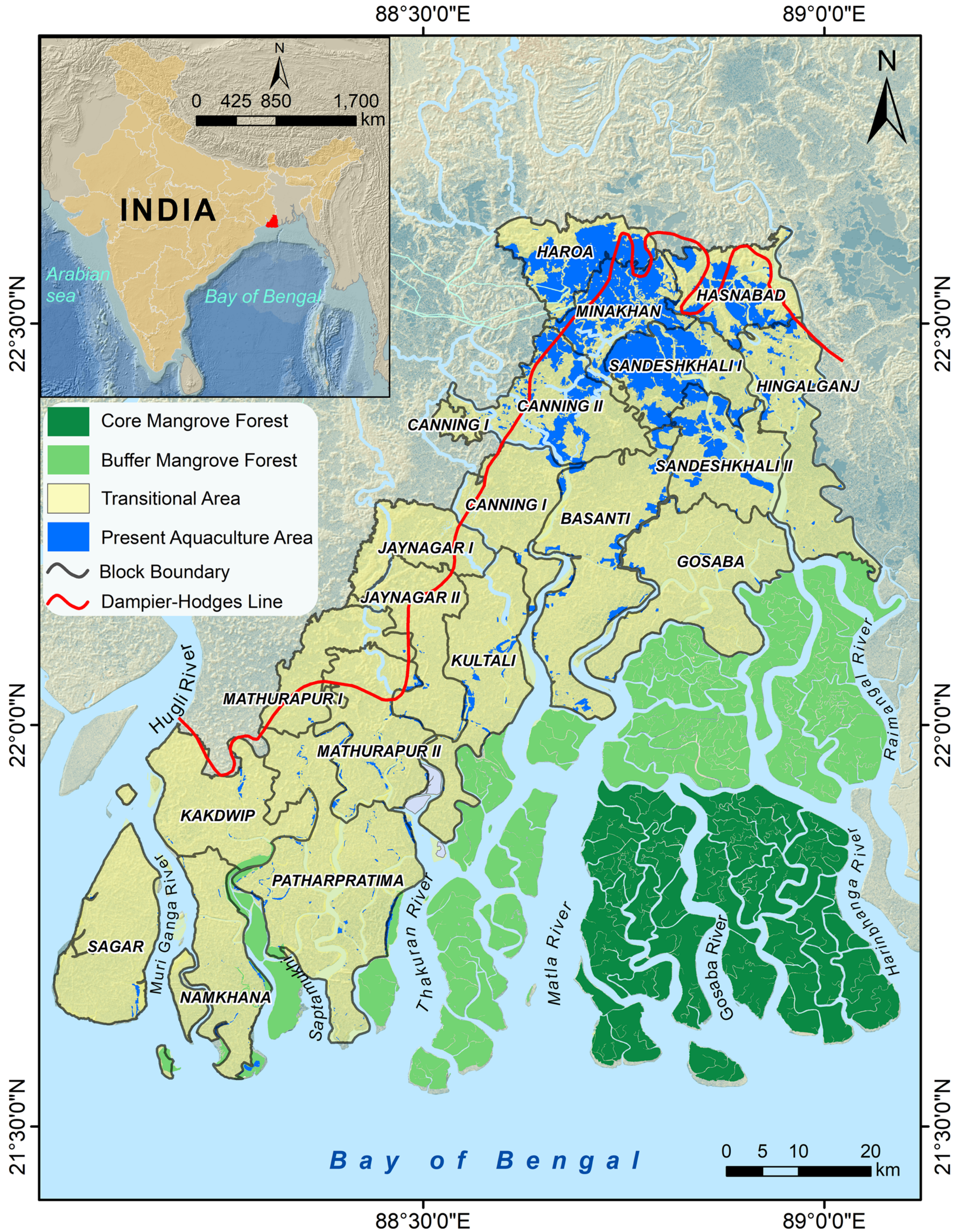

Fig. 1 Map showing the present study area. In the core area no human activities are allowed except research with the prior permission of the forest department. In the buffer zone, fishing and honey collection are allowed with permits from the forest department. All kinds of human activities are allowed in the transition zone only. Dampier-Hodges line which is indicated here is an imaginary line drawn in 1829–1830 to mark the northern boundary of saline influence in the Sundarbans delta

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rainfall in Sundarbans has been reported as 1625 mm sometimes raises to 2000 mm in the heavy rainfall year and may also drop to 1300 mm in the low rainfall years (Chand et al. 2012). Despite the numerous rivulets and creeks, the people of this region suffer from a paucity of freshwater. Groundwater is only available beyond the depth of 250 m (CGWB 2006; Sinha Ray 2010; Hazra et al. 2015). The river waters are saline in the SBR and often contaminate the groundwater. This scarcity of freshwater also hinders agricultural activity due to less availability of irrigation waters and the agriculture in the region is mostly dependent on monsoon water (Hazra et al. 2015). However, in the last few decades, a delayed onset and recession of monsoon have been observed (Chand et al. 2012) creating additional challenges for agriculture. Furthermore, there is evidence that the region is also experiencing temperature increases (Hazra et al. 2010), more frequent extreme climatic events such as cyclones and floods (Singh 2007), rapid sea-level rise (Pethick and Orford 2013), saline water intrusion (Hazra et al. 2015), and habitat loss due to high coastal erosion (Ghosh et al. 2014).

Survey framework and data collection

This study was based on interviews with 67 aquaculture farmers in the SBR (covering all the 19 community development blocks). Given the inability of physical fieldwork due to the COVID 19 pandemic, interviews for the present study were carried out over the telephone. Farmers' contacts were collected from the manager-technical (aquaculture), IFB Agro Industries Limited, and an official of Marine Products Export Development Authority (MPEDA), Govt. of India. Participants were sampled using the purposive sampling technique to target aquaculture farmers (farm owners who were actively involved with the aquaculture farming) in different areas of the delta and were not stratified by aquaculture type. All respondents had aquaculture as their primary livelihood (main livelihood that contributes to the lion share of the income). During the interview, very short and focused questions (Table 1) were asked to the respondents related to their aquaculture practices, type of land use transformed to aquaculture, driving forces behind the transformation, and profitability. All the interviews were recorded with the prior permission of the respondents.

The aquaculture farmers who were approached agreed to participate in the interview. 38 respondents (58.21%) provided detailed answers to all the questions, however, 29 respondents (41.79%) hesitated to answer the question of unit area profitability. Considering the sensitivity of the question, it was not repeated. The unit area productivity of the shrimps and fishes was shared by all the respondents. The respondents who shared the profitability also provided information about their farm gate selling price of the shrimps and fishes which was verified by an official of the Marine Products Export Development Authority (MPEDA) who has been involved in dealing with the aquaculture farmers in the entire state of West Bengal. Using those selling price data approximate profitability was estimated from production for those farmers who did not share that information. Given the sensitivity of the information regarding the annual income of the farmers, this question was also carefully omitted. However, the approximate annual income of the farmers only from aquaculture was calculated using the unit area profitability from aquaculture multiplied with the total area of the aquaculture farm. In addition to the aquaculture profitability, respondents were asked whether they had agricultural land and what was the unit area agricultural profitability. This provided an estimate of the profitability ratio between different aquaculture practices and agriculture of each respondent (as exhibited in Fig. 2).

Though this study is mainly based on the aquaculture farmers' interviews, however, some points came out from those interviews related to land use transformation and future sustainability of aquaculture practices in the delta. To get the plausible directives towards achieving sustainability in Sundarbans those points were discussed with a group of stakeholders (belonging to different govt. departments, reputed NGOs, academic and research institutions) having highly rich experience on the present scenario of Sundarbans.

RESULTS

Types of aquaculture practices in the Indian Sundarbans delta

The characterization of aquaculture practices in the Sundarbans is presented in Table 2. Different types of aquaculture practices exist of which brackish water polyculture of shrimps in combination with finfish is the most prevalent. In addition, freshwater polyculture of different carp species is practiced in different parts of the region. Aquaculture practices are usually characterized in terms of management practices including traditional, extensive, semi-intensive, and intensive. The aquaculture in the Sundarbans though followed these categories but with many modifications—*traditional* aquaculture (34 respondents), *improved-traditional* (14 respondents), *modified-extensive* aquaculture (9 respondents), and *semi-intensive* aquaculture (12 respondents). These are described below and contrasted in Table 3. In Sundarbans, except semi-intensive and a section of modified extensive aquaculture, all other aquaculture types have been adopted mostly with

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Table 1 Questions asked to the respondents during the interview

Sl. no	Interview questions
1	Caste and educational qualification of the respondents
2	Culture type (brackish water/freshwater)
3	Aquaculture types (traditional/extensive/semi-intensive/intensive)
4	Crop diversity (monoculture/poly culture)
5	Cultured species
6	Number of cropping
7	The yield of the farm
8	Net annual profitability from aquaculture per unit area (INR/bigha/year) [7.5 bighas = 1 ha]
9	Total aquaculture farm area
10	Landholding status of the aquaculture farm (own land/leased in/partial own land and rest are leased in)
11	If leased in then, what is the leasing amount per unit area land
12	Number of laborers employed in the farm
13	Which type of agricultural land was converted (single cropland/double cropland/triple cropland)
14	What was the agriculture yield before conversion (if own land is converted)/what is the agriculture yield of non-converted land belong to the respondent (if only leased land is converted)
15	Net annual agriculture profitability per unit area (INR /bigha/year) [7.5 bighas = 1 ha]
16	Reason for aquaculture growth and conversion of agricultural lands
17	Any other secondary sources of income
18	Additional remarks of the respondents (if any)

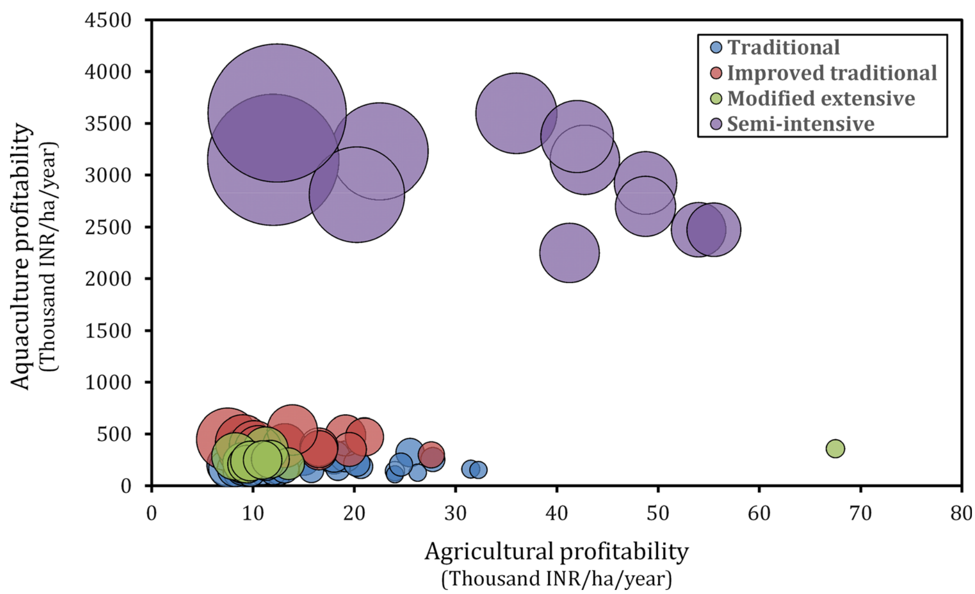

Fig. 2 Graphical representation of the ratio between aquaculture and agriculture profitability based on respondents' reported profits from aquaculture and remaining agricultural production. Respondents are categorized by the aquaculture types described in Table 3. Area of the bubbles represents the ratio

polyculture systems. Around 60% of the respondents practiced brackish water polyculture. The composite culture with a combination of Indian major carps, with monosex Nile tilapia (*Oreochromis niloticus*) and freshwater prawn (*Macrobrachium rosenbergii*), is also practiced by the farmers. However, freshwater monoculture of monosex Nile tilapia (*O. niloticus*) has also drawn the attention of the farmers due to the high proliferation rate of

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Table 2 Detail of the aquaculture practices in Sundarbans obtained from the farmers' interviews

Parameters	Description	No. of respondent
Culture type	Only brackish water	51
	Only freshwater	11
	Both fresh and brackish water	5
Diversity of crops	Monoculture	16
	Polyculture	49
	Both mono and polyculture	2
Aquaculture types[a]	Traditional	34
	Improved-traditional	14
	Modified-extensive	9
	Semi-intensive	12
Aquaculture farm area	< 1 ha	18
	≥ 1 ha–5 ha	36
	> 5 ha–10 ha	11
	> 10 ha	2
Landholding information of aquaculture farm	Only own land	27
	Only leased land	13
	Both own and leased land	27
Land type converted to aquaculture	Agriculture (single cropland)	61
	Agriculture (double cropland)	6
Leasing amount (INR ha^{-1} $year^{-1}$)[b]	INR 45 000–80 000 (607–1079 US$)	23
	$>$ INR 80 000–120 000 ($>$ 1079–1618 US$)	17
	$>$ INR 120 000–150 000 ($>$ 1618–2023 US$)	1
Currently have agricultural land other than aquaculture	Yes	67

[a]Total number of respondents here are 69 as 2 out of 67 respondents are involved in two types of aquacultures, they have been considered as two respondents

[b]1 INR = 0.013 US$ [on 21 November 2020]

Table 3 Comparison of quantitative responses between different types of aquaculture practices in Indian Sundarbans

Aquaculture type	Cultured species	Yield (tonne ha^{-1} $year^{-1}$)	Net profitability (INR ha^{-1} $year^{-1}$)[a]	Labour required (persons ha^{-1})	Seed source	No. of cropping $year^{-1}$
Traditional						
Brackish water polyculture	*Penaeus monodon, Metapenaeus monoceros, Metapenaeus affinis, Mystus gulio, Liza parsia, Mugil cephalis*	0.33–0.75	150 000–225 000 (2023–3034 US$)	1 to 2	Local market	Single
Freshwater polyculture	Indian Major Carps, *Barbonymus gonionotus, Hypophthalmychthys molitrix*, *Hypophthalmichthys nobilis, Ctenopharyngodon idella, Macrobrachium rosenbergii*	0.9–1.3	60 000–92 000 (809–1241 US$)	0	Local hatchery	Single
Improved-traditional	*Penaeus monodon, Metapenaeus monoceros, Metapenaeus affinis, Mystus gulio, Liza parsia, Mugil cephalis*	0.97–1.5	300 000–485 000 (4045–6540 US$)	1 to 2	Other state hatchery	Single

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Table 3 continued

Aquaculture type	Cultured species	Yield (tonne ha^{-1} year^{-1})	Net profitability (INR ha^{-1} year^{-1})[a]	Labour required (persons ha^{-1})	Seed source	No. of cropping year^{-1}
Modified-extensive	Monosex Nile tilapia	3–3.9	210 000–352 000[b] (2832–4746 US$)	2 to 3	Local hatchery	Double
Semi-intensive	*Litopenaeus vannamei*	15–24	2 200 000–3 600 000[b] (29 665–48 542 US$)	3 to 5	Other state hatchery	Double

[a]1 INR = 0.013 US$ [on 21 November 2020]

[b]Profit includes two cropping cycles

the fish species. Brackish water monoculture is also spreading throughout the Sundarbans. The white leg shrimp (*Litopenaeus vannamei*) is an introduced exotic species and it has almost replaced the tiger shrimp (*P. monodon*) in shrimp monoculture. All 12 respondents engaging in brackish water monoculture cultured the white leg shrimp.

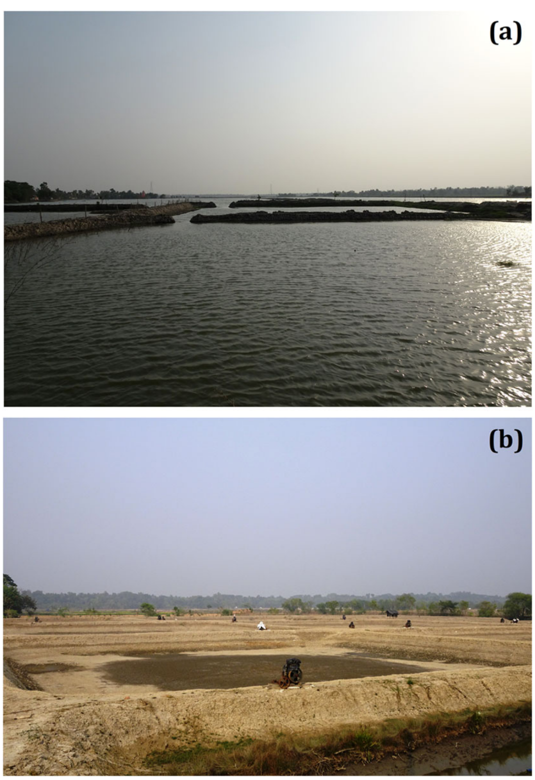

Fig. 3 **a** A traditional aquaculture farm **b** dried ponds of the semi-intensive aquaculture farm of *L. vannamei*. All the photographs are captured by Sandip Giri

'Traditional' aquaculture is mainly practiced by marginal and small-scale farmers as fewer investments are required. In this aquaculture type, tidally influenced low-lying areas near the river bank or creeks are encircled with a peripheral dyke locally called '*bheri*' where the water from the rivers or creeks is allowed to enter the impoundment during high tide through a sluice gate (Fig. 3a). Natural seeds of a diverse group of shrimps, finfish, and crabs enter into the impoundment along with the tidal water. Besides natural stocking, manual stocking is also done with wild seeds. The wild seeds are procured either directly from the post-larvae collectors or indirectly from the local auction market. Growth is limited in this aquaculture by the availability of natural feeds. Freshwater carp polyculture is also practiced using traditional aquaculture techniques in large ponds. In traditional aquaculture, cropping is done only once a year. However, many farmers have recently made improvements in their traditional aquaculture systems to increase yield and profitability. This '*improved-traditional'* system includes stocking with seeds bought on the market, that could originate from hatcheries of other maritime states of India such as Tamil Nadu, Andhra Pradesh, and Odisha. In addition, ponds are also prepared by tilling, liming, and fertilization to enable higher stocking and successively increase the yield. Many farmers in Sundarbans have also recently started carp polyculture and monoculture of monosex Nile tilapia with '*modified extensive'* techniques. This aquaculture type also follows improved management practices such as liming, fertilization, and importantly also use of supplemented feeds. However, the most scientific type of aquaculture found in Sundarbans is brackish water '*semi-intensive'* monoculture of white leg shrimp (*L. vannamei*) (Fig. 3b). This type of aquaculture is becoming more popular due to its relatively high yields and profitability. However, due to high investments, this practice is

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difficult to adopt for marginal and small-scale farmers. Unlike other aquaculture practices, the cropping of *L. vannamei* is usually twice a year for a period of three to four months. Table 3 presents a quantitative comparison of the four culture types based on interview data.

Farm area, landholding, land type converted, and leasing amount are not dependent upon the type of aquaculture. Mostly larger farm areas are observed in the case of traditional aquaculture. But it does not mean that semi-intensive farms cannot cover large areas. Again, in the case of semi-intensive aquaculture, many double croplands are converted but single croplands can also be converted, and double croplands can also be converted to other aquacultures. However, usually due to higher leasing costs of double croplands those lands are not targeted by the traditional aquaculture farmers. Further, the leasing cost is not dependent upon the aquaculture practice, rather it depends upon whether the land is single/double-crop and its distance from the water source. Most of the aquaculture farms in the Sundarbans are on leased agricultural land (Table 2) and the contract of leasing period usually varies from 3 to 5 years.

Factors driving the transition of agricultural land to aquaculture ponds

The interviews revealed eight key drivers behind farmers' transition to aquaculture. These are broadly categorized into—(i) socio-economic drivers and (ii) environmental drivers (Table 4). Socio-economic drivers include increased unit area profitability due to higher market demand and prices for the aquaculture products, increased leasing costs for agriculture lands, and less interest of the farmers in agriculture as food security is ensured by the Government ration. Environmental drivers include reduced agricultural productivity due to salinization (i.e., especially after cyclone Aila), easy access to brackish water for aquaculture, scarcity of freshwater for irrigation, and frequent inundation of agricultural lands due to embankment breaching. Strikingly, all respondents unequivocally identified higher profits from aquaculture as the main driver. However, all respondents continued practicing small-scale agriculture, i.e., paddy cultivation, as a source of secondary livelihood and provisioning of food. This allowed comparing profitability between aquaculture and agriculture and is presented in Fig. 2. The ratios between the profitability of different aquaculture practices and agriculture are indicated by the size of the bubbles in Fig. 2. The profitability in *improved-traditional* aquaculture is comparatively higher than *modified extensive* aquaculture even though the cropping intensity is single (one harvest per year). This is due to the economic importance of the shrimp species. Agricultural profitability greater than INR 40 000 (520 US$) ha^{-1} year^{-1} [1 INR = 0.013 US$ as on 21 November 2020] resulted from double-cropping (two harvests per year) the land. Although agricultural profitability ranged from as low as INR 7500 (97.5 US$) to as high as 67 500 (877.5 US$) ha^{-1} year^{-1}, traditional, improved-traditional, and modified extensive aquaculture had only developed where agricultural profitability was less than INR 35 000 (455 US$) ha^{-1} year^{-1}. However, semi-intensive aquaculture had been developed over the full range of agricultural profitability and resulted in the highest ratios between aquaculture and agriculture profitability. Besides economic profitability, scarcity of freshwater for irrigation, soil salinization driven by frequent embankment breaching and saline water inundation are also driving the conversion of agricultural lands to aquaculture. These environmental drivers severely affect agricultural activity as well as productivity. During the interview of the aquaculture farmers, they also pointed out that many agricultural farmers change their livelihood to aquaculture or lease out their lands to aquaculture as an adaptation strategy in the context of natural disaster.

Table 4 Key drivers identified from farmers' perception behind the conversion of agricultural land to aquaculture in Sundarbans

Key drivers	No. of respondents (n = 67)
Socio-economic drivers:	
Higher unit area profitability in aquaculture and high market demand of aquaculture products	67
Higher unit area leasing amount than unit area agricultural profit	58
Decreasing interest in agriculture as food security is ensured by the Govt. ration	7
Environmental drivers:	
Low agricultural productivity	55
Salinization of agricultural lands after cyclone Aila	51
Easy access to brackish water for aquaculture	48
The paucity of freshwater for irrigation in agriculture	46
Frequent inundation of agricultural lands due to embankment breaching	32

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Table 5 Socio-economic characteristics of the aquaculture farmers who were interviewed for the study

Parameters	Description	No. of respondent	Parameters	Description	No. of respondent
Caste	General (GEN)	38	Approximate	< INR100 000 (< 1300 US$)	8
	Scheduled Castes (SC)	15	Annual income[a]	> INR 100 000–200 000 (> 1300–2600 US$)	12
	Scheduled Tribes (ST)	2		> INR 200 000–500 000 (> 2600–6500 US$)	16
	Other Backward Class (OBC)	12		> INR 500 000–1 000 000 (> 6500–13 000 US$)	10
				> INR 1 000 000–2 000 000 (> 13 000–26 000 US$)	7
				> INR 2 000 000–3 000 000 (> 26 000–39 000 US$)	10
				> INR 3 000 000–4 000 000 (> 39 000–52 000 US$)	4
Educational qualification	Illiterate	5			
	Up to 5th standard	15			
	Up to 8th standard	21			
	Up to 10th standard	16			
	Up to 12th standard	7			
	Up to graduation	3			
			Other source of income (secondary sources)	Agriculture	67
				Livestock rearing	33
				Business	9

[a]1 INR = 0.013 US$ [on 21 November 2020]

Socio-economic and environmental characteristics of the aquaculture farming system

Since the different aquaculture farming in the Sundarbans are having a varied range of profitability, it also highly influences the socio-economic background of the farmers. The detailed socio-economic characteristics of the aquaculture farmers interviewed are presented in Table 5. The farming is controlled by the male members of the family. The educational qualification of the majority of the farmers is up to the secondary level (up to the 8th and 10th standard). Though the annual income depends on the aquaculture type, unit area profitability, and total area of the aquaculture farm, however, the annual income profile (approximate) of the farmers indicates a good financial status except the farmers practicing only freshwater polyculture are having comparatively low incomes [< INR 100 000 (< 1300 US$)]. On the other hand, farmers practicing semi-intensive aquaculture are having an approximate annual income greater than INR 2 000 000 (26 000 US$). However, the annual income of a few improved traditional aquaculture framers has exceeded INR 2 000 000 due to having a large landholding of the farm area. Irrespective of the farming practices two types of laborers are associated with aquaculture of which one is the construction workers for preparation of ponds and dykes and other workers for regular maintenance of the entire farm and farming (water quality monitoring, water exchange of the ponds, maintenance of the shrimps and fishes, and harvesting). The daily wages of the laborers for regular maintenance usually vary from INR 250 to 400 (3.25 to 5.2 US$) based on the farming practices. Often in very small traditional brackish water polyculture farming, the family members of the farm owners also get involved. Agriculture has been reported as a small secondary source of income for all the farmers, but they are not directly involved in the agriculture by themselves rather depend on the agricultural laborers or sometimes lease out the land to any agricultural farmer. In addition to agriculture, livestock rearing (poultry farming, duckery) and small business have been reported as other small sources of income. However, this livestock rearing is mainly monitored by the female members of the family.

In brackish water aquaculture, the source of water is nearby-rivers or creeks. In the case of traditional and

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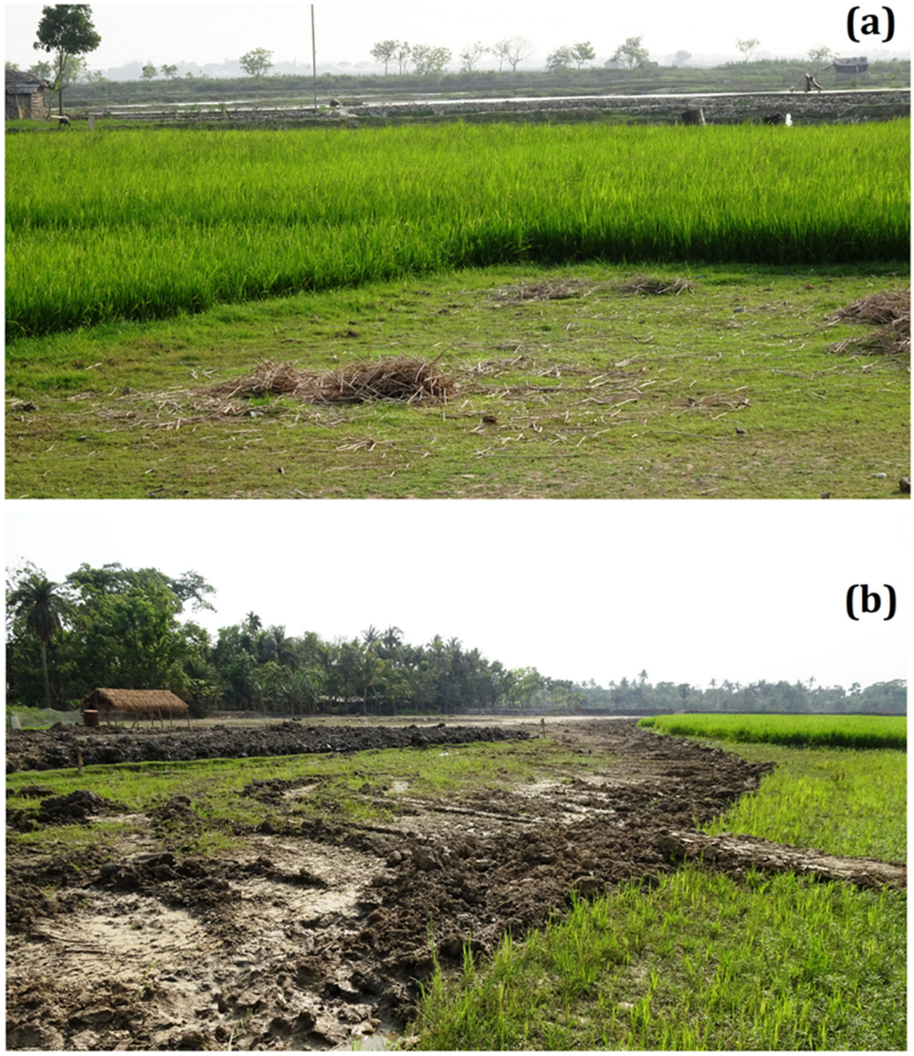

Fig. 4 **a** A portion of the agricultural area has already been converted to aquaculture (right after the paddy field) **b** ongoing conversion from agriculture to aquaculture. All the photographs are captured by Sandip Giri

improved traditional cultures, brackish water is exchanged through sluice gates following the tidal phase and lunar cycles. On the contrary, in modified extensive and semi-intensive cultures water is exchanged through pumping. During pond preparation use of lime and organic fertilizer is common for all the culture types. Lime is also applied for water quality management. In all the brackish water farming type water quality parameters like temperature, salinity, pH, Secchi depth, dissolved oxygen (DO) is regularly monitored especially in semi-intensive farming where these parameters are monitored every day as shrimps are highly susceptible to little change in water quality. As reported by the respondents, for shrimp farming 26–32 °C temperature, 12–25 ppt salinity, 8–8.5 pH, 22–30 cm Secchi depth, and 5–9 ppm DO are considered as optimum.

DISCUSSION

This study indicates that economic profitability has been the primary driver behind the conversion of agricultural lands to aquaculture within the Indian Sundarbans. However, environmental drivers were also seen to play a role in land conversion. Frequent cyclones, flooding due to embankment breaching, salinization of the soil, less freshwater availability for irrigation have driven down agriculture productivity (Sánchez-Triana et al. 2014) in several regions triggering some farmers to shift their livelihood to aquaculture by converting their land (Fig. 4), and compelling many others to lease out their land for conversion to aquaculture. A recent study by Giri et al. (2021) estimated that the total aquaculture area has

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Fig. 5 **a** Collecting the post-larvae from a river in Sundarbans **b** sorting of the post-larvae from the other bycatches. All the photographs are captured by Sandip Giri

increased from 3.59 to 5.82% of the entire SBR within the last two decades (1999–2019) and notable aquaculture growth was observed during the post-Aila (severe cyclonic storm Aila made landfall on 25 May 2009) period (2009–2019). After cyclone Aila, almost all the agricultural lands in the cyclone-affected area in the Sundarbans became unsuitable for cultivation for the next couple of years (DuttaGupta et al. 2021). Respondents reported that many agriculture farmers are leasing out their lands for aquaculture because the leasing amount is comparatively higher than agricultural profit and they are either migrating elsewhere in search of work or involved in other alternative livelihoods locally.

Historically, aquaculture farmers in Sundarbans have practiced the traditional culture of low-intensity shrimps in '*bheries'*, which are enclosed mudflats that allowed species to migrate in with the tide but not out, providing an inexpensive source of protein with low environmental impacts (Primavera 1998; Philcox et al. 2010). Since the 1990s, the increased demand has led to the development of culture practices depending on commercial feeds, and Government's policies have changed to favor the more intensive aquaculture practices (Philcox et al. 2010). The majority of the farmers interviewed within our survey still rely on traditional or improved-traditional techniques, despite having access to semi-intensive aquaculture techniques. This is in large part due to these less intensive systems having a lower perceived associated risk of financial loss and because they generally require less capital investment and management. For example, semi-intensive aquaculture can require three to four times more capital investment than traditional or improved-traditional aquaculture types (Ghoshal et al. 2019) increasing the risk of a financial loss if there is a shrimp crop failure. Furthermore, these traditional and improved-traditional techniques are now targeting new international market segments such as organic shrimp, which has increased the demand for these products. The Coastal Aquaculture Authority (CAA) regulations regarding the establishment of aquaculture farms in the coastal regulatory zone (CRZ) are also comparatively less stringent for the traditional and improved-traditional aquaculture types (http://caa.gov.in/uploaded/doc/pdfall.pdf). This is due to the concern regarding pollution associated with the discharge of unconsumed feed, pesticides, fertilizers, and antibiotics from semi-intensive and intensive farming of shrimp (Bhattacharya and Ninan 2011).

The exotic white leg shrimp (*L. vannamei*) was introduced into the Indian Sundarbans in 2013, by the Indian Council of Agricultural Research-Central Institute of Brackishwater Aquaculture (ICAR-CIBA) Kakdwip Research Centre. Survey results indicated that farmers within the SBR are attracted to the semi-intensive farming of this species due to its high yield and comparatively higher disease resistance to indigenous pathogens than tiger shrimp (Ghosal et al. 2019). However, semi-intensive aquaculture of *L. vannamei* requires large capital investment and as such, they can often be controlled by investors from outside the SBR working with a small number of local aquaculture farmers in Sundarbans. As semi-intensive aquaculture involves comparatively more sophisticated techniques and management, often the investors hire skilled labor from other parts of the country with limited employment opportunities for local people. Profits from this type of aquaculture are primarily going to groups of external investors and do not significantly improve the wellbeing of the local community. In comparison,

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traditional aquaculture techniques depend on mainly local laborers.

The development and regulation of issues related to aquaculture will play an important role in the sustainable development of the SBR going forward. Unregulated conversion of land aquaculture could have potentially significant negative impacts on the achievement of several environmental targets of the United Nations' Sustainable Development Goals (SDGs). For example, soil salinization and degradation of land caused by the expansion of aquaculture will hinder the achievement of SDG 15.3 and 15.1, which aim to end desertification, restore degraded land, conserve and restore terrestrial and freshwater ecosystems, respectively. A large-scale shift to semi-intensive or intensive practices within the region risks the introduction of non-native species and the leaching of fertilizers and other chemicals into the environment in direct contradiction to SGD 15.8 (prevent invasive alien species on land and in water ecosystems) and SDG 14.1 (reduce marine pollution). Furthermore, our analysis indicates that semi-intensive and intensive aquaculture practices potentially make very little impact on socioeconomic and food security development goals within the SBR, such as SDG1.2 (reducing poverty through employment) and SDG 2.1 (access to nutritious food), due to ownership by and employment of people from outside of the SBR.

Though the economic profitability continues to drive conversion to aquaculture, the lack of strict implementation of existing legislations also indirectly results in this conversion. However, implementation of legislation often becomes difficult due to non-cooperation and resistance from the aquaculture farmers, farm owners, and several corporate houses as huge financial interests are associated with the whole system. These issues were admitted by the stakeholders and everybody supported the need for regulating these land conversions through a suitable policy approach. In addition, the issue of illegal conversion of agricultural land to aquaculture in many farms is pointed out by some of the stakeholders. Many aquaculture farmers convert the agricultural land to aquaculture but in the official record, the land remains as agriculture. The reason behind this is as per the '*West Bengal Inland Fisheries (Amendment) Act. 1993'* (http://www.wbfisheries.in/pdf/Inland%20Fisheries%20Act.pdf) if any agricultural land is once converted to aquacultural land, it cannot be filled up for converting into solid land for any purpose even if it is required. In Sundarbans, most of the aquaculture farms are on leased agricultural lands, and the leasing contract usually varies from 3 to 5 years. After the contract period is over the lands again belong to the actual owner. If the land is officially converted from agriculture to aquaculture land, the actual landowner cannot use it for any other purpose [as per '*West Bengal Inland Fisheries (Amendment) Act. 1993'*] after the leasing contract period is over. That is why the landowners do not provide the consent to officially convert the land while leasing out for aquaculture. For the same reason, the aquaculture farmers who convert their agricultural lands to aquaculture do not convert the land by the official record. Therefore, it is highly imperative to regulate this kind of illegal land conversion. The already existing '*West Bengal Land Reforms Act, 1955'* (https://dllromsd.org/LAW_WEB/act15.pdf) has the provision to outlaw any illegal conversion and provide enforcement under the '*Sect. 4D*'. In addition, regulation of aquaculture development within CRZ areas can be possible through the implementation of '*The Coastal Aquaculture Authority Act 2005'* (https://legislative.gov.in/sites/default/files/A2005-24.pdf). A group of stakeholders also suggested zoning for aquaculture to reduce the environmental impact on adjoining agricultural farms and social conflict with the agricultural farmers. It was also suggested that the further expansion of aquaculture can only be permitted in those agricultural lands which are identified as unsuitable for agriculture. Apart from that, conservation of mangrove forests and aquatic ecosystems, rainwater harvesting to support more agricultural activity, and suitable technological intervention that can balance both the development and conservation of the fragile ecosystems were suggested as the plausible ways towards achieving sustainability in Sundarbans.

Among the four different aquaculture types, only traditional aquaculture depends on wild seeds (locally called '*meen*') of shrimps and fishes. The collection of wild seeds provides a livelihood option for a large number of marginal villagers especially women (Fig. 5) even though there is a significant risk to collectors of death due to man-animal conflict (crocodile attack) (Das and Jana 2017). The collected post-larvae are either sold directly to the aquaculture farmers or the local agents at the rate of INR 200 per thousand post-larvae during summer, INR 250 per thousand post-larvae during monsoon, and INR 400 per thousand post-larvae during winter respectively (Das et al. 2016). However, the cultured shrimp fetches an amount of INR 550–700 per kilogram (1 kg contains around 35 to 40 pieces). The price can increase to INR 1000 per kilogram (1 kg contains around 25 pieces) depending upon the size of the shrimps. Therefore, in the value chain, there is a huge economic discrepancy between the profitability of post-larvae collectors and aquaculture farmers or farm owners. Despite this and the negative impacts caused by the indiscriminate collection of post-larvae on the aquatic biodiversity, restriction of wild seed collection locally is thought to be difficult due to both the lack of alternate livelihood options for collectors and the absence of state-of-the-art hatcheries in Sundarbans (Sánchez-Triana et al. 2014).

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The establishment of state-of-the-art shrimp hatcheries in Sundarbans would be challenging. As per the guidelines for regulating coastal aquaculture set out by the Coastal Aquaculture Authority (CAA), the water to be used for shrimp hatcheries requires an optimal salinity of 30–34 ppt and should be free of all suspended solids. However, in the SBR area, the water salinity and turbidity are a major hindrance to shrimp hatcheries. For example, both salinity and turbidity vary throughout the annual cycle in the Hugli-Matla estuary adjacent to Indian SBR from 0.1 to 29.7 ppt and 75 to 402 NTU, respectively (Akhand et al. 2016; Das et al. 2017). Akhand et al. (2016) also reported the annual mean salinity in the Hugli estuary is $\approx$ 7.1 ppt and in Matla estuary $\approx$ 20.0 ppt. Therefore, the establishment of shrimp hatcheries in the SBR appears to be an unfeasible solution for reducing the harvest of wild shrimp post-larvae. An alternative approach would be to encourage traditional aquaculture farmers to shift towards improved-traditional shrimp culture techniques which do not require wild larvae collection and run interactive programs to discourage the culturing of wild shrimp variety. Over time this may reduce demand for wild shrimp post-larvae and eventually decrease the collection.

CONCLUSION

The information generated by the aquaculture farmers' interviews clearly showed that the higher profitability from practicing different forms of aquaculture (particularly semi-intensive) compared to agriculture constituted the main driver for ongoing land transformation. Additional drivers related to socio-economic and environmental factors were also identified. A strong and growing market demand for aquaculture products in combination with low agriculture productivity following inundation from cyclone surges was evident. The mapping of aquaculture types shows great diversity in the Sundarbans that includes traditional, improved-traditional, modified-extensive, and semi-intensive systems. Results also indicate that aquaculture farmers tend to keep a diverse product portfolio where agriculture still plays an important role. In terms of profitability, the semi-intensive aquaculture type provides an order of magnitude higher profitability than traditional culture techniques despite having huge associated financial risk due to crop failure. In contrast, improved-traditional and modified extensive aquaculture types are seen to be environmentally benign with reasonable profit margins. Although semi-intensive aquaculture has higher labor demands, the need for specific skills and preference for workers from other states means that few employment opportunities are generated for local people.

The rapid (and largely irreversible) conversion of agricultural lands to aquaculture, is a concern from the point of sustainability of Sundarbans. If financial incentives continue to drive conversion it may result in some food insecurity and local food sovereignty in the future. Therefore, given the present observations, the implementation of the following action points can be recommended through a suitable policy framework to support more sustainable futures for the delta.

(i) Though the existing '*West Bengal Land Reforms Act, 1955*' already outlaws any illegal conversion and provides enforcement under the '*Sect. 4D*', strict enforcement of these laws at the government level could prevent the long-term consequences of further illegal conversion of agricultural land to aquaculture.
(ii) The government may promote improved-traditional aquaculture practice for existing and new farms, the establishment of rearing centers of the shrimp larvae brought from other state hatcheries to stop the wild post-larvae collection.
(iii) Government-level initiatives to arrange for the alternate livelihood for a huge number of marginal post-larvae collectors through capacity building for non-farmed livelihood.
(iv) Rainwater harvesting for promoting agricultural intensity (double crop or triple crop).
(v) Preventing illegal conversion of mangrove forest to aquaculture and promoting conservation and expansion of mangrove forest.

Acknowledgements Authors are grateful to the Dept. of Biotechnology; Govt. of India for funding the project (Sanction Order No. BT/IN/TaSE/70/SH/2018-19) entitled "Opportunities and trade-offs between the SDGs for food, welfare and the environment in deltas" under TaSE (towards a sustainable earth) programme. Authors are highly indebted to Mr. Atanu Ray, State Co-ordinator, NETFISH-MPEDA, Govt. of India, and Dr. Subhra Bikash Bhattacharyya, Manager-Technical (Aquaculture), IFB Agro Industries Limited for their huge cooperation and technical guidance. The authors sincerely thank all the anonymous stakeholders from various Govt. Departments, institutes and NGOs for sharing their experience and knowledge regarding the aquaculture scenario in the Sundarbans. The authors also acknowledge Prof. Robert J. Nicholls, Director, Tyndall Centre for Climate Change Research, University of East Anglia, for his contribution during manuscript writing.

Author contributions SG: Conceptualization of the study, conduting survey, data analysis, preparation of the first draft manuscript; TMD: conceptualization of the study, data analysis, manuscript writing and editing; SH: conceptualization of the study, revision of the manuscript; MT: conceptualization of the study, manuscript writing and editing; SS: conduting survey; OB: conduting survey; CLJM: manuscript writing and editing; AC: manuscript writing and editing.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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