Influence of salinity on aquaculture species richness in the mangrove-river connected zone of southwest Bangladesh

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Abstract. Two export fishery commodities, black tiger shrimp (*Penaeus monodon*) and giant river prawn (*Macrobrachium rosenbergii*) are grown in the low-lying agricultural land known as 'gher' in Bangladesh. The gher area is interlinked to both upstream tributaries and adjacent mangroves by rivers, canals, channels and other watercourses. The mangrove-river connectivity (MRC), water salinity and tidal flush have made the system dynamic. The present descriptive study was carried out in the southwest coastal area of Bangladesh to provide a baseline for aquaculture species distribution and occurrence related to water salinity. Salinity and MRC network largely define the aquatic farming in the region with or without integration of rice and dyke crop. Based on the surface water salinity, soil salinity, underground water salinity and indicator species, the agro-ecology of the area is divided into: high saline area (HS; >10 ppt most of the time of a year); medium saline area (MS; 5-10 ppt); low saline area (LS; typically <5 ppt); and freshwater area (FW; <0.5 ppt). In addition, a pocket gher system, which is a low saline gher, in higher saline areas located in elevated land areas are proposed. From 200 randomly selected gher across 4 agro-ecologies, 56 different fish and crustaceans species were sampled both in dry and wet seasons. The species richness was correlated to salinity and MRC network. Proximity of HS to MRC network supported the occurrence of maximum number (34) of on-farm species, although the fragile MRC network evolving due to siltation led to a drop in the number of species by almost 50% (20 in number) in MS areas. The salinity tolerant Tilapia dominated the MS areas. Both LS and FW areas were suitable for dyke crop and rice along with a combination of wild and hatchery sourced fish/crustaceans species. The results showed that a group of species could potentially be used as biological indicators to represent the agro-ecological disparity. The outcome of this study should be useful to understand the role of the MRC network, and it could be a baseline for monitoring climate change impact, adopt sustainable and climate-resilient aquaculture program in the region and wider afield.

Key Words: agro-ecology, biological indicator, crustacean, shrimp-prawn farming, tidal water.

Introduction. The coastal belt of Bangladesh is 32% of the total area of the country, with 47201 km^2 (Islam & Haque 2004). About 2500 km^2 are classified as tidal areas, favorable for aquaculture (Deb 1998). The low-lying floodplain agricultural land is known as 'gher' or 'bheri' culture in Bangladesh. Gher areas are dedicated to aquatic farming with or without integration of rice (*Oryza sativa*) and dyke crop production. Aquaculture is one of the fastest growing food production sectors in Bangladesh (DoF 2015), which exports tiger shrimp (*Penaeus monodon*) and giant river prawn (*Macrobrachium rosenbergii*) obtained by farming in the coastal low lying areas. Shrimp production mostly takes place in extensive ghers, while prawn in semi-intensive systems either in monoculture or with shrimp (Jahan et al 2015; Murray et al 2013). Shrimp farms are situated in coastal margins, often on the shore of estuaries lined or previously lined with mangrove forests, with access to saline water (Bolanos 2012). About 80% of the shrimp farming area has been developed close to the world's largest single block mangrove forest, the Sundarbans in the southwest Bangladesh (Alam 2014). The Sundarbans mangroves in Bangladesh stretch in the southern part of 3 districts bordering the greater Khulna within an area of 5700 km^2, of which more than one-third (1700 km^2) is occupied by rivers, canals, channels and other watercourses (Lewis 2011). Mangroves have a positive impact on the availability of fish (Blaber 2007). For example, the Sundarbans support 250 species of fish (Gopal & Chauhan 2006). From the mangrove coastline, tidal saline water flows through numerous estuarine rivers and tributaries intruding up to 160 km inland (Haque 2006). The estuarine tributaries are connectively treated as areas of refuge and migratory routes for fisheries species (Elliott et al 2007).

The mangrove-river connectivity is brought from the various connectivity concepts, including hydrological (Freeman et al 2007) and ecological concepts (Stoffels et al 2016). For instance, river connectivity is defined as the nexus between spatial structure and function of river landscape, which is used to measure the degree of correlation between landscape units and represents a parameter of landscape function (Fausch et al 2002). In the perspective of landscape ecology, 'connectivity is a kind of corridor landscape that allows or hinders organisms to flow between resource patches' (Marlard et al 2002; Wiens 2002). A mangrove-river connectivity (MRC) network can be considered as divergence dynamics compared to other aquatic landscapes. MRC network is also a water mediated system that transforms matter and organisms from upstream to downstream and vice-versa, through freshwater influx and tidal flush, respectively (Allan & Castillo 2007). Such connection can feed the nearby floodplain and promote exchange of organisms and nutrients (Reid et al 2016). Fish and crustaceans follow the watercourse to reach the nearer habitat. Extensive shrimp/prawn farmers in the southwest coastal area typically keep the inlet open to allow the entrance of tidal water along with organisms and close it during low tide. The load of organisms and nutrients depends on the location and crisscross connectivity of the river network (Brown & Swan 2010). The proximity to mangroves is also positive to species richness, as tree trunks and roots provide shelter and leaves facilitate nutrients (Whitfield & Elliott 2012). Species richness in the system increase the functional diversity of items (Wood et al 2015), ensuring food security (Kanji & Barrientos 2002), and minimize environmental impacts in coastal landscapes (Primavera 2006). Species diversity loss has therefore determinant effects on diet quality and sustainability of the environment (Myers et al 2013). Farming crustaceans with fish has been proven successful and financially viable for farmers (Islam & Wahab 2005).

The saline water intrusion area and the shrimp farming are geographically co-located (Johnson et al 2016). The water salinity in the coastal estuary is largely determined by the quantity and seasonality of freshwater discharge and tidal flush (Peterson 2003). The saline tidal water intrudes inland through numerous estuarine rivers and tributaries, which increase the salinity levels both in water and soil (Haque 2006). In southwest coastal Bangladesh, about 70% of cultivated land (10200 km^2) is affected by various degrees of salinization (Haider & Hossain 2013). In this area, salinization not only reduces water for agriculture, but also for drinking, domestic needs and irrigation (Deb 1998). Salinization of groundwater also occurs in the southwest coastal region (Turner & Ali 1996). Salinity levels in this area of Bangladesh vary both seasonally (high during the dry season and low during winter) and spatially (Bhuiyan & Dutta 2012). The onset of monsoon rains and the freshwater flow from the Gorai-Modhumati river system, which is one of the major tributaries of the Ganges river system, reduces water salinity significantly from May onwards. During the dry season, the drastic fall of the Gange's water level and the water withdrawal at the Farakka (India) point, significantly reduce the freshwater flow (Gain & Giupponi 2014; Mirza 1998). The salinity is seasonal, and the timing of salinity levels determines the rice, fish and shrimp production schemes in the region (Belton et al 2014; Kabir et al 2015; Nuruzzaman 2006).

Estuarine fish tend to show tolerance to a wide range of salinity, between 1-30 ppt, depending on the physiological mechanism of each species (Whitfield 2015). Apart from the taxonomic classification of fish on seasonal and spatial variation (Blaber 2000), many studies have recently focused on the functional diversity of fish, where species are assigned to guilds/groupings based on certain attributes (Elliott et al 2007). An approach of biological based salinity gradients in an estuarine system was proposed in the early 90's in USA (Bulger et al 1993). Fish species are showing different responses to salinity gradients and the framework for such nexus is called BioSalinity index (BSI) (Christensen et al 1997). The attributes of fish communities are useful to determine and classify agro-ecologies and are becoming increasingly important for conservation, management and utilization. Many authors believed water salinity and tidal regime are the key predictors of fish distribution in the estuarine floodplain areas (Nagelkerken & Faunce 2007; Taddese & Closs 2019).

The water salinity context of the region is poorly studied to understand the hydrodynamics and seasonal fluctuations. This study aims to understand the species compositions of fish and crustaceans at different agro-ecological settings in southwest coastal Bangladesh. The study also purposes to know the influences of mangrove-river network on aquatic animal richness in the region.

Material and Method

Study settings and sites. Data collection was carried out between January 2017 and July 2017 in the southwest coastal area of Bangladesh. 4 villages across the saline agro-ecologies of southwest coastal Bangladesh were selected based on the purposively conducted cluster analysis of the SEAT (Sustaining Ethical Aquaculture Trade) project for the region. SEAT was involved with 36 communities in the region for over 4 years (2008-2012), and generated detailed information on agro-ecologies, farming system, cultured species composition and salinity. Selection of study sites was designed to include at least one community from each saline gradient. A single community from Shaymnagar sub-district of Satkhira district, Ashashuni sub-district of Satkhira district, Dumuria sub-district of Khulna and Chitalmari sub-district of Bagerhat district were selected as the representatives of high saline, medium saline, low saline and freshwater areas of southwest saline gradients (Figure 1). In addition to these 4 sites, a special type of gher, where elevated farmlands in high saline areas are dedicated for freshwater crop and fish/crustacean production, were selected (pocket ghers). A pocket gher based village from Paikgacha sub-district of Khulna district was purposively selected. Higher saline areas and pocket gher areas are close to the mangrove forest and low saline and freshwater areas are further inland.

Figure 1. Map showing the aquatic farming areas in the southwest coast of Bangladesh (source: ggmap; R Core Team 2016).

Study design, sampling and methods. To understand the complex salinity regime in the region, the evidence of groundwater, soil, river water salinity and biological indicators were used. The soil salinity, river water salinity, ground water salinity data were collected from the available report, scientific literature and relevant organizational websites. Both soil and water salinity data have a correlation to each other. The soil salinity data (Deci-Siemens per meter; ds m^{-1}) were transformed to water salinity units (ppt) multiplied by the conversion factor of 0.640 (1 ds m^{-1}=0.64 ppt). The salinity data throughout this paper is presented in ppt units. To bring a holistic scenario of agro-ecologies and hydrodynamics, a wide set of salinity data were sourced for existing literature, including case studies. The gher water salinity and aquatic animal samples were collected from the selected ghers. Gher were selected from each site randomly, but the selection covered all sizes, types and locations of ghers from adjacent tributaries. For pointing the location, Global Positioning System (GPS) tracker devices were used. A portable optical refractometer (model: ZS-RM612ATC) was used to record water salinity. For fish species, identification was based on both local knowledge and taxonomic literature.

Data collection. To gather adequate data on soil salinity, river salinity and ground water salinity, available case studies were also considered for area based salinity and fish species, as a predictive indicator of water salinity. Along with water salinity, the role of the MRC network is also considered to evaluate the ecosystem service and as a base line study for the future. At least 293 fish species were recorded in the riverine, pond, stream and floodplain systems in Bangladesh (Hossain et al 2012). Moreover, taxonomic information from both freshwater (260 species) and marine water (460 species) was used in identifying the collected fish and crustacean species (DoF 2016). Fish from ghers were randomly sampled and composition was recorded during the final harvest, from January to July. In total, 200 ghers were selected randomly, at least 40 from each site. Fish were collected directly from the gher, and, for proper identification, only larger size fish were considered. During the sampling, the local name of fish and the availability status were recorded from the farmers. Samples were then transferred to the Department of Fisheries and Marine Science at Noakhali Science and Technology University, Bangladesh. After taxonomic confirmation, the numeric method was followed, counting the number of fish species that exist in the ghers of each system. Similar numerical approach was incorporated in a large scale study on fish biodiversity in the river network system (Campbell et al 2012).

Data analysis. The data of fish and crustaceans species availability was verified with the community to correctly document the local name of fish species and their identity. This discussion was facilitated by digital images of species that allowed the validation of the results (Smucker et al 2004). Descriptive statistics were used to explain water salinity data. The analyzed data and graphical presentation were customized from the statistical package program R (R Core Team 2016), and Adobe illustrator version CC 2020 was used for some images.

Results and Discussion

Salinity in the southwest Bangladesh. In the 1960's, the limited supply and rising price of rice in the international market led the Government of Bangladesh (GoB) to support the adoption of the 'Green Revolution', introducing high yielding varieties (HYV) of rice in the coastal belt (Foxon 2005). To manage salinity in these low-lying tidal areas, the government built embankments to enclose land within a series of 'polders' as part of the Coastal Embankment Project (CEP). However, in the intervening years, silt deposits in drainage canals and rivers between the polders has contributed to saline water logging within many polder systems. Some farmers started shrimp farming in the region as a consequence of this trend, whilst in other cases, unilateral conversion of rice lands to shrimp ghers left other farmers little option other than to convert themselves. The low-lying floodplain agricultural lands in this area are dedicated to aquatic farming with or without integration of rice and dyke crop production. The integration of fish, rice, and dyke crops are dependent on the degree of water salinity. Bangladesh floodplains are diverse and complex (Brammer 2004). Empirical evidence illustrates the relationship of accelerating sedimentation and increased salinity in the region due to the reduced discharge of freshwater in the Gorai river, one of the major distributaries of freshwater to the southwest coast of Bangladesh (Figure 2) (Mirza 1998). During the dry season, the drastic fall in the Gange water level and the water withdrawal at the Farakka (India) point significantly reduced the freshwater flow (Gain & Giupponi 2014). The predominantly eastward movement of Gange contributed significantly in reducing salinity levels from the southwest corner to the northeast corner of the southwest region (Rahaman et al 2015). The saline tidal water intruded up to 160 km inland through numerous estuarine rivers and tributaries, which caused increased saline levels both in water and soil (Haque 2006). These hydrological changes in the region brought changes in land use patterns and salinity gradients, which varied seasonally across the agro-ecological areas.

Salinity regimes

Salinity in the soil and river systems. The salinity of tidal floodplain areas varied significantly depending on the elevated level of land from the saline water source and proximity to the saltwater rivers and tributaries. Brammer (2004) categorized the upstream part of southwest Bangladesh as non-saline, the middle part as saline, and the part between the middle area and mangrove forest (Sundarbans) as saline acid sulfate soil (Brammer 2014).

The Soil Resource Development Institute (SRDI, GoB) monitors and maintains soil salinity and river water salinity data across Bangladesh. Soil salinity data with SRDI is robust compared to water salinity. SRDI classified the region by soil salinity into 5 zones. The classification indicated that in the southwest coastal area, about 20-30% of it is under 5 ppt, 25-30% under 10 ppt and 5-15% above 10 ppt salinity, and the salinity level is gradually decreasing inland (SRDI 2012). Water salinity during dry season varied from >10 ppt, 5-10 ppt and <5 ppt from a sea line distance of >180, 100-180 and 100 km, respectively (Bhuiyan & Dutta 2012).

Salinity level variation in the major river systems in the region was observed by Rahaman et al (2015). The major river systems in the area include Kholpetua-Arpangashia (S1), Rupsha-Passur (S2) and Baleswar-Bhola (S3) (Figure 2). Yearly salinity level in the S1 river system ranged from 8 to 24 ppt. The salinities in S2 and S3 rivers ranged from 4 to 10 ppt (Rahaman et al 2015). The predominantly eastward movement of these rivers contributed significantly in reducing salinity levels. S2 and S3 systems uptake more freshwater and have lower salinities than the S1 system, indicating that the salinity level decreases from the southwest to the northeast corner of the region (Figure 2).

Seasonal water salinity. Apart from the location, the water salinity in southwest coastal Bangladesh differs seasonally. In the dry season (October-March) the water salinity varies between <5 ppt and >10 ppt, while during the wet season (June-October) salinity lowers to <5 ppt along the sea line (Bhuiyan & Dutta 2012). On a seasonal basis, water salinity in southwest coastal Bangladesh was divided into 3 distinct zones: high saline (>5 ppt at least for 6 months); medium saline (<5 ppt at least for 6 months); and low saline (<5 ppt at least for 3 months) (Mahmood et al 1994).

The monthly salinity data of the same rivers show significant seasonal differences across the region. Salinity, irrespective of location, rises from January onwards to May and then from the onset of the monsoon rains (June-July onward) it declines (Figure 3). Some village level case studies also prove fluctuations in the regional water salinities, both in ghers and rivers. At Shaymnagar, Satkhira had more than 10 ppt during the dry season and less than 5 ppt during monsoon (Grant et al 2015). Soil salinity in the village of Dumuria, near Khulna (low saline area), was around 5 ppt in the dry season and it reduced to half during the monsoon (Mondal et al 2006). Another study observed similar seasonal fluctuations of water salinity close to Satkhira town, near to Betravati river, where shrimp-prawn-rice are integrated (Ali 2006). Moreover, the alternate and/or concurrent rice (aman rice in rainy season) cultivation with aquatic animals in higher saline areas confirmed the seasonal and local variation of salinity in the region (Belton et al 2014; Nuruzzaman 2006).

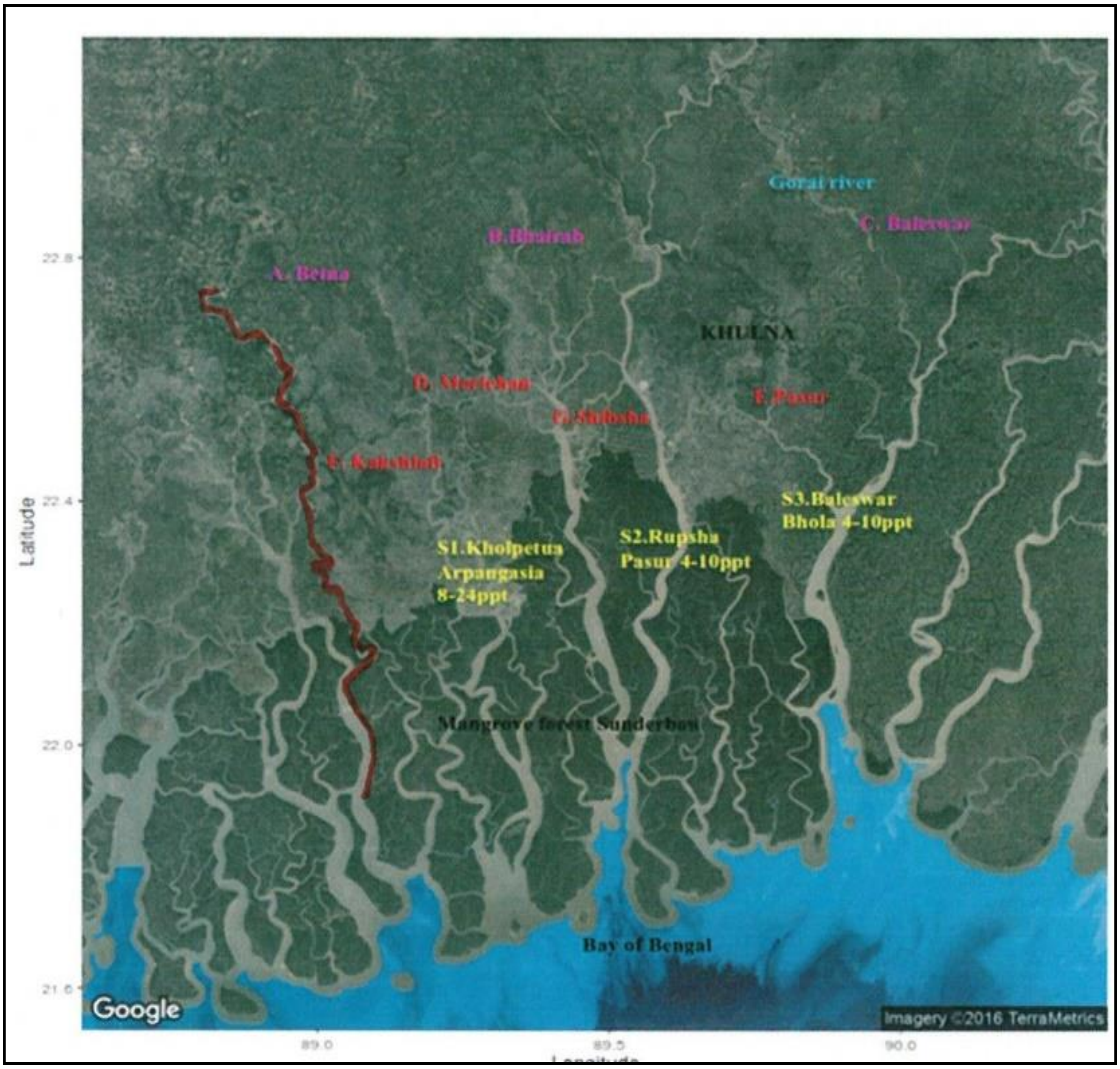

Figure 2. The range of water salinity in the major rivers and river systems of southwest Bangladesh. Data derived from Rahaman et al (2015) and SRDI (2016). From higher latitudes, the Gorai River is the main distributor of freshwater in the region. The salinity of rivers A-C, D-G ranged from 0.2-5 ppt and 0.3-16 ppt, respectively. The salinity in river system S1 ranged from 8 to 24 ppt, and in S2 and S3 ranged from 4 to 10 ppt. Map source: ggmap; R (R Core Team 2016).

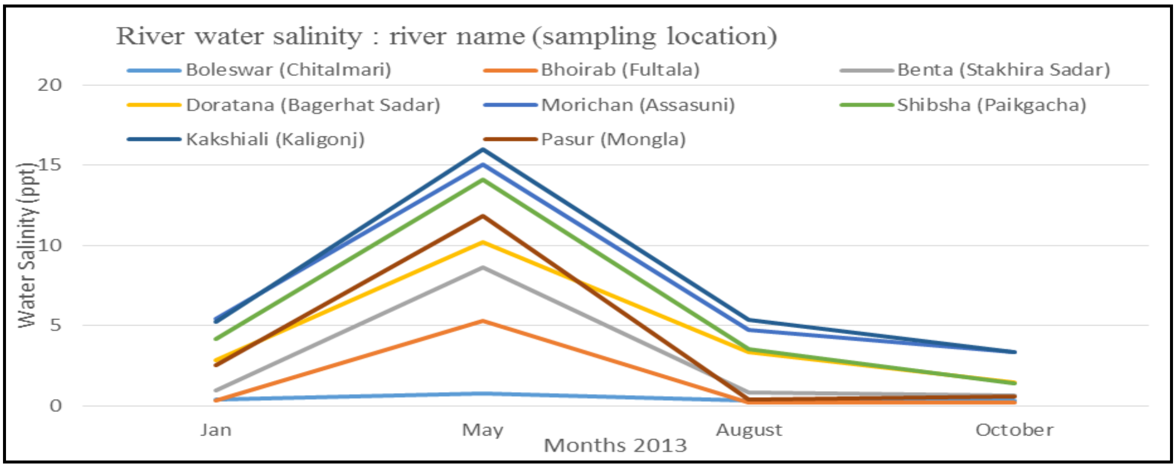

Figure 3. Seasonal variation of water salinity in the major rivers of southwest Bangladesh. Redrawn from SRDI (2016) from March 2012 to March 2013.

Groundwater salinity. Groundwater is vital for domestic, irrigation and industrial use. The groundwater salinity both in the shallow and deep aquifer was investigated across the southwest coastal area of Bangladesh. The area in proximity to the sea had higher water salinities both in shallow and deep aquifers compared to the more inland areas. In the shallow aquifer, the majority of the water salinity falls under 1-2 ppt values. It is only in Paikgacha, one of the coastline areas, where 40% of the water salinity was above 2 ppt (Table 1) (Hasan et al 2014).

Table 1

Groundwater salinity level variation within and among the communities of south-west coastal area of Bangladesh (source: Hasan et al 2014)

Area	*Area covered (%)*							
	Shallow aquifer (35-120 m)				*Deep aquifer (150-340 m)*			
Water salinity (ppt)	*<0.6*	*0.6-1*	*1-2*	*>2*	*<0.6*	*0.6-1*	*1-2*	*>2*
Paikgacha	20	4	35	41	0	4	26	70
Batiaghata	1	5	89	5	68	8	18	6
Tala	71	2	27	0	36	32	7	25
Dumuria	12	21	57	10	75	5	3	17

Salinity in the farming sites. The data of gher water salinity from 200 farms showed a consistency with the classification (Table 2). However, the salinity in gher differed due to factors related to seasonality, water exchange rate, rainfall and rate of evaporation.

Table 2

Gher water salinity (±SD) level across the agro-ecological zone of south-west coastal Bangladesh

Agro-ecological zone	*HS*	*MS*	*LS*	*FW*	*PG*
Gher water salinity (ppt)	12.7±2	7.5±2.1	3.3±1.9	0.48±0.1	1.3±0.9

Note: HS- high saline; MS - medium saline; LS - low saline; FW - freshwater; PG - pocket *gher*.

Categories of the agro-ecology by salinity. Considering all above, the aquatic farming systems in southwest coastal Bangladesh can be divided into 4 major agro-ecological areas: high saline area (HS; >10 ppt most of the time of a year); medium saline area (MS; 5-10 ppt); low saline area (LS; typically <5 ppt); and freshwater area (FW; <0.5 ppt) (Figure 4). This classification is based on the water salinity of adjacent rivers and canals in dry season. However, some exceptions like gher with low salinity exist in higher saline areas (pocket gher) as the salinity context depends on characteristics and proximity of the gher to the river/tributaries and their elevation.

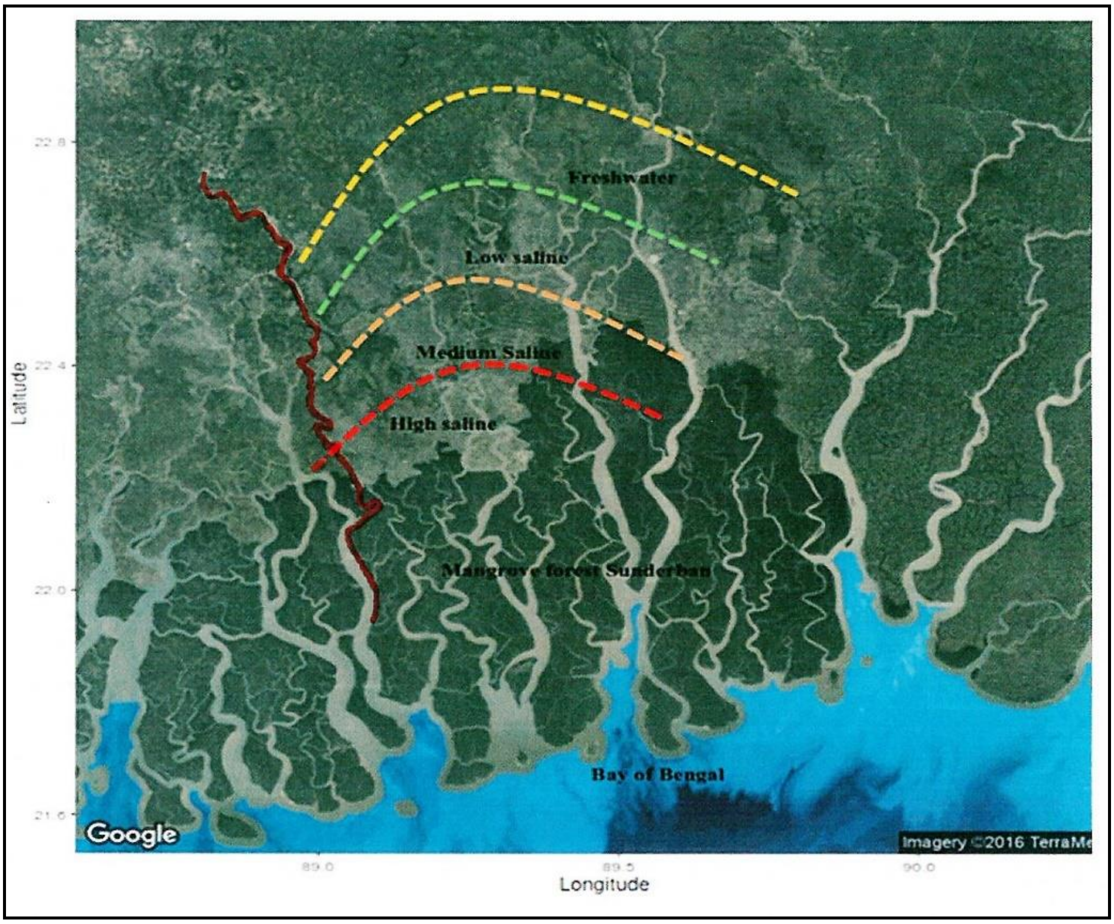

Figure 4. Categories of aquatic farming areas in SW Bangladesh on the basis of water salinity. The dotted line from lower altitude to higher altitude denotes the salinity boundary of each category. High saline is for >10 ppt, medium for 5-10 ppt, low saline <5 ppt and freshwater area <0.5 ppt. Map source: ggmap; R (R Core Team 2016).

Farming model by salinity regime

Shrimp-based aquaculture. Traditionally, shrimp are farmed with fish in polyculture systems, complementing the seasonal, social and ecological rhythm of rural life in Bangladesh (Pokrant 2014). Shrimp farmers typically fill the ghers with tidal water, which naturally carries shrimp post larvae (PL) and fry, trapping them. However, dependency on wild PL recruitment is decreasing, as farmers increasingly stock hatchery seeds (Azad et al 2009). Production mainly remains extensive, still relying on natural productivity for food and growth of aquatic animals with limited application of fertilizers and feeds, farm-made or formulated.

Based on an integration strategy, shrimp farming systems in Bangladesh can be divided into 3 distinct groups: shrimp alternate rice; shrimp alternate salt (in the southeast coast); and shrimp monoculture (Azad et al 2009) (Table 3). All the systems also yield other shrimp, fish and mud crabs. Shrimp is grown during the dry season (November-February) and rice in the monsoon season (June-October), following the flushing of water and soil salinity. In the southeast coast, shrimp is produced during the monsoon season and salt during the dry season. The third system involves shrimp culture alone and is practiced in areas where water salinity remains comparatively high for 6-9 months annually, and rice farming is impractical (Ahmed 2013).

Prawn-based aquaculture. Over 80% of prawn ghers are located in low-lying rice fields, and the rest in excavated ponds (Ahmed et al 2008). A range of freshwater fish species, including Indian major carps (*Labeo rohita, Gibelion catla, Cirrhinus cirrhosis*) are commonly cultured with prawns (Ahmed 2013). Prawn farming in low-lying rice fields is classified as integrated (concurrent culture of prawn and rice), and alternate (rotational culture of prawn and rice) (Figure 5). The first is more commonly practiced than the latter (Ahmed & Garnett 2011). In the integrated system, prawn PL are stocked in May and harvested in November-December (Ahmed 2013). Transplanted aman rice is cultivated during the monsoon (June-October) in the same field (Ahmed 2013). In alternate rice-prawn farming systems, prawn are cultured in rice fields during the monsoon season. This farming is practiced in deep flooded lowlands (Ahmed & Garnett 2011). Due to high water level in the field, farmers avoid the aman rice cultivation in the monsoon season (Ahmed 2013). Farmers cultivate summer rice (boro) in the dry season (November-February). Farmers are not able to produce prawn with boro rice due to the unavailability of prawn PL at that time (Ahmed 2013).

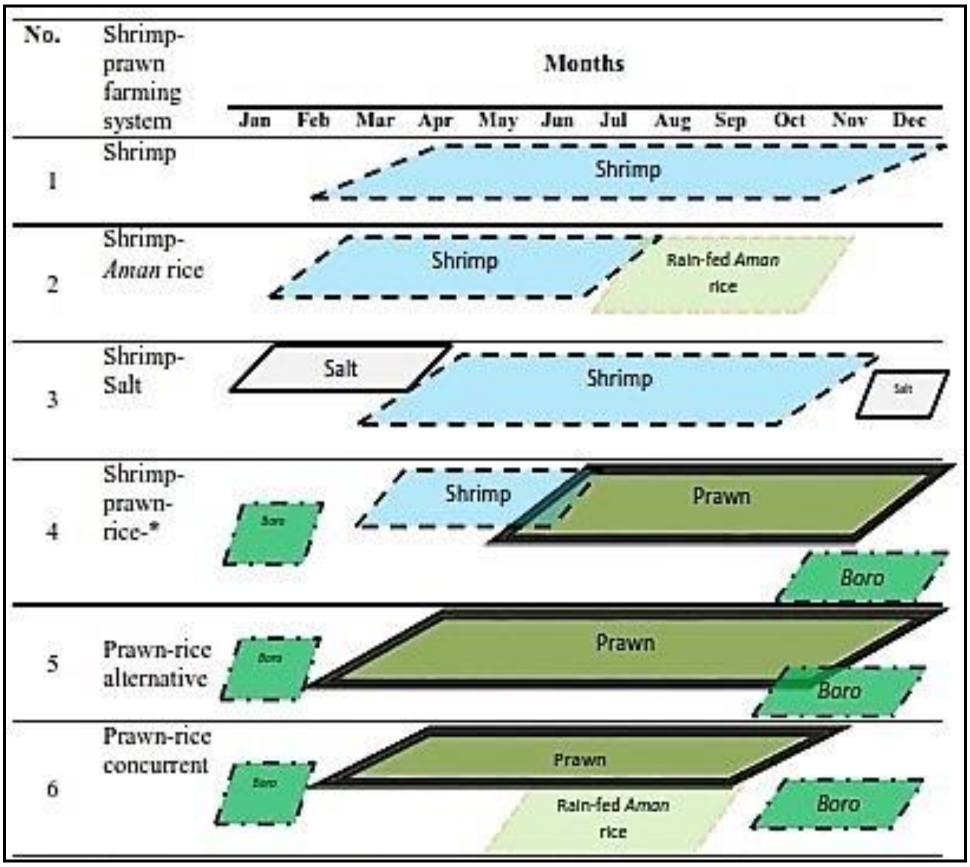

Figure 5. Shrimp and prawn farming systems in coastal Bangladesh. Dyke crop is common from the 4th row and gradually increases with progression of rows. Aman is transplanted rice mainly cultivates the during summer season, being also known as summer rice; Boro rice is mainly cultivated during winter season, being known as winter rice. * - row 4 has the characteristics of a pocket gher farm; organic farms are in rows 1 and 2. Row 1 and 3 are in Cox's Bazar region, while the rest, including row 1, are in the southwest region of Bangladesh.

On-farm biodiversity in agro-ecological areas

Species distribution and richness. Fish and crustaceans are considered as high quality animal protein sources destined for human consumption. Based on the ground information and key stakeholder consultations, fish were divided into 3 major categories: crustaceans; mangrove fish (fish from the estuary and adjacent mangrove forest); and freshwater fish. The volume of each type of fish in the systems greatly varies across the region. However, only the general presence is mentioned in this study (Table 3).

Table 3

Distribution of fish and crustaceans species in different agro-ecologies of southwest Bangladesh

Local name	*Common/English name*	*Scientific name*	*Salinity*				
			HS	*MS*	*LS*	*FW*	*PG*
Crustaceans							
bagda	Black tiger shrimp	*Penaeus monodon*	×	×	×		×
chaka	Indian prawn	*Penaeus indicus*	×	×	×		
chali	Yellow shrimp	*Metapenaeus brevicornis*	×	×	×		
goda	Goda River prawn	*Macrobrachium scabriculum*	×	×	×	×	
golda	Giant river prawn	*Macrobrachium rosenbergii*			×	×	×
horina	Speckled shrimp	*Metapenaeus monoceros*	×	×	×		×
rosna	Roshna prawn	*Exopalaemon styliferus*	×	×	×	×	
tiger chingri	Green tiger prawn	*Penaeus semisulcatus*	×				
Mangrove fish							
aamadi	Pointed tail anchovy	*Coilia dussumieri*	×				
ayza	Finny snake eel	*Caecula pterygera*	×				
bele	Tank goby	*Glossogobius giuris*	×	×	×	×	×
bhangon	Flathead grey mullet	*Mugil cephalus*	×	×			
bhola	Pama croaker	*Otolithoides pama*	×				
caine magur	Gray eel-catfish	*Plotosus canius*	×				
choto bele	Knight goby	*Stigmatogobius sadanundio*	×				
cucia	Mud eel	*Monopterus cuchia*	×				
datina	Bluecheek silver grunt	*Pomadasys argyreus*	×	×			
fesa	Gangetic hairfin anchovy	*Setipinna phasa*	×	×			
gaber dana	Spined anchovy	*Stolephorus tri*	×				
gullo/kalo chewa	Bearded worm goby	*Taenioides cirratus*	×				
gullo/lal chewa	Rubicundus eelgoby	*Odontamblyopus rubicundus*	×				
kakra	Mud crab	*Scylla serrata*	×	×	×		
kakshel	Ray-finned fish	*Barilius barna*	×				
kat koi	Crescent perch	*Terapon jarbua*	×				
khoira	Gizzard shad	*Nematalosa nasus*	×				
khorshola	Mullet	*Rhinomugil corsula*	×	×	×	×	×
nona tengra	Long whiskers catfish	*Mystus gulio*	×	×	×		
parse	Parse	*Liza subviridis*	×	×	×		×
payra/chitra	Spotted scat	*Scatophagus argus*	×	×	×		
pora bele	Dusky sleeper	*Eleotris fusca*				×	
shilong	Silond catfish	*Silonia silondia*	×				
taposhi	Paradise Threadfin	*Polynemus paradiseus*	×				
therol/ekthutu	Congaturi halfbeak	*Hyporhamphus limbatus*	×				
vetki	Barramundi/Sea bass	*Lates calcarifer*	×	×			
Freshwater fish							
bheda	Gangetic leaffish	*Nandus nandus*				×	
carpio	Common carp	*Cyprinus carpio*			×	×	×
catla	Catla	*Gibelion catla*			×	×	×
chanda	Asian glass fish	*Chanda nama*				×	
cheng	Gachua	*Channa gachua*				×	
grass carp	Grass Carp	*Ctenopharyngodon idella*			×	×	×
koi	Climbing perch	*Anabas testudineus*				×	
mirror carp	Mirror carp	*Cyprinus carpio*		×	×	×	
mola	Mola carplet	*Amblypharyngodon mola*				×	
mrigal	Mrigal carp	*Cirrhinus cirrhosus*			×	×	×
pangus	Thai pangus	*Pangasius hypopthalmus*				×	
puti	Pool barb	*Puntius sophore*			×	×	×
rekha	Silver tiger perch	*Coius quadrifasciatus*			×		
rohu	Rohou labeo	*Labeo rohita*			×	×	×
shing	Stinging catfish	*Heteropneustes fossilis*				×	
shoal	Striped snakehead	*Channa striatus*				×	
silver carp	Silver carp	*Hypophthalmichthys molitrix*			×	×	×
taki	Spotted snakehead	*Channa punctatus*				×	
tengra	Tengra mystus	*Mystus tengra*			×	×	×
thai sarputi	Silver barb	*Barbonymus gonionotus*		×	×	×	
tilapia	Mozambique tilapia	*Oreochromis mossambicus*	×	×	×		
tilapia (GIFT)	Nile tilapia	*Oreochromis niloticus*	×	×	×		

Note: HS - high saline; MS - medium saline; LS - low saline; FW - freshwater; PG - pocket *gher*.

Indicator species. Apart from using abiotic indicators, biological indicators like salinity tolerance of aquatic species and distribution pattern is also indicative of salinity variation. The salinity tolerance of aquatic species differed from species to species. In the current study, 4 species (*Glossogobius giuris, Rhinomugil corsula, Liza subviridis* and *Oreochromis niloticus*) were found to tolerate a wide range of salinity. There is a common trend observed from the study that few species and farming systems could potentially indicate the agro-ecology (Table 4). This observation is also supported by two other studies in the same region, by Carbonara (2012) and Murray et al (2013).

Table 4

Aquatic and terrestrial organisms as indicators for water salinity tolerance used to categorize aquatic farming systems in southwest coastal Bangladesh

Indicator Species/crop (name)	*Water salinity (ppt)*			
	High (>10)	*Medium (5-10)*	*Low (<5)*	*FW (<0.5)*
	Degree of intensity			
Mud crab (*Scylla serrata*)	√√√	√√	√	×
Bagda (*Penaeus monodon*)	√√√	√√	√	×
Golda (*Macrobrachium rosenbergii*)	×	×	√	√√√
Indian major carps (*Labeo rohita; Gibelion catla; Cirrhinus cirrhosis)*	×	×	√	√√√
Vetki (*Lates calcarifer*)	√√√	√√	√	×
Horina (*Metapenaeus monoceros*)	√√√	√√	√	×
Caine magur (*Plotosus canius*)	√√√	√√	×	×
Koi (*Anabas testudineus*)	×	×	√	√√√
Rice (*Oryza sativa)*	√	√	√√√	√√√
Dyke vegetables	×	×	√√	√√√

Note: degree of availability: √√√ - high; √√ - moderate; √ - low; × - nil or rare; FW - fresh water.

Role of salinity and mangrove-river connectivity on species richness. In the present study, a wide variation in species richness was observed. High saline areas are proximate to the mangrove forests and almost all the species are recruited from this natural system. Only tiger shrimp and tilapia are stocked in the gher from hatcheries. However, the later one is a prolific breeder and, in most cases, farmers share it from one gher to another, usually with a nominal price or, in some extent, free of cost. More than half of the fish species in the southwest coastal systems are available in high saline areas (Figure 6). The MRC networks play a pivotal role in fish distribution across the agro-ecologies. Similar findings were obtained in 8 African lagoons and estuaries where marine and riverine systems determined the species richness (Whitfield et al 2017). In medium saline areas, the species richness is almost half of that of high saline areas. Due to siltation and poor connection to natural water bodies, medium saline areas are struggling to get access to wild recruited species. Tiger shrimp, tilapia, barb and common crap are introduced from hatchery sources. Mozambique tilapia were found under all saline regimes (Whitfield et al 2006). A fragile connectivity to natural ecosystems impacts the biodiversity (Whitfield et al 2017). Fish species diversity has been increased by the introduction of alien and hatchery originated fish species. Tilapia is one of the major alien and hatchery fish in the medium saline areas, which are dominant. However, the impact of this species on the translocation of other mangrove fish species is not well studied.

Low saline areas have both hatchery originated and wild recruited species. In this study, 15 species are recruited from the wild and 11 from hatcheries. Freshwater area had a similar pattern with low saline area (Figure 6). The soil texture and influence of tidal water allowed species richness in both systems. The poor upstream water flow increases the water salinity in the region and invites marine juveniles for immigration further inland (Santos et al 2017). In most cases, fish juveniles and crustaceans immigrate during the tidal flush into the gher even in lower saline areas. In the Gulf of Mexico estuary, juvenile fish showed less sensitivity to salinity than adult fish (Christensen et al 1997). Both tidal flush and salinity play a key role in fish movement (Childs et al 2008).

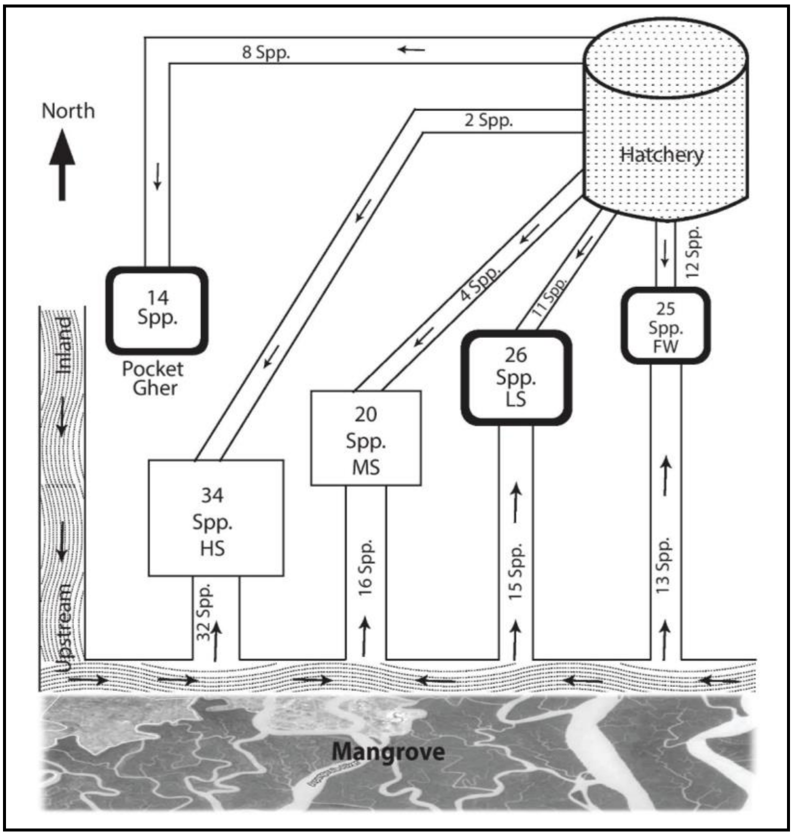

Figure 6. Impact of salinity on species richness in different agro-ecological zones of southwest coastal Bangladesh. Gher size gradually decreased from high saline to low saline areas. HS - high saline; MS - medium saline; LS - low saline; FW - freshwater; PG - pocket gher. Bold border indicates well-constructed dykes suitable for cropping.

The fish species diversity was very low in pocket ghers. 2/3 of species were supplied from hatcheries, and the rest entered by water exchange and/or other means (not direct tidal flush) (Figure 6). In this study, 4 species were found to tolerate a wide range of salinity and were present in all systems. Tilapia was surprisingly absent in the lower saline areas (LS and FW), due to the perception of farmers that tilapia feeds on prawn PL. Thus, the farmers intentionally avoid the introduction of tilapia where prawns dominate the system. The higher saline areas are dominated by black tiger shrimp and focus less on dyke production and rice. The dyke and rice crops are more present in the lower saline areas, due to favorable freshwater and the well-developed structure of dykes. Dykes in the lower saline areas are wide, allowing the culture of various vegetables throughout the year. However, in higher saline areas, the dykes are not suitable to grow vegetables.

Overall, freshwater species richness was low. Most of the species were introduced from hatcheries and some were recruited through tidal flush from the MRC network. The poor osmoregulatory mechanisms, higher predatory fish species in freshwater ecology, and the presence of predatory birds are key factors of such limitations. However, the physiological restriction is predominant. Generally, freshwater fish exhibit poor tolerance to fluctuations in salinity (Norris et al 2010). Only fish of the Cichlidae family were found to tolerate higher ranges of salinity (Whitfield 2015). MRC and water salinity were key parameters influencing the fish distribution, their occurrence being also supported by other studies (Shao et al 2019; Harrison & Whitfield 2006).

Conclusions. The coastal embankments (polders) were built to avoid tidal saline water. However, hydrodynamic events (siltation from upstream and tidal overflow) brought environmental changes and formed saline water logged areas. The changes appeared also in land use, from rice culture to shrimp culture, linked to the water salinity regimes in the region. Shrimp farming is considered as one of the few economic adaptations to saline water. Salinity levels in this area of Bangladesh vary both seasonally (high during the dry season and low during winter) and by location. The distributional differences of aquatic animals across the southwest coastal ghers indicated water salinity differences across the region or vice-versa, the salinity regime determining the species richness. This work provides a baseline study on biogeography and aquaculture species distribution in the southwest coastal floodplain of Bangladesh and their ecosystem services. This work will continue with studies on sustainability, econutrition (integrating both environmental health and human nutrition), nutrition sensitive aquaculture and conserving natural resources in the region and wider field.

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