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Impact of brackishwater shrimp farming at the interface of rice growing areas and the prospects for improvement in coastal India

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Abstract The coastal plain of Odisha in the northeastern region of India is designated the “rice bowl” of the state and is vulnerable to the impact of brackishwater shrimp farming, a prominent livelihood in southeastern Asia. Shrimp farming is highly profitable. However, owing to plentiful resources, shrimp farming has encroached on several rice-growing areas and a decline in the quality of natural resources in the coastal neighborhood has since been reported. This paper aims to study the effects of the unplanned expansion of brackishwater shrimp farming on natural resources and to provide a pathway to suitable utilization in order to improve the livelihood security of marginal shrimp farming communities in coastal Odisha, India. The practice of brackishwater shrimp farming has been determined to induce salt stress at 341–9387 ppt ha^{-1} $crop^{-1}$ with a soil EC ranging from 0.3 to 3.4 and 0.5 to 9.5 dSm^{-1} under the Scientific Extensive Traditional (SET) method and 0.1 to 1.4 and 0.2 to 3.6 dSm^{-1} under the Traditional/Improved Traditional (IT) practice during post– and pre–farming periods, respectively. Soil with ≥35% clay content underwent a severe loss of saturated hydraulic conductivity (K_s), and soil with a low exchangeable sodium percentage (6.09–8.03%) showed more susceptibility towards Na saturation than did soil with a high exchangeable sodium percentage (>10%) after brackishwater shrimp farming. Growing salt-tolerant rice in shrimp ponds during non–farming periods was observed to reduce soil K_s by only 1.2–1.3-fold compared to a reduction of 22–40-fold under shrimp farming. The paper concludes that by promoting salt washing and alleviating salinity hazards, the shrimp–rice sequence has shown promise to restore soil quality, reduce vulnerability, enhance resilience in brackishwater shrimp farming where the farms interface with rice-growing coastal areas, and provide support to conserve the coastal environment.

Keywords Brackishwater shrimp farming · Rice-growing areas · Soil and water qualities · Shrimp · Rice sequence · Sustain productivity · Coastal area

Introduction

India has an extensive, 8118-km-long coastline. This coastal area is rich in diverse biological resources that continue to decline due to rampant exploitation or alteration for such uses as aquaculture, agriculture and fisheries. Approximately 47% of the population lives in the coastal states, and 60% of the labor force is occupied in agriculture (Marale and Mishra 2011). Rice–rice, rice–non rice, and rice–shrimp are prevalent farming practices. Brackishwater shrimp farming is a popular practice due to an abundance of resources (12.4 lakh ha), and its high profit compared to the traditional farming common on the east coast of India. Shrimp, a major item of export, shares 51.35% of the total US dollar earnings in India (MPEDA Annual Report 2011 - 12). Nonetheless, persistent problems of self-pollution and the introduction of pathogens lead to the outbreak of major shrimp diseases, resulting in significant financial losses that make farming risky and create hardships for many small-scale farmers who invest in farming. These farmers rarely come back to traditional rice farming practices

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because of soil salinization and salinity-related impediments (MoST&E 1999; Salim et al. 1990).

The environmental impact of shrimp aquaculture is intimately linked with the nature of the practice (i.e., traditional/improved traditional or scientific extensive traditional) with stocking density ranging from 40,000 to 60,000 ha^{-1} and 60,000 to 100,000 ha^{-1}, respectively (CAA Act 2005). Acute dipping of rice yields (from 3 to 0.5 t ha^{-1}) and nutrient uptake, erosion of homestead vegetation and social forestry, and degradation of the physical and social qualities of the natural environment are evident in shrimp-growing areas across coastal habitats (Gadgil et al. 1990; Csavas 1995; Manju 1996; Hagler 1997; Karim 2006). Since coastal populations survive mainly on marine resources, the overexploitation of essential resources has threatened the security and sustainability of the ecosystem (UNEP 2003; UNEP/GPA 2006).

Inland brackishwater shrimp culture is a profitable occupation for farmers in India and is a highly remunerative livelihood option for small and marginal farmers (>1.0 ha) in coastal Odisha. Owing to huge profits from brackishwater shrimp culture, the conversion of rice fields to shrimp ponds has taken place on a large scale and the selling of agricultural land to shrimp growers at elevated prices has increased (Rao and Ravichandran 2000). These changes often take place in areas where income from rice farming is low, indebtedness is high, and limited off-farm employment opportunities exist. Thakur et al. (1997) reported that in India, only 12.5%–15% of agricultural lands have been converted to shrimp farms, and most of those lands were either less productive than their previous uses or largely underutilized. This rapid growth of shrimp farming by converting cultivable field to shrimp farm ponds started decades ago, and has encroached upon vast rice-growing fields in Bangladesh. After ≥10 years of the practice, many farms have been found to crash because of virus infection, the development of pathogens from shrimp and feed waste or infections in the pond that prevent further use. As a result, the farming is shifted to neighboring fields. In the process, more and more croplands become shrimp ponds and the coastal farmland is more likely to become saline and unproductive in the near future. Similar observations have also been reported from shrimp-growing areas in Vietnam (EJF 2003). In a number of studies from Bangladesh, the unplanned expansion of brackishwater shrimp farming has resulted in severe environmental degradation including water scarcity, increased salinity and health hazards, decreased land productivity, and a loss of biodiversity that eventually exacerbated food insecurity and livelihood vulnerability (Islam 2005; Islam Tariqul et al. 2011; Rahman et al. 2013; Swapan and Gavin 2011). The intrusion of salinity, the salinization of cropland and the decrease of soil fertility due to the unauthorized expansion of brackishwater shrimp farming are also reported from several locations across coastal areas (Ali 2006; Chowdhury et al. 2011; Hossain et al. 2013). Since coastal areas are the transition zones from marine to terrestrial environments, and unlawful expansion of one activity limits the resources for other activities, these destructive resource-consumption patterns are disturbing the soil-water–plant–marine life balance and destroying the integrity of the ecosystem. Activities that damage the resources thus need urgent attention to resolve so that the quality of this fragile environment can be protected and restored.

In comparison to commercial shrimp farming practices, this is an unorganized sector. Information on the recurrence of major shrimp diseases and the failure of the farming are therefore not documented. Often, disease outbreaks destroy shrimp production and ruin the fate of poor farmers who cannot go back to rice cultivation in the area because of soil salinity build-up and the deterioration of soil physical structures. However, in disease-free years, the practice brings huge incomes for farmers. Hence, without introducing any other livelihood option of similar scale and benefits, preventing the conversion of rice fields to shrimp ponds because of a potential environmental degradation problem is not reasonable in coastal areas. The coastal environment is fragile and its threats and problems are site and issue-specific. Impact evaluations of any issues influencing productivity should aim to set up a mechanism for conservation and should support implementing an action plan towards integrated management of the coastal ecosystem.

Odisha is located between 17°49′ and 22°34′ N and 81°27′ and 87°29′ E on the northeastern coast of India. The state has a narrow track of coastal plains along the eastern boundary by Bay of Bengal, covering six coastal districts (Balasore, Bhadrak, Kendrapada, Jagatsinghpur, Puri and Ganjam) which contribute to 24.37% and 2.5% of the rice-growing area of Odisha and India, respectively, and 29.58% and 1.925% of the total rice production of Odisha and India, respectively (www.indiastat.com). There are 32,587 ha with the potential for brackishwater shrimp farming in Odisha and an approximately 16,691.77 ha area is under shrimp cultivation until the end of the 2012–2013 season (AAR Govt. of Odisha 2011–2012). The rate of shrimp production has steadily improved from 6430 MT in 2000–2001 to 11,976 MT in 2011–2012, with an export capacity of 16,858 MT amounting to $161.55 Million USD in 2011–2012 (www.orissafisheries.com). The purpose of this study is to assess the impact of brackishwater shrimp farming on natural resources and to provide means for improving shrimp farming at the interface of rice-growing areas in coastal Odisha, India.

Methods

Odisha has a coastline of 480 km along the east coast of India. People belonging to rural communities in coastal Odisha are engaged in a range of livelihood activities, such as agriculture, fishing, poultry, aquaculture and mixed farming. Shrimp farming is prevalent because of its high market value and the abundance of saline water resources in coastal districts. On the basis of type and intensity of brackishwater shrimp farming practices, two coastal areas, Astaranga (19°59'N, 86°17'E) and Erasama (19°58' to 20°23'N and 86°31' to 86°45’E), of Odisha, India, were selected for this study.

Sample collection and analyses

Water

Fifty-nine samples including surface, groundwater and rice-field water surrounding shrimp farming areas were collected during pre- and post-shrimp farming periods along the coastal tract of Odisha from 2009 to 2011 (Fig. 1). The samples were analyzed for salinity, pH, Na, K, Ca, Cl, Mg, sulfate, carbonate and bicarbonate contents following the standard procedures outlined by APHA (1995).

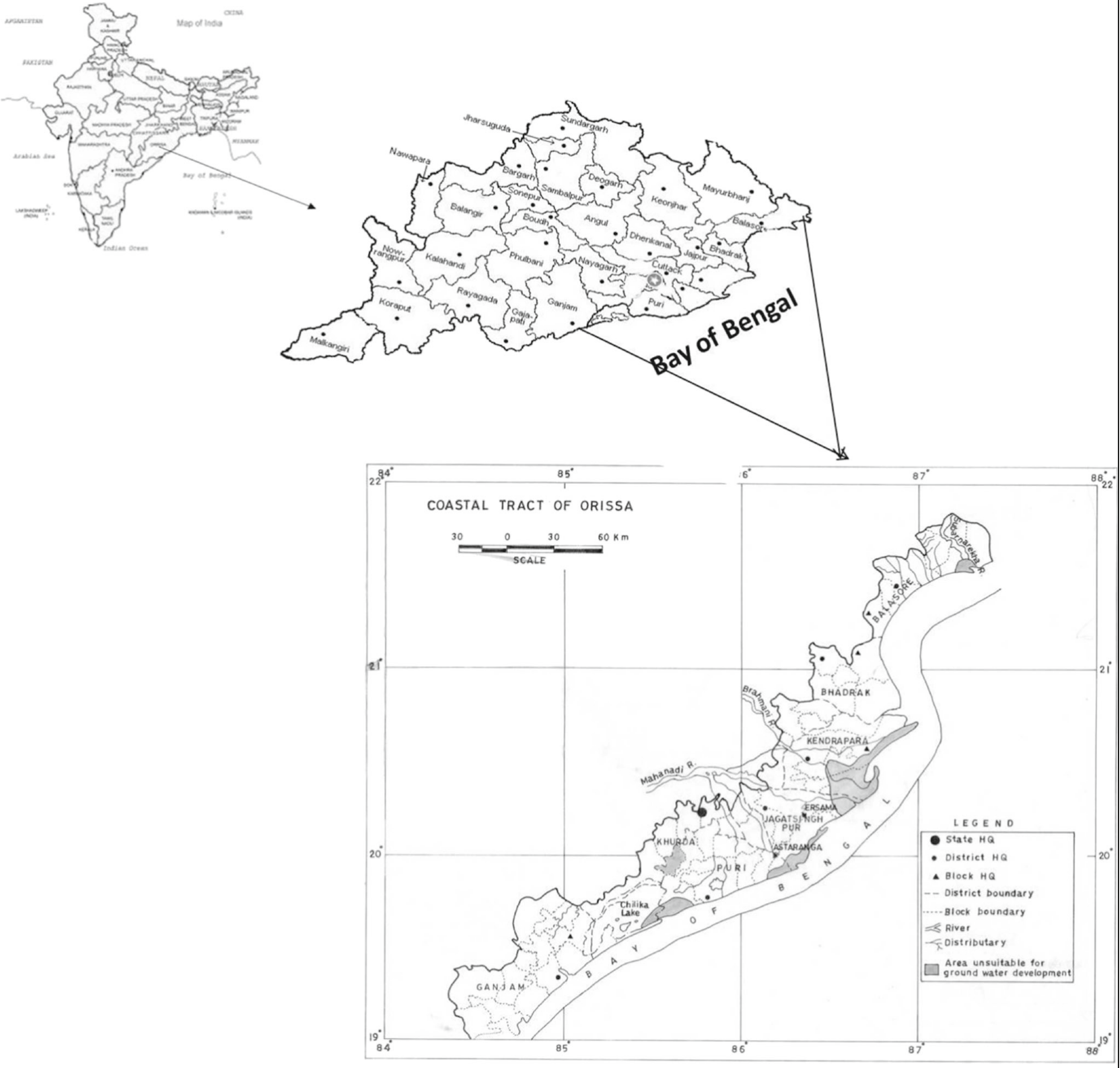

Fig. 1 Location of the study area

Soil

Forty-one soils, each from a 0–20 cm depth, were collected from various places, including shrimp ponds and their adjacent agricultural pastures at pre– and post–farming periods during 2009 to 2011 at both study areas. Samples were processed and analyzed for salinity, pH, organic carbon, exchangeable Na, K, Ca, Mg using Normal (N) ammonium acetate solution with neutral pH, water-soluble Na, Ca, Mg and available N and P following the standard methodologies (Jackson 1976). Soil salinity (EC) was found to vary enormously; therefore, a separate set of thirty-eight soil samples covering the major locations of shrimp farming areas from both Astaranga and Erasama was collected during pre– and post–farming periods (2010–2011), and analyzed for salinity and texture. Soil salinity and textural contours of the study area were drawn using the SURFER package (version 8.0) and presented in Figs. 2 and 3.

Assessment of brackishwater shrimp farming on soil salinity

To evaluate the impact of brackishwater shrimp farming on soil salinity and relevant physico-chemical soil properties, experiments were set up in the laboratory. Soil samples (0–20 cm) differing in texture were collected in brass cores (5 cm diameter and 6 cm length) from ten different shrimp ponds before the start of the farming, which usually begins in March or April and continues to June or July in the study area. Soil columns were leached following a constant head method (Klute 1965) with naturally available brackishwater of EC 7.00 ± 1.0 dSm^{-1} until equilibrium was attained; the same soil column was subsequently leached with a normal water till to reach a constant salinity value of the leachate. The salt content and the saturated hydraulic conductivity of soils after leaching with brackishwater and normal water were measured following the standard procedures.

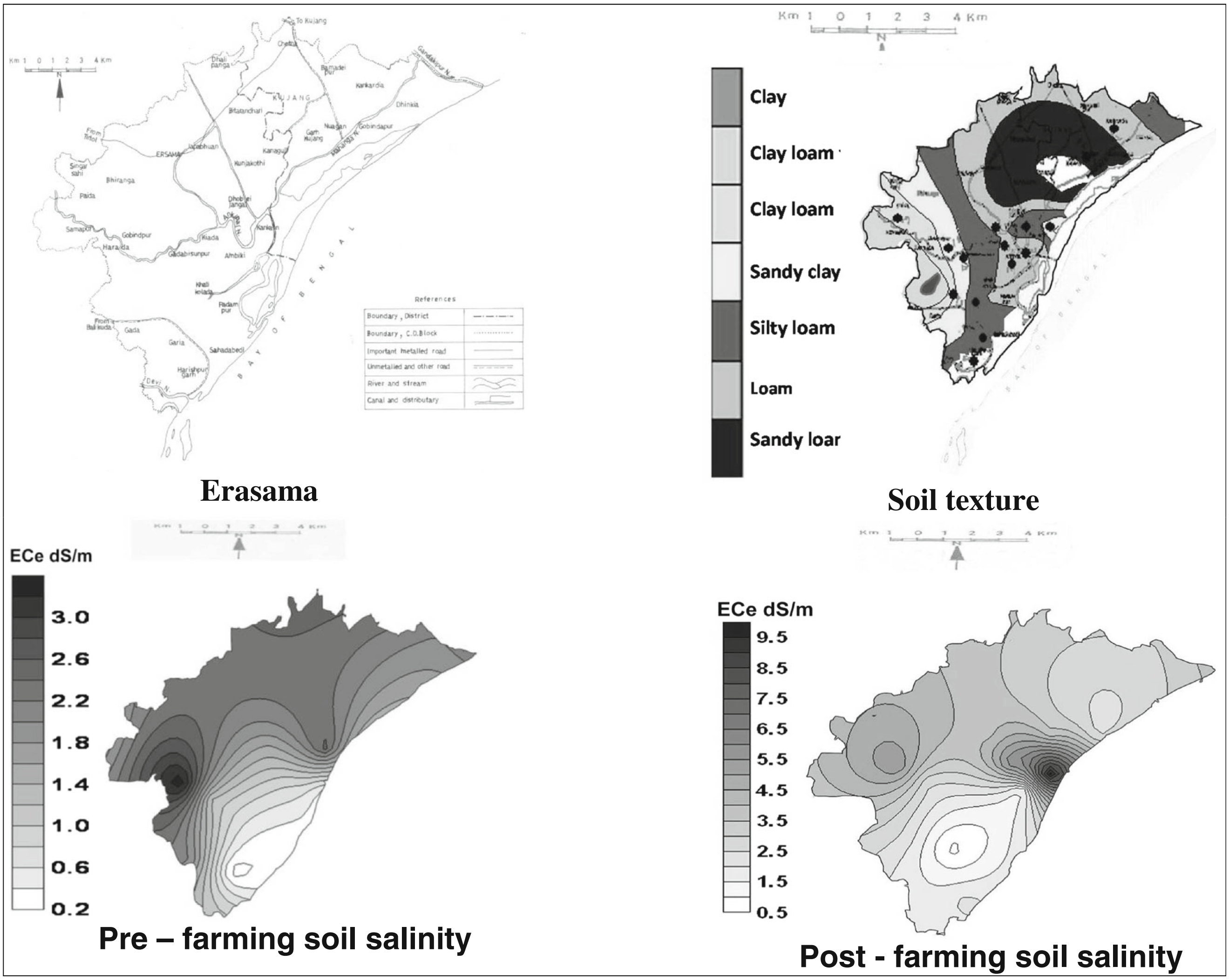

Fig. 2 Spatial variation of soil texture, pre and post farming soil salinity across the places under Scientific Extensive Traditional shrimp farming at Erasama in coastal Odisha

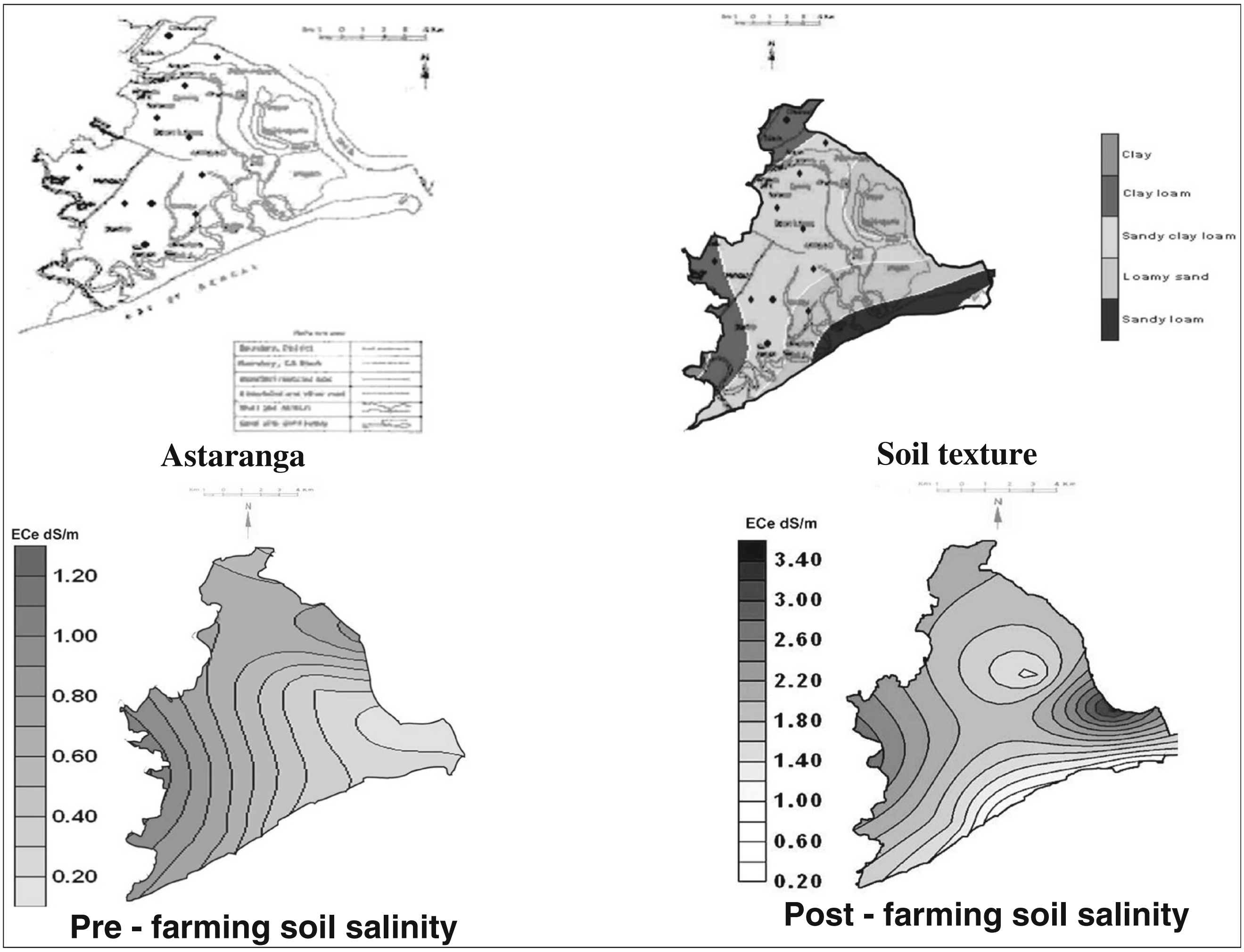

Fig. 3 Spatial variation of soil texture, pre and post farming soil salinity across the places under Improved Traditional shrimp farming at Astaranga in coastal Odisha

Field experiment with salt-tolerant rice

The leaching study of soil columns revealed a substantial decrease of saturated hydraulic conductivity after the application of normal water, irrespective of soil textures. A decrease of hydraulic conductivity delays the salt washing during monsoon season and intensifies its accumulation in subsequent brackishwater shrimp farming. To improve soil physical properties, five salt-tolerant rice cultivars (CR-2485-7-3-45-1, IR72046–B–R–3–3–3–1, OM–6051, OM–6050 and CR 2472–1–6–2) were collected from the neighboring Central Rice Research Institute, Cuttack, Odisha and grown along with a typical local variety (Khandagiri) as a control in a shrimp pond during the non-shrimp farming period (November–January) in 2009–2010 at the village Sundar in Astaranga. Rice was grown following the broadcasting method of sowing germinated seeds with N:P_2O_5:K_2O fertilizers at a 100:40:60 ratio applied to three splits (basal, top dressing at tillering and panicle initiation stages). The salinity of soil at the time of sowing was 2.3 dSm^{-1}.

In the second year of the study, four salt-tolerant rice cultivars were grown, with ‘Khandagiri’ as a control, at the village Kakan in Erasama during 2010–2011. Soil at Erasama was 2 to 3 times more saline at any point of time than the soil observed at Astaranga (Figs. 2 and 3). Rice seedlings were therefore established with normal water at the nursery, and transplanted after 20–25 days in the shrimp pond area. Soil salinity at the time of transplanting was 3.5 dSm^{-1}.

To identify the threshold salt tolerance level of the five salt-tolerant rice cultivars, an experiment was carried out with three salinity levels (EC_w = rain water, 3.0–3.5 and 5.0–6.0 dSm^{-1}) with a completely randomized design under net house conditions from 2009 to 2010. Biometric observations taken during crop growth periods, grain yield and the soil properties measured before and after the experiment are presented in Tables 5 and 7. All statistical analyses were performed using SPSS, version 10.0.

Results

Water and soil salinity appraisal

A comparison of salinity attributes in water (Table 1) reveals an increasing trend across the sources from pre– to post–shrimp farming periods. The salinity composition was of a Na–Mg–Ca type. The increased salt stress in river/creek/drain water was equal to brackishwater shrimp pond water followed by rice–field water, rainwater harvesting pond water, and groundwater. Salt stress was not a constraint in groundwater sources but it aggravated salt stress from 11% to 188% in the rice–field water and 55% to 92% in the rainwater harvesting pond. Apart from increasing salinity (4.93 to 203%), Na, Ca and Mg contents were also intensified from pre– to post–farming periods in shrimp pond water (Na: 1.11 to 2.45, Ca: 0.39 to 3.78 and Mg: 0.33 to 2.32 times). The water quality parameters, however, distinctly varied over the sample collection periods without reflecting any trend with shrimp farming practice types.

Data pertaining to relevant soil quality parameters (Table 2) reveal that the soil was invariably acidic in response to variable salt stress. A preponderance of Na over Mg and Ca in the soil exchange complex is evident, as observed in the water sources. Soil salinity, which is closely linked with soil texture, strikingly fluctuates with the seasons. The illustration of data in Figs. 2 and 3 reveals that the soil salinity of saturation extract (EC_e) at Erasama under the Scientific Extensive Traditional (SET) practice varied from 0.3 to 3.4 in the pre-farming period and 0.5 to 9.5 dSm^{-1} in the post-farming period and ranged between 0.1 and 1.4 in the pre-farming period and 0.2 and 3.6 dSm^{-1} in the post-farming period at Astaranga under the Improved Traditional (IT) practice. Soil texture varied from sandy loam to clay at both places (Figs. 2 and 3), while the occurrence of finer textures was relatively greater at Erasama than Astaranga. This property may contribute to the 2–3-fold greater salt stress observed at Erasama than in the soil at Astaranga.

Leaching effect of brackishwater followed by normal water on soil salinity

The leaching of soil columns with brackishwater followed by normal water under laboratory conditions revealed a significant increase in soil salinity (x) in the form of $0.81e^{2.61x}$, $R^2 = 0.82$, if '(silt + clay) / sand'(x) is between 0.44 to 0.83, and $-\,0.51 \times {}^{2} + 3.86\times - 0.3$, $R^2 = 0.86$, if the silt:clay:sand

Table 1 Source – wise mean value of water quality parameters

Type of water source*	Important water quality parameters															
	pH		EC dSm^{-1}		Na mgl^{-1}		K mgl^{-1}		Organic Carbon, gml^{-1}		Alkalinity mgl^{-1}		Sulfate mgl^{-1}		Hardness mel^{-1}	
	Period of sample collection**															
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
A. Traditional / Improved Traditional (Astaranga)																
A	7.63	7.90	3.55	11.2	535.86	5623.98	27.41	312.40	0.01	0	0.25	0.40	35.65	41.20	15.01	35.30
B	7.49	8.00	9.53	10.0	3817.3	4876.23	127.57	278.30	0.04	0.04	0.30	0.54	151.14	239.00	31.15	84.50
C	7.50	7.60	5.17	6.00	1139.9	2312.00	44.54	144.50	0.01	0.03	0.43	0.45	104.83	195.36	3.15	5.14
D	7.68	8.23	3.60	4.00	1108.7	456.56	28.28	90.20	0.02	0.03	0.39	0.67	35.02	79.30	2.65	6.70
E	8.03	8.40	2.90	7.40	466.00	1119.30	22.17	119.00	0.06	0	0.59	0.70	8.42	110.00	6.28	12.10
F	7.20	7.80	2.10	2.30	378.00	389.30	6.89	75.60	0.05	0.01	0.45	0.53	6.84	19.34	4.16	5.10
B. Scientific extensive traditional (Erasama)																
A	7.73	8.02	1.03	5.87	202.77	2010.15	10.33	127.47	0.03	0.06	0.96	0.29	48.01	79.38	2.00	33.76
B	7.00	7.73	4.32	13.10	784.96	4044.04	23.49	93.93	0.01	0.04	0.68	0.75	111.07	70.36	13.74	41.12
C	7.56	7.38	1.56	4.45	420.48	1041.25	18.01	45.39	0.01	0.01	0.61	0.25	48.42	137.36	2.38	10.73
D	7.63	7.75	4.60	8.10	3347.00	1408.32	49.27	46.51	0.02	0.07	0.26	0.35	140.34	23.81	40.07	21.28
E	7.58	7.74	2.18	10.65	544.60	3142.59	22.14	226.00	0.02	0.04	0.91	0.47	47.81	176.71	6.40	62.80
F	7.10	7.53	1.05	2.48	524.03	249.31	21.78	12.81	0.02	0.03	1.08	0.47	76.51	8.06	8.36	18.48

**A* River, *B* Shrimp Pond, *C* Stranded water on rice field, *D* Rainwater harvesting pond, *E* Creek / Drain, *F* Groundwater

**1 – Pre and 2 – post shrimp farming periods

Table 2 Important soil fertility parameters in Astaranga and Erasama area

Soil Parameters	Traditional/Improved Traditional Mean ± Std. Error	Scientific Extensive Traditional Mean ± Std. Error
pH	4.49 ± 0.58	5.33 ± 0.41
EC_2 dSm^{-1}	2.2 ± 0.6	3.9 ± 0.6
Organic carbon %	0.77 ± 0.27	0.54 ± 0.12
Bray's - P ($mgkg^{-1}$)	0.95 ± 0.11	1.13 ± 0.08
Exchangeable K ($mgkg^{-1}$)	575.73 ± 191.16	595.4 ± 180.56
Exchangeable Ca ($mgkg^{-1}$)	911.97 ± 166.45	496.94 ± 163.07
Exchangeable Mg ($mgkg^{-1}$)	1373.4 ± 337.26	1180.47 ± 306.63
Exchangeable Na ($mgkg^{-1}$)	2529.75 ± 844.35	4617.0 ± 1383.7

ratio varies from 1.04 to 3.66 (Fig. 4). Apart from developing salt stress, soils with ≥35% clay content showed a severe loss of saturated hydraulic conductivity (K_s) after leaching with brackishwater followed by normal water. A severe loss of K_s (45 to 100%) was evident without reflecting any consistent trend either with clay content or with the '(silt + clay) / sand' ratio in soil.

Response of salt-tolerant rice cultivars and the impact on shrimp pond soils

Data pertaining to biometric observations and the grain yield of rice grown in brackishwater shrimp ponds during the non–shrimp farming period in 2009–2010 at Sundar in Astaranga (Table 5) reveal that all five of the salt-tolerant cultivars performed significantly better than Khandagiri in terms of grain yield (CR 2472–1–6–2 > OM 6050 > IR72046–B–R–3–3–3–1 > CR–2485–7–3–45–1 > OM – 6051).

Results of the pot experiment with salt-tolerant rice cultivars (Table 6) carried out under net house conditions reveal that the number of tillers and height of each plant was not related to water salinity levels, but aboveground biomass decreased with rising salinity. The highest biomass yield was obtained in CR 2472–1–6–2 followed by CR 2485–7–3–45, even at high EC_w (5–6 dSm^{-1}). There was no yield reduction of IR72046–B–R–3–3–3–1 observed up to EC_w 3 to 3.5 dSm^{-1}, and the poorest yields were recorded for OM–6051 and OM–6050. This indicates that water of moderate salinity (2 to 3 dSm^{-1}) could be used for growing salt-tolerant rice varieties during freshwater scarcity.

Data pertaining to relevant soil properties before and after the cultivation of rice (Table 7) indicate an improvement in the saturated hydraulic conductivity (K_s) of soil, which was otherwise decreased by 1.2 to 1.3 times under the shrimp–rice method, and decreased 22 to 40 times the initial levels under a "shrimp only" practice. However, no improvement was evident in the soil exchangeable sodium percentage (ESP) for shrimp production in one season.

Discussion

Variation of salt stress

In coastal areas, soil and water salinity and salinity-related attributes vary with season, with their lowest values being observed during post–monsoon periods and their highest values being measured at pre-monsoon periods in humid and sub-humid regions. The water quality comparison from pre– to post–shrimp farming periods revealed that the shrimp pond water was 1.66 to 1.84 times more salt stressed, and contained excess amounts of Na (2.11 to 3.35 times), organic carbon (1.33 to 3.46 times) and K (1.92 to 2.86 times) relative to the concentrations observed in the adjacent rice–field water at Astaranga (Table 1). However, where the stocking density

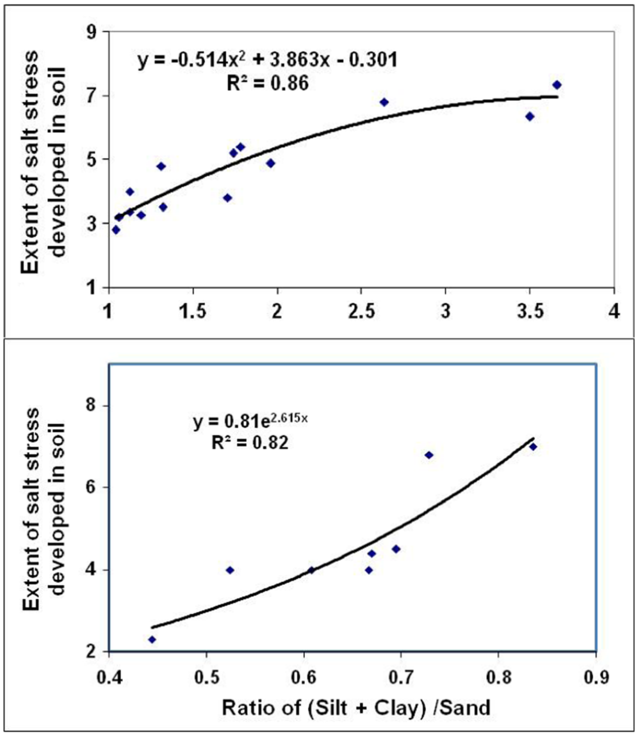

Fig. 4 Variation of salt stress built up with soil textural components

of shrimp is higher at Erasama (Scientific Extensive Traditional farming) than at Astaranga (by 0.6 to 1.5 times), the salt stress was higher (by 2.77 to 2.94 times) in the shrimp pond than in its adjacent rice-field water.

Shrimp farming is practiced from March/April to June/July in shallow ponds with depths of 0.8 to 1.0 m of water in both Erasama and Astaranga. The water quality of the pond deteriorates during the production cycle due to the presence of unused feed, fecal matter, and other metabolites that negatively affect shrimp growth and production. To maintain water quality suitable for shrimp production, a 50 to 60% exchange of water at 15 day intervals starting 30 to 45 days after stocking was followed by pumping water from a nearby river, creek, drain or similar water source, depending on their availability at a particular locality. High salt load may thus be the result of the intrusion and stagnation of saline water in the shrimp pond, which gets concentrated over time. The development of persistent salt build-up limits crop production in the absence of appropriate measures for desalinization to a considerable level of tolerance. Assessing the impact of the intensification of brackishwater shrimp farming on converted rice fields where they interface with rice farming areas is, however, difficult on the east coast of India. Except for some piecemeal information, such as the soil and water quality status in and around Bhitarkanika and Chilika lake in Odisha, Canning Town in West Bengal (Mitra and Santra 2011; Das et al. 2010; Das and Maji 2001), the real-time data on soil and water quality prior to the intensification of shrimp farming is barely available in the coastal states of India.

Soil texture, which plays a major role in determining soil salinity, varies widely in the study area (Figs. 2 and 3). Depending on the extent of salt retained, soils differed in textures after brackishwater shrimp farming followed by normal (rain) water washing. It has been estimated that the practice could induce the probability of increasing salt stress at 341 to 9387 ppt ha^{-1} shrimp crop^{-1}. However, no difference between the types of shrimp farming practice (i.e., SET and IT) on salt content was evident. The relationships established between salt stress and soil particles (Fig. 4) could thus be exploited for estimating the rate of increasing salinity in brackishwater shrimp farming area in coastal Odisha.

Impact of leaching with brackishwater followed by normal water on soil

Leaching with brackishwater followed by normal water revealed a severe loss of K_s at a pace of 45 to 100% without any consistent trend with clay content or '(silt + clay) / sand' ratio. This might be due to an increasing ESP >15 (Table 3), which led to the dispersal of clay particles, the blocking of soil pores and reduction of the permeability of soil. This has been corroborated by a Na enrichment of 6.27–62.74% over the initial levels, with a loss of Ca (14.29–42.42%) and Mg (17.5–62.29%) from the soil exchange complex. In addition, for a 1.0 unit alteration of K_s, a 0.65 unit change in salt content of the leachate was obvious, irrespective of soil textures. Soil with low ESP (6.09–8.03) appeared more vulnerable to Na saturation than soil with high ESP (Table 3).

Table 3 Salt constituents and textural attributes of soils used for leaching experiment

A. Pre - leaching period

Soil Textural class*	(clay + silt)/ sand	K_s cm min^{-1}	CEC	Na	K	Ca	Mg	ESP
← me 100 g soil^{-1} →								
scl	1.31	0.022	38.48	30.76	6.82	0.14	0.28	13.54
sc	1.13	0.025	20.64	10.43	2.73	0.33	0.4	8.3
sl	0.49	0.019	20.68	13.91	2.39	0.09	0.23	17.01
c	3.66	0.003	70.8	54.7	11.21	0.7	0.75	28.61
cl	2.64	0.002	50.36	35.53	11.91	0.38	0.42	13.77

B. Post - leaching with saline water (EC_w, 6.7 ± 0.5) followed by normal water

Soil Textural Class*	(clay + silt)/sand	K_s cm min^{-1}	CEC (me100 g soil^{-1})	Na (me100 g soil^{-1})	K (me100 g soil^{-1})	Ca (me100 gm soil^{-1})	Mg (me100 gm soil^{-1})	ESP
scl	1.31	0.01	42.68	38.05	7.5	0.12	0.16	23.35
sc	1.13	0.02	49.08	40.92	7.5	0.19	0.33	18.3
sl	0.49	0.008	16.96	10.31	5.11	0.14	0.14	13.71
c	3.66	0.0007	77.8	63.7	11.08	0.52	0.61	32.08
cl	2.64	0.0006	73.3	60.57	10.59	0.23	0.33	30.39

**scl* Sandy clay loam, *sc* Sandy clay, *sl* Sandy loam, *c* Clay, *cl* Clay loam

Table 4 Important characteristics of shrimp - pond and rice - field soils after one crop cycle

Locations	pH (1:2.5)	EC_2, dSm^{-1}	Org. Carbon, gm 100 gm $soil^{-1}$	Available N, gm 100 gm $soil^{-1}$	Available P, mg kg $soil^{-1}$	1 N NH_4OAc – Extractable				ESP
						Na me 100 gm $soil^{-1}$	K	Ca	Mg	
A. Typical brackish - water shrimp pond										
Sundar village, Astaranga	5.7	3.7	0.71	0.04	2.86	17.07	1.43	2.39	4.23	20.74
Chaulia gram panchyat, Ersama	7.6	5.8	0.32	0.07	7.34	26.97	1.52	2.98	1.43	42.82
Kakan village, Erasama	7.7	9.8	0.89	0.84	1.52	94.86	5.49	12.46	12.46	21.08
B. Rice - field soil										
Sundar village, Astaranga	7.0	1.60	0.23	0.04	0.80	6.19	0.76	1.81	3.02	5.55
Kakan village, Erasama	5.6	0.20	0.44	0.03	7.56	1.38	0.32	1.42	1.42	1.68

The reduction of K_s with the application of brackishwater followed by normal water was evident (Table 3) at a moderate extent in the soil containing 30–35% clay. The deterioration of soil structure impedes the water infiltration rate by affecting hydraulic conductivity, which is a function of the exchangeable sodium percentage (ESP), organic matter and Na content. The decrease of K_s with increasing ESP was reported in several studies (Shainberg and Letey 1984; McNeal and Coleman 1966; Suarez et al., 1984).

Response of rice and its effect on soil properties

Brackishwater shrimp ponds are not commonly being utilized for rice cultivation until they produce a good harvest in the

Table 5 Performance of salt resistant rice cultivars (per plant) in brackish - water shrimp pond

A. Astaranga

Paddy cultivars	Tiller Nos.	Primary branches per panicle	Panicle length (cm)	Plant height (cm)	Grain weight (q ha^{-1})
Khandagiri	10	11	17.08	73.03	0.35
CR −2485-7-3-45-1	5	4	18.80	72.67	7.45
IR72046 –B–R–3–3–3–1	12	6	19.00	79.80	8.47
OM – 6051	6	7	17.31	76.30	5.32
OM – 6050	4	3	20.84	75.00	9.18
CR 2472–1 – 6 – 2	7	7	18.79	74.30	13.93
F – ratio	2.72	2.75	1.85	0.82	16.60**
$LSD_{0.05}$					3.48
$LSD_{0.01}$					4.95

B. Erasama

Paddy cultivars	Tiller Nos. $plant^{-1}$	Mean LAI*	Panicle length (cm)	Plant height (cm)	Panicle weight (gm)	No. of grains per panicle	Grain weight (q ha^{-1})
Khandagiri	4	0.48	7.67	38.67	0.05	15	0.01
CR −2485-7-3-45-1	10	0.95	17.77	44.80	0.27	60	0.05
IR72046 –B–R–3–3–3–1	27	1.52	19.73	48.40	0.74	81	0.91
OM – 6051	18	0.94	19.83	42.40	0.95	75	0.62
CR 2472–1 – 6 – 2	28	1.08	19.63	74.30	1.41	99	1.20
F – ratio	14.39**	34.63**	30.48**	7.63**	15.68**	23.58**	37.07**
$LSD_{0.05}$	5.87	0.13	2.03	4.59	0.29	14.04	0.18
$LSD_{0.01}$							4.95

* Active tillering stage, ** Level of significance at 0.01 P

Table 6 Screening of salt tolerant rice cultivars under different salinity levels

Detail of cultivars	Plant observations per plant basis	Levels of irrigation water salinity (EC_w), dSm^{-1}		
		Rain Water	3 to 3.5	5 to 6.0
CR 2485–7 – 3 – 45 – 1	Tiller nos.	12	6	12
	Plant height (cm)	46.73	47.17	47.00
	Biomass weight (gm)	4.58	1.80	3.55
IR72046 – B –R–3–3–3–1	Tiller nos.	15	11	5
	Plant height (cm)	49.97	48.57	45
	Biomass weight (gm)	7.53	6.28	0.86
OM – 6051	Tiller nos.	7	11	5
	Plant height (cm)	44.83	44.83	46.17
	Biomass weight (gm)	2.84	4.12	0.70
OM – 6050	Tiller nos.	7	6	9
	Plant height (cm)	52	49.33	47
	Biomass weight (gm)	2.58	3.90	2.74
CR 2472–1 – 6 – 2	Tiller nos.	6	6	23
	Plant height (cm)	49.8	46.33	46.1
	Biomass weight (gm)	8.71	4.56	7.17
F- ratio for rice cultivar and EC_w	2.36*			
$LSD_{0.05}$	5.06			

*Level of significance at 0.05 P

study areas of Erasama and Astaranga. If the farming fails, farmers cannot go back to rice cultivation, even 2 to 3 years after leaving their shrimp farming practice.

Soils in typical shrimp ponds were relatively rich in organic carbon, available N, P, and K but were 5 to 6 times more salt stressed than their adjacent rice–field soil (Table 4). The enrichment of shrimp pond (bottom) soil with organic carbon, phosphorous, nitrogen and other substances is largely due to release from unutilized feeds and chemicals, which are used for shrimp growth as reported in several places (Thi et al. 2010; Funge-Smith and Briggs 1998; Avnimelech and Ritvo 2003).

The high salinity of shrimp pond soil is the major drawback for growing rice, as it is susceptible to salt stress. Periodic fluctuations of salinity from different water sources in Table 1 indicate that the salinity (EC) of rice–field water remains >4.0 dSm^{-1} in both pre– and post–shrimp farming periods, whereas the salt tolerance limit of rice paddy is ≅ 3.0 dSm^{-1} in flooded situations (Tanji and Kielen 2003). Salt-tolerant rice cultivars thus offer promise for growing in this

Table 7 Salient physico – chemical parameters of shrimp - pond soil

Important parameters	Soil texture	
	Sandy loam (sl)	Clay (c)
Sand %	71.75	36.5
Silt %	13.45	18.55
Clay %	14.8	44.95
K_s cm min^{-1}*	0.091	0.008
K_s with BW, cm min^{-1}	0.065	0.001
K_s with BW followed by normal water, cm min^{-1}	0.004	0.0002
K_s at post rice cultivation, cm min^{-1}	0.075	0.006
EC_e dSm^{-1}	2.3	4.5
ESP of shrimp pond soil at initial	13.71	16.32
ESP at post rice cultivation	14.11	15.11

*K_s of adjacent rice field soil; BW stands for brackish water

situation. Rice yield was very low in both the 2009–2010 and 2010–2011 periods and were not comparable with the yields obtained under conventional practice. Overall, the yield level of salt-tolerant rice cultivars was low in the second year of the experiment, carried out at the village Kakan of Erasama during 2010–2011, in comparison to the yield obtained at Astaranga during 2009–2010. Poor yield may be the result of more salt stress in the soil at Erasama (EC_e, 5–6 dSm^{-1}) than is in the soil at Astaranga, along with a water scarcity during critical growth stages.

The purpose of growing rice in brackishwater shrimp ponds was to improve soil hydro-physical properties, which contribute to salt stress, ESP and other salinity-related attributes despite utilizing nutrients from unused feeds in the system. The saturated hydraulic conductivity (K_s) was substantially improved (1.2 to 1.3 times) under the shrimp–rice combinations and eventually decreased the scope of salt accumulation over the "shrimp only" practice from its initial levels. The cultivation of rice after one cycle of shrimp farming helps to decrease nutrient concentration and improve soil quality, as is evident in freshwater *gher* culture in coastal areas (Ahmed 2001; Barmon et al. 2004a, b). The integrated practice of the shrimp–rice sequence together with the growing of salt-tolerant rice for maximizing return from the same land, is popular in southwestern Bangladesh in *gher* culture (Azad et al. 2009). Thus, the growth performance of salt-tolerant rice cultivars in shrimp ponds under two prevalent field situations along with a detailed analyses of relevant soil parameters indicate that the shrimp-rice combination has more potential to improve and sustain the productivity of the system than shrimp farming alone does for small and marginal farmers in coastal areas.

Conclusions

Coastal area support a variety of livelihood options ranging from agriculture to aqua-farming. Brackishwater shrimp aquaculture is a profitable livelihood and has invaded rice-growing fertile lands. With the goals of improving soil hydraulic conductivity and reducing the risk of salt accumulation and salinity-related attributes, this study reveals the benefit of growing salt-tolerant rice cultivars in brackishwater shrimp farming areas and provides essential information on soil and water qualities during pre– and post–shrimp farming periods. Additionally, we document the salinity variation of soils differing in textures and the change of soil parameters subjected to brackishwater shrimp farming practice in coastal Odisha, India.

The issues and problems of coastal areas are diversified and depend on traits, tradition, accessibility of resources and many other factors. Sharing experiences learned from any such issues enhances the possibility of their application and helps to restore the sanctity of coastal ecosystems. The present study thus offers promise for sustaining productivity by providing livelihood security to small and marginal farmers without compromising soil and water qualities where brackishwater shrimp farming interfaces with rice-growing areas on the east coast of Odisha, India.

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