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The impact of shrimp farming on the diversity of mangroves leading to build sustainable aquaculture models in Puttalam Lagoon, Sri Lanka

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Abstract
Wetlands consist of mangroves are the prime areas for aquaculture, particularly shrimp farming. Hence, the study was aimed to ascertain the impact of shrimp farming on the diversity of mangrove species in Puttalam lagoon to build models for sustainable aquaculture. Using various data collection methods the mangrove diversity and shrimp cultivation assessed. The mangrove cover has been reduced into a patchy distribution where the active shrimp ponds were significant. Particular floral composition identified among shrimp pond areas including rare and very rare mangrove species. Diversity hotspots were identified within the abandoned shrimp pond areas indicating natural succession act as a passive approach. Salt pans and crab fattening also identified as an increasing threat on the diversity of mangrove species. Pilot methods applied to restore and conserve were shown positive effects. Thus, is timely important to restore abandoned shrimp ponds to rejuvenate the species diversity of mangroves.

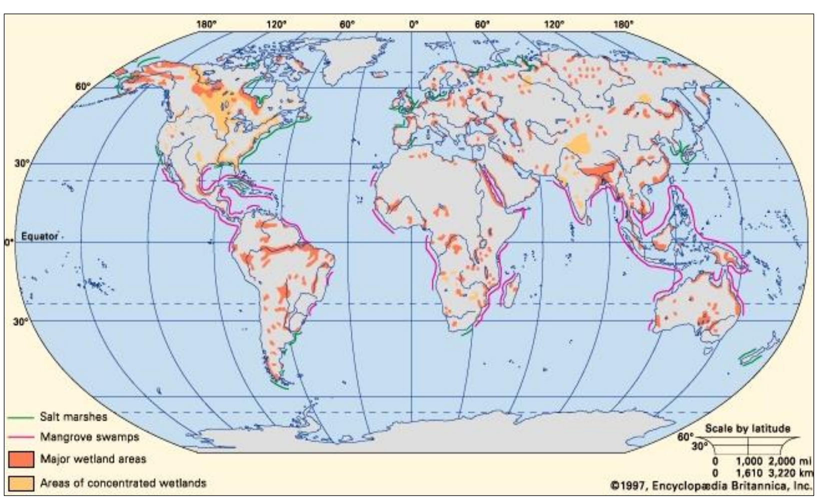
Keywords: mangrove diversity; models; Puttalam lagoon; restoration; shrimp farming

1. Introduction

1.2. Shrimp farming

Shrimp farming is one of the major sectors of aquaculture. The history of aquaculture dates back to 4000 years which was first started in China (Billard, 1999) [4]. Shrimp farming has dramatically expanded over the last four decades with respect to the increasing demand for the exploding population size (Queiroz *et al*, 2013 [22]; Stokstad, 2010) [29]. The largest demand for shrimps comes from America, Japan and European countries (Paul *et al*, 2010) [18]. Most of the growth of shrimp farming reportedly been from Asia. Being the largest three exporters Thailand, China and Vietnam (Paul *et al*, 2010) [18] play a major role in shrimp farming. China is the leading producer contributing 62.3 per cent of farmed shrimp (Paul *et al*, 2010) [18] although Thailand is the number one exporter (Kelly, 2012) [14].

When the fisheries industry in the world collapsed due to declined population sizes with overexploitation of fisheries resources, the requirement of alternative methods to fulfil the growing demand for protein deficiency was highly stressed. Thus, the increase of shrimp farming identified as a suitable solution and intensified the production (Paez-Osuna *et al*, 2003) [17]. The conditions for shrimp farming is optimal where mangrove distributed. The climate, hypersaline environment, root system and occurrence of wild populations of shrimp larvae (Tenorio *et al*, 2015) [30] were well matched. As well as, construction of shrimp ponds in mangroves was profitable due to low cost and increase the productivity as mangrove root system supply suitable breeding grounds for these species with maximizing the production (Islam *et al*, 2015) [13].



Source: Thomas, 2012 [31]

Fig 1: Distribution of mangroves in the world

1.2. Mangroves

Mangroves are distributed within tropical and sub-tropical coastal areas (Fig1) where the developing and less-developed countries are located. People in these countries look shrimp farming as a worthy source of income which stimulates income and support food security while alleviating the poverty of the poor (Queiroz *et al*, 2013 [22]; Tenorio *et al*, 2015) [30]. The political and economic support from both private and public sector at the beginning of the 1970s stimulated shrimp farming. As a result, the transform of mangrove forests into shrimp farms was intensified particularly in Asia, Africa and Latin America. While a gigantic jump was occurring in the shrimp farming, the heavy loss of mangrove forest coverage was distinguished. Among the various environmental problems occurred due to shrimp farming (Fig2) the richness of mangrove forests has declined. According to the Millennium Ecosystem Assessment in 2005 [15], more than 35 per cent of densely grown mangrove forests have disappeared within the last two decades.

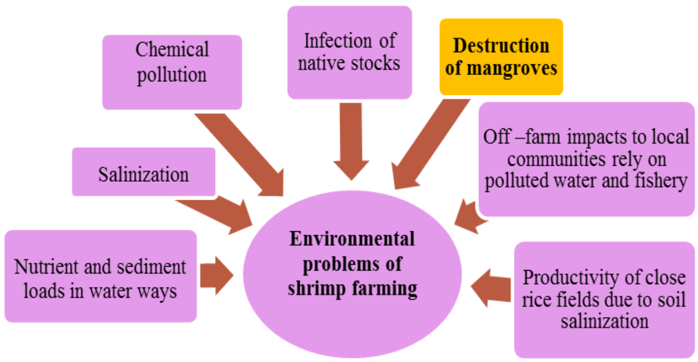
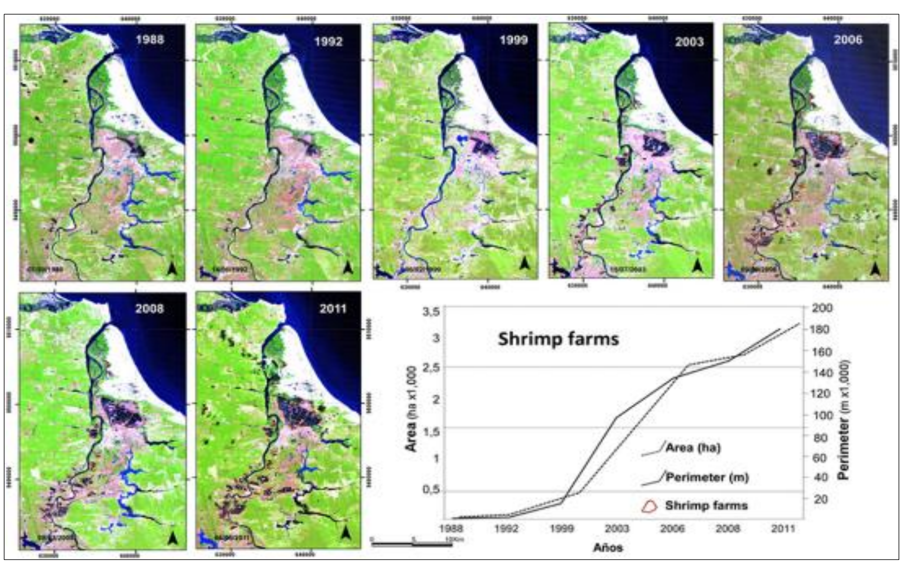


Fig 2: Various environmental problems associated with shrimp farming

In 2015 it was estimated that approximately 1.5 million hectares of global mangrove forests have been converted to shrimp farms (Tenorio *et al*, 2015) [30]. This rapid and huge loss of mangroves toll on the ecosystem services produced by once well-grown mangrove forests. The evidence from various published literature shows the rapid decline of mangrove forests due to extensive shrimp farming. Queiroz (2014) [21] in his study showed the rapid disappearance of mangrove vegetation in relation to the increase in shrimp farms along the Jaguaribe River estuary in Brazil. The satellite images (Fig3) demonstrates the spatial distribution of vegetation changes detected along the Jaguaribe River, since 1988. Mangrove vegetation at the proximity of the Gulf of Fonseca in Honduras is another example of rapid loss of mangroves as a consequence of intensified shrimp farming. The Landsat images(Fig4) In 1987 and 1999 clearly shows the expansion of shrimp ponds and declined extent of mangrove vegetation while the image captured in 2011 shows the degraded mangrove wetlands due to the drained shrimp ponds in Honduras and Nicaragua (Earth Observatory, 2018). The literary evidence also shows that tiny shrimp can cause big change due to its direct economic value. However, the impact of this big change is invaluable as mangroves provide various indirect intrinsic values and ecosystem services; provisional, regulation and recreation services. When comparing both the direct and indirect environmental services and ecological functions (Fig5) of intact mangrove ecosystems, usually underestimated when allocating land for coastal shrimp farming (Arquitt and Johnstone, 2008 [2]; Dewalt *et al*., 1996 [8]; Hai and Yakupitiyage, 2005 [12]; Sousa *et al*., 2006) [27].

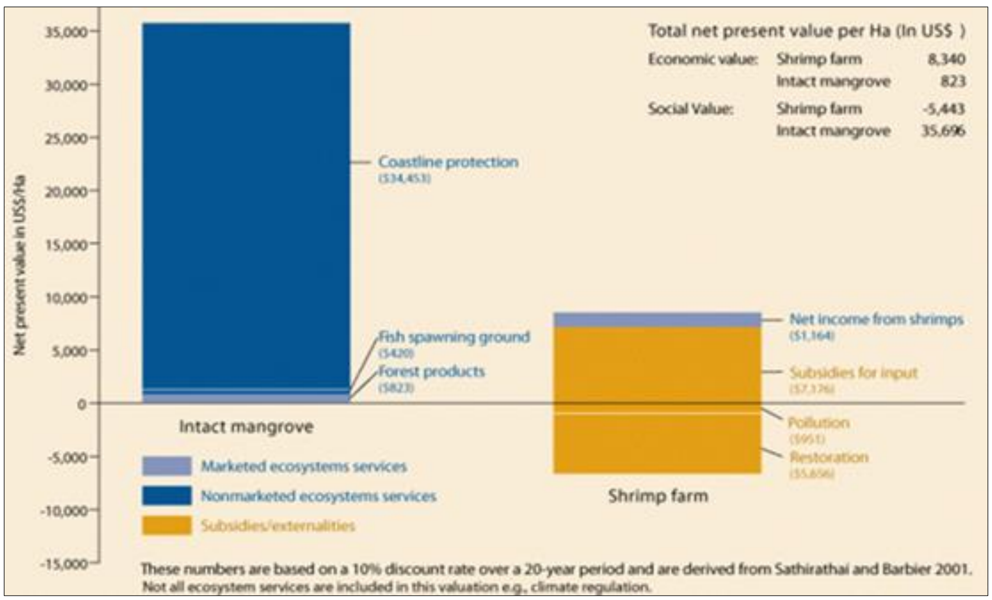


Source: Queiroz, 2014 [21]

Fig 3: The spatial distribution of vegetation changes detected along the Jaguaribe River

Source: https://earthobservatory.nasa.gov/images/78178/tiny-shrimp-big-changes [11]

Fig 4: The evolution of shrimp farms around the Gulf of Fonseca



Source: World resource institute, 2009 [34]

Fig 5: Value comparison of mangroves and shrimp farm

1.3. Sri Lankan scenario

Sri Lanka has 1700km of coastline consisting of 45 lagoons (Silva *et al*, 2013) [26] and sheltered bays that are prime sites for aquaculture development (Dayananda, 2004 [7]; Drengstig, 2013) [10]. Since shrimp farming is associated with lagoon water bodies, therefore, the encroachment of shrimp farms towards the densely grown mangrove forests has become tragic. Sri Lanka is home to 25 exclusive or true mangrove species and many associate species limited only to lagoons and estuaries located in the coastal belt of the island (Fig6a). Among the true dominants *Rhizophora apiculata*, *Rhizophora mucronata*, *Avicennia marina*, *Avicennia officinalis*, *Bruguiera cylindrica* and *Bruguiera sexangula* are common to wet and dry climate zone of the country. Shrimp farming in Sri Lanka started in the northwestern coast of the country, with pioneer farms established around Chilaw Lake (Senerath and Visvanathan, 2001) [25], which were followed by dramatic expansion significantly concentrated along the coast from Chilaw to Puttalam lagoon in the northwestern province (Dahdouh-Guebas *et al*, 2001 [6]; Munasinghe *et al*, 2010) [16]. Although during the peak harvesting period, shrimp farming was an important source of foreign exchange, accounting for 40-50 per cent of total aquaculture (Dayananda, 2004 [7]; Senerath and Visvanathan, 2001[25]; Munasinghe *et al*, 2010) [16], the destruction of mangrove habitats by direct conversion of natural mangrove forests to shrimp ponds, has led to drastic loss of mangrove forests, salt marshes, seagrass beds and mudflats (Senerath and Visvanathan, 2001) [25] along with many of their associated ecosystem services in these areas. Approximately, 34 per cent of the remaining mangrove area has been lost between 1992-1994 and 2012 in Puttalam lagoon (Table1).

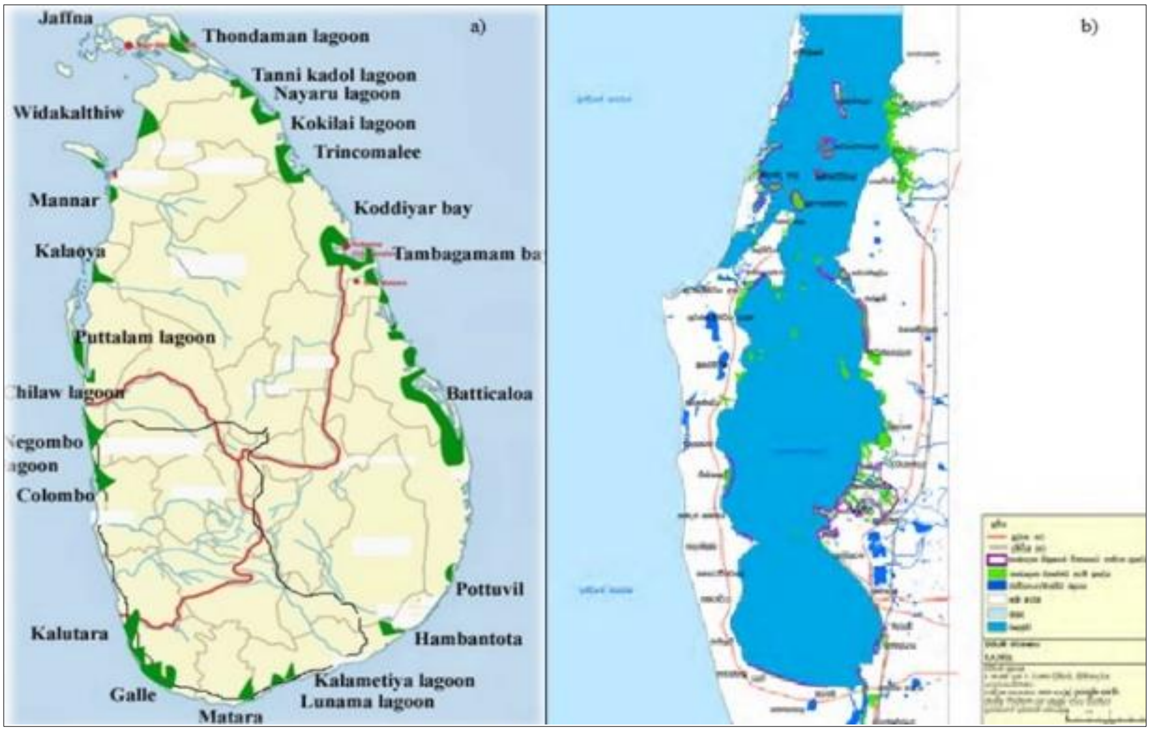
Table 1: Land use areas in 1992-1994 and 2012 in Puttalam lagoon

Land use	1992-1994 (ha)	2012(ha)	Net change (%)
Shrimp farms	39.63 (1%)	1140.3 (20%)	+2777.3
Mangroves	1093.7 (26%)	726(13%)	-33.6
Shrimp farms: Mangrove ratio	1:28	1:0.6	

Source: Bournazel *et al*, 2015

Puttalam lagoon is located in the Northwestern province (Fig7) of Sri Lanka at 7º44’46-8º35’60N and 79º48’25-79º49’17E.

Being the second-largest lagoon in the country (34,938ha) (Weragodathenna, 2010) [32], as well as one of the most productive basin estuaries in the country, Puttalam lagoon comprised the largest mangrove forests, in turn, the largest degrading mangrove forests (Fig6b) (Weragodathenna, 2010) [32] in the country too. Puttalam lagoon in particular for the significant distribution of several rare and very rare mangrove species; *Pemphis acidula*, *Scyphiphora hydrophyllacea* and *Cynometra iripa.* Mangroves provide important habitat for a wide range of species, therefore, the removal of mangroves also reduces local biodiversity (Pathirana *et al*, 2008) [19]. Mangrove ecosystems are well-identified for their ability to sequester carbon (Alongi, 2012) [1]. If disturbed by land-use change, the carbon buried in mangroves has the direct potential to become a significant source of greenhouse gas (Donato *et al*, 2011) [9]. Though various studies have stressed that the extent of mangrove forests in Puttalam lagoon has reduced during the past decades, this study focused on the relationship between shrimp ponds and mangrove species diversity to fill the gap in Sri Lankan policies to the sustainable management of ecosystem integrated aquaculture.



Source: Pilbrighty, 2015 [20] and Weragodathenna, 2012

Fig 6: a) Mangrove distribution in Sri Lanka b) Mangrove destruction in Puttalam lagoon

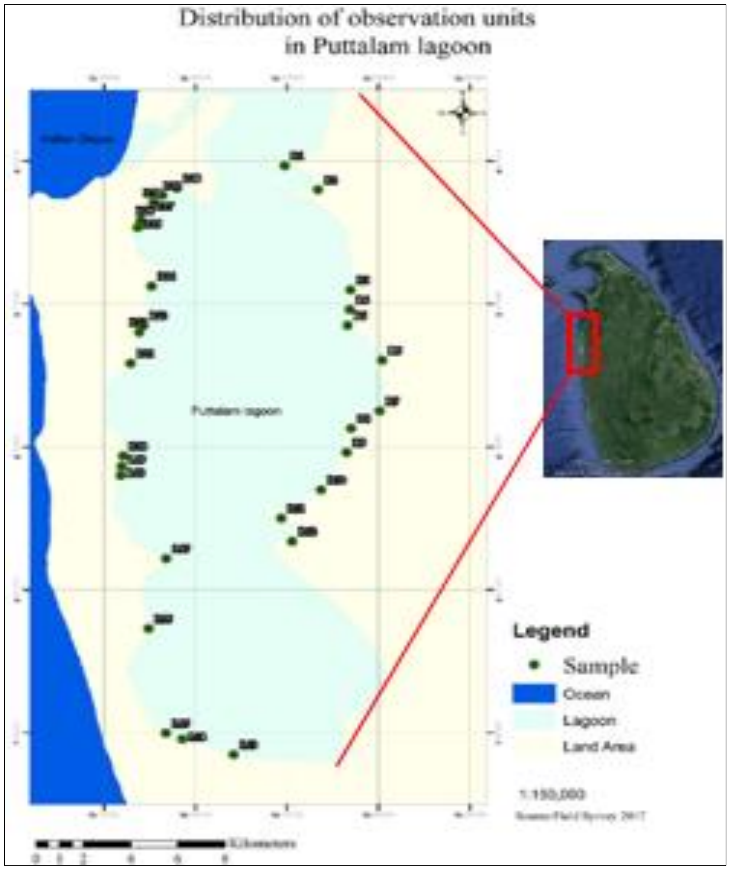
2. Objective

The general objective of the study was to ascertain the impact of shrimp farming on mangrove species diversity in Puttalam lagoon in order to identify and develop suitable models for both active and abandoned shrimp pond restoration with mangroves.

3. Methodology

3.1. Data collection

Various types of data collection methods were used to collect primary and secondary data. The study was carried out from March 2017 to March 2018. A field survey was performed to assess the mangrove composition, richness and diversity. The vegetation survey was carried out for a total of purposively selected; considering the Distribution of shrimp ponds 30 observation units (Fig7) using 5m × 5m quadrats. The quadrats were placed in two belt transects as per the Right (R) and Left (L) periphery (Table2). Distribution of shrimp ponds (Fig8) was identified and digitized by using Quantum GIS 2.10.1 version along with Google Earth satellite image and verified the status; active or abandoned, during the field observation. Randomly selected 300 individuals were interviewed in order to find out existing sustainable aquaculture methods. The interview consisted of thirty semi-structured questions. A comprehensive literature-based survey further carried out to study restoration of abandoned shrimp ponds. It was difficult to find an area to apply the developed models identified as a limitation of this study. Thus, the pilot survey was limited to a very small patch.



Source: Prepared by the author, 2018

Fig 7: Distribution of sampling points

3.2. Data analysis

While using thematic content analysis for the interviewed information, statistical methods and Inverse Distant Weighted interpolation technique in Arc GIS 10.1 version also have been used to analyze the data. The vegetation data collated and calculated the Shannon-Wiener diversity index (1) to find out the mangrove diversity in each observation unit. The value of the 'H' is range from 1 to 5. Higher the value of H higher in diversity and lower the value of H lower the diversity.

$$H = -\sum_{i-l}^{s} Pi \ln(Pi) \qquad (1)$$

Analyzed data presented as graphs, charts, maps and figures while two models were created based on the literature and results of the pilot survey.

Table 2: Locating samples

Transect	Sample ID/Observation unit	Number of samples
Right	R1-R12	12
Left	L11-L30	18

4. Results

4.1. Distribution of shrimp ponds

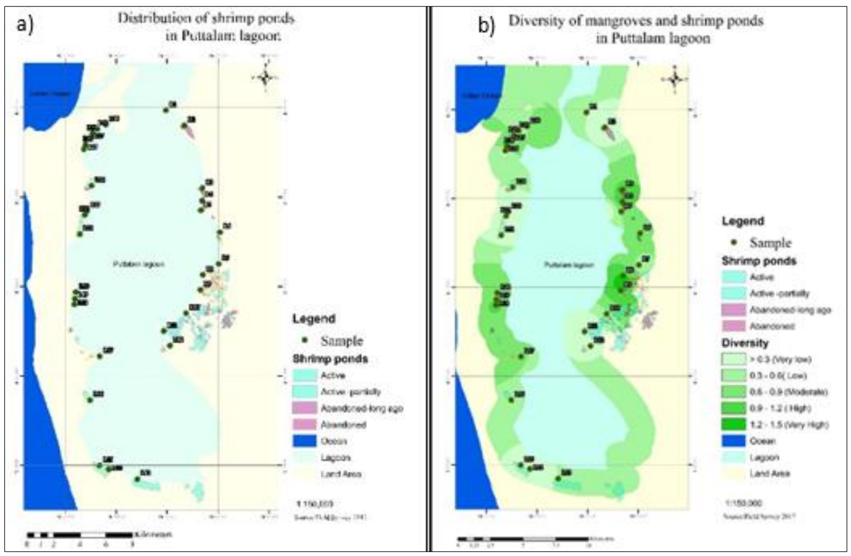
Four types of shrimp ponds were identified based on their current situation such as active and abandoned. The active shrimp ponds were distributed in Daluwa, Mampuriya and Puttalam while partially active ponds were almost distributed in Puttalam area in the right periphery. These partially active ponds were identified according to the information given by the interviewees. The shrimp ponds in Serakkuliya, Tirikkapallama and landward of Puttalam area were almost abandoned. Pubudugama, Anekuththiya and few ponds in the left periphery were abandoned recent past. Figure 8a demonstrates the distribution of each type of shrimp pond in Puttalam lagoon area while figure 9 exhibits a part of the satellite imagery of digitized shrimp ponds located in the right periphery.

4.2. Species composition, distribution and diversity of mangroves

A total of 715 individual mangrove species were enumerated. Among them, 15 mangrove species identified belonging to 13 genera and 9 families. Total of 15 mangrove species consisted of 8 true mangrove species and 7 mangrove associate species. *Rhizophora mucronata*, *Rhizophora apiculate*, *Avicennia marina*, *Excoecaria agallocha*, *Sonneratia alba*, *Avicennia officinalis*, *Lumnitzera recemosa* and *Aegiceras corniculata* were the identified true mangrove species while *Thespesia populnea*, *Hibiscus tiliaceus*, *Phoenix pusilla*, *Clerodendrum inerme*, *Salicornia bigelovii*, *Suaeda maritima* and *Pemphis acidula* were the enumerated mangrove associate species. A patchy distribution of mangroves could be seen along the coast of the Puttalam lagoon and also a low range of diversity of mangroves; 0.3-1.5 has reported where the diversity hotspots (Fig8b) were significant with the abandoned shrimp ponds due to the natural succession. This natural succession has identified as the passive restoration of abandoned shrimp ponds. Shrimp ponds in R3, R4, and R5 were abandoned a long time ago while R8 and R9 abandoned in the recent past are the locations identified as mangrove diversity hotspots in the right periphery of the lagoon. R3-R5 located in Tirikkapallama and R8-R9 located in Anekuththiya.

4.3. Mangrove diversity and shrimp farms

A high density of active shrimp ponds has still existed in the western periphery of the lagoon showing a patchy narrow distribution of mangrove. Though it seems, passive restoration of shrimp ponds has created good habitat for *Aegiceras corniculata*, *Scyphiphora hydrophyllacea*, *Avicennia officinalis*, *Avicennia marina* and *Suaeda maritima*. *Aegiceras corniculata* and *Scyphiphora hydrophyllacea* are rare and very rare mangrove species that can be seen in Puttalam lagoon respectively. *Rhizophora mucronata* and *Rhizophora apiculata* also passively restored true mangrove species. Among the passively restored mangrove species, *Excoecaria agallocha* also found in few areas. However, the most common species found in passively resorted shrimp ponds were Avicennia spp. Particularly *Suaeda maritima* was the most common among the mangrove associates which is a halophyte species (Fig.10). This shows that the decreasing number of active shrimp ponds positively correlated with the increasing number of mangrove plants. The effluents of shrimp ponds have directly connected to the lagoon water body and the canals leading to shrimp ponds through mangroves could be identified in Eththale while polluted sewage canal leading to the lagoon through mangroves identified in Kalpitiya.



Source**:** Created by the author, 2018

Fig 1: a) Distribution of shrimp ponds in Puttalam lagoon b) Spatial distribution of mangrove diversity and association of shrimp ponds

Source**:** Google earth, 2018

Fig 9: Digitized satellite imagery of shrimp ponds in the right periphery of Puttalam lagoon

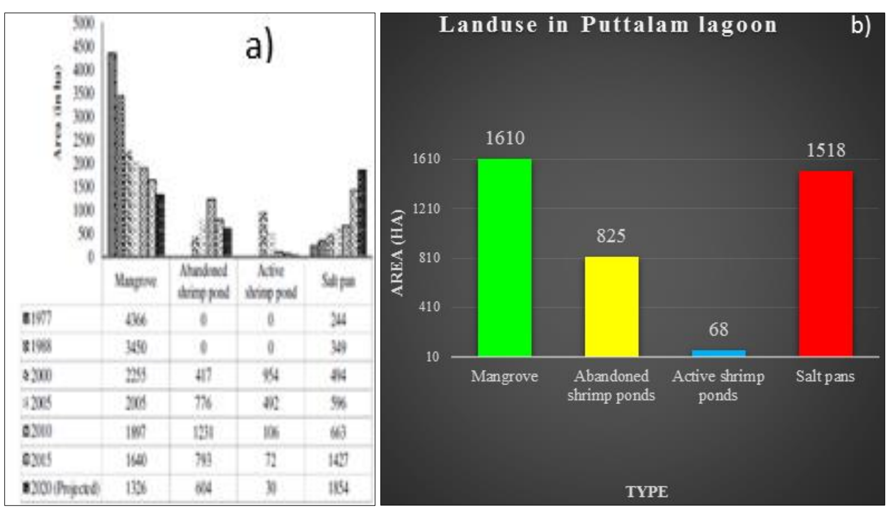
***Source*:** Field observation, 2018

Fig 10: Passively restored halophytes in abandoned shrimp ponds in the left periphery

5. Discussion

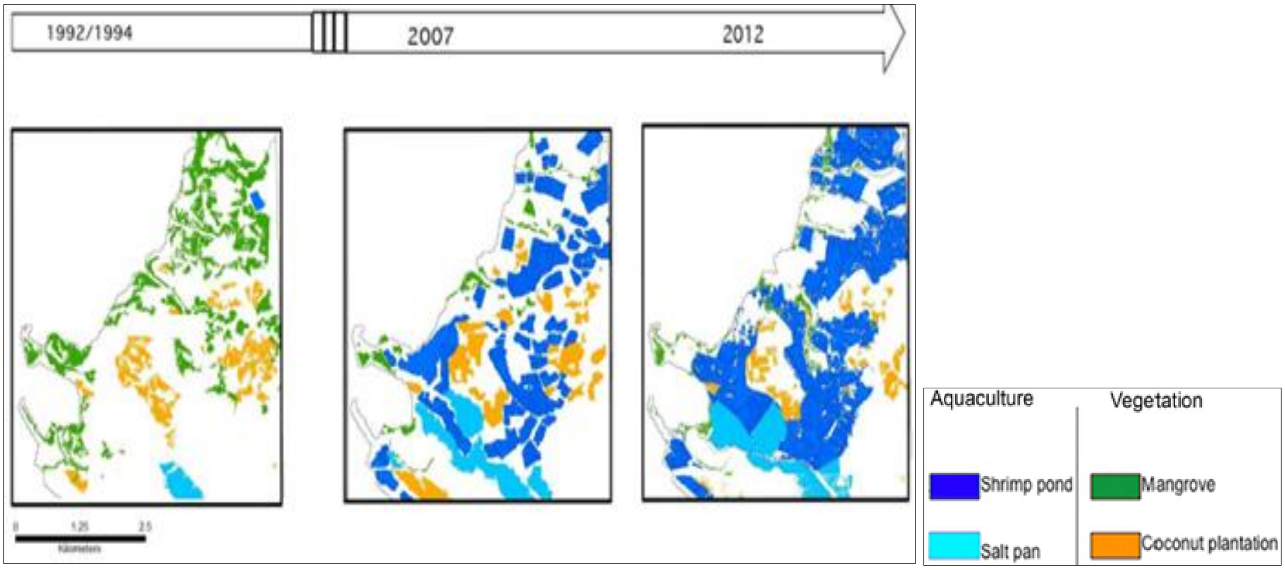
It was revealed that the number of active shrimp ponds has reduced dramatically due to the spread of White Spot Syndrome Virus throughout the shrimp farms. This has led to an increase in the clearings of new areas to establish new ponds, as well as infected ponds, were abandoned. The frequent fluctuations of the development of intensive shrimp farming collapsed the industry, besides the damage caused by these land-use changes, destroyed a range of ecosystem services. Despite the economic loss of collapsed shrimp farming, the loss of intrinsic economic value has led the entire lagoon environment into an ‘ecology of disaster’. The removal of mangrove species directly affect the aquatic species population size as the root system of mangrove species is home to a wide range of fish and shrimp larvae and juvenile brackish water species. There is a trend to convert abandoned shrimp ponds to salt pans which were an emerging silent threat. Thus, land use has been changed. The number of salt pans increased inversely to abandoned shrimp ponds. It was reported as 1427ha (Weeragodathenna and Gunarathne, 2015) [33] (Fig11a) of salt pans have now increased up to 1518ha (Fig11b). This could be identified by the part of Daluwa, Nawakkadu, Kuringampitti and Kandakuda areas. While converting the abandoned shrimp ponds, the extent of the salt pan also extended toward the mangrove forest patches found in the right periphery of the lagoon. The extended extents of salt pans identified in the lower right periphery of the lagoon (Fig12). This trend was also detected by Bournazel *et al* (2015) [5] and Weeragodathenna and Gunarathne (2015) [33]. Bournazel *et al* (2015) [5] detected the changes in four land uses including shrimp farms, mangroves and salt pans. The clearest change detected around the Mee Oya estuary and Puttalam. Crab fattening is also placed in the main water body or brackish water-filled areas. Though this was not salient, very smaller mangrove patches have cleared for this.

Considering the findings and the results of the study restoration of abandoned shrimp ponds with mangroves identified as an essential process as none of sustainable shrimp farming method were unable to find through the study. Passive restoration identified in the study is the natural recovery of these abandoned ponds was rather a slow process due to the limits on the dispersal potentiality of propagules. Sedimentation caused by shrimp ponds also blocks the dispersal as a result of physical and chemical unsuitability of sediments. Thus, the necessity of active restoration could be identified as a solution to minimize this disaster. On the other hand, it is required to establish powerful laws and regulations to control conversions of shrimp ponds into salt pans. While the active restoration of abandoned shrimp ponds could be applied to increase the extent of mangroves, ‘earthen mounds model’ (Fig13) and ‘integrated mangrove cultivation and fish/crab culture model’ (Fig14) could be applied as win-win approaches for existing shrimp ponds. These models have the potentiality to increase both numbers of fauna and flora species within the shrimp pond area. These models have applied in India where they have obtained benefits from these sustainable methods. The pilot test carried out to assess the applicability was also demonstrated that the literary evidence was true (Selvam, 2012) [24]. The integrated mangrove cultivation and fish/crab culture model can be used in shrimp ponds where the population size increased as a consequence of increased breeding grounds due to restored mangroves. Apart from the mangroves in the inner bund halophytes can be grown as cash crops.



***Source*:** a) Weeragodathenna and Gunarathne, 2015 b) Field survey, 2017-2018

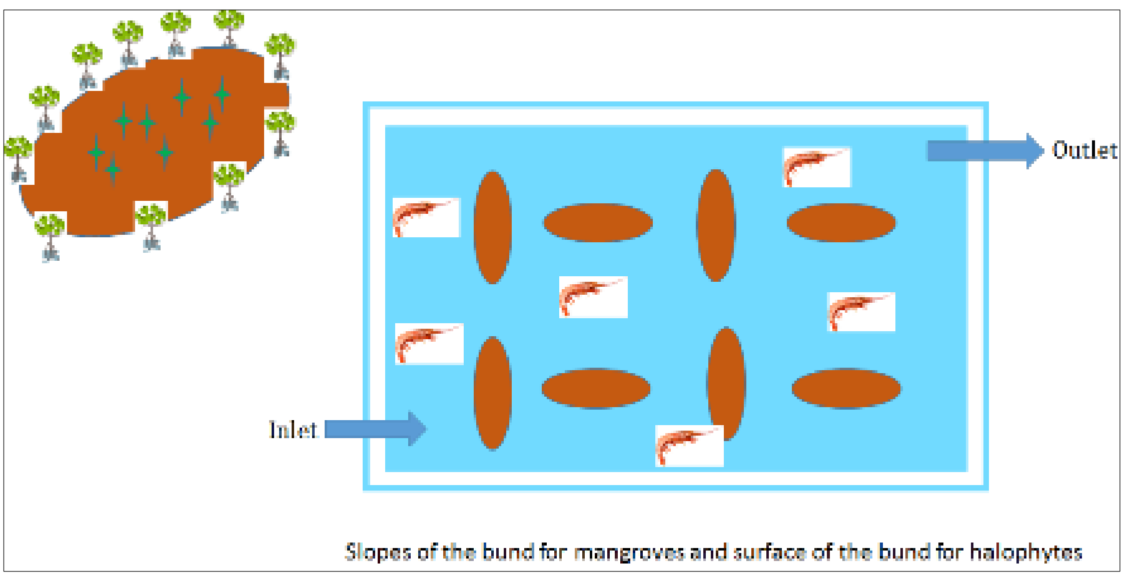
Fig 11: Land use change in Puttalam lagoon



Source: Bournazel *et al*, 2015

Fig 12: Expansion of salt pans in Pubudugama and Puttalam

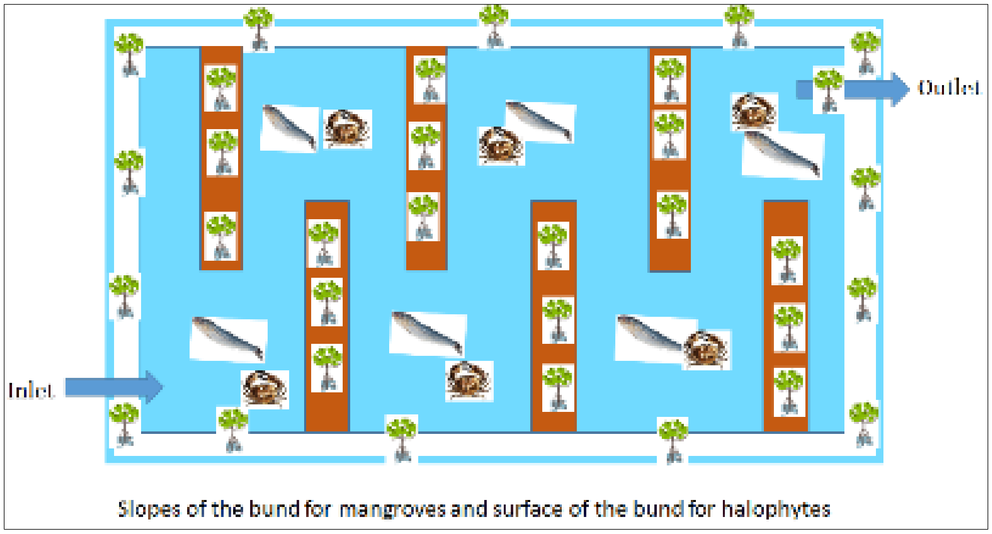
Particularly Salicornia spp and Suaeda spp can be grown. It is referred to as 'Umari/Omari' (local name) can be used to grow as a cash crop since it is edible (Field observations, 2017-2018). Within the model fish species, Mangrove crabs and prawns can be cultured. So this is a well-balanced ecosystem with proper simple food web. The scenario of the earthen mound model is also the same.



Source: Designed by the author based on study results and literary evidence, 2018

Fig 13: Earthen mound model

When selecting mangrove species for shrimp ponds Rhizophora apiculata and Rhizophora mucronata are well applied. The same species have used for shrimp ponds in disused shrimp pond in Haad Sai Khao in Rangoon, Thailand (Stevenson *et al*, 1999) [28].



***Source*:** Designed by the author based on study results and literary evidence, 2018

Fig 14: Integrated mangrove cultivation and fish/crab culture model

Despite to restoration of abandoned shrimp ponds, the advantages of these models vary. These ponds are tidal fed thus zero energy, no need of artificial feed and chemicals, well-modelled ponds are suitable for crab culture after mangroves grown, less carbon footprint in shrimp farming; identified by the aquaculture authority in India and increase in adaptive capacity of the coastal community to cope up the salinization.

6. Conclusion

The study shows shrimp farming had a direct impact on mangrove extent, however, an increasing number of abandoned shrimp ponds have passively increased the mangrove diversity showing the opportunities of the restoration of the degraded ecosystem. However some of the areas once flourished with mangroves, are now unable to restore due to severe ecological damage occurred, such as in Karathivue (R1 and R2). The experienced dramatic land-use change in the Puttalam lagoon area also demonstrated by the study. It is clear and obvious that the expansion of shrimp farms has had a negative impact on the coastal ecosystem in Puttalam. Further, the loss of ecosystem services has not been balanced by restoring the ecosystem to obtain permanent economic benefits since almost ninety per cent of shrimp ponds are now abandoned. As projected in the study carried out Weragodathenna and Gunarathne (2015) [33] the mangrove coverage is a further decline by 7 per cent (1326ha) in 2020, as well as active shrimp ponds, would be declined to 30ha. In contrast, salt pans would be approximately 1854ha and abandoned shrimp ponds would decline (604ha) with respect to the rapid increase of salt pans. Though passive restoration occurs it takes time to rehabilitate naturally, in the meantime, application of active restoration for abandoned shrimp ponds, as the most essential requirement, is appropriate to minimize this ecology of disaster while strengthening the rules and regulations for land use policies in Sri Lanka. It is recommended to apply the identified models to have sustainable shrimp farming since it is evident that penaeid shrimps (Ronbacc *et al*, 2001 [23]; Selvam, 2012) [24] and mangrove crabs make extensive use of the intertidal mangroves.

7. Acknowledgement

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