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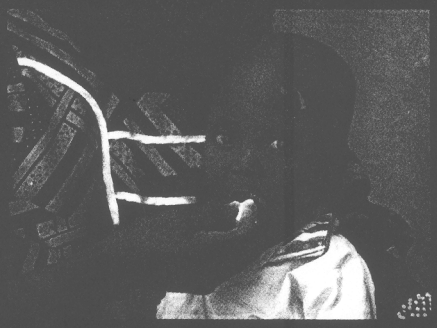

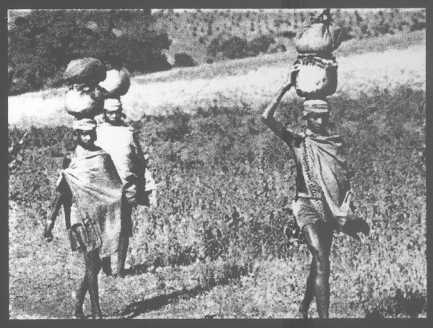

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Wetland dynamics - links with spatial, ecological and socio-economic related issues in the western coastal belt of Sri Lanka

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Abstract

The debate on the future of wetlands has often been polarized between antagonists seeking either development or conservation related goals. This is partly because the values of wetlands have often been mis-stated, disregarded or are unknown. Further, the patterns of change in wetlands can be complex and difficult to decipher, especially when heavily influenced by human interventions. Effective inventory, mapping and monitoring of wetlands along with assessment of the ecosystem services they provide, can improve our understanding of the ecological and socio-economic hierarchies that effect wetlands. They can also help identify the inter-linkages between the various components that comprise the wetland and that support the livelihood and well-being of many people. The Muthurajawela-Negombo coastal wetland complex in Sri Lanka is located alongside a rapidly developing urban area and has long been used for agriculture and, in more recent times, for localised aquaculture and other developmental processes, making it an extremely vulnerable ecosystem. However, the wetland is being rapidly degraded by inadequately planned development activities and growing anthropogenic pressure.

Along with local partners we are undertaking a multiple-scale inventory and assessment of the extent of biophysical change in the wetland complex over the past few decades and investigating some of the socio-economic drivers of change. This includes the identification of 'indicators of stress' in the wetland and a geospatial analysis of the extent of ecological change and future threats. It is being done within a multi-disciplinary environment incorporating urban and coastal zone management, ecological sustainability and the socio-economic aspects of local livelihoods. In conjunction with the technical analyses a capacity building module is being developed to assist partners and stakeholders to promote the wise use of wetland resources.

Keywords: Wetland dynamics, ecological, socio-economic, spatial analysis, ecosystem services, Sri Lanka

Introduction

Wetlands have many beneficial uses-they provide fertile agricultural land; support a wide diversity of animals and plants; they regulate the water and nutrient flows through many landscapes; and provide many cultural benefits, including opportunities for scientific investigations. The recently concluded Millennium Ecosystem Assessment (Finlayson *et al.*, 2005) incorporated a reassessment of the polarized debate over wetland development and conservation and highlighted the importance of wetlands for human well-being and the extent of degradation and loss that has occurred. It also emphasized the absence of effective inventory and assessment that could support a more interactive and beneficial relationship between participants in the debate about the future of wetlands.

Within the context of the Ramsar Convention on Wetlands this includes describing and assessing the ecological character of wetlands, noting that the latter includes the ecosystem services provided by a wetland as well as the ecological components and processes that comprise the wetland, as a basis for better informed management. It also comprises the development and implementation of wetland polices and strategies at multiple levels in society, especially those covering the major causes of wetland loss and degradation, including the paramount role of agriculture and water regulation (Finlayson *et al.*, 2005). At the same time as the role of agriculture in wetland loss and degradation has been debated wetland issues have been an important part of agricultural and environmental policy debates since the mid-1970s (Ralph *et al.,* 1998). Globally, many wetland policies have witnessed numerous changes in recent decades from promoting wetland conversion and infilling to promoting wetland protection and rehabilitation to stabilise public and private interests. Whilst there have been many advances in wetland policy and management in many developed countries sustainable management of tropical wetlands still requires comprehensive assessment and periodical monitoring to provide an adequate information base documenting, for example, the ecology, environmental flow patterns, socio-economic gradients, potential use, policy development, and conservation priortization (Junk *et al.,* 2006).

Conserving and managing wetlands requires regular monitoring programs and activities that focus on development pressures to ensure environmental protection and sustainable use of these vulnerable ecosystems. Monitoring the status, change and dynamics of wetlands is important as it provides the information needed to understand the structure, functionality and ecological processes that influence the ecological character of a wetland, and where applicable, the potential and success of rehabilitation activities. The pattern of change in wetlands is multi-faceted and complex to interpret, especially when profoundly influenced by anthropogenic activities. Multi-scalar inventory, mapping and assessment of wetlands is being

increasingly recommended (e.g. Finlayson *et al.*, 2002, 2005) as a means of providing the information that is required for maintaining the ecosystem services that wetlands provide and which support livelihoods and well-being of many people. While, field surveys have long been the mainstay for collecting information on changes in wetlands, imagery-based spatial approaches are increasingly been shown to be useful tool for monitoring change (Barry and Joe, 1997). This is because they can provide a synoptic view with frequent coverage and archives of past data while advancements in sensor technology have opened new opportunities for assessing and quantifying the change in wetlands (and other ecosystems). Spatial data combined with a GIS-based medium can be used to describe wetlands and detect trends in specific features as well as provide baseline data for management needs.

Over the past few decades, global efforts have been initiated to investigate global wetland dynamics using geospatial approaches. Field *et al.* (1991) emphasized the value of geospatial approaches for coastal wetlands, especially for determining negative impacts on specific habitats and for providing quantitative information for management policies and practices. Vegetation distribution was mapped and elevation characteristics were modelled to correlate vertical growth of mangroves with tidal range. Pringent et *al*, (2001) further led the global effort to quantify global wetland dynamics with a collection of satellite observations, including passive and active microwave, visible and infrared measurements.

The present case study provides a foundation for further research and a platform for decision-making on wetlands affected by aquaculture and agriculture-related issues in a tropical lagoon-marsh wetland complex. This is done by analysing the drivers of wetland change based on a temporal analysis of remote sensing data along with ecological and socio-economic components to address the prevailing issues. The work included a review of existing information, identification of surrogates of change, collaboration with ongoing research assignments, and an investigation of spatial multi-scalar approaches to provide the scientific data needed for assessing change in a complex and diverse tropical location.

Muthurjawela Marsh and Negombo Lagoon also known as the 'conservation island" provides an opportunity to study gradients of anthropogenic influences on wetland communities. The area is one of high endemicity and uniqueness for marine and terrestrial biodiversity (Bambaradeniya *et al.*, 2002). It also supports approximately 300,000 people with about 80% of the people in lagoon marsh complex involved in industrial and commercial enterprises. The region has undergone extensive agricultural development over the past 500 years with increased debate on its sustainability and resilience. Over the last two decades their has been a noticeable decline in agricultural practices owing to the increase in soil salinity (GCEC/Euroconsult, 1991)

The present study uses multi-temporal (1992-2002) Landsat TM imagery to spatially capture changes in land use with ancillary data being integrated into the analyses at different stages for refinement and validation purposes. The location of the Muthurajawela wetland in a rapidly developing area makes it an extremely vulnerable ecosystem; it is being rapidly degraded by inadequately planned development activities and other detrimental activities related to an increasing human population pressure. Development of an international airport and an access expressway were recent additions to the stress profile of the wetland. The current concern is to identify critical threats along with indicators and develop the key actions required to support the management of the wetland complex.

Ecological issues already of concern include habitat degradation and shrinkage, and general loss of biodiversity and in-filling of the wetlands, while socio-economically, over-exploitation of natural resources, some localised aquaculture, fuel collection and overgrazing are also of concern. Further, an expanding population, rising poverty, changing livelihoods and sanitation barriers are important social factors. Within the broader context of management there is an acknowledged lack of appropriate scientific data while on the planning side the balance between urban expansion and conservation policies needs to be addressed.

Area Description

Muthurajawela Marsh and Negombo Lagoon is diverse complex wetland systems located on the western coastal belt of Sri Lanka covering an area of about 12,000 hectares falling under four administrative divisions (Ja Ela, Katana, Wattala and Negombo) and 85 GN levels (Fig1). Muthurajawela is the largest saline coastal peat bog in Sri Lanka, between the Negombo Lagoon and Kelani River opening to the sea at the northern end. It further spreads into the inland covering Ragama and Peliyagoda in Gampaha District. The marsh, together with the Negombo lagoon forms an integrated coastal wetland ecosystem. It was listed as one of 12 priority wetlands in Sri Lanka in 1996 and its northern part was declared as a wetland sanctuary due to endemicity and uniqueness in marine and terrestrial components (including emergent vegetation; sea grasses and filamentous green algae). Reports confirm the origin of the marsh-lagoon complex dates back to about 5000 years BC (CEA/Euroconsult, 1994).

The key water source to the marsh is Dandugan Oya (catchment of 727 sq km). The marsh is also crossed by canals constructed during the colonial period. The rainfall in the region is 2000-2500 mm and the average annual temperature reaches 27^0C (Samarakoon and Renken, 1999). Many previous studies have been conducted in the region. Bambaradeniya et al. (2002) identified seven major wetland vegetation communities in the lagoon viz., marsh, lentic flora, shrub land, reed swamp, grassland, stream bank and mangrove forest. Survival strategies of

people in the Muthurajawela wetland complex, primarily focusing on livelihood, health and nature conservation were documented by Hoogvorst (2003).Emerton, (2002) however, worked towards defining the industrial sector of the wetland system concluding that 80% of the industrial belt is concentrated in the Colombo and Gampaha Districts. As mentioned above, four major administrative divisions are covered in the area. The human communities from Ja Ela and Wattala (towards the southern end of marsh) are mainly employed in an expanding industrial zone. The Muthurajawela marsh falls mostly in the Wattala-DS. The Katana division east of the lagoon has people engaged in small self-owned businesses or in industrial employment. Many people also cultivate small-scale crops and coconut plantations. The Wattala division, adjoining the marsh also has a mixed occupation pattern. In the Negombo division, fishing (lagoon and sea) is a significant mode of income generation with fewer people employed in industrial enterprises.

Methods

A geospatial method was designed for analysising and modelling the changes in the coastal wetland-agriculture-aquaculture complex (Fig 2). Multi-temporal (1922 & 2002) Landsat TM satellite imagery with few clouds or haze was used to spatially capture change in the land use pattern, along with the support from ancillary data and the existing topographic maps (Fig 2). The land cover /use map included both land uses (e.g. coconut grooves, plantations) and semi-natural marshlands and water bodies. This provides a base map for analysing change, including that from near natural to heavily human-modified systems and vice versa. Analysis of spatial, ecological change supported by socio-economic data provides a pathway for identifying indicators of wetland loss using a simulated ecological sustainability application in IDRISI-LCM modeller.

Parallel to the collection of ground data on ecological communities a socio-economic survey was designed at multilevels from household to GN (Grama Niladharai- the smallest unit of administration in Sri Lanka) to Divisional Secretariat (DS) level. The detailed survey at household level was done at a specific site) to collect information on the livelihood patterns and its distribution along with dependency on wetland resources. In terms of the socio-economic aspects of the study, there were two components; first the inclusion of socio-economic parameters in the environmental change detection geospatial model that is being developed and second, to present a case study that highlighted in more detail, the inter-linkages between environmental change and livelihood systems at the site (the present paper deals with the first module of the socio-economic analysis).

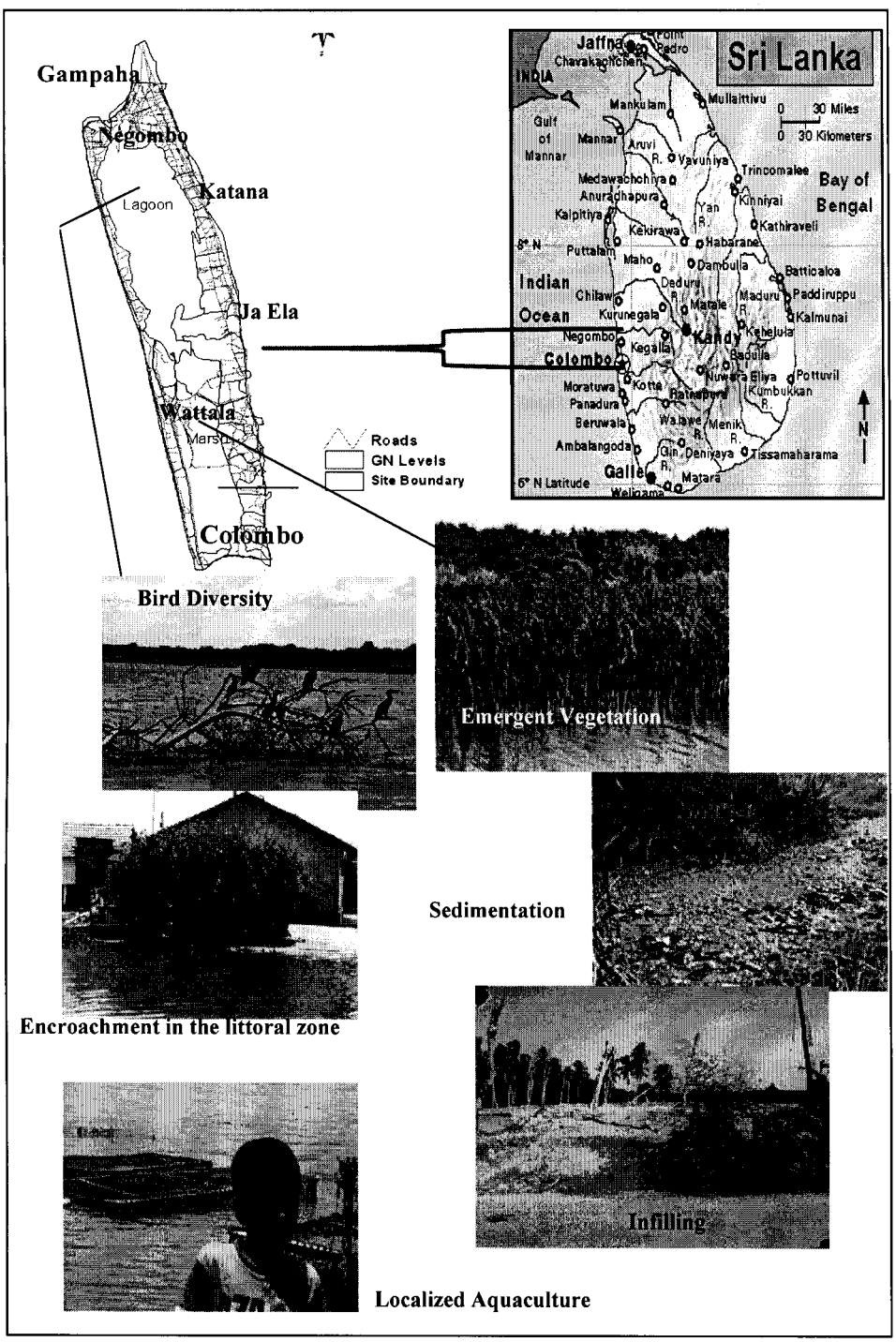


Fig 1- Insight into the lagoon-marsh wetland complex

For the first component, secondary data was collated at the GN level to complement the biophysical parameters that were included in relation to the environmental change detection. For example demographic, economic and poverty related data were collated for each of the 85 GN level divisions which made up the study site. For the second component, a site (comprising one village, Sedewatte, located in Wattala-DS) was selected within one of the GN divisions, to carry out a more in-depth livelihoods analysis. Site selection was based on a set of criteria which took into consideration requirements of the environmental change detection exercise. Primary data is being currently collected for this component and involves carrying out socio-economic assessments using a combination of participatory methods (i.e., community mapping of the village, wealth ranking exercises, focus group discussions) and a conventional household survey on environmental change and livelihoods issues. The survey was undertaken with a representative sample of households based on primary livelihood activity and wealth rank. A spatial multivariate logistic regression model was developed to link ecological and socio-economic variables to work out stress indicators. Authors have tried to address change in wetlands related to the complex interface between urban development, shrinking agriculture and localised aquaculture practices at different levels (in the present case the socio-economic data at the GN level was used for analysis).

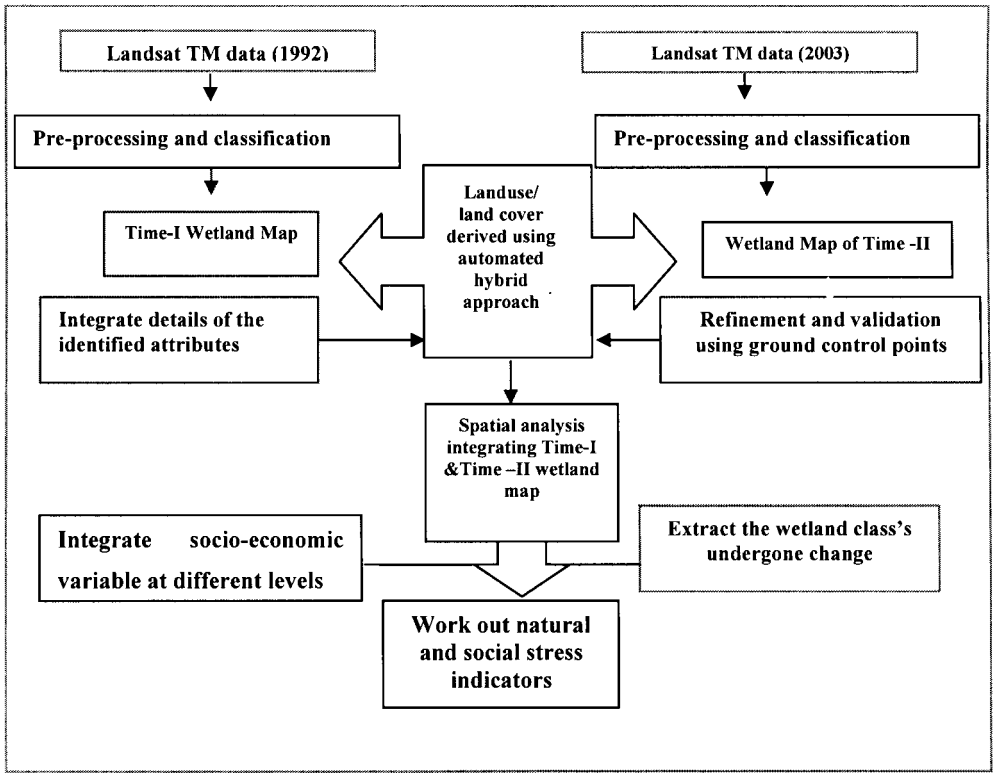


Fig.2-Methodological flow of the process involved in linking ecological and socio-economic variables

Stakeholder (Central Environmental Authority of Sri Lanka) participation was considered from the start of problem identification, proposal development and field surveys in order to cope with the uncertainties in the system. Informal discussions with the inhabitants, local authorities helped to built case scenarios and understand the dynamicity in the system.

Results

The present research is part of a wider initiative that aims to develop an integrated approach for addressing wetland-related environmental issues in a holistic manner. Land cover/use classes have been taken as a unit to trace interchange between wetland and non-wetland areas. Maps have been created to show wetland change and the dynamism of change. The information about the changes was then qualified (natural and created) and quantified (with area statistics in hectares; total area of the classified landscape is 11,922 ha) to explain the increases, decreases and interchanges in the wetland complex.

Noticeable changes in the landscape were shown in the 1992 and 2002 images. These were due to disturbance from waves and storms, a reduction in agricultural activity and anthropogenic transitions, especially those due to an expansion in human settlements and industrialisation. Whilst the latter are seen as particularly important, increases in fallow land, in-filling and encroachment have also resulted in a considerable decrease in the area of the marsh (Table 1 & Fig 4). Industrial, domestic and agricultural discharges over many years have disturbed the pattern of water flow into the lagoon and increased sedimentation. The increased sedimentation is assumed to have adversely affected fish productivity and hence adversely affected the livelihood patterns of the local people; Seedawatte village has been selected as part of ongoing efforts to develop the understanding of the livelihood details (with data being collected from 85 house holds).

The extent of increased sedimentation in Negombo lagoon between 1992 and 2002 is shown in Figure 4. This change was corroborated during focus group discussions held with villagers from Seedawatte who fished in the lagoon. The villagers were of the opinion that the increase in sedimentation had decreased the depth of the lagoon in particular areas, thereby impacting the overall fisheries productivity. They stated that sedimentation had increased over the years due to industrial effluents and other waste material being dumped into the canals that flow into the lagoon.

The existing literature and management plan (CEA, 1994) supports the practice of rice cultivation in the region; however, rice fields are being abandoned due to increased salinisation of the soil. The abandoned fields have been invaded by opportunistic species, especially grasses and a few shrubs. As the rice fields have been abandoned the agriculture

communities have shifted to alternative livelihoods. At the same time the expansion of industry around the periphery of the wetland complex has provided livelihood opportunities and led to an increase in built up areas.

Table1 Land cover/use change from the wetland complex from 1992-2002 (area in hectares)

Land cover (land use)	**1992**	**2002**	**Change (magnitude and direction of change from 1992)**
Coconuts (gardening)	2791	2860	69
Water Body /deep lagoon (fishing)	3140	2105	-1035
Shallow water body (aquaculture)	356	1360	1004
Littoral vegetation (mangrove. (timber and fuel collection)	904	458	-446
Marshland with shrubs (grazing)	2629	1589	-1040
Grasslands (abandoned paddy)	1066	883	-183
Grassland (paddy with other crops)	348	254	-94
Bare soil (fallow agriculture)	69	158	89
Built up (settlements and industrial)	619	2255	1636

An analysis of change using different thresholds and defined algorithmic equations in IDRISI to capture the gradients of change was used to depict the contribution to net changes in associated wetland types (abandoned paddy, littoral vegetation) (Fig 5). Detailed statistics of the change from one land cover/use to another over the past decade were analysed (selected examples of change are shown in Table 3) and an aggregated change map was generated (Fig 4). It was noted that expanding settlements, overgrowth of marshes with shrubs and infilling activities for industrial developments were the major causes for a reduction in the area of the marsh. The hydrodynamics of the lagoon have played an important role in the change in land cover/use classes; in some places the water level has increased and flooded adjacent marsh, while at the urbanised end of the lagoon increased sedimentation has reduced the depth of the water and converted it to a shallow water body. Based on the spatial analysis it is reasonable to conclude that industrial and domestic expansion is a clear indicator of the conversion of the marshes and lagoon into shallower systems. The conversion of abandoned paddy to naturalised grass communities does not appear to have had much of an effect on the wetlands.

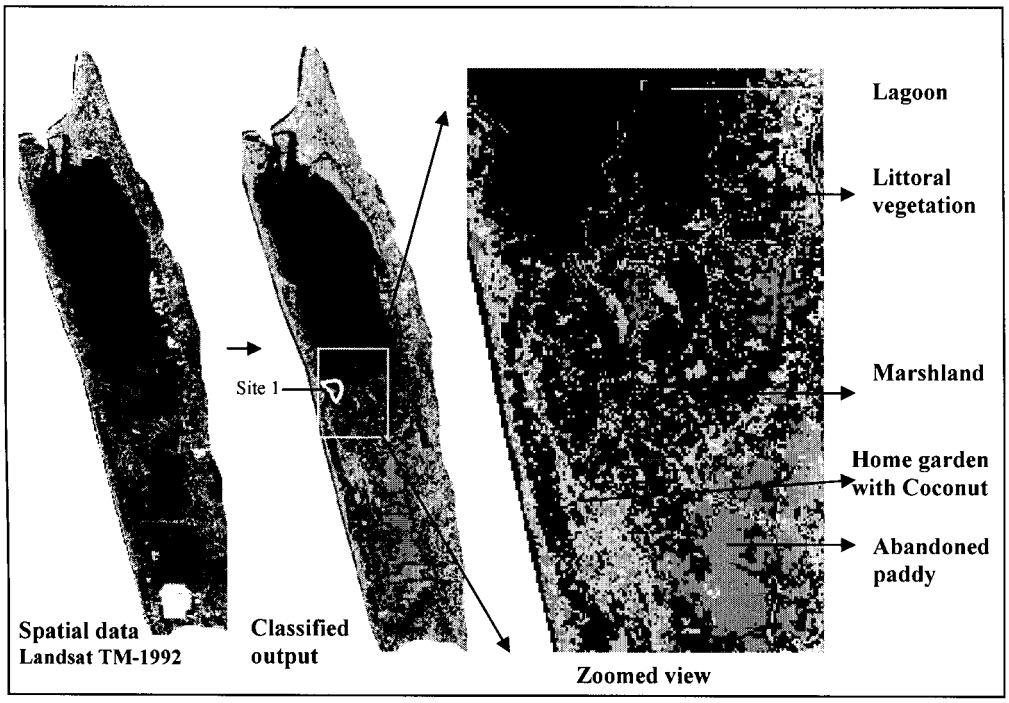


Fig-3 Spatial approach to assess the land cover/use and its juxtaposition in the wetland complex

Increases in urbanisation and changes in livelihood patterns have been recorded during the livelihoods survey at different levels (secondary information collected at divisional secretariat (DS) level, population and natural resource consumption statistics at GN level and primary date on livelihood patterns at the household level). At this stage the information at the GN level is used in our analysis to explain the change and response of the system. For this process the change benefit ratio at a scale from 0-5 (represented as + small increase, ++ medium increase, +++ moderate increase, ++++ significant increase and – less decrease, -- medium decrease, --- significant decrease) reflects that expanding population and increasing industrialisation and developmental active in the surrounding area has contributed toward an increase in built up areas/settlements. Therefore, there has been a noticeable increase in the extent of human-induced modifications (Table 4).When the livelihood patterns are observed at the Divisional Secretariat (DS) level the industrial sector is the most dominant (Fig 6). The industrial activities are concentrated in the Ja Ela, Wattala and Katana DS divisions, south of the lagoon-marsh complex. Fishing activities are prominent only in the Negombo DS division that includes the Negombo lagoon area.

Table 2 Livelihood categories and measurement in Seedawatte village- Site 1

Occupation categories	Number of Households	% of sample	Resources used
Fisherman	7	5.2	N
Retail fishmonger	6	4.4	N
Agricultural workers and services	5	3.7	N
Labour work	23	17	B
Carpenter	3	2.2	B
Mason	4	3	B
Service workers & shop and market sales workers	16	11.9	B
Driver	15	11.1	B
Factory work	3	2.2	I
Garment worker	5	3.7	I
Government worker	5	3.7	B/O
Private sector worker	9	6.7	I
Overseas	4	3	O
Pensioner	2	1.5	O
Unemployed	28	20.7	O
Total	**135**	**100**	

N: Natural resource; B/O: Business/ Others; I :Industrial

Conclusion

In this paper we attempt to show how a geospatial change detection model that incorporates both ecological and socio-economic parameters can be used as a tool to monitor and assess changes in wetland systems. Developing an integrated approach that quantifies and establishes linkages between ecological and socio-economic processes in wetland systems is critical for the better-management of wetlands and for the long-term sustainability of these management regimes.

There were several important facts that were highlighted by our study. Firstly, that there are significant changes in land cover/use patterns that can be observed in the Muthurajawela marsh-Negombo lagoon wetland complex between 1992 and 2002. For example, the conversion of the lagoon into a shallow water body with sediments and the fragmentation and conversion of the marshland into built up areas and settlements are two of the most prominent changes that have occurred over this time period. In the case of the former, primary socio-economic data collected at the village and household level was useful to validate this observation in the lagoon; while in the case of the latter, secondary sources of socio-economic data (specifically demographic data) proved useful to validate that settlements and population numbers had increased in our study area.

Table 3 Selected examples of change of one land cover/use to another

Land cover /use		Change in area	% Change
From	**To**		
Home garden with Coconut	Open Areas / Fallow	68	0.7
Marshy area with shrubs	Built up / settlements	967	10.5
Littoral Vegetation	Marshy mudflats	97	1.0
Marshland	Open Areas / Fallow	72	0.7
Grassland (abandoned paddy)	Shrubby Patches	61	0.6
Shallow Water with Sediments	Marshy mudflats	56	0.6
Littoral Vegetation	Home garden with coconut	122	1.3
Home garden with Coconut	Built-up/ Settlements	229	2.5
Marshland	Home garden with coconut	574	6.2
Grassland (abandoned paddy)	Home garden with coconut	250	2.7
Agriculture with other Vegetation	Home garden with coconut	88	0.9
Littoral Vegetation	Marshy land with grass	157	1.7
Marshland	Shrub land	228	2.4
Marshland	Littoral Vegetation	346	3.7
Grassland (abandoned paddy)	Scrubland	287	3.1
Shallow Water with Sediments	Shrubby areas with sea grass	96	1.0
Home garden with Coconut	Built-up/ Settlements	248	2.7
Littoral Vegetation (Mangrove, Shrubs...)	Built-up/ Settlement	161	1.7
Marshland	Built-up/ Settlements	561	6.1
Grassland (abandoned paddy)	Built-up/ Settlements	127	1.4
Agriculture with other Vegetation	Built-up/ Settlements	129	1.4
Home garden with Coconut	Marshland	1385	15.0
Littoral Vegetation	Marshland	236	2.6
Built-up/ Settlements	Marshland	213	2.3
Grassland (abandoned paddy)	Marshland	134	1.4
Paddy with Other Vegetation	Marshland	149	1.6
Grassland (abandoned paddy)	Marshland	168	1.8
Water Body Deep / Lagoon	Shallow water with sediments	1997	21.7

Table 4 Changes in wetland cover and use

Wetland cover type	Aerial distribution (ha)	Status of change from 1992	Benefits: ecological and socio-economic
Water body/ Lagoon	2105	_	lagoon fishing, breeding grounds for fish species, natural system of water filtration/purification
Shallow water / Canals	1360	+++	fishing, bathing, landing site for boats, water discharge
Mangroves / Scrubland	458	- - -	Fishing gear, firewood, feed for livestock, breeding grounds for fish species, natural system of water filtration/purification, buffer against flooding
Marshland	1589	--	grazing for livestock, firewood, natural system of water filtration/purification, buffer against flooding
Grassland (abandoned paddy)	1066	-	grazing for livestock, conversion to home gardening
Home garden with Coconuts	2860	+	Home consumption, addition for improved food security
Settlements	2255	++++	Provide homes for encroaches of marshland, improved sanitation, poverty alleviation

In addition there have also been natural transitions taking place for example, the abandoned paddy fields have naturalised over time into grasslands with shrub patches, thus contributing habitat for flora and fauna within the system

Our findings also suggest that regular monitoring of the lagoon marsh systems in terms of ecological and socio-economic concerns can play an important role in the overall management of the wetland. Spatial analysis in the GIS-medium is a promising approach and supporting information from socio-economic analyses assist in developing a balance in management approaches to accommodate key conservation and development needs. While a capacity building module for local institutions and stakeholders is planned in the second phase of the project for establishing a regular monitoring system and knowledge transfer; the detailed livelihoods case study that is underway will provide us with insights into how local communities can also contribute to this process and play a role in the long-term management of the wetland. Amplifying the levels of awareness, knowledge and skills with advancing tools and technologies along with stakeholder participation at all levels is critical for sustainable management.

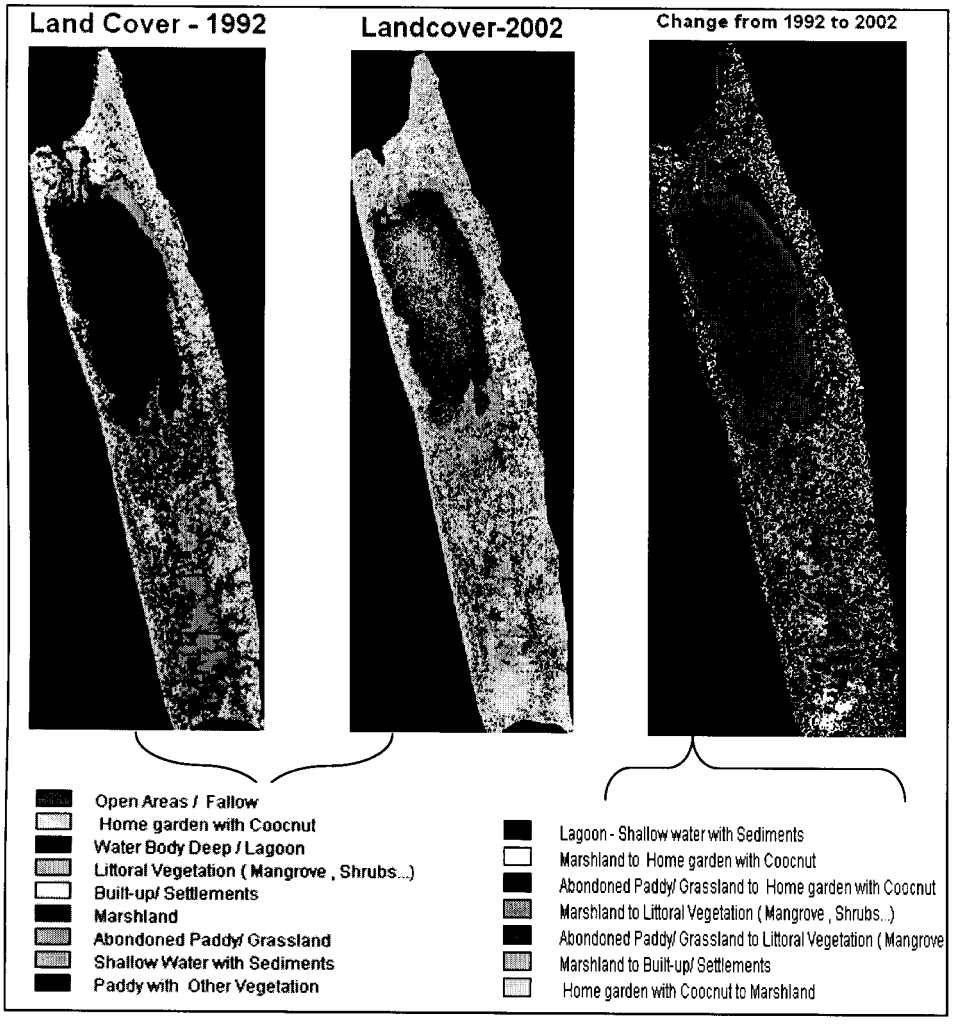
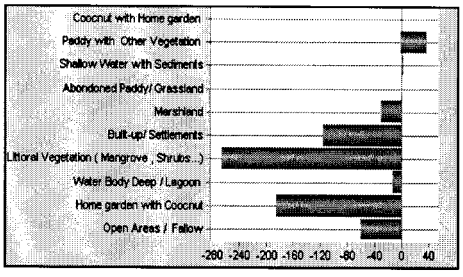
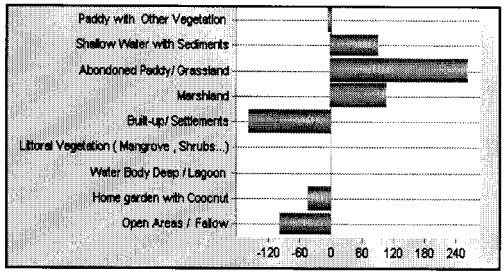


Fig 4 Change analysed in dominant land cover classes in the lagoon marsh complex



(a)



(b)

Fig 5 Depicting two scenarios form the Change analysis (area in ha)
a) Contribution to net changes in abondaned Paddy / Grassland
b) Contribution to net changes in littoral vegetation (mangrove, shrub lands ...)

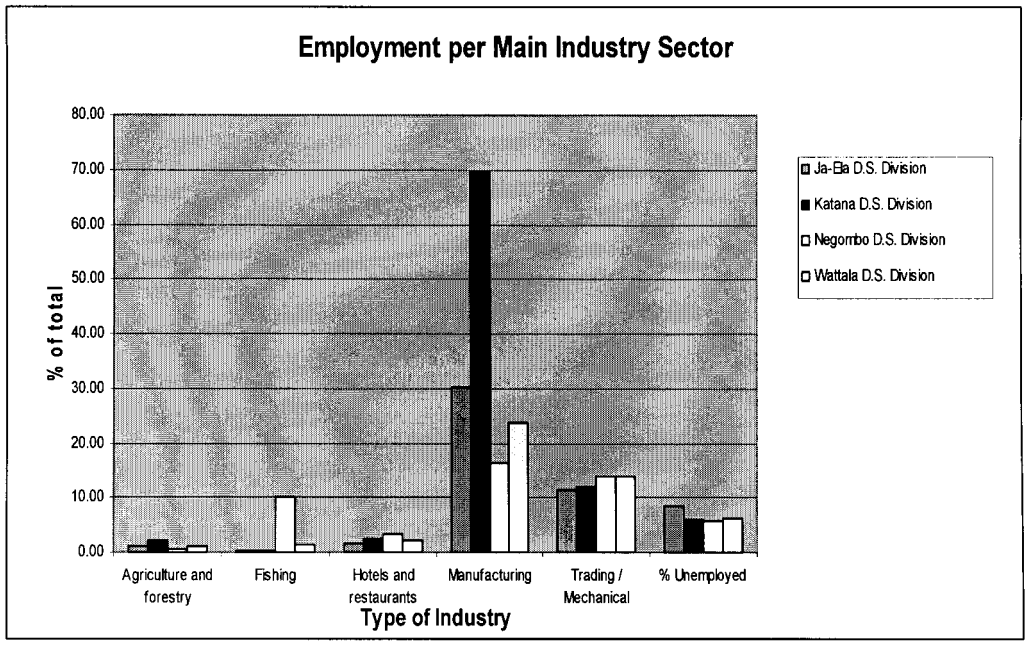


Fig 6: Distribution of employment per sector at the Divisional Secretariat level
(Source: Census Data (2001), Sri Lanka)

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