An Appraisal of Challenges in the Sustainable Management of the Micro-tidal Barrier-built Estuaries and Lagoons in Sri Lanka

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges.

IUCN works on biodiversity, climate change, energy, human livelihoods and greening the world economy by supporting scientific research, managing field projects all over the world, and bringing governments, NGOs, the UN and companies together to develop policy, laws and best practice.

IUCN is the world's oldest and largest global environmental organization, with more than 1,200 government and NGO members and almost 11,000 volunteer experts in some 160 countries. IUCN's work is supported by over 1,000 staff in 45 offices and hundreds of partners in public, NGO and private sectors around the world.

The IUCN in Sri Lanka was established in 1986 and is guided by IUCN's mission and the environmental concerns embodied in successive National Environmental Action Plans of the Government of Sri Lanka.

An Appraisal of Challenges in the Sustainable Management of the Micro-tidal Barrier-built Estuaries and Lagoons in Sri Lanka

Researched and Compiled
by

Dr. Jayampathy Samarakoon
and
Prof. Saman Samarawickrama

Published by : IUCN (International Union for Conservation of Nature), Sri Lanka Office.

Citation : Samarakoon, Jayampathy and Saman Samarawickrama (2012). An Appraisal of Challenges in the Sustainable Management of the Micro-tidal Barrier-built Estuaries and Lagoons in Sri Lanka. IUCN Sri Lanka Country Office, Colombo. xxii + 171pp.

ISBN : 978-955-0205-11-0

Cover Photographs : Negombo Lagoon
© Ranjith Mahindapala

Produced by : IUCN Sri Lanka Office

Design and layout by : K. Amila Tharanga

Printed by : Karunaratne & Sons Ltd.
67, UDA Industrial Estate,
Katuwana Road,
Homagama, Sri Lanka.
info@karusons.com

Available from : IUCN
Sri Lanka Country Office,
53, Horton Place,
Colombo 07,
Sri Lanka.
www.iucnsl.org

Contents

Preface

This study, based on a colloquium, field assessments of development activities and technical analyses pertaining to barrier-built estuaries and lagoons, was inspired by the positive response to a preceding report captioned *'An Appraisal of Mangrove Management in Micro-tidal Estuaries and Lagoons in Sri Lanka'* (IUCN, 2011). The colloquium on mangroves gave IUCN an opportunity to recognize the complexity of outcomes that are associated with planting and/ or restoration of the vegetation in the dynamic setting of micro-tidal estuaries and lagoons. It also exposed the gap in information and knowledge that would result in the event that the even more complex parents ecosystems in which mangroves exist, the barrier-built estuaries and lagoons, are left inadequately understood. Therefore IUCN initiated the present study.

IUCN has initiated and supported diverse interventions in barrier-built estuaries and lagoons in Sri Lanka since the decade prior to the Indian Ocean Tsunami in 2004. Following the tsunami, IUCN supported several interventions in selected barrier-built estuaries and lagoons under the Small Grants Programmes of the Green Coast Project and Mangroves for the Future initiative (MFF). The focus of the MFF Initiative in its current phase is integrated coastal management with particular attention to livelihoods and poverty. Therefore, it was necessary to garner insights into sustainable management of barrier-built estuaries and lagoons as 'ecosystems' and as development infrastructure for both livelihoods of dependent communities and compatible multiple uses. Participants at the colloquium were surprised to learn that the total annual earnings from fishing in three barrier-built estuaries, Batticaloa, Negombo and Puttalam Lagoon exceeds Rs. 2 billion – indicative of the significance of these ecosystems for livelihood.

IUCN recognized that *"sustainable solutions to complex problems, such as those encountered in barrier-built estuaries and lagoons, do not come from science, academics, lobby groups, industries or government; they are the product of a society-wide dialogue, and the resulting consensus that is negotiated".*

Participation at the colloquium included government agencies, representatives of community organizations, private sector, academia, the Navy, and experienced scientists.

Field work was conducted by Dr. Jayampathy Samarakoon and Prof. Senevi Epitawatte supported by the IUCN team at two barrier-built estuaries Batticaloa Lagoon and Negombo Lagoon. Field discussion and analysis generated valuable insights on development activities that had 'unintended consequences' for the ecosystem and dependent livelihoods.

The Sri Lanka National Steering Committee of MFF, ably chaired by Dr. L.P.Batuwitage, Additional Secretary, Ministry of Environment up to August 2011 and since then by Mr Ajith Silva, Director Policy & Planning/ Director, Biodiversity Secretariat, Ministry of Environment supported the study as a priority. The colloquium participants' enthusiastic engagement provided valuable information on relevant issues from different perspectives. This was the foundation that made this report possible. Dr. Samarakoon served as lead writer of the report and Prof Saman Samarawickrema authored the section on *'Hydrology, Hydraulics and Hydro-morphology of Barrier-built Estuaries and Lagoons'*. The report was critiqued and edited by Dr. Tilak Wettasinghe whose assistance is gratefully acknowledged.

The report provides valuable conclusions and recommendations for remedying some problems and issues and for formulating policies for sustainable management of barrier-built estuaries and lagoons.

Shamen Vidanage
Acting Country Representative

December, 2011

Summary Overview

Introduction

1. Estuaries, including barrier-built estuaries and lagoons, are a conspicuous constituent of coastal ecosystems associated with Sri Lanka's 103 rivers. The barrier-built estuaries such as Batticaloa, Puttalam, Chilaw and Negombo Lagoons and true lagoons such as Rekawa and Kalametiya Lagoons are degrading rapidly in parallel with diminishing small-scale fisher livelihoods. Jaffna Lagoon, the largest barrier-built estuary in Sri Lanka, is exceptional since it is not associated with a river. Estuaries form where freshwater from land drainage mixes with sea water to produce brackishwater. The conventional names of the brackishwater bodies in Sri Lanka do not distinguish between barrier-built estuaries and lagoons and require to be reviewed.

2. The barrier-built estuaries and lagoons provide livelihood and food security to an estimated 1% of the nation's population. The yearly earnings from fisheries in three of the most productive barrier-built estuaries, Batticaloa, Negombo and Puttalam Lagoons, alone, exceeds two billion rupees (Rs. 2 billion). Estimations of annual earning for others has not been made. Reliable economic valuations of the totality of ecosystem services provided by these brackish water bodies has not been done.

3. These barrier-built estuaries and lagoons are ecologically significant, in addition to their own fishery productivity, for supporting the nearshore coastal fishery both as a nutrient source and a nursery for a wide range of fishery organisms including fish and shrimps. Production from the nearshore coastal fishery contributes 60% of the animal protein in the Sri Lankan diet. Some such (e.g. shrimp) fisheries would collapse in the event that estuaries and lagoons fail to function.

4. The progressive decline of barrier-built estuaries and lagoons is noted as a public concern in the *Mangroves for the Future: National Strategy and Action Plan – An Ecosystem-based Coastal management for Sri Lanka and in the Sri Lanka Coastal Zone Management Plans* (IUCN, 2009). Barrier-built estuaries and lagoons are common property resources, the management responsibility for which, therefore lies with the state (government and associated institutions). However, the knowledge base is inadequate for promoting sustainable interventions at the policy level.

5. This report based on the findings of a colloquium held in February, 2011 with participation of responsible government agencies, community representatives, scientists and conservation organizations contributes toward building the knowledge base for sustainable management. This is based on the recognition that sustainable solutions to complex problems do not come from science, academics, lobby groups, industries or government; they are a product of a society-wide dialogue, and the resulting consensus that is negotiated.

6. Barrier-built estuaries and lagoons are complex systems whose structure and functioning are based upon relationships and interactions among the parts that constitute these natural ecosystems. But the parts as well as the relationships among them are constantly changing under the influence of natural and socio-economic processes. As a result new attributes, known as emergent properties, arise that create dynamic system-wide changes. Therefore, these complex systems (comparable with human body systems) require holistic management (i.e. the interacting parts considered together). The influence of human actions is superimposed on the physical and biological change processes. Meaningful approaches to sustainable management must combine bio-physical, socio-economic, and political consideration. Therefore, barrier-built estuaries and lagoons are regarded as social-ecological systems (SESs) as the proposed foundation of the knowledge base for sustainable management.

7. The trustworthiness of information and knowledge generated through the colloquium is a necessary attribute for policy relevance. Therefore, analysis and synthesis of the information gathered at the colloquium not only considers the science aspect of verifiability through actual experience, but also uses three analytical frameworks to provide coherence:

    - Social-ecological system (SES): Here eight the relevant layers of variables that influence change in SESs are considered in a diagnostic approach toward understanding the most significant causes.

- Social political system: Here the exercise of power in decision-making that has caused unintended consequences of planned development resulting in degradation of the SES are considered and brought into the analysis.
- Ecosystem sustainability system: Here the findings of the Millenium Ecosystem Assessment are considered to promote comprehensive valuation of ecosystem services as a mechanism to enable balance decisions to slow the loss of ecosystems.

8. Fishery-based livelihoods associated with barrier-buillt estuaries and lagoons is taken as a high priority indicator of sustainability since the income aspect of livelihood is based on fish stocks. Adequate fish stocks can exist only if the environmental quality is adequate. *"A livelihood comprises the capabilities, assets and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain its capabilities and assets both now and in the future, while not undermining the natural resources base"*. Drawing from this a fishery system is a combination of the social-ecological and livelihood approaches.

9. The geographic distribution of estuaries (including barrier-built estuaries) and lagoons is explained as an evolutionary product of the interaction of geologic, geomorphologic, river hydrology, and coastal processes driven by sea-level rise that occurred about 10,000 years before present. The barrier-built estuaries and lagoons, thereafter, have been accumulating sediments received from watersheds. These sediments cannot be adequately flushed to sea because of Sri Lanka's micro-tidal setting (difference between high and low tide being less than 1 meter).

10. Because of their relative smallness and shallowness barrier-built estuaries and lagoons are highly vulnerable to land use influences (e.g. pollution, sediment infilling, etc.). The major degradational changes therefore are associated with planned and indiscriminate development activities that have not considered their system attributes 'holistically'. However, owing to ready availability of food these have been attractive sites of human settlements. Thus a high element of 'risk' is associated with barrier-built estuaries and lagoons stemming from the potential for harm to people and property from natural hazards. This was demonstrated during the Indian Ocean tsunami in 2004.

11. Considering these complexities, the Coast Conservation Department has advocated the Special Area Management (SAM) Planning approach in regard to coastal ecosystems including barrier-built estuaries and lagoons.

12. Assessments of environmental management (EM) worldwide has demonstrated its inadequacy where it exists only as a technocratic problem-solving initiative with the aim of providing 'practical assistance' to government officials. More recent assessments have revealed positive shifts toward incorporating sub-disciplines such as environmental governance and political ecology. These sub-disciplines give attention to the role of power (the capacity to influence), politics (relationships among groups of people for influence), inclusiveness/exclusiveness of groups of resource users in decision-making and resistance to top-down policy implementation. This dimension is examined in the context of power relationships as they impact structure and functioning of barrier-built estuaries and lagoons and livelihoods in relations to government and private development activities, their lack of legitimacy and causes.

Colloquium Findings

13. The colloquium was planned for implementation in a manner that brought together specialists and non-specialist stakeholders. Two questions were addressed: (i) Why is deterioration of barrier-built estuaries and lagoons proceeding unabated while a range of government agencies exist for their sustainable management? (2) Why are changes occurring in these brackishwater bodies perceived in many different ways that deter appropriate interventions? The colloquium was conducted in four sessions: The first three technical sessions included expert presentations while the final session was open discussion leading to suggestions for action.

    Session 1: Addressed (i) the nature of micro-tidal barrier-built estuaries and lagoons and their changes during the past 30 years under the influence of multiple uses; (ii) hydrology, hydraulics, and hydro-morphology; (iii) seasonal behaviour of tidal inlets; and (iv) coastal fisheries and linkages with estuaries and lagoons.

    Session II: Addressed (i) urban planning implications with Negombo Lagoon as a case study; (ii) whether or not the barrier-built estuaries and lagoons are worth the cost of management, and the needed interventions; and (iii) the need for a landscape approach incorporating cultural aspects to long-term management.

    Session III: Addressed (i) the need for a comprehensive valuation including ecosystem services; (ii) the regulatory and managerial aspects; and (iii) community perspectives on the relationship between management of barrier-built estuaries and lagoons and livelihoods.

Session IV: Plenary Discussion addressed (i) main causes of degradation; (ii) prioritization of barrier-built estuaries and lagoons based on management needs; (iii) the required institutional systems; (iv) sharing of scientific information with local communities aimed at empowerment with knowledge; (v) techniques for classifying the brackishwater bodies appropriate for management planning; (vi) ways of information sharing with policy makers that incorporates science and people's wisdom; (vii) management of tidal inlets for multiple uses; and (viii) promotion of policies based on multiple criteria including economics, ecology, culture and sociology.

The suggestions for continuity based on awareness generated at the colloquium included:

- dissemination of the information to the widest audience including policy makers;
- take the thematic findings forward to build greater awareness;
- conducting awareness programs to share information at the resource user community level;
- enrolment of the Irrigation Department in aspects of management of watersheds;
- giving greater attention to climate change impact mitigation / adaptation.

Field Observations

14. Coastal environmental management, in regard to barrier-built estuaries and lagoons, involves addressing problems on various scales. Some problems created by inadequately integrated development activity which occupies a small extent of the water body creates impacts that reverberate through the entire aquatic system. Therefore, development activities that have many unintended consequences in the long term (directly visible at the ground level, or in large scale maps and photographs) dissolve into invisibility when included in bird's eye view images (satellite images, small scale maps or photographs). It is in this context that photographs provide indirect but verifiable visual evidence of particular situations in the field. Some engineering interventions although highly desirable from a public interest standpoint have entrained cumulative impacts that progressively aggravated as chronic disasters. The major source of chronic disasters in barrier-built estuaries and lagoons are those infrastructure developments that either obstruct the free flow of water and which fragment (compartmentalize) a unitary water body.

15. Batticaloa Lagoon and Negombo Lagoon were used as case study sites to demonstrate evidence of unintended harmful consequences of various development activities. A series of recent photographs convey the unintended consequences that may otherwise escape attention. It is notable that most such development activities have resulted from technocratic, problem-solving projects, implemented by the state (government technical agencies) with support from multi-lateral and bilateral financing agencies. Some such activities have been implemented by organizations dedicated to conservation of natural resources, having reverse effects such as mangrove planting under the label of 'mangrove ecosystem restoration' among others. At the community level, many activities including land encroachment into the productive water body are driven by poverty.

Hydrology, Hydraulics and Hydro-morphology

16. Barrier-built estuaries and lagoons are water-dominated ecosystems formed at the interface between land and sea. Hence, the attributes of water determine the life or death of estuaries and lagoons. These attributes are the outcome of processes that are fundamentally the interactions of physics and chemistry which may be mathematically defined. In that context, the physical evolution of estuaries and lagoons may also be defined as expressions of physics and chemistry. Appropriate measurements allow recognition of their behaviour in keeping with fundamental laws. Both common sense and science require that we accept the consequences of such behaviour. The laws of gravity ensure the behaviour of water borne particles of sediment, influenced by for instance the salinity and density of brackish water in ways that may be described with a high level of precision. Information in this part of the narrative provides the mathematically definable foundation for understanding the implications of multiple land uses for fishery and livelihoods in barrier-built estuaries and lagoons.

17. Barrier-built estuaries and lagoons cannot be considered in isolation; the whole system has many interdependent parts. Within an estuary/lagoon the river water is mixed with sea water by the action of wave and tidal motions. The tidal rise and fall governs the magnitude of the oscillatory currents, though high river discharge can have a considerable effect in modifying them. Residual currents may also occur due to vertical and horizontal density differences, between river water and sea water, which depends on the mixing process. Movement of water, under the action of tides and river flow, is closely inter-related with movement of sediment. Tidal currents, sediment movement due to the action of waves & currents, and fresh water inflows are the main factors that govern the seasonal and long-term behaviour of estuaries/lagoons. The dynamic nature and inter-dependency of these

governing factors, make estuarine dynamics a very complex process. A thorough knowledge of these parameters is very important to understand the behaviour of estuaries/lagoons.

18. Studies done for Negombo Lagoon aimed at improving environmental management are explained to illustrate the basics of a modelling approach. The exchange of water in the lagoon is influenced by the tides from the ocean side and fresh water supply from the inland side. The tide is semi-diurnal and the tidal range in the lagoon varies from 0.07 m at neaps to 0.2 m at springs and the tidal range in the sea varies from about 0,2 m to 0.6 m. Thus the volume of water stored and released varies between 1.5 million m^3 and 7 million m^3 per tide. Fresh water enters the lagoon from the south through Dandugam Oya, Ja Ela and several streams from the Muthurajawela marsh. The supply of fresh water varies from virtually zero during dry seasons to more than 100 cusecs during rainy seasons. The lagoon and the entire wetland are separated from the sea by a narrow stretch of land, consisting of a very fragile coastal dune system situated on beach rock, formed during sea level changes over geological periods of time. The conservation of this coastal dune system plays a vital role in the long term stability of the lagoon.

19. In addition to the review of previous investigations, extensive field investigations and modelling studies were carried out to evaluate the existing hydraulic regime and to evaluate a range of dredging options. A two dimensional hydrodynamic (HD) model of the lagoon and entrance channels formed the basis of the most important modelling activity. An advection-dispersion (AD) model and a sediment transport (ST) model were built on top of the HD model to investigate the transport of salinity and sediment.

20. A total of seven dredging scenarios were investigated and the percentage increase/decrease in flood discharges was assessed. Thereafter, the socio-economic aspects of the options, relating to the problems and issues of the users, were discussed with lagoon management officers and the users. Option number 6 with minor modifications was selected as the preferred option. Modelling showed that the proposed dredging will increase the tidal range in the lagoon water body by about 45-60%. Under the existing conditions there is a time lag of 4 hours; the proposed dredging is expected to reduce it to about 2.5 hours and contribute to the increase in tidal range.

21. Ecological restoration of barrier-built estuaries and lagoons is expensive. But restoration by engineering interventions including dredging is the only way that can temporarily reverse the cumulative impact of sedimentation that decreases the available water ‘space’ for fish stocks that support livelihoods. However, implementation of engineering works is fraught with uncertainty as in the case of Negombo Lagoon even when funds are available. Politics i.e. the balance among wishes of groups of people who would gain or lose

eventually determine implementation. Thus technocratic approaches to solve problems cannot be successful unless aspects of politics and socio-economics are adequately combined.

Synthesis – What Management Approaches Could Improve Resilience of Estuaries and Lagoons?

22. The synthesis was necessitated by the complexity of bio-physical and socio-political relationships that have shaped changes in barrier-built estuaries and lagoons during the past several decades. Clarity can be imparted toward understanding complex social-ecological systems (SESs) by unpacking and addressing the many layers of interacting relationships. To do so, information is required from many disciplines to constitute a synthesis. An attempt has been made to draw together information from sources that were situated outside the scope of the discourse at the colloquium. This synthesis explores the changes in barrier-built estuaries and lagoons as complex social-ecological systems from three different but overlapping standpoints:

    (i) *Social-political systems' function:* This flows from the manner in which access to resources of the barrier-built estuary is assigned to all eligible stakeholders in a balanced manner without discrimination (equity and balanced law enforcement), and without creating side effects (e.g. negative externalities) that undermine the ecosystem as by pollution. This relates also to the structures that distribute power among stakeholders. This incorporates the outcome of the analysis of 'unintended consequences of planned development' associated with 'complex systems' such as estuaries and lagoons, to define the lessons that may be extracted for safeguarding livelihoods and food security in 'common property resource systems'.

    (ii) *Social-ecological systems' structure and function:* Here a diagnostic approach is applied toward understanding the 'big picture' which brings out why fishery-based livelihoods require safeguards due to inadequate appreciation of physical geography and politically driven interventions that lack a moral vision (legitimacy). A moral vision exists where actions are carried out in keeping with a road map based on the ethical principle of 'doing unto others as you would like them to do unto you'. This implies that the synthesis begins with a focus on micro-geomorphology (the local small scale) embedded in macro-geomorphology (the large scale) and the assumption that the interests of the weakest segment of resource users would be optimally considered. This means that households / clusters of households and their interaction with the environment represent the smallest scale.

(iii) *Valuation of Ecosystem Services*. This includes building coherent economic arguments to enable management of investments to develop barrier-built estuaries and lagoons and enable co-existence of multiple users and ecosystem services based upon verifiable economic values.

23. The diagnostic approach to unraveling problems of social ecological systems, probably a first in Sri Lanka, is illustrated by using the Negombo Lagoon barrier-built estuaries as a case study. It is done by first deconstructing the many layers of variables into eight primary layers, and sub-variables contained within them. In a highly complex system such as Negombo Lagoon many interactions occur among the eight layers of variables and sub-variables preventing identification or definition of any linear cause-effect relationships. The objective here is the representation of a methodology (technique) for setting about the task of understanding a complex SES and prioritizing the most significant variables and sub-variables for management. The same methodology may be applied toward improved understanding of the other barrier-built estuaries and lagoons in a long-term effort to mobilize their sustainable environmental management.

24. The causes of the unintended consequences of planned development in respect of Negombo Lagoon are explained. The inferences reveal that the foremost (parallel first rank) causes of harmful, but unintended consequences are:

    - Ignorance,
    - Immediate self interest (greed), and
    - Values - a deficit in ethics and morality.

    The second rank cause is:
    - Error.

    The third rank is attributable to:
    - Self fulfilling (and/or self defeating) prophesy.

    Justification is provided for the ranking of the causes.

25. The changes in Negombo Lagoon are analyzed and explained in terms of the diagnostic approach for dealing with social ecological systems. It is based upon physical geography and the evolutionary history of geomorphology. The eight primary layers of variables used in the analysis are:

    - *Socio-economic and Political Setting:* including the sub-variables mainly associated with the national attribute, economic development, demographic trends, political stability, government settlement policies, and market availability.

- *Resource System/s*: including the sub-variables boundary, size, productivity, human constructed facilities, equilibrium poroperties, predictability of system dynamics, storage characteristics and location.
- *Resource Units*: including sub-variables resource unit mobility, growth or replacement rate, interactions, economic value, size, distinctive markings, and spatial/temporal distribution.
- *Users*: including the sub-variables numbers of users, history of use, location, leadership/entrepreneurship, norms/social capital, knowledge/ models, dependence on resource, and technology used.
- *Governance System*: including sub-variables governmental, relevant organizations, network structures, property rights systems, operational rules, collective choice rules, constitutional rules, and monitoring/ sanctioning processes.
- *Interactions and Outcomes*: Although taken together, Interactions and Outcomes are separate primary variables. The *Interactions* include sub-variables harvesting levels of diverse users, information sharing among users, deliberation process, conflicts, and lobbying activities. The *Outcomes* include the sub-variables social performance measures, ecological performance measures, and externalities to other SESs.
- *Related Ecosystems*: including sub-variables climate patterns, pollution pattrerns, and flows in and out of Negombo Lagoon SES.

26. The valuation of ecosystem services was considered in the context of the findings of the Millennium Ecosystem Assessment and the suggested context represented by the driving linkages. This was supplemented by recent findings regarding the need for valuation giving consideration to the time spans required for incorporating 'intergenerational equity'.

27. Historical reflections on the impacts of developments in water management for expansion of agriculture reveals a consistent neglect of the economic interests of fishing communities dependent upon fish stocks in barrier-built estuaries and lagoons in particular.

28. The synthesis based on a coherent framework of the 'big picture' and the application of the diagnostic approach to the Negombo Lagoon case study have revealed the following inferences that may be generalized to a considerable extent for barrier-built estuaries and lagoons in Sri Lanka:

    - The complexity of the 'sustainability problem' requires that it be addressed as a system including societal objectives, post-harvest sector, fishery (occupational) diversification, women in fisheries,

household decision-making in interaction with fishery management, land use within the framework of ICM with due regard to factors of unsustainability such as poor governance, lack of secure rights, poverty and absence of alternatives and the unbalanced treatment of sustainability components.

- The harmful changes that have occurred are associated predominantly with developmental interventions (human constructed facilities) by the government which neglected the livelihood needs, concerns and rights of segments of coastal populations that were already regarded as socially and politically on a lower level. Their marginalization perhaps unintended may then be regarded as a product of structural and cultural violence as defined by Johan Galtung. A first step toward amelioration requires characterization of each affected community that provides them with a spatial identity.
- Any effort at sustainable environmental management of barrier-built estuaries and lagoons will need to address the cumulative impacts of decades of neglect now visible as chronic disasters. The possibility of ecosystem restoration is considered.
- Any corrective measures in keeping with Sri Lanka's existing development vision would require organization of the fisher households based primarily on comprehensive awareness of the economic values of the system that they depend on, either as a fishery system or as a 'land resource', for other forms of equitably planned development including aquaculture and tourism.

Conclusions

29. The conclusions were based upon a simplified form of ranking based upon selected criteria. The summarized conclusions relate to:

    - gaps in knowledge on the reality of change in estuaries and lagoons, as ecosystems.
    - meaningfulness of information being shared pertaining to such changes.
    - lessons from intended and unintended consequences of development on these ecosystems and the need to improve governance and equity.
    - necessity for learning from past mistakes and to sustain benefits from estuaries and lagoons to society since the cost of doing nothing could have unpleasant consequences for the state.
    - risks stemming from the continuing neglect of integrated management of ecosystems, especially in the island context of Sri Lanka.

- the need to take immediate steps to mobilize interventions based on education, skill development and health that would provide alternative employment to those who may lose livelihoods from degraded barrier-built estuaries and lagoons.

30. The conclusions were broadly classified under:

- Loss of space for fishery stocks in barrier-built estuaries and lagoons that support livelihoods.
- Meaningfulness of information.
- Actions necessary for sustainability.
- Intended and unintended consequences of development.
- Risks stemming from the neglect of integrated management including appropriate values.

Recommendations

31. Recommendations were selected on the basis of ranking of conclusions based on significance for ecosystem sustainability and capacity for implementation within the MFF initiative.

(i) *Information and Knowledge:* Prepare ecosystem services valuation models for selected, politically and economically significant, barrier-built estuaries that are most threatened by development. Among others, Batticaloa Lagoon, Chilaw Lagoon, Jaffna Lagoon, Negombo Lagoon and Puttalam Lagoon may be considered for such an exercise. In view of the urgent need for technical guidance, the selection may be narrowed down to the two estuaries for which adequate information is already available, namely, Negombo Lagoon and Puttalam Lagoon. The core values and principles and guidelines that are flexible and adaptable to other estuary systems, are likely to emerge from these models to en sure win-win outcomes. Guidelines should be disseminated through appropriate training programmes. The practical value of ecosystem services valuation models will increase appreciably when maps (in the form of atlas pages) support the form and content of land allocations that form the substance of the models. Then guidelines can be formulated as location-specific actions.

(ii) *Institutions:* Develop co-management partnerships between community-based organizations and law enforcement agencies to manage estuaries and lagoons as 'systems'. These partnerships should be fostered and nurtured by mechanisms such as CCD's Special Area Management

Programme (SAM), appropriately modified using the colloquium findings, especially by incorporating aspects of rights (e.g. rights to livelihood, property rights, structural violence, ecosystem services etc.).

(iii) *Awareness and Training:* Strategic awareness and training will be the key to bringing about institutional change. The aim should be to instill consciousness of the need to generate 'countervailing' power among communities that depend on the fishery productivity of barrier-built estuaries and lagoons, and the linked coastal (traditional, small-scale) marine fishery.

Section 1

Introduction

1.1 Introduction

This report on the state of barrier-built estuaries and lagoons, their problems and solutions, is based on an analysis of the proceedings of the colloquium convened in February 2011 by IUCN (International Union for Conservation of Nature) Sri Lanka. The Ministry of Environment and Natural Resources (MENR) collaborated in this endeavour. Building a knowledge base on coastal ecosystems was prioritized in the *National Strategy and Action Plan – An Ecosystem-based Integrated Coastal Management in Sri Lanka* (IUCN, 2009. The colloquium, with participants from relevant regulatory bodies, community level coastal community organizations, universities, non-governmental organizations (NGOs) and the private sector, stemmed from this requirement *(Annex 1)*. Barrier-built estuaries and lagoons associated with the 103 river basins within which they are situated are economically significant in the relatively small island of Sri Lanka.

Fifty thousand and some members of coastal communities depend full-time and part-time upon the fishery productivity of the barrier-built estuaries and lagoons. The social justification for the colloquium flowed from this fact. This fishery income is the mainstay of livelihood today for an estimated population of 250,000 persons, i.e. 1% of the present national population. At independence in 1948, these same ecosystems supported coastal livelihoods of a population of about 30,000 households particularly when fishing at sea in traditional fishing craft was not possible during Monsoonal rough seas (Government of Ceylon, 1951). Today, when the population is threefold greater, while several previously productive 'lagoons' are already 'dead', the remaining barrier-built estuaries and lagoons continue to silently provide their many ecosystem services. Therefore, public concern about these resilient coastal ecosystems is warranted.

The need for a colloquium was re-emphasized by recent events of public significance, highlighted in the media, concerning estuaries and lagoons and

their relationship to economic development. Two such events also exemplified the concept of countervailing power (Galbraith, 1977):

- Political agitation by Negombo fisherfolk against construction of a seaplane landing strip in Negombo Lagoon proposed by the state (e.g. Sunday Observer 28/11/10; Sunday Leader 28/11/10; Newsfirst: <www.newsfirst.lk> 01/12/10). It was argued, by the fisherfolk, that the proposed development would destroy the fishery and associated livelihoods.
- Flood damage suffered by the Batticaloa fishers and paddy farmers during the unprecedented northeast monsoon rains in 2010. It was argued that the flooding, that harmed economic activity and livelihoods, was aggravated mainly due to failed drainage through Batticaloa Lagoon. Both spontaneous and organized protests by affected people resulted in the physical breaching of the Dutch Bar Road (see Section 3) to mitigate the flood.

The media raised questions relating to the role of estuaries in development, their economic value, the need to safeguard food security, etc. Some questions were highly relevant while many others revealed some confusion regarding sustainable development. This flows from individuals being prisoners of their particular experiences with little opportunity to cross knowledge boundaries to understand the 'big picture'. Sustainable development seemed to be a little-understood concept. Hence, it became the starting point for the colloquium with the participants discussing:

> *"sustainable solutions to complex problems, such as those encountered in regard to barrier-built estuaries and lagoons, do not come from science, academics, lobby groups, industries or government; they are the product of a society-wide dialogue, and the resulting consensus that is negotiated"*

Solving problems by way of questions and answers, as in a colloquium, is a tested method in harmony with the Asian approach to learning and the Socratic tradition in acquiring knowledge. This method is commonly used even today, in diverse situations, where the questioning is not only to draw individual answers, but also to gain fundamental insights to problems and issues *(Figure 1.1)*. In the present colloquium the central questions were on the changes that occur in estuary and lagoon ecosystems relating to biodiversity, livelihood, food security and risk. The previous IUCN Sri Lanka colloquium on mangroves and its report *"An Appraisal of Mangroves Management in Micro-tidal Estuaries and Lagoons in Sri Lanka"* and the public response, served as a model for the present intervention (IUCN, 2011).

The Goal

The goal of the colloquium was to raise awareness through questions and answers about the present state of, and future prospects for, livelihoods and food security associated with estuaries and lagoons. The two questions that will provide the base for further inquiries to bring out information of fundamental importance were:

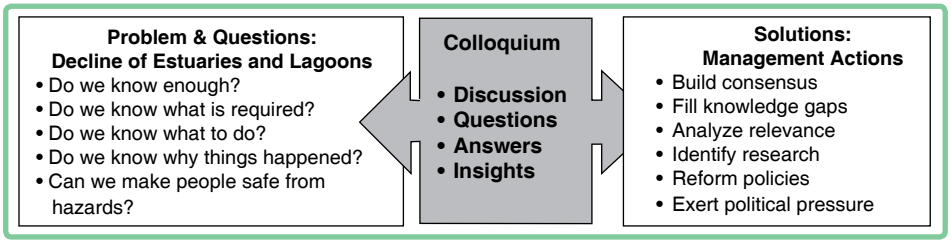
- Should the future of estuaries and lagoons and dependent livelihoods be left to 'business as usual'?
- Should a serious effort be made to change the prevailing indifference and continuing 'destruction by default' of estuaries and lagoons?

The Objectives

The objectives, embodied in the questions raised, related to:

- Gaps in information, knowledge and understanding about the reality of change in estuaries and lagoons as ecosystems, i.e. do we know enough about the many ways in which their complex structure and functioning are being altered by nature and by people, and whether these changes are beneficial or harmful?
- Is the generated information useful to comprehend these changes, particularly in relation to livelihood, food security and risk, i.e. does the information about the changes occurring in estuaries and lagoons, which are complex systems, take into account the many relevant economic, physical and hydrological relationships and ecosystem services including implications for equitable sharing of benefits by all segments of society?
- Actions necessary to sustain equitable sharing of benefits from estuaries and lagoons by society, i.e. the activities that the government (more realistically, the state i.e. the government and associated private sector and religious organizations etc.) and non-state stakeholders including fisherfolk could engage in and support as safeguards for livelihoods?
- Intended and unintended consequences of development on these ecosystems, i.e. the range of impacts, short-term and long-term, beneficial and adverse, that may result from planned development activities in the area of influence of estuaries and lagoons?
- Risks, including climate change implications, that could stem from current approaches to the development and management of estuaries and lagoon ecosystems, i.e. the potential of these development approaches to harm people's lives and property, especially of the fisherfolk who directly depend upon them for livelihood and food security?

Figure 1.1 *Schematic diagram of a colloquium to deliberate on the continuing decline of estuaries and lagoons in Sri Lanka and come up with solutions.*



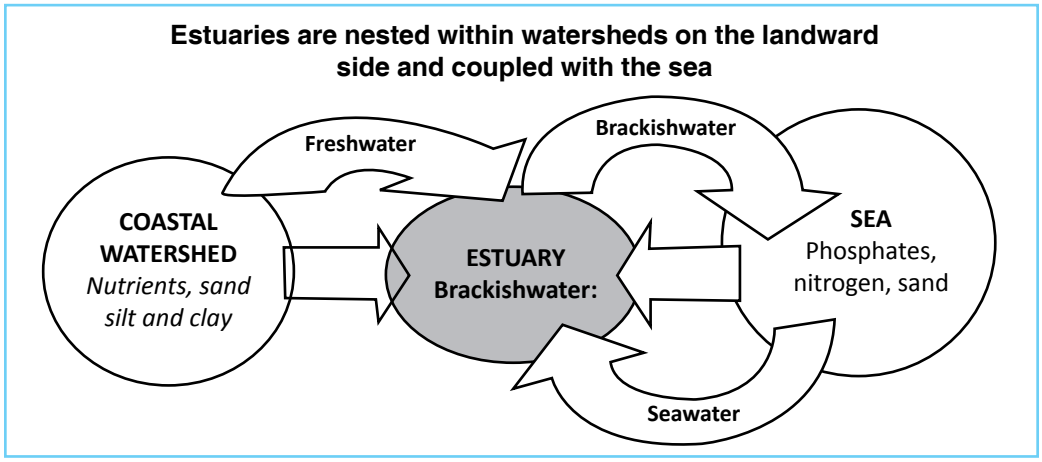
The following facts reveal the significance of the topic under discussion:

- The progressive, visible deterioration of estuaries and lagoons over the past several decades (CCD, 2006) despite ongoing investments by the state in government agencies responsible for their sustainable management including, the Coast Conservation Department (CCD), Central Environmental Authority (CEA), Department of Fisheries and Aquatic Resources Development (DFARD), National Aquatic Resources Research and Development Agency (NARA), and by some NGOs concerned with natural resources management.
- Inadequate understanding of the sources (natural resources and institutions) that support fisher livelihoods.
- Inadequate recognition of estuaries and lagoons as important sources of nutrients for nearshore coastal fisheries, to supplement nutrients derived from monsoon driven ocean upwelling in the Bay of Bengal.
- People generally find aquatic environments strange; hence are insensitive to their complexity. Their imagination and understanding are trapped in a 'terrestrial outlook' where they stand on stable land, and build on the surface to serve their needs, where only the air moves usually without disrupting the outcome of their 'building' activity. An extreme geological or weather event is usually required to cause a disturbance. So, people fail to anticipate uncertainties in aquatic environments including estuaries and lagoons.
- There is a wide gap in power, i.e. the capacity to influence others, and financial capability among the fisherfolk, state agencies and civil society organizations, all of whom must contribute in unison towards change management in estuaries and lagoons. Unfortunately, the primary victims of adverse change, the fisher folk, possess the least power as a consequence of the structure of Sri Lankan society (Alexander, 1995). They are poor and unorganized, their financial resources do not go beyond satisfying their basic needs and therefore they are not considered as significant participants in decision-making even in matters relating to their own wellbeing. The

implications of thus marginalizing these communities was well understood and the need to correct contributing policies was recommended by the Prersidential Commission that deliberated youth unrest following the events in 1988/1989 (Government of Sri Lanka, 1990). They, nevertheless, can acquire power through organizing and empowering themselves by way of knowledge to acquire a voice, i.e. countervailing power (Galbraith, 1952).

A major cause of societal damage to barrier-built estuaries and lagoons is ignorance as demonstrated in Section 5. The strangeness of the aquatic environment here requires emphasis. It is very different from the stable terrestrial environment people are familiar with. Most people never see what lies below the surface of an aquatic environment. Water is constantly in motion and it insidiously changes the form of the physical structure of the 'container' in which it resides. In the aquatic environment water and sediment are two sides of the same coin. Various materials easily dissolve in water and increase in concentration. This goes unnoticed until toxic levels are reached and fish kills become obvious or smells become noxious. Thus the management of aquatic environments requires attention to processes that are unfamiliar and invisible to 'terrestrial' humans. Section 3 illustrates several instances where inadequately integrated development activity has caused serious problems to ecosystem functioning. Estuaries and lagoons are ever more dynamic (changeable) since they are influenced by freshwater from land and the twice-daily flow of tidal seawater. The very existence of an estuary or a lagoon depends on the mixing of adequate quantities of freshwater and seawater, of the right quality, within its boundaries *(Figure 1.2)*.

Figure 1.2 *Estuaries are nested within watersheds on the landward side and coupled with the sea. They contain brackish water formed by the mixing of freshwater and seawater. Physical form and biology in an estuary system are based upon flows and mixing of water* (Sorensen, 1993).



Unfamiliarity with complex aquatic environments generally results in a high level of indifference to changes in these settings that pose risks to life and property. The gravity of risk is at times demonstrated in the fury of extreme events such as the 2004 Tsunami that are termed acute disasters. Acute disasters are so named simply because it is possible to assign a date and time to them (Adger *et al.*, 2005). In contrast, gradual changes go unnoticed, particularly in aquatic environments, until they reach a level of aggravation that is unpleasant, as in the case of pollution. Gradual processes of change resulting in unpleasant outcomes are termed chronic disasters (Adger *et al.*, 2005).

Most processes of change in Sri Lanka's estuaries and lagoons are chronic disasters. One form of chronic disaster is the progressive obstruction of water flow through estuaries and lagoons due to sediment build-up. This chronic disaster results in floods that damage life and property with increasing frequency. The floods themselves are acute disasters, but the process of causation, progressive sedimentation, is a chronic disaster. Jared Diamond's 'creeping normalcy', introduced in his landmark book *"Collapse: How Societies Choose to Fail or Survive"* (Diamond, 2005), corresponds with 'chronic disaster'. Sometimes human responses to acute disasters (Tsunami 2004) may entrain chronic disasters as in the case of the Kallar Bridge, and Dutch Bar Road, Batticaloa (see Section 3).

Escaping the impact of coastal chronic disasters in Sri Lanka is not a simple matter. With the increasing population and urbanization, coastal communities are compelled to reside where the risk of chronic disaster is already present. The risk will continue to aggravate with time, parallel to climate change. The people no longer have the ability to migrate *en masse* to safer locations. Thus they are trapped until the government/state or humanitarian organizations mediate to reduce risk. A significant segment of these 'trapped populations' depend on fishery income for their livelihood. The magnitude of this livelihood income passes unnoticed because of deficiencies in natural resources accounting procedures that inform policies and decisions *(Table 1.1)*. The actual value of ecosystem services is presently disregarded by political and development planning authorities whose priorities are driven by immediate interests and not long term interests that pertain to livelihood sustainability and national food security (see sub-section 1.5B).

1.2 The Economic Value of Estuaries and Lagoons

Communities whose livelihoods depend on the earnings from the natural capital of estuaries and lagoons are well aware of the value of these resources. However, the majority of the non-dependent stakeholders who are unaware may very well influence relevant policies. The key question is:

- What is the verifiable rupees and cents value of fisheries in estuaries and lagoons?

The answer is known for some estuaries. However, the comprehensive economic value of the estuaries and lagoons, which takes into consideration the income from fishing as well as the ecosystem services including waste disposal, anchorage for marine fishing, risk mitigation, etc, has not been estimated in Sri Lanka. The rupees and cents value that can be most readily calculated is the aggregate earnings of fishermen, based on cross-checked interviews. *Table 1.1* presents the value of fishery production from three barrier built estuaries for which reliable information is available, and compared also with marine fisheries. The value of the Negombo Lagoon fishery in 1996 is based on a rigorous study done by FAO (FAO, 2000). Similar studies are sorely required for all the major barrier-built estuaries in Sri Lanka in order to assess their socio-economic significance for livelihoods and food security. Comparing their earnings with that of the marine fisheries in Sri Lanka will provide a measure of their importance.

Significance for Livelihood
In order to understand the relationship between earnings from fishing and livelihood it is necessary to define the term 'livelihood':

'A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain its capabilities and assets both now and in the future, while not undermining the natural resources base' (Carney, 1988).

The fishing family (household) livelihood strategy tends towards combining various ways of earning a living. The most dynamic livelihood strategies rely on a large range of approaches and available assets to reduce the risk of natural or market vagaries. A proven fisheries livelihood strategy is to engage in different fisheries with different gear, according to the season. Another is to generate adequate resources during the active season and simply do nothing during the "dead" period (particularly when the climate is very harsh). Still another – a popular and solid strategy in the rural areas - is to engage in fisheries during the "peak abundance" main season and at other times engage in productive activities, such as transplanting rice, raising animals or repairing farm tools (http://www.fao.org/fishery/topic/14753/en). Within such a livelihood strategy, income from fishing activity is the mainstay. Removal of this income causes severe hardship and vulnerability, and may even result in destitution.

The data in *Table 1.1* provide for interesting comparisons of the estuary fisheries in Batticaloa Lagoon, Negombo Lagoon and Puttalam Lagoon, and four classes of marine fisheries: multiday boat fishery, FRP (fiberglass reinforced plastic)

boat fishery, the beach seine fishery and the traditional marine fishery. These comparisons serve only to recognize the relative importance of estuary fisheries and not to in any way decry the promotion and development of the other fishery sub-sectors.

Distribution of fishery wealth

The estimated annual value of earnings from fishing in Batticaloa, Negombo and Puttalam Lagoons, ignoring for our purpose the differences in the years of assessment and exchange rate fluctuations, is in the rough amount of more than Rs. 2.06 billion/year distributed among about 31,000 households. This is a substantial magnitude of wealth acquired from the natural capital of just three barrier-built estuaries. The total amount from all barrier-built estuaries and lagoons would be substantially more. Since these are common property resources competition occurs among fishermen who have free access. Forms of property rights and limitations on access exist only where traditional forms of resource management operate as in the case of the stake-net fishery in Negombo Lagoon.

The consequence of competition for common property resources is that the fishermen cannot become wealthy as pointed out very early by Gordon (1954). Owing to the numbers of traditional fishers, no individual can 'concentrate' the wealth into one's own possession owing to the high risk of violent reaction. This is one reason, theoretically, that has entrained general neglect of the ecological health of barrier-built estuaries and lagoons. This distribution of wealth from natural capital, however, is important in a country such as Sri Lanka where alternative employment and sources of income are scarce, The remedy for increasing poverty of segments of the population dependent on diminishing wealth from natural capital, such as in the case of small-scale coastal fishers, requires strong and equitable policies.

Table 1.1 *The annual value of fishery production in the Batticaloa Lagoon, Negombo Lagoon and Puttalam Lagoon and of marine fisheries in 2002 (FAO, 2006). Although named 'lagoons' and sometimes even 'lakes' in the genral literature, Batticaloa, Negombo and Puttalam Lagoons are technically barrier-built estuaries which are used for livelihood activities by low income coastal communities. These livelihood activities date back many centuries.*

Location of Economic Activity	Surface Area (ha)	Total Production 2002 (Metric tonnes)	Dependent households population (number of fishers)	Estimated annual value Rs (US $)	Production: tonnes in 1948 and in 2006 (50 years after motorization)	Remarks (all conversions for the 1990s at Rs/USD at 52/1; for Batticaloa Lagoon the current conversion rate of Rs/US $ at 110/1)
Batticaloa Lagoon	15,000	---	> 15,000 (2011)	1,350,000,000 (12,272,727)	---	Based on interviews, January 2011, average earning of Rs. 300/= per day; 300 fishing days/year. Rs/USD = 110/1
Negombo Lagoon	3,000	---	> 3,000 (1996)	250,000,000 (4,812,230)	---	Source: FAO, 2000. Average monthly earning by a fisherman in 1996 was estimated as Rs. 6,950/=. No fuel cost.
Puttalam Lagoon	40,000	---	12,647 (1993)	455,292,000 (8,755,615)	---	NARESA/NARA/SIDA/Stockholm University, 1997. Based on earnings of Rs. 120/day in 1993. Marginal fuel cost.
Total	**--**		***>30,647***	***2,055,292,000***		***This is an underestimate as values of 2011, 1996 and 1993 have been combined.***
Multi-day boats - offshore	--		9,684	904,800,000 (17,400,000)	(none in 1948) 87,000 (2006)	Not corrected for imported fuel and material cost. FAO, 2006.
FRP boats – nearshore coastal	--		16,668	3,121,000,000 (60,000,000)	(none in 1948) 90,330 (2006)	Not corrected for imported fuel and material cost. FAO, 2006.
Beach-seine fishery – nearshore coastal		19,920 (2002)	39,840	520,000,000 (10,000,000)	32,000 (1948) 19,920 (2006)	No fuel cost. FAO, 2006.
Traditional marine fishery - coastal		35,132 (2002)	38,088	1,040,000,000 (20,000,000)	8,000 (1948) 35,132 (2006)	Marginal fuel cost. FAO, 2006.
Total			***104,280***	***5,585,800,000***		***This is the 1996 value; it is an under-estimate of the present value.***
Imported canned fish		18,198 (NARA 2008)	Not applicable	15,000,000,000 (137,000,000)		The canned fish include mostly fish varieties captured by FRP boats. Daily News, 14.06.2010.

- The total annual value of the fishery in the three barrier-built estuaries (Rs. 2,055,292,000) is more than twice that of the multi-day boat fishery (Rs. 904,800,000).
- The income from the three barrier-built estuaries supports more than 30,000 households. The multiday boat fishery supports less than 10,000 (boat owners and crew members).
- The fishery in the barrier-built estuaries receives marginal investment and other forms of social support from the state, but none in the form of ecosystem management aimed at sustainability. The multi-day boat fishery on the other hand is heavily subsidized (investments, fuel, lubricants, and infrastructure services).
- The nearshore coastal marine fisheries generate five times more value and support ten times more livelihoods than the multiday-boat fishery.
- These comparisons demonstrate the indispensability of estuarine and nearshore coastal marine fisheries for livelihoods and food security in Sri Lanka. The animal protein requirement in the daily diet of fisher households is met from their catch; the surplus goes to the retail supply chain.
- Production in nearshore coastal waters has increased significantly since the FRP boats were motorized. Motorization significantly increased the fishing range over the continental shelf. The production is almost entirely from small pelagics (sardines and herrings), species that are comparable to imported canned fish.

1.3 Imparting Meaningfulness and Trustworthiness to the Colloquium Report

The readership for this report will no doubt go beyond the colloquium participants, and include researchers, development planners, policy makers, stakeholders and concerned citizens. Therefore, the findings of the colloquium must be presented in a manner which combines simplicity with trustworthiness, i.e. scientific reliability (NAP, 2009). The report provides an authentic representation of the findings of the colloquium (Section 2) supported by both verifiable pictures from the field (Section 3) and by simplified but reliable science (Sections 4 and 5). Will that ensure trustworthiness for the conclusions and recommendations? Maybe, maybe not!

Hopefully, the information communicated in this report:

- generates a positive attitude among the bureaucrats concerned and other stakeholders including researchers,

- promotes public opinion through the popular media so as to have a political impact, and
- is verifiable using testable and measurable criteria.

Re-shaping public opinion is a long-term activity which is expensive as well as time-consuming. Nevertheless, public opinion based on the discussion of verifiable facts is a pillar of democratic society and is necessary for defining public policy.

For the purpose of achieving the required level of trust for information derived from the analysis of complex natural systems, more attributes are required, namely other reference analytical framework/s. The functions of analytical frameworks according to Kuhn (1970) are to:

- Enable simplification of information and knowledge about complex systems such as estuaries and lagoons, based upon already tested scientific (comparative) interpretations.
- Provide an opportunity for alternative ways of examining the same subject, and testing the factual attributes of information.
- Enable rejection or refinement of the existing reference framework if it is demonstrably inapplicable, and alternatively to create a new framework which has greater explanatory strength, Viz. a new paradigm.

Before presenting a brief justification for the analytical frameworks selected, it is necessary to explain why estuaries and lagoons are called complex systems. The key question is:

- What distinguishes complex systems from simple and complicated systems?

1.4 Why Are Estuaries and Lagoons Complex Systems?

All systems, man-made or natural, consist of interacting parts. Consider a **simple system**, a dish of food prepared according to a recipe. When all the ingredients have been cooked together, according to instructions, the result is a dish whose taste and flavour is different from any of the individual ingredients because of their interactions. With the recipe in hand the same dish can be repeated endlessly.

A car is a **complicated system**. Making a car requires much greater planning and engineering precision. Nevertheless, once a car has been made, by following basic design criteria and operational rules, it is possible to make more

cars with the same predictable properties. The interactions among the different parts characterize the performance of a particular car model. If the carburettor does not pump petrol, the car cannot run. Each part interacts with other parts but the parts themselves do not change, except for wear and tear. When a worn out part is replaced the original interactions are restored. Here, design of the system is the key.

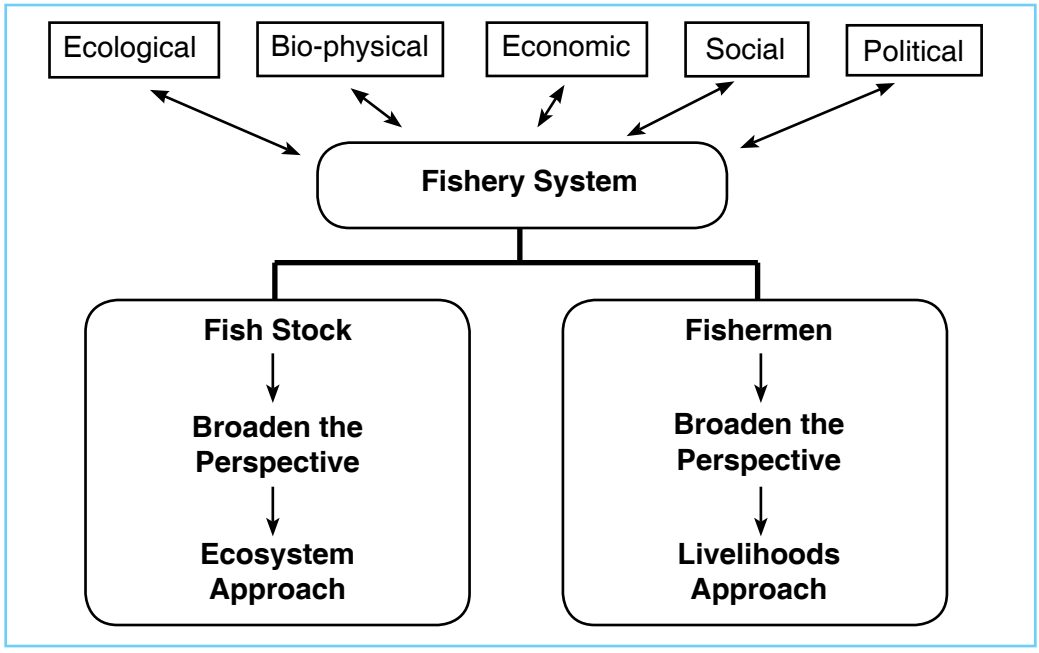
Imagine taking the best individually designed part from the best cars in the world, e.g. the transmission from a Rolls Royce, the carburettor from a Porsche, the suspension of a BMW, the engine from a Mercedes, etc, and assembling them to make the supreme car. Does it work? Certainly not. In complicated systems, the parts have to be assembled in particular relationships according to sophisticated designs (Ackoff, 1974).

Complex systems possess attributes of both simple and complicated systems, and something more. Living organisms and natural ecosystems are complex systems. In complex systems, the parts as well as the relationships among the parts are constantly changing. The human body is a complex system; the parts (organs) as well as the relationships among the interacting parts, change. Think of growth, aging and death. With growth, learning takes place, behaviour changes, adaptations to new conditions occur. Estuaries and lagoons are also complex ecosystems where relationships not only change but new relationships also emerge. The big difference between a human being and an estuary is that the human being learns and adapts to retain its basic properties. An estuary cannot do this. When the relationships among the parts change and keep changing in an estuary or lagoon, it cannot make readjustments by itself. So, when the change reaches a particular level it switches into a different state, like a fishery that collapses because of heavy pollution. Therefore it is a 'state maintaining system' without control of changes caused by external factors (Ackoff, 1971). People associated with an estuary can change the state of this complex system. However, the same people can also set goals for the 'state maintaining system'. This means, when the bio-physical component and the social component operate together, as a 'fishery system', coping with change through integrated management becomes a possibility *(Figure 1.3)*.

What an estuary or lagoon cannot do, i.e. make readjustments by itself, may be performed by society by way of management. As the relationships among the physical parts of an estuary or a lagoon changes, a society that values particular properties of these ecosystems, becomes the thinking and learning component. If, for example, society values the fish produced in an estuary, and if it notes that pollution is undermining fish production, society has the option of stopping the discharge of polluting materials to keep the fishery alive. It may also decide otherwise. Thus human society has the option of interacting with a natural ecosystem and becoming partners in learning and adapting (Holling,

1978). A natural ecosystem, in interaction with society, is a 'social-ecological system'which is capable of adaptive learning (see Section 1.5A). 'Systems thinking', which is required to find solutions to problems in complex social-ecological settings, is further clarified in Section 5.

Figure 1.3 *In the integrated approach to management of an estuary as a social-ecological system, the fish stock in the 'bio-physical estuary ecosystem' and the livelihood interests of the fishers together constitute a fishery system* (Charles, 2001). *Together this social-ecological system will consist of ecological, bio-physical, economic, social, cultural and political components that change together or independently. Where they change, together or independently, in a manner that is desirable, integrated management exists.*



1.5 Analytical Frameworks

The analyses of colloquium findings, presented in Section 5, employs three inter-connected frameworks:

- Social-ecological system – this analytical framework considers the physical, biological and social aspects that have shaped changes through interacting relationships in estuary and lagoon ecosystems. It enables the diagnosis of the causes of problems (Ostrom, 2007; Holling, 1978).

- Social-political systems – this framework considers the different impacts, on groups of people, of the intended and unintended consequences of planned development in complex systems, such as estuaries and lagoons, and the legitimacy of the development interventions (Merton, 1936, 1996). Legitimacy in development flows from ensuring that development decisions do not make some groups winners by gaining favoured access to resources while depriving other eligible groups from access to a share of the same resources. Where some eligible groups are deprived of access they become losers. This undermines legitimacy.
- Ecosystem sustainability systems – this framework flows primarily from the findings of the Millenium Ecosystem Assessment. It considers the manner in which society assigns economic value to the many functions (ecosystem services) such as fishery, waste disposal, biodiversity, transportation, etc provided by complex systems such as estuaries and lagoons (WRI, 2006).

A. Social-Ecological System (SES): Diagnostic Framework

Estuaries and lagoons are ecosystems as well as social-ecological systems (see IUCN, 2009). They are ecosystems because they are "units that include all the organisms (plants and animals) making up a 'community' in a given area interacting with the physical environment so that a flow of energy leads to a clearly defined set of feeding relationships, plant and animal diversity, and material cycles (i.e. exchange of materials between living and non-living parts) within the system" (Odum, 1971). They are social-ecological systems because the ecosystem component is inextricably tied to human activity including development interventions *(Figure 1.3)*. The most significant contribution from the application of the SES diagnostic framework is that it enables identification of new properties that arise from change in the system in unpredictable ways which may be positive or negative (emergent properties). These emergent properties may eventually define the possible outcomes of management of complex systems *(Figure 1.4)*.

B. Social-Political Systems : Development and the Law of Unintended Consequences

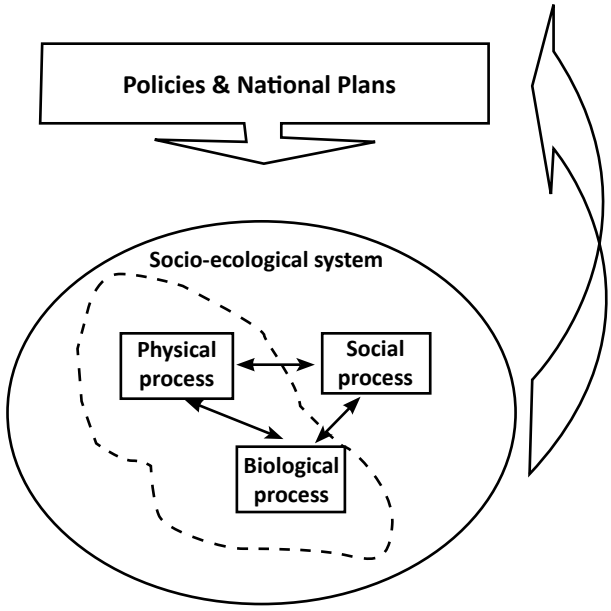
The social-ecological framework enables analysis of the process of change in estuaries and lagoons under the combined influence of physical, biological, and human social factors. However, this framework does not provide for the examination of the power structure that creates change. It is assumed that a government creates change that is planned and meets legitimacy criterion:

- Optimal utilization of opportunities that estuaries and lagoons offer to increase benefits equitably.

The colloquium also addressed the matter of planned development interventions in estuaries and lagoons that are intended to increase benefits to society. The key question that arises here is:

- Who benefitted and who lost as a result of the development of estuaries and lagoons?

Figure 1.4 *An abstract depiction of a social-ecological system (SES) composed of interacting physical, biological and social processes as component parts. The entire SES operates on the basis of relationshiops among the component parts. These relationships themselves are changing (see note accompanying the depiction of the SES).*



An SES is a complex adaptive system (CAS) that is constantly changing in the face of new circumstances in order to sustain itself. This process of change is only partially open to explicit human direction, e.g. as influenced by policies and national plans. Importantly, change cannot be predetermined. From this perspective, capacity development (skills, organization, learning, adaptation) are emergent properties characterized over time by coherence, collapse and re-emergence. Emergence is an unplanned and uncontrollable process in which properties such as capacity emerge from the complex interactions among the actors (the social process component of the SES) in the system and produce characteristics not found in any of the elements of the system. The power and influence of emergence grows as complexity and uncertainty increase, and feedback occurs <www.ecdpm.org/pmb22>

This question immediately raises the political issue of whether or not 'groups of people' are involved. In this context too, a social-political analytical framework is warranted. The sociological framework requires clarification because it relates most directly to the development interventions that have impacted the estuaries and lagoons. The framework flows from the idiomatic 'law of unintended

consequences' based upon the contribution of the sociologist Robert Merton, (1936; 1996). It is a warning that an intervention in a complex system, such as an estuary or lagoon, always creates unanticipated and often undesirable outcomes. This enables understanding why things happened as they did, from a combined sociological and ecological perspective. Merton, (1936) popularized the concept, speaking of the "unanticipated consequences" of "purposive social action," emphasizing that his term "purposive action… [is exclusively] concerned with "conduct" as distinct from "behavior." That is, with action which involves motives and consequently a choice between various alternatives" (Merton, 1936, 1996). Merton listed five causes of unanticipated consequences which are used in the analysis of human-caused impacts on estuaries and lagoons in Sri Lanka, in Section 5.

C. Sustainability: Ecosystems Services Valuation Framework

The sustainability framework flows from the Milennium Ecosystem Assessment – MEA (WRI, 2006). This analysis enables identifying what should be done to improve the existing situation by revising how economic value is assigned to attributes of estuaries and lagoons. These analyses are applied to the findings of the colloquium in Section 5: The Synthesis.

1.6 Structure of the Report

This report is composed of six sections:

Section 1: *Introduction*. This section explains the problem at hand, the continuing decline of estuaries and lagoons, and why a colloquium was convened. Estuaries and lagoons are presented as complex ecosystems where issues of sustainable management require good governance, i.e. participation of all stakeholders. Information exchanged during the colloquium was diverse and complex and the need for appropriate analytical frameworks to simplify and facilitate the drawing of credible trustworthy conclusions is discussed.

Section 2: *Colloquium findings.* Contains summaries of technical presentations and discussions.

Section 3: *Photo documentation.* Field observations and photographic documentation on two economically significant barrier-built estuaries discussed at the colloquium.

Section 4: *Hydrology, Hydraulics and Hydro-morphology.* Contains technical explanations of the water-based processes that determine the state of estuaries and lagoons.

Section 5: *Synthesis.* An ecosystem perspective of the material presented in the previous sections that sets a scientific foundation for drawing conclusions and recommendations.

Section 6: *Conclusions and Recommendations.*

How to read this report: This appraisal report combines opinions, perceptions and science. Its content is diverse and the messages are complex. It addresses several layers of readership; policy makers and development planners are a key component of the audience. Section 1, the *Introduction*, clarifies the concepts and terms used and seeks to prepare a framework for improved understanding. Some readers, less familiar with the scientific concepts, may prefer to start with Section 2 which summarizes the discussions at the colloquium, and then glance through Section 3 which presents related field observations and photographs. Sections 2 and 3 will provide the reader with a good idea of the output of the colloquium. They may either return to Section 1 or proceed to Sections 6 which presents the *Conclusions and Recommendations* without recourse to scientific terms while retaining a science foundation and deals with how the findings of the colloquium may be translated into action. Section 4: *Hydrology, Hydraulics and Hydro-morphology* provides the technical foundation underlying the behaviour of water in estuaries and lagoons. Section 5: *Synthesis* seeks to provide a comprehensive ecosystem-based outlook. It may be most interesting to readers with adequate science background and to planners since it sets the minimum standards for integration of land use planning with water management, particularly in barrier-built estuaries and lagoons.

1.7 What are Estuaries and Lagoons and Where are They Found?

Estuaries and lagoons are conspicuous features of Sri Lanka's coastline together with sand dunes, beaches, and bays. They are situated in the country's 103 river watersheds *(Figure 1.5);* more common along the east coast. Some estuaries and lagoons are large, greater than 1,000 ha in surface area (see *Annex 1* for a map and complete list). Jaffna Lagoon, the largest, is in the north and Puttalam Lagoon, the second largest, is situated in the northwest. Apart from the distribution and size of the estuaries and lagoons, their occurrence in the context of the ***island*** structure of Sri Lanka and its geology is very important (Cooray, 1982; Erb, 1970; Swan, 1983; IUCN, 2009).

Estuaries and lagoons are recent geo-morphological events. The estuaries originated when the sea level rose some 10,000 years ago (during the Holocene Era) and flooded the river valleys. Lagoons evolved during the later stages in the development of estuaries which became partially filled with sediment, mainly deposited by the rivers (Swan, 1983; Day, 1989). The present state of estuaries

and lagoons in Sri Lanka is the result of physical changes over the past 10,000 years or so, which are,explained in greater detail in Section 5. *An estuary is a semi-enclosed body of water connected freely with the open sea and within which measurable dilution of sea water occurs by mixing with freshwater from land drainage* (Lauff, 1967*).*

Fisheries in the estuaries and lagoons have supported livelihood and food security throughout history, do so today and have the potential for continuing to do so in the future (CCD, 2006; Pieris, 1949, 1956; Alexander, 1995). Most estuaries and lagoons in their lower reaches are nested in river floodplains with alluvial deposits that support rice cultivation (De Silva, 1936). Thus estuaries and lagoons are ecosystems, situated within watersheds that support multiple land uses. They are also coupled with the sea. Consequently, they interact both with freshwater drainage and tidal sea water to provide livelihood and food security *(Figure 1.2)*. Nevertheless, their socio-economic value, biodiversity, ecological structure and functioning, and ecosystem services are taken for granted, as increasing groups of people, migrate to the coast, and compete to benefit from their services and to use their economic resources. Estuaries and lagoons being complex, dynamic ecosystems, they change naturally and with the manner in which they are used. The challenge is to understand and manage that change, in the long term, in a way that supports wellbeing of all stakeholders of coastal resources without being discriminatory towards fishers who depend on them for their livelihood (see Section 5).

Each estuary and lagoon is unique based on its geology, geo-morphology (the ongoing processes that influence its form), the quantity of water from land drainage flowing through it, and the volume of sea water flowing into it with the tides. Relevant aspects of geology and geomorphology are explained in greater detail in Section 5. On account of their various properties, estuaries and lagoons have high fishery productivity associated with high biodiversity. Therefore, they are a source of livelihood and food security (see IUCN, 2009; CCD, 2006). Connectivity to land drainage and tidal flow from the sea is an essential feature of estuaries and lagoons and they are sensitive to the disruption of these connections. Most of the smaller estuaries and lagoons have already changed irreversibly because of disruption of their hydrological connections with land and the sea (Erb, 1970; Swan, 1983; Cooray, 1982). The vulnerability to change is relatively less in the larger estuaries and lagoons; progressive sedimentation, however, is evident.

Figure 1.5 *Estuaries and lagoons nested in 103 river basins characterize Sri Lanka's coastal and regional diversity* (IUCN, 2009; Sri Lanka Survey Department, 2007).

The pale blue water bodies at the junction of rivers and the sea, some of which are labelled as lagoon eg. Jaffna Lagoon, Puttalam Lagoon, Negombo Lagoon, Batticaloa Lagoon and Kokkilai Lagoon, are examples of the more significant estuarine ecosystems. Note that the larger estuarine ecosystems occur between Kelani Ganga and Moderagam Aru on the west coast; and occur more frequently from around Gal Oya to the junction where the island land mass meets the Jaffna Peninsula. Thus regional diversity is evident. Along the southern coast the estuarine ecosystems (mainly true lagoons) are relatively small. Between Moderagam Aru and Poonereyn near the mouth of Jaffna Lagoon, the rivers flow directly into the sea. Jaffna Lagoon itself receives river discharges from the mainland. Note that rivers do not flow into Jaffna Lagoon from Peninsula Jaffna. This is because there are no rivers in Jaffna. Note the elongated form of the more conspicuous 'lagoons' on the west and east coasts. These are in fact 'barrier-built estuaries'. The form of the estuaries, barrier-built estuaries and lagoons are influenced by complex interactions among geology, land-based geomorphologic processes and coastal processes that shape their surface form. See text for explanation.

1.8 Risk and Vulnerability

Estuaries and lagoons are gateways, nested in watersheds and coupled to the sea. Seasonally, floodwater flows through them into the sea by way of tidal inlets. Early stages of fishery organisms migrate from the sea through these tidal inlets to replenish fish stocks. They constitute the frontline in the island's interaction with the sea, and climate-generated hazards arising there. These interactions create both opportunities and dangers. The Indian Ocean 2004 Tsunami demonstrated the sensitivity of some estuaries, lagoons and associated human populations to extreme hazards. The surges penetrated through the tidal inlets and devastated life and property nearest to the water's edge (Samarakoon, Epitawatte and Galappatti, 2008). Estuaries and lagoons are complex ecosystems that interact with land drainage, the sea, tidal flows and human uses, among others. If these interactions are not in balance, risk arises (see Section 5 for a more technical explanation). Risk is the probability of harm to life and property of people associated with these ecosystems. The ultimate goal of the colloquium was to initiate a more effective institutional process to address risk and vulnerability associated with estuaries and lagoons.

The quantity and quality of water in estuaries and lagoons have visibly diminished (CCD, 2006). Simultaneously, people who depend on estuarine and lagoon fishing for income and livelihood, assert that catches have declined. People who depend on fishery and live closest to the periphery of estuaries and lagoons (and the sea) were predominant among those who lost lives, livelihood and property during seasonal floods and extreme hazards such as the 2004 Tsunami. The IPCC (2006) predicts that the vulnerability of coastal ecosystems and associated populations will increase in parallel with more frequent hazards, including a predicted sea level rise. The coastal fishing communities, in fact, are already experiencing the many consequences of unmanaged risk.

The proper management of estuaries and lagoons must address vulnerability and risk with a view to decreasing adverse consequences. Defining risk and vulnerability could contribute towards a better understanding of their management.

- *Risk*: is the probability of harm to life and property of a community (Gallopin, 2006).
- *Vulnerability*: is defined as the exposure, sensitivity, and resilience of a community as well as a natural system, such as an estuary or a lagoon, to change (Gallopin, 2006).

It is important to note that 'risk' is an attribute of society since it relates to human life and property. Risk is greater where population density and property value

are higher. For example, risk is high in the area near the mouth of Negombo Lagoon as many people have built houses and live there. However, in the south of the same ecosystem, near Dandugam Oya, risk is low since few people live there. In this sense an ecosystem or an estuary, by itself, is never at risk. They may be more or less vulnerable, exposed, sensitive or resilient to change but not at risk.

Vulnerability differs from risk in that both ecosystems and society may be vulnerable depending on their exposure, sensitivity and resilience. The Indian Ocean Tsunami caused changes such as breaching of mouths closed by sand barriers, deposition of sea sand, uprooting of fringing mangroves in some estuaries and lagoons, but not in others situated along the same coastal stretch (Samarakoon, Epitawatte and Galappatti, 2008). Change occurred in those that were more exposed. Some ecosystems that were affected (changed) reverted back to their condition before the impact of the tsunami - they were more resilient (bounced back). Risk, vulnerability and resilience associated with the estuaries and lagoons differ from place to place depending upon both surrounding physical geography and size of human populations. Hence it is always location-specific.

1.9 The Need for the February 2011 Colloquium

The MFF National Steering Committee under the Ministry of Environment, in collaboration with IUCN Sri Lanka and the Coast Conservation Department (CCD), recognized the need to build consensus on, and partnerships for, meaningful and practical approaches to the sustainable management of the country's estuaries and lagoons. This standpoint was supported by a recommendation made in a colloquium held in 2009 and its report *"An Appraisal of Mangrove Management in Micro-tidal Estuaries and Lagoons in Sri Lanka"* (www.iucnsl.org). Suchlike interventions on mangroves and estuaries, are recommended in the MFF: National Strategy and Action Plan (NSAP), Programme of Work 1: 1.1 (IUCN, 2009: www.iucnsl.org). The major focus of this endeavour is to build knowledge on how the quest for livelihoods and food security impact on the structure and functioning of estuaries and lagoons, and also biodiversity. The floods that impacted the surrounds of Batticaloa Lagoon recently, and Negombo Lagoon in 2010/2011 added urgency to this endeavour. The frequency of flooding, which is expected to increase, is directly and indirectly attributable to climate change. Inevitably, the risk to people and property will increase proportionately.

The CCD, the regulatory body primarily responsible for safeguarding coastal natural resources, recognized the occurrence of many visible changes that will degrade coastal habitats, including estuaries and lagoons. The relevant problems and issues were addressed in successive Coastal Zone Management Plans (CCD, 1990; 1997; 2006). Recognizing the visible changes, identifying

the problems, raising public awareness and formulating policies and strategies for their management are all necessary steps in the right direction. However, the problem of degradation of estuaries and lagoons persists unabated even three decades after CCD's establishment. Following the Indian Ocean Tsunami 2004, and under the Regional Mangroves for the Future (MFF) Programme, *The National Strategy and Action Plan: An ecosystem based integrated coastal management for Sri Lanka* (IUCN, 2009) has drawn attention to some of the invisible and insidious aspects of the degradation of estuaries and lagoons, both as planned and inadequately integrated development activities. The February 2011 Colloquium is a further initiative to focus attention on the continuously aggravating problem of degradation of estuaries and lagoons and its adverse consequences for coastal livelihoods.

What is actually happening now could be termed 'the reality of change in estuaries and lagoons as complex ecosystems'. This reality has readily visible attributes observed from outside the water, such as expansion of settlements, roads, jetties etc. The difficulty of managing water bodies such as highly dynamic estuaries and lagoons is mainly associated with the limitations of 'terrestrial' humans. People do not see what is happening beneath the surface of water. As an example, sediment movement and patterns of deposition are neither seen nor experienced. Hence, human beings become conscious of invisible change only when its effects are large enough to be seen. At that stage some changes are difficult or even impossible to reverse. Skilful management anticipates adverse change and addresses the root causes. Anticipation requires information and knowledge. This is comparable to early detection and diagnosis of human ailments facilitating their treatment.

Visible and invisible changes in complex natural systems are the outcome of their interactions with people. People have used accessible estuaries and lagoons for food supply, livelihood, navigation, safe settlements, waste disposal, among others (Sivasubraminam, 2009). History may reveal the causes of gradual change over many years that have led to their present status. However, the solutions to existing problems do not lie in the historical causes since the context now is different. How the changes are understood depend on the different ways in which they are psychologically grasped by people. As an example, a fisherman understands change differently from a university academic. The former understands change in terms of impacts on income and wellbeing. The latter may understand the same change in a context of a wider set of relationships and as an opportunity for a scientific publication of significance. Each understands the same reality in relation to particular interests. Both forms of understanding are important in resources management. Therefore these different forms of understanding require harmonization by way of discourse.

Options for management are about choices a society has for resolving conflicts among/with the users that cause harmful change. Such conflicts may arise among individual users of the resources, for example, fishers competing for the same stock. This, however will not necessarily destroy an ecosystem unless destructive technologies are involved, e.g. trawling that destroys seagrass beds (IUCN, 2009). There are many examples of competition among fishermen, eventually ending happily in cooperation and mechanisms for sharing benefits as illustrated by the 'stake net fishery' in Negombo Lagoon (IUCN, 2009; Ostrom, 2007).

The more significant changes in land use that cause harm, stem from the exercise of state power (government and all associated interests, including private sector institutions) in development planning and implementation, without adequate sensitivity to the livelihood needs of civil society, particularly the poor *(Box 1.1)*. Where the exercise of power ensures that human interaction with estuaries and lagoons are based on democracy, equity and justice, the adverse impacts on ecosystems and livelihood are minimal. Fundamentally, this means, proper law enforcement will ensure that estuaries and lagoons retain an adequate quantity of water of acceptable quality for multiple uses, with functional connectivity to land and the sea. In its absence estuaries and lagoons die and with it, the livelihood of fishers.

The massive floods in Batticaloa District in 2010/2011 could not be controlled until some mistakes made in the name of development, were corrected. One significant mistake was the obstruction to drainage provided by Batticaloa Lagoon – an ecosystem service - by a responsible government agency (see Section 3). This revelation added impetus to the urgent call for a colloquium. The same flood abatement measure was implemented during the great flood of 1957/1958 (C.L.Arulpragasam, Sunday Island 16 January 2011). Were any lessons learned? Evidently, even if lessons were learnt, they were quickly forgotten. The cost of relief, reconstruction work, and rehabilitation of livelihoods in Batticaloa District, on account of the flood damage in 2011, was estimated as Rs. 160 million (OCHA, 2011). The relevant questions are: 'could this cost have been reduced if there was awareness of the flood abatement measures implemented about 50 years ago', and 'are we willing to implement management measures now that are adequate for dealing with future uncertainty'? At this point it is important to reflect on numbers. The Rs. 160 million spent of flood relief was a mere tenth ($1/10^{th}$) of the annual value of earnings from the Batticaloa Lagoon fishery (see *Table 1.1*).

Box 1.1 The growing global food crisis and its implications for Sri Lanka

Sri Lanka is inextricably intertwined with globalized food markets. Giant multi-national corporations, with balance sheets many times larger than the economies of relatively small developing countries such as Sri Lanka, use the global food system to manipulate people and magnify their profits (Korten, 2006). In a recent Oxfam International report *'Growing a Better Future: Food justice in a resource-constrained world'* (Oxfam, 2011 http://www.oxfam.org/sites/www.oxfam.org/files/growing-a-better-future-010611-en.pdf), the crisis is presented thus:
"Our global food system works only for the few – for most of us it is broken. It leaves the billions of us who consume food lacking sufficient power and knowledge about what we buy and eat, almost a billion of us hungry, and the majority of small food producers disempowered and unable to fulfil their productive potential. The failure of the system flows from failures of government – failures to regulate, to correct, to protect, to resist, to invest – which mean that companies, interest groups, and elites are able to plunder our resources and to redirect flows of finance, knowledge, and food to suit themselves. Every day, it leaves 925 million people hungry.

And now we have entered an age of growing crisis, of shock piled upon shock: vertiginous food price spikes and oil price hikes, devastating weather events, financial meltdowns, and global contagion. Behind each of these, slow-burn crises continue to smoulder: creeping and insidious climate change, growing inequality, chronic hunger and vulnerability, the erosion of our natural resources. The broken food system is at once a driver of this fragility and highly vulnerable to it. Without urgent action to tackle the interlinked challenges of production, equity, and resilience, the future will be one of zero-sum competition between states, resource grabs by powerful elites, and ecological collapse."

1.10 Existing Management Interventions for Estuaries and Lagoons by the Coast Conservation Department

The Coast Conservation Department (CCD) institutionalized the management of estuaries and lagoons as 'critical habitats' within the framework of the Coastal Zone Management Plans (CZMPs), as mandated by the Coast Conservation Act of 1981. The first CZMP for Sri Lanka devoted a chapter to critical habitats (CCD, 1990), as have the subsequent revisions. Nevertheless, CCD (2006) notes that *"Sri Lanka's coastal habitats have undergone degradation to different degrees during the past resulting in the decline of their resources as well as extents, at an unprecedented rate".* This has occurred despite the wide range of supportive legislation and mandates of government agencies. At the same time there were also diverse supportive management interventions, for example, by the DFARD; National Aquatic Resources Research and Development Agency

(NARA) - (NARA/NARESA/SIDA/Stockholm Uni., 1997); Central Environmental Authority (CEA) - (CEA/Euroconsult, 1994; CEA/Arcadis-Euroconsult, 2003) among others including multilateral finance institutions and bilateral donors.

CCD is the primary regulatory body. Given the magnitude of the task, the CCD needs to be strengthened to be more effective. The Ministry of Environment and Natural Resources and IUCN, with guidance from CCD, prepared *'A National Strategy and Action Plan: An Ecosystem-Based Integrated Coastal Management in Sri Lanka - NSAP"* (IUCN, 2009) under the Regional Mangroves for the Future Programme (MFF). Among the foremost programmes in the NSAP is promoting the knowledge base for integrated coastal management, especially in regard to coastal ecosystems, and financial support for projects related to coastal ecosystems. The colloquia conducted by IUCN on mangroves, and estuaries and lagoons are contributions to improvement of the knowledge base.

1.10.1 Special Area Management (SAM)

The Coastal Zone Management Plan (CZMP) (CCD, 2006) lists the estuaries and lagoons *(Table 1.2)* that have been identified as sites for 'special area management' (SAM) - a more targeted management approach (White and Samarakoon, 1994). CCD's achievements in the sustainable management of estuaries and lagoons should be applauded. Nevertheless, the CZMP 2004 (CCD, 2006) recounts the continuing loss and degradation of coastal habitats ever since it was first noted in the early 1980s. This colloquium provides an opportunity to reflect on current approaches to managing change in estuaries and lagoons to understand the 'big picture' of factors (forces) that drive change in an undesirable direction.

When the CZMPs were prepared in the 1980s, the basic thinking on critical habitats management planning, including estuaries and lagoons, was simplistic as reflected in Samarakoon and Pinto (1983). It is outmoded in the context of emerging approaches and fundamental changes in the current thinking about complex systems. It is no longer acceptable to regard estuaries and lagoons as 'critical habitats'. They now need to be addressed as complex socio-ecological systems, whose structure and functioning are based on diverse relationships and interactions (ADB, 2009; EU; IUCN, 2009). This would require, to start with, a revision of the applicable names (nomenclature) as well as the classification of coastal ecosystems and habitats with least amibiguity. In this approach for more precise knowledge-based management, system complexity needs recognition along lines that include:

- Listing of information needs in a manner that is suited to a diagnostic approach to management problems as illustrated in Section 5 (Ostrom, 2007); and

- Identification and definition of good governance criteria that are inclusive, participatory and provides legitimacy through discourse among all resource users.

Table 1.2 *List of estuaries and lagoons identified for Special Area Management (SAM) Projects (CCD, 2006). The sites where SAM processes have been completed are in the shaded section; others are potential SAM sites.*

District	SAM Sites	Remarks
SAM sites already operationalized		
Colombo	*Lunawa Lagoon*	*Very small (less than 100 ha), does not support a fishery, main significance associated with urban property value.*
Galle	*Madu Ganga Estuary* *Koggala Estuary*	*Need to examine the transaction costs of management* *No information on fishery value.*
Hambantota	*Mawella Lagoon* *Kalametiya Lagoon*	*No information on fishery value.* - *Rekawa Lagoon not listed although it was the first SAM site? (CCD, 1995)*
Gampaha	*Negombo Lagoon – Muthurajawela Marsh*	*About 3,000 ha. A bar-built estuary worth managing. Annual value of fishery alone estimated as Rs. 50 million in 1990.*
SAM sites intended for operationalization		
District	**Class of SAM Intervention: Level 1 / Level 2 / Remarks**	
	Level 1	**Level 2**	**Remarks**
Ampara	• Periya Kalapu and Koorai Kalapu (lagoons) • Arugam Kalapu (lagoon)	• Komari Kalapu	Fishery value not konwn
Batticaloa	• Batticaloa Estuary • Upper Panichankerni Estuary (Vakarai) • Valaichenai Estuary		Fishery value not konwn
Galle	• Dodanduwa Estuary (Rathgama Lagoon)	• Kosgoda Lagoon • Madampe Lake	Fishery value not konwn

Hambantota	• Rekawa-Ussangoda-Kalametiya Cluster	• Rekawa, Kalametiya and Lunama Lagoons	Rekawa and Kalametiya Lagoons are in accomplished SAM sites. Fishery value not konwn
Jaffna	• Jaffna Estuary (Lagoon) • Thondamannaru Lagoon		
Kalutara		• Kalu Ganga Estuary	
Mullaitivu	• Nanthi Kadal Lagoon • Nayaru Estuary		Fishery value not konwn
Puttalam	• Puttalam Lagoon • Chilaw Estuary • Mundel Lake & Puttalam corridor channel		Fishery value not konwn
Trincomalee	• Periyakarachchi & Sinnakarachchi Estuaries		Fishery value not konwn

Report of the recent colloquium on mangroves (IUCN, 2011) revealed the unintended consequences of haphazard mangrove planting, based on the misconception that they enhance structure and functioning of estuaries and lagoons http://www.iucn.org/about/union/secretariat/offices/asia/asia_where_work/srilanka/publication/. Haphazard planting of mangroves in barrier-built estuaries and lagoons, their parent ecosystems, diminishes the system hydraulics and accelerates sedimentation. This unknowing action harms the fishery and reduces their contribution to human well-being. Hence, the need for information that empowers resource users (problem diagnosis) to engage in informed participation in decision-making (governance).

1.11 Value of Ecosystem Services

The United Nations Environmental Programme (UNEP) noted that the loss of ecosystems and the supportive biodiversity is a challenge to humanity, especially for the world's poor and thus for the attainment of the UN's Millennium Development Goals (UNEP, 2010). In Sri Lanka, arguably, estuaries and lagoons are the coastal ecosystems most threatened by both loss and degradation that undermine livelihoods and food security of the poorest segment. Ecosystems are managed for long-term use, for the benefit of all levels of society, only to the extent they are percieved as valuable (Constanza *et. al.*, 1997; Liu *et. al.*, 2010). Many of Sri Lanka's estuaries and lagoons are ecologically dead, dying or faced with the danger of death due partly to the island's physical geography, and to a

greater extent its culture where estuaries and lagoons have not been seen as valuable. This is paradoxical since Sri Lankans take pride in their culture that greatly respects nature and life.

Historically, estuaries and lagoons were valued largely for agriculture and drainage. Only default value was assigned to livelihood and food security such as fisheries directly dependent on ecosystem structure, function and productivity (IUCN, 2009; Brohier, 1934). Of course, this attitude must change in keeping with the changing times. The present approach in valuing ecosystems is comprehensive and is based on the ecosystem services valuation (ESV) method that has evolved during the past several decades (Constanza *et. al*, 1997; Liu *et. al*, 2010).

The divergence in attitudes toward estuaries and lagoons has roots in history as well as in current opportunities for development. Therefore, the previous comment on how society understands a shared situation/event is not trivial. The same 'reality' is understood differently by members of society depending on how it affects their lives. A person who catches a fish to feed his family understands land filling, in a part of the estuary, as a threat to his food security and livelihood while a shopkeeper who erects a shed on the same land fill understands it as an opportunity to create an asset - private property. A farmer may understand estuaries and lagoons as a nuisance that creates a seasonal backflow of salt water into his paddy field and causes crop damage. An investor in tourism development views an estuary as a blank sheet of water suitable for landing a seaplane. The consequences of their actions bring fishers, investors and farmers into conflict. The contesting parties seek to assert the importance/value of, and their right to, the particular fragment of the ecosystem that matters to them. This process diminishes the overall value of the ecosystem. Therefore, the many faces of reality require reconciliation to enable society to appropriately value estuaries and lagoons based on mutual respect. Section 3 presents a pictorial representation of some problems in the Batticaloa and Negombo Lagoons that stem from the inability to reconcile competing perceptions and expectations.

1.12 Differences in Scientific Opinions

Scientists also do not have a uniform understanding of events that occur in a complex system such as an estuary or lagoon, because their interests are divided, for convenience, by disciplines such as fishery science, hydrology, mangrove ecology, among others, all constituting fragments of reality (Ackoff, 1974; Holling, 1978; Chomsky, 1995 http://www.chomsky.info/articles/1995----02.htm). This amounts to an attempt to understand the whole through understanding a part of a complex system. This, of course, is impossible. For instance a detailed study of the heart, brain, liver or kidney, in isolation, is not enough understand how the entire human body system functions. Therefore,

creating a shared understanding of estuary and lagoon systems is a major challenge. This colloquium was regarded as a constructive initiative for building knowledge based on the experience and recommendations of a previous 'colloquium' which focused on the diverse perceptions of mangroves in the context of the physical geography of Sri Lanka (*Box 1.2*).

Box 1.2 What the Mangrove Colloquium Thaught

The results of the colloquium are reported in *"An Appraisal of Mangrove Management in Micro-tidal Estuaries and Lagoons in Sri Lanka"* (www.iucnsl.org). Conclusions and recommendations arising from the colloquium and the associated review of field observations, revealed the ways in which, an action believed to be beneficial, such as 'mangrove planting in estuaries and lagoons' produces unintended negative consequences. In the context of Sri Lanka's physical geography (i.e. micro-tidal coastal environment) this activity obstructs water flow. Thereby, opportunistic mangrove planting, labelled 'mangrove restoration', accelerates sediment deposition and leads to the demise of some estuaries and lagoons.

Consensus among stakeholders engaged with 'mangroves' and 'systemic structure and functioning of estuaries' is made more difficult by linkage of the former with financial interests. The majority of NGOs and iNGOs that uphold the virtues of mangroves and cloud the distinction between 'planting' and 'restoration' actually acquire funds measured in terms of 'headcounts' of mangrove seedlings put in place regardless of where they are planted and their long-term impacts.

Evidently, individual or group beliefs, however strongly they are promoted internationally by 'scientific generalizations' based on findings in some countries, are not necessarily scientific truths applicable to other countries with different coastal processes. Scientific truth emerges from testing in particular contexts and not through hegemony. The basic lesson learned was: In Sri Lanka, mangroves constitute relatively small parts of estuary and lagoon systems. Therefore knowing these parts, in isolation, does not provide the level of understanding required for sustainable management of estuaries and lagoons. (Source: www.iucnsl.org)

1.13 The Hidden Story and Different Points of View

The colloquium provided a platform to discuss the untold and hidden story of estuaries and lagoons in an island context, and look at the same reality from different points of view. Understanding, based on different points of view, is the key to managing the present, in a way that helps in the future. What does that mean in the context of estuaries and lagoons?

- Many industries and municipalities (e.g. Ekala Industrial Estate, Negombo Municipality) discharge untreated waste into estuaries and lagoons to save money on treating the waste and making it less

poisonous. Managing the present means changing over to treating the waste before releasing to the estuaries and lagoons. The aggregate result is rapid and measurable. Managing the future, is conceptually different since, it actually means postponing waste treatment while plans are made for implementation. In managing the future, i.e. planning without immediate action, every moment of the future becomes the present as pollution aggravates. If the future is placed before the present, what happened in Lunawa Lagoon, Ratmalana may be repeated.

Waste treatment was postponed until Lunawa Lagoon was killed by pollution and became an intolerable stinking mess. The cleanup, even in that small 27 ha lagoon was very expensive. Generally, an industry owner or municipality may argue that waste treatment is too expensive. The fishermen would argue that the pollution by untreated waste is killing the fish and his livelihood now. Inevitably, an economist's point of view will be sought. The economist will first determine whether the present value of the fishery is high or low. If it is high, then the future value will remain high. The likely conclusion - society will benefit if money is spent now to treat the waste and not harm the fish. If the present value of the fishery is low, then the future value will remain low or even decline further. Here, the likely conclusion - spending money on treating the waste will be unwise and it is better for society to let the fish and fisher livelihood perish. What is happening here is the devaluation of the fishery and fisher livelihood. The pivot in the exchange of viewpoints among industry, fishers and economists is the 'discount rate' – by how much does something decrease in value with time? Can fisher livelihoods be equated with the cost of treating waste? A colloquium (free discourse in a group) enables the viewpoint of the fishermen and others, to be expressed clearly, and provide inputs that will assist an economist to arrive at a professional opinion that is better balanced between now and the future.

1.14 System Thinking

The entirety of the appraisal report is based on the 'systems' thinking approach applied to complex ecosystems. "A system is a set of interrelated elements. Thus a system is an entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set". Consider the example of Negombo Lagoon! Two integral elements here are "water and fish". These two interconnected elements alone cannot define the system without a third element: the connection of the water body though "channels" with the sea that enables mixing of freshwater and seawater. Further analysis would demonstrate other connected elements which forms a

web of interactions. In this web, each of a system's elements is connected to every other element, directly or indirectly. Furthermore, no subset of elements is unrelated to any other subset" (Ackoff, 1971). See *Annex 1* for a further explanation illustrated by a simplified estuarine ecosystem.

This appraisal is anchored primarily to the 'island' nature of Sri Lanka and its geologic, geomorphologic, coastal ecosystem, and cultural peculiarities. The island nature of Sri Lanka and its size scale are usually neglected in the planning, development and management of estuaries and lagoons. *Figure 1.3* shows the framework that served as the foundation for the colloquium. Also see *Figure 1.1.*

Systems thinking is holistic (taking the whole together) versus reductionist thinking (breaking up the whole into parts for convenience of study); synthetic (making a whole out of the parts) versus analytic (separation of the whole into parts to simplify the study). Reductionist and analytic thinking derives properties of wholes from the properties of their parts. Holistic and synthetic thinking derive properties of parts from the properties of the whole that contains them. Think of an architect who designs a house. First the house is sketched as a whole and then rooms are put into it. The principal way he thinks in evaluating a room is what effect it has on the whole. It is better to make a room worse, if doing so makes the house better (Ackoff, 2004). Thinking about an estuary and a lagoon must be done the same way. This colloquium seeks to share thoughts in that perspective.

An estuary system, in a highly simplified form, may be conceived as a set of the following interrelated elements: the estuary (brackish water): freshwater mixed with seawater, the plants (e.g. sea grasses and mangroves) and animals (e.g. fish and shrimps) connected with three other basic elements, the watershed, the sea and people and their cultural effects such as roads and buildings. Together these elements constitute a complex, interrelated system. The biophysical form of an estuary cannot exist without freshwater from a watershed mixing with tidal seawater inflow (IUCN, 2009).

1.15 Environmental Management, Political Ecology and Governance

Coastal ecosystems, specifically barrier-built estuaries and lagoons, stubbornly change naturally (e.g. sediment trapping from watersheds) mostly in an undesirable manner given the geology of Sri Lanka and patterns of land use. The human-induced changes are superimposed on the natural change processes. Positive and negative influence on 'change processes' in barrier-built estuaries is associated with approaches to environmental management (EM) and its many dimensions. Worldwide, EM during the past several decades has focused mainly on technocratic problem solving initiatives with the main objective of providing 'practical' assistance to state officials involved in planning and law enforcement

(Bryant and Wilson, 1998) In a later review Wilson (2009) noted the encouraging effort toward making EM more inclusive by incorporating political ecology and good governance. In Sri Lanka coastal environmental management has not been any different although initiatives were also in place to incorporate community participation in the early 1990s (CCD, 2006; CEA/Arcadis/Euroconsult, 2003). Nevertheless, the degradation of barrier-built estuaries and lagoons together with marginalization of dependent communities has been expanding despite protests by affected fisherfolk (see paragraph 1.0).

Estuaries and lagoons are public goods, which means that everyone can use (consume) them without diminishing their availability to others. As such, they do not belong to anybody, which means that anyone is free to harvest its resources, e.g. fish . Therefore, the authority for safeguarding these public resources has been transferred to the state in the form of a social contract – to manage on behalf of the people. This social contract is reflected in the constitution of the country *(Box 1.3).* In order to impart efficiency the state has assigned responsibility to government agencies that are maintained by public funds. Chief among these agencies are the:

- Coast Conservation Department,
- Central Environmental Authority,
- Department of Fisheries and Aquatic Resources,
- National Aquatic Resources, Research and Development Agency,
- Land Reclamation and Development Corporation,
- Department of Wildlife Conservation.

Box 1.3 Constitutional Duty

The Constitution of the Democratic Socialist Republic of Sri Lanka provides in Chapter VI – Directive Principles of State Policy and Fundamental Duties. This is to guide the Parliament, the President and the Cabinet of Ministers in the enactment of laws and governance (decision-making) in Sri Lanka for the establishment of a just and free society. Principle 14 pertains to the environment: (14) The State shall protect, preserve and improve the environment for the benefit of the community. In regard to Fundamental Duties, the Constitution requires of every person: (f) to protect nature and conserve its riches.

Shifts that have been occurring in Sri Lanka toward more inclusive forms of environmental management of barrier-built estuaries and lagoons are partially documented (e.g. CEA/Arcadis/Euroconsult, 2003; CCD, 2005; CCD, 2006). The implications of these shifts toward power sharing and good governance are examined in Section 5.

Section 2

Colloquium: Presentations and Findings

2.1 Presentations

The colloquium sought to encourage active discussion among participants by creating an environment for 'telling and listening'. Accordingly it was organized to include 'telling' by specialists with actual field experience in estuaries and lagoons, and 'listening' by the non-subject specialists and the lay-participants, followed by discussion. The objectives of the telling part was to present for discussion aspects of the structure and functioning of barrier-built estuaries and lagoons as ecosystems that generally are not exposed to non-subject specialists, thereby:

- facilitating a multidisciplinary environment for discourse, and
- subjecting the discourse to questioning by practitioners and community representatives.

A unique feature of participation was the representation of the armed forces by an officer of the Sri Lanka Navy which is frequently receiving media attention for their role in aspects of coastal area development by the government. An open plenary discussion ended the colloquium.

The two problems which were clarified by the discourse, as indicated in Section 1, are stated below as two questions:

- Why is the deterioration of estuaries and lagoons, associated livelihoods and fisheries continuing despite the wide range of regulations, responsible government agencies and plans?
- Why is the change in estuaries and lagoons perceived in many different ways such that appropriate interventions are either confused or deterred?

'Why' questions are more important than 'what' and 'how' questions because they require explanations. 'What' and 'how' questions can be answered by stating observed facts, which may be interesting, but do not explain the underlying causes. 'Why' questions can enlarge the discourse by exploring the cause and effect relationships of observed change. This will inevitably bring out the complex nature of estuaries and lagoons.

The first two technical sessions focused on aspects of geo-morphological evolution, structure and functioning of estuaries and lagoons as ecosystems, their fundamental hydrological attributes, geographic diversity, multiple uses and cultural interaction as evolving landscapes shaped by land uses. The third technical session focused on regulatory aspects, balanced interpretation of economic values and perceptions of local communities. These three sessions provided food for thought for the final session (Annex 2).

The final session, the open plenary discussion, was to draw conclusions and formulate recommendations. The main thoughts in the presentations were summarized before proceeding to the discussion which was stimulated by questions prepared beforehand to enable focusing on key aspects. The questions were discussed in some detail although available time was limited. However, the level of detail in the analyses was constrained by the limitations of fields of study represented. For example, history of resource uses, cultural anthropology, political ecology, aspects of poverty reduction, food security, womens' role, good governance, macro-economic development policy, etc. were not represented. This gap is partially compensated by Section 5 of the report which provides some relevant insights. A summary of the questions and discussion points are recorded along with comments to provide perspective.

Sections 3, 4 and 5 of the report further substantiate the discussion points and the comments.

Technical Session 1. Estuaries and Lagoons – their nature, hydrodynamics and links to coastal fisheries (Chair: Dr L. P. Batuwitage, Additional Secretary MoE)

A brief introduction by Dr Ranjith Mahindapala, Country Representative of IUCN Sri Lanka, traced the evolutionary process leading to this colloquium from the time of the Indian Ocean Tsunami, and explained the specific objectives and expectations of the colloquium.

- **What are micro-tidal barrier-built estuaries and lagoons?**

Dr Jayampathy Samarakoon explained the geomorphological evolution of estuaries to 'barrier-built estuaries and lagoons" as a continuing process.

Barrier-built estuaries are the most significant economically. He noted that a colloquium of this nature was first held in 1984 for the preparation of the first Coastal Zone Management Plan for Sri Lanka, at which time coastal ecosystems were regarded as critical habitats. Today, in the context of a set of vastly different conditions, it is now necessary to understand coastal ecosystems not as 'critical habitats' but as 'social-ecological systems' that are complex and support many uses. These uses at present are both conflicting and contradictory. In conclusion he said that, i) there was a need for aligning these uses with the structural and functional characteristics, ii) physical geography makes barrier-built estuaries and lagoons very vulnerable, iii) society must decide what it wants in the long term, through a process of discussion and contributing toward policy making, and iv) since barrier-built estuaries and lagoons are public goods, only the state can provide meaningful leadership.

- **Hydrology, hydraulics and hydromorphology of lagoons and estuaries.**

Prof. Saman Samarawickrema described the types of estuaries and lagoons in Sri Lanka. Hydrology, hydraulics and hydromorphology factors operating in estuaries and lagoons include i) tidal currents, ii) alongshore and cross-shore movements, and iii) freshwater inflows. Estuaries, where the river meets the sea, can be categorized into three types based on the relative dominance of these physical processes. Sediment movement and wave height constitute a dynamic situation. He showed how seasonal changes affected the beach profiles and thereby the mouths of estuaries and lagoons. The interconnections amongst the tidal flows, coastal sediment transport and fresh water inflows add to the complexity of hydrology, hydraulics and hydromorphology. He described some of the studies undertaken by the University of Moratuwa jointly with Lanka Hydraulic Institute, on several estuary and lagoon sites in Sri Lanka, especially on the feasibility of dredging lagoons, and preventing sandbar formation at tidal inlets where riverine estuaries, barrier-built estuaries and lagoons connect with the sea, Based on these studies, specific recommendations have been made to mitigate and/or resolve problems concerning estuaries and lagoons from a civil engineering standpoint.

- **Seasonal closure of lagoons and estuaries.**

Dr Nalin Wikramanayake presented an overview of estuaries and lagoons in Sri Lanka while identifying the relevant issues related to i) the causes and repercussions of the closure of tidal-inlets (or mouths), ii) the geomorphological background, iii) identification and mapping by GIS, and identification of catchment boundaries, iv) preparation of databases and

a preliminary classification, v) field observations, vi) the physical process involved, and vii) the expected future investigations. In regard to management of tidal inlets and sand bars that form there, he identified human interference as a major concern, especially artificial breaching for flood control and discharge of irrigation water, including permanent passages for discharge of irrigation drainage as could be witnessed at Kalametiya and Koggala. In conclusion he said that the preliminary classification of tidal inlets by a multi-disciplinary research group of which he is a member has to be validated. This could be done in relation to relevant variables including seasonality of inlet closure, the role of long shore and cross shore sediment transport, changes in run-off, wave climate and engineering structures that have affected their status.

- **Coastal Fisheries – linkages with estuaries and lagoons**.

Prof. Sunil Jayakody began with a brief overview of coastal fishery and growing concerns on the degradation of coastal waters globally due to habitat alteration, eutrophication, toxic pollution and excessive fishing. He said investigations worldwide show a high positive correlation between the length of mangrove-lined sections of rivers and estuaries and the mean annual commercial catch of shrimps such as the banana shrimp *(Penaeus merguiensis)*. He described the diversity of estuarine fauna, fishing gear and crafts currently in use in Sri Lanka, and stated that all the niches occupied by shrimp stocks have been identified by fishermen, and are being successfully exploited. In conclusion he said that coastal ecosystems are being adversely impacted by multiple driving forces, and accelerated efforts are needed to manage coastal resources from an ecosystem perspective.

Technical Session 2 – Estuaries and Lagoons - values and perceptions, urban expansion and the landscape approach to management (Chair: Dr Anil Premaratne, Director General, Coast Conservation Department)

- **Planning implications of urban expansion on micro-tidal estuaries: a case study of Negombo Lagoon.**

Prof. P. K. S. Mahanama described cities as dynamic entities that grow and occupy increasing extents of land (i.e. grow spatially). Therefore, urban expansion needs planned management. Characteristics of managed and unmanaged urban expansion includes, land use zoning supported by signage, low density development, leap-frog development, spontaneous regional growth, and encroachment (both haphazard and politically motivated with support from local government authority representatives) on public or common property land. Urban expansion in relation to Negombo Lagoon occupies land which is a public good; hence the concern to prevent

it from being driven only by self interest. Negombo is a first order city, where the population stagnated up to 1980, and then expanded rapidly, with the lagoon, primarily, providing space for people to encroach and build houses. With time, siltation has created 13 islands, some of which are inhabited. The inhabited islands are where about 15,000 people lived by the 1990s. UDA which was not involved until 1996, now has a plan with new controls, setting out boundaries to limit further encroachment. However, plan enforcement is weak. The solution to uncontrolled expansion includes establishment of property rights (both private and at the collective community level), voluntary or forced cooperation through law enforcement, and government interventions to provide land for settlements with regulation of impacts from negative externalities such as sewage.

- **Barrier-built estuaries and lagoons – is their management worthwhile in the long-term?**

Dr Jayampathy Samarakoon placed this question in perspective,with specific examples from the Batticaloa and Negombo Lagoons.

The long-term trend in fishery value is a good measure of the significance and worth of estuaries and lagoons. Estimated earnings from fisheries provide the most reliable economic indicator. Indicative values from fishery earnings are: Negombo Lagoon - Rs. 50 million annually (1991 estimate), supports 3,000 households today; value over 20 years – at least Rs. 1,000 million. Batticaloa Lagoon – Rs. 1,500 million annually (2011 estimate) supports 22,000 households. Puttalam Lagoon - Rs. 133 million annually (1996 estimate) supports 2,000 households. Rekawa Lagoon - Rs 1.8 million (1994 estimate) supports 250 families. Degradation trends can be readily interpreted from regular comparison of estimates of earnings.

The basic problems and issues that undermine fishery earnings and livelihoods include: i) estuary fragmentation, ii) drainage obstruction, iii) waste of funds on inadequately planned development, and iv) haphazard mangrove planting with hidden agendas and unintended consequences. In Negombo Lagoon, because of its high value as a marine anchorage, investment in engineering structures prevents closure of the mouth. However, the same problems of unintegrated land uses that prevail in Batticaloa Lagoon are observed.

Management options are to do nothing or do something meaningful? If nothing is done, ecological death is inevitable because of their geomorphological nature. The cost of providing alternative income will impose an unmanageable burden on state coffers. Meaningful action will require, among others, i) an interdisciplinary research framework to acquire meaningful information,

ii) prioritization of sites for integrated management based on ecosystem principles, and iii) integration of change trends with management decisions through stakeholder participation (good governance).

- **Barrier-built estuaries and lagoons – landscape approach to long-term management.**

Prof. Senevi Epitawatta proposed that a new vision is required for the integrated management of estuaries and lagoons which incorporates ecology, history, culture, geography, land use and economics. This vision could be the 'landscape approach'. 'Landscape' is a polysemic term because it has many but related meanings. It may refer to the appearance of an area, the assemblage of objects used to produce that appearance, and the area itself, but they are all related to each other by a shared unit of land. The landscape approach seeks to describe the interrelations between humans and the environment with primary attention given to the human impact on the environment. This is different from the popular form of geographical explanation known as environmental determinism which seeks to specify the influences of the environment as causing the behaviour of humans. The landscape approach shows that during human history, cultural landscapes (surface features resulting from diverse land uses) were superimposed on natural landscapes. There emerges the question, 'who created the cultural landscape'? The answer is: 'the demands and values of the population are integrated to form landscapes – physical and cultural'. This means that people also have the capacity to alter their landscape in keeping with economic demands and values without destroying it.

Technical Session 3 – Estuaries and lagoons - valuation, use regulation and people's needs (Chair: Dr Nalin Wikramanayake).

- **Lagoon ecosystems: a framework for valuation.**

Dr Prasanthi Gunawardena, Senior Lecturer, Sri Jayawardenapura University, discussed the key economic issues involved in micro-tidal estuaries and lagoons, and explained the meaning and the importance of valuation. She emphasized that environmental goods are not free of charge: both benefits and costs are involved. Therefore, a cost–benefit analysis is required for projects in addition to environmental impact assessments (EIAs). These analyses set levels of incentives for natural resource use, and in greening development. Accounting for development interventions that consider benefits and costs should be done in a way that enhances the environment. Such valuation may be used for justifying restoration/ rehabilitation/conservation activities. She listed the economic potential and value of these systems, and the need for multidisciplinary, interdisciplinary

and trans-disciplinary approaches in valuation. From a policy and decision making perspective, valuation provides the basis for choosing between competing contexts. Likewise, cost/benefit analysis can provide economic values for designing economic instruments for management; damage assessment of natural resources; and even for the establishment of environmental education centres. Green accounts in natural resource damage assessment (negative), as well as benefits from estuary and lagoon fishery (positive) should be taken into account in calculating the country's GDP. Hitherto, this has been ignored.

- **Regulatory and management aspects of estuaries and lagoons**.

Dr Anil Premaratne, Director General, CCD, explained that the management issues involved in basin estuaries (the equivalent term used in the colloquium is 'barrier-built estuary') and riverine estuaries are different. In the case of basin estuaries, the main concerns are encroachment, sedimentation, pollution, salinity variation and habitat degradation, whereas in riverine estuaries, the concerns are sand mining, pollution, salt water intrusion, bank erosion and lowering of ground water levels. He then listed the existing management and legal instruments, and the laws and regulations, governing coastal resources and habitats. The possible solutions to the above concerns include, a) the use of SAM planning processes for management of estuaries, b) strengthening the CCD Act, c) strengthening SAM planning with a more rigorous ecosystem focus, d) strengthening community participation, e) strengthening enforcement procedure, f) identification of alternative livelihoods, and g) collection of more scientific information. Finally, a list of proposed amendments to the CCD Act, as well as a list of proposed actions to minimize the threats to estuaries and lagoons from solid waste disposal, were presented.

- **Community Perspectives of Estuaries and Lagoons in Sri Lanka.**

1. General issues

Mr Herman Kumara, National Convener, National Fishery Solidarity Movement (NAFSO) recalling his personal experience, and that of the fishing community, said that fishery was the only livelihood of communities that depend on estuaries and lagoons for income. Based on direct experience he listed the following problems faced by the fishers:

i) Environmental damage resulting from unregulated expansion of shrimp aquaculture farms have undermined natural fish stocks. This has occurred in parallel with the removal of mangrove areas that serve as fish and shrimp nurseries.

ii) Legal measures governing estuaries and lagoons have been framed without considering how they affect the lives and livelihoods of the poor fisher families.

iii) We believe that environmental issues are the root cause of the hardships to these people, including pollution.

iv) Regulatory measures for estuaries and lagoons without considering the livelihoods of people is not reasonable.

v) How can we learn from past experiences? Are we going to repeat the same mistakes without conveying (communicating) the proper information, and creating an appropriate awareness of the problems?

vi) How can the community's voice be heard, and how can the people be informed properly and helped to resolve these problems?

vii) Finally, the community needs guidance so that they will not suffer in the end.

2. Batticaloa Lagoon after the floods:

Mr D. Johnson, a victim of the 2010/2011 flood, stated that he spent several days in an emergency shelter until the flood level receded. The flood level was about 2 meters at his house situated by the side of the lagoon. The intensity of the floods shocked the people of Batticaloa. Information was not provided to the affected people regarding rescue and relief efforts. People who had absolutely no means of feeding themselves did not receive any emergency relief for 36-48 hours. Children suffered intensely from hunger and thirst. Clearly, the authorities, both political and administrative, were taken by surprise. As a consequence, much confusion prevailed on the steps to be taken to address the emergencies, simply because there was no planned response procedure.

Initially the water level in upstream irrigation tanks was reduced by fully opening the sluice gates to prevent large scale breaching of the embankment. In some situations subsidiary embankments were breached to reduce pressure on the main embankment. Rupture of the main embankment would have caused severe damage to downstream settlements. These initial measures did not abate the flood in the densely populated Batticaloa town and its environs.

The police and military authorities were eventually persuaded to breach the road built recently by the RDA with assistance from the Asian Development Bank (ADB). See Section 3 for relevant photographs. The floods immediately receded as the water from inundated areas rushed through the breach to the sea. This experience re-taught the authorities, including infrastructure planners, the lesson learned from the previous flood of 1957. The main question is, will the authorities learn?

Technical Session 4: Plenary discussion: problems, solutions, conclusions and recommendations (Moderator: Dr Ranjith Mahindapala).

The discussion was guided by some key questions formulated in consultation with the presenters. Of course the participants were encouraged to bring in further questions for open discussion. However, the technical information base on which the discussion proceeded appears to have been inadequate to properly formulate conclusions and recommendations. Therefore the findings from the discussion at the colloquium are placed within a systems framework in Sections 3, 4 and 5 of this report. Section 3 contains photographs and narratives that provide perspective. Thereby, the Conclusions and Recommendations presented in Section 6, incorporating the viewpoints expressed in the discussion, are placed on a sound scientific (empirical, directly experiencable) footing.

Question 1. **What are the main causes for the deterioration of estuaries and lagoons?**

Answer: The responses included:

- Sedimentation is critical in almost all the estuaries and lagoons
- Encroachment
- Unplanned mangrove planting (instead of restoration)
- Reclamation (filling of water areas)
- Changing the hydrology
- Discharging of untreated waste
- Weak law enforcement.
  It was noted that management interventions in regard to Negombo Lagoon had proceeded to a stage where it was declared as a Fishery Management Area (by Gazette notification), and to implement this a Negombo Lagoon Management Authority (NLMA) exists. But there is more to be done; NLMA needs to build case laws, file public interest litigation (a few cases have been filed) and lay a foundation of legal precedents to guide law enforcement.
- Over extraction of resources
- Pollution caused by point discharges and non-point sources

Comment: The discussion focused on immediate causes/events or 'short-term causes'. However, these short-term causes are embedded in root causes, linked to:

- long-term natural processes
- poverty arising from development failure and/or inappropriate policies
- inadequate 'rule of law'
- development activities that ignored negative externalities

See Section 5 for a more comprehensive systems outlook.

Question 2. **What lagoon systems need urgent attention to safeguard livelihoods?**

Answer: The responses were:

- o Beira Lake
- o Nanthikadal Lagoon
- o Puttalam Lagoon
- o Periyakalapu Lagoon
- o Batticaloa Lagoon
- o Kalametiya Lagoon
- o The lagoons on which people depend, and are presently at risk, include:
  - Nanthikadal Lagoon
  - Lagoons in the Jaffna Peninsula

Comment: The estuaries and lagoons listed here emerged as off-the-cuff, impulsive responses to the question. The criteria used to identify the sites were not discussed. Management processes have already been implemented in some sites such as Kalametiya Lagoon. A list of sites identified for special area management (SAM) is given in Section 1, *Table 2.* Time constraints did not allow participants to discuss the multiple criteria required for site prioritization. This is a critical issue that requires serious consideration in order to optimize the limited resources available.

Question 3. **What institutional systems are appropriate to manage estuaries and lagoons?**

Answer: Government agencies and elected bodies (Negombo Municipality, other local government bodies) already exist but with overlapping responsibilities.

- Need rules of behaviour – empower people to take legal action
- Need community participation
- We have the SAM system, which is good
- Negombo Lagoon Management Authority has shortcomings: no real responsibility nor accountability.
- The Stake-net Fishery Management Authority (without Government involvement) works well (the membership secured financial benefits). The village level committees' behaviour was more responsible

Comment: The meaning of 'institution' is provided in Section 5. Broadly, institutions range from traditional community-based organizations, where members adhere to a code of behaviour, to the state institutions such as CCD which operate under the Constitution of Sri Lanka and the associated rules and regulations. During the discussion the representative of the Sri Lanka Navy referred to the recent attempt to construct a seaplane landing site in Negombo Lagoon. He said construction work was initiated without adequate awareness of the implications of unplanned dredging of the lagoon bed on fishery-related livelihoods. When the implications were understood, based on the public protest by the Negombo Lagoon fisherfolk, the initial decision was changed. However, this begged another question - how is it that the Government authorities were unaware of the cabinet approved (1991, 1995) Master Plan for Muthurajawela Marsh and Negombo Lagoon and CCD's SAM process which was also supported by GOSL? See Section 5 for a relevant synthesis.

Question 4. **How can scientific information be conveyed to local communities to make them stronger participants in the decision making process?**

Answer: The discussion confirmed that scientific and technical information does not reach the communities in a way that will empower them with knowledge. The mechanisms suggested for better dissemination of information included.

- First, concentrate on the younger generation by including the information in school curricula; thereafter take it to the people in general
- Participatory awareness campaigns preferably led by religious leaders: Rural appraisal methods, posters, books, simple maps, TV documentaries
- Consensus amongst scientists is a pre-requisite
- Categorize the recipients and convey ideas accordingly
- Professional bodies should participate. This should include the National

Academy of Sciences of Sri Lanka, Sri Lanka Association for the Advancement of Science, Sri Lanka Institute of Biology, Sri Lanka Institute of Engineers, and Organization of Professional Associations. We need appropriate approaches to convey information effectively and in simplified ways to communicate key messages

- Community organizations need effective leadership, capacity building and empowerment.

Comment: This report uses 'scientific information' in the sense of 'data and descriptions that can be tested and verified under applicable conditions and therefore are credible' (NAP 2009). Fisher communities have effectively used scientific information to participate in discussions on development projects, deemed to be in conflict with fishery and livelihood interests, and win concessions e.g. ADB-supported fishery harbour construction in the mouth of Negombo Lagoon, Katunayake Expressway Project, ADB-supported Negombo Drainage and Flood Control Project, private sector hotel construction in the channel segment, etc.

See Section 5 for a synthetic response to Question 4. The colloquium discussion on awareness and application of available information in participatory decision-making (good governance) was relevant, but generally this discussion referred more to the subject of 'science literacy' (see Section 5).

<u>Question 5.</u> What are the best techniques for classifying lagoons and barrier built estuaries, and for preparing management plans?

Answer: The responses were:

- Tidal inlet is the crucial parameter. Use the barrier-built character as a variable.
- Use physical features (catchment area, slope, inlet, coastal conditions; and also use hydrology).
- Needs examination from sociologists regarding the geographical context
- Apply principle component analysis (morphological aspects) for a more technical and unbiased classification.

Comment: This question is related to Question 2. The necessity to incorporate the sociological and geographic contexts from the changing landscape standpoint, livelihood needs and change trends in land use, were briefly referred to in the discussion. Section 5 contains a fuller description.

Question 6. **In what ways could the policy makers be convinced to utilize scientific information and peoples' wisdom, for better policy formulation on lagoons and estuaries?**

Answer: The responses were:

- Policy makers need to be enlightened on how to highlight economic aspects
- Use case studies to show what has gone wrong for example, the collapse of fisheries due to extraneous causes, etc.
- Use professional bodies such as SLAAS, which have powerful channels of communication
- Disseminate findings and recommendations from colloquia such as the present one.
- Public protest is a highly effective approach as demonstrated by the recent protests by the Negombo Lagoon fisherfolk.

Comment: The most fundamental way in which policy makers understand their relationship with 'people' in a democracy is related to the number of votes they can win or lose in the next elections. Pressure from elected policy makers could result in non-elected policy makers also becoming more responsive to needs of communities unless stronger technical arguments prevail. The Negombo Lagoon fisherfolk have shown they can make policy makers listen and change policies by demonstrating the power of their numbers through agitation (see comment on Question 3). Scientific information can be used to provide legitimacy, as necessary and appropriate, to the arguments that are brought forward by the people. Where people can demonstrate legitimacy of their opinion by way of numbers, policy makers may respond with:

- hard power (mobilization of the coercive apparatus of the state: police and military force),
- soft power (discussion and negotiation for persuasion without resorting to the exercise of police and military force), or
- smart power (a wise combination of soft and hard power, where the latter is applied mainly to overcome malicious opposition to legitimate development).

The use of information and knowledge alone would be ineffective in changing decisions of policy makers if hidden financial interests (corruption) are also involved (Chomsky 1995; Nye, 2004).

Question 7. **How can we manage the seasonal inlets to satisfy as many people as possible?**

Answer: The responses were:

- It is impossible to satisfy every individual
- Need an Authority
- Need to study the behaviour of outfalls
- Natural mechanisms do not work anymore; engineering interventions are needed.

Comment: The need for both participation of interested stakeholders and engineering interventions to manage the seasonal outlets was recognized. Section 4 demonstrates the manner in which engineering studies on the dynamics of water may be applied in decision-making. However engineering models alone cannot be the basis for effective decision making as demonstrated by the recent experience in Negombo Lagoon (CCD 2005). Funds allocated for improving hydraulics in the channel segment of Negombo Lagoon in CCD's ADB-CRMP could not be utilized because of political differences based on conflicting interests of the key stakeholders. The discussion addressed the possibility of a dedicated management authority with powers mandated by an Act of Parliament. Its feasibility was in doubt based on the experience of the Master Plan preparation process for Negombo Lagoon and Muthurajawela Marsh in 1990/1991. The cabinet rejected the recommendation for a new authority since the existing acts provide the powers needed for management activities. The danger is that new institutions may only add to the baggage of unimplemented laws.

Question 8. **Policy decisions should be based on economic values (with emphasis on multi criteria – cultural, ecological, social and economic)**

Answer: The responses were:

- Economic valuation should not be the only criterion
- Need to know distributional aspects of decisions, meaning who gets what in relation to decisions in barrier-built estuaries and lagoons
- Dead lagoons – should be considered for other purposes, such as aquaculture, recreational activities etc., for better income generation.
- Need to look at equitable sharing of benefits; benefits to the local people.

Comment: Balanced economic valuation which takes into account, the cost of side effects of development on the long-term productivity of complex systems such as estuaries and lagoons, is rare in Sri Lanka. As discussed previously, policy decisions need to be based on many appropriate criteria. Generally, the distributional aspects of development policies and entrained activities, are not planned with equity, thereby creating winners and losers.

Other suggestions made at the colloquium

- Provide the presentations at this colloquium to a wide readership, including policy makers. The challenge, however, is conveying the meaningfulness of the concerns expressed to policy makers, in a way that would impact prevailing policy.
- Take the outcomes forward – especially of the thematic topics
- Conduct awareness programmes in the environs of selected lagoons
- Focus on the Irrigation Department, which is responsible for major and minor irrigation systems. The roles and responsibilities need to be identified, also in respect of traditional management systems
- Climate change vulnerability/mitigation/adaptation should be taken into account

Summary of key questions.

The following list of questions reflects aspects of uncertaintly that were expressed during the discussion but could not be addressed adequately during the plenary discussion. Some answers are provided in Sections 4 and 5 of the report.

1. Why have practical approaches not been implemented to manage the ongoing natural processes of change (evolution) in estuaries, barrier-built estuaries and lagoons in a manner that contributes to human wellbeing?
2. Why have the hydrology, hydraulics and hydro-morphology of estuaries, barrier-built estuaries and lagoons not been adequately studied and used in a manner that can contribute towards long-term management of water quantity and quality?
3. What steps are necessary to integrate both fisheries and aquaculture within estuaries and lagoons and the aspects of the same fisheries (based on life-cycle relationships) that are linked to coastal inshore fishery ecology? What would happen to, for example, the shrimp fishery if barrier-built estuaries and lagoons are killed by sediment infilling, pollution and other forms of unwise uses.

4. Can urbanization in densely populated locations associated with estuaries and lagoons be harmonized with the multiple uses and values of estuaries and lagoons?
5. Do the livelihood and food security values of estuaries and lagoons warrant investment in their integrated management?
6. Do we need to shift our thinking about estuaries and lagoons to a holistic 'landscape approach' which recognizes the dynamics of human culture on the physical system?
7. How may the multiple uses of estuaries and lagoons be given economic value in a way that reveals their role in human wellbeing at the national, regional and local levels?
8. Is the regulatory role of the Coast Conservation Department adequate for management of estuaries and lagoons as ecosystems for human wellbeing?
9. How can the needs and expectations of local resource user communities become incorporated into decision-making in a manner that safeguards livelihoods and food security.

Section 3

Evidence of Conflicts and Contradictions from Planned and Haphazard Development and Land Uses in Barrier-built Estuaries and Lagoons: Case Studies -Batticaloa and Negombo Lagoons

The purpose of this section is to convey to the readers messages on impacts by way of an authentic and verifiable visual statement of some forms of change that are occurring in two economically significant barrier-built estuaries; Batticaloa Lagoon and Negombo Lagoon. These changes resulted from both planned, government-financed development projects and haphazard development activities of individuals. The human-made changes have combined with natural processes to result in some irreversible trends. Comparable changes driven by natural and human-made causes are occurring in all the other estuaries and lagoons. That generalization, although valid, cannot be substantiated with evidence simply because of the limitation of space. IUCN (2009; 2011) provide additional information in this regard.

Some may argue that such changes, particularly in communication infrastructure, produced benefits, but the irrefutable counterargument is that their long-term (time spans of 10 years and 25 years) impacts have been obviously negative. Death of fisheries is already imminent in some smaller estuaries and lagoons along the southwestern and southern coasts, e.g. Kosgoda Lagoon, where a community-managed fishery existed until the 1960s (Atapattu, 1970). In others such as Rekawa Lagoon and Kalametiya Lagoon, the decline of the fisheries is accelerating despite substantial amounts of project money spent by government agencies, iNGOs and NGOs to stabilize the situation in a sustainable way (Ganewatte *et. al.* 1989; CCD, 2006), and highly positive short-term interpretation of impacts (Lowry, Dainis and Pallewatte, 1999). Of course, none will contradict the position that sustainability rests on long-term consequences and not on short-term effects. The larger barrier-built estuaries such as Negombo lagoon and Batticaloa Lagoon have proved that they can support food security and

livelihood over the long-term. Only brief reflection on numbers (see *Table 1.1*) is required to demonstrate that the earnings from the Negombo Lagoon fishery across a span of only 10 years adds up as Rs. 2.5 billion (Samarakoon and Van Zon, 1991; Sanders *et. al.*, 2000).

It is likely that the first impressions from the photographs may not convey the implications for fishery-based livelihoods. Therefore brief explanations are provided that would assist in making the transition from the initial visual impression to a deeper understanding of long-term consequences stemming from impeded hydrology. Some may question why fishery livelihood is pivotal in the narrative. It is simply because a healthy fish stock that supports dependent livelihood is the most reliable evidence of an optimally functioning barrier-built estuary and lagoon.

This section is illustrated with recent photographs, images downloaded from the internet, pictures from existing literature and pictorial narratives on sequential past events. Illustrations are a highly effective means of conveying messages about these complex ecosystems, especially to an audience with widely differing backgrounds, and including many who may not have visited the sites. Illustrations of mistakes made during development activities offer an opportunity to learn and avoid repetition. Interestingly, the illustrations reveal the manner in which many right things have been done in the wrong way. As an example, consider the Kallar Bridge, Batticaloa *(Figure 3.2)*.

Restoration of essential communication infrastructure by replacing the old causeway damaged by the 2004 Tsunami with an improved bridge is undeniably a right thing to be done for society – building back better after a disaster! Infrastructure development in the form of an improved road is undeniably a right thing to do. But should it not be done in a manner that is environmentally friendly and does not do any harm? The picture shows that the bridge spans are inadequate to allow floating vegetation to move freely under the bridge and be flushed into the sea. The entrapped decaying vegetation worsens the problem of sedimentation and impedes water flow in the entire system. A more appropriate design with adequate spans would have facilitated flow through and flushing, of course supported by maintenance. Increased costs, if any, could have been justified by considering the economic impact on the fishery in Batticaloa Lagoon (see *Table 1.1*). This aspect is discussed in greater detail in Section 5. Doing the right thing wrong, however, has its benefits in hindsight since it facilitates learning from mistakes where people show willingness to learn and to improve behaviour, i.e. adaptive learning.

The bridge, unquestionably an engineering achievement, has become environmentally a chronic disaster (see Introduction sub-section 1.1) because of unintended consequence of planned development. The clogging and

sedimentation by blocked vegetation recurs cyclically every year, with each successive year's sediment load adding to what is already there – resulting in exponential raising of the lagoon bed. A more appropriate bridge design would have been possible if planning was integrated with the hydraulic needs of the estuary system and its fishery based upon a proper environmental impact assessment that included community participation.

3.1 Batticaloa Lagoon

Brief description of the area: Batticaloa Lagoon is a barrier-built estuary with a surface area of 14,000 to 15,000 ha, stretching from Eravur (Batticaloa District) in the north to Kalmunai (Ampara District) in the south, a distance of about 60 km. The lagoon opens to the sea at three points through tidal inlets or 'lagoon mouths'; one at its southern end at Kallar and two in the vicinity of Batticaloa town. The openings near Batticaloa town are narrow (about 200 m wide) with one situated near the light house, and the other, called the Dutch Bar, near Kallady. The water flow through these openings varies with the season. In the dry season the mouth of the lagoon gradually decreases in width and closes up completely due to sand-bar formation. With the onset of the North East Monsoon rains the volume of drainage water from the watershed increases sharply. As the water level rises and the pressure increases the sand bar breaches spontaneously and drains excess water.

In terms of biodiversity, apart from the fishery stock, the lagoon has extensive beds of seagrass, marshes with mangrove along the fringes, inter-tidal mud flats, and attracts a wide variety of water birds.

The lagoon is fed by a number of small rivers. It is surrounded by a densely populated region where coconut, rice and other crops are cultivated. Some land at the periphery has recently been converted to shrimp ponds.

3.1.1 Livelihood and food security

Many people living around the lagoon depend on agriculture and fishing for their livelihood and food security. Fishing is predominantly traditional and an economic activity of last resort *(Figure 3.2).* AsiaNews, 16 February 2011, reported widespread fish deaths in Batticaloa Lagoon from an unknown cause, and that 11,750 fishermen were dependent on the lagoon for food and livelihood. Estimates of the number of traditional fishers, based on interviews with lagoon fishers in 2011, range from 11,000 to 25,000. Their standard of living is marginal, with no savings and burdened with permanent indebtedness. They seek any and every form of assistance from the government and from charitable organizations. Their survival becomes perilous during natural disasters since they become absolutely dependent on charitable handouts. Owing to

discriminatory practices in regard to gender-based entitlements in respect of transfers of cash entitlements, particularly following disasters, the male heads of households predominantly are the recipients. Reportedly such payments are frequently spent on liquor consumption by the men with little or no benefit to other members of their households (Fuenfgeld *et. al.*, 2004).

Figure 3.1 *The Google image of Batticaloa Lagoon shows its spread extending about 60 km from Eravur in the north to Kalmunai in the south. Note that the water body is separated from the sea by a sand barrier cum dune. Predominantly Tamil and Muslim settlements are situated at various points at the periphery. Their foremost economic activity is paddy cultivation. Numerous fisher communities are dispersed among the agricultural settlements. More toward the hinterland Sinhala agricultural settlements exist. A significant fisher community resides in Kokkadicholai.*

The labels accompanying the map show the scatter of some land uses. Note that Dutch Bar road is in the vicinity of Batticaloa Town. Drainage obstruction there aggravates flooding of dense urban settlements. Unnachchi Tank bund was tactically breached in 2010 to reduce pressure and to prevent massive collapse of the bund which may have resulted in aggravated flooding in downstream Batticaloa Town. Extensive paddy fields surround the northern segment of the lagoon at Eravur. The drainage canal to relieve congestion runs through the town. It is severely constricted and obstructs drainage thereby causing backflow and inundation of paddy fields. The about 22,000 fisher households, both Tamil and Muslim are scattered along the peripherywith some caste-based concentrations of Tamil fishing Villages as in Kokkadichlai. The tidal inlets (two) at Kallar are important for drainage. The new bridge constructed after the 2004 Tsunami provides improves road infrastructure, although at some cost to drainage. Mangement needs to address the complex setting.

The average income from fishing, a daily activity, was modestly estimated at Rs. 300/= per household in January 2011. Earnings increase during the shrimp fishing seasons. An off-the-cuff estimate of the total value of earnings from fish captured from the lagoon each day is Rs. 6 million (300 x 20,000 households). Hence, the annual value of the fishery, based on 300 fishing days, is Rs. 1.8 billion (about US$ 16 million). The livelihood value of this income acquires greater significance when aggregated across a generation span of 25 years (the long term). It is this income that has enabled individual fisher families to support their children's needs until they become independent. For two generations since National Independence was achieved in 1948 the lagoon fishery has been the mainstay of their livelihoods.

Some special features are associated with the Batticaloa Lagoon fishing community since they have recently emerged from about three decades of ethnic conflict which ended in 2009. These communities have been subjected to various forms of violence and deprivation (Goodhand, Hulme and Lewer, 2000). Linked to such aspects, the dependence on fishery resources escalated both among the regular fishing communities and the internally displaced persons (IDPs). Lagoon fishing as an economic activity of last resort is easy to enter since the investment in equipment is relatively low (e.g. a cast net alone is adequate). However, once begun it is difficult to leave since subsistence income from it can be readily acquired. Nevertheless, evidence exists of a high level of 'structural violence' occurring in such communities stemming from activities of administrative authorities, fish traders and middlemen. More detailed information on the complex relationship between diverse forms of violence, including cultural/ structural forms (Galtung, 1990) and livelihood in relation to Batticaloa Lagoon is available in Bohle and Fuenfgeld, 2007; Fuenfgeld *et. al.*, 2004.

Paddy cultivation and related agricultural practices are the most significant land use in the surrounds of the lagoon *(Figure 3.3)*. Land drainage necessary for paddy cultivation is provided by the lagoon. Wherever drainage has been obstructed, mainly by ill-conceived development, waterlogging and flooding have occurred resulting in abandonment of cultivation *(Figure 3.3).* The government has invested substantially in diverse irrigation schemes for water supply and management. At the same time rainfed cultivation occurs where irrigation water is not available.

Figure 3.2 *Lagoon fishing is predominantly a traditional activity and serves subsistence as well as income supplementation. (©J. I. Samarakoon)*

Fishing activity in Batticaloa Lagoon is predominantly traditional using cast nets from outrigger canoes or by wading into the water, using gill nets, trammel nets among others. Fish catches are partially used as food, and the excess sold. Shrimp constitutes the most valuable component of catches.

A young couple engaged in lagoon fishing as the only source of income. The head of household earns to feed a family of three (child and a dependent elder). Their house is semi-permanent situated on a small piece of land to which the father of the lady has a title-hold. Her husband sometimes hires an outrigger canoe, and at other times wades into the water to use his fishing gear. He has a gill net (small, fine mesh), a trammel net and a cast net. The average daily income was estimated to be Rs. 300/=. About 80% of the daily income is spent on food. Medical expenses sometimes rise because the head of household is asthmatic. Floods cause severe hardship and loss of income. The family does not have any assets other than the plot on which the house stands.

Figure 3.3 *Paddy farming is the most important economic activity on the alluvial soils surrounding the lagoon. Numerous water control structures, tanks, irrigation canals, sluice gates, are used in the management of agricultural water. Paddy farmers are faced with numerous challenges. (©J. I. Samarakoon)*

Paddy farmers complain about the rising cost of production, inadequacy of extension services, drainage and water logging problems. Generally the farmers are resilient and recover from floods to return to cultivation activity. In recent times the impact of floods have been prolonged by inadequate drainage. The resulting water logging and soil salinization have resulted in significant losses in cultivated area (below). The service provided by agriculture extension workers is inadequate for coping with the emerging problems. Extension workers rarely, if ever, visit the field. The downstream paddy farmers at the periphery of the lagoon suffer most from the obstructed drainage in the lagoon.

Optimal returns from the investments in water management including water control structures (above left) cannot be obtained where impeded drainage results in waterlogging. The large extent of previously cultivated land (above) has been abandoned because of waterlogging and high soil salinity.

The scale on which rice cultivation occurs on land situated at the periphery of the lagoon, and extending further into the interior, warrants the use of combine-harvesters. Several of these large machines were in operation at locations on the east as well as the west of the lagoon in February 2011.

3.1.2 Infrastructure Development: The Impacts on Hydraulics and Sedimentation

The images in this section demonstrate the manner in which the development of infrastructure, mainly roads, has contributed to obstruction of water flow causing changes in sedimentation processes, and fragmentation of the Batticaloa Lagoon ecosystem (hydraulic system) into smaller compartments *(Figure 3.4)*. The form of road construction is both simple-minded and haphazard. The simple-mindedness is demonstrated by roads and bridges taking the form of sophisticated but unintegrated engineering design *(Figure 3.4)* or a lack of engineering design altogether irrespective of hydraulic impacts. The latter has resulted in strips of the lagoon being filled to allow vehicle movement at the cost of water flow. Haphazardness is demonstrated with regard to the choice of areas that were used for stockpiling material – simply the cheapest, i.e. a part of the lagoon by the side of the filled strip. There is little evidence of former stockpiling areas being restored as functional parts of the lagoon. This evidence of the lack of integrated planning based on ecosystem structure and a long-term vision of the interaction of parts of complex systems has resulted in both intended and unintended consequences of development *(Figure 3.4)*.

Figure 3.4 *The new Periyakallar Bridge built with assistance from the Japanese International Development Cooperation Agency (JICA) has provided tremendous benefits through improved transportation, access to markets and trade. The adverse impact includes obstruction of water flow and acceleration of sedimentation. The reverberation effects of impeded drainage include water logging of paddy fields. (©J. I. Samarakoon)*

Could an alternative bridge design reduce the problem of sedimentation? The connection of Batticaloa Lagoon with the sea at Kallar is now permanently open following breaching by the 2004 Tsunami. Any improvement in the fishery is undermined by the accelerated sedimentation. The images on the right show damage caused by the 2004 Indian Ocean Tsunami at the Bar Road (top right) and Kallar causeway - bottom right (source: http://www.pwri.go.jp/eng/ujnr/tc/g/pdf/21/21-3-3kusakabe.pdf). The new bridge is unquestionably an essential intervention. The continuing challenge is integration with ecosystem services. The attitudes of engineers and ecologists are different. The engineers seek stability of the structure. Ecologists are interested more in dynamic stability, i.e. maintaining functional integrity that harmonizes with physical change.

Figure 3.5 *The road constructed by RDA with ADB support as a post-2004 Tsunami response had to be breached to ease the 2010/2011 flood. This road replaced a previous bridge that allowed drainage. (©J. I. Samarakoon)*

The new tarred road built by the RDA with ADB assistance (post-tsunami) at the Dutch Bar Road was deliberately breached by the military to facilitate drainage of flood water (February 2011). The deliberate breaching occurred precisely as it was done in 1957 to ease the flood a half century earlier. Was any lesson learnt? Was attention given to it by RDA and ADB during planning?

The new road was a major infrastructure investment project. The tarred road was protected on both sides by gabions. It was implemented as a part of the post-2004 Tsunami Response by ADB. Reportedly,the road may be rebuilt in the same manner. If the road is rebuilt without adequate provision for tidal flow, it would be at the cost of future flood damage as well as fishery productivity. Do planners learn from mistakes?

Figure 3.6 *The Kallady Bridge in Batticaloa town being improved. Undoubtedly a necessity. How much of the water area will be sacrificed. Little evidence exists of measures to safeguard the hydraulics of Batticaloa Lagoon. What is the role of CCD in impact monitoring?*

The new Kallady Bridge will undoubtedly become a great benefit toward road transportation when completed. Material stockpiling for construction is being done at present with little attention to ecosystem requirements. Did an environmental impact assessment (EIA) precede bridge construction. Were impacts during construction envisaged? What could be the role of the CCD in monitoring impacts on the water system since the 'water area' that is being impacted is situated within the 2 kilometer stretch from the tidal inlet? Will the stockpiling area be permanently lost to the 'hydraulic attributes' of the ecosystem following completion of the bridge? Such questions need to be addressed by law enforcement agencies by way of participatory good governance practices. (©J. I. Samarakoon)

Figure 3.7 *Roads in Pullinativu, near proposed new bridge that divide the Batticaloa Lagoon into compartments is evidence of opportunistic development of essential infrastructure without any 'integrated' planning to address the requirements of multiple uses that support livelihood and food security. Provisions for drainage and maintaining the integrity of the 'hydraulics' of the system are not evident. (©J. I. Samarakoon)*

The roads above have been constructed in a simple-minded manner by filling parts of the lagoon resulting in separation of the 'unitary' hydraulic system into segments. Note the compartmentalization on the two sides of the road in the photo on the left. The segment of the road shown in the photo on the right demonstrates the manner in which the lagoon has been segmented into three compartments (foreground, background and to the right). See the photo below for a view of the unintended consequences of the compartmentalization

The two frames above demonstrate the unintended consequences of road development that has compartmentalized the 'unitary hydraulic system' (see caption for the two frames above). The frame on the left shows how obstructed water flow (impeded hydraulics) has resulted in acceleration of sediment deposition along the periphery. The sedimented fringe provides opportunities for 'recreational infrastructure encroachment' and 'misplaced mangrove planting' labeled as mangrove restoration (mangroves did not exist here previous to artificial 'planting') (IUCN 2011*). The frame on the right shows persistent sedimentation through drains that are designed without sediment traps, compounded by opportunistic dumping of construction waste.*

Figure 3.8 *Opportunistic conversion of the lagoon fishing area into shrimp culture ponds by the SLAF, a powerful government entity, during the period of ethnic conflict preceding 2009 (leftt). This has contributed to the obstruction of water flow and partial expropriation of a public good. Less powerful non-government entities have also converted lagoon area into shrimp ponds, now partially abandoned (right). (©J. I. Samarakoon)*

Figure 3.9 *Necessary infrastructure for fisherfolk, a modern fish market. The land on which it is situated, unfortunately, has been created by filling a part of the lagoon. (©J. I. Samarakoon)*

Fishing activity has increased sharply in the lagoon and in the nearshore coastal sea following the indiscriminate distribution of fishing craft following the 2004 Indian Ocean Tsunami (Stirrat, 2006). Intended to replace boats lost in the tsunami surge, the number of operational craft far exceed the fishing effort that existed prior to the tsunami. A market is necessary for ensuring optimal prices. Was it necessary to fill a part of the water body?

Figure 3.10 *Planned development activities supported by the Forest Department, UN FAO, ADB and USAID, following the 2004 Tsunami, which have produced unintended consequences. Little evidence exists of monitoring, evaluation and correction of mistakes made. (©J. I. Samarakoon)*

The four images above depict the changes that occurred at the same location in the vicinity of the light house between 2006 and 2011. It demonstrates the intended and unintended consequences of planning and implementation of interventions with divergent visions. Note the *neem* tree in the images at bottom right, testifying to the identity of the location. In 2007 (bottom right) the board describes a collaborative project among the FAO, The Green Coast Project and the Department of Forest for planting of mangroves as a bioshield. The planted *Rhizophora* seedlings cannot be seen today. Parallel with this project a USAID supported project was engaged in excavation and building of a revetment for establishment of a recreation park (note the yellow backhoe in the background). In 2009, the board of the FAO/Green Coast/Forest Department was nowhere to be seen. In its place the green structure appeared. The mangroves (bioshield) planted in the lagoon had already perished. The situation today (2011) is shown in the two images at the top right and left. Excursion rides are advertised and boat rides are in operation – lagoon tourism appears to have taken off. The image top left shows the build up of sediment where the boats are parked. A previous productive fishing area has been sacrificed. Who are the winners? Have the lagoon fishers lost? Note that the image at top left shows that sediment shoal formation left of one of the excursion boats. All contributing agencies may be assumed to possess a high technical capacity to avoid such mistakes.

Figure 3.11 *The drainage canal from the Batticaloa Lagoon (northern segment) to the west of Ertavur was designed to convey excess flood water to the sea. The paddy lands continguous with this lagoon segment has expanded parallel with the supply of irrigation water from Maduru Oya development. Impeded drainage reportedly causes severe flood damage to life and property.*

Poorly maintained drainage canal from the northern part of the lagoon through Eravur town into the sea. Failed drainage causes backflow of brackishwater into adjoining paddy fields resulting in crop damage. This becomes particularly serious during floods. In the absence of maintenance by the authorities, owners of property alongside the drainage canal infringe beyond the canal boundary/reservation. Of course 'immediate interest' is served.

Figure 3.12 *The two pairs of photographs below represent changes to sedimentation processes in Batticaloa Lagoon caused by misconceived mangrove planting as 'bioshields' (see IUCN, 2011). The photos on the right represent the situation that existed in 2009 following mangrove planting by various NGOs at considerable cost. The photos on the right, taken in February 2011, represent the situation where all the planted mangroves were washed way by the floods. Nature sometimes corrects human folly. (©J. I. Samarakoon)*

These mangroves are the remanants from a few rows of *Rhizophora sp.* seedlings planted by an NGO as a bioshield in 2006. see IUCN 2011, page 21, for additional reference photos from 2009.

The same site after the flood in 2010/2011. The floods washed away all traces of mangroves planted as bioshields. An analysis of the event is presented in Section 5 in relation to the aphorismic 'Law of Unintended Consequences.

The photo above depicts the situation in 2008/2009 with patches of mangroves seedlings planted as 'bioshields', nursery areas for enhancing fisheries and other ecosystem conservation objectives.

The photo above depicts the same stretch of water in Batticaloa Lagoon after the 2010/2011 floods. All seedlings have been washed away together with the investment.

3.2 Negombo Lagoon

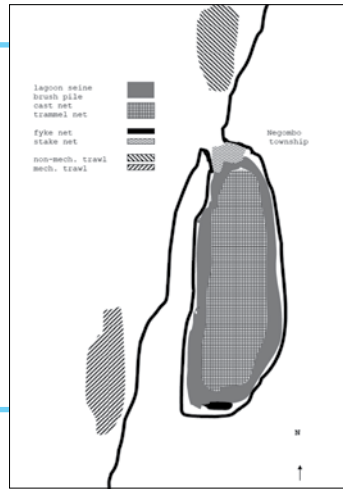
3.2.1 A Brief Area Description

Negombo Lagoon is a barrier-built estuary situated in Gampaha District and has a surface area a little less than 3.000 ha (Samarakoon and Van Zon 1991). It is situated in the Dandugam Oya watershed and receives drainage from an area about 75-fold larger. Its economic significance is high despite the relatively small size. It is about 1/5th the size of Batticaloa Lagoon. An estimated population of about 3,000 households earns livelihood income from fishing in the lagoon. Negombo Lagoon is a nationally significant anchorage for a wide range of sea-going fishing craft, both traditional and modern *(Figure 3.13; 3.14)*. A large number of households depend upon the fishery supply-chain activities generated at this anchorage ranging from unloading, wholesale trading, retail selling, cold storage, processing among others. The services component includes fuel and ice supplies, boat repairs, gear suppliers among others. The numerous land uses directly and indirectly linked to fisheries is only the tip of the iceberg. Settlement expansion, both planned and unplanned is a serious threat to the functioning of the system (see Section 4). Other land uses that compete with fisheries based on ecosystem structure and functioning, include industrial and municipal waste disposal, urbanization, tourism, infrastructure development among others *(Figure 3.15)*. A more detailed description of the system is available in Samarakoon and Van Zon, 1991; CEA/Euroconsult, 1994, CEA/Arcadis/Euroconsult/MENR, 2003 and CCD, 2005.

A cabinet-approved Master Plan and Conservation Management Plan (Greater Colombo Economic Commission/Euroconsult, 1991; CEA/Euroconsult 1994) for the sustainable management of Negombo Lagoon exist. The Coast Conservation Department also prepared a Special Area Management (SAM) Plan for the same system. Despite investment in planning, implementation has not occurred to arrest or even to slow the degradation. At present an additional planning process is proceeding with support from the Spanish Livelihood Project/FAO and under supervision of the Department of Fisheries and Aquatic Resources (DFAR). The unanswered question is who benefits from planning without plan implementation. The glaring omission is the absence of 'interventions to solve existing problems' while planning for improvements in the future. This is fundamental blunder in the management of systems as explained by Ackoff (2004).

Figure 3.13 *Negombo Lagoon (left) showing some places referred to in the text. Fishing in the lagoon is traditional, intensive and exploits all ecological opportunities with gear types adapted to particular locations* (Amarasinmghe *et. al.* 1997; FAO 2000)*. The high value lagoon fishery shall be sustainable only to the extent that the many existing land uses are brought together into a co-existence framework. The hydraulics of the ecosystem are under severe strain because of land uses that impede flow through the channels that connect the tidal inlet to the expanded basin.*

The Google image on the left shows the entire Negombo Lagoon water body with a single connection with the sea at the northern extremity, the tidal inlet. The sand barrier-dune system on the left separates the water body from the sea. The channels that form the tidal inlet are constricted by many land uses and impede both drainage and traditional fishing. The high density of settlements that surround the channels are shown in the Google image below. Dandugam Oya, the main freshwater source, flows into the lagoon by way of an estuarine delta with mangroves. The white meandering line depicts the Colombo-Katunayake Expressway being built by the RDA. Note how it has separated a part of the integrated water body to the east. This water strip (encircled in red) is now rapidly, and illegally being 'grabbed' for private development. This is in violation of the conditions set in the environmental impact assessment (EIA) approved by the Central Environmental Authority (CEA). Without monitoring and law enforcement the 'illegal land grab' is diminishing the traditional fishery. The land to the south of the water body is a 'march' – Muthjurajawela Marsh. A cabinet-approved Master Plan for the Negombo Lagoon – Muthurajawela Marsh system exists.



The abstraction of the Negombo Lagoon depicted above shows its linkage with two shrimp fishing grounds situated in the sea. The two shrimp grouds are shown as shaded areas in the sea. The Negombo Lagoon serves as the nursery and refuge for the penaeid shrimp stock in the sea. The seagrass beds, fringing mangroves, mud beds and reed habitats in the lagoon provide food and shelter from predators during the 'lagoon-stage' of the life cycle. Without the nursery the shrimp fishery may collapse

The Google image on the right represents the channel segment of the Negombo Lagoon where the stake net fishery is carried out in a highly organized manner under co-management principles. This is also the segment of the lagoon which is intensively utilized as a marine anchorage (see photos below). The traditional fishery can coexist with the anchorage function since both support livelihoods and contribute to food security. Better management of the anchorage is highly desirable. The channel segment is surrounded by the densely populated 'electoral wards' of the Negombo Municipality. Expansion of settlements (marked X) into the continuously narrowing channels is a serious threat to the hydraulic requirements of the lagoon system. In the event of further weakening of tidal flushing of wastes discharged into the lagoon by the Negombo Town, the Ekala Industrial Estate and the more recent industrial establishments in the Katunayake Free-trade Zone, the fishery may collapse because of severe pollution. Serious loss of livelihood would then be unavoidable. The already narrow channels though which water exchange occurs is being further narrowed by uncontrolled mangrove planting (in the guise of restoration) to facilitate land grabbing by both the destitute and private sector interests. Law enforcement agencies, apparently, have become inactive bystanders.

Figure 3.14 Negombo Lagoon is an anchorage of national significance for sea-going fishing craft. (©J. I. Samarakoon)

A significant proportion of the national fishing fleet, Viz. modern multi-day fishing craft use the channel segment for anchorage and services. Concurrently traditional sea-going outrigger canoes (encircled) depend on shrimp fishing. Negombo Lagoon serves as the nursery for the coastal shrimp population. Impact on hydraulics and water quality are severe (CEA/Euroconsult 1994; CCD 2005)

Any and all accessible sub-channels are used for landing craft. The increasing population of these fiberglass-reinforced plastic (FRP) boats make a significant contribution to the supply of low-priced protein by supplying herrings and sardines captured in the nearshore coastal waters. A bridge constructed and then abandoned has facilitated sediment build up.

Figure 3.15 Housing expansion into the water body and capture of parts of the 'common property resource system' for private income generating activities is continuous and unregulated. (©J. I. Samarakoon)

Any and all accessible sub-channels are used for landing craft. The increasing population of these fiberglass-reinforced plastic (FRP) boats make a significant contribution to the supply of low-priced protein by supplying herrings and sardines captured in the nearshore coastal waters. A bridge constructed and then abandoned has facilitated sediment build up.

Siriwardena Pedesa: a set of fish rearing cages have been established for grouper culture. Thereby a part of a common property resource system (the Negombo lagoon) has been captured as 'private property'. This form of livelihood activity is being promoted by various organizations that obtain funds from various sources, mainly international, for so-called natural resources management projects. These impacts may be considered under the purview of 'the law of unintended consequences'. The yellow board erected by the Forest Department proclaims that cutting of mangroves is prohibited by law. The house has been constructed where planted mangroves stabilized the soil. What may be the future of the remaining mangrove stand?

Figure 3.16 Housing is a basic human need that must be satisfied to acquire a minimal level of wellbeing for a household. This basic need is being satisfied by ones own earnings or bay way of support from charitable organizations, both local and foreign. Predominantly with funding from foreign religious organizations. Unfortunately these planned good deeds have unintended consequences that adversely impact the Negombo Lagoon. (©J. I. Samarakoon)

A concrete boundary marker post erected under successive projects conservation management projects. This was to have a reference for removal of mangroves that naturally spread into the water body, thereby obstructing hydraulics

The segment of the 'sand blanket', the foundation constructed for the Colombo-Katunayake Expressway (CKE) by the Road Development Authority (RDA). This road obtrudes into the water body and separates the section on the right hydrologically and hydraulically from the functional ecosystem. This separated section is already a 'dying area' from a fishery standpoint. This occurred despite the many efforts to improve road design in consultation with the RDA, mediated by the Cabinet-appointed Muthurajawela Management Committee. See Figure 3.13 for a bird's eye view of the direct and entrained impacts of the CKE on the lagoon as a fishery ecosystem.

Section 4

Physical Processes: Hydrology, Hydraulics and Hydromorphology of Barrier-built Estuaries and Lagoons

Estuaries and lagoons are water-dominated ecosystems formed at the interface between land and sea. Hence, the attributes of water determine the life or death of estuaries and lagoons. These attributes are the outcome of processes that are fundamentally the interactions of physics and chemistry which may be mathematically defined. In that context, the physical evolution of estuaries and lagoons may also be defined as expressions of physics and chemistry. Appropriate measurements allow recognition of their behaviour in keeping with fundamental laws. Both common sense and science require that we accept the consequences of such behaviour. The laws of gravity ensure the behaviour of water borne particles of sediment, influenced by for instance the salinity and density of brackish water in ways that may be described with a high level of precision. This part of the narrative provides the mathematically definable foundation for economic consequences including fishery and livelihoods.

Barrier-built estuaries and lagoons cannot be considered in isolation; the whole system has many interdependent parts. Within an estuary/lagoon the river water is mixed with sea water by the action of wave and tidal motions. The tidal rise and fall governs the magnitude of the oscillatory currents, though high river discharge can have a considerable effect in modifying them. Residual currents may also occur due to vertical and horizontal density differences, between river water and sea water, which depends on the mixing process. Movement of water, under the action of tides and river flow, is closely inter-related with movement of sediment. Tidal currents, sediment movement due to the action of waves & currents, and fresh water inflows are the main factors that govern the seasonal and long-term behaviour of estuaries/lagoons. The dynamic nature and inter-dependency of these governing factors, make estuarine dynamics a very complex process. A thorough knowledge of these parameters is very important to understand the behaviour of estuaries/lagoons.

4.1 Tides

4.1.1 Tides at coastal sites

Tides in the sea result from the gravitational pull of the moon, the sun and the planets, and from local meteorological disturbances. The effect of varying gravitational pull can be predicted quite accurately. Meteorological effects, however, occur randomly and apart from some seasonal trends, cannot be predicted much in advance. Rise and fall of sea-level is essentially independent of conditions within an estuary; occasionally, a very large discharge of fresh water may slightly increase the water level up to a km inland of the mouth of an estuary. A tidal wave, due to its great length, is accompanied by the movement of a large mass of water.

4.1.2 Tides at estuaries

Tidal rise and fall of the water surface, at the entrance of an estuary, causes surface gradients that propagate gravity waves into the estuary. The rate of propagation depends primarily on the depth of water and consequently on the tidal range at the mouth. The tidal wave travels more slowly as the depth decreases and consequently the wave form becomes distorted as it travels inland. A semi-diurnal tide in the sea has a period averaging about 12hr 25min, and the mean time taken to rise roughly equals the mean fall time. Within an estuary, the time taken to rise from low to high water, decreases as the distance from the sea increases; over 6 hours at the seaward end to less than 3 hours near the upstream tidal limit, is quite common. Since the whole process repeats 12hr 25min later, the ebbing tide must occupy the remaining time, which can be over 9.5 hours near the tidal limit. The tides at the coast of Sri Lanka are mixed, predominantly semi diurnal tides with pronounced diurnal inequality. Tides are low with only marginal differences in the tidal constituents along the coast. Tidal range varies from 0.2 m (during the neap period) to 0.8 m (during the spring period). Tidal velocities are of the order of 5 cm/s. Storms may cause a limited set up on the narrow continental shelf, resulting in an additional rise of 0.3 m in extreme cases.

4.2 Waves and sediment movement

4.2.1 Wind and waves

The wind and atmospheric pressure variations are responsible for generating waves, wind set-up and surges as well as wind-generated currents. Furthermore, wind has a direct impact on the morphology of a coastal area through wind transport of sand from the beach to the dunes. The southwest (SW) monsoon is reckoned from May to September and the northeast (NE) monsoon lasts

from December to February. The period between February and May is the first inter-monsoon period and the period between September and December is the second inter-monsoon period. The regional wind system is influenced locally by the daily variation of sea to land and land to sea winds. Some studies show that the sea breezes affect the strength of the SW monsoon winds without affecting the direction. However, during NE monsoon period with rather weak winds, a daily change of sea to land wind (during the day) and land to sea wind can be established. During the SW monsoon period the magnitude of the wind varies from 10-20 m/s and blows from the west and southwest. During the NE monsoon period the magnitude varies from 10-15 m/s whereas during two inter-monsoon periods the magnitude varies from 5-15 m/s.

Short waves are the single most important parameter in coastal morphology. Wave conditions vary considerably from site to site, depending mainly on the wind climate, and on the type of water area. Short waves are divided into:

- Wind waves (sea waves) are generated and influenced by the local wind field. Wind waves are normally relatively steep (high and short) and are often both irregular and directional. Wind waves tend to be destructive for the coastal profile because they generate offshore (as opposed to onshore) movement of sediments which results in a generally flat shore face and a steep foreshore.

- Swell waves are generated by wind fields far away and have travelled long distances over deep water, away from the wind field which generated them. Their direction of propagation is not necessarily the same as the local wind direction. Swell waves are often relatively long, of moderate height, regular and unidirectional. Swell waves tend to build up the coastal profile to a steep shore-face.

The average significant swell wave height during the southwest monsoon is 1.0 m, and at other times around 0.5 m. The average mean wave period is 10.5 seconds. The average significant sea wave height during (a) the southwest monsoon is around 1.1 m, (b) the northeast monsoon and the first inter-monsoon period (Mar-April) is around 0.5 m, and (c) the second inter-monsoon period (Oct-Nov) is around 0.75 m. The average mean sea wave period is 5.5 seconds. These values are based on measurements carried out in Colombo at a water depth of about 20 m.

The longshore current is the dominating current in the nearshore zone. The longshore current is generated by the shore-parallel component of the stresses associated with the breaking process for obliquely incoming waves, the so-called radiation stresses, and by surplus water which is carried across the breaker-

zone towards the coastline. This current has its maximum close to the breaker-line. The longshore current carries sediment along the shoreline, the so-called littoral drift.

4.2.2 Sediment transport process

Sediment transport can be broadly classified into longshore and onshore/ offshore transport. Longshore transport is also called littoral transport or littoral drift. When waves approach the shoreline obliquely, refraction will tend to turn the wave front towards being parallel to the shoreline. At the same time, when approaching the breaker zone, they will undergo shoaling which means that they will get steeper and higher. Finally, the waves will break. During the breaking process, the associated turbulence will cause some of the seabed sediments to be brought into suspension. These suspended sediments, plus some of the sediments at the seabed, will thereafter be carried along the shoreline by the longshore current which has its maximum near the breaker-line.

The magnitude of the littoral transport of drift, Q, depends on several parameters of which the most important are:

- Wave height: The littoral drift is proportional to the wave height to the power of approximately 3.
- Grain size: The littoral drift is inversely proportional to the grain size to the power of approximately 3.
- Wave incidence angle: The littoral drift is approximately proportional to $Sin^{2.5}(2)$, where is the wave incidence angle.

Protected coastlines with smaller wave heights have smaller sediment transport capacity. On the other hand, the exposed coastlines with larger wave heights experience high sediment transport capacity. Waves propagating at an angle of 45 degrees from the normal to the coastline give the maximum sediment transport capacity. Sediment transport capacity gradually reduces with the deviation of the angle from 45 degrees. Varying wave conditions result in varying onshore and offshore transports over the coastal profile. These transports are to some extent reversible and therefore irrelevant in terms of longshore littoral drift.

When the coastal profile is exposed to high waves and storm surge, the sediments near the shoreline will be transported offshore and typically be deposited in a bar resulting in an overall flattening of the slope of the shoreface (storm profile). However, the inner part of the shoreface as well as the foreshore will get steeper in this process, and the shoreline will recede. During subsequent periods of smaller waves, swell and normal water-level conditions, the bar will travel very slowly towards the coastline again, practically rebuilding the original coastal profile (swell profile).

4.3 Fresh water inflows

The rainfall pattern is influenced by the monsoon winds of the Indian Ocean and Bay of Bengal and is marked by four seasons. The first season is from mid-May to October, when winds originating in the southwest, bring moisture from the Indian Ocean. When these winds encounter the slopes of the Central Highlands, they unload heavy rains on the mountain slopes and the southwest sector of the island. Some of the windward slopes receive up to 2,500 mm of rain per month, but the leeward slopes in the east and northeast receive little rain. The second season covers October and November, the intermonsoon months. During this season, periodic squalls occur and sometimes tropical cyclones bring overcast skies and rains to the southwest, northeast, and eastern parts of the island. During the third season, December to March, monsoon winds blowing from the northeast bring moisture from the Bay of Bengal. The north-eastern slopes of the mountains may get up to 1,250 mm of rain during these months. The fourth season, from March until mid-May, another intermonsoon period with light, variable winds and evening thunderstorms.

Rainfall is caused by three fundamentally different processes:

1. Convection rains, in the form of local thunderstorms
2. Monsoon rains, with the southwest monsoon bringing more precipitation
3. Tropical cyclones, which occur rarely, but could be expected mainly in the months of October and November

Figure 1 shows the typical variation of tides over a one month period, in Colombo. The daily variation giving rise to two high tides and two low tides is clearly seen. It also shows the weekly variation from neap tides (smaller range) to spring tides (higher range).

Figure 2 shows the predicted cumulative fresh water discharge into the Negombo Lagoon over a one month period, ranging from 25 m^3/s to over 200 m^3/s.

Figure 3 shows the percent distribution of sea waves, by wave direction (deg), that occur over a year, in Colombo. The main peak with a direction of 250-260^0 represents the southwest monsoon conditions whereas the smaller peak with a direction of 310-320^0 represents the northeast monsoon conditions. The sea waves represented in the figure together with the swell waves govern the sediment transport and beach profile variations.

It is evident from the figures that wave parameters vary on a daily, weekly and/or seasonal basis. The relative magnitude of each of these parameters and

their interactions govern the behaviour of estuarine and/or lagoon mouths. As described earlier, variability and inter-dependency of these governing parameters make the estuarine dynamics a very complex process.

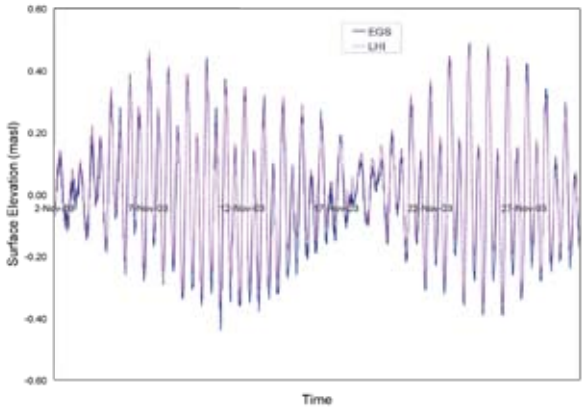


Figure 1

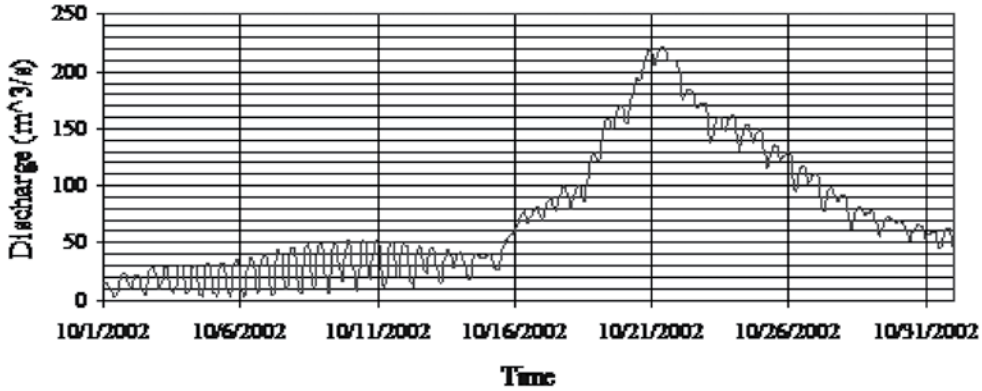


Figure 2

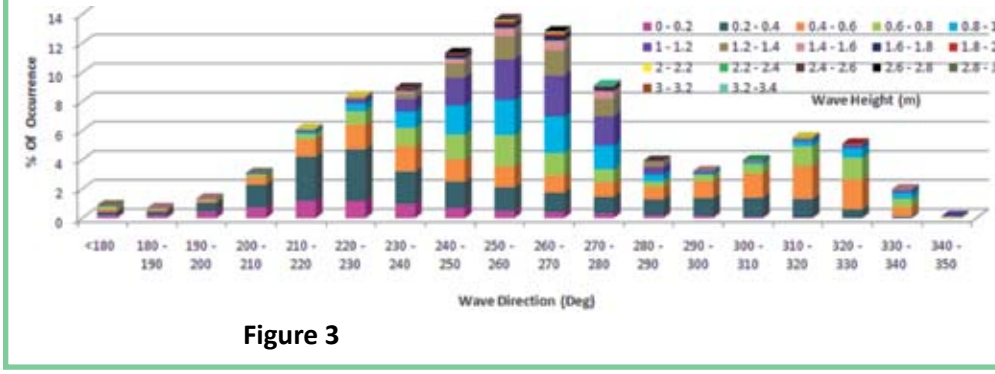


Figure 3

4.4 Approach to investigations

Planning and implementing engineering interventions at the inlets to estuaries and lagoons and assessing their impact on the environment, require a very good understanding of the system to be managed. A review of their natural conditions and human/development activities can identify some problems that affect the estuarine/lagoon environments. Generally, siltation of the estuary/lagoon and its inlets has been a major issue. In this context, the lagoon inlet should, for all practical purposes, be considered as an integral part of the aquatic system, consisting of the lagoon and the ocean on either side.

Developing the investigation strategy requires qualitative and quantitative information to gain a clear understanding of the natural changes in inlet stability. Methodology to predict how the hydraulic behaviour would respond to the proposed engineering interventions is also required. The aim is to assess the likely impact or efficiency of proposed interventions, and objectively evaluate and compare different options. Simulation studies are needed to achieve this objective and two main methods are available to assess the effects of the proposed engineering schemes on the aquatic environment.

i Small-scale hydraulic model testing
ii Mathematical modelling of the estuary system

With the development of computer-based numerical techniques, mathematical modelling has become the preferred option. Application of reliable mathematical models provides accurate information on probable changes. This is a powerful technique capable of integrating, by means of mathematical equations, the many diverse processes involved in the functioning of aquatic systems, thereby simulating such systems and predicting quantitatively the effects of changes in these systems.

The hydraulic behaviour of a tidal inlet is investigated in **three stages**. In the **first stage,** an initial but sufficiently detailed assessment of the physical processes occurring at the inlet can be made by studying existing information, such as

- Historical information and data from different investigations carried out in the study area, including information on previous schemes in the area and their impact on neighbouring regions.
- Results of semi-quantitative conceptual models and preliminary modelling studies that rely on an understanding of the varying processes in the natural systems that affect the hydraulic regime.
- Results from case studies of similar situations from which likely impact of change can be inferred.

In the **second stage** attention is focused on planning and implementing field investigations to strengthen the existing information/data bank. The depth of these investigations will depend entirely on the outcome of the first stage.

The **third stage** involves detailed mathematical modelling. Once the existing physical processes are fully understood and modelled, engineering interventions for improving the environment are formulated. The candidate interventions are then be modelled to determine their comparative efficiency and input on the hydraulic regime. Such studies could also be used to assess the impact of the intervention on the aquatic and neighbouring environment.

The following subsections give two case studies on Negombo Lagoon and Madu Ganga, which successfully used this investigative approach. The objective of the Negombo sudy was to improve the circulation in the lagoon, minimize further siltation, and improve water quality. The main objective of the Madu Ganga study was to identify measures that would preserve/improve water quality to ensure the health of the ecosystem. Prevention of flooding of low-lying lands due to the build up of water levels was also given due consideration.

4.5 Towards improved environmental management of the Negombo Lagoon

The Negombo Lagoon is a shallow coastal body of water located on the west coast of Sri Lanka. It forms an integral part of the Muthurajawela Marsh-Negombo Lagoon coastal wetland, 6,230 ha in extent. The lagoon is approximately 12.5 km in length and its width varies from 0.6 to 3.6 km. The estimated mean depth is approximately 0.65 m and the surface area is 35 km^2, giving it a volume of around 22.5 million m^3. A unique feature of the lagoon is that its transition to the sea consists of several narrow channels. The total cross-sectional area of the inlet channels is estimated to be 250 m^2 with a length of 2.5 km. This transition area also serves as a principal anchorage for a large fleet of fishing vessels of different types.

The exchange of water in the lagoon is influenced by the tides from the ocean side and fresh water supply from the inland side. The tide is semi-diurnal and the tidal range in the lagoon varies from 0.07 m at neaps to 0.2 m at springs and the tidal range in the sea varies from about 0.2 m to 0.8 m. Thus the volume of water stored and released varies between 1.5 million m^3 and 7 million m^3 per tide. Fresh water enters the lagoon from the south through Dandugam Oya, Ja Ela and several streams from the Muthurajawela marsh. The supply of fresh water varies from virtually zero during dry seasons to more than 100 cusecs during rainy seasons. The lagoon and the entire wetland are separated from the sea by a narrow stretch of land, consisting of a very fragile coastal dune

system situated on beach rock, formed during sea level changes over geological periods of time. The conservation of this coastal dune system plays a vital role in the long term stability of the lagoon.

The Negombo Lagoon and its coastal environment has had a long association with tourism and the fishery industry. One of Sri Lanka's leading beach resorts is located north of the Negombo Lagoon inlet. The lagoon inlet serves as a principal coastal fishery anchorage for a fleet of fishing vessels and the lagoon estuarine fishery supports at least 3000 families from around 25 villages dispersed at the perimeter of the lagoon. Haphazard expansion of piers and landing points has contributed to altering the flow patterns leading to sedimentation in the channel segments. As a result, the flow into and out of the lagoon is affected. Large quantities of solid and liquid waste are dumped at various locations in the lagoon, including the flow channels and nursery areas, causing pollution and loss of vital functional components of the ecosystem

It is evident that unplanned development along the waterfront, reduction of tidal flow, siltation and pollution are major problems affecting the Negombo Lagoon. These have contributed to the overall degradation of the aquatic environment at the tidal inlet and within the lagoon. If siltation continues it will, in the long-term, adversely affect the lagoon environment, in particular, its biodiversity. The objective of the study was to improve the circulation in the lagoon so as to minimize further siltation and improve its water quality.

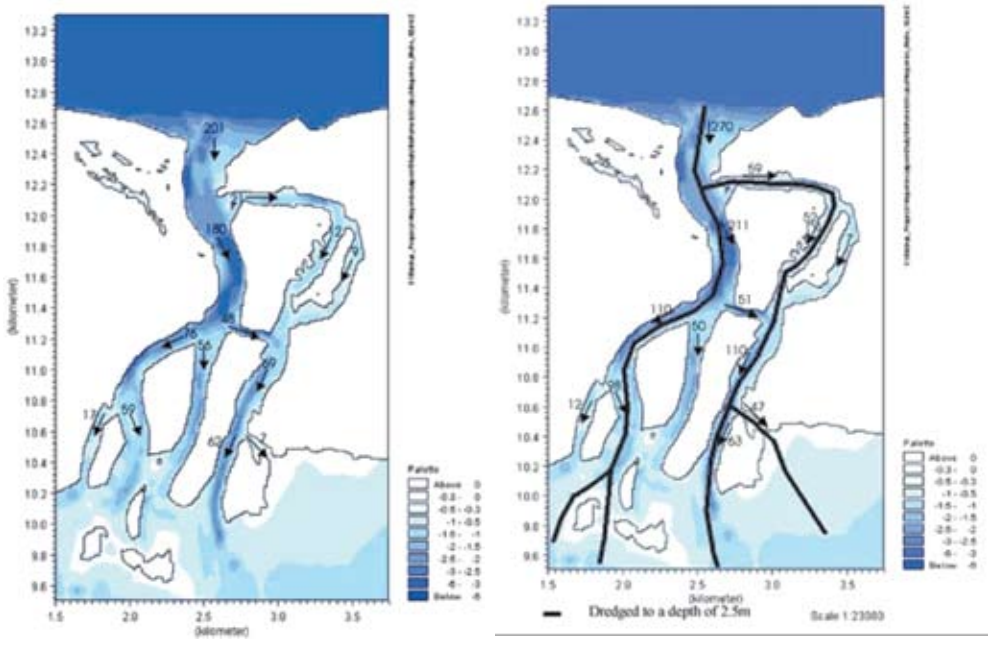
In addition to the review of previous investigations, extensive field investigations and modelling studies were carried out to evaluate the existing hydraulic regime and to evaluate a range of dredging options. A two dimensional hydrodynamic (HD) model of the lagoon and entrance channels formed the basis of the most important modelling activity. An advection-dispersion (AD) model and a sediment transport (ST) model were built on top of the HD model to investigate the transport of salinity and sediment.

A total of seven dredging scenarios were investigated and the percentage increase/decrease in flood discharges was assessed. Thereafter, the socio-economic aspects of the options, relating to the problems and issues of the users, were discussed with lagoon management officers and the users. Option number 6 with minor modifications was selected as the preferred option.

Modelling showed that the proposed dredging will increase the tidal range in the lagoon water body by about 45-60%. Under the existing conditions there is a time lag of 4 hours; the proposed dredging is expected to reduce it to about 2.5 hours and contribute to the increase in tidal range.

The proposed dredging is expected to increase longitudinal velocities on the western side of the lagoon water body by 25-50%, and on the eastern side by 50-75%. The higher percentage increase on the eastern side results from dredging the south eastern channel segment, which supplies water to this area. It was also evident that the circulation in the eastern side of the lagoon will improve up to the present conditions in the western side. An 18% reduction in velocity in the main entrance channel is expected, but the predicted velocity is still high enough to prevent an increase in sedimentation. A 25-50% increase in volume exchange, into and out of the lagoon, is expected with the proposed dredging.

Figure 4(a) shows the maximum flood discharge through the entrance channel segments under the existing conditions, and **Figure 4(b)** shows the expected conditions after the proposed dredging. Channel segments to be dredged are also indicated in the **Figure 4(b).** This study on "Feasibility of Dredging the Negombo Lagoon" was carried out jointly by the University of Moratuwa and Lanka Hydraulics Institute (LHI) for the Coastal Resources Management Project (CRMP). Authors wish to thank the CRMP, the LHI and University of Moratuwa for their assistance.



(a) Existing Condition (b) After proposed dredging

Figure 4: Maximum Flood Discharges in m^3/s

4.6 Feasibility of preventing the formation of a sand bar at the outlet of the Madu Ganga

Madu Ganga is situated on the southwest coast of Sri Lanka, about 35 km northwest of the city of Galle. This is a major wetland with around 900 ha of water area, about 64 islands, most of which are inhabited, and a catchment area of about 5,500 ha. Several streams feed fresh water to Madu Ganga and Randombe Lake.

Madu Ganga and the surrounding lands support numerous economic activities such as inland fisheries, irrigated rice cultivation, cinnamon plantations, tourism, etc. These activities will impact negatively on the ecosystem as they increase in intensity. Unchecked or unmanaged they will eventually destroy the very livelihoods they support in a remarkably scenic area of Sri Lanka. Exchange of water with the ocean, when the connection to the sea is open, has shaped the Madu Ganga ecosystem. Usually the wetland connects with the sea when the sand bar is cut open to save the upstream lands threatened with inundation. This connection closes after a few days if there is insufficient runoff from upstream to keep it open.

The objectives of the study were to identify measures to

a) Preserve/improve water quality in Madu Ganga to ensure a healthy ecosystem and continuance of eco-tourism.

b) Ensure salinity levels, and access between the sea and Madu Ganga, necessary to complete the life cycle of prawns and other important estuarine life.

c) Prevent flooding of low-lying lands due to water levels building up when the sea outfall is closed.

The impacts of opening the outlet to the sea, on the lagoon's ability to flush out pollutants, and on its salinity regime, were quantified using mathematical models. Model results and ecological studies were used to determine the best scenario to prevent further deterioration of the lagoon's water quality, fauna and flora, and to meet the economic needs of people whose livelihoods depend on the lagoon.

The following conclusions were reached based on the modelling results:

a) Carry out a moderate amount of engineering work at the outfall to reduce the height and width of the naturally occurring sand bar

b) For flood prevention, the sand bar should be breached when the water level in the lagoon is between 1.5 and 2.0 m amsl.

c) Provide flood protection to households that will get inundated below the maximum level of 2.0 m amsl.

d) In timing the breaching of the sandbar, consider the migration of important species in and out of the lagoon, and the need to flush out surface drainage from cinnamon plantations

e) Dredge the two channels that link the sea outfall to the two lakes; do not dredge the channel that links the two lakes

The project “Engineering study on the feasibility of preventing the formation of a sand bar at the outlet of the Madu Ganga” was carried out by Central Engineering Consultancy Bureau (CECB), with Lanka Hydraulic Institute (LHI) and Environmental Resources Management (ERM), as associate partners.

Section 5

Synthesis - What Management Approaches Could Improve Resilience of Estuaries and Lagoons?

5.1 Why a Synthesis?

The discussion at the colloquium, the photographs from the field, and their hydrological representation in the preceding four sections reaffirmed the continuing and stubborn decline of barrier-built estuaries and lagoons. This decline, predominantly caused by human activity, is dragging down livelihoods and food security of dependent communities. This is a recent phenomenon since barrier-built estuaries and lagoons have survived by bouncing back to their essential form after numerous natural shocks from floods, droughts and even tsunamis during their evolutionary history. This resilience, the capacity to bounce back after a shock (Gallopin 2005; Adger *et al.*, 2005) has been the attribute that has attracted human populations to associate with them culturally mainly as a source of food security. Even the Indian Ocean Tsunami of 2004 caused negligible damage to the barrier-built estuaries and lagoons that were impacted (Samarakoon, Epitawatte and Galappatti, 2008; MENR/UNEP, 2005). The decline caused by impacts of human influence is different from natural shocks. This is because they are persistent and cumulative in particular directions in the form of chronic disasters, e.g. accumulation of pollutants, sediments.

Reversing the process of decline, i.e. correcting the loss of resilience, by way of ecological restoration likely is impossible because of the huge costs involved in reversing the many associated chronic disasters (e.g. such as overfishing, infilling by sedimentation, increasing pollution, etc) and the nature of the associated geomorphologic processes. A chronic disaster occurs where a process of change, e.g. sediment accumulation, is allowed to proceed to a level where ecosystem structure is threatened and or harmed. Since barrier-built estuaries and lagoons are common property resources (CPRs), civil society generally is indifferent, while responsibilities of state agents overlap in a manner that makes the exercise of their powers ineffective.

Should society sign the death warrants for barrier-built estuaries and lagoons, and forget about them altogether? Or should something be done? The participants at the colloquium asserted that many things should be done in this regard. At the least, stabilization of ecosystem processes that sustain livelihoods and food security may be feasible. The Constitution of the Democratic Republic of Sri Lanka, states in Chapter VI Principles of State Policy 52 (6) that: "*The State shall protect and preserve and improve the environment and safeguard the reefs, shores, forest, lakes, watercourses and wildlife of Sri Lanka".* Therefrom flows the obligation of all patriotic citizens to wisely manage barrier-built estuaries and lagoons. However, investment in safeguarding common property resources rarely occurs unless society in general demonstrates consciousness of that need through expressed public opinion.

The colloquium findings and the supporting evidence reveal that contributions toward damage to barrier-built estuaries and lagoons arise from a broad cross-section of society that includes:

- resource-dependent communities driven by poverty that seek to extract livelihood from available resources, mainly fisheries;
- government agencies responsible for environmental protection through law enforcement which are unable to resist pressures from political authorities;
- private sector institutions that seek to minimize costs of production through disposal of untreated wastes;
- iNGOs, NGOs and CBOs that seek to provide services oriented toward biodiversity conservation, and/or poverty reduction in a fragmented manner and diverse agendas;
- state agencies involved with infrastructure development without due consideration to ecosystem dynamics;
- international financial institutions, UN agencies, donors which neglect ecosystem sustainability;
- research and academic institutions operating with fragmented standpoints.

The literature, reviews, brochures, public notice boards and diverse other sources of displayed information, where available, regarding activities that impact barrier-built estuaries and lagoons reveal 'praiseworthy intentions' (IUCN, 2011). There the question arises '… how and why are such activities deemed harmful to the structure and functioning of barrier-built estuaries and lagoons'? The only meaningful answer is that '… many activities with good intention are undertaken without understanding the complexity of ecosystems in which they

have impacts'. This aspect is addressed in greater detail in the following sections. A second factor is the political structure of society, i.e. the power relationships among the relevant segments of society in Sri Lanka and the equitablility with which decisions that affect CPRs are made and implemented.

Public opinion in the direction of 'safeguarding common property resources' must arise from 'how we think' (cognitive psychology) i.e. the mechanisms through which people receive, store, retrieve and otherwise process information about barrier-built estuary and lagoon ecosystems as 'CPRs'. The alternative is to rely entirely on perceptions and beliefs based on untested assumptions. Thus arises the need for this synthesis drawing on many disciplines to sharpen the 'public' cognitive process. Thereby, a barrier-built estuary may be perceived from many standpoints including geomorphology, hydrology, coastal processes, biology, sociology and others. The conclusions that are drawn from the synthesis, hopefully, may also contribute to policy reforms based on priorities focused on requirements of barrier-built estuaries as social-ecological systems, social-political systems and ecosystems sustainability systems (see Section 1: Introduction; sub section 1.5). Otherwise, the focus will be on interests associated solely with immediate needs and state power, a sure path to ecosystem destruction.

This part of the report is a synthesis because it uses material from the colloquium and a range of other sources for comparison and analysis. The sources include different disciplines (e.g. ecology, fishery science, urban planning, civil engineering, geography, economics, resource management, history), oral discourse at the colloquium, technical explanations of relevant phenomena from the scientific literature, photographs that substantiate 'problems' in the field to create mental images (cognitive maps), experiences of a range of stakeholders, and aspects of civil engineering solutions. Implicitly this means that the synthesis uses:

(i) diverse forms of scientific thinking about barrier-built estuaries and lagoons based on particular forms of disciplinary training (e.g. civil engineer versus ecologist),

(ii) contrasting mental images (or cognitive maps) of barrier-built estuaries and lagoons based upon different user / occupational interests (e.g. fisherman versus academic),

(iii) a coherent framework to understand and to reduce the contradictions that arise from (i) and (ii), and

(iv) to prepare the foundation for conclusions and recommendation that follow in the final part of the report, Section 6.

The relevance of the above aspects flows from the fact that failures in management of barrier-built estuaries and lagoons have arisen not because of a lack of information and knowledge, but in spite of their availability (see *Box 5.1*). This is because acceptable information and knowledge today must be both scientific and holistic. To be scientific, information must be based on testable predictions that allow logical conclusions to be drawn. To be holistic, the information must provide a representation of the 'big picture'. For example, if management of hydraulics in a barrier built estuary is required it is necessary to know the speed of flow at particular locations but also the variables that influence the flow pattern in the entire system (Section 4). However, proper scientific information although trustworthy, is not necessarily neutral in actual use (Mooney, 2005; De Soto, 1989).

The use of neutral scientific information may be influenced by various motives. The politically powerful, i.e. those who can influence the behaviour of others, use information selectively to achieve their own ends with the support of bureaucracies that benefit from career favours (De Soto 1989; UNDP, 2006). Achievement of political ends does not necessarily mean that the public good also is achieved. Contradictions, more specifically the disparity between intended and actual outcome, may arise from (i) incoherence in scientific information, and (ii) the asymmetrical sharing of the information among the politically powerful and the powerless for making decisions which may result in the neglect of important attributes that are required for equity. Information, then, is the foundation of knowledge, but it may be used wisely or unwisely. Where information is used in a manner that undermines natural capital (e.g. barrier-built estuaries and lagoons), unwise use occurs. In other unwise contexts, the attributes of particular barrier-built estuaries and lagoons may be leveraged to support multiple uses well beyond their natural limits (carrying capacity).

The objective of the synthesis, therefore, is to combine the rich information from the colloquium (see Section 2), with actual consequences of planned development on ecosystem processes including wise and unwise use (see Section 3), and to analyze them in a manner that enables identification of the causes of benign and harmful impacts. The balance sheet of successes and failures must take into account evidence from bio-physical systems and socio-economic benefits. Hopefully the framework for coherent information used in this synthesis, mainly the social-ecological systems approach, may contribute toward reduction of future contradictions.

Box 5.1 Successive Misadventures in Planned Management of an Economically Significant Barrier-built Estuary

The most recent effort to provide sustainability to management of Negombo Lagoon, arguably the most economically significant barrier-built estuary in Sri Lanka, started in 1989 with a Presidential order. It proceeded in five stages, of which the current phase, supported by UN FAO, is due to end in 2013 (almost 25 years later). Each stage produced information and knowledge. Much of it is documented. The amount of money spent on the process is not precisely known, but is estimated to exceed Rs. 50 million (US$ 500,000), mostly on generating technical information, the sharing of that information with the fisher communities to build consensus on management interventions, and investment in diverse projects. Is there any evidence of success? Evidence, must be measurable using quantitative and/or qualitative indicators. The most meaningful quantitative indicator would be the (i) the stabilization of the hydraulic forces that enable more efficient flushing of sediment that is now clogging the tidal inlet, (ii) 'number of fishery resource units' (kilograms of fish) taken from the brackishwater body, and (iii) improved water quality. The qualitative indicators may be linked mainly to governance (decision making), social empowerment and increased countervailing power of the poorest resource users. All these indicators directly and indirectly reflect benefits. What is the evidence?

Quantitative indicators: An interview with an official of the Stake-net Fishery Society in 2011 revealed that the fish catches have declined partly because of jellyfish blooms (attributable to pollution). Many previous fishing sites are now inaccessible because of settlements and natural sedimentation. The decline in water quality is observable as permanent 'filamentous algal blooms; that express eutrophication in brackishwater bodies.

Qualitative indicators: Random interviews with fisher households in 2011 suggested declining income from fishing and serious hardship in putting food on the table for family members. Nevertheless the spontaneous protests in 2010, later more organized, against the construction of a seaplane landing strip in Negombo Lagoon suggested an impressive level of countervailing power. Participation in political agitation was provided mainly by the womenfolk who recognized the challenges to livelihood supported by fishing income. Law enforcement visibly has weakened since blatant violations of relevant regulations abound.

The contribution from law-enforcing bureaucracies toward maintaining the integrity of the system remains increasingly debatable Nevertheless, they may argue, without evidence, that their contribution has been significant and successful.

Sources: Samarakoon and Van Zon, 1991; GCEC-Euroconsult, 1991; CEA-Euroconsult, 1994; CEA-Arcadis-Euroconsult-MENR, 2003; CCD, 2005.

5.2 General principles and methodologies (guidelines)

Technical information from different estuaries, barrier-built estuaries and lagoons becomes transformed into knowledge when the differences are evaluated on the basis of comparisons to produce general principles. By comparing the attributes of fish populations from barrier-built estuaries and lagoons where tidal inlets remain open or closed, it becomes possible to evaluate the contribution of migratory shrimps to fishery catches. Thus knowledge based on a combination of technical information and experience become meaningful as general principles for action in managing other barrier-built estuaries and lagoons. In the absence of general principles the behaviour of complex systems remains incomprehensible.

The 'general principles' in turn become meaningful in formulating 'methodologies (guidelines) for addressing diversity' at new locations. Responsiveness of methodologies (or guidelines) to diversity increases at the particular locations of barrier-built estuaries and lagoons when the range of variables assessed is adequate *(*see *Figure 5.1* which shows variables of complex systems*)*. The general principles based on after-the experience events (not blind theory) will then provide coherence to the 'solutions' that may be applied anywhere in Sri Lanka and enable more analytical comparison for continuous learning. The methodology (guidelines) would incorporate steps in a sequential procedure that leads to a solution for a management problem. If applied with appropriate record keeping, a methodology itself becomes a learning opportunity for drawing more insights and generalizations. The analysis of the Negombo Lagoon as a case study of a social-ecological system demonstrates a methodological approach that may be applied to other barrier-built estuaries and lagoons (sub-section 3.1).

5.3 Policy Relevance

In order for the colloquium report to acquire acceptance at a policy level it must also communicate conclusions and recommendations that are anchored in a reality that is testable with measurements. Truths about complex systems can be bewildering. However, the basic reality, without exception, is composed of two classes of policy interests: humanity and money. By 'humanity' is meant people, livelihoods and basic rights (of the public) in interaction with physical geography (Erb, 1970). By 'money' is meant the government effort to improve the efficiency of public finances committed toward development (human wellbeing) and the manner in which decisions are made to allocate those investments. Therefore, the synthesis proceeds through the following steps that include the three analytical frameworks that lead to coherent knowledge (see Section 1: Introduction):

I. *Social-political systems' functioning:* In relation to the structures (e.g. administration, legal, political) that distribute power among stakeholders in the quest for equitable development. This incorporates the outcome of the analysis of 'unintended consequences of planned development' associated with 'complex systems' such as estuaries and lagoons to define the lessons that may be extracted for safeguarding livelihoods and food security.

II. *Social-ecological systems' structure and functioning:* The diagnostic approach to understanding changes in social-ecological systems (SESs). This treats SESs to a multi-layer system of interactions *(Figure 5.1)*. This brings out why fishery-based livelihoods require safeguards as barrier-built estuaries and lagoons fill with sediment as a consequence of inadequately appreciated physical geography. This implies that the synthesis considers both micro-geomorphology (changes caused by land uses at a small-scale local level) embedded in macro-geomorphology (changes occurring at the large scale of an entire system) as well as relationships with larger systems.

III. *Valuation of Ecosystem Services:* This includes building economic arguments that are coherent to enable management of investment in development of barrier-built estuaries and lagoons for co-existence of multiple uses and ecosystem services in balance with fishery productivity and dependent livelihoods in the long-term.

5.4 Complex Natural Systems and the 'Law of Unintended Consequences'

The goal of this particular analysis in relation to the axiomatic 'Law of unintended consequences' is learning and innovation. If learning is desired the best opportunity lies in actual experience. Concerns about 'what is being done wrong' reverberated in all discussions at the colloquium. Understanding the drivers of 'what is done wrong' must logically be the starting point. The identification of the dominant cause or combination of causes provides the first step in assessing potential remedies. In the event that identified remedies are implemented, system collapse or failure may be either avoided or postponed. To that extent existing benefits from the barrier-built estuaries and lagoons system may be safeguarded.

The poignancy of lessons from mistakes is sharpened when real life situations provide a context. All development interventions associated with Negombo Lagoon were planned and implemented by government agencies, by community groups, individuals and by service organizations among others. They were all intended to improve economic growth, enhance wellbeing of diverse segments

of the population and generally to increase benefits to society. However, there has been an undesired impact (cost), albeit unintended, imposed upon the ecological structure of Negombo Lagoon. That unintended adverse impact, initially un-noticed, and assumed to be slight, has accumulated over the years (exponentially - at a compounding rate). Now the cumulative impact has become a threat. This is the typical manifestation of impacts of development activities that are implemented in complex systems. Robert Merton explained this phenomenon in a classic scientific paper originally published in 1936 (Merton, 1936; 1996). Since then his arguments have acquired explanatory strength toward understanding the impacts of planned development on complex systems. The key word to note is 'planned' because planning means implicitly the capacity to address uncertainties in a context of the best available information and to choose optimal activity paths for development (e.g. Friend and Hickling, 1987).

Merton (1936; 1996) explained that unintended consequences of planned activities can be roughly grouped into three types:

(i) a positive, unexpected benefit (usually referred to as a windfall);

(ii) a negative, unexpected detriment occurring in addition to the desired effect of the policy (e.g., while irrigation schemes provide people with water for agriculture, they can increase waterborne diseases that have devastating health effects such as malaria); and

(iii) a perverse effect contrary to what was originally intended (when an intended solution makes a problem worse), such as when a policy has a incentive that causes actions opposite to what was intended.

Examples of (i) *Windfalls* are conspicuous by their absence in the case of barrier-built estuaries and lagoons which are common property resources. Globalization which provided a temporary opportunity for shrimp exports that created a surge in income may be regarded as one such incipient event. However it did not last because of competition for the 'common property resource'; (ii) *Unexpected detriment* are abundant, some of which are addressed below; (iii) *Perverse effects* also are many as illustrated by 'mangrove planting' which instead of increasing fishery production have reduced fishing areas by sedimentation (IUCN, 2011).

Proceeding from the above three types, Merton (1936, 1996) listed five possible causes of unanticipated consequences of planned development. These are explained in relation to impacts of development on barrier-built estuaries and lagoons. This is intended to set a foundation from experience to enable analysis of the variables of social-ecological systems.

1. *Ignorance:* It is impossible to anticipate everything, thereby leading to incomplete analysis of both short-term and long-term impacts. At the time Siriwardena Pedesa in Negombo Lagoon was selected as a site for housing construction under the Million Houses Programme in early 1980s, planners in the Urban Development Authority (UDA) and the National Housing Development Authority (NHDA) gave thought only to the availability of state land 'free of charge' to minimize the cost of programme implementation. They did not have the luxury of time to engage in comprehensive planning, taking into consideration the impacts on the fishery in Negombo Lagoon and the obstruction of hydraulics and entrained increase in sedimentation. The information on annual earnings from the fishery was not available at the time. If such consideration was given, perhaps, high rise housing could have been provided to optimize land use that avoids uncontrollable urban sprawl. A basis for such arguments based upon the structure and functioning of the 'ecosystem' was provided later during the preparation of a Master Plan for Muthurajawela Marsh and Negombo Lagoon (GCEC/Euroconsult, 1991; Samarakoon and Van Zon, 1991; CEA/Euroconsult, 1994).

2. *Error:* Incorrect analysis of the problem or following habits that worked in the past but may not apply to the current situation. The calculation of benefits from providing permanent housing to the poor can be readily justified on both humanitarian and political grounds. Financial justification also can be provided with ease by discounting (at a high rate) the value of inter-tidal areas and water exchange channels for the fishery. This may be achieved by allocating a low 'net present value' to the areas to be filled since their benefits in relation to the entire ecosystem were not given consideration. The correct value of earnings from the fishery may not have been taken into consideration since EIA procedure was not mandatory at the time. The main error, however, was neglecting the value of the ecosystem to livelihoods of about 3,000 households spanning a period of at least 25 years (the time span of a generation). The Negombo Lagoon fisher households built the lives of their children from earnings from fishing. The correct approach to valuation must actually utilize an inter-generational discount rate since the fishery has been supporting livelihoods of parents as well as their children for periods exceeding many decades (Sumaila and Walker, 2005). Depressing the present value of complex ecosystems is one of the commonest planning habits (errors) in relation to barrier-built estuaries and lagoons.

3. *Immediate interest*: The virtues and the power of immediate interest as a part of human nature in the wider arena is not in anyway denied in what is written here. It is important to recognize, however, that immediate interest (self-interest, greed, rational behaviour) has the potential to cause harm to natural systems because the rates of change imposed by such short term activity is relatively more rapid than the rate of natural change. Activities based

upon immediate interest are hasty and thereby include combined aspects of ignorance and error. Immediate interest is a frequent cause of unintended consequences and also a part of basic human nature. Immediate interest is more effectively recognizable when it is stated as 'greed' or 'seeking short-term profit'.

It may override long-term interests also because their consequences are difficult to envisage in complex systems which are dynamic such as barrier-built estuaries. Nevertheless, undetectable impacts may accumulate to become a 'chronic disaster'. Financially lucrative relationships among decision makers and the private sector (e.g. building contractors), think Siriwardena Pedesa, also tend to discourage adequate consideration being given to long-term impacts. Looking again at the Siriwardena Pedesa housing project, decision-makers may have been driven, at the least, by short-term political expediency if not financial deals.

A more difficult recent trend that displays immediate interests is the behaviour of NGOs and iNGOs in the guise of 'biodiversity conservation' and 'poverty reduction'. Such organizations may use the respectability provided by 'biodiversity concerns' and humanitarian aims to engage in piecemeal activities such as mangrove planting without appropriate consciousness of ecosystem structure and functioning (IUCN, 2011) since immediate financial interests are linked to availability of international funding (Cooley, 2007). Many of these activities rely upon rapidity of implementation to acquire access to more funds, thereby they short sell the ecosystem interests to obtain project funds. At the end of project activity these organizations go away neglecting all obligations toward monitoring, evaluation and correcting any mistakes made. In the forestry sector this is known as 'cut and run', perhaps for the barrier-built estuaries and lagoons the expression could be 'plant, run and let-fill'. Access to such project funds is generally facilitated by networks both national and international. The funds are applied to short-term projects, irrespective of long-term ecosystem interests, mainly to satisfy the needs of institutional survival (Cooley, 2007; Chapin, 2004; Stirrat, 2006).

One may question balance in the foregoing interpretations as ignoring the contribution toward ecosystem destruction by fisher communities stemming from fishing practices in their own self interest. Undeniably the destructive impact of the poor on the fishery is not denied. They are the traditional users of the system, descendants of several generations, who must continue to eke out a living in the absence of other life-opportunities. The cumulative impact of a 'million pin-pricks' can be as destructive as some activities referred to in the preceding paragraph. The rate of impact also matters. At the same time it is necessary to acknowledge that, some of these traditional fishers, as demonstrated in the case of the stake-net fishery in Negombo Lagoon

among others, have modulated pure self-interest by way of community-based management practices where greed is kept in check by resource-sharing practices and long-term interests (Amarasinghe et al., 1997; CEA/ Euroconsult, 1994; CEA/Arcadis, Euroconsult, 2003).

4. *Basic values:* This refers mainly to the role of ethics and morality. Equitable distribution of benefits from planned development is one of the attributes that imparts legitimacy. This is also a 'basic value' resoundingly articulated in political rhetoric, but found wanting in implementation. This basic human value of fairness is frequently distorted by way of 'political favoritism' toward particular groups while neglecting others in order to strengthen power bases of decision makers/political authorities and to increase profits of financial backers. In this process respect for ecosystem services and the fishery productivity that supports low-income livelihoods may be ignored as are the sustainability values. The ethical values (doing unto others as one would like done unto oneself), and moral values (the should dos, rather than the can dos) largely determine the equitability of decisions that are implemented.

   Equitability is strengthened where decision makers implement planned activities that either 'do no harm' or increase a flow of benefits to the weakest segments of society. In the case of barrier-built estuaries and lagoons, the poorest are those segments of society that that depend predominantly on fishing for livelihood. The values that drive planning may prohibit certain actions that carry long-term interests simply because they are not politically expedient. All development activities that have had direct and indirect impacts on fishing communities in Negombo Lagoon arguably are inequitable because they undermine fishery productivity. These development activities include settlement establishment, marine fishing anchorage expansion, mangrove planting, industrial and municipal waste disposal among many others.

   Corruption also is an expression of weak societal values. Decision makers and others in authority may bend to incentives provided by parties with immediate interests. Their long-term consequences may eventually cause changes in basic values when affected people react. In this social values and ecosystem equation livelihood priorities are rarely given consideration unless the political voice of users of the resources acquires countervailing power (e.g. political agitation against the construction of a seaplane landing strip). The ability to acquire countervailing power through organizing also rests upon values such as mutual trust. Distortion of basic values may also have roots in 'ignorance' of economic values. Meaningful and equitable planning assumes comprehensive information and knowledge. However, as seen in the case of barrier-built estuaries and lagoons little information is available in regard to the economic values of multiple uses that may be

genuinely compared to arrive at balanced planning decisions. Even where communities agitate against decisions that are deemed to be discriminatory, they do so without awareness of the economic facts that can strengthen their arguments.

5. *Self-fulfilling prophesy*: This refers to behaviour of planners who predict an outcome and strive to demonstrate its manifestation even when feedback events undermine the realization of the predicted outcome. By way of fixation with an inflexible notion the implementation process itself loses flexibility to adjust to outcomes that may not have been included in the initial prophesy. This may be illustrated by Sri Lanka's efforts to develop its marine fishery toward self-sufficiency based on the notion of:

   - its island nature; and
   - modernization in the 'western, developed country format' as the optimal strategy.

   During the early years after independence planners feared the drain on foreign exchange for importing dried fish to supply the demand. At the time about 50% of the fish requirement was being imported as dried fish. Fish is the most important source of animal protein in the Sri Lankan diet – without fish the probability of malnutrition increases particularly in children. Driven by this concern planners pushed modernization of the fishery based on the European model of trawlers and other large motorized boats – i.e. become self sufficient with fish captured by modernized fishing craft (Government of Ceylon, 1951).

   The planners assumed (i) that since Sri Lanka is an island, fish were abundantly available in the surrounding sea, and the challenge was to catch them and deliver to the market, (ii) increased fish catches by modernized fishing would attract all traditional fishers to switch from outrigger canoes to motorized boats. This perception, more imagined than real, drove the planners to ignore the complexity of fishery systems as a combinations of ecosystems, technology and culture *(*see Introduction, *Figure 1.3)*. The traditional coastal fishers did not vanish as wished by the planners. Thus the planners were imposing a solution without understanding the problem. Sixty years later, Sri Lanka continues to be dependent on imported fish, but while continuously destroying the coastal ecosystems, including barrier-built estuaries and lagoons, which support the traditional small-scale fishery. The modernized fishing craft (based on an industrial fishing model) simply cannot operate in the coastal ecosystems which include barrier-built estuaries, lagoons and inshore coastal waters. Even six decades after independence the small-scale coastal fishers provide 60% of the fish supply.

Fishery development planners, blinded by their own prophesy, are continuing with the same 'modernization strategy' while denying that food security depends mainly on the traditional coastal fishery that supplies affordable fish from coastal ecosystems. The problem as initially envisaged did not occur after all. The 'imagined' solution, however, has created many new problems including 'expensive restoration of coastal ecosystems'. This example illustrates how 'Fear of some consequence drives people to find solutions before the problem occurs, thus the non-occurrence of the problem is unanticipated'.

Present threats to optimal structure and functioning of Negombo Lagoon may be summarized to provide generalizations. For this purpose some actual events from experience in Negombo Lagoon are used *(Table 5.1)* including:

- Construction of settlements on the islands and associated inter-tidal areas in the channels segment in the vicinity of the tidal inlet.
- Construction of piers and fishery anchorage service centers which abut on the water body for servicing multiday offshore fishing boats in association with fishery modernization.
- Construction of the Colombo Katunayake Expressway which separates a segment from the productive water body.
- Planting of mangroves under pretext of biodiversity enhancement but yielding eventually to private property expansion into the water body.
- Cage aquaculture which expropriates common property resource space and discharges concentrated wastes.
- Discharge of industrial wastes from the Ekala Industrial Estate.

The combination of causes associated with the unintended consequences of the above development interventions are shown in *Table 5.1.*

The ranking of causes of unintended consequences that emerges from *Table 1* suggests inferences as follows:

- Ignorance, immediate interest (greed) and values (deficiency) rank in parallel as the foremost causes of unintended consequences;
- Error follows as the second most important contributing cause.
- Self-fulfilling prophesy ranks as the least significant causes of unintended consequences. Generally inter-disciplinary planning does not allow self-fulfilling prophesy to dominate as it did in the case of 'modernization of the marine fishery'.

Table 5.1 *Summary of the causation of planned human constructed facilities and management activities in Negombo Lagoon. 'X' in a cell denotes dominant causes, 'C' represents a contributing cause, and 'U' expresses that the contribution from this cause is unclear. See text for explanation. Since causes also interact, it is usually difficult to attribute causation to a single factor.*

Type of Human-Constructed facility	Causes of Unintended Consequences					Remarks
	Ignorance	Error	Immedeiate interest (greed)	Values	Self-fulfilling prophesy	
Settlement expansion on islands and inter-tidal areas	X	C	X	X	C	The Prime Minister in the 1980s, later to be the Executive President ordered implementation of 'million houses' programme. Bureaucrats had the only option: meet targets or lose the job. Planning was hurried, using whatever state land. Potential externalities not considered.
Piers and service facilities for multiday offshore marine fishing boats	X	C	X	X	X	National fishery policy from 1980s onward focused on increasing privatized marine fishing capacity by way of 'low cost' infrastructure development where possible, including the use of barrier-built estuaries as anchorages. Potential negative impacts not considered.
Colombo - Katunayake Expressway fragmenting the water body	C	C	X	X	C	The Road Development Authority was indifferent to safeguards already embodied in the Master Plan for Negombo Lagoon. Their cost-benefit in 2000 applied a high discount rate to the brackishwater fishery to depress the present value in the EIA.
Mangrove planting for land capture – pretended biodiversity enhancement	X	X	X	C	U	Private 'land capture' interests used 'naïve' support of the Regional Mangrove Project of NARESA and the Mangrove Project of the Forest Department for mangrove protection for the hidden agenda. Mangrove 'cognoscente' perceived mangrove planting as a positive outcome.
Cage culture on expropriated 'common property resource space'	X	X	X	X	NA	Support provided by NARA and humanitarian NGOs for aquaculture development and poverty reduction through income generating projects for expropriation of common property resources.
Ekala Industrial Estate waste discharge	C	X	X	X	NA	The planners in the 1960s established the industrial estate assuming that Negombo Lagoon was an adequate sink that could dilute and convey industrial waste to the sea. This eliminated the cost of waste treatment at origin and lowered cost of production. There was little appreciation of the limitations of a 'micro-tidal' barrier-built estuary
Significance (presumptive)	**4X**	**3X**	**4X**	**4X**	**1X**	**The higher number of Xs suggests greater significance of a cause that contributes to unintended consequences.**

5.4.1 Justification of the Interpretation

Settlement expansion on inter-tidal islands and areas contiguous with inhabited islands has a historical pattern associated primarily with poverty and desperate immediate interest. The poorest brackishwater fishers become virtually destitute in old age when they lose the strength and endurance to earn a daily income by fishing. They have adopted a livelihood tactic that partially enables them to overcome uncertainty in old age by creating a 'piece' of property on which to build a house, i.e. an asset in which their children may become adequately interested to provide care-taking to the aging parents in anticipation of inheritance. This is done generally by trapping sediment in an inter-tidal location to create a slight platform that can be stabilized with fill material to support a temporary structure (IUCN, 2009; Samarakoon, 2007). This historical behaviour pattern of slow, pin-point encroachment, into the water body became co-opted partially into an institutionalized programs:

(a) the Million Houses Programme of the NHDA, and

(b) the UNESCO Regional Mangrove Project implemented in the 1980s by the Natural Resources Environment and Science Authority (NARESA) of Sri Lanka (later to become the National Science Foundation).

Under the housing programme, the responsible government bureaucrats had to achieve targets (numbers of houses built) in their own career interest. The limiting factor was state land which could be acquired without any cost. The intertidal lands in Negombo Lagoon were ideal candidates in that perspective.

Under UNESCO/NARESA mangrove programme in the 1980s, mangrove research was promoted in parallel with which local residents at locations such as Negombo lagoon were encouraged to plant mangroves, based on the knowledge available in 1980s. Cash incentives were paid. Poor fishermen gladly supported the program for the additional income while mangrove scientists published research papers and participated in international meetings. Here the self interest of poor fisherfolk and career ambitions of scientists converged. In the process micro-geomorphic change (pin-point landfill) entrained cummulative changes in the entire ecosystem (macro-geomorphology) while impeding the hydrological system. This occurred at a time when the scientific knowledge was highly limited in Sri Lanka about relationships between sedimentation in micro-tidal estuaries. Now, IUCN (2011) provides perspective and guidelines to ensure that similar mistakes do not happen again in Sri Lanka's particular geomorphological setting.

In both the hosing development pragramme and the mangrove programme 'doing good' was a firmly held belief. Nevertheless ecological values, livelihood rights and environmental justice were not included among the driving values

Development of the first industrial estate at Ja-Ela in a cost-effective manner was a priority of the state during the 1960s. Waste treatment and pollution prevention were not values prevailing within the 'planning consciousness' of the time. EIA procedure also did not exist. Livelihood interests of traditional fishers in Negombo Lagoon may not have entered the planning equation in the development drive toward industrialization. Nevertheless the ethos of planning assumes training including case studies from countries where mistakes have been made. Was ignorance sanctimonious?

5.5 A Coherent Framework – Social-ecological System Relationships

The application of the axiomatic 'law of unintended consequences' to some planned development activities that impacted barrier-built estuaries and lagoons revealed the ease with which harm is done to the structure and functioning of complex systems. The next question is 'how is it possible to minimize such harm being done now'? For this purpose stakeholders must develop consciousness of the way the interacting parts of barrier-built estuaries and lagoons are impacted by society, and the manner in which society is impacted by these same complex systems. For this purpose a coherent analytical framework is necessary that enables disaggregation of the complexity without obscuring the most significant relationships among the parts.

The coherent framework for the way we think about barrier-built estuaries and lagoons requires expansion of the scope of our 'mental maps' (cognitive maps) of the structure and functioning of barrier-built estuaries and lagoons coupled with awareness of political aspects of human behaviour. By cognitive maps is meant the way in which people receive, store, retrieve, visualize and otherwise process information that puts in perspective the relationships among geographic places within a complex system. By politics is meant the 'power relationships among groups of people' and the 'the capacity of a group of people to resist imposed change' (Etzioni, 1968).

The reformulation of the ecosystem concept as an inclusive social-ecological system which combines bio-physical aspects and humanity was introduced in Part 1: Introduction, section 1.4. The practical application of the concept is addressed in this synthesis based on Ostrom, 2007. The interaction among factors (variables) that make up complex systems is the most serious challenge in understanding SESs and potential interventions in improving their performance. The challenge somewhat is eased by (i) partitioning the variables into classes and subclasses (the many relevant layers); (ii) identifying the range of subsystems that are independent of each other but at the same time can affect each other (relationships among the layers), and (iii) that the properties of whole complex systems are greater than the sum of their parts.

(i) The first aspect is essential for building coherent and cumulative scientific understanding and is illustrated in *Figure 5.1.* In the case of barrier-built estuaries for example, the two defining variables that are supreme are micro-geomorphic processes nested within macro-geomorphology, the hydraulic forces, and the social, economic and political settings.

(ii) The second aspect, i.e. identifying the subsystems that apparently are independent but actually affect each other, is essential for building solutions to complex SESs that are generating perverse outcomes, e.g. the urban settlements on islands in Negombo Lagoon, assumed to be independent of the water body, but actually diminish the forces of water flow (hydraulics) in the most sensitive area, the tidal inlet, and thereby undermine critical linkages between the brackishwater body and the sea..

(iii) The third aspect makes it essential to recognize that combining some variables (e.g. from those listed in *Tables 5.3a-5.3f)* assumed to be independent of others may create emergent properties (see Introduction, *Figure 1.4*) that have trajectories different from an anticipated linear path. As an example, consider, mangroves (variable A), assumed by botanists to be an independent variable from the hydraulics of a micro-tidal barrier-built estuary (variable B), and meant to increase fishery nursery function (variable C). In comparison consider variable B and C in combination with seagrasses (variable D). Combining A, B, and C actually results in the loss of fishery habitat; whereas A,B, and D would have a positive instead of a negative impact.

To begin with is the importance of identifying the conceptual tiers and linkages among variables that constitute an SES as it affects and is affected by larger and smaller SESs within the 'big picture' *(Figure 5.1)*. At the broadest conceptual level, one can posit a general framework—a conceptual map—that can be used as the starting point for conducting the study of linked SESs. The significance of linkages can be illustrated by considering the consequences of tidal inlets with sand bars that block the reciprocal flow between the sea and a barrier-built estuary. *Figure 5.1* presents a simple, very general framework that captures the range of variables that must be analyzed when examining linked SESs. At this broad level, one can begin to organize an analysis of how attributes of the layers affect and are affected by each other, Viz.

- a resource system (RS) (e.g. a micro-tidal barrier-built estuarine system which supports fishery within which human activities are transforming processes that support natural productivity),
- the resource units (RU) produced by that system (e.g., kilograms of fish, land units for property development, the value of these units, etc.),

- the users (U) of that system (numerous because of multilplicity of uses including traditional fishers, marine fishers, urban poor, etc), and
- the governance system (GS), i.e. the manner in which decisions are made particularly in regard to human activities that impact the bio-physical system. These decisions may be made by government agencies in isolation or with the participation of all stakeholders including community organizations.

These four layers jointly affect (and are indirectly affected through feedback from):

- the patterns of interactions (I) and resulting outcomes (O) achieved at a particular time and place,
- how these interactions (I) and outcomes (O) are affected by larger or smaller socioeconomic and political settings in which they are embedded (S), and
- larger SES such as watersheds (ECO).

Each of the eight major variables shown in bold letters in *Figure 5.1* (Viz. **RS, RU, U, GS, S, I, O** and **ECO**) are unpacked into their constituent sub-variables; separately numbered and shown below a major variable (e.g. S1 – S5). The major variables and the sub-variables are spelt out more explicitly in *Tables 5.3a-5.3f* in respect of the Negombo Lagoon which is used as a case study. This framework will hopefully enable development of, ultimately, a cumulative, coherent, and empirically supported set of answers to three broad questions:

1. What patterns of interactions and outcomes—such as overuse, conflict, collapse, stability, increasing returns—are likely to result from using a particular set of decisions (rules) for the governance, ownership, and use of a resource system and specific resource units in a specific technological, socioeconomic, and political environment?
2. What is the likely endogenous (e.g. community-based) development of different governance arrangements, use patterns, and outcomes with or without external financial inducements or imposed rules?
3. How robust and sustainable is a particular configuration of users, resource system, resource units, and governance system to external and internal disturbances?

Explanation of *Figure 5.1* is likely to assist in understanding the subsequent case study. Particular examples are taken from the Negombo Lagoon case study to illustrate the explanation where necessary at the risk of repetition. Greater clarity is therefore useful in regard to each of the major variables in *Figure 1*.

5.5.1 Social, Economic and Political Variables (S)

An SES cannot exist in isolation. Every SES is sandwiched between a layer of social, economic and political variables (S), and linkages with related ecosystems (ECO). Thus the activities that occur within an SES are shaped by the state of economic development of the wider environment (S1). The households that depend upon the fishery production from Negombo Lagoon are compelled to engage in that uncertain pursuit mainly because they do not have access to forms of employment that otherwise would be available if the surrounding economy was more developed. Until the onset of the 1980s, womenfolk in fisher households, even though educated, were engaged in activities associated with fishing including rope making, net weaving, retail selling of fish and such-like. With the establishment of the investment promotion zone at Katunayake, these young girls obtained training and employment in factories. Upward social mobility and escape from poverty accompanied wage employment. The employed women postponed marriage by several years unlike their uneducated counterparts, while opting for smaller families and even chose to migrate to more attractive jobs outside the village, and even in Gulf countries.

Their male counterparts were culturally attracted to fishing at an early age. They rarely developed other marketable skills and were compelled to remain within the sector. As income from fishing in the barrier-built estuary diminished, they shifted to wage labour in seagoing fishing boats. In the post-1990 years, many youths from the Roman Catholic communities migrated to Italy where supportive networks had already developed. A foremost economic aspiration of Negombo youths in the early 2000s was either legal or illegal migration to Italy (CEA/ Arcadid/Euroconsult/MENR, 2003). Evidently employment in the fishery sector was inadequate to meet youth aspirations.

The population in the surrounds of Negombo Lagoon has increased about three-fold during the post-independence period from1948. The development policies of the state have not contributed adequately toward reducing unemployment. Nevertheless the wealth generated from productivity of natural capital (barrier-built estuaries, lagoons and near-shore coastal ecosystems) has increased substantially over the same period because of both technology and globalization (e.g. shrimp exports). People attracted by wealth created from the natural capital of Negombo Lagoon and contiguous coastal waters were culturally different and did not share traditions and values of 'fisherfolk'.

Settlement policies of the state have not integrated with environmental safeguards. As a consequence haphazard expansion of housing on state land, including barrier-built estuaries and lagoons' has contributed to their degradation. State policy in the 1980s actually used productive inter-tidal land of Negombo Lagoon for building settlements. Entrained consequences have been severely damaging to the structure and functioning of this particular barrier-built estuary.

Markets in the vicinity of the majority of barrier-built estuaries have been expanding because they exist already in urbanized settings. Early colonial forts are associated with the most urbanized barrier-built estuaries including Puttalam Lagoon, Negombo Lagoon, Batticaloa Lagoon and Jaffna Lagoon. Much of the fish supplied to the population came from these brackishwater bodies during the seasons when the Monsoons prevailed. Markets have expanded further inland with the growth of fish transportation and distribution. Colombo later became the primary urban center which determined prices island-wide, while concurrently markets expanded internationally with the free-market policies and globalization that followed from the late 1970s.

5.5.2 Related SESs (ECO)

Every barrier-built estuary and lagoons as an SES owes its structure and functioning to freshwater drainage from its watershed and tidal connection with the sea. In the event where the role of either of these related SESs becomes attenuated, imbalance occurs in the water quality. In the absence of adequate freshwater to mix with and to dilute the sea water brought in by tides, brackishwater cannot result. Similarly, inadequate inflow of sea water also prevents the formation of brackish water. The 'ideal' fishery stock in barrier-built estuaries and lagoons is a physiological attribute of brackishwater.

Wastes and material discharges from watershed land uses, by the inherent nature of gravitational streamflow, enter barrier-built estuaries and lagoons. The quantity of wastes may vary with the seasons, but they must ultimately reach the brackishwater body. The total catchment in these watersheds greatly exceed the size of the associated brackishwater bodies. In the case of Negombo Lagoon, the area of the watershed is twenty-fold larger than the surface area of the brackishwater body. Because of the micro-tidal nature of these ecosystems material and weak flushing, material reaching them tend to become concentrated.

5.5.3 The Resource System (RS) - foundation

The clarification of physical geography of a resource system provides the most basic foundation of information since such processes are difficult for humans to change. Thus an opportunity is provided to explore where human-driven development attempts that were insensitive to physical geography went awry (for details see IUCN, 2009: NSAP, pp 89-145). Analysis of the insensitivity to physical geography is based on the diagnostic approach to understanding complex ecosystems. The application of the axiomatic 'law of unintended consequences' toward identification of causes in sub-section 2.1 has already revealed a wider range of causes. This section is also an argument synthesis since different aspects of resource use and management are brought together for comparison and analysis in order to reveal optimal choices. The combination

of explanatory and argument syntheses is meant to better provide insights on approaches toward dealing with the problem of barrier-built estuary and lagoon degradation. A brief reminder of the main point pertaining to physical geography stated in the introduction may contribute to clarity.

The evolution of the existing physical geographic state of barrier-built estuaries and lagoons has been caused by micro-geomorphic processes within macro-geomorphic (geologic) settings of island Sri Lanka. The macro-geomorphic elements that constitute Sri Lanka's surface attributes are small-scale because of the relatively small surface area of the country and its subdivision into smaller watersheds. In regard to barrier-built estuaries and lagoons, they are also small-scale surface features, made relatively more vulnerable by shallowness. In these aquatic environments, the micro-geomorphic processes are rapid and they are rarely observed until they become progressively aggravated. These micro-geomorphic processes may be accelerated by human engineering interventions as well as multiple uses that result in creeping normalcy or chronic disaster (Diamond, 2005). Therefore, diagnosis leads eventually to options for dealing with chronic disaster.

Geomorphic change and fishery livelihood

Change in ecosystems is the unavoidable fact that underlies the entire synthesis as presented here. The nature of change in complex systems must be understood in particular country settings before discussion of how that 'change' may be managed. Therefore, a generalized comparison of rates of change in estuaries is the first step that could assist in identifying the diverse approaches that could contribute to sustainable development of estuaries for multiple uses *(Table 5.2)*. Early management responses are required mainly for those causes of change which accelerate degradation (*Table 5.2),* i.e. the shaded cells marked with an 'X'.

The diagnosis must begin with a narrative of the geologic, geomorphic mico-geomorphic evolutionary history of barrier-built estuaries and lagoons in Sri Lanka. That perspective:

- enables clearer understanding of the immutable relationship between coastal geomorphology and human activity in complex social ecological systems (see Introduction section 1.5), and
- the dominance of physics and chemistry over all biological processes (see Section 4).

Although geomorphology is a cause of slow change, it is this same geomorphic nature, in particular country settings, that accelerates more rapid micro-geomorphic change. Frequently, even though fast-paced, micro-geomorphic change caused by people when they interact with estuaries and lagoons is insidious.

Figure 5.1 *The process of deconstructing the Negombo Lagoon SES (shaded rectangle) to enable reconstruction of prioritized management needs for sustainability. The major eight variables (bold characters) are arranged in rectangular, unshaded boxes. Within each 'major variable' box are listed the sub-variables. In a complex system such as Negombo Lagoon all major variables are linked. The linkages are denoted by the arrows See explanation in the text.*

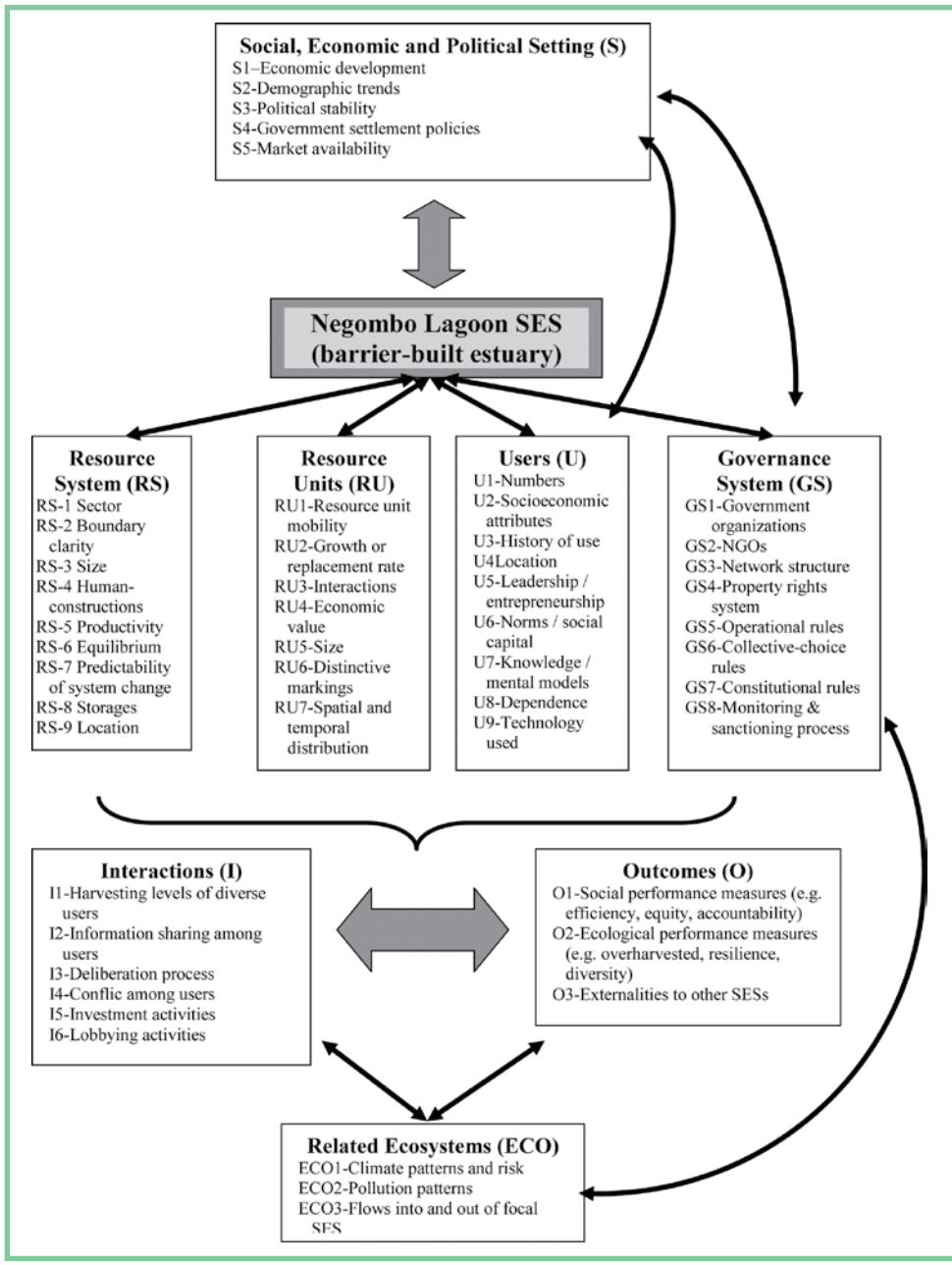


Table 5.2 The main causes of change in estuaries and lagoons classified according to how they influence the rate of change.

Main Cause	Rate of Change			Remarks
	Slow (millenia)	Moderate (10-30 yrs)	Rapid (< 10 yrs)	
Natural but modified by historical land uses				
Geomorpholgy & embedded micro-geomorphology	X	X	X	Natural change spanning about 10,000 yrs produced the existing form of barrier-built estuaries
Hydrology (total)	X	X	X	Natural hydrological cycle has remained stable
Hydro-morphology (changes in parts of the total form)		X	X	Impeded natural, catchment flow and upstream land clearing, accelerated shoal accelerating owing to increased sediment yield
Hydraulics (force of water flow)		X	X	Recently stabilized shoals in tidal inlet areas impede the force of natural flows
Development interventions including biodiversity enhancement				
Water management for agriculture		X	X	Fisheries within lagoons such as Kalametiya and Rekawa have diminished drastically. Impeded natural flows.
Flood control and drainage (FC&D) - urban		X	X	FCD structures in many lagoons have obstructed behaviour of tidal inlets causing fishery losses within a few years
Urbanization – settlement growth		X	X	Uncontrolled encroachment - insidiously under various pretexts including mangrove planting. Rapid loss of fishery habitat.
Fishery infrastructure - anchorages		X	X	Rapid growth has occurred to minimize costs of constructing fishery harbours
Communication infrastructure – roads and bridges			X	The changes caused by poorly constructed roads is immediate and expensive to reverse
Aquaculture infrastructure – ponds etc			X	Loss of functional 'common property' fishing area
Aquaculture – waste discharge without treatment		X		Progressive and may kill fishery as in Mundel Lagoon in a few years.
Fishery nursery: pretended mangrove restoration		X	X	Refer IUCN, 2011 (www.iucnsl.org)
Hazard mitigation – e.g. mangrove bioshields		X	X	Refer IUCN, 2011 (www.iucnsl.org)
Industry discharges – untreated		X		Pollution – nutrient and toxin build up occurs progressively over decades
Municipal waste - untreated		X		Pollution
Tourism - recreational				
Tourism - infrastructure		X	X	Seaplane landing strips, hotels on landfills
Political – relating to nature of organization of people with estuary-dependent livelihood				
Capacity to resist imposed change – organized activism			X	Rapid results where The countervailing power of the Negombo small-scale fisherfolk enabled relaocation of sea-plane landing.

This narrative is brief and targets the needs of the synthesis. More details are available in section 4 of this report from an engineering perspective. The synthesis provides explanations of:

- Physical geography of the coastal plains of Sri Lanka and the manner in which estuaries and lagoons have evolved to their existing condition.
- The impact of sediment deposition in general, and the outcome of more detailed study in a 'better-studied barrier-built estuary' that reveals the concept of exponential change associated with micro-geomorphology.
- The role of people in accelerating micro-geomorphic change, particularly in the entrapment and stabilization of sediment deposition and entrained impacts.

Evolution of barrier-built estuaries and lagoons

The ancient rivers in Sri Lanka with their meeting points with the sea long preceded the evolution of estuaries and lagoons as seen today. The existing funnel-shaped estuaries at river mouths (also termed riverine estuaries in CCD, 1991) began evolving into their present state about 10,000 years ago when the sea stabilized at the level seen now *(Figure 5.2)*. Even before the sea level rose to the level of 10,000 years ago, the ancient rivers flowed through valleys that they themselves had carved through the coastal plains, reaching bedrock in some locations. At some of these river mouths the bed rock of the land extended as narrow platforms into the sea. Sand was progressively deposited on these rock extensions by wind and waves. These sand depositions later grew into sand barriers and sand dunes that were stabilized for human habitation. As the sea level rose to the present state the defining changes occurred at river mouths that gave birth to barrier-built estuaries. The rising sea level drowned the river valleys as their water spread expanded inland behind the stable, combined sand barrier-sand dune systems *(Figure 5.2)*. From that point in time, through the succeeding period of about 10,000 years, these barrier built estuaries have been evolving into the form that is seen today. Details of geological events and the land forms that emerged by way of interaction with rivers and associated environmental factors resulting in barrier-built estuaries are provided by Erb, 1970; Swan, 1983; Cooray, 1982; Katupotha, 1992 among others.

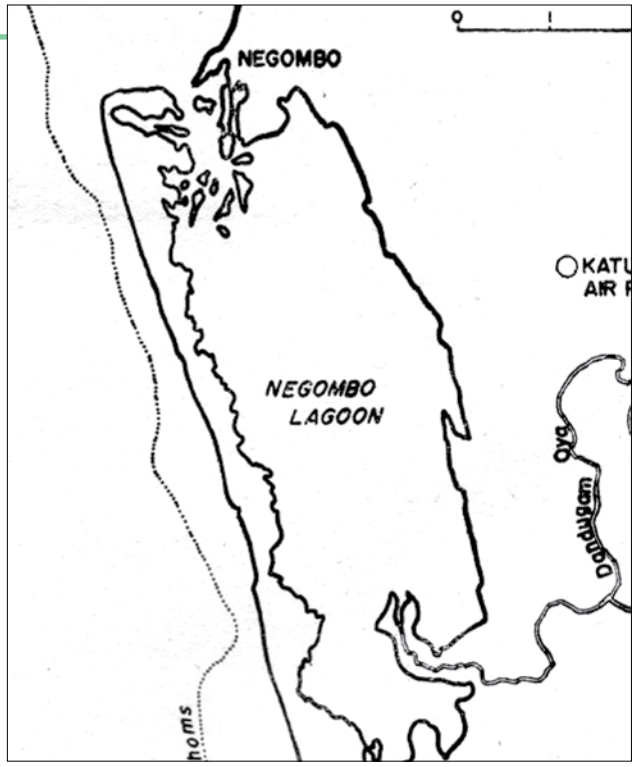
It is important to note that the rock-dominated geology of Sri Lanka allowed the formation of estuaries of particular types, and not others similar to those that occur in neighbouring India, other South Asian and East Asian countries. Drowning of river valleys and land subsidence combined to produce inundated riverine estuaries and barrier-built estuaries (also termed estuarine deltas). The initial macro-geomorphic land features continued to evolve under the influence of micro-geomorphology. Because of the latter, some barrier-built estuaries subsequently changed into lagoons. A notable feature of the macro-

geomorphology of Sri Lanka is the absence of alluvial deltas. The macro-geomorphic land forms in Sri Lanka, did not allow the formation of deltas that protrude into the sea, also referred to as shorefront deltas (Erb, 1970; Swan, 1983). The sediment loads delivered to the sea from river mouths and tidal inlets of barrier-built estuaries were relatively small and easily removed by currents and waves. Even today, when sand deposits occur at the mouth of main distributaries of the Mahaveli Ganga *(Figure 5.2)* during the calm months, the energy of the North East Monsoon waves and currents inevitably remove them.

The consequence of the instability of sediment deposits at river mouths and tidal inlets was the inability of mangrove seedlings and seagrasses to take root there. The micro-geomorphic impact of waves and currents thereby prevented the formation of stable deltas at the shorefront. To some extent delta-like land forms exist along the north western coastline which is highly sheltered (Swan, 1983). The denial of this geomorphic attribute of Sri Lanka by a segment of scientists (mainly botanists) has resulted in major negative consequences for barrier-built estuaries and lagoons.

Figure 5.2 *Two estuarine tidal inlets in Sri Lanka that serve as examples of sediment interrelationships where (A) conditions for barrier formation, extensions of base rock into a platform, does not exists, and (B) where such a platform exists in the form underlying the sand dune system separating Negombo Lagoon from the sea. See text for explanation.*

(A) River outflow (tidal inlet) from Mahaveli Ganga into Koddiyar Bay. The decline is rapid from the coastal land into the sea. An extension of base rock that assist in sand barrier formation does not exist at the tidal inlet. The sand spits that have formed at the river mouth (tidal inlet) are temporary and seasonal. The distributary (channel) to the right from the main river path has not expanded into a wide basin as in the case of Negombo Lagoon (Photo: Jayampathy Samarakoon 2011).



(B) The tidal inlet of Negombo Lagoon is at the northern extremity of the stable sand dune that has formed on a rock shelf on the left (Pamunugama Reef). The expanded drowned river valley extends southward. Dandugam Oya is the main river that flows into the expanded basin .The stable sand barrier-rock shelf combination characterizes the barrier-built estuaries along the west coast. See text for explanation.

The absence of shorefront deltas prevented the development of vast mangrove forests that characterize them as seen at mouths of rivers such as the Krishna and Godavari on the east coast of India *(Figure 5.3D)*. This is a fundamental peculiarity of macro-and micro-geomorphology of river mouths in Sri Lanka. The mangroves that occur in Sri Lanka occur within barrier-built estuaries (also termed estuarine lagoons) and along the intertidal margins of drowned river valleys *(Figure 5.3B,C)*. This micro-geomorphic peculiarity of barrier-built estuaries (and lagoons) in Sri Lanka make them highly vulnerable to infilling by sediment entrapment and thereby proportionately limit their ability to be resilient (bounce back) and to recover fishery productivity when habitat loss occurs.

Erb (1970) comments "The Negombo spit, which almost completely encloses Negombo Lagoon, has a core of rock which may have been responsible for initiating the deposition of sand. This is apparently an extension of a bedrock ridge or 'reef' called Pamunugama Reef, first noted in the vicinity of Kelaniya just north of Colombo. The Provisional Geological Map of Ceylon also shows rock to be present in the spit at Puttalam and on Mannar Island. Configurations further south along the Bentota Coastal plain substantiate the probability that most of the major north trending spits of the west coast of Ceylon are rock controlled". The relationships between sea level rise and the formation of spits that partially enclosed barrier-built estuaries is shown in *Figure 5.4*.

Figure 5.3 *Evolution of barrier-built estuaries and lagoons was the product of geology and macro-geomorphic land forms peculiar to Sri Lanka. As a consequence deltas that protrude into the sea with vast mangrove coverage are absent along the coastline.*

Evolution: Generally a river estuary such as Kelani Ganga estuary (A) as depicted in the centre of the drawing below may evolve towards a lagoon such as Rekawa Lagoon (B), passing through a transitional barrier-built estuary such as Negombo Lagoon (C). In Sri Lanka river estuaries cannot evolve to form deltas which progressively expands into the sea, such as the Krishna River delta (D) in India. Deltas (D) of the form shown in the inset do not exist in Sri Lanka because the geomorphologic processes are not favourable (see text on 'drivers'). Therefore mangroves also do not occur at the interface of the land and the sea (shorefront) in Sri Lanka, although it may be so assumed falsely. Where deltas occur in Sri Lanka they take the form of 'estuarine deltas' situated within a barrier-built estuary. Negombo Lagoon (C) is a barrier-built estuary that combines the features of an 'estuarine lagoon' and an 'estuarine delta' (Day *et.al*. 1989). See text on 'drivers' below for further clarification. Sri Lanka, being a relatively small island, has short rivers and restricted watersheds from which sediment is eroded and carried to sea. This sediment load is not enough to form stable deposits at the coast. When deposited strong waves carry it off.

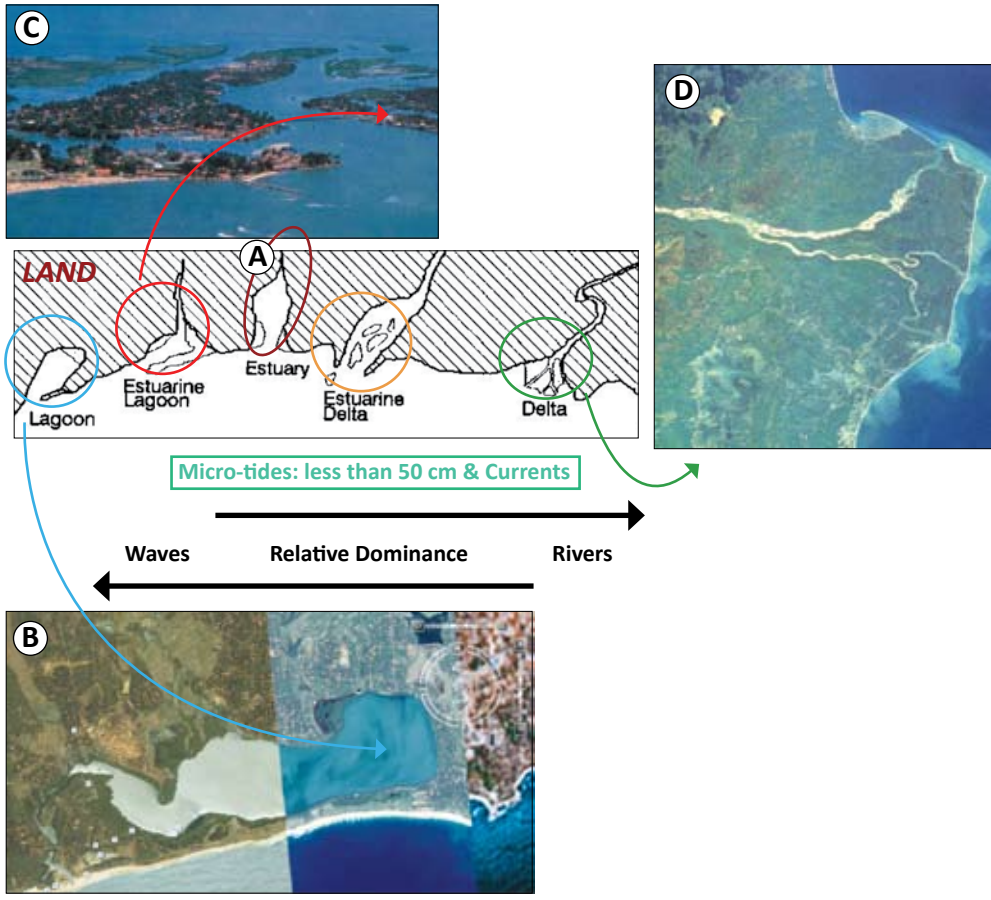
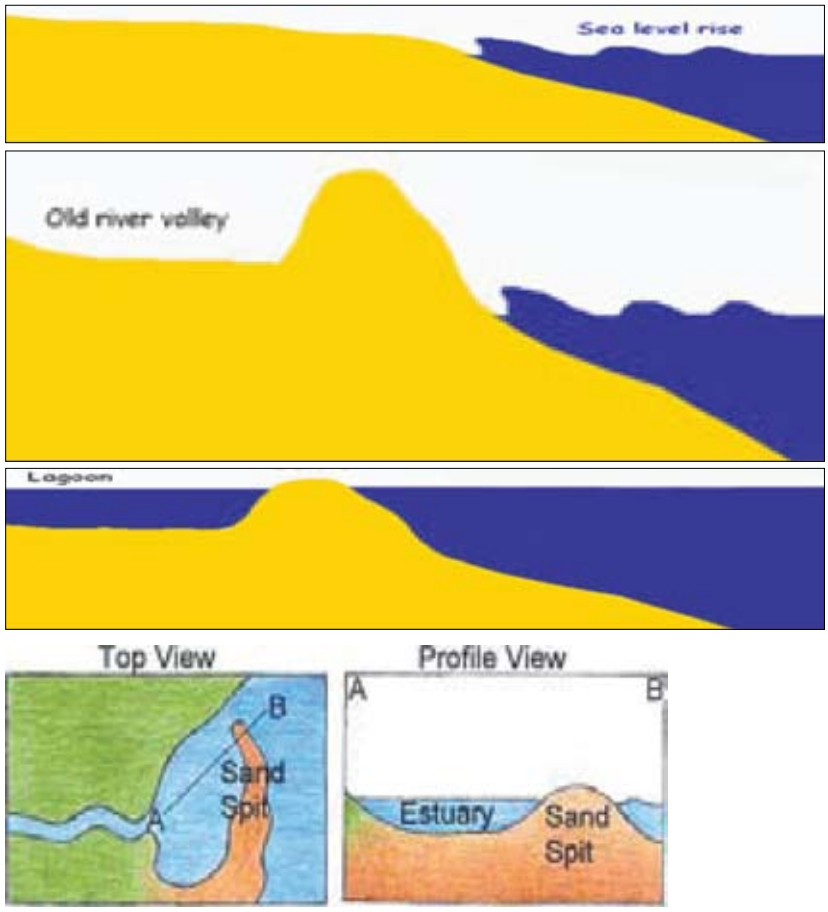


Figure 5.4 *This figure illustrates the manner in which the sea level would have risen (eustasy) and filled an existing river valley to form an area of 'brackish water' - sea water mixed with freshwater in an estuary. The same processes that gave birth to estuaries continue today including aspects of climate change and sea level rise increasingly influenced by anthropogenic impacts on global temperature (IPCC 2006).*



The three drawings, showing land in yellow and the sea and estuarine water in blue, is a profile of the relationship between relative sea level rise and the filling of a river valley to form an estuary. The raised land in the two lower figures represent the position of a sand barrier, beach/dune land form that separates the sea from the estuary. The two drawings below show the surface view (left) of the barrier that partially separates the sea from the estuary. The A-B profile view is the manner in which the sand spit would appear in cross section. Imagine the spit expanding and blocking the connection with the sea – thus commences the transition to a lagoon (adapted from Mead and Moores, 2004). A transect through any barrier-built estuary or lagoon in Sri Lanka viewed in profile shows the separation from the sea by a highly stable dune (also see *Fig 5.3*).

Sediment entrapment and stabilization by seagrasses and mangroves

Over the vast period of about 10,000 years, ever since estuaries of the form seen in Sri Lanka originated, much of the sediment transported into them by the rivers became trapped within the expanded basins of the barrier built estuaries. This is a known attribute of barrier-built estuaries. Perkins (1974) and Sorensen et al. (1993) comment, based on a world-wide review, that barrier-built estuaries have only a single definable destiny – death by sediment infilling. The duration of this process may be short or long depending on the form of a barrier-built estuary at birth. The smaller and shallower ones, such as those in Sri Lanka, have a relatively short life span measured in geological and ecological time scales (1,000s and 100s of years respectively). Nevertheless, long before the estuary becomes infilled by sediments, the fishery may collapse with substantial negative impact on livelihoods in the event that water quality and/or 'aquatic space' (fishery habitat) diminishes below a particular threshold.

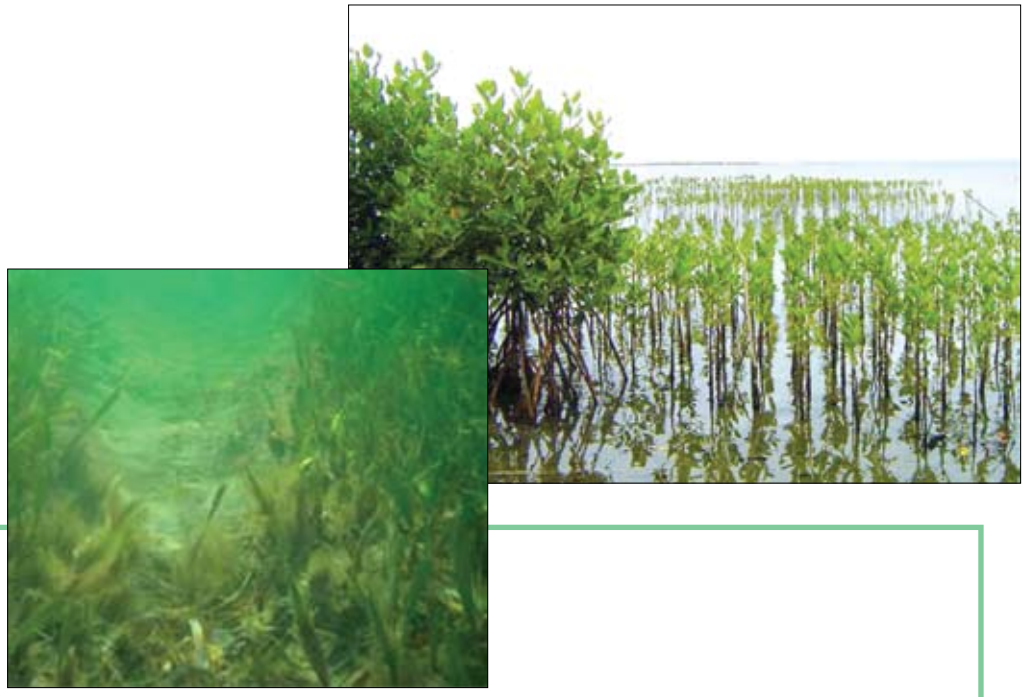
Two factors that contribute to acceleration of infilling are seagrasses and mangroves *(Figure 5.5)*. The soft sediment deposits create ideal conditions for colonization by seagrasses in the submerged basin. Similarly the soft unstable sediment in the intertidal fringes create suitable conditions for colonization by mangroves *(Figure 5.5)*. Readers must remember that the seeds (propagules) of mangroves and seagrasses are at all times floating and migrating with ocean currents. Seagrasses and mangroves, as opportunistic vegetation types, colonized the barrier-built estuaries and progressively took on stable configurations and added to the complex geomorphology of the barrier-built estuaries. The seagrasses and mangroves, as opportunists, stubbornly expand and stabilize fresh depositions of sediment. In fact, today, the tail-end of the evolution of barrier-built estuaries is being witnessed in Sri Lanka. Of course, fortunately or unfortunately, anticipated sea-level rise may extend the lives of these barrier-built estuaries.

Micro-tides and weak hydraulics

The single most important driving factor that contributes to sediment entrapment within barrier-built estuaries is the nature of the tides in Sri Lanka (see Section 4). They are termed micro-tides since the difference between the high tide level and the low tide level never exceeds 1 meter (on average about 50 cms). Therefore the force of water flow generated as the high tide changes to the low tide, roughly at intervals of 12 hours, is weak and insufficient for flushing all the fresh sediment that gets deposited in the interim. The result is progressive accumulation of sediment and inevitable raising of the estuary floor. It is for this technical reason that planting of mangroves within barrier-built estuaries and lagoons, under the pretext of 'mangrove restoration' and for increasing fishery productivity, has precisely the reverse of the intended effect. The water area that could function as fishery habitat for livelihood is converted into unproductive sediment shoals. Of course, these same mangroves may add to biodiversity by

increasing habitat for non-aquatic organisms. Can these life forms compensate the loss of fishery stock that is crucial for supporting livelihood and nutrition security?

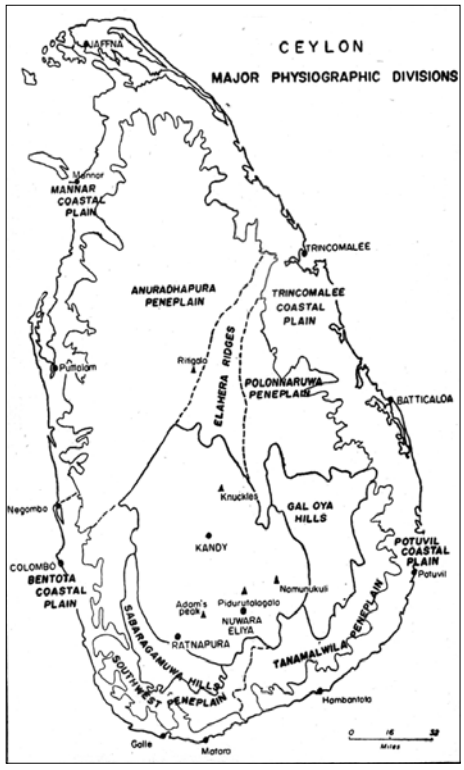
Figure 5.5 *Mangroves (Rhizophora sp.) planted in a barrier-built estuary in Sri Lanka at Eththala, Puttalam Lagoon, Sri Lanka and left to expand without control (Miththapala 2008, photo credit: S. Lelwala). This vegetation will predictably convert the water body (fishery habitat) to land where fish no longer can inhabit. Note that land has been already built up above the water level where the tallest row of mangroves are situated. The agency that planted the mangroves regards it as a praiseworthy achievement since they are focused narrowly on the vegetation (not the water body). A system ecologist who takes a 'total' view regards indiscriminate mangrove planting (under pretext of restoration) as 'sedimentation stabilization' that eventually destroys the water body in micro-tidal settings. Underwater, seagrasses keep building the floor upward by accelerating sediment deposition.*



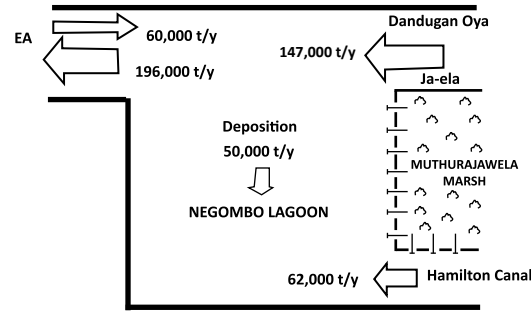
Above: Seagrass growing underwater on the floor of an estuary. Haziness is because of suspended sediment. The vegetation is dense and slows the speed of water flow thereby accelerating sediment deposition. The soft deposits are bound by the extensive root system of the seagrasses. The 'shallow' trench between the stands of seagrass is a micro-geomorphic feature of water flow (www.adventureenvironmental.net/About.html)

Barrier-built estuaries once formed could not escape infilling by sediment because of the form of Sri Lanka's coastal plains *(Figure 5.6)*. Erb (1970) in his study of the physiography of Sri Lanka argues that the coastal plains are 'submergence landforms' which have received layers of sediment during periods of inundation. Soil core studies done at the Muthurajawela Marsh, a southward extension of Negombo Lagoon, have revealed sequential layers as explained by Erb (Samarakoon and Van Zon, 1991).

Figure 5.6 *The physical geography of Sri Lanka includes coastal plains in which the estuaries and lagoons are situated. Erb (1970) demonstrates that these coastal plains are submergence landforms where sediment deposition occurs naturally.*



The form of the coastal plains of Sri Lanka and the elevated sand barrier/sand dune that fringe the coastline ensure sediment entrapment within the basins of estuaries and lagoons. The pattern of sediment accumulation was measured and modeled for Negombo Lagoon as shown in the inset below (Samarakoon and Van Zon, 1991). The dunes are resilient and do not breach as demonstrated by the impact of the Asian Tsunami 2004 (Samarakoon, Epitawatte and Galappatti, 2008). Therefore raising of the estuary bed is predicatable and inevitable. The sole remedy is removal of sediment by dredging, coupled with prevention of human activities that accelerate sediment entrapment including mangrove planting in the water body. Also see IUCN, 2011. Also see *Figure 5.2.*



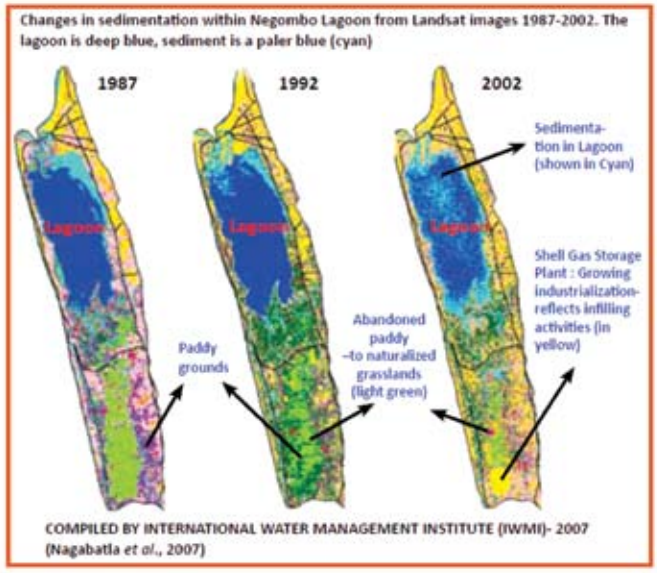
The information presented at the colloquium was mainly facts without inadequate context. Information without context cannot build knowledge with understanding. The narrative on geomorphology in this section fills that gap. It is necessary to emphasize here that much of the decline in estuaries and lagoons has been caused by policy failure combined with planned and purposeful development that resulted in unintended consequences. In this context it is necessary to note that *'… problems created by a particular form of thinking cannot be solved by the same form of thinking'* (Einstein quoted in Ackoff 1974). Aspects of unintended consequences of planned development were addressed in sub-section 2.1.

During earlier decades the limitations of estuaries to recover from uses that increased sedimentation was inadequately known. Today, a more sophisticated form of thought is required if the problem of estuary degradation is to be mitigated. This awareness is enabled by remote sensing technology which detects and separates water quality based on reflectance associated with suspended sediment loads and associated sedimentation patterns. Such earth observation data and geospatial tools have assisted in developing integrated geospatial models/methods for wetland mapping and change analysis (Nagabatla *et. al.*, 2008). Thus water with a greater quantity of sediment shows up in a particular colour *(Figure 5.7)*. The colour 'cyan' – a lighter tint of blue has been used for depicting the sedimentation pattern in Negombo Lagoon during the 15 years period from 1987-2002 (Nagabatla *et. al.*, 2008). It demonstrates that 'infilling' by sediment has accelerated particularly where the main feeder river flows into the lagoon and in the channel segment which connects the wide basin to the sea (the tidal inlet area).

The form of thinking that caused the problem of decline in estuaries is 'fragmented thought' about ecosystems combined with compartmentalized institutions (see Introduction). Both fragmented thought and compartmentalized institutions focus upon the parts of the estuarine systems (e.g. fishery, hydraulics, investment opportunity, mangroves, among others) instead of the whole. The form of thinking required for solving the problem must be based on the 'whole' that means systems thinking that considers the 'whole', and the 'parts' as interrelated, functional components of that whole (Ackoff 1974; Holling 1971; Odum 1971). The recognition for systems thinking flows from the General Systems Theory (GST) propounded by Von Betalanffy (1950) and applied to open systems in biology, specifically living organisms. Odum (1971) extended this form of thinking also to ecosystems that include an interacting combination of physical and biological processes. Therefore systems thinking flows from a well-founded theoretical base, some ingredients of which constitute the backbone of fishery science. Therein lies also the need to be conscious of the hydrodynamics of estuaries and lagoons. Simply put, fish cannot survive without water. In the social-ecological systems approach we impart greater wholeness to ecosystems by combining them with society.

Figure 5.7 *Acceleration of sedimentation that causes 'infilling' is demonstrated by the expansion of the area with the colour 'cyan' a lighter tint of blue which contrasts with the darker blue of deeper water in the lower part of the figure (Nagabatla et al., 2008).*

The view looking south into a placid lagoon belies the hydrological reality (1989). The mouth is stabilised by engineering. The set of three geographic information system images below show the state of sediment infilling (cyan – pale blue) in a period of 15 years.



The sequential changes in one of the most significant barrier-built estuaries in Sri Lanka is depicted by the increasing incidence of sediment deposition (physical change) that has occurred during the past several decades. The total annual value of the fishery in the lagoon was estimated as Rs. 150 million two decades ago (Samarakoon and Van Zon 1991). This fishery resource has persisted through the past two decades despite contradictory land uses, and because the rising value of shrimps and crabs compensate for falling catches. Remote sensing by aerial photography and through satellite imaging combined with geographic information systems (GIS) technology enable construction of narratives of change that are compelling simply because they are undeniable and verifiable. The increase in the areas shown in pale blue (cyan) from 1987 to 2002 shows shrinking of the water quantity and area. This is verified by the experience of Negombo Lagoon fishers who now cannot operate their fishing gear in many locations where they fished in previous years. If unmanaged, sediment deposition will eventually choke the narrow channels that allow the exchange of water between the sea and the lagoon basin. The water exchange is essential to carry early stages of shrimp, crab and many fish species into the safety of the lagoon where they grow to a commercial size before migrating back to the sea to breed. At present the mouth of Negombo Lagoon is kept open by engineering structures since it is necessary for navigation by the multi-day fishing craft. Negombo Lagoon is arguably the most significant anchorage for marine fishing craft. Together withfishery collapse, the livelihood of 3000 households also will suffer (CEA/Euroconsult 1994; CCD 2005).

5.6 Case Study of an SES – Negombo Lagoon Barrier-built Estuary

Analysis of an SES is difficult because of its complexity, the inter-relationships among the many variables *(Figure 5.1)*, and the newness of the approach. A case study facilitates understanding. Therefore, Negombo Lagoon, the best studied barrier-built estuary is Sri Lanka, is used for the purpose. It is the intention of this report to encourage case study analyses of other barrier-built estuaries and lagoons. The narrative is presented in a highly summarized form, but with adequate reference to the key attributes that relate to the main variables in *Figure 5.1,* unpacked into component variables in *Table 5.3a – 5.3f.*

Why Negombo Lagoon?

Negombo Lagoon is used as a case study since it:

- has a long history of traditional land use for fishery, settlement and trade,
- was the national focal site for initiation of fishery modernization starting in the mid-1950s,
- was the sink for waste disposal from the first national industrial estate established in the 1960s,
- allows changes in the resource system can be traced from of aerial photograph sequences dating back to the 1957,
- demonstrates community-based fishery management practices that demonstrate sustainable resource sharing,
- has a history of impacts of water management for agriculture dating back several centuries,
- shows impacts of planned and unplanned urbanization,
- has a strategic land use zoning plan (Master Plan) based upon a detailed ecological survey,
- allows analysis of the sequential transfer of institutional responsibility for implementation of planned management,
- shows impacts of major infrastructure development projects (marine fishery anchorage, Colombo Katunayake Expressway),
- reveals progressive ecosystem degradation owing to private self interest ‘dressed’ as public interest,
- demonstrates countervailing power of ‘organized’ traditional fisher communities in resisting imposed development,

- continues to provides livelihood income on a significant scale (Part 1: Introduction, *Table 1.1*).
- has potential for sustainable inter-generational transfer of livelihood benefits in the event of wise management of multiple-uses,
- exposes fragmented scientific study (simplified science) driven by disciplinary demands with remarkably low inter-disciplinary exploration to address inherent complexity.

Resource System (RS)

Some explanations that relate to Negombo Lagoon are already provided in an earlier section on 'Evolution of barrier-built estuaries and lagoons'. *Table 5.3a* addresses the other relevant variables of the particular RS. The estuaries are conspicuous geomorphological attributes of island Sri Lanka with its 103 rivers. Each river is associated with a simple, funnel-shaped riverine estuary at the junction with the sea, or it passes by way of an expanded basin as in the case of Negombo Lagoon. Most early settlers in Sri Lanka travelled inland by way of estuaries, and generally established settlements in the vicinity (Sivasubramaniam, 2009). The ready availability of fish as food was a major factor. These historic entry points subsequently became, trading stations, international ports as in the case of Negombo Lagoon, as well as expanded settlements. Such historical legacies have driven some of the changes in the form and functioning of many barrier-built estuaries.

Lagoons did not become sites of settlement in the same way. Problems of navigation through frequently blocked lagoon mouths, appear to have prevented settlement expansion. Nevertheless, plans for expansion of industry, particularly in post-independence Sri Lanka, included estuaries and lagoons as ready-made natural sinks for waste. In this planning scenario, Negombo Lagoon which was a traditional sink for human sewage, from the mid-1960s also served as the sink for industrial waste from the first industrial estate in Sri Lanka established at Ja-Ela.

Subsequently, Negombo Lagoon developed as the main fishery anchorage with the largest fishery output in the island. Most fishery modernization interventions were first tested at Negombo. With the growth of urbanization and trade, pressure on land in the vicinity of the tidal inlet, escalated. The demand for housing land was boosted further by the establishment of the first investment promotion zone in Sri Lanka on the eastern border of the water body. Today the Negombo Lagoon serves as a Resource System for several categories of Resource Units including fish, property (mainly land for housing), and the absorptive capacity for diluting wastes. However, there is no effective law enforcement and management for balancing the impacts on the total RS.

Table 5.3a. Characteristics of the resource system (RS) driving change in the Negombo Lagoon SES defined in terms of the sub-variables (Ostrom, 2007).

Resource System - RS	
Sector	Environment / inland fishery in the barrier-built estuary coastal ecosystem
1. Clarity of system boundary	The boundary is recognized as the intertidal shoreline situated within four administrative divisions (Negombo, Katana, Ja-Ela and Wattala)
2. Size of resource system:	Estimate surface area 3,000 ha, but the more critical determinant of system performance, water depth and dimensions of tidal inlet are diminishing. Annual sediment deposition rate is 70,000 tons / year since 1990 (Samarakoon and Van Zon, 1991). Habitat space for fishery stock diminishing.
3. Productivity system	Freshwater from land drainage mixing with twice daily tidal inflow from the sea to form brackishwater, with species that have high physiological tolerance to salinity frequent salinity fluctuations. The main base of the food web is provided by seagrasses, and secondarily by mangrove roots systems and litter fall which also support rich 'aufwuchs'. Most valuable penaeid crustaceans grow in brackishwater and migrate to sea for breeding.
4. Human constructed facilities	Planned settlements that have spread to filled inter-tidal areas, piers and pier-side facilities for fish landing, engine repair shops, fuelling stations, roads and bridges, hotels, aquaculture cages and ponds, mangrove parks, erosion protection revetments, municipal waste discharge systems, industrial waste discharge systems.
5. Equilibrium properties	Daily tidal flushing, seasonal stormwater flooding, cyclical change from freshwater to brackishwater accompanied by cyclical migrations of fishery organisms from the sea and river to supplement entirely brackishwater organisms.
6. Predictability of system dynamics	Continues with seasonal weather changes since the tidal inlet is kept open by engineering interventions.
7. Storage characteristics	Volume of water is diminishing because of exponential increase in sediment deposition, severe seasonal eutrophism because of unflushed industrial and municipal wastes as indicated by filamentous algal blooms, replacement time has increased from 20 days to 30 days.
8. Location:	Gampaha District, highly industrialized and urbanized.

Resource Units (RU)

Intuitively, resource units (RUs) associated with Negombo Lagoon connect with the fishery *(Table 5.3b)*. Negombo is legendary for shrimp, e.g. 'Meegamu isso'. However, because of the urban setting in which the northern segment of the RS is situated, inter-tidal land has taken on resource unit character with which distinct market prices are associated. Additionally, the land-water linkage is significant for the functioning of the RS as an anchorage for the marine coastal, and marine offshore fisheries. The parking of boats alongside piers and inter-tidal shoals progressively encroaches into fishery habitat *(Figure 5.7)*. These boat parking areas would have some 'economic value'. Thus the value of the anchorage, in terms of RUs, the number of boats serviced, may be estimated on the basis of the cost of building a fishery harbour outside of the Negombo Lagoon (as proposed in 1988). The water body of Negombo Lagoon which has a measurable volume also has a limited capacity to absorb and dilute waste material from industry and domestic sources. These diverse values have not been given consideration in planning development activities.

Users (U)

Table 5.3c pertains to variables that relate to the number of primary stakeholders, traditional fisher households that depend on it for livelihood. However, the classes of users of the whole barrier-built estuary system include marine fishers who use it as an anchorage, the landless and land speculators who perceive the inter-tidal areas as investment opportunities for property development, the industrialists and local government authorities (LGAs) that regard it as a sink for waste disposal among others, biodiversity conservation NGOs that satisfy immediate interests by implementing diverse projects that are not harmonized with the functioning of the system, among others

Governance System (GS)

The GS (the decision-making processes) that shapes the development activities that are implemented within Negombo Lagoon, its periphery (the inter-tidal areas), the watershed and the contiguous coastal sea flow from policies and jurisdictions of government agencies *(Table 5.3d)*. These aspects are examined in greater detail in the technical report captioned "Building Interactive Societal Terrain for Environmental Management" (CEA/Arcadis-Euroconsult/MENR, 2003). The structure of decision-making is highly top-down and anchored in political power. Simultaneously, the stake-net fishery which is co-managed demonstrates all five attributes of effective and sustainable common property resources management (CEA/Arcadis-Euroconsult/MENR, 2003). However, this system is confined to a small part of the barrier-built systems – the channel segment and within a defined period of about 12 hours each day between sunset and sunrise. All other fishery practices have diverse forms of limitations of access based upon traditional territorial use rights of village communities (Samarakoon and Van Zon, 1991).

Figure 5.8 *Competition for space for parking sites occurs among modernized marine fishing craft for which Negombo Lagoon has become a 'free' anchorage and traditional fishing craft. In the scramble for parking space and establishment of fish landing sites, Land along the fringes are being lost from the fishery habitat (*photos - Jayampathy Samarakoon*).*

Top left: Multiday offshore marine fishing boats pack the piers along the waters' edge for convenience of loading and offloading. The outrigger canoe with a collapsed sail in the foreground is a traditional shrimp fishing craft returning home. *Top right*: Fibeglass reinforced plastic (FRP) boats with outboard engines parked on sand banks, some stabilized by mangroves. The FRP boats fish in the nearshore coastal sea and supply a major part of the small pelagic fish (sardines and herrings). *Bottom left:* A traditional stake-net fishing craft, with the elongate hull parked alongside 3 ½ ton (displacement) inboard motor boats. Note that the FRP boats and the fishing craft in the picture on the left use sediment banks as parking areas. *Bottom right:* Traditional fishing craft crowd the site of fish landing shed provided by way of a roofed-concrete platform. The low elevation of the bridge in the background is the sole barrier controlling the spread of the multi-day boats through the water body. This continuous competition for parking space is driving land use in a way that reduces fishing area. This shrinkage of the water body is aggravated by other land uses, mainly settlement expansion on intertidal areas. The land units are not assigned any economic value.

Table 5.3b *One of six primary variables, resource units obtained from the system (RU) driving change in the Negombo Lagoon SES defined in terms of the sub-variables (Ostrom, 2007).*

Resource Units (only the fishery) - RU	
1. Resource unit mobility	Two classes of resource units are identified: fishery (species and harvested quantity); and inter-tidal land measured in square meters. Three components of the fishery resources have differing mobilities: (a) adults migrate to freshwater, (b) adults migrate to the sea for breeding, (c) purely brackishwater and complete life cycle within Negombo Lagoon but migrate to different locations. Category (b) is higly significant and contributes to livelihood income. The adult population in the sea depend upon nursery function of the estuary. The second class of resource units, inter-tidal land does not possess mobility. As a consequence, every square meter of RU lost to land capture causes shrinkage of the RS.
2. Growth or replacement rate	Fish: Highly seasonal and varies from 3 to 6 months. In terms of land area, measured in square meters of inter-tidal area, Inter-tidal land: Neither growth nor replacement.
3. Interaction among resource units	Fish: Top predators such as sea bass feed upon early life stages of less economically important abundant species. The two resource units 'fish' and 'inter-tidal land' interact intensely. Every unit of inter-tidal land lost diminishes fishery habitat, seagrass habitat and fish nursery.
4. Economic value	Fishery: Annual value of earning in 1995 was Rs. 250 million (about US$ 5 million) Inter-tidal land: not assessed.
5. Size	Fish: Not adequately known by weight, and by numbers of ornamental fish collected. Inter-tidal land: not estimated
6. Distinctive markings	The highly significant species are identifiable by taxonomic characteristics and traditional names
7. Spatial & temporal distribution	Fish: Highly complex, related to substrate and benthic ecology, fishing methods are adapted to the micro-niches characterized by benthic ecology, different species and life stages. Inter-tidal land: the distribution occurs along a north-south gradient. The demand is highest in the north which is situated in the densely urbanized Negombo Municipality. Every unit lost to development results in the diminishment of the hydraulics that are important for sediment transportation and flushing of the channels.

Table 5.3c *One of six primary variables, users of the system (U) driving change in the Negombo Lagoon SES defined in terms of the sub-variables (Ostrom, 2007)*

Users – U (only the estuarine fishers and marine fishers)	
1. Number of users	3,000 traditional estuarine fishers; and an equal number or more marine fishers who use the estuary as an anchorage.
2. Socio economic attributes of users	Estuarine fishers who are unorganized within traditional management systems are the poorest and lowest in the social hierarchy. The youths have moved as labour into the marine fishery. Many female members of traditional fishing households have become migrant labour in Gulf countries (women), while males havemigrated to European countries, mainly Italy. Members of community-based management systems such as the co-managed stake-net fishery have a part-time income which boosts social status.
3. History of use	Traditional fishery dates back centuries. The modern marine fishery operators date back to mid-1950s.
4. Location	Majority of traditional users are from local villages. Owners of marine fishing craft may reside outside of local area while labour is local.
5. Leadership / entrepreneurship	Highly organizable in regard to development activities that threaten estuarine livelihood directly as in the case of organized protest against construction of a fishery harbour in Negombo Lagoon, seaplane landing strips, hotels. Inadequate anthropological information to define leadership and entrepreneurial roles. Roman Catholic church leadership dominates except in direct confrontations with state power
6. Norms / social capital	Roman Catholic church plays a major role in community cohesion, education and selected welfare activities. A wide range of foreign Roman catholic organizations contribute diverse forms of development funds for social welfare. The stake-net fishery society imposes discipline in resource extraction including limitations on access.
7. Knowledge of SES / mental models	Traditional knowledge abounds but not captured in scientific studies. Most mental models are based on mental maps of fishery stock movements
8. Dependence on resource	The lower income hoseholds are highly dependent upon the brackishwater fishery for livelihood.
9. Technology used	Traditional and non-motorized.

Table 5.3d *One of six primary variables, the attributes of the decision making process, the governance system (GS) driving change in the Negombo Lagoon SES defined in terms of the sub-variables (Ostrom, 2007)*

Governance System - GS	
1. Governmental,	Several bureaucracies are manadated with responsibility but none can be regarded as accountable. Department of Fisheries and Aquatic Resources Development (DFARD) primarily responsible for enforcing fishery regulations, co-management measures and social welfare. Ceylon Fishery Harbours Corporation is responsible for anchorage for marine fishery. Coast Conservation Department (CCD) is the regulator for land use in the official coastal zone. The Forest Department is responsible for mangrove vegetation. Central Environmental Authority primarily responsible for pollution control and EIA. National Aquatic Resources and Development Agency is mandated with research on relevant aspects. Bureaucratic fragmentation is high and cripples decision-making. Institutional arrangement mandated by the Fisheries Act generally are undermined by power-conscious bureaucracies.
Roman Catholic Church, NGOs, international NGOs, community organizations	Leadership at the community level is provided by the Roman Catholic Church. Efficient operation exists solely in the community-based management of the stake-net fishery. Patronage of Roman Catholic politicians coupled to their own immediate interests drive most land uses. Diverse non-governmental organizations and community-based organizations exist but constrained by funding shortages. Most are interested in staff renumeration for continuity. NGOs that have access to adequate funds such as NAFFSO plays a pivotal role in agitation and advocacy. NGOs with access to international networks implemented fragmented social welfare programs with little regard to the structure and functioning of the RS.
2. Network structures	A few have demonstrated effectiveness such as NAFFSO which is linked to the International Collective of Fishworkers
3. Property-rights systems	Informal village-centered TURFs exist within the estuary system. The Stake net Fishery Society has been allocated legal property rights through a co-management intervention.
4. Operational rules	Exists in the Stake–net Fishery. Otherwise 'uses' operates on the 'might over right' principle in a political culture that incorporates a high level of "structural violence" (*sensu* Galtung, 1990).
5. Collective-choice rules	Inadequately visible
6. Constitutional rules	Inadequately visible
7. Monitoring and sanctioning processes – "right to information"	Highly effective in the Stake-net Fishery. Bureaucratic negligence by default is the norm owing to intense interference of politicians based on 'party-political' allegiances.

Interactions (I) and Outcomes (O)

The relatively small size of the water body does not allow impacts of the divers uses to be confined to local areas. The oil pollution from marine fishing boats in the tidal inlet area is disperse widely though the water body by the tidal currents. The interactions and outcomes are both complex and dynamic *(Table 5.3e)*.

Table 5.3e Two of six primary variables, interactions (I) and outcomes (O) driving change in the Negombo Lagoon SES defined in terms of the sub-variables (Ostrom, 2007)

Interactions (I) – Outcomes (O)	
Interactions relates to fishery in the brackishwater body	
1. Harvesting levels of diverse users	Unregulated in most fishing methods except in the Stake-net Fishery. In the Stake-net Fishery, harvest levels are regulated by rules of operation
2. Information sharing among users	Occurs informally during peak fishing seasons and by way of imitation 'following the examples' of fishers with better catches
3. Deliberation process	Applies in the case of the Stake-net Fishery
4. Conflicts among users	Ranges from intense to opportunistic. Periodically violence erupts. Violent conflict in the past stimulated the evolution of the 'community-based management' and equitable resource sharing in the Stake-net Fishery
5. Investment activities	Mainly in relation to gear maintenance and replacement including FRP substitutes for timber hulls of boats. Some investment in aquaculture (cage culture) but discouraged because of expropriation of common-property resource space.
6. Lobbying activities	Marginal in relation to other uses of the resource system including marine fishers, investors in activities that discharge wastes into the brackishwater body, tourism and communications infrastructure developers. Political activism high when the traditional fishers observe and understand threats to the resource system.
7. Social performance measures	Sporadic and inadequately monitored.
8. Ecological performance measures (e.g. overharvested, resilience, diversity)	Sporadic and inadequately monitored for understanding species and ecosystem trends. Sporadic monitoring of key indicator of resilience, sedimentation rate and loss of water quality, reveal exponential rates of increase.
9. Externalities to other SESs	Pollution impacts noted in the linked coastal marine fishery. Depletion of shrimp fishery in the coastal, nearshore traditional shrimp grounds.

Related Ecosystems (ECO)

The dominant related ecosystems are the watershed and the coastal sea *(Table 5.3f)*. Pollution in the water body is chronic and continuously increasing. The main source of industrial pollution is from the watershed where the Ja-Ela Industrial Estate. The industrial estate consists of medium and small-scale industries. Some medium-scale industries treat their wastes, while several others including the majority of small scale industries do not have any treatment facilities. Domestic and municipal wastes from settlements at the periphery of the water body add to the pollution load. Filamentous algal blooms, the surest indicator of eutrophication in brackishwater bodies, have now become chronic features. The fishery productivity of the bracksihwater body depends upon the seasonal recruitment of larval (planktonic) stages of fish and crustaceans. The vigour of recruitment appears to be diminishing because of the combined effects of toxic oil pollution from the marine anchorage at the tidal inlet and impeded water exchange.

Table 5.3f *One of six primary variables, related ecosystems (ECO), driving change in the Negombo Lagoon, SES defined in terms of the sub-variables (Ostrom, 2007)*

Related Ecosystems (ECO)	
1. Climate patterns	Sea level rise may restore filled areas of the brackishwater body to the fishery production area. Anticipated increases in rainfall may assist ion flushing sediment and pollutant deposits. Increased runoff from a rapidly urbanizing and industrializing watershed may undermine benefits from improved flushing.
2. Pollution patterns	Likely to increase unless waste treatment is implemented, including oil pollution from marine fishing craft.
3. Flows into and out of focal SES	Hydrology, expected to be steady annually unless an extreme event such as a river diversion occurs.

5.6.1 Case study inferences

The purpose of applying a diagnostic analysis to the Negombo Lagoon social-ecological system (SES) was to demonstrate a methodology. Such a methodology is required if we need to develop a reliable approach toward generating information adequate for managing such complex ecosystems. The disaggregation of the SES into variables and sub-variables that could be assembled in eight layers that directly and indirectly influenced the processes of change in the interacting component parts assisted understanding of change trends in the total system. Many variables appear to be in need of simultaneous attention – a daunting challenge. Techniques, however, are available for reducing the magnitude of the challenge. The scope of this report does not allow

the analytical process to be taken to the next stage – i.e. organization of variables and sub-variables in hierarchies of dominance. This enables identification of the strategic points at which management interventions would be most effective. The benefit of such hierarchical ordering is that it provides for substantial reduction of the number of variables that need to be addressed in an integrated management plan. As an example, land uses that shrink the water exchange pathways would rank very high in such an ordering of variables. In that context investing money in other management interventions of lower rank would be wasteful of limited funds. Any meaningful strategy, however, for addressing management problems would require the application of inclusive, good-governance procedures to develop codes of conduct (sets of rules) coupled to appropriate incentives and penalties.

5.7 Ecosystem Sustainability System: Economic Valuation

The preceding sub-section 5.5 demonstrated that the effective management of complex systems such as barrier-built estuaries and lagoons requires that particular sets of variables need to be prioritized. The manner in which such prioritization occurs is highly technical and requires inter-disciplinary and trans-disciplinary discourse and planning. However, even more fundamental is the recognition that a particular barrier-built estuary or a lagoon must be properly managed. That recognition must arise from the standpoint of money, i.e. relative economic value of a particular system. *Table 1.1* showed at the outset that the total earnings from the fishery in the Negombo Lagoon reported in 1996 exceeded Rs. 250 million (US$ 4 million) annually. This is a snapshot of a high 'present value' in 1996. Is this an adequate appreciation of economic value? Specialists in economic valuation of ecosystems argue that the time spans across which economic value is calculated must expand to include 'intergenerational equity' (Sumaila and Walters, 2005). An appropriate valuation would include the following stages (Sumaila *et.al.*, www.http://oregonstate.edu/dept/IFET/2000/papers/sumail1.pdf):

i. Constructing present and past ecosystems using ecosystem models;
ii. Computing the market value of past and present ecosystems;
iii. Valuing Ecological-Economic benefits of past and present ecosystems;
iv. Determining the Ecological-Social-Economic value of past and present ecosystems; and
v. Analyzing the outcomes of evaluations in stages (i) – (v).

The evolving approach to valuation of ecosystems was inspired by the UN's Millenium Ecosystem Assessment (MEA) completed in 2005. It demonstrated that many options exist to conserve or enhance specific ecosystem services, such as livelihood support and food security, in ways that reduce negative trade-offs or that provide positive synergies with other ecosystem services. The bottom

line of the MEA findings is that human actions are depleting Earth's natural capital, putting such strain on the environment that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted. At the same time, the assessment shows that with appropriate actions it is possible to reverse the degradation of many ecosystem services over the next 50 years, but the changes in policy and practice required are substantial and not currently underway (WRI, 2006). Estuaries and lagoons rank among the most threatened ecosystems on earth. The experience in Sri Lanka confirms the findings of the MEA for the barrier-built estuaries and lagoons.

5.7.1 Ecosystem services of barrier-built estuaries and lagoons

The social-ecological systems approach and the MEA are congruent. *Figure 5.8* provides indications of the extent to which it is possible for socio-economic factors to mediate the linkages. Mediation means, as an example, whether or not it is possible to purchase a substitute for a degraded ecosystem service. In that event, a high potential exists for mediation. The strength of the linkages and the potential for mediation differ in individual estuaries and lagoons. In addition to the influence of ecosystem services on human well-being shown here, other factors – including other environmental factors as well as economic, social, technological, and cultural factors – influence human well-being, and ecosystems are in turn affected by changes in human well-being (see *Figure 5.9*). A common example in Sri Lankan estuaries and lagoons is that between poverty and fishing. As poverty increases in communities associated with these water bodies, more members of these communities begin to fish as an activity of last resort.

5.8 What Are The Sustainability Options For Barrier Built Estuaries and Lagoons?

The synthesis demonstrates that barrier-built estuaries and lagoons together with communities that depend on them for livelihood and food security are in a state of progressive and fatal decline. The problems that directly or indirectly impact the SES as a whole, and livelihoods in particular, will not respond to short-term remedies. They are embedded in diverse layers of causes which require progressive unraveling and building of mutual trust among stakeholders. In order to intervene positively requires an altered consciousness which combines:

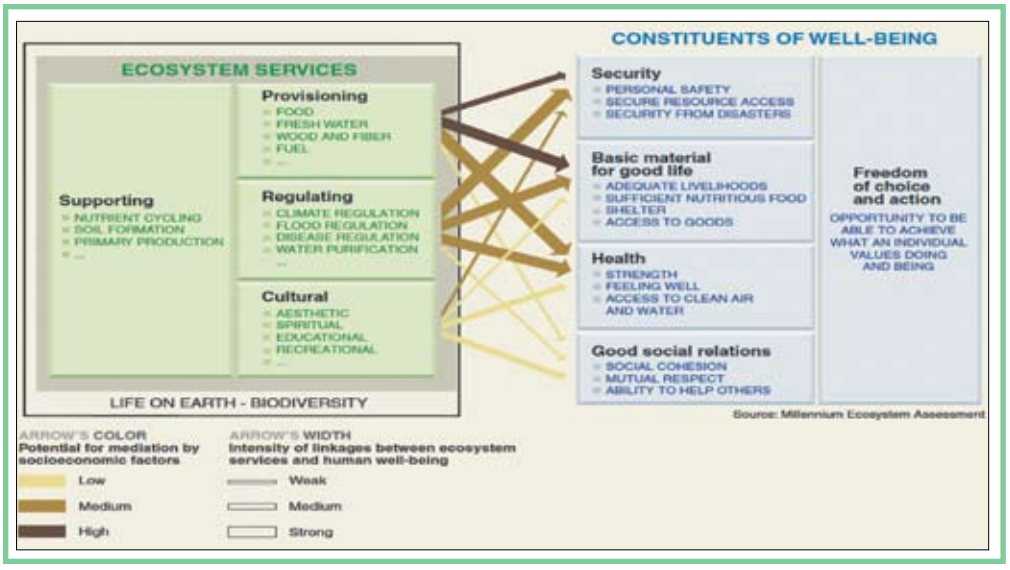
- Moral vision firmly based on developmental equity that rejects existing poverty.
- Understanding that mismanaged ecosystems result in loss of natural capital resulting in negative implications for the national and regional economies including employment.

- Recognizing the heavy socio-economic burden, including social unrest, that the state may have to face in the event that alternative livelihoods cannot replace those lost by way of degraded barrier-built estuaries and lagoons.

The available options therefore may be examined in the:

- national poverty context, and
- implications of ecosystem restoration.

Figure 5.9 *The figure depicts the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered in the relationship between estuaries and lagoons and people who use their resources or depend upon their amenities.*



5.8.1 National poverty context

The distribution of poverty in Sri Lanka parallels the dependence of the population on natural resources for employment and income and their rural settings *(Figure 5.10)*. The key natural resource for coastal communities include barrier-built estuaries and lagoons (see Introduction, *Table 1.1).* In order to at least support incomes that enable these communities to even exist at a poverty level, the decline in fishery productivity needs arresting and/or reversal. Here again policies and investments come into play. This is an aspect that has to be analyzed at a level that goes beyond the scope of the present narrative. Nevertheless, it is useful to reflect on some aspects of Sri Lanka's historical experience in regard to equity in development.

Figure 5.10 *The figure depicts relationships among indirect and direct drivers of ecosystem change, impacts on ecosystem services, and eventual consequences for human well-being. Changes in drivers that indirectly affect ecosystems such as population (demography), technology, lifestyle (upper right corner in figure) can lead to changes in drivers directly affecting ecosystem structure and function, such as land clearing and settlement expansion that create filling of the water body (lower right corner). These result in changes to the ecosystem and the services they provide such as fishery and drainage (lower left corner), thereby affecting human wellbeing. These interactions can take place at more than one scale and can cross scales. For instance an international demand for shrimp may lead to overfishing. Similarly the interactions can take place across different time scales. Different strategies and interventions can be applied at many points in the framework to enhance human wellbeing and to conserve ecosystems (source: WRI 2006).*

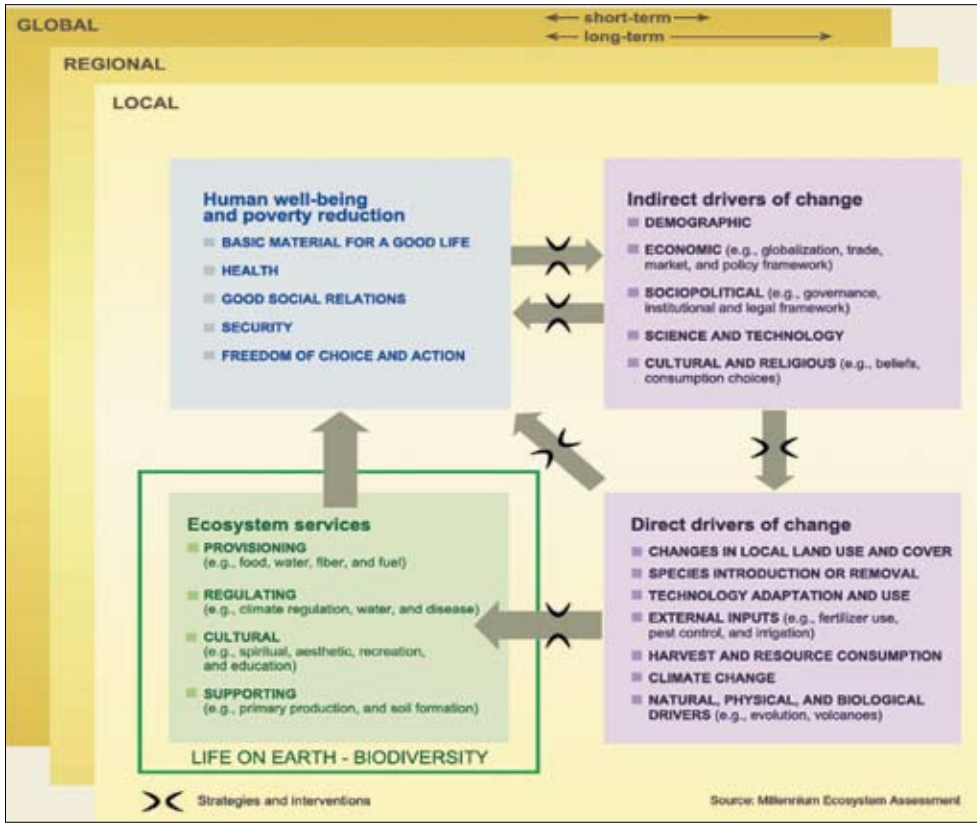
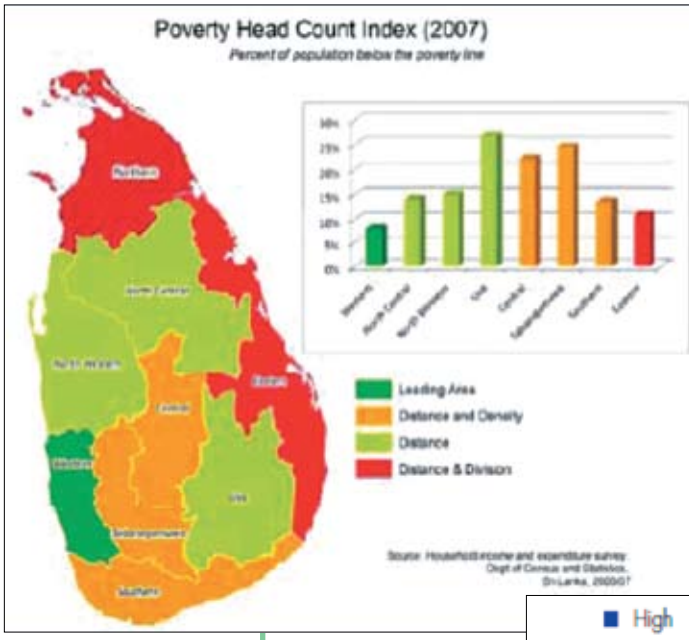
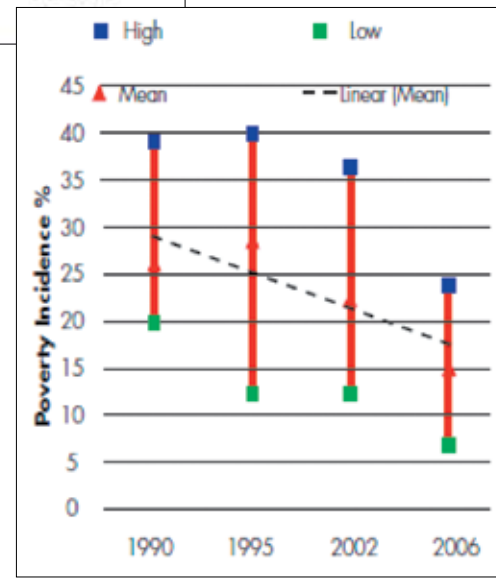


Figure 5.11 *Poverty distribution in Sri Lanka reveals that the poverty headcount index is higher in all Districts with a coastal boundary, with the exception of Colombo. The distribution of poverty shows the failures of the existing development model to ensure distributional benefits from national economic growth. Poverty incidence, however, has been declining since 1990 (*World Bank 2010). *Child manourishment (under 5 years) shows a pattern similar to distribution of poverty. The form of coastal livelihood based on fishing ensures a substantial contribution to nutrition from fishing.*





5.8.2 Marginalization of barrier-built estuaries and lagoons and associated livelihoods

The foregoing narratives based on the unintended consequences of development and the diagnostic analysis of barrier-built estuaries and lagoons as socio-ecological systems (sub-sections 5.3 and 5.4) demonstrate that they have not been assigned significance in national development planning. Thereby marginalization of the natural resource system and dependent livelihoods was inevitable. Economic marginalization of segments of the population has social consequences as demonstrated by recent history in Sri Lanka.

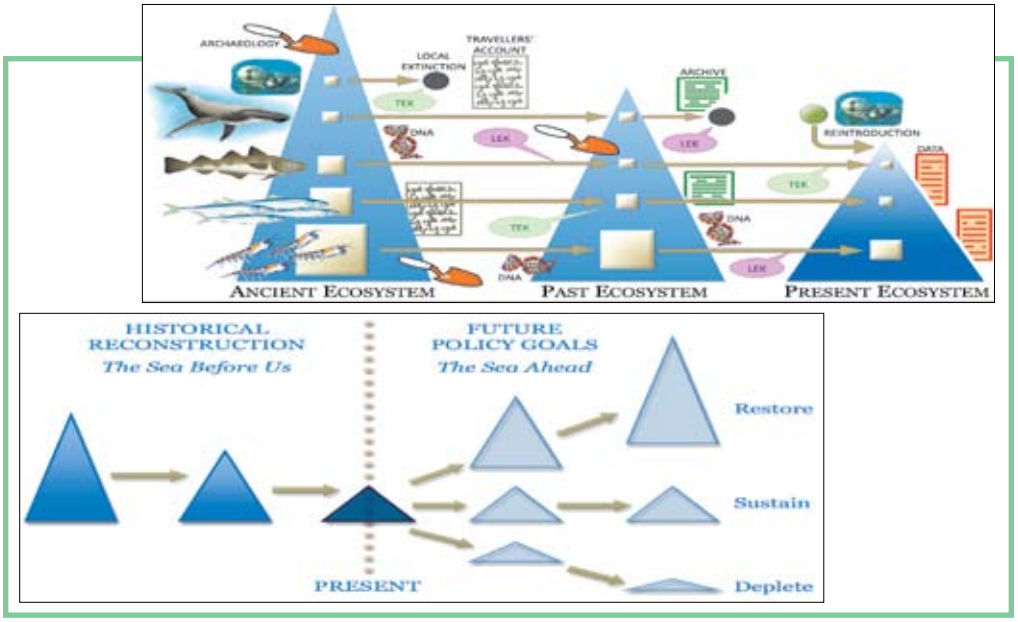
Marginalization of segments of a population is largely an expression of the exercise of government authority (practice of administrative procedures and law enforcement) and biases in state interest (those that ar associated with collaborations among government, private sector and other organizations). Government and state practices are inextricable linked with 'political power', i.e. the capabilities of groups of people to change the behaviour of others for diverse reasons including public good or private interest (Nye, 2004; Etzioni, 1968). A similar situation was revealed in sub-section 5.3 where the unintended consequences of planned development of barrier-built estuaries and lagoons was considered.

On a wider scale, also, the Sri Lankan polity has passed through a series of episodes since independence in 1948 where marginalized communities have engaged in violent protests against the 'state' (Government of Sri Lanka, 1990; Weiss, 2010). Grievances that sparked violence and loss of life originated in diverse forms of marginalization than increased poverty. The factors of marginalization included, economic status, caste, language, ethnicity, education among others (Government of Sri Lanka, 1990; Weiss, 2010). Coastal communities have been mentioned as having been discriminated against based upon caste and associated factors, driving them to participation in violent conflict (Government of Sri Lanka, 1990). Recent protests by the Negombo Lagoon fisherfolk, the Kalpitiya coastal small-scale fishers, among others appear to signal the persistence of a sense of marginalization that may produce a range of grievances. Therefore, the problem of degradation of barrier-built estuaries and lagoons needs to be considered in the context of 'political ecology' in addition to other technical aspects that were brought together at the colloquium. The concept of 'structural violence' (Galtung, 1990) was used by Bohle and Funfgeld (2007) in their research into the political ecology, i.e. control of fishery resources in Batticaloa Lagoon. These aspects are beyond the scope of the present report.

5.9 Ecosystem restoration

Restoration of barrier-built estuaries and lagoons requires many intervening steps including research, planning and public consultation (e.g. Pitcher, 2008). The only situation in Sri Lanka in which restoration was actually carried out was in Lunawa Lagoon, a small brackishwater body (27 ha). The economic justification was urban restoration rather than 'lagoon restoration for fishery-based livelihood' (CCD, 2005a). The CCD was provided with ADB funds for partial hydraulic restoration in Negombo Lagoon under the Coastal Resources Management Project supported by loan/grant funds from the Asian Development Bank (CCD, 2005b). However, implementation of hydraulic restoration was impossible because of political obstacles (see Sections 1 and 4). Lessons from these experiences have not been adequately assessed for purposes of longer-term planning. The recent literature demonstrates that three options are available in regard to management of degraded coastal ecosystems (social-ecological systems) and dependent livelihoods: (i) depletion, (ii) sustainability, and (iii) restoration. These options require serious consideration based upon site-specific social-ecological system attributes. Pitcher (2008) provides a detailed analysis of ecosystem restoration.

Figure 5.12 *Ecosystem restoration requires harmonization between the historical processes that led to the existing state and policy goals backed by investment* (Pitcher, 2008)*. In the absence of clarity in the understanding of the barrier-built estuaries and lagoons as social-ecological systems, policy goals themselves could be illusive while resource depletion becomes inescapable.*



5.10 Synthesis Summary

This summary draws out the main arguments from the synthesis that supports the conclusions and recommendations in Section 6: Conclusions and Recommendations.

1. The most serious cause of degradation of barrier-built estuaries and lagoons is planned development activities supported by the state. The foremost causes of the unintended, harmful consequences of planned development are a combination of ignorance, error and immediate interest. Both ignorance and error are linked to inadequate understanding of barrier-built estuaries and lagoons as complex systems.

2. The bureaucracies that are mandated with law-enforcement responsibilities and which are integral participants in policy-making are fragmented and lack a coherent mental framework to consider barrier-built estuaries and lagoons holistically.

3. The primary stakeholders, the traditional fishers are desperately engaged in livelihood activities within systems where the fish stocks are diminishing because of interactions among unmanaged micro-geomorphic processes, pollution, overfishing, weak law enforcement and fragmented policy among others. Even where exemplary community-based fishery management exists as in some aspects of the fishery, e.g. the stake-net fishery in Negombo Lagoon, learning is stunted and adaptive management illusive.

4. Neither the primary stakeholders nor the policy makers have a meaningful appreciation of the economic value of 'ecosystem services' of whole barrier-built estuary systems nor lagoon systems. Both primary stakeholders and bureaucrats are surprised when made aware of the magnitude of annual earnings from the fishery alone in the major barrier-built estuaries. Development planners will be in a position to arrive at more balanced decisions among tradeoffs if they are provided with:

    - mental maps of entire systems linked to micro-geomorphic change trends, and
    - economic valuations based on intergenerational equity.

5. The economic marginalization of communities dependent on fishery-based livelihoods appears to be an aspect of power relationships with more privileged groups that have access to state power. This requires mitigation in the event that unpleasant consequences are to be avoided of economic marginalization that increases poverty.

6. Avoidance of unintended consequences of planned development is the foremost priority for increasing the resilience of barrier-built estuaries and lagoons. This can flow only from broadened discourse, and fully participatory (inclusive) decision-making (good governance) and sharing access to resources of the ecosystems (power sharing).

Section 6

Conclusions and Recommendations

6.1 Preamble

> *"People can foresee the future only when it coincides with their own wishes, and the most grossly obvious facts can be ignored when they are unwelcome."*
> *– George Orwell*

Humanity and money drive all problems associated with development of natural resources, and so it is with barrier-built estuaries and lagoons.

- The humanitarian aspect includes livelihoods, food security and the fishery-dependent communities' expectations for themselves and their children (the next generation). When the behaviour of government and civil society causes deprivation among the less priviledged segments of society it results in 'structural violence' (Galtung, 1990). Structural violence resulting in marginalization, as opposed to physical violence, generally occurs when policies, administrative procedures and entrained behaviour are discriminatory. It may occur through loss or diminishment of livelihoods, for example, in the weaker and poorer segments of society from unintended consequences. Such segments of society lack countervailing power that flows through organized mechanisms for political activism. Therefore, the conclusions are linked to measures that could reduce the incidence and magnitude of structural violence against communities that depend on barrier-built estuaries and lagoons for their livelihood.

- The money aspect includes the interests of the 'state', i.e. government and associated interests, civil society institutions, including the private sector, and non-lagoon fishing resource users, in determining how development policies and projects are implemented in relation to economic benefits and costs.

The conclusions and recommendations regarding the management of barrier-built estuaries and lagoons, stem directly and indirectly from the discourse at the colloquium and the technical analysis (see Sections 4: Hydrology and 5: Synthesis). The points made during the discourse were set in a scientific context by comparison and analysis, where necessary, to enable the formulation of conclusions and recommendations. Thus, many aspects of the reality of barrier-built estuaries and lagoons were addressed to reveal change processes that are generally not perceived, or ignored even when seen. People understand these complex systems based on how they recognize reality, that is, based on cognitive maps of barrier-built estuaries and lagoons (i.e. how information is received, stored and retrieved to assist in thinking and analysis).

The summarized conclusions relate to:

- gaps in knowledge on the reality of change in estuaries and lagoons, as ecosystems
- meaningfulness of information being shared pertaining to such changes
- lessons from intended and unintended consequences of development on these ecosystems
- actions necessary to benefit from lessons learnt and to sustain benefits from estuaries and lagoons to society,
- risks stemming from the continuing neglect of integrated management of ecosystems, especially in the island context of Sri Lanka.

The conclusions serve to:

- highlight the problems and issues of public concern that merit early attention, especially those that lead to structural violence, and
- focus on high priority items that can be addressed with available financial resources and also serve as demonstration models included as recommendations.

The problems and associated practical issues pertaining to complex systems such as barrier-built estuaries and lagoons are themselves wide ranging and inter-related with each other in many ways in addition to being a part of national economic policies (macro-economic) and processes. Therefore the presentation of problems/issues in *Table 6.1* attempts to simplify this complexity and facilitate selecting those that need to be addressed directly as an outcome of the colloquium.

Mostly, specific conclusions are presented in *Table 6.1* for the purpose of simplification. See Section 5, subsection 5.10 for comments on the broad conclusions and actions thereof already taken by the government or which need to be addressed. The specific conclusions are taken a step further, in the framework of the colloquium findings and the synthesis, to formulate recommendations. The specific conclusions are ranked in relation to the nature of the problem, the public concern and the issues that arise. The recommendations pertain to those issues that rank as 'very high (VH) and couple with moderate (MP) and high priority (HP)' in the Activity Rank column *(Table 6.1)*. The criteria for the ranking of issues and activities are:

Ranking of Problems/Issues: The most important criterion is the connection between the problem/issue and the occurrence of ecosystem degradation coupled to loss of livelihood (through structural violence) without adequate measures for mitigation and/or providing alternatives. Such problems are assigned high priority (HP). Implementing solutions, however, may be very expensive because of the civil engineering requirement. Where a HP rank is coupled with high cost (HC), it becomes downgraded in the activity ranking to low priority (LP). This is simply for the purpose of assisting the MFF implementation to identify suitable problems that may be addressed within its capacity. The LP in the activity ranking does not mean to convey absence of significance in an ecosystem management perspective.

Ranking of Activities:

- The highest priority (HP) is assigned to problems and issues that may be addressed in accordance with the NSAP, and funds may be may be available within the MFF implementation framework.
- Moderate to High Priority (MP – HP) is assigned when affordable, meaningful interventions may lead towards encouraging solutions which are very expensive. For example, ecological restoration involving major civil engineering works is very expensive while community-based interventions such as strategic de-silting are more affordable. If this community-based intervention reveals high gains from the fishery the need for overall restoration will gain more acceptance.

When the Problem/Issue is ranked as very high (VH) and the relevant Activity is ranked as moderate priority (MP) or high priority (HP), the proposed intervention can be recommended for implementation.

Table 6.1 *The problems and issues of public concern shown below are relatively specific. The estimation of magnitude of financial investment is based on a combination of experience and intuition. Problem/issue ranking is very high (VH) because of ecosystem significance. However it may be coupled with very high cost of implementation (HC). Because of inability to generate funds for implementation within the MFF initiative, the same is given low priority (LP) in the activity ranking. Where possibility of implementability is high within the MFF Implementation, it is given moderate to high priority (MP; HP). Also see text for explanation.*

Problem/Issue	Nature of Public Concern caused by the problem/ issue	Proposed Intervention	Problem/ Issue Ranking	Activity Ranking
Loss of 'aquatic space' for fishery stocks in barrier-built estuaries and lagoons that support livelihoods (see section 5.2) because of competing land uses rhat occupy aquatic habitat	Alternative sources of livelihood are not available (NSAP) resulting in unemployment and poverty increase. Failures and deficiencies in the national development process, e.g. absence of targeted skill development to wean youths away from the fishery	Ecological restoration – physical desilting, opening tidal inlet, improving hydraulics	VH - HC	LP
		Mitigating industrial pollution – treatment at source	VH – HC	LP
		Mitigating municipal pollution – treatment at source	VH – HC	LP
		Mitigating encroachment, filling of estuaries and lagoons for urbanization	VH	LP
		Arresting mangrove planting under the pretext of 'mangrove restoration' (NSAP)	VH	HP
		Skill development, mainly for youths, to enter alternative occupation, promote entrepreneurship	VH	HP
Leveraging natural wealth (natural capital) to provide services that undermine sustainable use	The water body of significant barrier-built estuaries is used for providing anchorage to marine craft 'free of cost'	Imposition of fees, penalties and incentives for use of the anchorage. The fees and penalties for infringements could be allocated to safeguard traditional livelihoods and to promote skill development for alternative occupations	VH - HC	LP
Lack of appreciation of economic value: e.g. earnings from fishing, inter-generational significance and linkages	Partial information available for some barrier-built estuaries, inadequate to indicate national significance (NSAP)	Generating testable inter-generational economic valuation to enable comparison of 'wealth' from estuaries and lagoons with other forms of natural capital. Identified in the NSAP	VH	HP

Problem/Issue	Nature of Public Concern caused by the problem/ issue	Proposed Intervention	Problem/ Issue Ranking	Activity Ranking
Inadequate countervailing power to enable negotiation with legislators regarding physical fragmentation of estuary water system	Political fragmentation mediated by political agents, inadequacy of sustained activism based on community organization, inadequacy of planning dialogue (NSAP)	Knowledge (awareness) sharing as a basis for self-organizing by dependent communities founded on collective memory, improving governance, and understanding of ecosystem economic value. Providing spatial identity by placing them on maps. Identified in NSAP.	VH	HP
Fragmentation of estuary water system by communications and Flood Control & Drainage infrastructure	Flood aggravation, loss of life and property, historical carryover from past development projects	Mapping of flood sensitive locations at estuary periphery, risk level, impediments to drainage, etc, Urgent in the face of impending climate change and sea level rise	VH	HP
Marine fishery anchorage development at the cost of estuary habitat quality	Reduction of 'space' for fishery stock, oil pollution, urbanization (housing expansion)	Comparative economic valuation of 'offshore marine fishery' and estuarine fishery incorporating the public cost of subsidies for the former	VH - HC	HP
Financial support being provided for some activities that are discouraged in the NSAP	Persistent aggravation of 'unintended consequences' of plan implementation as recorded by 'small grant' and 'large grant' projects under the MFF initiative	Improve and systematize monitoring and evaluation in an 'ecosystem perspective', preferably in the ;socio-ecological system; diagnostic framework.	VH	HP
Inability of relevant agencies to provide continuity to 'cabinet approved' integrated development plans e.g. Muthurajawela and Negombo Lagoon Master Plan.	Lack of adequate commitment of relevant agencies to the 'conservation ethic' and associated law enforcement.	Review all pertinent plans and sift finding and recommendations in the context of the 'social-ecological system diagnostic framework' to create a coherent database and to facilitate identification of information and knowledge gaps.	MP	HP

6.2 Conclusions

This section focuses on all the problems and issues that are included in the ranking column. Note that some high priority problems/issues in the respective ranking column are coupled with a high cost (HC) for implementation. This does not in any manner suggest that those problems and issues may be ignored. If ecosystem sustainability is to be achieved all problems and issues in *Table 6.3* must be addressed in whatever manner implementation funds are available. This section also focuses on the more addressable problems/issues that were ranked VH, but not coupled with a high cost (HC). Those problems and issues which rank as HP but are not coupled to high cost (HC) for implementation are considered for early implementation under sub-section 6.3: Recommendations. The high priority ranking from which the recommendations flow are shown in shaded segments in *Table 6.1.*

6.2.1 Loss of space for fishery stocks in barrier-built estuaries and lagoons that support livelihoods *(Rank VH)'*

1. Local populations depend on the fishery resources in the main estuaries and lagoons for their livelihoods. They know that their wellbeing and income are threatened by the accelerating ecosystem changes. While their population is increasing the income from fishing is decreasing. Alternative forms of employment and income are not available to their youth entering the labour force, mainly due to an inadequacy of education and skills training opportunities. Therefore they are compelled to fall back on the depleting fishery resources or to emigrate. They reckon the 'government' is insensitive to their plight.

2. What actions would serve the best interests of the local communities? On this matter there is a gap in understanding between the local communities and other stakeholders, including scientists, decision makers and political authorities. Sustainable solutions can be found only if the 'understanding gap' is progressively reduced and eventually bridged.

3. The physical vulnerability of micro-tidal barrier-built estuaries and lagoons to infilling (sedimentation) is not recognized and acknowledged by primary stakeholders (dependent fishers) or even other stakeholders and decision-makers. This is due to a poor understanding of the coastal area as a submergence zone, wherein barrier-built estuaries and lagoons are sediment traps, destined to die from sedimentation. Some organizations actually pay cash incentives to local community members to engage in activities that undermine the ecosystem, e.g. planting mangroves.

4. Estuaries and lagoons are indispensable ecosystems for sustaining livelihoods. They contribute to the food supply from both the 'brackishwater body' and the 'linked nearshore coastal fishery'. Generally, this role is not recognized. When estuaries die, the linked coastal fisheries also decline.

5. The annual economic value of fishery production from the major barrier-built estuaries and lagoons and the linked nearshore coastal fishery is considerable. This is not adequately recognized when planning infrastructure development that impact their hydrology, hydraulics and hydro-morphology, with consequences for livelihoods and fishery. The estimated annual value of the Batticaloa Lagoon fishery (2011) alone is Rs. 1,350 million (> US$ 12 million).

6.2.2 Meaningfulness of information

6. Ecosystem information produced by scientists is generally sporadic and focuses on the short-term, or does not adequately recognize ecosystem inter-relationships and ecosystem services of these complex systems. Therefore the reality of physical change in the form of creeping normalcy or chronic hazard goes unrecognized. Hence management approaches are fragmented and produce adverse, unintended consequences.

7. Information on relevant geographic aspects, including physical geography, land use, value of production and associated anthropology, spanning at least a decade, is not available. The available technical information is inadequate to understand the long-term trends and facilitate proper management.

8. The response of governmental authorities to events such as floods reveal that lessons from past events have been ignored. The recent floods in Batticaloa (2010/2011) brought out starkly the pivotal role of the tidal inlets of Batticaloa Lagoon in mitigating both the hazard (probability of harm) and risks (probability of damage to life and property). Simultaneously, it demonstrated that responsible decision makers had learnt nothing from the lessons of the great flood in 1957. Both hazard and risk associated with 2010/2011 were reminiscent of the events of 1957. Unless careful attention is paid to learning from the minor and major disasters development mistakes will surely recur., and the people (and government) have to bear the cost in terms of life and property.

9. Political agitation by fisherfolk against the siting of a seaplane landing strip in the Negombo Lagoon succeeded in shifting it to Dandugam Oya. It was an organized political agitation (countervailing power) propelled by their awareness of how sensitive fishery livelihoods are to physical disturbance

of the lagoon ecology. This awareness was created during the preparation of the Master Plan for Muthurajawela and Negombo Lagoons (GCEC/ Euroconsult, 1991) based on an ecological survey (Samarakoon and Van zon, 1991). Evidently enhanced environmental awareness encourages community participation and improves development decisions.

10. If sustainable management of barrier-built estuaries and lagoons is to be achieved, all stakeholders must begin to understand the limitations of physical geography of Sri Lanka. It is necessary to understand that small-scale physical changes (at a micro-geomorhic level) can trigger reverberations through the relatively small, brackish water bodies of the type that exist in Sri Lanka. Such changes then acquire dimensions of chronic disasters that eventually undermine the wider ecosystem,

6.2.3 Actions necessary for sustainability

11. Education and awareness, at all levels of society, is the essential foundation to facilitate appropriate decisions based on the economic value of long-term ecosystem services.

12. Case studies should be developed in this regard, based on a social-ecological system approach, starting with the most significant barrier-built estuaries, namely, Batticaloa, Jaffna, Negombo and Puttalam Lagoons. The methodology used in Section 5 could serve as a guideline.

13. The responsibility for the effective management of estuaries and lagoons has been entrusted to the Coast Conservation Department. This is too large a burden for a single department with highly limited powers of law enforcement. Broad-based support from community level institutions, civil society organizations and other relevant government agencies is essential to accomplish this task. To achieve this genuine governance measures based on power-sharing is required.

14. Appropriate forms of property rights should be devised and allocated in a participatory, democratic and equitable manner to support sustainable management.

15. Ways and means should be found to decrease the negative externalities of planned development. This is a core action which is considered in Section 5..

6.2.4 Intended and unintended consequences of development

16. Negative externalities of development is a subject in its own right. To gain a proper understanding of this problem requires information generated through geographic studies which use the 'landscape concept' supported by trend mapping. This can be achieved through an appropriate inter-disciplinary approach suited to the physical geography of Sri Lanka.

6.2.5 Risks stemming from the neglect of integrated management

17. The risks include loss of livelihood and employment.

18. Closing of the 'understanding gap' may be facilitated by putting into operation a set of core values, principles and guidelines, based on consensus among stakeholders. These terms may be defined as follows (Vanclay, 2006):

    - *Core Values:* Fundamental, ideal-typical, enduring, statements of belief that are strongly held and accepted as premises (is-statements).
    - *Principles:* General statements of either a common understanding or an indication as to a course of action about what ought to be done (ought-statements or should-do statements).
    - *Guidelines:* Statements by which to plan a specific course of action and which clarify how it should be done (action statements).

    The MFF initiative may contribute towards formulation of the core values, principles and guidelines by giving them substance and meaning. Core values, principles and guidelines can acquire substance and meaning to the extent that they embody economic sense, in order to make them relevant to national development policy. It is economic sense, based on generating adequate awareness, that would enable sectors involved in the development of estuaries and lagoons to balance the relevant tradeoffs.

19. Awareness of tradeoffs may be effectively generated on the basis of how human psychology and learning operate, i.e. simplified examples, models and case studies that represent complex reality. Ecosystem services valuation is a tool that is available to develop such models that would serve as cognitive maps. This evolving tool may be adequately implemented by giving consideration to the following attributes:

    - multi-disciplinarity,
    - generational and inter-generational time spans,
    - unintended externalities.

6.3 Recommendations

Information and Knowledge

1. Prepare ecosystem services valuation models for selected, politically and economically significant, barrier-built estuaries that are most threatened by development. Among others, Batticaloa Lagoon, Chilaw Lagoon, Jaffna Lagoon, Negombo Lagoon and Puttalam Lagoon may be considered for such an exercise. In view of the urgent need for technical guidance, the selection may be narrowed down to the two estuaries for which adequate information is already available, namely, Negombo Lagoon and Puttalam Lagoon. The core values and principles and guidelines that are flexible and adaptable to other estuary systems, are likely to emerge from these models to ensure win-win outcomes. Guidelines should be disseminated through appropriate training programmes.

2. The practical value of ecosystem services valuation models will increase appreciably when maps (in the form of atlas pages) support the form and content of land allocations that form the substance of the models. Then guidelines can be formulated as location-specific actions.

Institutions

3. Develop co-management partnerships between community-based organizations and law enforcement agencies to manage estuaries and lagoons as 'systems'. These partnerships should be fostered and nurtured by mechanisms such as CCD's Special Area Management Programme (SAM), appropriately modified using the colloquium findings, especially by incorporating aspects of rights (e.g. rights to livelihood, property rights, structural violence, ecosystem services etc.).

Awareness and Training

4. Strategic awareness and training will be the key to bringing about institutional change. The aim should be to instill consciousness of the need to generate 'countervailing' power among communities that depend on the fishery productivity of barrier-built estuaries and lagoons, and the linked coastal (traditional, small-scale) marine fishery.

References and Selected Bibliography

Ackoff, R L (1971) Towards a System of Systems Concepts. *Management Science*, 17(11): July

Ackoff, R L (1974) Redesigning the Future. Wiley, New York City

Ackoff, R L (1999) A Lifetime of Systems Thinking. (Leverage Points Issue 115) Copyright @ 1999 Pegasus Communications, Inc. (www.pegasuscom.com)

Ackoff, R L (2004) Transforming the Systems Movement www.acasa.upenn.edu/RLAConfPaper.pdf.

Ackoff, R L & S Rovim (2003) Redesigning Society. Stanford University Press, Stanford, California

ADB (1999) Asian Development Bank - RRP:SRI 31287. Report and Recommendations of the President to the Board of Directors On A Proposed Loan to the Democratic Republic of Sri Lanka for the Coastal Resource Management Project, November 1999

ADB (2009) Understanding Complexity. Knowledge Solutions November 2009/6. Asian Development Bank. http://www.adb.org/Documents/Information/Knowledge-Solutions/understanding-complexity.pdf.

Adger, W N, T P Hughes, C Folke, S R Carpenter & J. Rockstrom (2005) Social-Ecological Resilience to Coastal Disasters. *Science* 309 (5737): pp 1036 – 1039

Alexander, P (1995) Sri Lankan Fishermen: Rural Capitalism and Peasant Society (2nd Revised & Enlarged Edition). Sterling Publishers Private Limited, New Delhi

Amarasinghe, U S, W U Chandrasekera & H M P Kithsiri (1997) Traditional practices for resource sharing in an artisanal fishery of a Sri Lankan estuary. *Asian Fisheries Science*, 9:311-323

Atapattu, A R (1970) Territorial use rights in fisheries (TURFs) in Sri Lanka: Case studies on Jakottu Fisheries in the Madu Ganga Estuary and Kattudel Fishery in Negombo Lagoon. Indo-pacific Fisheries Commission, papers presented at the Symposium on the Exploitation and Management of Marine Resources in Southeast Asia, 16-19 February 1987, Darwin, Australia. RAPA Report 1987/10. Regional Office for Asia and the Pacific, FAO, Bangkok: 379-401

Berkes, F & C S Seixas (2005) Building Resilience in Lagoon Social-Ecological Systems: A Local Level Perspective. *Ecosystems*, 8: 967-974

Blaber, S J M (1997) Fish and Fisheries of Tropical Estuaries. Chapman and Hall, London

Blaber, S J M, D P Cyrus, J J Albaret, Chong Ving Ching, J W Day, M Elliot, M S Fonseca, D F Hoss, J Orensanz, I C Potter & W Silvert (2000) Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems. *ICES Journal of Marine Science*, 57: 590-602

Bohle, H-G & H Fuenfgeld (2007) The Political Ecology of Violence in Eastern Sri Lanka. *Development and Change*, 38(4): 665–687
http://graduateinstitute.ch/webdav/site/developpement/shared/developpement/cours/E719/printemps%202010/10.a-Bohle-Fungfeld_2007.pdf

Brohier, R L (1934) Ancient irrigation works in Ceylon. Government Press, Colombo

Bryant, R & G A Wilson (1998) Rethinking environmental management. *Progress in Human Geography*, 22(3): 321-343

Carney, D (1988) Implementing the Sustainable Livelihoods Approach in Sustainable Rural
Livelihoods: what contribution can we make? Papers for the DFID Natural Resources Advisers' Conference, July1998. DFID, London

CCD (1990) Coastal Zone Management Plan. 81 p. Coast Conservation Department, Maligawatte, Colombo

CCD (1997) Revised Coastal Zone Management Plan, Sri Lanka. Coast Conservation Department, Maligawatte, Colombo

CCD (2006) Sri Lanka Coastal Zone Management Plan – 2004. Ministry of Fisheries and Aquatic Resources Development and Coast Conservation Department, Colombo

CCD (2005) Special Area Management Plan for Negombo Lagoon. Ministry of Fisheries and Aquatic Resources Development and Coast Conservation Department, Colombo

CEA/ARCADIS-Euroconsult (2003) Final Report: Integrated Resources Management Programme (IRMP) in Wetlands – Building Interactive Societal Terrain for Environmental Management. Central Environmental Authority and Ministry of Environment and Natural Resources, Colombo

CEA/Euroconsult (1994) The Conservation Management Plan for Muthurajawela Marsh and Negombo Lagoon. Central Environmental Authority; Euroconsult. The Netherlands and Ministry of Environment and Parliamentary affairs, Colombo

Chambers, R (1983) Rural Development: Putting the Last First. London: Longman. 246 pp

Chambers, R (1995) 'Poverty and Livelihoods: Whose Reality Counts?' *Environment and Urbanization*, 7 (1): 173-204

Chapin, M (2004) A Challenge to Conservationists. *World Watch Magazine*, November/ December 2004: 17-31. http://www.worldwatch.org/node/565

Charles, A (2001) Toward Sustainable and Resilient Fisheries: A Fishery-System Approach to Overcoming the Factors of Unsustainability http://www.fao.org/docrep/009/ a0312e/A0312E13.htm

Chomsky, N (1995) Rationality/Science. *Z Papers Special Issue,* 1995

Clemett, A, S Senaratna & R. Banda (2003) Can Coastal Zone Management in Sri Lanka Sustain Local Livelihoods and Ecosystems? Improving Policy-Livelihood Relationships in South Asia Policy Process Analysis Report 2 (UK Department for International development – DFID)

Constanza, R (1989) What is Ecological Economics? *Ecological Economics*, 1: 1-7

Constanza, R & C Folke (1997) Valuing ecosystem services with efficiency, fairness and sustainability as goals. In: *Nature's Services: Social dependence on Natural ecosystems*. G. Daily (*Ed*): Island Press, Washington, D.C; 49-68

Cooley, A (2007) "Contracting Global Governors: How Project Contracts Transform Global Governance Networks". Prepared for the Authors' Conference "Who are the Global Governors?" George Washington University November 15-16, 2007

Cooray, P G (1982) An Introduction to the Geology of Ceylon. National Museum Publications, Colombo

Daily News (14/06/2010) Canned fish imports cost Rs. 15,000 b (*sic*). http://www. dailynews.lk/2010/06/14/news14.asp

Day, J, C Hall, M Kemp & A Yanez-Arancibia (1989) Estuarine Ecology. John Wiley-Interscience Publication. John Wiley and Sons, New York

De Silva, S F (1936) A Regional Geography of Ceylon. The Colombo Aporthecaries' Company Ltd. Colombo, Ceylon

De Soto, H (1989) The other path: the invisible revolution in the third world. Harper Row, New York

De Soto, H (2000) The mystery of capital: why capitalism triumphs in the west and fails everywhere else. Bantam Press, London

Diamond, J (2005) Collapse: How Societies Choose to Fail or Survive. Penguin, London

Erb, D K (1970) Landforms and Drainage of Ceylon. *The Ceylon Geographer*, 20: 1966-1970

Etzioni, A (1968) The Active Society: A Theory of Societal and Political Processes. Collier Macmillan, London

European Union (2010) Guidelines No. 4. Guidelines on the Integration of Environment and Climate Change in Development Cooperation http://ec.europa.eu/europeaid/infopoint/publications/europeaid/documents/172a_en.pdf

FAO (2000) Preliminary Assessment for the Shrimp Fisheries of the Negombo Lagoon (Sri Lanka). FAO Fisheries Circular No. 958. (Report prepared by M Sanders, A Jayawardena & S Ediriweera)

FAO (2003a) Fisheries Management 2. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries, No. 4 (Suppl. 2)

FAO (2003b) Country review: Sri Lanka (by P Flewelling & G Hosch). Review of the state of the world marine capture fisheries management: Indian Ocean. FAO FISHERIES TECHNICAL PAPER 488. http://www.fao.org/docrep/009/a0477e/a0477e00.htm#Contents

FAO (2006) Sri Lanka. Fishery and Aquaculture Country Profile http://www.fao.org/fishery/countrysector/FI-CP_LK/en

FAO (2007) Proceedings of the workshop on coastal area planning and management in Asian tsunami-affected countries. 27-29 September 2006, Bangkok, Thailand

Flewelling, P & G Hosch (2003) Country Review: Sri Lanka. In: *Review of the State of World Marine Capture Fisheries Management: Indian Ocean.FAO Fisheries Technical Paper*. No. 488. C. De Young (Ed.) FAO, Rome. 458p (http://www.fao.org/docrep/009/a0477e/a0477e0e.htm#bm14)

Foell, J, E Harrison & R L Stirrat (1999) Participation, Patrons and the Village: The Case of Coastal Zone Management in the Puttalam District, Sri Lanka. University of Sussex, UK

Friend, J & A Hickling (1987) Planning Under Pressure: The Strategic Choice Approach. Pergammon Press, London

Fuenfgeld, H, S T Hettige, M Mayer & S Senaratne-Sellamuttu (2004) Investigating Social Vulnerability in Community-based Poverty Monitoring in Sri Lanka: Scaling Down to the Household Level IMCAP - May 2004. IMCAP Program – University of Colombo (draft paper)

Gallopin, G C (2006) Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change,*16 (3):293-303

Gailbraith, J K (1952) American capitalism: The Concept of Countervailing Power. Boston: Houghton Mifflin

Galbraith, J K (1977) The Theory of Countervailing Power. In: *The Galbraith Reader*. Penguin Books Ltd, Middlesex, England; pp117-153

Galtung, J (1990) 'Cultural Violence', *Journal of Peace Research,* 27(3): 291–305

Ganewatta, P, R A D B Samaranayake, J I Samarakoon, A T White & K Haywood (*Eds*) (1995) The Coastal Environmental Profile of Rekawa Lagoon: To Support Special Area Management Planning for Rekawa Lagoon and the surrounding area. CCD, CRMP and USAID, Colombo

GCEC/Euroconsult (Greater Colombo Economic Commission & Euroconsult) (1991) Environmental Profile of Muthurajawela and Negombo Lagoon (J I Samarakoon & H van Zon *Eds*); Board of Investment of Sri Lanka, Colombo

Goodhand, J, D Hulme & N Lewer (2000) Social capital and the Political economy of Violence: A Case Study of Sri Lanka. *Disasters*, 24 (4): 390-406

Gordon, H S (1954) The Economic Theory of a Common Property Resource: The Fishery. *The Journal of Political economy*, 62 (2):124-142

Government of Ceylon (1951) Ceylon fisheries: recommendations of experts on fisheries development, research, socio-economics and industrial problems. *Sessional Paper VI*, Government Publications Bureau,
Colombo

Government of Sri Lanka (1990) Report of the Presidential Commission on Youth. *Sessional Paper No. 1,* Government Publications Bureau, Colombo

Holling, C S (1978) Adaptive Environmental Assessment and Management. John Wiley and Sons, London

Groffman, P M, J S Baron, T Blett, A J Gold, I Goodman, L H Gunderson, B M Levinson, M A Palmer, H W Paerl, G D Peterson, N L Poff, D W Rejeski, J F Reynolds, M G Turner,
K C Weathers & J Wiens (2006) Ecological Thresholds: The Key to Successful Environmental Management or an Important Concept with No Practical application? *Ecosystems*, 9:1-13

IPCC (2006) Intergovernmental Panel on Climate Change, (2001-2008) Report Series. (http://www.ipcc.ch/)

IUCN (2009) Sri Lanka National Strategy and Action Plan. Mangroves for the Future, IUCN Sri Lanka Country Office, Colombo. xxxii + 219pp

IUCN (2011) An Appraisal of Mangrove Management in Micro-tidal Estuaries and Lagoons in Sri Lanka. IUCN Sri Lanka Country Office, Colombo. viii + 116pp http://www.iucn.org/.

Joseph, L & L Kumara (2001) Report on Rekawa Lagoon. FCDRMP, GTZ, Sri Lanka

Kularatne, M G (1999) "Fishermen Without Fish", The Effects of Productivity Decline in Lagoon Fisheries on a Fishing and Farming Community and its use of Natural Resources, a Case Study of Malala Lagoon, Hambantota, Sri Lanka. MSc Thesis, International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherlands

Katupotha, J (1992) New evidence of Holocene sea-level changes in Sri Lanka. *Journal of Geological Society of Sri Lanka,* 4:39-44

Katupotha, J (1995a) Evolution and Geological Significance of Holocene Emerged Shell Beds on the Southern Coastal Zone of Sri Lanka. *Journal of Coastal Research*, 11 (4):1042-1061

Katupotha, J (1995b) Sea-level changes in Sri Lanka. Handbook of Geology and Mineral Resources of Sri Lanka. K Dahanayake (*ed.*); GEOSAS-II, Colombo, Sri Lanka

Korten, D C (1990) Getting to the 21st Century: voluntary action and the global agenda. Kumarian Press, Hartford, Connecticut.

Korten, D C (2005) The Great Turning from Empire to Earth Community. Kumarian Press, Inc. Bloomfield, Connecticut

Kuhn, T S (1970) The Structure of Scientific Revolutions. University of Chicago Press

Lauff, G H (ed.) (1967) Estuaries. American Association for the Advancement of Science Publication, 83. AAAS: Washington D.C. xv, 757 pp

Liu, S, R Constanza, S Farber & A Troy (2010) Valuing ecosystem services: Theory, practice and the need for a transdisciplinary synthesis. *Ann. N. Y. Acad. Sc.*, 1185: 54-78

Lowry, K, Pallewatte, N & A P Dainis (1999) Policy-relevant Assessment of Community Level Coastal Management Projects in Sri Lanka. *Ocean and Coastal Management*, 42: 717-745

Mead, S & A Moores (2004) Estuary Sedimentation: a Review of Estuarine Sedimentation in the Waikato Region. Environment Waikato Regional Council, New Zealand

Merton, R K (1936) The Unanticipated Consequences of Purposive Social Action. *American Sociological Review*, 1(6): 894-904

Merton, R K (1996) On Social Structure and Science. The University of Chicago Press, Chicago

Miththapala, S (2008) Mangroves. Coastal Ecosystems Series Vol. 2. IUCN Ecosystems and Livelihoods Group Asia, Colombo, Sri Lanka

Ministry of Fisheries and Aquatic Resources Development (2007) Ten Year Development Policy Framework of the Fisheries and Aquatic Resources Sector. Ministry of Fisheries and Aquatic Resources Development, Colombo. http://www.fisheries.gov.lk

Mooney, C (2005) The Republican War On Science. Basic Books, Cambridge, Massachusetts

Nagabatla, N, C M Finlayson, S Senaratna Sellamuttu & A Gunawardena (2008) Application of Geospatial Tools to Monitor Change in a Micro-tidal Estuary for the Purpose of Management Planning. *Cey. J. Sci. (Bio. Sc.)* 37 (1): 73-86

NARA/NARESA/SIDA/Stockholm University (1997) The Puttalam/Mundel Estuarine System and Associated Coastal Waters – A report on environmental degradation, resource management issues and options for their solution. P Dayaratne, O Linden & R De Silva (*Eds*); NARA, Colombo

NAP (National Academics Press) (2009) On Being a Scientist (3rd Edition). Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, Washington D.C. http://www.nap.edu/catalog/12192.html

Newsfirst 01/12/10. Negombo fishers protest seaplane. www.newsfirst.lk.

Nye, J N Jr. (2004) Soft Power: The Means to Success. In: *World Politics*; Perseus Book Group, Cambridge, Massachusetts

OCHA (2011) Batticaloa flood report 2011. http://www.OCHA_maps\OCHA_Home.mht

Odum, E P (1971) Fundamentals of Ecology. W B Saunders Company

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. *PNAS,* 104 (39):15181-15187. http://www.pnas.org/cgi/content/ abstract/0702288104v1

Ostrom, E, M A Jannssen & J M Andereis (2007) Going Beyond Panaceas Special Feature: Going beyond panaceas. *PNAS,* 104(39):15176-8 http://www.pnas.org/cgi/content/abstract/0702288104v1

Oxfam (2011) Harnessing Agriculture for Development (by Arabella Fraser). Oxfam International Research Report, Oxfam International. www.oxfam.org

Perkins, E J (1974) Biology of Estuaries and Coastal Waters. Academic Press Inc. (London) Ltd

Pieris, P E (1949) The Ceylon Littoral. Times of Ceylon, Colombo

Pitcher, T J (2008) The sea ahead: challenges to marine biology from seafood sustainability. *Hydrobiologia*, 606:161-185

Ratner, B D & E Baran (2008) From Sound Economics to Sound Management: Practical solutions to Small-Scale Fisheries Governance in the Developing World. *MAST*, 6(2): 29-33

Samarakoon, J I, S Epitawatte & R Galappatti (2008) Challenges to ICM Emerging from the Tsunami Impact Assessment in Sri Lanka. COPEDEC VII, Conference Proceedings, 2008, Dubai, UAE. 12 pp.

Samarakoon, J I, S Epitawatte & R Galappatti (2009) Moving from the rapid Investigation of Tsunami 2004 Impact on coastal ecosystems to disaster preparedness. Paper presented to the 'National Symposium on Promoting Knowledge Transfer to Strengthen Disaster Risk Reduction & Climate Change Adaptation, July 7-8, 2009, Colombo

Samarakoon, J I (2007) Land tenure and land-use change in relation to poverty, livelihoods, the environment and integrated coastal management in Asian tsunami-affected countries. In**:** *Proceedings of the workshop on coastal area planning and management in Asian tsunami-affected countries*, 27-29 September 2006, Bangkok. Food and Agricultural Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok *(*www.fao.org/docrep/010/ag124e/AG124E04.htm).

Samarakoon, J I & L Pinto (1983) Synthesis report for information on critical habitats in the coastal zone. CCD/USAID/URI. 106 pp. Unpublished report used at the Workshop on Critical Coastal Habitats in Sri Lanka leading to preparation of the First Coastal Zone Management Plan for Sri Lanka (CCD, 1990)

Samarakoon J I & H Van Zon (*Eds*) (1991) Environmental Profile of Muthurajawela and Negombo Lagoon. Euroconsult & Greater Colombo Economic Commission, Colombo

Sanders, M, A Jayawardena, & S Ediriweera (2000) Preliminary assessment for the Shrimp Fisheries of the Negombo Lagoon (Sri Lanka). FAO Fisheries Circular No. 958. Food and Agricultural Organization of the United Nations, Rome, 2000

Sivasubramaniam, K (2009) Fisheries in Sri Lanka: Anthropological and Biological Aspects. Vol. 1: Anthropology of Fishing in Sri Lanka. Kumaran Book House, Colombo and Chennai

Sorensen, J, F Gable & F Bandarin (1993) The Management of Coastal lagoons and Enclosed Bays. American Society of Civil Engineers, New York

Stirrat, J (2006) Competitive humanitarianism: Relief and the tsunami in Sri Lanka. *Anthropology Today*, 22 (5) October

Stoddart, D R (1987) To claim the high ground: geography for the end of the century. *Trans. Inst. Br. Geogr. N.S.*, 12: 327-336

Sumaila, U R & C Walters (2005) Intergenerational discounting: a new intuitive approach. *Ecological Economics*, 52;135 – 142

Sumaila, U R, S Guenette, J Alder & R. Chuenpagdee (2000) Ecosystem effects of using marine protected areas. ICEA Journal of marine Science, 57: 752-760

Sumaila, U R, T J Pitcher, N Haggan & R. Jones (2001) Evaluating the Benefits from Restored Ecosystems: A Back to the Future Approach. In: *Proceedings of the 10th International Conference of the International Institute of Fisheries Economics & Trade*. R S Johnston & A L Shriver (*Eds*); Corvallis, Oregon, USA, R.S; pp1-7, Chapter 18

Sunday Island 16/01/2011. The Batticaloa Floods of 1957-1958 by C L Arulpragasam. http://www.island.lk/index.php?page_cat=article-details&page=article-details&code_title=15981

Survey Department of Sri Lanka (2007) National Atlas of Sri Lanka. Department of Surveys, Colombo

Swan, B (1983) An Introduction to the Coastal Geomorphology of Sri Lanka. A publication of the National Museums of Sri Lanka, Colombo

UNDP (2008) Making the Law Work for Everyone. High Level Commission on Legal Empowerment of the Poor. UNDP, New York

UNEP. 2010. Blue Harvest: Inland Fisheries as an ecosystem service. World Fish Center, Penang, Malaysia. http://www.unep.org/pdf/Blue_Harvest.pdf

United States Geological Survey (2000) Vulnerability of U.S. National Parks to Sea-Level Rise and Coastal Change. United States Geological Survey. http://pubs.usgs.gov/fs/fs095-02/fs095-02.html

Vanclay, F (2006) Principles for social impact assessment: A critical comparison between the international and US documents. *Environmental Impact Assessment Review*, 26 (1): 3-14

Von Bertalanffy, L (1950) The Theory of Open Systems in Physics and Biology. *Science*, New Series, 111(2872): 23-29

Weiss, G (2010) The Cage: The Fight for Sri Lanka and the last Days of the Tamil Tigers. The Bodley Head, United Kingdom

White, A T & J I Samarakoon (1994) Special Area Management for Coastal Resources: A First for Sri Lanka. *Coastal Management in Tropical Asia Newsletter*, 2: 20-24

Wilson, G A (2009) Rethinking Environmental Management – Ten Years Later: A view from the author. *Environmental Journal*, 36(3)

World Resources Institute (2006) Millennium Ecosystem Report. World Resources Institute, New York

(Kumudini Ekaratne ©IUCN)

Annexes

Annex 1	List of Participants at the colloquium
Annex 2	Programme of the Colloquium on *Dynamics of Micro-tidal Estuaries and Lagoons in Sri Lanka*, Albatross, Water's Edge, Battaramulla, 25 February, 2011
Annex 3	Abstrac of the presentations made at the Colloquium (only those made available by the authors)

(Kumudini Ekaratne ©IUCN)

Annex 1

Participants at the Colloquium

	Name	Organization
1	Mr Hasantha Amerasinghe	MCRCF
2	Commandre W C P Ariyadase	Sri Lanka Navy
3	Dr K Arulananthan	NARA
4	Dr Padmini L Batuwitage	MOE
5	Mr M A T De Silva	Consultant
6	Mr Rathika De Silva	HOLCIM (Lanka) Ltd
7	Mrs D M T K Dissanayake	CEA
8	Ms Dilrukshi Ekanayake	National Science Foundation
9	Professor S Epitawatte	Consultant, IUCN
10	Dr Prasanthi Gunawardena	Univ. of Sri Jayewardenapura
11	Mr D Hettiarachchi	UDA
12	Eng Karunasena Hettiarachchi	National Water Supplies & Drainage Board
13	Dr D S Jayakody	University of Wayamba
14	Ms R A D Jayanthie	Irrigation Department
15	Mr J M A R Jayaratne	Disaster Management Centre
16	Mr Raj Kumar	National Water Supply & Drainage Board
17	Mr Herman Kumara	National Fisheries Solidarity Movement
18	Dr Susil Liyanarachchi	CARE Sri Lanka
19	Professor P K S Mahanama	University of Moratuwa
20	Dr Ananda Mallawantantri	UNDP
21	Dr T Mathiventhan	Eastern University
22	Mr A Navaratnaraja	-
23	Mr L Nirodhawardane	Small Fishers' Federation
24	Dr U K G Padmalal	Sri Lanka Association for the Advancement of Science
25	Dr C Pathiraja	Department of Wildlife Conservation
26	Dr Anil Premaratne	Coast Conservation Department
27	Dr J Samarakoon	Consultant, IUCN
28	Ms P Samarakoon	CARE
29	Prof Saman Samarawickrema	University of Moratuwa
30	Mrs M D J S Saparamadu	Open University of Sri Lanka
31	Ms Dinushika Seneviratne	Environmental Foundation Ltd
32	Mrs L L U Soysa	Sri Lanka Land Reclamation and Development Corporation
33	Mr Douglas Tissera	Small Fishers' Federation
34	Mr Bandula Wickramarachchi	Coast Conservation Department
35	Ms Gayani Wickramarahchi	Sewalanka Foundation
36	Dr Sanjeeva Wickramaratne	Lanka Hydraulic Institute Ltd
37	Dr Nalin Wikramanayake	Open University of Sri Lanka
38	Dr Ranjith Mahindapala	IUCN
39	Mr Shamen Vidanage	IUCN
40	Mrs Kumudini Ekaratne	IUCN
41	Mr Kapila Gunarathne	IUCN

Annex 2

Colloquium on Dynamics of Micro-tidal Estuaries and Lagoons in Sri Lanka
At the Albatross, Water's Edge, Battaramulla
25 February, 2011
Programme

08 30 – 09 00	Registration and Tea
09 00 – 09 10	Address of Welcome **Dr R Mahindapala, Country Representative, IUCN Sri Lanka**
Chair: Dr L P Batuwitage	
09 10 – 09 25	An Introduction to the Colloquium – What are the barrier built estuaries and lagoons? **Dr J I Samarakoon, Freelance Consultant, Integrated Coastal Management**
09 25 – 09 45	Hydrology, hydraulics and hydro-morphology of lagoons and estuaries in Sri Lanka **Prof Saman Samarawickrema, University of Moratuwa**
09 45 – 10 05	Seasonal closure of lagoons and estuaries: processes and implications **Dr Nalin Wikramanayake, Open University**
10 05 - 10 25	Coastal fisheries – linkages with estuaries and lagoons **Dr D S Jayakody, University of Wayamba**
10 25 – 10 45	Tea
Chair: Dr Anil Premaratna	
10 45 – 11 05	Comparative analysis of morphometry and fishery productivity in freshwater systems and potential implications for estuaries and lagoons **Prof Ivan Silva, NAQDA**
11 05 – 11 25	Planning implication of urban expansion on micro-tidal estuaries: A case study of Negombo lagoon **Prof P K S Mahanama, University of Moratuwa**
11 25 – 11 45	Are barrier-built estuaries and lagoons worth the cost of long-term management? If so, what may be needed? **Dr J I Samarakoon, Freelance Consultant, Integrated Coastal Management**
11 45 – 12 05	The Landscape approach to long-term management of barrier-built estuaries and lagoons **Professor Senevi Epitawatta**
12 05 – 13 30	Lunch
Chair: Professor Ivan Silva	
13 30 – 13 50	Lagoon ecosystems: a framework for valuation **Dr Prasanthi Gunawardena, University of Sri Jayewardenapura**
13 50 – 14 10	Regulatory aspects related to estuaries and lagoons **Dr Anil Premaratna, Coast Conservation Department**
14 10 – 14 20	Community perspectives of estuaries and lagoons in Sri Lanka **Mr Herman Kumara, National Fisheries Solidarity (NAFSO)**
14 20 – 14 40	Panel Discussion with all Presenters
14 40	Tea

© Ranjith Mahindapala

Annex 3 Abstract of the presentations made at the Colloquium (only those made available by the authors)

1. **Are Barrier-built Estuaries and Lagoons Worth the Cost of Long-term Management? If so What is Needed?**
   Dr Jayampathy Samarakoon

2. **Hydrology, Hydraulics and Hydromorphology of Lagoons and Estuaries**
   Prof Saman Samarawickrema

3. **Comparative analysis of morphometry and fishery productivity in freshwater systems and potential implications for estuaries and lagoons**
   Prof Ivan Silva

4. **What Are Micro-tidal Barrier-built Estuaries and Lagoons?**
   Dr Jayampathy Samarakoon

5. **Lagoon and Estuarine Ecosystems: A framework for valuation**
   Dr Prasanthi Gunawardena

6. **Regulatory aspects related to estuaries and lagoons**
   Dr Anil Premaratna

7. **Community perspectives of estuaries and lagoons in Sri Lanka**
   Mr Herman Kumara

(Kumudini Ekaratne ©IUCN)

Are Barrier-built Estuaries and Lagoons Worth the Cost of Long-term Management? If so What is Needed?

Dr Jayampathy Samarakoon
Freelance Consultant, Integrated Coastal Management

A previous presentation clarified the structure and functioning of barrier-built estuaries and lagoons; it serves as the foundation for this presentation. To facilitate effective communication some key words are explained below:

Worth: The totality of benefits to society is greater than the investment required to generate the benefits.
Management: Reduction of conflict and contradictions among land users or resource users.
Long-term: Decadal (10 years) and generational (25 years) time spans.
Cost: The investment for (i) co-management of the fishery by the resource user community in partnership with the government, including expenditure on law enforcement, research, education, community organization where the major management responsibility is borne by the local community, and (ii) expenditure incurred for restoration of natural wealth including engineering costs.
Needs: Institutional arrangements – the rules of behaviour for groups of people in particular resource settings, including government agencies.

The numerous resource use conflicts and contradictions presently observed in the Batticaloa and Negombo Lagoons were used to illustrate management issues in barrier-built estuaries, in general. The conflicts and contradictions arose mainly from isolated and fragmented developement planning and implementation by government agencies and groups of individuals. For example, the construction of roads and bridges by the Road Development Authority, without adequate provision for drainage, was the main cause of the 2010 floods in Batticaloa. Eventually, the road at the Dutch Bar, recently constructed after the 2004 Tsunami, had to be physically breached to mitigate the flood impact. These inadequately planned developments harm hydrology and the fishery. Similar development activities are in progress. In Negombo Lagoon the expansion of the anchorage for marine fishery, mainly multi-day boats, is cramping the space available for fishing. Settlement expansion and encroachment into this water body is causing a similar negative impact. The cumulative impact is reduction of living space for the fishery stocks that support livelihoods.

The annual earnings from only the Batticaloa Lagoon fishery, where 22,000 fishermen operate, are estimated at Rs. 1.5 billion. These earnings provide incomes for 22,000 fisher households at an average daily rate of Rs. 300/=. Similarly, in Negombo Lagoon, the annual earnings from fishing alone, for

3,000 fisher households, are estimated at Rs. 250 million. The true livelihood value of these two barrier-built estuaries can be fully appreciated only when these earnings are extended across generational time spans, since the fishers support their next generation primarily on fishing income.

The science community should undertake the task of providing reliable information on the value of all ecosystem services of barrier-built estuaries and lagoons. This would enable a meaningful, informed political discussion, leading to sustainable management decisions. In this regard scientists may provide information on:

(i) how the productivity of the fishery could be maintained,

(ii) the number of 'fishery units' (kilograms) produced from the system and their value over the long-term, and

(iii) the number of persons dependent on the system,

(iv) the institutions that determine how decisions are made by the groups of people (stakeholders) who depend on the system.

Any scientific research must begin from an integrated conceptualization of a barrier-built estuary or a lagoon as a social-ecological system that combines bio-physical, societal and political aspects of natural resource use.

Hydrology, Hydraulics and Hydromorphology of Lagoons and Estuaries

Prof Saman Samarawickrema
University of Moratuwa

The presentation will cover the main factors: i) Tidal currents ii) Alongshore and cross-shore movement of sediment and iii) Fresh water inflows that govern the hydrology, hydraulics and hydromorphology of lagoons and estuaries. The dynamic nature and the interdependence of these factors will also be discussed. Finally, an overview of two studies carried out on lagoon systems will be presented.

I. Feasibility of dredging the Negombo Lagoon to improve water flow and water quality
II. Feasibility of preventing the formation of a sand bar at the outlet of the Madu Ganga

Comparative analysis of morphometry and fishery productivity in freshwater systems and potential implications for estuaries and lagoons

Prof Ivan Silva
Email: eils.mecamp@gamail.com

One of the prime goals of fisheries management and aquaculture development is to predict fish yields using known climatic, morphometric and watershed characteristics of the water body. Lakes with shallow basin morphology, coupled with irregular shorelines and wind derived mixing, are reported to be more productive than those with circular shorelines and deep basins surrounded by mountainous landscape. The Morpho-Eadaphic Index (MIE) is widely used to predict the fish yields of North American temperate lakes. This index has been tested for shallow irrigation reservoirs in Sri Lanka and found to be applicable under certain conditions. Primary productivity is a good predictor of fish yield. It has been shown that D_{mix}: D_{max} plays an important role in pelagic algal biomass and in turn fish yields in Sri Lankan reservoirs. When the hydraulic balance of reservoirs, which is primarily a monsoonal rainfall bound human regulated factor, is coupled with wind induced D_{mix} : D_{max} value, the yields of phytoplanktivourous fish of Sri Lankan reservoirs can be predicted with dependable precision. However, it has not been validated for the entire reservoir network.

Micro-tidal estuaries and lagoons are more diverse, stable and unique ecosystems adapted to wider ranges of physical and chemical processes, in the geological timescale, compared to man-made reservoirs several hundred years old or less. Their geomorphological forms are determined by variation in antecedent topography and fluvial and marine sediment supplies. Shallow micro-tidal estuaries and lagoons in Sri Lanka are more productive ecosystems in terms of total animal biomass yield (fish, shrimp, crabs, mussels, sea cucumber, etc.) although they are either oligotrophic or mesotrophic with respect to pelagic algal biomass compared to eutrophic or hyper-eutrophic shallow lowland reservoirs. Further, there are strong pelagic, benthic and littoral eco-linkages within the ecosystems, and catadromous and anadromous migratory fluxes, influenced by marine and fluvial ecosystems. Therefore, the morpho-climatic or morpho-hydraulic models developed for natural lakes or man-made water bodies are not likely to predict fish yields of micro-tidal estuaries and lagoons.

What Are Micro-tidal Barrier-built Estuaries and Lagoons?

Dr Jayampathy Samarakoon
Freelance Consultant, Integrated Coastal Management

Barrier-built estuaries and lagoons are evolutionary stages of water bodies that have formed at junctions where rivers meet the sea. From about 10,000 years ago the sea level rose intermittently and stabilized at the current level. Parallel to this, sand barriers formed at the junction of rivers and the sea, the funnel-shaped riverine estuaries (river valleys), and partially separated a section where freshwater and seawater mixed to form brackish water. These partially enclosed brackish water bodies evolved over some 10,000 years, first into the barrier-built estuaries such as Negombo Lagoon, and later into lagoons such as Rekawa Lagoon. In Sri Lanka, because of its geology, some of these barriers formed on base-rock projecting into the sea (e.g. Negombo Lagoon, Puttalam Lagoon, Rekawa Lagoon), while others formed freely as sand spits projecting into the sea. These barriers consolidated largely because in Sri Lanka the difference between high and low tides is less than one meter. All around Sri Lanka the tidal difference never exceeds one meter; hence our tides are micro-tides.

The combined effect of sea level stabilization, micro-tides and the form of waves and currents in the sea (coastal processes), ensures that sediment brought to the coast by rivers never form coastal deltas that project out to sea. Instead, the sediment gets trapped within the original barrier-built estuaries, some of which (the smaller ones) produced lagoons. Therefore, Sri Lanka does not have deltas covered by mangroves as in some other countries. The mangroves that are found in Sri Lanka occur exclusively along margins of riverine estuaries, barrier-built estuaries and lagoons. The consequence of all these interactions is that barrier-built estuaries and lagoons are continually filling up with trapped sediment and become progressively shallower. This process is accelerated by mangroves that spread into the brackish water bodies and by human development activities that include deliberate filling. Therefore, the primary challenge in managing barrier-built estuaries and lagoons is controlling the rate of infilling by sediment.

The geological form of the island, the structure of the coastal plains, the micro-tides, the coastal processes and the rate of sediment entrapment within barrier-built estuaries and lagoons is an ongoing process which cannot be reversed, except through engineering restoration. As the infilling proceeds, the populations of fishery organisms have less water to live in and the fish catches naturally decrease. Eventually, fisheries begin to die; this process has already begun in some lagoons such as Rekawa Lagoon. If the fishery value at the present level, and the dependent livelihoods are to be sustained, the rate of

infilling by sediment, the root cause, must be controlled. Irrefutable evidence of infilling has been demonstrated by recent sequential geo-spatial studies done by the International Water Management Institute (IWMI).

Sri Lankan nomenclature for coastal brackish water bodies is highly confusing and not related to their ecosystem form. Barrier-built estuaries such as Negombo, Puttalam, Batticaloa, etc., are all lumped as lagoons. Revising this nomenclature will facilitate planning and prioritizing the integrated management of these water bodies. Safeguarding the multiple ecosystem services of primarily the barrier-built estuaries is urgent. These services include food security, livelihoods, sink for wastes and navigation, among others. Sustainable management is not solely an outcome of science; it must flow from society as a whole through both awareness and balanced law enforcement.

Lagoon and Estuarine Ecosystems: A framework for valuation

Dr Prasanthi Gunawardena
Department of Forestry and Environmental Science
University of Sri Jayewardenepura

Micro-tidal estuaries and lagoons are characterized by the multitude of environmental services provided, and the diverse range of resource users and interest groups with conflicting interests. Management of such complex systems has been hampered by inadequate information on different uses, especially on economic values. This study aims to develop a framework to value benefits of lagoons and estuarine ecosystems.

Valuation becomes necessary since many goods and services provided by the ecosystems are generally not recognized by the market. Estimation of economic values would enable appropriate use of such values in decision making contexts both at micro and macro levels. The economic potential of these systems are very complex and justifies a transdisciplinary approach in understanding and framing the economic values.

Total economic value provides a suitable framework to value such complex systems which include a range of different values. Accurate definition and classification of ecosystem goods and services, and estimation of economic values are the essential basic steps in valuation. Issues related to such economic estimations include inability to incorporate the full range of values, problems stemming from high discount rates, and using the weak sustainability framework.

New indicators to highlight the specific importance of these systems are proposed, including economic footprints of estuary regions, the proportion of the national economy found in estuary regions, the relative size of the economic activity in a province's estuary districts as a proportion of the province's total economy. In addition, new economic instruments such as payments for environmental services and investigating the applicability of economic values in assessing and compensating natural resource damages should be considered. Strong sustainability dimensions could be added by accounting for both benefits and damages of lagoons and estuaries into the national accounts. Multicriteria decision making frameworks provide a novel approach for incorporating other dimensions into the decision making context.

Regulatory aspects related to estuaries and lagoons

Dr Anil Premaratna
Coast Conservation Department

In the management of estuaries a distinction needs to be drawn between ”Basin Estuaries” and “Riverine Estuaries”; their management issues differ. In regard to basin estuaries, the main concerns are encroachment, sedimentation, pollution, salinity variation and habitat degradation, whereas in riverine estuaries, they are sand mining, pollution, salt water intrusion, bank erosion and lowering of ground water levels.

There are several management and legal instruments as well as laws and regulations governing coastal resources and habitats. These include the Coast Conservation Act of 1981, its Amendment Act of 1988 and 2011, and the Coastal Zone Management Plans of 1990, 1997 and 2004. Apart from these there are many other related laws such as, The National Environment Act, Forest Ordinance, State Lands Ordinance, Fauna and Flora Protection Ordinance, Fisheries and Aquatic Resources Act, Urban Development Law, Marine Pollution Prevention Act, Mines and Minerals Act, and the Land Reclamation and Development Act.

The possible solutions to alleviate the above noted concerns include, a) the use of SAM planning processes for the management of estuaries, b) strengthening the CCD Act, c) strengthening SAM planning, d) strengthening community participation for coastal resources management, e) strengthening enforcement procedure, f) identification of alternative livelihoods, and g) collection of more scientific information.

A list of proposed amendments to the CCD Act, and a list of proposed actions to minimize threats to estuaries and lagoons posed by solid waste disposal were presented.

Community perspectives of estuaries and lagoons in Sri Lanka

Mr Herman Kumara,
National Fisheries Solidarity (NAFSO)

Fishery was the only source of livelihood for the fishing community around Negombo Lagoon. Based on this premise the author recounted his personal experience and that of the fishery community and listed the problems faced by the fishers:

1. Environmental damage resulting from the loss of mangroves has affected prawn farming.
2. Legal measures are well and good, but the manner in which these measures affect the lives and livelihoods of the poor fisher families are being ignored.
3. Environmental issues are the ultimate cause of the hardships faced by the fishing community.
4. Regulatory measures for estuaries and lagoons are formulated without considering the peoples' livelihoods.
5. Lessons should be learnt from past experiences? Without proper information and a proper awareness of the problems the same mistakes are being repeated.
6. The community's voice should be heard; the people should be properly informed and helped to resolve their problems.
7. The community needs guidance so that they will not ultimately suffer.