Can Tidal Power Promote Sustainable Integrated Coastal Development in Bangladesh?

Md. Salequzzaman

This thesis is presented for the degree of

Doctor of Philosophy

Institute for Sustainability and Technology Policy (ISTP)
Murdoch University
Western Australia
November 2003
DECLARATION

I declare that this thesis is my own account of my research and contains, as its main content, work that has not previously been submitted for a degree at any tertiary educational institution.

Md. Salequzzaman
ABSTRACT

Tidal power is a clean renewable energy. Furthermore, electricity is acknowledged as a key need for development. However, until recently, due to high capital costs and extensive environmental concerns, few tidal power plants are operative around the world. These problems are now being mitigated by the application of appropriate, modern practices and technologies. In particular the use of small-scale technologies, innovative financing and the involvement of local communities creates the potential for tidal power to be a tool in coastal development. This thesis examines the appropriateness of tidal power in the rural coastal community of Bangladesh, where electricity demand is a major development problem.

Coastal Bangladesh is highly vulnerable to natural disasters, especially from cyclones, tidal surges and the effects of global warming on sea-level rise. Consequently, most of this coastal area has been protected by embankments and sluice gates, which can accommodate the normal tidal head rise and fall. The potential of tidal power to use this infrastructure, together with its associated problems and mitigation measures, have been analysed by comparing existing and potential tidal power technologies around the world, including a proposed Kimberley tidal power project in Western Australia. The research has identified that a significant amount of power could be produced from the tidal range of coastal Bangladesh by using the simple low-cost technology of tidal wheels in the tidal embankment sluice gates. The electricity produced could be utilised by various coastal interests, such as agriculture, shrimp aquaculture and other resource producing activities. However, the real benefits of this technology are that it can be applied in a way that simultaneously enables the development of local infrastructure and the improvement in living conditions of the
local people by creating income generation and employment opportunities in these coastal communities. The thesis puts forward a community based co-management model as a means of effectively integrating tidal power in coastal area management in Bangladesh.
ACKNOWLEDGMENTS

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Abstract

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CHAPTER I
Chapter I
INTRODUCTION

“Our biggest challenge in this new century is to take an idea that seems abstract -- sustainable development -- and turn it, too, into a daily reality for all the world’s people”.

Kofi Annan
Secretary General of the United Nations
The International Conference Centre, Dhaka, Bangladesh
14th March 2001

1.0 Background
Coastal resources provide much of what supports daily life: food, livelihood, economic development, clean water, and even the air we breathe (Barnabe and Barnabe-Quet, 2000; Cicin-Sain and Knecht, 1998; White and Savina, 1987). Consequently, coastal regions are highly valued and greatly attractive as sites for urban development, industry, fishing and tourism (Bower and Turner, 1996; Carter, 1991; Cicin-Sain and Knecht, 1998). However, population and economic growth place increasingly greater demands on coastal resources (Verdegen, 1998; Wallström, 2001). These resources are critical to coastal sustainable development, particularly in developing countries like Bangladesh where low-lying coastal areas are vulnerable to the effects of global warming and sea level rise (Alam, 2001; Bala et al., 2000; Soussan, 1999). Development in such areas must, therefore, respond to climate change issues as well as coastal socio-economic,

2 Development involves management in time and space of the interactions between economic and ecological, and social and natural variability, where ecosystems and the lifestyles can exist side by side (Serageldin and Steer, 1994; Parent, 1990; Barnabe and Barnabe-Quet, 2000).
environmental and cultural improvements (Agenda 21, 1992; Bijlsma et al., 1996; Mashishi, 2002). Evidence suggests development is more sustainable when integrated across sectors, such as energy, agriculture, industry, health and the environment (Bower and Turner, 1996; Cicin-Sain and Knecht, 1998). Integration is a process that acknowledges the interrelationships among components (such as sectors or disciplines) and seeks to bring them together to create an interactive whole (Cicin-Sain and Knecht, 1998; Kay and Alder, 1999). In fact, integration across sectors will be essential to meet the growing challenges in the 21st century, as concluded in a major conference in Canada recently - Managing Shared Waters, 2002 (Ogilvie, 2002).

The management of coastal resources should also be based upon a strongly participatory approach to decision-making, with involvement of all interested and affected parties (Ruddle, 2001; Vallega, 2001). Local community participation is the key to any development success (Flint, 2001; White, 1989; Wirojanagud, 2002). Communities can make meaningful, sustainable choices by adopting integrated frameworks that bring together social, economic, and ecological concerns (Coastal Community Network, 2000; Newman, 1996; Renard, 1991).

Electricity is an important component for enabling integration to bring maximum benefits to the community (Barua, 1998; Chua, 1993; Joskow, 1998; Lowe, 2002). It is a key factor in development and is one of the main indicators for modernisation of society (Bala et al., 1989; Hotta and Dutton, 1995; Moskovitz et al., 1998; Winrock International, 2002). Integrating electricity coastal development is vital (Calderon and Alvarez-Villamil, 2000; Courtney and White, 2000; Fabbri, 1998; Kazmierczak and
Caffey, 2001) because it enhances the much needed resource productivity of the system (Verdegem, 2001).

A reliable electricity supply has not been available to remote coastal communities in Bangladesh for several reasons, mainly due to the high cost of providing national grid connections, the frequency of natural disasters and lack of political will (Choudhuiy-Gaisuddin, 2001). However, coastal tides are an important ongoing resource and have a vast potential for generating tidal power (Bala, 2003). In the past, experts have suggested that the relevant infrastructure, such as large barrages and sluice gates, would be extremely expensive and well beyond the capacity of third world countries like Bangladesh (Clark and Prys-Jones, 1994; Fujita Research, 2001). This thesis will examine whether there is a more cost-effective tidal power technology for Bangladesh which could be easily integrated with existing coastal industries such as shrimp aquaculture to create more sustainable development for the local population. The thesis will thus analyse whether tidal power plants could be developed in coastal Bangladesh and whether tidal power has a role in sustainable integrated coastal development.

In this introduction some definitions will be provided, the context of the Bangladesh coastal area explained and tidal power introduced. The central questions which lie behind this thesis are then posed. Lastly, the structure of the thesis will then be outlined to show how the research has been carried out to answer these questions.
1.1 Definitions

There is a host of definitions for terms relating to the coastal environment. These vary according to their legal, ecosystem and hydrological contexts. The followings are the definitions that will be used in the thesis.

1.1.1 Coastal environment

The coastal environment or zone\(^3\) can be considered from a number of perspectives for a number of purposes. Generally, the coastal environment represents the interface between the land and the sea (Scura et al. 1992). Here, the weather, vegetation, wildlife, soils, smells and sounds of the coastal environment are obviously different to the senses from those of non-coastal areas (Clark, 1977; Mohammed and Abdalah, 2002). International organizations, academic institutions, scientific associations and government agencies have defined the coastal environment/area/region/zone for legal purposes in different ways. Fabbri mentions that:

“the actual delineation of the coastal environment depends upon the purpose- its physical extent will tend to vary according to the nature of the problem, the extent of the resource and the boundaries of government with jurisdiction and responsibility for management in coastal area (Fabbri, 1998, p. 53)”.

Fixed distances defined (table 1.1) for the ocean component of a coastal environment usually apply to the limit of governmental jurisdiction, for example the limits of

\(^3\) Environment means the surroundings (in air, water and terrestrial) and zone means a definite region or area. Coastal area itself is a zone. Kaluwin (1996) describes the notion of delineating a zone or area or environment as an essentially western concept which places artificial boundaries on geographical extent of this transition. In the thesis, to avoid the confusion I use the term coastal environment instead of coastal zone or coastal area or coastal region.
Territorial Seas (Kay and Alder, 1999). In Bangladesh, this definition is not established yet.

Table 1.1: Fixed distance definitions of coastal environment (Coastal Committee of New South Wales, 1990; Kay and Alder, 1999; Sorensen and McCreary, 1990).

<table>
<thead>
<tr>
<th>Country</th>
<th>Inland Boundary</th>
<th>Ocean Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia (State of New South Wales)</td>
<td>1 km from low water mark</td>
<td>3 nautical miles from coastal baseline</td>
</tr>
<tr>
<td>Brazil</td>
<td>2 km from mean high water</td>
<td>12 km from mean high water</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>200 m from mean high water</td>
<td>Mean low water</td>
</tr>
<tr>
<td>China</td>
<td>10 km from mean high water</td>
<td>12 m isobath (depth)</td>
</tr>
<tr>
<td>Spain</td>
<td>500 m from highest storm or tide line</td>
<td>12 nautical miles (limit of territorial sea)</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>300 m from mean high water</td>
<td>2 km from mean low water</td>
</tr>
</tbody>
</table>

The coastal environment can be defined simply as extending from the high-water mark on shore to the shelf break (Barbané and Barbané-Quet, 2000). However, this definition ignores the fact that a dynamic continuum exists between land and the open sea. From a dynamic perspective, the coastal environment includes the coastal waters (including the lands therein and thereunder) and the adjacent shore lands (including the waters therein and thereunder), and their interactions that produce coastal ecosystems (Bower and Turner, 1996; Carter, 1991; Cicin-Sain and Knecht, 1998). Coastal ecosystems include islands, tidal rivers, estuaries, transitional and inter-tidal areas, salt marshes, wetlands, and beaches (Alongi, 1998; Cicin-Sain and Knecht, 1998; Vallega, 2001). From an ecological perspective, the coastal environment is a link between land-based productivity and the open ocean, where micro- and macro-
processes of mixing and renewal take place at time scales from a split second to a day, month and year (Rozengurt and Haydock, 1991).

Hydrologically, the coastal environment effectively varies in breadth depending on the strength and salient characteristics of coastal topography local ocean circulation, tidal impacts, river discharge, shelf width, climate and latitudinal position (Su, 1990; Wang, 1995; WCC, 1993). Tidal current or height/range or wave are usually the most important aspects of circulation as they create a lot of potential energy that interacts with coastal boundaries and generate the turbulence, advective mixing, and longitudinal mixing and trapping (Days, 1994; Dronkers, 1988).

Barnabe and Barnabe-Quet states that:

“the development and ecology of coastal waters constitutes a vast subject involving knowledge belonging to a wide range of disciplines including oceanography, hydrology, biology, ecology, fisheries science, aquaculture, civil engineering, geography, economics, law and social sciences (Barnabe and Barnabe-Quet, 2000, p. 37)”. 

This account underscores the importance of the integrated management of the coastal resources.

In the context of human usage, the coastal environment represents a complex and dynamic system where uncertainties exist in the understanding of the behaviours and processes of its natural, socio-economic, political and organizational levels (Carter, 1991; Zedler, 1984); hence the coastal environment is called the: “crossroads of human activity and the sea” (Weber, 1993, p. 66).
For the purpose of this thesis objective, the term ‘coastal environment or zone or area or region’ indicates an area with undefined limits, comprising sea and land, where both elements have some kind of interaction, and which is characterised by its numerous uses and resources. Tidal energy is such a coastal resource, which could be used as an important element for integration with different socio-economic, environmental and cultural infrastructures.

1.1.2 Sustainability and sustainable development

‘Sustainable development’ was widely popularised by the ‘Brundtland Commission’ in its landmark 1987 report, ‘Our Common Future’. In ‘Our Common Future’, the World Commission on Environment and Development famously defined the term 'sustainable development' as development that ' . . . meets the needs of the present generation without compromising the needs of future generations' (WCED, 1987). Jacobs et al. (1987) described the elements of sustainable development from Brundtland’s definition as integration of natural resources, conservation and development; satisfaction of basic human needs; opportunities to fulfil other non-material human needs; progress towards equity and social justice; respect and support for cultural diversity; provision for social self-determination and the nurturing of self-reliance, and the maintenance of ecological integrity.

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4 In 1987, the Prime Minister of Norway, Gro Harlem Brundtland, launched the book *Our Common Future* that effectively began the era of sustainable development. Prime Minister Brundtland chaired the United Nation’s World Commission on Environment and Development which had worked for two years to try and resolve a major problem in global politics: the apparent conflict between the environment and development.
In 1990, the Australian Commonwealth Government defined ecologically sustainable development as:

“using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased (Commonwealth Government, 1990)”.

The term ‘sustainability’ is now often used almost inter-changeably with sustainable development. Sustainability is a long-term dynamic process that allows individuals, organisations and societies to flourish as members of their ecological communities (ISTP, 2001). According to the Government of Western Australia:

“Sustainability is meeting the needs of current and future generations through an integration of environmental protection, social advancement and economic prosperity (Government of Western Australia, 2003, p. 4)”.

It is based on the need to think long term, understand systems, recognise limits, protect nature, transform business-as-usual, practise fairness in context and fairness over time, and embrace creativity (AtKisson, 1999; Heij, 2001; Sutton, 2001). No longer concerned with just ecological and economic issues, sustainability has taken on distinctly human dimensions. It is also a philosophy or ethic affording people and groups the ability to consider long-term consequences of actions and to think broadly across issues, disciplines, and boundaries (Flint, 2001). In Bangladesh, there is no definition of sustainable development is set up yet. Peoples are used the definition of ‘Brundtland Commission’ for all purposes. Sustainability, however, is very challenging to implement.

In this thesis, I focus on the coastal environments of developing countries like Bangladesh, community empowerment and renewable energies like tidal power. These
issues are all mandated for special attention in the fundamental principles of Agenda 21 (Box 1.1).

**Box 1.1: Principles of Agenda 21 that relate to community empowerment, and renewable energies and developing countries**

- **Principle 5:** All States and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development, in order to decrease the disparities in standards of living and better meet the needs of the majority of the people of the world.

- **Principle 6:** The special situation and needs of developing countries, particularly the least developed and those most environmentally vulnerable, shall be given special priority. International actions in the field of environment and development should also address the interests and needs of all countries.

- **Principle 10:** Environmental issues are best handled with the participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities in their communities, and the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making information widely available. Effective access to judicial and administrative proceedings, including redress and remedy, shall be provided.

- **Principle 17:** Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority.

- **Principle 22:** Indigenous people and their communities and other local communities have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognize and duly support their identity, culture and interests and enable their effective participation in the achievement of sustainable development.

Principle 17 is relevant to the mutual influences of the coastal environment. Principle 5 is relevant to the energy demands to decrease disparities in standards of living and better meet the needs of the people. Principles 6 emphasises the development of less industrialised countries like Bangladesh. Principle 10 and Principle 22 emphasise community empowerment through community participation. In conclusion, sustainable development is a process of continued economic and socio-cultural development without
detriment to the environment and natural resources. It depends on the geographic and operational context of interest, ecological conditions, the consequences of climate change on the subsequent biogeochemical processes, economic and social features, and the establishment of decision-making systems, and other factors (Vallega, 2001). Because of the complexity of sustainability, its research requires the integration of economic, environmental and social disciplines.

1.1.3 Sustainable integrated coastal development

Development of the coastal environment means the development for human beings in terms of food, shelter, health, electricity, and leisure, and also for the protection of coastal ecosystems including aquatic and terrestrial environments (Barnabe and Barnabe-Quet, 2000; Panneau, 1990; Re-focus, 2002). Integrated coastal development is a continuous, adaptive, iterative, participatory, consensus-building day-to-day process which consists of a set of tasks, typically carried out by several/many public and private entities that set out to achieve a desired set of goals and objectives (Murthy et al., 2001; Bower et al., 1994). Sustainable integrated coastal development is a multidisciplinary process that integrates different levels of government, community, science and industry for the purpose of providing programs that protect natural resources while planning for the economic and socio-cultural viability of coastal communities (Glaeser, 2001; Managing Shared Waters, 2002). Sustainable integrated coastal development applies the concept of

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5 Related to integrated coastal development is integrated coastal zone management (ICZM) which is comprised those activities that achieve sustainable use and management of economically and ecologically valuable resources in coastal areas. It considers interaction among and within resource systems, as well as interaction between humans, their environment, ecosystems, institutions, and political boundaries (Turner et al., 1997; Bower and Turner, 1996; White and Lopez, 1991).
sustainable development to coastal areas and encourages sustainable coastal resource use through an iterative process of regulation and policy development, institutional coordination and education (Courtney and White, 2000). However, various organizations, such as the United Nations Environment Program (1995), Food and Agriculture Organization of the United Nations (1991), World Bank (1993), World Coast Conference Report (1993), International Union for the Conservation of Nature and the Organization for Economic Co-operation and Development, all have different frameworks for the process (Pernetta and Elder, 1993). The proliferation of integrated coastal development frameworks has led to efforts to identify core principles or guidelines.

In all of the above frameworks, the core aim of sustainable integrated coastal development is to guide coastal development in an ecologically sustainable fashion. Frameworks are guided by the Rio Principles (UNCED, 1992), with special emphasis on the principle of intergenerational equity, the precautionary principle, and the polluter pays principle (Bower and Turner, 1996; Christie, 2001; Courtney and White, 2000; ESCAP, 1988). As sustainable integrated coastal development is holistic and interdisciplinary in nature, its main functions are to strengthen and harmonise sector management in the coastal environment. It preserves and protects the productivity and biological diversity of coastal ecosystems and maintains amenity values (Lamotte, 1985; Lawton, 1972; Parent, 1990). The process also promotes rational economic development and sustainable utilisation of coastal and ocean resources and facilitates conflict resolution in the coastal environment (Verdegem, 2001). A sustainable integrated coastal development program can embrace all of the coastal and upland areas, the uses of which can affect coastal waters and the resources therein, and can embrace the coastal seas,
which affect the land of the coastal environment (Hildreth and Gale, 1995; Hotta and Dutton, 1995; Vallega, 2001; WCC’93, 1994). A program may also include the entire ocean area under national jurisdiction (Exclusive Economic Zone), over which national governments have stewardship responsibilities both under the Law of the Sea Convention and UNCED (Hussain and Acharya, 1994; Kay and Alder, 1999; WCC’93, 1994).

Threats to coastal areas span from the top of the mountain, where deforestation and subsequent siltation degrade coastal water quality and coral reef growth, to the sea, where over-fishing and shoreline development result in the decline of coastal fisheries and habitats (Ali, 1991; Hussain, 1994; Verdegem, 1997). To this end, sustainable integrated coastal development emphasises the integration of management across both environmental and human realms to solve complex problems that span sectoral concerns, ecosystems, institutions, and political boundaries (ESCAP, 1988; Flood et al., 1993; Managing Shared Water, 2002). Integration has to occur at many levels and across many dimensions (Box 1.2). Sustainable integrated coastal development is a participatory process of planning, implementing, and monitoring sustainable uses of coastal resources through collective action and sound decision-making (Murthy et al., 2001; Ruddle, 2001).

In conclusion, sustainable integrated coastal development is a continuous and dynamic process by which decisions are made for the sustainable use, development, and protection of coastal resources. First and foremost, the process is designed to overcome fragmentation inherent in both the sectoral management approach and the splits in jurisdiction among levels of government at the coastal environment. This is done by
ensuring that the decisions of all sectors such as energy, agriculture, aquaculture, industry, business and others; and all level of government are harmonised and consistent with coastal policies of the coastal environment.

**Box 1.2: Sustainability and integration**

Integration of coastal resource development is an important element of coastal sustainability. UNCED Agenda 21, chapter 17 states that management should be based on the holistic view of the coastal and ocean systems, i.e. an integrated management concept. According to Vallega (2000, p. 280), this integration should be concerned with:

- **Integration of objectives**: includes the integrity of the ecosystem, efficiency of the economy, and social equity, including the rights of future generations;
- **Spatial integration**: includes the integration of coastal land, the brackish belt, the marine areas, and the adjacent atmosphere;
- **Time integration**: short-term actions and strategies need to be framed into long-term prospects and programs;
- **Legal integration**: national and international legal frameworks need to provide appropriate regulations to develop and diffuse integrated coastal development;
- **Jurisdictional integration**: all coastal areas are prescribed in certain jurisdictional zones, therefore integrated coastal sustainable development should maintain this jurisdiction;
- **Decision-making integration**: all the actions of decision-making centres involved in coastal management should be vertically and horizontally coordinated in order to optimise the adoption and implementation of ICD programs; and
- **Social integration**: top-down and bottom-up processes must be harmonized, and the participation of the local community in coastal management decisions, including the design, adoption and evaluation of the management program, should be optimised.

**1.1.4 Community-based coastal co-management**

Community is usually understood as being to do with locality, with actual social groups, and with a particular quality of relationship. According to Flecknoe and McLellan:

“Community is the web of personal relationships, group networks, traditions and patterns of behaviour that develops against the backdrop of the physical neighbourhood’s environmental, cultural and socio-economic situation (Flecknoe and McLellan, 1994, p. 8)”.

Co-management is defined as the sharing of responsibility and/or authority between the government and local resource users to manage a specific resource or resources (e.g. fishery, coral reef, renewable energy, agriculture, etc.) (Coastal Resources Co-Management Research Project, 1998). Community-based coastal co-management is a system in which the responsibility of coastal resources management is shared among the government, local community, and/or any other management authority (Coastal Resources Co-Management Research Project, 1998; Ruddle, 1998; Salequzzaman et al., 2001). Community participation is the most important factor for sustainable integrated coastal development (Shi et al., 2001; Verdegem et al., 1996). Sustainability generally requires a collaborative approach to problem solving. Collaborative management or co-management is based specifically on the participation of all individuals and groups that have a stake in the management of the resource (White et al., 1994). Therefore, community-based coastal co-management implies that individuals, local groups, and community organisations have a major role, responsibility, and share in the resource management and decision-making process (Coastal Community Network, 2000). Government is also always a part of the management process to some extent (Oceans Actions Bulletin, 2001; Renard, 1991). Governments can introduce the legislation necessary to delegate authority to the community committees so that they may implement the policies decided by the committee. However, the amount of responsibility and/or authority exercised by the government and local resource users will differ and depend upon country and site-specific conditions (Coastal Resources Co-Management Research Project, 1998; Salequzzaman et al., 2001; White et al., 1994).
Sustainable integrated coastal development will only succeed if plans are appropriately designed for conditions in the community, focused on issues of high concern to the community, and enjoy a high level of community support and participation. Involving communities in coastal management requires additional information on community organizing, participatory tools, and education and outreach activities that are needed throughout planning and implementation to gain community support for coastal management efforts. Public awareness of the problems with coastal resources and the best management solutions are needed to continue this process. Box 1.3 sets out the principles in this process.

**Box 1.3: Community-based coastal co-management principles**

Sustainability of the coastal environment requires a program incorporating the following principles (Simpson *et al.*, 2001, p. 3):

- Have a clear, common sense statement of purpose that can be used to measure success or failure;
- Have a clear, understandable process;
- Have clearly defined thresholds for pathways in the process and reasonable, specific timelines for performance by staff, with specific criteria for allowing flexibility;
- Be streamlined. Reviews should not rely on duplication to ensure thoroughness;
- Be open and transparent to the public; and
- Have an effective compliance component that relies on follow up inspections and penalties for non-compliance that are fair and effective deterrents.

Community participation in every phase of the process should be encouraged. Community members have important contributions to make in the identification of issues important to them, collection of baseline information, and development and implementation of management strategies. Day-to-day decisions on the part of local residents as to how they utilise their coastal resources will have a big impact on management success. Convincing local residents of the importance of coastal management and their role in the process is a critical part of the program (Christie *et al.*, ...
1994; White et al., 1994). In this thesis, I will use ‘community-based coastal co-
management’ or in short, simply ‘co-management’ to describe this participatory
management practice. These aspects of sustainable integrated coastal development are
expanded in Chapter II.

1.1.5 Tidal power: the key to integrated coastal development

Tidal power means using the energy of the tides to create electricity. Similar to the more
conventional hydroelectric dams, the tidal power generation utilises the natural motion of
the tides to fill reservoirs, which are then slowly discharged through electricity-producing
turbines. Tidal power is not a new concept; in fact, the waterwheel is one of the oldest
known sources of mechanical power. By the middle of the 1800s, the use of tidal power
had decreased, with increasing use of hydro-electricity and fossil-fuel-based energy.
Since the contribution of modern science, hydroelectric power production grew to an
astonishing 2,044 billion kilowatt hours worldwide at the middle of 19th century (Ullman,

Oceans cover over 75% of the earth’s surface and the energy contained in waves and tidal
movements is enormous (Baker, 1991; Charlier, 2001; Clark and Karas, 1979; Day,
1994).

“It has been estimated that if less than 0.1% of the renewable energy
available (in the form of tidal power or wave power) within the oceans
could be converted into electricity, it would satisfy the present world
demand for energy more than five times over (Wavegen, 1999, p. 1)”.

However, tidal power remains well below its potential in terms of its application in the
field (Newman et al., 1999). Modern tidal power plants have operated in France since
1967 (La Rance), Canada since 1984 (Annapolis Royal), and in China (the Bay of Kislaya and Jiangxia Creek). The station that generates the most electricity is on the Rance River, in France, which generates 320 megawatts of power. In addition to the existing tidal power plants, there are many tidal projects now being considered for implementation, including seven projects in England; Derby in Western Australia (120 MW); Corova on the south coast of Alaska; southern Chile; Gujarat in India (1000 MW); Mexico (500 MW); the Philippines (2200 MW) and China (20,000 MW) (ACRE, 1999; Tidal Energy Inc., 1999). There are many other possible sites for tidal power production around the world (Charlier, 1993).

Traditional tidal power stations are very expensive to build and often create electricity at a time when demand for power is low. The tides are always changing, and the need for electricity is much smaller at night then during the day. Tidal power stations also have environmental problems. Many fish, like salmon, swim up the estuaries towards the barrages and can be killed by the turbines. Another problem which arises is the effect of tidal power stations on riverine, estuarine and marine ecosystems. Many rivers, before being dammed, have spring floods that wash out the backwaters and deposit silt to form sandbars. Dams put an end to those spring floods and allow vegetation to clog up river backwaters. This process kills many different kinds of fish and other aquatic organisms that live in those areas. In addition, if chemicals or oils mix with the water running through the turbines, animals downstream will die. The construction of such dams requires large areas for water retention and subsequent discharge, necessitating the relocation of the whole communities. For example, in 1961 almost 80,000 people had to
be evacuated in Rangamati, Bangladesh within a period of only a few weeks (Turner and Boesch, 1987).

Using appropriate technology\(^6\) and improved devices might solve the problems of traditional tidal power plants discussed above (Bala, \textit{et al.}, 2000). The operation of this improved technology has generally been positive and proved reliable. A modern tidal generator may last for many years because it uses no fuel and maintenance is minimal. The cost of electricity, after the capital costs have been paid off in 15 or 20 years, has been estimated at nearly zero (Newman \textit{et al.}, 1999; Salequzzaman \textit{et al.}, 2000). Any new and improved system for harnessing the oceans’ tides must be (Tidal Energy Inc., 1999):

\begin{enumerate}
  \item[(a)] economic in terms of capital requirements,
  \item[(b)] able to solve the environmental problems of the traditional barrage technology,
  \item[(c)] competitive in terms of generation cost, and
  \item[(d)] socially acceptable with potential to enhance local communities.
\end{enumerate}

There have been very few studies in the academic literature that analyse how tidal power can become more mainstream and acceptable (Barreau, 1997; Newman \textit{et al.}, 1999; Wood, 2000). Generally speaking, it is possible to harness energy from the tides but until

\(^6\) Appropriate technology is defined as technology that is essential, affordable, requiring low maintenance and promotes the sustainable management of resources and opportunities, keeping in mind the local environmental, social, economic and political settings, conditions and values (Source: http://www.gdrc.org/techtran/a-tech/define-at.html (Accessed on 08 July 2003)).
now little research has been conducted scientifically, and the issues of tidal power generation in poorer coastal areas of the Third World have not been seriously addressed (Bala, 2003). An attempt to resolve these issues will be the primary focus in this thesis. Tidal power has the added problem of being in a coastal environment where engineering is likely to be even more costly due to the changeability of the coast\textsuperscript{7}. However, there is no research that has yet been conducted where the coastal engineering infrastructure is already present, such as in coastal Bangladesh. This thesis analyses the possible role of tidal power in Bangladesh, where the necessary infrastructure, such as coastal embankments and sluice gates, already exist. It also explores ways of resolving current problems for tidal power in Bangladesh.

1.2 Bangladesh coastal environment: the context

As the location of the current research is coastal Bangladesh, we need to understand the details of this socio-economic, environmental, geographical cultural context. This section provides a brief background and justification to the selection of coastal Bangladesh as a study site for this research. Coastal Bangladesh, comprising the complex delta of the Ganges-Brahmaputra-Meghna river system, has immense resources for development (Barua, 1993; ESCAP, 1992). This system constitutes one of the largest river systems in the world, which originates from the Himalayas and flows through Bangladesh on its way

\textsuperscript{7} The place where the sea meets the land. The coast is a unique place in an economic sense as the site for port and harbor facilities that capture large monetary benefits associated with waterborne commerce and as a location for industrial processes requiring water cooling, such as power generation plants. It is also highly valued and greatly attractive for resorts and as vacation destinations. Generally, however, the coast is not stable and it is continuously undergoing breakdown or accretion though the erosion process (Cicin-Sain and Knecht, 1998).
to the Bay of Bengal (Miah, 1975). Low wave energy, high tidal range and a normally low littoral drift characterise the Ganges-Brahmaputra-Meghna delta (ESCAP, 1988; Khondaker et al., 1993). It has a narrow basin resulting in the formation of finger-like channels and sands passing offshore into an elongated tidal current ridge (figure 3.1 in Chapter III) (ESCAP, 1992; Hossain, 1996). This system carries a massive sediment load to coastal Bangladesh, which is subject to dynamic processes generated mainly by river flow and tidal and wind actions, leading to accretion and erosion in the coastal belt (Miah, 1975). The rate of sediment influx suggests a regional rate of denudation in the Himalayan source area of over 70 cm per 1000 years (Curray and Moore, 1971; ESCAP, 1992). As a result of this natural land accretion system, coastal Bangladesh is naturally enriched with fertile land and a lot of potential resources and opportunities, such as the sustainable development of mangrove forests and the rich coastal fisheries.

Presently, a significant portion of the country’s population lives in the coastal area and depends completely or partially on the natural coastal resources (Salequzzaman, 2001). However, due to the lack of modern facilities such as energy, communication, planning and sustainable management practices, some natural resources are over-utilised and some are under-utilised.

Due to its geographical location, coastal Bangladesh has regularly faced natural disasters. Cyclonic storms are an important feature of this area and have caused great suffering to people and damage to structures in the cyclone path.
The coastal area also suffers from frequent natural disasters, in particular periodic tidal inundation by seawater and storm surges. As a protective measure against the effects of natural disasters, a long coastal embankment and sluice gates were constructed along most of the coastal belt in the 1960s. The embankment was constructed without any kind of environmental assessment, thus various environmental impacts and unsustainable activities have resulted from its construction. Unsustainable shrimp aquaculture is one such activity (Verdegem and Verreth, 2001). The Bangladesh coastal environment, its soil, water, climate and local cultural heritage all provide an advantageous natural setting for shrimp aquaculture, which is an important source of foreign currency income. However, this shrimp aquaculture has now created socio-economic, environmental and cultural problems, due to unsustainable farming practices. Politically influential and rich men presently dominate shrimp aquaculture operations and, as a consequence, more than 95% of coastal people, most of them very poor marginal farmers and fishermen, do not enjoy the benefits this industry can provide (Salequzzaman, 2001). Moreover, shrimp aquaculture has not been economically sustainable due to the lack of practical knowledge, faulty selection of land, absence of modern methods in farming and lack of infrastructure (Karim and Aftabuzzaman, 1999; Khan and Hossain, 1996; Salequzzaman, 2001). The primary impacts of this unsustainable aquaculture development are the conversion of coastal ecosystems (mainly mangroves) to fish or shrimp ponds. This activity alone has replaced more than 50% of the original mangrove forest in the Sundarbans with unsustainable aquaculture (Khan and Hossain, 1996). Another significant impact results from various kinds of pollution generated by aquaculture, as it is essentially a farming system that uses fertilisers, feeds, and chemicals (Verdegem,
In concentrated form, they are detrimental to near shore water quality, natural fisheries, and human health (Salequzzaman, 2001).

The thesis will discuss in detail how this unsustainable coastal aquaculture may become sustainable with integrated tidal power development. Sustainable integrated coastal development provides the tools for slowing and, hopefully, reversing the negative impacts of uncontrolled use of various coastal resources. This system of coastal management provides the essential processes for integration of all sectoral, spatial, temporal, policy, and institutional components necessary to achieve the goal of sustainable development (Mazid and Alam, 1995; NACA, 1994; Sorensen, 1997).

The current loss of essential natural resources and declining community capacity in coastal Bangladesh is characterised by the preponderance of low-income families, with a rapidly increasing birth rate and correspondingly high infant mortality rate caused by lack of nutrition and poor living conditions (BBS, 2001). The skewed distribution of wealth and power has created a serious long-term threat to the region's rich natural resources, economic prosperity and security through the unsustainable exploitation of these resources (Flint, 2001; Salequzzaman, 2001; Vallega, 2001). The primary goal of this research is to identify solutions to overcome declining economic status and strengthen the abilities of low-income, most at-risk populations, while simultaneously sustaining agriculture, fisheries, and the integrity of this rural coastal area (Salequzzaman and Newman, 2002). Electricity supply could increase the supplementary resources and income of the local people, and could enhance the integration among existing coastal natural resources (MWR, 2001; Newman et al., 1999; Nishat, 1986).
Renewable energy sources present one of the few opportunities to produce electricity in this remote coastal location (Bala, 2003). Coastal tides may be used as a source of renewable energy. The existing coastal embankment has been set at a height equal to the normal maximum recorded water level plus some freeboard to protect against cyclonic surges and tidal waves (ESCAP, 1992; Verdegem, 2001). Generally, tidal surges/ranges with an enormous energy potential affect the coastal environment twice a day. This tidal range could be utilised for the production of small-scale tidal energy by utilising the existing infrastructure of coastal embankments and sluice gates (Newman et al., 1999; Salequzzaman et al., 2000; Salequzzaman and Newman, 2002). The energy could then be utilised for the sustainable integrated coastal development of Bangladesh.

In the near future, climate change and sea level rise scenarios may increase this opportunity. Bangladesh is one of the most vulnerable countries to global warming and concurrent sea level rise. A yearly seasonal change of mean sea level of approximately 1.22 metres has been reported in the Ganges-Meghna estuary, the largest on record in the world (Alam, 2001). From several studies, it is projected that by the year 2050 the mean sea level may rise as much as 1.8 metres, which may change the current and water movement, precipitation, run-off and tidal behaviour of coastal Bangladesh (Alam, 2001).

Bangladesh has many worthwhile laws related to coastal resource management, including laws which govern their coastal and marine areas, their resources and the environmental impacts of development. If these laws are effectively enforced, then many problems might be solved. Unfortunately, the existing laws are not adequately enforced due to the
lack of political will, transparency in governance and the practice of corruption (Wirojanagud, 1986). Awareness, education and participatory community-based co-management practices may solve these problems.

The challenges and opportunities of coastal Bangladesh can be summarised as follows:

(a) The population is generally very poor, but work hard and have successfully adapted to natural calamities;

(b) The soil is very fertile and opportunities exist to develop small-scale to medium size industries;

(c) Fisheries productivity is declining due to over-harvesting, loss of habitats, and increasing human population;

(d) Poverty is an important factor which dictates dependence on natural coastal resources rather than their conservation;

(e) Over-fishing, the use of destructive fishing methods, unsustainable shrimp aquaculture practices and conversion of natural habitat (wet land and mangrove forests) to agricultural and aquacultural uses are gradually increasing environmental damage;

(f) People are disadvantaged by lack of access to modern facilities, such as electricity supply, financial support and technical know-how;

(g) Pollution from land-based activities, industrial and urban development, deforestation and agriculture are increasing. Cumulatively, all contribute to the declining bio-geo-chemical balance of the marine and coastal environment;

(h) Corruption and inadequate law enforcement clog genuine progress;
and

(i) There is excellent scope to develop participatory, community-based coastal co-management practice in different sectors of coastal resources, given the traditional culture of working together and sharing the benefit amongst one another.

This section has demonstrated the diversity and complexity of the coastal environment of Bangladesh and the challenges facing their development of the area. As part of the integrated tidal power model, the thesis will elaborate on community-based coastal co-management, and how it could apply to the sustainable development of coastal Bangladesh. These coastal Bangladesh issues are expanded in Chapter III and with particular reference to shrimp aquaculture in Chapter V.

1.3 Tidal power suitability in coastal Bangladesh

Specifically in relation to energy, Bangladesh is characterised by low electricity use (average per capita consumption of 95.85 kWh) despite a considerable need for development along its coastal area (BBS, 2001; ESCAP, 1998); and electrification levels of only 16% of the population, with coastal rural access to electricity of less than 5% (BCAS, 1999), placing Bangladesh’s electrification rates amongst the lowest in the world.

Therefore, the thesis analyses how the application of diversified, decentralised community-based tidal power as a source of renewable energy can offer sustainable alternatives for the provision of energy to satisfy the fast growing demand in rural and
coastal Bangladesh. The concept will have to be set up as a pilot project so that its benefits can be demonstrated first hand to the local people.

Bangladesh has a long coastal area (710 km) with 2-8 m tidal height/head rise and fall (BIWTA, 1999). Among this tidal head, there are some large tidal sites and many channels of low tidal range in a large number of deltaic islands (where barrages and sluice gates already exist). The potential for tidal power to be developed is significant, because the barrages necessary for creating controlled flow through turbines (to tap tidal power) are also needed for flood control. This process will avoid the problem of high capital cost as the engineering is either already there or will be needed for cyclone/tidal surge protection.

Coastal Bangladesh, particularly the Khulna, Barisal, Bagerhat, Satkhira and Cox’s Bazar regions are geographically extensive deltaic areas with levees and sluice gates. The existing infrastructure could therefore be used for electricity generation from tidal flow by applying simple technology that can have widespread application. This technological opportunity will be expanded in Chapter IV.

Tidal power in coastal Bangladesh would provide many related economic opportunities through integration of scientifically improved aquaculture, agricultural modernisation and adaptation to climate change, industrial development, improved navigation and communication systems, eco-tourism opportunities and service provision employment. Other direct employment opportunities are available in the operation of the tidal power station and maintenance of the extensive transmission lines and systems. Many of the
employment opportunities in the aquaculture and tourism service industries tend to be labour intensive and do not require highly skilled people. It is expected that the bulk of the workforce requirements will be satisfied through local people who have undergone appropriate training.

Other significant benefits of this proposed tidal power concept in coastal Bangladesh, could be:

(a) Access to electricity and demand side appliances thus offering improvements in the quality of night lighting, access to information through radio/TV and cooling through the use of fans;

(b) Access to income generation opportunities through shrimp farming and other cottage industries;

(c) Opportunities to commence community-based co-management with landless poor people, marginal farmers and fisherman; and

(d) Development of coastal Bangladesh through electrification which will enable people to improve their socio-economic status.

The current research investigates how the integrated development concept could improve the health, education, access, safety, economic and community life of coastal people. It will also scope out any potential problems associated with changes to the local hydrology through technical assessments and detailed discussions with the people involved. The potential to expand and extend the concept to other locations exists. Globally, the tidal power concept is also very significant as it is a non-greenhouse gas emitting energy source. The opportunity to attract international funds through the clean development
mechanism (CDM)\(^8\) is thus apparent. Climate change predictions suggest low-lying areas of Bangladesh will be more susceptible to flooding in future. However, there is also expected to be more sediment in the rivers and hence Bangladesh may not be as susceptible as many have thought, due to increased soil deposition\(^9\). Whatever happens, enhanced coastal engineering will be necessary (Wirojanagud, 1991) and tidal power offers an added benefit to moves designed to improve barrages and water management. Thus climate change preparations can be turned to advantage in Bangladesh. The integration of tidal power with coastal development is expanded in Chapter VI with two case studies in Chapter VII.

1.4 Significance of the research

"Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of ecosystems on which we depend for our wellbeing. However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future- for sustainable development (Agenda 21, 1992)."

The research will directly promote the social, economic and environmentally sound development of coastal Bangladesh. I seek to show how tidal power can promote a higher

\(^8\) The Clean Development Mechanisms (CDM), which can bridge the North-South divide that has long characterised international climate change negotiations, is the principal means by which industrialized and developing countries can work together to promote sustainable development, lower the carbon intensity of new investments, and reduce the cost of meeting the Kyoto Protocol obligations (Jacob et al., 2001; Huq, 2002).

\(^9\) Coastal Bangladesh is the catchment of several main rivers (such as the Ganges and the Brahmaputra) of this region. These rivers always bring a huge load of sediments to the coast; therefore the coast is reducing its depth and increasing its flooding range at monsoon every year. On the other hand, climate change is increasing the sea level at a rate of about 3 mm per year along the Bangladesh coast (World Bank, 2001).
integration of agriculture, aquaculture and livestock productivity, enhance food security, and improve quality of life for communities in coastal Bangladesh.

The academic significance of this work is:

(a) Little applied research has been conducted on sustainable integrated coastal development to date (Cicin-Sain and Knecht, 1998; Gardiner, 2002; McNally and Tognetti, 2002; Verdegem and Verreth, 2001);
(b) Tidal power has not been analysed as a small scale process integrated into coastal development (Bala, 2003; Newman et al., 1999; Salequzzaman and Newman, 2002);
(c) Neither of the above has been studied in third world situations (Bernshtein, 1997; Brinkworth, 1998; Corry and Newman, 2000).

The study will also be significant because of its focus on Bangladesh - a country with little use of electricity and considerable need for development along its coastal area. The potential for tidal power to be applied there is significant, because the barrages necessary for creating controlled water flow through turbines are also needed for flood control. This synergy is a powerful motivation for the study as it reaches to the heart of a sustainable future in coastal Bangladesh.

1.5 Objectives of the research
The fundamental question behind the research is: can tidal power be used to promote socially, economically and environmentally sound sustainable development in coastal Bangladesh? Therefore, the broad objectives of the research are:

(a) To propose an environmentally sound, sustainable development framework in the coastal region of Bangladesh;
(b) To examine how the development and implementation of tidal power plants could be integrated with other coastal resources;
(c) To analyse how to harness very low-head tidal movements (2-5 m) in the existing levees, embankments and sluice gates of coastal Bangladesh to produce electricity by using simple appropriate technology, and to explore the potential for larger scale tidal projects; and
(d) Based on tidal power provision, to develop a participatory, local community-based, coastal co-management system that integrates the sustainability policy and planning frameworks of agriculture, aquaculture and other small-scale industries and community development in coastal Bangladesh.

1.6 Research questions

I have selected the research questions against the research objectives. The following are the research questions:

Sustainable development of coastal environment in the world situation

(a) What are the issues of sustainable development in the coastal environment around the world?
Sustainable development of coastal environment in Bangladesh

(a) What are the issues for ‘Sustainable Integrated Coastal Development’ in Bangladesh?

(b) Is shrimp aquaculture sustainable at its current levels in coastal Bangladesh?

(c) What is the role of shrimp aquaculture in sustainable integrated coastal development in Bangladesh?

Regarding utilisation of tidal power for sustainable development of coastal environment in Bangladesh and around the world

(a) To what extent is tidal power a low-cost, long-term and appropriate technology? Why has it not been utilised extensively yet and when will it be feasible?

(b) How can tidal power be sustainably used as a small-scale technology, instead of on a large or medium scale, in a developing country like Bangladesh?

(c) What are the prospects for integrated development by using tidal power in coastal Bangladesh?

(a) How can tidal power be integrated with various resources in coastal Bangladesh?

(b) How can integrated tidal power bring about sustainable development in coastal Bangladesh?

(c) How can the sustainable integrated coastal development model be applied to small islands and other coastal projects that already have embankments and sluice gates?
The research questions will be discussed in the next corresponding chapters separately.

1.7 Methodology of the research

The approaches, methods and techniques used in this research are:

(a) Literature review from secondary documents (journals, books, previous case studies and other documentation), internet/web page searching and email communication;

(b) Qualitative survey of interviews with stakeholders to ascertain potential, possible impacts in order to find out the socio-economic, cultural and environmental potential for sustainable integrated coastal development in Bangladesh;

(c) Development of primary data and information by field visit, survey and interview;

(d) Analysis of various existing and potential tidal power technologies around the world; and, finally,

(e) Identifying and evaluating the appropriate tidal range stretch at different locations in coastal Bangladesh.

As mentioned above, presently only few tidal power plants are working around the world. The scarce scientific data exist in only a few countries, especially in United Kingdom, USA, China, South Korea and France. Firstly, I have collected this scarce information through personal communication, internet search, review of various journals, reports, and books. Secondly, I have assessed this information through identification of similarities
and dissimilarities among various sources of information, and selected the key characteristics for the tidal power resource for the specific country such as Bangladesh.

I have also collected data on the tidal characteristics of Bangladesh. Surface Water Modelling Centre of Bangladesh supplied me all their sampling data of tidal ranges for the whole of Bangladesh. I have cross-checked these data again with Bangladesh Water Development Board’s tide table, and selected the strongly tide affected areas of the country for this research. Then I have studied these areas based on their socio-economic, cultural, geographical, and environmental characteristics, in particular their energy supply situation and their suitability for application of tidal power. This part of the research has mainly been done through secondary literature, field visits and personal communication.

All of this information I have analysed with the help of my Principal Supervisor Professor Peter Newman, my Co-Supervisor Dr. Laura Stocker, my ISTP colleague Mr. Mark Ellery (Mechanical Engineer), Mr. Brendan Corry of Tidal Energy Australia, Professor Nazrul Islam (Renewable Energy Expert and Mechanical Engineer of Bangladesh) from Bangladesh University of Engineering and Technology (BUET), Mr. Md. Abdul Halim Mollah (Chief Engineer, Bangladesh Rural Electrification Board), and Professor Ainun Nishat (Water Resources Management Expert and Country Director, IUCN Bangladesh).

In addition, I have visited the selected strongly tide affected areas of Bangladesh during 20 September 2000 to 15 November 2000 and completed informal interviews with the stakeholders of these tide affected areas, including farmers, researchers, academics, social
scientists, NGO-personnel, and others. I have finally selected some suitable areas for the detailed case studies.

At the end of this research, I have developed a conceptual integrated tidal power model through the analysis of the practical situation of coastal Bangladesh that I will discuss in Chapter VI.

1.8 Thesis Chapter Orientation

This section provides an outline of the structure of this thesis.

(a) Chapter 1 is the introductory chapter including a background and aims of the study. It provides and discusses definitions and terminology that are used in the thesis including the main research questions. Finally, it presents the objectives of the study, the research questions, and methodology that was adopted to achieve those objectives.

(b) Chapter 2 examines the meaning of sustainability as it is applied to the coastal environment and its present global situation, including an overview of the factors necessary for sustainable integrated coastal development.

(c) Chapter 3 examines the coastal environmental situation in Bangladesh. It includes the characteristics of coastal Bangladesh, describes the factors impacting on coastal sustainability and suggests how the existing practices can be integrated into sustainable development processes.
(d) Chapter 4 discusses the details of tidal power technologies around the world and their applicability to the coastal environment. This chapter also presents the history, principles and benefits of tidal power, the barriers to developing tidal power in coastal regions and how these barriers could be solved. Finally, it outlines how tidal power could be implemented sustainably in different coastal regions around the world, including coastal Bangladesh.

(e) Chapter 5 describes shrimp aquaculture in coastal Bangladesh, including the present situation, and assesses the potential for sustainable development of coastal aquaculture.

(f) Chapter 6 discusses the sustainability of coastal Bangladesh as a whole, based on the integration of tidal power with various coastal resources, as they currently exist, such as coastal embankments and sluice gates. The suggested tools are small-scale technologies and integration of tidal power with an aquaculture industry to create more active income generation activities and sustainable coastal development.

(g) Chapter 7 sets out two case studies on the sustainability of tidal power integration in coastal Bangladesh: Sandwip near Chittagong and Gazi Fish Culture near Khulna. Both case studies include the creation of tidal power and their subsequent prospects of developing more income generating activities.
(h) Chapter 8 provides recommendations and conclusions, and discusses the answers to the research questions. It also outlines further work required.
Chapter II
SUSTAINABLE DEVELOPMENT IN THE COASTAL ENVIRONMENT

"Human beings are at the centre of concerns for sustainable development, they are entitled to a healthy and productive life in harmony with nature."

Thabo Mbeki
The President of the Republic of South Africa
Johannesburg Earth Summit’ 2002

Research Question
What are the issues of sustainable development in the coastal environment around the world?

2.0 Introduction

The coastlines of the world, over 440,000 km in length, represent one of the most dynamic of natural environments and one of the most important contexts in which human activity, ecology and geomorphology interact (Fabbri, 1998). From the beginning of human civilisation, peoples have concentrated around the coastal region. It provides the basic human needs (food, shelter, water, transportation and others) as well as functional (trade, infrastructure and other such facilities), aesthetic (leisure environments) and strategic (territorial and defence options) resources. It is also a major source of inputs for fertiliser, pharmaceuticals, cosmetics, aquaculture, agriculture, household products and construction materials (Alcala, 1981 & 1988; Azim et al., 2001; Christie and White, 1994; White and Savina, 1987). In addition, as Tamburrino states,

“the coastal environment is one of the places where one is led spontaneously to reflect more on the meaning of life (Tamburrino, 1991, p. 104).”
Peoples from around the world are still moving towards the coastal environment to live, to retire or to make a living. As the coast can generate a range of different products and services, not all of which are naturally compatible, conflicts are likely and trade-offs are necessary (Nash, 1995; Pauly and Thai-Eng, 1989; Schoonbee; Prinsloo, 1988).

Presently, around 60% of the human population lives in a coastal band of 50 km wide that represents approximately 10% of the earth’s surface (Chua, 1993; Lakshmi and Rajagopalan, 2000). In Australia in 1996, 83% of people lived within 50 kilometres of the coast (Annual Environment Report, 2001). In the Southeast Asian region, over 70%-75% of the population lives in coastal areas which are characterised by intensive exploitation of resources brought about by increasing population pressure and associated economic activities over the last two decades (Barnabe and Barnabe-Quet, 2000; Pauly and Thai-Eng, 1989). Half of the world’s coast-dwellers live in developing countries (Barnabe and Barnabe-Quet, 2000; Goldberg, 1994; Lakshmi and Rajagopalan, 2000). The in activities place increasing pressure on coastal sustainability. The theme of this thesis is sustainable integrated coastal development, therefore this chapter is mainly concerned with those fundamental issues of coastal development around the world.

### 2.1 Issues for coastal sustainability

As a result of human intervention, the coastal environment has been subject to continuous degradation and even irreversible changes such as alteration of tidal flow characteristics.
Many organisations (for example, GESAMP\textsuperscript{10} and NRC\textsuperscript{11}) have identified the key factors responsible for coastal degradation. These include various forms of pollution (for example, eutrophication in coastal waters), over-fishing and unsustainable aquaculture practices, modification (destruction and alteration) of coastal biogeochemical and hydrological cycles, introduction of exotic species into local ecosystems, unsustainable land-use practices (for example, poor urban design and deforestation) and global warming (Alongi, 1998; Verdegen \textit{et al.}, 2001).

Presently, the coastal environment is under pressure from human modification and destruction in such a way that ecosystem services and natural production from coastal marshes, estuaries, coral reefs and mangrove forests are disturbed and some micro environments are endangered (Alongi, 1998; ENS, 2001; Hussain and Acharya, 1994). Estimates vary but most experts agree that a large proportion of the world’s coastal habitats are in various stages of degradation (Goldberg, 1994; National Research Council; 1994). Sometimes this destruction process has gone to such extreme levels that the coastal environment and its resources have become more susceptible and vulnerable to stress and shock (Bower and Turner, 1996; GESAMP, 1990; Viles and Spencer; 1995). These coastal environmental issues are barriers for sustainable integrated coastal development around the world, and demand urgent attention from stakeholders. Below, I discuss those areas that are related to my thesis.

\textsuperscript{10} The Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) is an advisory body to the heads of eight organisations of the United Nations (UN, UNEP, FAO, UNESCO, WHO, WMO, IMO, and IAEA).

\textsuperscript{11} The Committee To Identify High-Priority Science To Meet National Coastal Needs, Ocean Studies Board Commission on Geosciences, Environment, and Resources, National Research Council of the National Academy of Science, Washington, D.C.
2.1.1 Mangrove destruction and deforestation

Mangroves are the most valuable resources in coastal areas because the mangrove habitat contains a rich and unique biodiversity which can supply many resources to human beings such as food, shelter and employment. Unfortunately, mangroves are now becoming endangered around the world particularly in South-East Asian countries due to unsustainable deforestation, urbanisation, agriculture, aquaculture, mineral and oil extraction and industrialisation (Gong and Ong, 1990; Semesi, 1992). Globally, about 50% of mangrove forests have been lost (ENS, 2001). Nearly 43% of the world’s 17 million hectares of mangrove forests are found in Southeast Asia where more than 50% of mangrove forests have been cleared, mostly for timber and mariculture; this is the greatest loss in the world (Alongi, 1998; Fortes, 1994; Ong, 1994). Indeed, the greatest threat to mangroves worldwide is conversion of forest areas to aquaculture (mainly finfish and shrimp) ponds. In the Philippines, Thailand, Indonesia, South China and Bangladesh, roughly 50-80% of mangrove forests have been lost to shifting aquaculture, primarily for the cultivation of milkfish and shrimp aquaculture (Hussain, 1995; Mann, 2000; Ong, 1994). But mangrove forests have been managed in a sustainable manner for a long time in some specific areas of the world (for example, in specific area of Indonesia, Thailand, Bangladesh, Vietnam, and the Philippines) where reforestation and rehabilitation of degraded shrimp farms have been undertaken successfully (Aksornkoae, 1989; Courtney and White, 2000). This experience could be helpful for sustainable integrated coastal development in Bangladesh (DFID Bangladesh, 1999; Ruddle, and Johannes, 1989).
2.1.2 Nutrient pollution

Coastal waters are the most important of all marine environments with respect to their commercial resources, recreational and ecological roles. Pollution is the common thread that links an array of problems along the world’s coastlines. Pollution includes: harmful algal blooms from eutrophication, heavy metal pollution from untreated sewage water and toxic chemical outfall (Howarth, et al., 2001; Weber, 1993).

The excessive, nutrient-induced increase in the production of organic matter is called eutrophication or nutrient pollution, and it is linked to a number of problems in aquatic ecosystems (Brodie, 1995; Grey, 1992; Turner and Rabalais, 1991). Nutrient pollution has impacted on the coastal environment in a number of ways such as depletion of oxygen, sudden death of aquatic organisms, and economic declines in fisheries (Cambridge and McComb, 1984; Townsend and Cammen, 1988; Turner and Rabalais, 1991). Therefore nutrient pollution is an important barrier to sustainable integrated coastal development. The overall impact of pollution on coastal areas and marine waters and ecosystems is degradation of the ecosystems, lower environmental quality and, most significantly, lower natural production. Various strategies might help to maintain or improve the health of the coastal waters. These include pollution prevention, treatment, and disposal measures that must be implemented to maintain the life support system provided by coastal ecosystems (Levenson, 1991; Verdegem et al.,...
1996). In the case of commercial and economic aquaculture production in coastal environments, input of artificial energy will be needed for the function of aerators or other machinery which can mitigate the nutrient pollution (Barnabe and Barnabe-Quet, 2000; Justic, 1991; Rogers and Fast, 1988). Treated water could be purified by aeration processes as well as being used for aquaculture (Grobbelaar et al., 1981; Barnabé, 1990). Ali and Khan (1993) describe wastewater purification ponds which are extensively used for shrimp and prawn cultivation in West Bengal and Bangladesh. This technology has also created employment opportunities (Barnabe and Barnabe-Quet, 2000; Becker, 1985; Costa-Pierce, 1989). Coastal shrimp aquaculture is one of the research topics in this thesis, and the topic of nutrient pollution and its mitigation technology will be an important part of the proposed strategy for sustainable integrated coastal development of Bangladesh.

**2.1.3 Unsustainable shrimp aquaculture**

Presently unsustainable shrimp aquaculture has been practised in the coastal environment around the world. It is one of the important causes for clearing the mangrove forests, not only in Bangladesh but many South-Asian countries. Unsustainable shrimp aquacultural practices are important barriers for sustainable coastal development (Rasowo, 1992; Verdegem, 2001). As mentioned above, around 50% of mangrove areas worldwide have already disappeared to shrimp farming (Barnabe and Barnabe-Quet, 2000). One of the important goals of this research is sustainable coastal aquaculture in coastal Bangladesh, therefore this aspect will be fully discussed in Chapter V.
2.1.4 Sedimentation and erosion

Unnatural rates of sedimentation\textsuperscript{12} and erosion\textsuperscript{13} are serious problems for sustainable integrated coastal development. They are the major causes of the modification of hydrology and geomorphology of the coastal environment. Sedimentation (and siltation\textsuperscript{14}) is important in the development and maintenance of numerous coastal habitats such as coastal wetlands, lagoons, estuaries and mangroves. Reduction in natural rates of sedimentation can compromise the integrity of these habitats, as can excessive sediment loads, which may bury benthic communities and threaten sensitive habitats such as coral reefs, mangroves, seagrass beds, and rocky substrates (Hotta and Dutton, 1995). In the same way, contaminated sediments, whether they are fresh inputs or dredged, may also lead to pollution, the latter through resuspension or improper disposal (Ong, 1995). Anthropogenic modifications to sediment

\textsuperscript{12} The settling out of suspended particles (known as sediment, such as phytoplankton, zooplankton, CaCO\textsubscript{3}, etc) from a body of water (natural or artificial water body).

\textsuperscript{13} The deterioration and weathering away of coast’s soil or rock. These could happen either by detachment of individual particles from soil/rock aggregates or transport of particles by erosive agents such as wind, tide, wave and any other factors.

\textsuperscript{14} Siltation is a process by which finely divided soil and rock particles (commonly known as silt) settle out upon the bottom of natural water body (stream, river and reservoir). There is very minute differentiation between siltation and sedimentation. Siltation is a function of Total Suspended Solids settling out and sedimentation is a product of Total Suspended Solids (TSS). In another ward, all siltation processes could be called by sedimentation, but all sedimentation process could not be called by siltation (Hardy, 2000).
mobilisation and sedimentation are made, by *inter alia*, construction activities, forestry operations, agricultural practices, mining practices, hydrological modifications, dredging activities, and coastal erosion. These activities change the original natural behaviour of the coastal environment. In addition, the surface of the coast is constantly being sculptured into new forms through erosion. The shapes of continents are continuously changing, as waves and tides cut into old land while silt from the coast builds up new land (Williams *et al.*, 1991). Ocean tides provide a natural means of circulating water and maintain a level of water quality and nutrients that support a variety of plants and animals (Bertolotti and Crumpley, 1991; Taylor, 1991). However, increased rates of sedimentation and erosion have long-term social, environmental and economic consequences to the coastal environment around the world (Nailon and Seidensticker, 1991). Details of coastal sedimentation and erosion of Bangladesh will be discussed in Chapter III.

### 2.1.5 Impacts from tourism industries

In recent years, an international eco-tourism industry has grown up around the unique and sensitive biophysical and ecological characteristics of the coastal environment (Annual Environment Report, 2001; ESCAP, 1992a; UNESCO. 1992). Eco-tourism has become a significant part of world current economy (Auyong, 1995; Lindberg, 1991; Wight, 1993), and is often seen as an environmentally friendly industry. However, this industry has had serious impacts on the coastal environment (Clarke, 1989; OECD, 1993; SPREP, 1993) including: elimination of habitats, acceleration of erosion impact on local cultures and communities, destruction of natural features, water pollution, and damage to historical places (Auyong, 1995; Cohen, 1978; Hall, 1991). Therefore careful planning and conservation in tourism development is
necessary for achieving sustainable integrated coastal development (Auyong, 1995; McNeely and Thorsell, 1989; Office of Technology Assessment, 1992). One key determinant as to whether tourism, particularly eco-tourism, could enhance coastal sustainability is to what extent the benefits people receive from eco-tourism are linked to protecting the resource base (Brandon, 1993; Wight, 1993; Ziffer, 1989). The benefits of conservation must be considered significant to a large portion of the community if conservation is to be an incentive. As this thesis takes an integrated approach, eco-tourism is a small but important component of the research. A sustainable integrated coastal development strategy has the greatest chance of dealing with issues tightly coupled to tourism such as habitat loss, water quality degradation, over-fishing, industrial development, and socio-economic development. Integration of tourism has great scope in coastal Bangladesh. Further details on eco-tourism are presented in Chapter VI.

2.1.6 Salinisation\textsuperscript{15} of the coastal environment

Unplanned and unsustainable methods of coastal management have lead to increased salinity\textsuperscript{16} levels in the coastal environment around the world, for example, in Western Australia, Thailand and the Aral Sea region (Government of Western Australia, 2002; Williams and Aladin, 1991). As salinity increases, the coastal ecosystem balance decreases and affects biodiversity, fertility of land and other coastal resources (Barnabe and Barnabe-Quet, 2000; Levesque, 1994; Pauly and Thai-Eng, 1989). Presently, a major portion of the coastal area around the world is affected by salinisation such as some parts of coastal Western Australia.

\textsuperscript{15} The process by which salinity increases in a specific area in terms of time and space.

\textsuperscript{16} A measure of the total concentration of dissolved solids in seawater usually expressed as parts per thousand (‰).
and most parts of coastal Bangladesh. The salinisation process is an important barrier to sustainable integrated coastal development. As salinity now affects coastal Bangladesh, this issue will be discussed more elaborately in Chapter III.

### 2.1.7 Impact of climate change and sea-level rise

Climate change\(^{17}\), including global warming and sea level rise are the most important threats to global sustainability in the 21\(^{st}\) Century (Rayner and Malone, 1998; Watson, 2002; World Bank, 2001). Global warming and sea level rises are expected to impact coastal environments, where, presently, 50-70\% of the world’s estimated 5.6 billion people live (Cicin-Sain and Knecht, 1998; Klein and Nicholls, 1998; Rahman and Huq, 1998). The impact of these changes includes inundation or submersion of existing infrastructure with adverse effects on food production, fisheries, forestry, tourism, recreation, and transportation (Bijlsma \( et al., 1996; O’Meara, 1997; Toepfer, 2001). The main reasons for climate change are burning of fossil fuels (such as coal, oil, and natural gas that produces carbon dioxide and other GHGs) to produce energy for transportation, manufacturing, heating, cooling, and other applications; and deforestation (Khan, 2001; UNFCCC, 2001). In addition, various agricultural and industrial practices are increasing the composition of the atmospheric concentrations of a number of greenhouse gases (Bala, 2003).

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\(^{17}\) According to Intergovernmental Panel of Climate Change (IPCC), climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity that alters the composition of the global atmosphere.
Green house gases include: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and ozone in the lower part of the atmosphere (Hansen et al., 2000; IPCC, 2001; Rob, 2001). GHGs allow incoming solar radiation to pass through the Earth's atmosphere but prevent most of the outgoing infrared radiation from the surface and lower atmosphere from escaping into outer space. This process occurs naturally and has kept the Earth's temperature about 59°F warmer than it would otherwise be (Bytes, 2001; IPCC, 2001).

However, the atmospheric concentration of CO₂ has increased by 31% since 1750, mainly due to the activities of industrialised nations, which have created more than 80% of the current problem of global warming by burning fossil fuels (Anna, 2001; Rahman and Mallick, 2002). The USA emits 720 million tonnes CO₂ annually and has a per capita emission of 20.5 tonnes, which is the highest in the world. China and India have total annual CO₂ emissions of 200 and 300 million tonnes, and per capita emissions of 2.5 and 0.9 tonnes CO₂ respectively. Australia produces 16 tonnes CO₂ per person from a total annual emission of 306 million tonnes (Anna, 2001; Plotkin, 2002). From all of these sources, 16 billion tonnes of CO₂ would be belched into the air each year from fossil fuels (Lovell, 2002). Methane is the second most important greenhouse gas, produced by rice cultivation, cattle and sheep ranching and decaying materials from landfills with an increased concentration in the atmosphere of about 145% (Khan, 2001).

Increased greenhouse gas emissions are very dangerous for environmental sustainability in coastal areas, because global warming enhances the melting of
polar ice that ultimately causes the sea level rise. Scientists estimate the global surface temperature will increase by 1.4 to 5.8°C over the period of 1990 to 2100 with an associated rise of sea level of 15 to 95 cm (Biswa et al., 2001; ENS, 2001; Khan, 2001). The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during the last 10,000 years (Khan, 2001). Studies combining tide gauge measurements around the world have concluded that the average global sea level has risen 10-15 cm (4-6 inches) in the last 100 years (Biswa et al., 2001; Hansen et al., 2000; Watson; 2002). According to all of the statistics of climate change, many scientists and researchers (such as Barnabe and Barnabe-Quet, 2000; Biswa et al., 2001; Boesch et al., 2000; Burke et al., 2001; Frederick and Gleick, 1999; Goldberg, 1994; Han et al., 1995; Hoozemans et al., 1993; Jackson et al., 2001; Kennedy et al., 2002; Khan, 2001; Kjerfve; 1991; Najjar et al., 1999; Neumann et al., 2000; New England Regional Assessment, 2001; NOAA, 1998; Nuttall, 2001; Pacific Islands Regional Assessment, 2001; Poff et al., 2002; Pugh, 1990; Resort, 2001; Robert, 2001; Sudara, 1996; Titus, 1987; Toepfer, 2001; Tol, 1998; Twilley et al., 2001; Wigley, 1999) predict that impacts of climate change will result in stresses on coastal development and coastal habitats. Fisheries, biodiversity and other coastal resources, particularly in low-lying coastal areas like Bangladesh, will be impacted.

The developed countries are largely responsible for global warming yet developing countries are mainly affected by its impact (Benioff et al., 1996; Climate Action Network Australia, 2001; Gribbin, 2001). These impacts on

18 USA is world’s worst polluter. Reuters news service by Anna, R. (2001) Climate Action Network
coastal regions require mitigation\textsuperscript{19} measures to reduce GHGs and adaptation\textsuperscript{20} to its consequences (Easterling III, \textit{et al.}, 1989; IPCC, 2001; Watson \textit{et al.}, 1996). Parry \textit{et al.}, (1998) suggests that climate change adaptation and mitigation should utilise innovative, low-cost, locally available, and appropriate technology. The adaptation of coastal regions should include coastal infrastructure through major rehabilitation, construction, and technical changes in harbour, industrial, and urbanised coastal areas through application of land-use planning, management, and engineering design principles (Klein and Nicholls, 1998; Stakhiv \textit{et al.}, 1991; Yim, 1996). To ensure the sustainability of these adaptation processes, it is important to identify low-cost, appropriate, locally available, technically feasible technologies and no-regret responses that maintain or enhance the choices in the future for maximum flexibility (Downing \textit{et al.}, 1996; Nicholls and Leatherman, 1996; Stossel, 2001). The applicability of any such option must be evaluated against, among other things, a background of a country’s technical and human resource capability, financial resources, cultural and social acceptability, and political and legal framework (Bijlsma \textit{et al.}, 1996). The selection of adaptation options will require integrating and/or making trade-offs, such as environmental, economic, social, and cultural values among all the stakeholders in the coastal zone (Klein and Nicholls, 1998; Pearce and Turner, 1992; WCC’93, 1994).

\textsuperscript{19} Mitigation involves actions to prevent or retard GHGs emissions. Mitigation can only slow down the rate of climate change and cannot prevent its occurrence (Ahmed \textit{et al.}, 1999).

\textsuperscript{20} Adaptation refers to all those responses to climate change that may be used to reduce vulnerability (vulnerability is susceptibility to harm or damage potential, such as the ability of a system to cope or absorb stress or impacts and to ‘bounce back’ or recover) (Burton \textit{et al.}, 1998). Measures can be passive, reactive, or anticipatory and can respond to anticipated or actual consequences associated with climate change (Carter, 1996) for the well-being of human generations (Burton, 1992). But in my thesis, I mainly use the definition “Adaptability refers to the degree to which adjustments are possible in practices, process, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or anticipation of changes in conditions” (Watson \textit{et al.}, 1996).
In the mitigation process, renewable energy has the major role for reduction of GHGs. The world continues to use electricity in ever-increasing amounts, despite the problems associated with fossil fuels. Therefore a shift from fossil fuels to renewable energy sources would be a strategic way to improve climate change scenarios and hence sustainable development. Renewable energy is a generic term for electricity generated from clean, environmentally friendly energy sources such as wind, water, solar, tidal, energy-from-waste and energy-from-crops (bio-mass). Its low-to-zero carbon emission levels provide an opportunity for citizens and corporations to act on their environmental concerns and to demonstrate support for public policies supporting renewable energy (Salequzzaman, 2002). As this thesis aims to model an integrated sustainable coastal development framework for Bangladesh, responses to climate change and sea level rise in the coastal environment are crucial. The details of this issue in coastal Bangladesh has discussed in Chapter III.

2.1.8 Conflicts over coastal resources

There are many conflicts presently observed in the coastal environment around the world. The conflict becomes destructive when it decreases human dignity, degrades the productive capacity of an ecosystem, or forecloses options for present and/or future generations (Flint, 2000). Conflicts are created by the choices people r therefore can be resolved by electing different choices with resolution so : mind that it naturally leads to a shared vision of the future towards which to build (Lowry et al., 1988; Lowry, 1989). Conflict resolution can reframe the understanding
of the issues, renegotiate the people’s participation with one another and the environment, and in so doing realise what costs human-beings are passing on to their children and those of the future to pay for current decisions and behaviour. Thus, the management of conflicts in coastal governance has taken several forms (Lowry, 1989). A community committed to sustainable integrated coastal development seeks the synergism of ecology, culture, economy, and the environment to promote a healthy, sustainable environment that enriches the lives of all its inhabitants. This thesis deals with conflict mitigation in coastal Bangladesh as a component of an integration model for integrated sustainable coastal development in Chapter VI.

2.2 Sustainable integrated coastal development

Living and non-living coastal resources are part of interactive systems, have multiple uses, and generate many outputs (OECD, 1993). Therefore coastal resources should not be viewed in isolation from the rest of the ecosystem, nor from other socio-economic activities impacts (Fabbri, 1998). In addition, the community of different stakeholders that is usually present in any given coastal environment need to be consulted (Ruddle, 2001). All of these principles can be worked together under the one rubric – sustainable integrated coastal development. Furthermore, sustainable integrated coastal development could incorporate resources which are still under utilised, for example tidal power. Many developing countries, particularly in remote coastal areas, are now suffering from lack of electricity and tidal power can meet this electricity need (Corry and Newman, 2000; Salequzzaman et al., 2000). However the overall coastal environment needs an integrated approach to ensure its sustained development (Cicin-Sain and Knecht, 1998).
Sustainable integrated coastal development provides the tools for slowing and hopefully reversing the negative impacts of uncontrolled use of coastal resources. It also provides the essential processes for integration of all sectoral, spatial, temporal, policy, and institutional components necessary to achieve the goal of sustainable development (Hopkins and Cruz, 1982; Quinh, 1996; Sorensen, 1997). As stated earlier, the main objectives of sustainable integrated coastal development are to restore and maintain the ecological integrity of coastal ecosystems, improve the quality of life of the communities that depend on coastal resources (such as maintenance of biodiversity and productivity of coastal ecosystems) and maintain the human values and uses associated with the coastal resources (Murthy et al., 2001; Ogilvie, 2002).

Successful coastal development requires the participation of all stakeholder groups of the coastal community such as local people, government authorities, non-governmental organisations, scientists, investors and others (Sudara, 1996; Wirojanagud, 1991 & 2002). Non-government organisations might play an important role in providing the opportunities for all sectors to meet and talk with each other (Rozengurt and Haydock, 1991). All the parties involved should have the chance to express and exchange their opinions. They should be able to discuss the problems they are facing and how they would like them to be solved. When all needs and problems have been discussed, scientists or academics could then provide their expertise in formulating the sustainable integrated coastal development plan. The plan should reflect all needs for each sector as well as mitigation measures for implementation. In the present thesis, this collaborative approach is commonly
as ‘community-based coastal co-management’ or in short, simply ‘co-management’. Sections 2.2.2 and 2.2.3 will discuss these aspects further.

2.2.1 A brief history of sustainable integrated coastal development

Going under various names, the concept of sustainable integrated coastal development is at least 30 years old. Sustainable integrated coastal development has been given priority since the 1972 Stockholm Declaration. In the 1970s and 1980s, sustainable integrated coastal development was the subject of many international programmes, such as United Nations Environmental Program (UNEP), International Union for the Conservation of Natures (IUCN), World Wildlife Fund (WWF), Organisation for Economic Co-operation and Development (OECD) and others. Then sustainable integrated coastal development was emphasised at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil in 1992. In 1988, the 17th IUCN General Assembly called upon nations:

“to address the particular need for integrated development in the coastal and marine environments of the world (IUCN - The World Conservation Union, 1988)”.

In the assembly, it recommends that:

“Coastal states commit themselves to integrated management and sustainable development of coastal areas and the marine environment under their jurisdiction. To this end, it is necessary to, *inter alia*, provide for an integrated policy and decision making process including all involved sectors, to promote compatibility and a balance of uses (The General Assembly of IUCN: 17th Session, 1988)”.

The UNCED conference highlighted sustainable integrated coastal development as a central organising concept of sustainable ocean and coastal use. For example,
sustainable integrated coastal development got priority in the Framework Convention on Climate Change and the Convention on Biological Diversity and also in Agenda 21. Since the Earth Summit, there have also been several significant international conferences and agreements reinforcing the call for sustainable integrated coastal development such as:

(a) The Global Conference on Sustainable Development of Small Island Developing States, held in Barbados in 1994 that explored the special problems of small-island developing states and called for the formulation of new policies and programs in the context of sustainable integrated coastal management (Cicin-Sain et al., 1995); and

(b) The International Coral Reef Initiative, first announced in 1994 at Dumaguete City, is a partnership among several nations, United Nations agencies, and international NGOs that called for a ‘framework for achieving the sustainable use of, and maintaining the health of, coral reefs and associated environments’ (White, 1996).

In 1997, sustainable integrated coastal development was adopted as an independent program by the 19th session of the International Oceanographic Council (IOC) Assembly of USA, and in November 1998 the program was established. The objective for this program is to assist International Oceanographic Council member states in their efforts to build marine scientific and technological capabilities in the field of sustainable integrated coastal management as a follow up program to be United Nations Conference of Environment and Development (UNCED) (Agenda 21, 1992). The program will provide reliable scientific marine data, develop methodologies, disseminate
information and build interdisciplinary capacity through symposia, workshops, seminars and training courses (Calderon and Alvarez-Villamil, 2000). This way, a sustainable integrated coastal development program encompasses a broad constituency of coastal programs with varying degrees of integration (Cicin-Sain, 1993; Kay, 1996).

2.2.2 Conventional versus sustainable integrated coastal development

In the past, active management of the coastal environment was not as high a priority as it is today. Management was sustainable in the local environments of coastal inhabitants, mainly because human pressure was comparatively low. The coastal area is now overpopulated in many developing countries like Bangladesh and people have constructed a lot of infrastructure in this area to meet their accommodation, food and other requirements. Prior to the 1950s in Bangladesh, remote coastal communities lived sustainably with respect to environmental impact because population levels were low. As a complex of social, political and economic factors began to assert themselves, inadequate and inappropriate management and development practices evolved in a largely unconstrained manner, as in many parts of the world.

Fig. 2.1 shows the conventional and sustainable patterns of coastal resource allocation, management and development (after Hotta and Dutton, 1995). Fig. 2.1A shows the typical conventional pattern of coastal resource over-use and collapse. Chua suggests that:
“Unsustainable coastal management has become a major threat to economic sustainability and environmental quality; intensifying use conflicts, creating social unrest and deflating the national economy (Chua, 1993, p. 88).”

Fig. 2.1: Conventional and sustainable development patterns of coastal resource usage (after Hotta and Dutton, 1995).

The decline of a resource is often an urgent warning that we need to find an alternative, more sustainable approach to development and management of coastal resources (Hotta and Dutton, 1995). Fig. 2.1B shows the progression from conventional post-war approaches to management and development towards a more sophisticated and intelligent system.
To make development sustainable, various system components may be necessary depending on the nature of the political systems, level of knowledge of coastal resources and propensity of exploiters and decision-makers to act (Gomez, 1994). Fig. 2.2 shows most of these components to make an ideal sustainable integrated coastal development model.

Fig. 2.2: An ideal model for the sustainable integrated coastal development (after Bower and Turner, 1996).

The criteria for ‘sustainable development’ are discussed in Chapter 1. Here I wish to highlight several elements which I see as key to the success of sustainable
integrated coastal development. The first is Principle 15, “the precautionary principle” under the Rio Declaration:

“where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (UNCED, 1992)”.

Without the precautionary principle coastal environments will continue to be destroyed by unplanned and unchecked mal development. Recognition of the primacy of environmental safety should now be a mandatory condition in any development because a safe environment is a fundamental right of every human being. Thus the precautionary principle constitutes an important element in sustainable integrated coastal development (Barnabe and Barnabe-Quet, 2000). Ecological engineering or eco-technology is another component, the “too sustainable integrated coastal development. Ecological engineering is based on scientific theory and principles, and a deep understanding of ecology (Mitsch and Jorgensen, 1989). Odum states that:

“ecological engineering consists of manipulation of the environment by man, by using low inputs of complementary, or auxiliary, energy in order to control the systems in which the main energy leading the system comes from natural resources (Odum, 1989, p. 201)”.

Ecological engineering has an important role in sustainable integrated coastal development (Barnabe and Barnabe-Quet, 2000; Frontier and Pichod-Viale, 1991). Addressi (1993) showed that anthropogenic activities have had a long-term effect on coastal environments, particularly intertidal communities, that could be addressed in part by the application of coastal ecological engineering principles. Ecological engineering is interdisciplinary and integrates the disciplines of engineering, the environmental sciences and ecology to solve problems affecting
the natural environment, for the mutual benefit of humans and nature (Wang et al., 1998). Ecological engineering has application to sustainable integrated coastal development in the specific fields of eco-technology, synthetic ecology, bio-engineering and bio-technology, agro-ecology, habitat reconstruction, restoration ecology, ecosystem conservation, ecological economics, ecosystem rehabilitation, and global eco-politics (Barrett, 1999; Mitsch, 2000).

As with any development process, good governance is an important element in sustainable integrated coastal development (Wallström, 2001). Good governance again depends on participation of all stakeholders in the coastal society, integration among sectors, and levels of government. The importance of good governance is further discussed in 2.3. Good governance also requires transparency (elements/process should be clearly understood by all participants), certainty (process should have clear objectives, be consistent, and be conducted within agreed time-frames), accountability (decision-makers should provide clear and detailed reasons for their decisions to all stakeholders), integrity (decisions need to be based on the best available information, and all relevant factors need to be taken into account by decision-makers), cost-effectiveness (the process should meet its objectives while imposing the least cost to participants), flexibility (the process should be able to accommodate proposals varying in type, scope of impact, and complexity), and practicality (the process should recognise community concerns, commercial realities, best practice technology, and scientific uncertainties) (Filho, 2001).
The elements of precaution, ecological engineering and good governance could help solve the problems of the coastal environment and provide a sound basis for sustainable integrated coastal development (Salequzzaman, 2001).

2.2.3 Approaches to sustainable integrated coastal development

Any development or management process for the coastal environment must be dynamic and adaptive in order to cope with changing circumstances, changing social tastes and values, increased knowledge of the behaviour coastal processes, human attitude, changing technology, changing factor prices and changing government policies (Ehler and Bower, 1995; Turner and Bower, 1995).

Various forms of and approaches to the management of coastal areas – sectoral and integrated – have been practised in various parts of the world for centuries. How different human interests are focused in the coastal area in any of these manage systems. In order to integrate industrial growth and ecological safety, as well as to solve other environmental, social and economic problems, sustainable integrated coastal development is being developed as an interdisciplinary activity where natural and social scientists, coastal managers and policy makers, focus in the long-term on how to manage the diverse problems of coastal areas (Calderon and Alvarez-Villamil, 2000). To achieve the above goals, the following fundamental approaches can be followed for developing an ideal sustainable integrated coastal development option.

(a) Assess the need: Needs assessment is a systematic exploration of the way things are and the way they should be. Therefore, early on in the
consideration of sustainable integrated coastal development, the need generally arises for a formal statement of the reasons why it or some version of a more integrated approach to coastal management is needed, either for the country as a whole or to address specific problems in a given area. These needs can be assessed by general techniques such as direct observation, questionnaires, consultation with persons in key positions, and/or with specific knowledge, review of relevant literature, interviews, focus groups, tests, records and report studies, and work samples (Frihy, 2001). The major reasons why an integrated approach is needed for managing coastal environment are: the effects that ocean and coastal uses, as well as activities farther upland, can have on ocean and coastal environments; and the effects ocean and coastal users can have on one another (Karim and Aftabuzzaman, 1999). Coastal development activities such as structures, mining, dredging, etc. can significantly affect the ecology of the coastal environment functioning of coastal processes and resources. For example, industrial development in the coastal environment can decrease the productivity of wetlands by introducing pollutants, including heavy metals, and by changing water circulation and temperature patterns. Different coastal uses such as fishing and offshore oil development also often conflict with or adversely affect one another. As mentioned earlier, coastal development and management is linked to the general level of economic development and the severity of environmental problems; therefore sustainable integrated coastal development could be initiated in developing countries like Bangladesh to achieve more economic, social and environmental benefits (Cicin-Sain and Knecht,
Therefore the needs assessment is an important fundamental approach for sustainable integrated coastal development. However, it is important that the need for sustainable integrated coastal development be clearly and accurately analysed and stated. Emphasis should be on presenting unambiguous evidence of the problems associated with continuing solely with the existing (sectoral) approach together with a clear and realistic account of the increase in efficiency and effectiveness of management outcomes that can be expected with sustainable integrated coastal development in place.

(b) Consideration of community’s view and need for community-based coastal co-management: The community is the key actor as well as the primary beneficiary of sustainable integrated coastal development (Cicin-Sain and Knecht, 1998). As the coastal environment is facing the greatest pressure from population and overall economic developments, public understanding and awareness are essential for its sustainable development (Vallega, 2000). McNamee and Townsend-Gault (1995) mention the success of environmentally friendly sustainable coastal development depends on understanding and appreciating the concepts of community-based coastal co-management or simply ‘co-management’. According to UNDP (1992):

i. Most community people, in particular poor local communities, wish to protect the place where they live and manage their resources sustainably;
ii. Community peoples have better knowledge of their local environment than do planners or representatives of other sectors of society;

iii. The experience of development in environmental policies and regulations over the years has resulted from people’s claims to a safer and cleaner environment; and

iv. Community participation maximises the decentralisation of government by ensuring decision-making and management of the local environment and its resources.

Co-management of the coast has been highly successful in many developing countries, such as the Philippines, Thailand, Indonesia, Vietnam, Nepal and some parts of Bangladesh (Jarantilla, et al., 2001; Sudara, 1996). It decreases the level of poverty, encourages the environmentally friendly coastal enterprises, successfully conserves coastal and marine sanctuaries, and separates economic and preservation zones. It attempts to prevent further destruction of preserved mangroves and introduces participatory monitoring and evaluation (Courtney and White, 2000; White and Deguit, 2001). According to Shi et al. (2001), the conventional ‘command and control’ approach to environmental management cannot solve problems efficiently, especially those at a local level. In this situation, community-based coastal-co-management may actively and  

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21 The preservation zone includes the valuable natural environment that and provides with strong protection from any human impacts and from any explorative use. An Economic Zone promotes the establishment of forest utilization on a sustainable yield basis, particularly for charcoal making and
permanently solve various conflict and problems, and actively develop and improve resource producing economic activity. This process may also increase community participation through public meetings, participatory research, facilitated workshops, hearings and inquiries of local representatives on the advisory committees (Renard, 1991; Wood et al., 2000). According to an extensive literature search (Fabbri, 1998; Frihy, 2001; Lakshmi and Rajagopalan, 2000; Masalu, 2000; Matischov et al., 1998; Murthy et al., 2001; Ruddle, 1996, 1998, 1999 & 2001; Shi et al., 2001; UNDP, 1992; Vallega, 2001 and 2001a), the following common techniques could be useful to achieve the community-based coastal co-management in any country:

i. Working at the grassroots level with local organisations and the poor through people’s motivation;

ii. Utilisation of local conditions, cultures and traditions;

iii. Engendering trust in the community, enabling its members to serve as intermediaries between the community and the central government or external aid agencies;

iv. Being responsive to, and supportive of, community initiatives; and

v. Utilising experience with small-scale projects, being ready to adapt as needed during project implementation, and bring valuable insights and alternative viewpoints into policy dialogue.

other community uses and for the purpose of development activities, with consideration being given to the potential impacts to the environment.
According to Flint (2000), community-based coastal co-management could work better when activities in a variety of different sectors such as agriculture, industry, health, environment, aquaculture, and others are integrated across disciplines and boundaries. This type of integrated coastal co-management is now mandatory for sustainable integrated coastal development in many countries (Rose, 2002; Ruddle, 2001). In a real sense, communities can exercise authentic choices to achieve sustainability by adopting integrative frameworks that balance social, economic, and ecological concerns (Salequzzaman et al., 2001). The involvement of local people should be on a long-term basis and directed broadly across issues, disciplines, and boundaries to ensure effective problem solving (UNDP, 1992). Community development through local knowledge will greatly enhance the achievement of sustainable integrated coastal development. Generally, the local knowledge in coastal societies and communities are empirically and practically oriented, and some are complex and highly organised (Ruddle, 2000). Local knowledge has great practical value in the modern world for sustainable integrated coastal development (McNamee and Townsend-Gault, 1995; Ruddle, 2000). It can provide an important information base for local resources management, especially in the tropics where conventionally sourced data are usually scarce to non-existent, as well as providing a shortcut to pinpoint essential scientific research needs (Pauley et al., 1993). It is also of fundamental socio-cultural importance to any society. Local knowledge can understood as a system of power, and thus can provide a basis for empo of communities to undertake community-based resource management. Ruddle (2000) mentioned that during the past 20 years the deep and rich local knowledge systems that underpin many community-based renewable natural resource use
and management systems have been widely demonstrated, especially in agriculture, animal husbandry, forestry and agro-forestry, medicine, technology innovation, and biological, physical and geographical phenomena. In fishing communities, local knowledge is an important cultural resource that guides and sustains the operation of traditional community-based management systems; knowing where, when, and how to fish, for example, governs most of the fishing decisions made by small-scale fishers. Therefore, local knowledge of the environment and resources used, as well as of the society within which the resultant goods and benefits are distributed, is fundamental to the continuity of sound community-based coastal co-management practices and to the design of new systems of sustainable resource management (Ruddle, 1994; 1994a & 1994b).

(c) Adaptation of political will:

An adequate measure of political will is generally needed by decision-maker at the executive and legislative levels to commit the resources such as fund, staff, etc necessary to undertake an initiative of sustainable integrated coastal development (Cicin-Sain and Knecht, 1998; Ogilvie, 2002). Decisions of this nature do not tend to occur spontaneously or readily. Typically, the way must be prepared by providing decision-makers with timely information on program benefits and costs, and the relevant experiences of other similarly situation in another country. Making a decision that involves some political cost to make a sustainable integrated coastal development program is far easier if the decision-maker perceives that the proposed action has the support of the groups or interests most likely to be
affected by it (Sorensen, 1997). Non-controversial decisions do not require political will. In general, if existing and potential users of the coastal area evidence clear support for sustainable integrated coastal development, government leaders will find it much less controversial, and therefore less costly in a political sense, to decide to undertake a sustainable integrated coastal development program. Therefore, these groups should be brought into the discussions early and provided with sufficient detail that both their input and suggestions as well as their general support can be obtained and retained throughout the sustainable integrated coastal development formulation process.

(d) Framing the proposal: As mentioned earlier, sustainable integrated coastal development should be presented as a means to strengthen and enhance the existing management efforts rather than as a replacement for them. The proposal should describe clearly the limitations of the existing management approach, a description of sustainable integrated coastal development concept, and the steps, schedule and cost-benefit analysis needed to develop and implement the concept (Kay and Alder, 1999; Vallega, 2001). Therefore, sustainable integrated coastal development should be proposed as a complement to any existing sector-based programs, which will in general continue and, indeed, be integral parts of the new effort (Cicin-Sain and Knecht, 1998; Christie; 2001; Huda, 1999). It is best to delay politically sensitive topics, such as designation of a lead agency and the nature of the coordination and harmonisation mechanism. Such issues are better dealt at a later stage, when the scope of the program is better known and its goals and

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22 The term political will to refer to the resolve or determination needed by a decision-maker to
objectives are more defined. However, the proposal should be framed by the consideration of following factors (Calderon and Alvarez-Villamil, 2000; Christie and White 1994; White, 1996):

i. The proposed integration should improve each of the separate components or sectors that will help to achieve overall national goals.

ii. The proposal should adaptable to the physical, socio-economic, cultural, and political context (such as level of development, concentration of population in coastal areas, types of coastal and marine ecosystems, nature of problems present in coastal areas, socio-cultural traditions, and type of political system) of the community in which it is to operate.

iii. The proposed method should coordinate among existing coastal and ocean management programs, and should not be seen as a threat to the existing sectoral programs.

iv. The proposal should make a cross-sectoral consideration of the coastal environment to avoid the conflicting issues such as urban, industrial, residential and recreational land use, and the use of coastal and shelf resources arising from the expanding spectrum of human activities. Therefore, it is important to consider the interaction between natural processes and economic development, such as ecological safety and conservation of natural resources.

course of action that involves expenditure of political capital or comes with some political cost.
v. The proposed design should increase the efficiency and cooperation in effective government actions.

vi. The format of the proposal should be as simple as possible, but the methodology should cover all possible coastal issues.

vii. The proposal should describe in a legitimate way the expected government accountability and the measurable outcomes.

(e) Institutional and legislative adaptation: Sustainable integrated coastal development needs to be in an appropriate institutional setting. The biggest hurdle in putting a sustainable integrated coastal development program in place is to obtain the various levels of support, particularly the government’s decision to undertake its initiative. In any country, the various levels of government perform services and operate programs; each level will be made up of a number of different administrations and/or institutions, each specialised in a particular functions in the specific field, and each field consisting of separate staff, space, facilities, budgets, and procedures. Therefore, it is a challenge for sustainable integrated coastal development to ensure the harmonised actions of relevant coastal institutions (Cicin-Sain, 1993; Kay and Alder, 1999). The problems could be solved by legislative approach through limiting and regulating new development, maintaining set-back lines, restoring degraded habitats, and encouraging appropriate settlement through building roads, water systems, and other coastal infrastructure in environmentally sensitive ways (Cicin-Sain and Knecht, 1998; Vallega, 2001).
One of the options is to create a powerful leading institution consisting of members from central government, planning and economic committees, environment department, local government and agencies, different experts and representatives from different community groups including local communities, with effective links among different sectors and interests, and with correspondence among their policies, plans and programs for achieving sustainable integrated coastal development (Christie, 2001; Vallega, 2001). This participatory approach could work better by involving various organisational channels through community concerns, interests and aspirations of environmental planning, implementation and evaluation that would be contributed from the knowledge and skills of grassroots communities (Matsuno et al., 1998; Ruddle, 1998a; Vallega, 2001). The channels include organisations such as social clubs, women’s groups, youth groups, non-government organisations and municipal and district-level institutions (Fabbri, 1998; Frihy, 2001; Salequzzaman et al., 2001). Bower and Turner (1996); Fabbri (1998), Frihy (2001), Lakshmi and Rajagopalan (2000), Murthy et al. (2001), Shi et al. (2001) and many other scientists have stated that coordination can be successful through the setting up an adequate coastal information database and harmonise their sources.

The legislative aspect varies considerably from country to country, but there are some common coastal issues such as fisheries (White and Lopez, 1991), tourism, recreation, shoreline erosion (Chapman and Hildreth, 1985; Qu et al., 1993), and common coastal ecosystem features such as mangroves, coral reefs (Clark et al., 1989; Wells, 1993) and beaches, which dictate coastal
management techniques, as well as the specific legal and institutional approaches used by many countries in the South-East Asian region (Hildreth and Gale, 1995). McNamee and Townsend-Gault (1995) have suggested that legislative change theme can be examined in the two following ways:

i. Constraints on unilateral sectoral policy-making within a country, and

ii. Limits of national freedom of action imposed by international legal obligations.

In this literature search, many review papers clearly indicated that sectoral policy-making in the coastal environment can seldom be undertaken unilaterally with any degree of confidence that adverse impacts can be avoided. McNamee Townsend-Gault mentions that:

“experience suggests that uncertainties or dysfunction in the division of legislative power and management function between the central and provincial or local governments will be a critical factor in hampering optimum coastal management (McNamee and Townsend-Gault, 1995, p. ix)”. Dysfunction in policy and management can result in rival aims being pursued by different actors, sometimes within a single institution. It is difficult to overstate the importance of resolving such issues, and of doing so on a functional basis. Since such an approach may involve the surrender of authority by one level of government to the other, or the development of a partnership, such reforms are not accomplished easily (McNamee and Townsend-Gault, 1995). However, the lesson is clear – failure to address overlapping regulatory policies will exacerbate management problems in sustainable integrated coastal development.

Common coastal management problems derive from conflicts among coastal resource users such as tourism development or shrimp aquaculture which
adversely affects mangrove reserves, or from unsustainable exploitation such as over-fishing (Jackson et al., 2001). To complicate this situation in both developed and developing countries, relevant laws and policies often contain conflicting goals due to the accumulation of legislation over years and the common inability of legislative bodies to achieve political consensus on how particular resource use conflicts should be resolved (Hildreth and Gale, 1995).

Evidence from Asia-Pacific regions would seem to indicate that a good institutional and legal structure is a necessary, although inadequate, condition for managing coastal resources on a sustainable basis (Hildreth and Gale, 1995). In fact, one of the leading studies of institutional arrangements for coastal management recommends an issue-based institutional and legal analysis as a first step towards improved coastal management (Sorensen and McCreary, 1990). However, the institutional and legal analysis should be integrated with coastal management issues to encourage the sustainability process. Examples of legislation integrating coastal management with other natural resources management and environmental protection goals are found in the Resource Management Act of New Zealand (Flood et al., 1993; Palmer, 1992) and the Land Use Planning Approvals Act, 1993 of the Australian State of Tasmania. The inter-ministerial councils in many countries (such as in Indonesia, the Philippines and Thailand) formulate and coordinate such policy, planning and regulations (Sorensen and McCreary, 1990). In Bangladesh, this legislation is not formulated yet. However, the present research recommends such legislation in Chapter VIII to initiate integrated sustainable coastal development.
(f) **Introduce an education program:** As any proposed initiative in the public sector will probably encounter barriers to its acceptance and implementation, it is therefore important to place the proposed sustainable integrated coastal development program in the proper context at the earliest possible moment, by including all potentially affected organisations. At least four kind of resistance can occur, including bureaucratic inertia, turf protection, ideological opposition, and opposition from economic interests (Cicin-Sain and Knecht, 1998; Frihy, 2001). However, some barriers could be overcome through a multi-disciplinary education system and awareness program (DelValls, *et al.*, 2001). Education is critical for raising awareness and improving the capacity of people to understand issues and problems. It is also critical in any efforts to reinforce and develop suitable knowledge, values, attitudes and practices, skills and participation required for sustainable integrated coastal development (Crawford, 1991). According to Filho (2001), the education program should have the following context:

i. The different aspects of sustainable integrated coastal development’s education program should include multi-media interactive computer displays (where electricity is available), interactive learning methods like puppet shows, drama, cinema, and other relevant methods that could be organised by the relevant educators.

ii. An information booklet series on the coast including topics like ‘Estuaries and Lagoons’, ‘Rocky Shores’ should be distributed among the coastal people, schools and conservation agencies free of charge.
iii. An inventory of relevant experience and expertise, both human and institutional, making full use of existing compilations of information should be presented to the coastal people.

iv. Specialists in environmental sciences and coastal management should be trained at the postgraduate level; and special courses run for professionals, such as teachers, government officials, managers, lawyers, teachers, business persons and journalists.

v. Courses on coastal environmental issues should be required in university undergraduate programs, and relevant associated projects coordinated to promote consistency and integration on a national level.

vi. Environmental education should incorporate sustainable development in educational policies, with financial and logistic support for curriculum development.

vii. The environmental dimension should be incorporated into the school curriculum in a progressive manner through the cooperation and exchange of information and experiences in curriculum development and teacher training.

viii. Indigenous community knowledge should be incorporated, as well as other social and cultural values.

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**2.3 Conclusions**
The coastal environment is a complex ecosystem that needs an integrated sustainable development process to engender the optimum social, cultural, environmental and economic benefits to present and future generations, without prejudicing its resources and ecological processes. This process of coastal development has the potential to reduce and eliminate the various negative impacts and conflicts, and increase more resource-producing activities for future generations. In order to achieve this potential, development needs the support and cooperation from all stakeholders of the coastal community. Non-government organisations can promote and enhance this cooperation among all stakeholders to increase the understanding of environmental concerns and sustainability, through public awareness, motivation and consultation with all sectors of the coastal community. This participatory approach is known as ‘community-based coastal co-management’, as the local coastal community are involved in planning, decision-making, and implementation of various issues in the coastal environment. The thesis will examine how sustainable integrated coastal development could be facilitated in tidal prone coastal Bangladesh through the application of community-based coastal co-management which will be discussed in detail in Chapter VI.
CHAPTER III
Chapter III

COASTAL ENVIRONMENT AND DEVELOPMENT OF BANGLADESH

“To make the coastal zone a place where people will pursue their life and livelihood within secure environmental and social conditions and will use its natural resources in a sustainable way”

Dr. M. A. Quassem, Director General of WARPO
National Workshop ‘Vision Development for the Coastal Zone of Bangladesh’
Bangladesh Institute of Administration and Management
12 September’ 2001

Research question

What are the issues for ‘Sustainable Integrated Coastal Development’ in Bangladesh?

3.0 Introduction

The river systems of coastal Bangladesh carry highly fertile sediment and thus the catchment is characterized by rich biodiversity and natural resources - both renewable and non-renewable (Hussain and Acharya, 1994). The world largest mangrove forest, the Sundarbans, is an important world heritage area situated in this coastal system. It is the habitat of where the ‘Royal Bengal Tiger’, one of the most elegant creatures of nature. The flat flood plains are among the most important components and resources of the Bangladeshi coast. The floodplains of the Bangladesh river support crop production, livestock rearing, and salt manufacture from seawater; shrimp aquaculture, and harbour facilities including the ship breaking industry (DFID, 1999; Gain, 1998; MWR, 2001). Recently, coastal Bangladesh has also attracted international attention for its high potential of inshore and offshore natural gas,

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minerals, aquaculture, food availability, tourism industry and tidal power (Levenson, 1991; Salequzzaman, 2001; Siddique and Chowdhury, 2000).

Coastal Bangladesh is extremely susceptible to the impacts of natural disasters such as frequent tropical cyclones and climate-related disturbances (Ahmed, 1999; Ahmed and Mirza, 2000; Clarke, 1989). As a result, the coastal belt and its connected riverbanks are at serious risk due to their geographical locations. However the coastal area supports a variety of very productive habitats, such as mangroves, marshes, mudflats, sea grass and seaweed beds and coral reefs (NEMAP, 1997; Pokrant, 1996; Thai-Eng et al., 1989). The expanding population, increasing demand of food, and widespread poverty have placed tremendous pressure on these coastal resources (Ahmed and Mirza, 2000; Hussain and Acharya, 1994; Khalequzzaman, 2000). Some of these coastal resources are over utilised, some are under utilised and others are not utilised (Lincoln-Smith, 1998; Salequzzaman, 2001). Furthermore, a range of conflicts dominate the utilisation of these resources (ESCAP, 1992; Flood et al., 1993; Masalu, 2000). The coastal area is ecologically sensitive and climatically vulnerable, due to the continuous process of land accretion and erosion. In addition, current global climatic change is expected to result in loss of human habitation and destruction of coastal resources through increasing sea levels (Alam, 2001; Huq, 1998; Huq, 2001a; Salequzzaman and Newman, 2002). The management systems of coastal resources are also not organised well (Ali, 1991; Mazid and Gupta, 1995; Parkes and Panelli, 2001).

In management terms, there are numerous organisations presently involved in the management of the coastal resources of Bangladesh, such as various government departments, numerous non-governmental organisations (NGOs), local agencies, community volunteers, and other such organisations. But, there is no co-ordination among them and there is a clear lack of collaboration between government organisations and NGOs. Most organisations have no connection to the coastal community and there is a serious lack of information on past and present coastal development activities. Many have no clear accountability, transparency or good governance in their management processes. There is a clear lack of the use of scientific and ecological knowledge (Biswas et al., 2001; Burbridge et al., 2001; Ministry of Planning, 1995). In this situation, many scientists, policy makers, community organisers and other community leaders have suggested that community
participation and community-based co-management is an important way to ensure the sustainability of coastal management and development (Rahman, 2002; Salequzzaman and Newman, 2002; Underwood and Chapman, 1999), as discussed in Chapter II.

Coastal Bangladesh has also been neglected in terms of sustainable development due to the absence of basic components of development like electricity supply, communications, education, health, disaster management plans and other facilities (ESCAP, 1998; McNamee and Townsend-Gault, 1995; NEMAP, 1997). Coastal Bangladesh is not highly industrialised apart from numerous labour-intensive, small-scale-industries like shrimp aquaculture, which are unsustainable in their present form (Salequzzaman, 2001; Siddique and Chowdhury, 2000; University of Leeds, 2000). In addition, some coastal areas are becoming urbanised into port-cum-mega cities and semi urban towns (such as Chittagong and Khulna), but these development trends are also unsustainable (University of Leeds, 2000; Urk, 2001). Numerous environmental, cultural and socio-economic problems are interconnected. Waterlogging, salinity intrusion, river siltation, and reduction in the agricultural production are increasing poverty and social conflicts (Panaullah, 1993; World Bank, 2001a; Yunus, 1998).

Many researchers and scientists (such as Addessi, 1993; Alabanza, 1989; Christie et al., 1994; Chou et al., 1991; Coastal Community Network, 2000; Coastal Resources Co-Management Research Project, 1998; Cohen and Tol, 1998; Flecknoe and McLellan, 1994; Lowe, 2002; Newman, 1996; Nishat, 1996; Rahman, 1992; Renard, 1991; Rose, 2002; Ruddle, 1996; Salequzzaman and Newman, 2002; Salequzzaman et al., 2001; United Nations Environment Program, 1995; White and Deguit, 2001; Wirojanagud, 1986 & 2002) have commented that sustainable development of coastal Bangladesh could be possible through proper integration of various coastal resources, and by ensuring that modern facilities like electricity supply and other resources are managed by community-based coastal co-management system. This chapter of the thesis will identify the issues of sustainable integrated coastal development and recommend how sustainable integrated coastal development could be achieved in Bangladesh.
3.1 Characterisation of coastal Bangladesh

3.1.1 Location, boundaries and climate

Coastal Bangladesh is located in the tropics of South-Asia between 20 34" and 26 38" north latitude and 88 01" and 92 41" east longitude. It is surrounded by the Bay of Bengal of the Indian Ocean, the Gangetic plains of India and the forest of Myanmar (Burma) (Fig. 3.1) (Hossain, 1966; Rob, 2001). It consists of four agro-ecological zones (AEZ), namely the Ganges Tidal Floodplain (Agro-ecological zone, AEZ-13), Meghna Estuarine Floodplain (AEZ-18), Chittagong Coastal Plain (AEZ-23) and St. Martin Coral Island (AEZ-24) (Uddin and Islam, 2000). These zones run from the North-Western part of Satkhira district to the southern part of Cox’s Bazar and are characterised by fertile, low lying deltaic land.

Coastal Bangladesh is mostly flat with wooded marshland and jungle, except for a range of hills in the southeast area. A vast network of river systems, an ever-dynamic estuary, a drainage basin and a saline waterfront interpenetrate the whole coastal region of Bangladesh (Acharya and Kamal, 1994; Rob, 2001; Salequzzaman, 2001). Coastal Bangladesh comprises 2.85 million hectares (7.6 million acres) in area and is 200 km in length (120 miles) including about 148,000 square km of crisscrossed watercourses of the mighty rivers - Padma, Jamuna, Meghna and Karnophuli (Mazid and Alam, 1995; Qadir, 2000). Since 1974, the coastal area has also been expanded to include an exclusive economic zone (EEZ) of 200 nautical miles that reaches the edge of the continental shelf. This is now under the economic jurisdiction of the country for exploration, exploitation, conservation and management of its living and non-living resources (Gupta et al., 2001). A number of small islands situated in this area are subject to strong wind and tidal interactions throughout the year. This tidal affected area is covered by 16 coastal districts (Barisal, Barguna, Bhola, Chandpur, Chittagong, Cox’s Bazar, Feni, Khunla, Lakshmipur, Noakhali, Patuakhali, Bagerhat, Faridpur, Pirojpur, Jessore and Satkhira) that comprise 42,154 square km (MWR, 2001).

As mentioned before, Bangladesh has a 710 km long coastline. Along the northern tip of the Bay of Bengal, the land is not more than 3 m above sea level and is divided into three zones (fig. 3.1).
Fig. 3.1: A. The location of Bangladesh on a world map; B. The location of coastal Bangladesh; and C. The structure of coastal Bangladesh (Bangladesh Map, 2003; Hossain, 1996, p.6; HRW World Atlas, 2003).
The eastern zone comprises the narrow strip of low land between the Bay and the hills that cover the Karnaphuli estuary and the Matamuhuri delta. The central zone comprises the present delta of the rivers Ganges, Brahmaputra and Meghna. The western zone comprises a complex network of tidal rivers and creeks, and comparatively low erosion and accretion (Choudhuiy-Gaisuddin, 2001; Huq, 1998). The central zone is characterised by a heavy sediment inflow as well as large-scale erosion and accretion that carries an estimated sediment load of 1.7 billion tonnes annually (Choudhuiy-Gaisuddin, 2001). The annual rainfall in all of these coastal regions is from 2000 to 4000 mm, of which 90% occurs during May to October (BSS, 2000). The average lowest temperature is from 18.6 to 20.2°C, which occurs in January. The average highest temperature is from 28.7 to 30.1°C, which generally occurs in May (BBS, 2000). The settings of these characteristics are now affected by the global warming and climate change impacts, such as heavy silted runoff is coming through the Ganges (ice melted water from the Himalayas) to this catchment area. Also, the whole geography of the coastal Bangladesh is gradually changing, as a result of increasing sea level which is discussed in section 3.3.8.

3.1.2 Natural resources: arable land, fisheries, mangroves and other forests, energy and minerals

Coastal Bangladesh is rich with both renewable and non-renewable natural resources, both seawards and land wards, in both fresh, salty and brackish water. These resources include mangrove forest, beaches, coral reefs, and water-based energy resources (for example, tidal, wave, and geothermal) (Islam, 2001; NEMAP, 1997; Pauly and Thai-Eng, 1989). Agricultural resources are very rich with more than 100 local varieties of native rice that can survive in flood situations (Barua, 1993; ESCAP, 1992; GOB, 1999). These resources are presently threatened by the introduction of HYV24, shrimp aquaculture and saline soil in the coastal region (Khan-Hasan, 2001). Fishery resources are also very rich in coastal Bangladesh (Hussain and Acharya, 1994; NEMAP, 1997; World Bank, 2001). About 200 species of fish and shrimps

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24 High yielding variety (HYV) is an agricultural product of breeding technology, which can be deployed in areas where it adds value for the farmer. Encouraging farmers to adopt HYV in an environmentally friendly manner could be a short-term objective that gives results in the form of improved productivity and value addition.
(including 53 fresh water fin fish species and 123 brackish water fin fish species, and 24 species of shrimps) have been identified from 450 rivers in coastal Bangladesh (Gupta et al., 2001; Salequzzaman, 2001). Among all of the fisheries resources, hilsa fish (*Hilsa ilisha*), shrimp (*Penaeus indicus, P. monocerious*, etc), crab (*Scila serrata*) and others are the main commercially important fisheries (Azim et al., 2001). Gupta and others stated:

“The standing stock of demersal fish is about 150,000-185,000 tonnes, among them about 3,000-4,000 tonnes shrimp is exploitable from the coastal waters (excludes below 40m depth of sea, but includes up to 250m depth of deep sea (Gupta et al., 2001, p. 5)).”

However the most important coastal resource of Bangladesh is the Sundarbans mangrove forest, which was recently declared as a site of national as well as international heritage (Johannesburg Summit, 2002). The total area of this natural mangrove forest is about 587,400 ha, which is further extended by 100,000 ha of planted mangroves (Gupta et al., 2001). The natural mangroves have been deforested since 1964, when construction of dams, shrimp aquaculture, embankment, barrage and other such developments commenced in this ecologically sensitive environment (Hussain and Acharya, 1994). The disappearance of the Chakoria Sundarbans of Cox’s Bazar and Kewa forest of the Jaliardwip on the bank of Naf River are two examples of the worst form of this destruction. As a result, the area is now suffering from increased salinity intrusion, due to decreases in the water flow (Acharya and Kamal, 1994; Aksornkoae and Saraya, 1986; Field, 1995; Macintosh, 1996). Mangrove forest (both natural and planted) plays an important role in sheltering the coastal belt, including saving thousands of lives and millions of dollars worth of property from cyclone, tidal surges, wave actions and others (Mutaleb and Shaheduzzaman, 2001; Salequzzaman, 2001).

Besides the biological resources, coastal Bangladesh is also rich in mineral resources, such as zircon, monazite, rutile, ilmenite, lecoxene and magnetite that have been found in the beach sands of Cox’s Bazar-Teknaf, Moheshkhali, Kutubdia-Materbaria Islands, Nijhum-Manpur Islands and other coastal areas. Recently, oil and gas have

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25 Personal communication with Professor Dr. M. Rafiqul Islam, Director (Research and Publication, University Grants Commission of Bangladesh, Agargaon, Dhaka-1207, Bangladesh.
also been found in the coastal regions. These mineral resources are not utilised, due to the lack of infrastructure in the area.

3.1.3 Natural and anthropogenic processes: flooding, erosion, accretion and resultant fertility characteristics

Coastal Bangladesh is very vulnerable to natural disasters like cyclonic storms and tidal surges (Siddique and Chowdhury, 2000; D’Ercole and Pigeon, 1998; Islam, 2000) (for details, please see Appendix A). Generally, cyclones are created in the coastal offshore area in a counter-clockwise pattern during low atmospheric pressure. Sometimes the storm pushes water at a height of up to 10 m with a wind velocity of about 150-200 km/hour, causing both death and property damage, with huge losses of infrastructure, including temporary and permanent assets like livestock (both mammals and birds). The storms also create health hazards and diseases in the coastal community (Khalequzzaman, 1988; MWR, 2001; Paul and Awal, 2001). In April 1991, coastal Bangladesh was hit by a catastrophic cyclone that led to the loss of 138,000 lives (University of Leeds, 2000). Khalequzzaman mentioned:

“The most frequent storm surges return every 2-10 years with a surge height of 2-10 m and wind velocity of 50-200 km/hour (Khalequzzaman, 1988, p. 39)”.

Natural disasters are the main barrier to the growth and development of coastal Bangladesh. Around 17% of this type of cyclonic storm occur in the coastal area of the Bay of Bengal and have hit around 59 times during the last 200 years (Choudhuiy-Gaisuddin, 2001; MWR, 2001).

Flooding is another regular phenomenon of coastal Bangladesh, because it is a low-lying flat area with the catchment of a river network that originates from the Ganges-Brahmaputra-Meghna system (LRP, 1991; Miah, 1975; Pramanik et al., 1981). Flooding can occur due to river overflow or surface runoff. There are two types of floods which occur in Bangladesh: annual floods (barsha) that inundate up to 20% of the land area; and low frequency floods (bonna) of high magnitude that inundate more than 60% of the area. Therefore a huge amount of runoff drains on to coastal

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26 Personal communication with Dr. Md. Khalequzzaman, Assistant Professor, Department of Geology & Physics, Georgia Southwestern State University, Americus, GA 31709, USA, khaleq@canes.gsw.edu
Bangladesh (Ahmed and Mirza, 2000; Siddique and Chowdhury, 2000). Normal annual floods are essential and desirable for overall growth of the delta and the economy (Nishat, 1986; Siddique and Chowdhury, 2000; The World Bank, 1989). Like cyclones, annual floods destroy many properties. Severe floods occur every 6–7 years and cause serious damage to human life, property, crops and the economy (FAP 7, 1992; MPO, 1987; UNDP, 1989). However, the number of flood disasters has increased during the past century, because human intervention has increased during this time, causing deforestation in the coastal mangroves, drainage congestion in the growing urban centres of coastal cities, expansion of land into the seabed and other such factors (D’Ercole and Pigeon, 1998; Islam, 2000). This vulnerability to flooding is increased by climate change in coastal Bangladesh (ESCAP, 1998). Flooding enhance the encroachment into coastal floodplains, and further increase the different socio-economic, cultural and environment consequences in the coastal communities (FAO, 1992; Khalequzzaman, 2000). In a bid to control the impacts of flooding, a total of 5,695 km of embankments, including 3,433 km in the coastal areas, 1,695 flood control/regulating structures, and 4,310 km of drainage canals have been constructed by the Bangladesh Water Development Board during the last several decades (Khalequzzaman, 2000).

Coastal erosion and accretion are regular phenomena of coastal Bangladesh which impact on the social, economic and safety issues in the coastal area (David, 2001). Destruction of the foreshore mangrove forests have resulted in increased beach erosion and erosion of the embankments (Islam et al., 1999; Nailon and Seidensticker, 1991; Pramanik et al., 1981). Another coastal erosion problem is some of the constructed embankment’s toes being laid below the normal high tidal water level which does not provide for hard protection (Islam et al., 1999; Salequzzaman, 2001). As mentioned before, river runoff brings a huge amount of sediment to the coastal catchment area that will favour the coastal accretion process. The newly accreted coastal land is relatively rich in nutrients, therefore it creates a highly productive ecosystem. Islam et al. (1999) stated that erosion and accretion are the concurrent phenomena in coastal Bangladesh. In this accretion-erosion process, many small chars27 such as Udaykal and Char Clark have been eroded and some new chars like

27 Accreted land.
Char Dhal, Char Shabani and Nijhumdwip have been formed (Jabbar, 1979; Miah, 1975). However, recently, the accretion process has declined, because the embankment system and other barriers decrease sediment availability, and its supply, dispersion, and accumulation process on coastal land (Jabbar, 1979; Pramanik et al., 1981). For example, sediment in the Ganges-Bramhaputra river system has declined from 2.4 billion tonnes/year (67% delivered by the Ganges) to 1.8 billion tonnes/year after the Farakka-Barrage28 damming project (Khalequzzaman, 1988). According to a study conducted by the Land Reclamation Project (LRP, 1991) in the lower Meghna Estuary, between 1940 to 1963 an area of 1356 square km of land was accreted and 1077 square km eroded. Moreover, accretion has decreased where the embankment has been established, for example in Bhola (accretion 85 square km and erosion 376 square km), Hatiya (accretion 64 square km and erosion 172 square km) and Sandwip (accretion 35 square km and erosion 227 square km).

As a result of the above activity in the coastal area, the soil of coastal Bangladesh is characterised by sandy to loamy alluvial and deltaic deposits, inter-layered with comparatively thin marine sediments, which make both coastal soil and water the most productive and richest habitats on earth (Gong and Ong, 1990; Howarth et al., 2001; NRC, 2000). Therefore estuarine and marine fish and other aquatic biodiversity are rich in the long coastal area of Bangladesh (Hussain and Acharya, 1994). However, human activity decreases the fertility of the area and, as a result, biodiversity is now declining sharply (Choudhuuyi-Gaisuddin, 2001). In an analysis, it was found that less than 2% organic content presently exists in the soils of coastal Bangladesh29, whereas a minimum of 5% organic matter in soil is essential for the production of good crops.

The main reason for the decrease in soil fertility is the increase of soil salinity (Panaullah, 1993). Uddin and Islam (2000) have identified that tidal flooding during the wet season (June-October), direct inundation by saline or brackish water and upward or lateral movement of saline ground water during the dry season (November-

28 A big dam has been created by the Indian authority at the mouth of the Ganges between India and Bangladesh border since 1970s.
29 Personal communication with KBD. Md. Shafiur Rahman of Department of Agriculture Extension, Khulna, Bangladesh.
May) are mainly responsible for the increase of soil salinity (Uddin and Islam, 2000). Soil salinity is the most dominant limiting factor with regard to the agricultural potential of coastal Bangladesh, especially during the dry season (FAO, 1991; RDV Technology Notes, 1998; Simpson and Pedini, 1985). At different levels it affects certain crops at critical stages of their growth, which reduces yield, and in severe cases the total yield is lost (Panaullah, 1993). Over 30% of the net cultivable area of Bangladesh lies in the coastal region, where about 1.5 million hectares out of 2.85 million hectares of coastal land are affected by varying degrees of salinity (Seraj and Salam, 2001; SRDI, 1998). Salinity in the soil fluctuates according to the seasons of the year and different coastal regions (table 3.1) with higher salinity found during November-December to March-April and lower at the monsoon time.

Table 3.1: Extent and distribution of coastal saline soils in Bangladesh (Panaullah, 1993).

<table>
<thead>
<tr>
<th>District</th>
<th>Area under saline soils ('000 ha)</th>
<th>District</th>
<th>Area under saline soils ('000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satkhira</td>
<td>146.35</td>
<td>Bhola</td>
<td>40.33</td>
</tr>
<tr>
<td>Khulna</td>
<td>120.04</td>
<td>Chittagong</td>
<td>45.70</td>
</tr>
<tr>
<td>Bagerhat</td>
<td>107.98</td>
<td>Cox’s Bazaar</td>
<td>54.70</td>
</tr>
<tr>
<td>Barguna</td>
<td>103.55</td>
<td>Noakhali</td>
<td>49.60</td>
</tr>
<tr>
<td>Patuakhali</td>
<td>115.10</td>
<td>Lakshimpur</td>
<td>19.30</td>
</tr>
<tr>
<td>Pirojpure</td>
<td>20.30</td>
<td>Feni</td>
<td>9.00</td>
</tr>
<tr>
<td>Chandpur</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>833.45</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the rainy season, sometimes the salinity decreases up to 2 EC (electrical conductivity) from 10 EC\textsuperscript{30} (Seraj and Salam, 2001). The sources and effects of salinity in the coastal land of Bangladesh are discussed more in Chapter V.

3.1.4 Coastal community: population, culture, education and economics

The population of Bangladesh is estimated to be 120 million, at a density of 813 persons per square km (BBS, 2000). This ranks Bangladesh as the most densely populated country in the world (World Bank, 2001a). Presently, the majority of the population (80%) live in rural areas; however, by 2020 it is predicted that almost 50% of the population will be located within urban centres (Huq, 1998). Presently the per

\textsuperscript{30} Salinity and Coastal Agriculture. Char Development & Settlement Project – II, April - June 2001. Government of Bangladesh [For more information, contact CDSP at chardsp@citechco.net].
capita GDP\textsuperscript{31} of Bangladesh (purchasing power parity) is estimated as US$ 1,570 where its real growth rate is 5.3\%\textsuperscript{32}. A recent assessment by the World Bank classified 36\% of the population as very poor and a further 53\% as poor, with the incidence of poverty in rural areas significantly higher than in urban areas (Huq, 1998; World Bank, 2001a). In 1991, 28 million (20-25\%) of the total Bangladesh population lived in the coastal area. Presently (2001 population census), this number is 35 million (35\%) but this could increase to 45-50 million (40-45\%) by 2050 (Ahmed, 2003; Daily Star, 2001; MWR, 2001). The increase of this population broadly reflects population growth in the whole country. However, the population of coastal Bangladesh as percentage of the total population of the country has declined in the 1991 to 2001 census period. During this period, the annual population growth was 1.29\% in coastal Bangladesh compared to 1.56 \% in rest of the country (Ahmed, 2003), because there has been a net migration away from the coast during this period (11\%) (Ahmed, 2003). Peoples of coastal Bangladesh have migrated to away due to decreased availability of agricultural land (erosion, conversion to shrimp farm, etc) and lack of jobs. Of the 28 million coastal Bangladeshis, 0.2 million are Indigenous from ten ethnic communities\textsuperscript{33} (BBS, 2000). As per the 1991 census, ethnic communities living in the coastal zone are Chakma, Garo, Khiiyang, Marma, Munda, Murang, Rakhaing, Saotaal, Tanchangya and Tripura (MWR, 2001). Presently, the Indigenous peoples are in a worse situation on the coast than in any other part of the country, because the Indigenous peoples are pressurised by a group of Bengali people. This group of Bengali people are now capturing the land resources and property of Indigenous peoples by robbery. However, the government is trying to protect them from this type of activity, and have given them a special quota in higher education and the job market. But this protection and opportunity is insignificant compared to the existing risk to their livelihoods. Both the Bengali and Indigenous populations are more concentrated along the coastal embankments, especially on the islands, and along the roadsides and riverbanks in the eastern coastal districts (NEMAP, 1997; NOAA, 1998). Scattered settlements are especially pronounced in the newly formed

\textsuperscript{31} Gross domestic product.
\textsuperscript{33} Here ethnic communities mean those communities who are ethnically minority communities.
char lands, which are often isolated from the main land with minimum facilities, such as transport and communication systems (ESCAP, 1992).

As discussed above, the coastal people are involved in diverse occupations such as agriculture, livestock rearing, salt production, fishing, fish and crab farming, and crab gathering (Pokrant, 1996). Fishing and woodcutting are the dominant livelihoods. Fishermen and woodcutters have been living within or at the fringes of the mangrove forests for generations (Acharya and Kamal, 1994). The forest provides a wide variety of economic goods and services including timber for domestic fuel wood, poles for fish-drying platforms, fishing stakes and building materials, and nipa for roof and wall thatching. These traditional activities have co-existed harmoniously in coastal communities and have had minimal impact on the ecosystem (Thai-Eng et al., 1989). In recent years, however, these traditional occupants have faced many problems, such as the limitations on their right to use coastal common property and the poor health of coastal ecology. As a result of small catches of fish such as *Hilsha ilisha* (the national fish of Bangladesh), many poor fishermen who have borrowed money from local moneylenders at high rates of interest cannot repay their debts (Dev, 1998).

Traditionally, coastal land had mainly been used for paddy/rice and other cereal crops together with the grazing of livestock. Due to regular inundation of coastal land by saline water, this traditional practice has changed to other forms of agricultural and aquacultural activities, such as shrimp aquaculture (Bala and Satter, 1986; Salequzzaman, 2001; Verdegem, 2001). However, the recent practice of shrimp aquaculture inside the coastal embankments has had adverse socio-cultural, environmental, ecological and economic repercussions in the local communities (Karim, 2000; Karim and Aftabuzzaman, 1999; Salequzzaman, 2001) (please see Chapter V for details). This changed environment has also impacted on traditional salt production, navigational routes along the coastal river and industrial activities in the remote coastal areas (ESCAP, 1992; World Bank, 2001a).

Socio-cultural changes can be seen in various religious beliefs and practices; traditions and customs; sources of livelihood; the degree of social, cultural, economic and locational heterogeneity or homogeneity; asset ownership; and the level of community integration into the economy and polity, particularly in the fishing
community (Hussain and Acharya, 1994; Lakshmi and Rajagopalan, 2000; Pokrant, 1996). These changes have occurred due to the influence of western culture, random adaptation of new technology, inadequate education, and pushed more rules and regulations into the coastal community. The livelihoods of coastal peoples are characterised by: dependency on agriculture which is adversely affected by regular natural disasters; limited livelihood opportunities and poorly developed economic linkages (such as poor access to national and international markets); and unequal social structures with a small powerful elite dominating the mass of people (DFID Bangladesh, 1999; University of Leeds, 2000; UNB, 2000). The local people also suffer from poor institutional structure and changing patterns of land use.

The literacy rate\textsuperscript{34} of coastal people is 48%, much less than the Bangladesh average (65.5%) with significant disparity between female and male literacy\textsuperscript{35}. However, with the inception of Universal Primary Education program, the literacy rates have been going up. Education for women is free in government schools and collages up to Higher School Certificate Examination (equivalent to High School in the American System). Low literacy levels in most of the coastal area are exacerbated by remoteness, poor communications, the frequencies of natural disasters and poverty (Directorate of Secondary and Higher Education, 1996). Table 3.2 shows the literacy rate in some coastal districts of Bangladesh.

<table>
<thead>
<tr>
<th>District’s Name</th>
<th>Literacy Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Satkhira</td>
<td>30.5</td>
</tr>
<tr>
<td>Khulna</td>
<td>43.9</td>
</tr>
<tr>
<td>Bagerhat</td>
<td>44.3</td>
</tr>
<tr>
<td>Barisal</td>
<td>43.0</td>
</tr>
<tr>
<td>Noakhali</td>
<td>37.1</td>
</tr>
<tr>
<td>Cox’s Bazar</td>
<td>21.9</td>
</tr>
<tr>
<td>Chittagong</td>
<td>43.2</td>
</tr>
<tr>
<td>Bhola</td>
<td>23.9</td>
</tr>
</tbody>
</table>

\textsuperscript{34} In 1991 census, literacy have been defined as the ability to write a simple letter in any language for the population 7 years and over.

\textsuperscript{35} Personal communication (30 March 2003) with Chairperson, National Council for Primary and Mass Education, Dhaka, Bangladesh.
Most of the schools in the coastal area are now used as a school-cum-cyclone shelters. This type of school conducts the ‘Food for Education Program’\textsuperscript{36} aimed at increasing enrolment and attendance, and reducing drop-out in primary schools, particularly for the children of very poor and distressed families. This ‘Food for Education Program’ is particularly applied to girls’ education up to grade 10, with provision of a stipend in the rural areas to accelerate the retention of girls up to year 12. The Government, NGOs and voluntary organisations also conduct informal education for out-of-school children, adolescents and adult illiterates. Mass communication and the media are being employed to create awareness amongst the people regarding primary and mass education programs by using posters, short films, dramas and musical sessions organised through Department of Mass Communication.

\textbf{3.1.5 Energy characteristics}

Bangladesh per capita annual fuel consumption is only 56 litres of oil, which is one of the lowest in the world (Bala, 2003; Barua, 1998). With a predominantly agro-based population, bio-fuel is the main cooking fuel in the rural sector. Lighting needs are met with kerosene and most families have short evening hours and limited night activities (Barua, 1998). Coastal Bangladesh is characterised by insignificant energy supply and the country as a whole has the lowest usage of electricity (only 95.85 kilowatt hours (kWh) per capita) in the world (table 3.3)\textsuperscript{37} (Salequzzaman \textit{et al.} 2000). This usage is tiny compared to the per capita electricity consumption of Norway (24,602.30 kWh), the United States (12,407.44 kWh), the United Kingdom (9,211.17 kWh), Australia (5,582.97 kWh), and even India (411.69 kWh)\textsuperscript{38}. According to the 2001 World Bank Report (World Bank, 2001a), per capita energy consumption in Bangladesh (including electricity) is only 197 KgOE\textsuperscript{39} per person per year in comparison to average per capita consumption of low-income countries of 563 KgOE per person per year (table 3.4). Thus total energy usage patterns are similar to those of electricity. Within coastal Bangladesh, the existing energy use and supply is

\textsuperscript{36} Under this program, very poor parents of primary school children are entitled to receive 15 kg. wheat/rice of equivalent price for sending one child and 20 kg. for sending two children to school, if the child maintains 85\% attendance every month. As a result, poor parents are now keen to send their children to schools instead of employing them in income earning activities. Now about 2 million children of poor families are benefiting from the program.


\textsuperscript{39} Kilogram of oil equivalent.
much lower than for the average village in Bangladesh generally (Salequzzaman and Newman, 2001).

Table 3.3: Trends of electricity supply of Bangladesh during 1972-96 (year ending June) (Bala, 2003).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity (MW)</td>
<td>550</td>
<td>608</td>
<td>752</td>
<td>822</td>
<td>1,141</td>
<td>2,352</td>
<td>2,908</td>
<td>2,908</td>
</tr>
<tr>
<td>Effective Generation (MW)</td>
<td>469</td>
<td>455</td>
<td>557</td>
<td>625</td>
<td>1,018</td>
<td>1,834</td>
<td>2,133</td>
<td>2,105</td>
</tr>
<tr>
<td>Maximum Demand (MW)</td>
<td>183</td>
<td>222</td>
<td>396</td>
<td>462</td>
<td>887</td>
<td>1,509</td>
<td>1,970</td>
<td>2,087</td>
</tr>
<tr>
<td>230 kV Transmission Line (km)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>179</td>
<td>250</td>
<td>419</td>
<td>419</td>
<td>419</td>
</tr>
<tr>
<td>132 kV Transmission Line (km)</td>
<td>828</td>
<td>828</td>
<td>1,395</td>
<td>1,596</td>
<td>1,971</td>
<td>2,235</td>
<td>2,469</td>
<td>3,017</td>
</tr>
<tr>
<td>66 kV Transmission Line (km)</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
</tr>
<tr>
<td>Distribution Line (Km) (33 kv &amp; below)</td>
<td>9,010</td>
<td>9,086</td>
<td>17,003</td>
<td>20,256</td>
<td>34,796</td>
<td>69,731</td>
<td>103,549</td>
<td>121,817</td>
</tr>
<tr>
<td>No. of Consumers</td>
<td>254,584</td>
<td>277,884</td>
<td>403,518</td>
<td>529,660</td>
<td>848,152</td>
<td>1,670,137</td>
<td>2,766,765</td>
<td>3,090,829</td>
</tr>
<tr>
<td>Per Capita Generation (kwh)</td>
<td>15.6</td>
<td>22.9</td>
<td>27</td>
<td>46</td>
<td>70</td>
<td>92</td>
<td>95</td>
<td></td>
</tr>
</tbody>
</table>

The vast disparity in energy utilisation suggests that the world is highly unsustainable, volatile and environmentally dangerous regarding the energy sources. Industrialised/developed countries are characterised by excessive consumption rates and developing countries have great energy inefficiencies and population growth rates (Howes and Fainberg, 1991). The current global primary energy use is 350 EJ/year, 86% of which is met from fossil fuels (Byrne, 1998).

Table 3.4: Comparative Status of Per Capita Energy Consumption and GNP\(^{40}\) (of Bangladesh, including coastal area) (Islam, 2001).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Income Countries (LIC)</td>
<td>563</td>
<td>410</td>
</tr>
<tr>
<td>Lower Middle Income Countries (LMIC)</td>
<td>1178</td>
<td>1200</td>
</tr>
<tr>
<td>Upper Middle Income Countries (UMIC)</td>
<td>2068</td>
<td>4900</td>
</tr>
<tr>
<td>High Income Countries (HIC)</td>
<td>1368</td>
<td>2000</td>
</tr>
<tr>
<td>All the Countries of the World</td>
<td>5346</td>
<td>25,730</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>1692</td>
<td>4890</td>
</tr>
<tr>
<td>India</td>
<td>197</td>
<td>370</td>
</tr>
<tr>
<td>Nepal</td>
<td>479</td>
<td>450</td>
</tr>
<tr>
<td>Pakistan</td>
<td>321</td>
<td>220</td>
</tr>
<tr>
<td>SriLanka</td>
<td>442</td>
<td>470</td>
</tr>
<tr>
<td>SriLanka</td>
<td>386</td>
<td>820</td>
</tr>
</tbody>
</table>

It is predicted that by the year 2050, global energy requirements will have grown to over 2.5 times current values, with an increase by a factor of more than 6 in China, and a factor of 5 in Africa, the Middle East, South and East Asia (Raskin and Margolis, 1995). Scientists and policy makers calculate that the majority of this large

\(^{40}\) Gross National Product.
growth in energy supply within developing countries will probably occur within the rural and coastal areas, which are currently characterised as lowest per capita energy users. In Bangladesh, 83% of the energy consumption is based on traditional fuels such as biomass and the remaining 17% from commercial sources (fig. 3.2) (Barua, 2001; Rahman, 1996; Roy, 2000).

According to BCAS (1998), the forecasts for the period 1992-2020 show a doubling in demand by the end of this period, with commercial energy increasing by 400% and traditional energy by 45%. The use of traditional energy is predominates within the rural and coastal areas of Bangladesh; around 88% of the energy demand in rural and coastal areas of Bangladesh is met by traditional biomass fuel (Biswas et al., 2001; Jhingram, 1990; Marcel, 1990). Among the biomass fuel, agricultural paddy straw contributes about 70% of the total energy supply, the rest is from wood fuel, crop residue, cow dung and others (Hussain, 1995; Khan, 1986; Rahman, 1996).

The key environmental issue for all energy sources, including rural and commercial energy supply, is the generation of various pollutants and greenhouse gases from the burning of fossil fuel (Wirojanagud, 1991; Wolfensohn, 2002). As pollutants (in particular air pollutants) and greenhouse gases do not maintain any geographical boundary, these have seriously impacted on the surrounding

<table>
<thead>
<tr>
<th>Source</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>0.03</td>
<td>100</td>
</tr>
<tr>
<td>Electric</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.89</td>
<td>17.3</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>13.79</td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag. Residues</td>
<td>43.49</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>16.59</td>
<td></td>
</tr>
<tr>
<td>Dung</td>
<td>14.39</td>
<td>82.7</td>
</tr>
<tr>
<td>Woodfuel</td>
<td>8.23</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 3.2: Energy sources of the rural and coastal areas of Bangladesh (Rahman, 1996).**
environment and human health including crop damage and acid rain. Presently coastal Bangladesh is one of the victims of these effects. The burning of biomass for cooking in rural households is a major cause of respiratory disease and indoor air pollution (Dincer, 2000; Rahman, 1996; Raskin and Margolis, 1995). Although insignificant, the greenhouse gases produced in Bangladesh also contribute to global climate change (Ali, 1991; Re-Focus, 2002; UNESCO, 1992).

To counter the effects of greenhouse gases, Bangladesh (including coastal and rural Bangladesh), in common with the rest of all other countries of the developed and developing world, will need a huge proportion of energy to be produced from high efficient renewable sources (New Statesman, 1996; Re-focus, 2002). In Bangladesh, the large growth in demand for commercial energy could be met in the medium run through an expansion of the natural gas sector, which is the only significant, indigenous, commercial energy resource in Bangladesh (The World Bank, 1995). As the natural gas is a fossil fuel and non-renewable, Bangladesh needs a renewable energy source that will meet the energy demand in the long run. Renewables are the only long run option for all nations including Bangladesh, as fossil fuels run out. But even in the short term, Bangladesh needs renewable energy or clean non-renewable sources of energy, in particular in the coastal area where availability of natural gas in the near future is not possible (Bala, 1998). This thesis proposes tidal power as an important source of renewable energy on which the sustainable development of coastal Bangladesh could largely depend.

3.2 Development history of policies and programs for sustainable integrated coastal development in Bangladesh

Various scientists and researchers (such as Ahmed et al., 1999; Annan, 2001; Cicin-Sain and Knecht, 1998; Pokrant, 1996; Salequzzaman, 2001; Scura et al., 1992; The World Bank Bangladesh; 2002; World Coast Conference Report, 1993;) have broadly identified the following issues as the crucial factors for the management and sustainable development of coastal Bangladesh:
(a) **Policy and planning issues:** Lack of land-use planning and its implementation; conflicts between different resource users; lack of comprehensive and regular financial planning; lack of a comprehensive administrative agency for coastal resources management due to hierarchy often ineffective; lack of comprehensive development planning; under-valuation of the economically and environmentally important natural resources; and

(b) **Management issues:** Lack of modern facilities (such as communication, electricity supply, etc); lack of integration of sound economic and environmental management concepts in the planning and management processes where there is a big gap of co-ordination and cooperation between various agencies and government departments; lack of understanding of coastal ecosystem issues; lack of coastal protection by appropriate measures; lack of comprehensive and effective regulatory measures; and pollution and degradation of the coastal environment.

I have set out below the specific issues for sustainable integrated coastal development in Bangladesh:

### 3.2.1 Past initiatives

#### 3.2.1.1 Development of coastal embankment and sluice gate

The history of coastal embankment in Bangladesh can be traced back as early as the British Empire (1757-1947), when the Zamindars (landlords) constructed low height embankments for the farmers to protect agricultural lands from saltwater inundation during tides, for which the farmers paid taxes (Khondaker *et al.*, 1993; Leedshill-Delew Engineers, 1968). Due to their low height, these embankments were frequently flooded (Khondaker *et al.*, 1993). In 1958, East Pakistan Water and Power Development Authority (EPWAPDA, presently known as Bangladesh Water Development Board, BWDB) again commenced the construction of embankments in the low-lying coastal agricultural area which is known as the ‘Coastal Embankment Project’. This covers an area of approximately 13765 square km, of which 9717 square km are agricultural lands (GoB, 1999; Khondaker *et al.*, 1993; Rahman, 2002). Before construction of the embankments, the CEP project
was divided into several polders\textsuperscript{41} and three types of embankments were constructed (table 3.5).

**Table 3.5: Design features of Coastal Embankments (Khondaker et al., 1993).**

<table>
<thead>
<tr>
<th>Embankment Type</th>
<th>Sea side slope</th>
<th>Country side slope</th>
<th>Crest width (m)</th>
<th>Crest level (m)</th>
<th>Set back distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea-dike</td>
<td>1:7</td>
<td>1:2</td>
<td>4.27</td>
<td>$X+1.52$</td>
<td>76</td>
</tr>
<tr>
<td>Interior-dike</td>
<td>1:3</td>
<td>1:2</td>
<td>4.27</td>
<td>$X+0.91-1.52$</td>
<td>53</td>
</tr>
<tr>
<td>Marginal-dike</td>
<td>1:2</td>
<td>1:2</td>
<td>2.44</td>
<td>$X+1.52$</td>
<td>38</td>
</tr>
</tbody>
</table>

The sea-facing embankments (sea-dikes) are located at the banks of the Bay of Bengal and major rivers where high waves and currents are expected. Interior embankments are at the locations along the major or secondary streams where current and wave action is relatively moderate. Marginal embankments are placed along the banks of streams with mild wave and current action (Leedshill-Delew Engineers, 1968). The crest level of embankment was selected on the basis of maximum-recorded water levels between 1960 and 1968 and a maximum water level during monsoon of 20 years was considered (Khondaker et al., 1993; Leedshill-Delew Engineers, 1968). The embankments were not compacted, but were constructed at a 20% greater height than that required for the allowance of settlement and consolidation (FAP 7, 1992). The construction materials for the embankment were borrow pits on the sea or river side, grass turfing was used for the slopes and tips, but sandy and organic materials were avoided (fig 3.3) (Khondaker et al., 1993; Leedshill-Delew Engineers, 1968).

The Coastal Embankment Project was the single most dominant program in the coastal zone until the late 1970s. In 1978 the Government of Bangladesh, with technical assistance from the Government of the Netherlands, embarked on a program of erosion control and development of newly accreted land in the estuary through the Land Reclamation Project. The project went through several pilot studies with some positive results.

\textsuperscript{41} A group of ponds surrounded by the embankment.

\textsuperscript{42} $X$ is the normal maximum-recorded water level of 20-year return period.
The overall conclusion of the Land Reclamation Project was that the new khas land (newly created land) takes many years to produce reasonable agricultural yields and enable farmers to make a suitable living. But the crucial point is that the construction of khas land had not been scientifically engineered to mitigate adverse effects such as accelerated erosion at undesirable locations, unacceptable siltation patterns, siltation of drainage outlets, the loss of fish spawning grounds, and hindrance of commerce dependent on navigation (Barua, 1993). Even the constructed embankment has not been sufficiently protected from cyclonic tidal flooding (Leedshill-Delew Engineers, 1968). Khondaker et al., (1993) and Salequzzaman and Newman (2002) have identified a number of positive and negative impacts of this coastal embankment project, which are shown in table 3.6.
Table 3.6: Environmental impacts matrix of coastal embankment project of Bangladesh showing the degree of impacts on environment (Khondaker et al., 1993; Salequzzaman and Newman, 2002).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Impacts</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone</td>
<td>±3</td>
<td>Positive in the sense that the embankment has provided protection against cyclonic storm surge of low to moderate intensity; negative in the sense that after the embankment if breached, damage to lives and economy would be catastrophic. However since the embankment, a large number of economic activities would be initiated and people will be safer from storm surge disaster because of polder.</td>
</tr>
<tr>
<td>Crop production</td>
<td>+3</td>
<td>Crop production has been increased due to protection against saltwater inundation during normal high tides.</td>
</tr>
<tr>
<td>Soil fertility</td>
<td>-3</td>
<td>Soil fertility would have been decreased by saltwater, if saltwater intruded into the lands.</td>
</tr>
<tr>
<td>Alluvial soil on flood plains</td>
<td>-1</td>
<td>Deposition of alluvial soil with micronutrient on agricultural lands has been stopped by embankment.</td>
</tr>
<tr>
<td>Drainage</td>
<td>-1</td>
<td>Temporary drainage congestion due to inadequate link channels to convey rainwater from various rain pockets; in some places the link channels have been silted-up with washed soils from agricultural lands or from embankment erosion by rainfall-runoff.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>±1</td>
<td>Increased the ground water salinity and arsenic pollution, but this situation has improved in some places.</td>
</tr>
<tr>
<td>Surface water salinity</td>
<td>±3</td>
<td>Surface water salinity has been decreased due to removal of flooded saline water contamination with fresh water.</td>
</tr>
<tr>
<td>Surface water for irrigation</td>
<td>-3</td>
<td>Surface water for irrigation is scarce for irrigation in the project area.</td>
</tr>
<tr>
<td>Ground water for irrigation</td>
<td>+3</td>
<td>Ground water is extensively used for irrigation.</td>
</tr>
<tr>
<td>Open water fisheries</td>
<td>-3</td>
<td>Open water fisheries resources have declined for disruption in the water bodies inside and outside the embankment.</td>
</tr>
<tr>
<td>Fish cultivation</td>
<td>+3</td>
<td>Due to reduction in contamination of freshwater with saline water by flood protection, and an improvement in flood control, fisheries are cultivated in the water bodies of the project area.</td>
</tr>
<tr>
<td>Use of embankment for communication</td>
<td>±1</td>
<td>Because of the location of the embankment, road communication facilities have been increased significantly. On the other hand, navigation facilities comparatively decrease.</td>
</tr>
<tr>
<td>Human health</td>
<td>±2</td>
<td>Improved, because the flood situation assures reduction in water contamination. Decreased, in some areas due to water logging.</td>
</tr>
<tr>
<td>Land value</td>
<td>+3</td>
<td>An improvement in flood situation and increase in crop production attract people to inhabit and invest capital for agriculture and industries.</td>
</tr>
<tr>
<td>Industry</td>
<td>±2</td>
<td>New industries have been set-up in the project area. Damage to industries would be more from the risk of embankment failure by storm surge.</td>
</tr>
<tr>
<td>Socio-economic conditions</td>
<td>±3</td>
<td>Some peoples have improved, because they have enjoyed more benefit with flood protection. But most people’s socio-economic conditions have been decreased, because of land-use conflicts, particularly from shrimp aquaculture.</td>
</tr>
</tbody>
</table>

In the initial, post-construction stage of the coastal embankments, the Bangladesh Water Development Board (BWDB) banned the release of saline water into the polders from its canals along the embankment sides (Ahmed and Mirza, 2000). Later that embargo was lifted and many shrimp farmers in Khulna and Satkhira districts started shrimp aquaculture in the polders by discharging saline water from the nearby polders of inside embankments (ESCAP, 1992). Once coastal shrimp production started earning foreign currency, the Bangladesh government permitted saline water intrusion into some of the polders for shrimp aquaculture (Karim,
2000). Presently coastal shrimp farmers are using these embankments for shrimp aquaculture and haphazardly changing the original structures (Mahmood, 1986; Salequzzaman and Bhuiyan, 2000; Salequzzaman, 2001). For this reason, the existing length of the embankment has been reduced to about 4037 km. This embankment supports about 2500 allied structures including about 1400 sluice gates (Choudhuiy-Gaisuddin, 2001).

### 3.2.1.2 Other coastal development history

In the late 1980s, the Economic and Social Commission for Asia and Pacific (ESCAP) took the first initiative to formulate a coastal management policy in Bangladesh. In 1988, a report titled ‘Coastal Environmental Management Plan for Bangladesh’ was prepared that includes different problems faced by the coastal areas (ESCAP, 1988). One of the unique aspects of this study was the integration of socio-economic considerations into the environmental issues, but the study did not formulated specific plans or proposals for implementation.

In 1989, the European Communities reached an agreement with the government of Bangladesh to finance the Cyclone Protection Project II comprising feasibility and design studies for protection measures against cyclonic flooding that were undertaken under the Flood Action Plan. The study recommended the need for a more holistic approach to cyclone damage reduction as ‘an integrated master plan study for protection measures against cyclones covering all aspects including coastal embankments, warning system, cyclone shelters, means of evacuation, emergency planning and others’ (Mott MacDonald Int. Ltd., 1992).

In 1992, the Planning Commission of Bangladesh commissioned a study titled ‘Multi-purpose Cyclone Shelter Program’ for storm surge prone areas of the coastal belt of Bangladesh with financial assistance from the United Nations Development Program and World Bank. The Bangladesh University of Engineering and Technology and Bangladesh Institute of Development Studies jointly conducted this. The study analysed the needs for physical safety of the existing facilities, inter-agency collaboration, and improvement of the physical infrastructure through provision of effective warning systems, awareness raising and post-cyclone relief and rehabilitation measures (BUET-BIDS, 1993).
In 1995, the ‘Cyclone Shelter Preparatory Study (Cyclone Risk Area Development Plan)’ was launched with financial support from the European Union. The objectives of this study were to provide sustainable life-saving protection for communities at high risk from cyclones through the upgrade of disaster preparedness and management systems for use by schools and other agencies (Ingenieria and Sistemas, 1998).

The government of Bangladesh recognises the relationship between development and disasters, and hence in 1993 the Disaster Management Bureau was created to strengthen disaster management capabilities at the district, thana/upazila (administrative unit of local government), union (sub-unit of local government) and village levels. Initially the activity of the Bureau was funded by United Nations Development Program, but later received co-funding from the United Nations Infant and Children Emergency Fund and the Department for International Development (University of Leeds, 2000). In 1999, the World Bank, the Netherlands Government and the World Food Program jointly tried to convert this disaster management program into the integrated management of coastal Bangladesh (Soussan, 1999). But the new program has not yet been wholly successful.

In addition to the above programs, an organisation of parliamentarians called CARDMA (Coastal Area Resource Development and Management Association) organised a workshop in October 1988 to develop a comprehensive coastal development plan based on the principles of sustainable development. The workshop suggested 67 different recommendations on 17 different topics in coastal Bangladesh, such as shrimp cultivation, forests, land reclamation, wildlife preservation, database, eco-tourism, communications, habitat, crop development, livestock development, salt production, seabed resources, marine pollution, energy, disaster preparedness, mass awareness and institutional mechanisms (Barua, 1993; Choudhuiy-Gaisuddin, 2001).

All the above initiatives are now viewed as piecemeal efforts since they could not stimulate follow-up activities. However, through these initiatives a number of
documents were generated which captured knowledge known at that stage of development and provided a sound background for further consolidation of information.

### 3.2.2 Current initiatives

Presently, a number of sustainable integrated coastal development programs are being conducted separately around coastal Bangladesh but in a real sense, these programs are not very integrated or only partially integrated. Scientists, researchers and academics (such as Abedin et al., 2001; Alam, 2001; BSS, 2002; Choudhuiy-Gaisuddin, 2001; DFID Bangladesh, 1999; GOB, 1999; Gupta et al., 2001; Huq, 1998; Ingenieria and Sistemas, 1998; Khalequzzaman, 2000; Khan-Hasan, 2001; MWR, 2001; Nishat and Ullah, 2001; PDOICZM, 2001; Rahman, 2002; Soussan, 1999; The World Bank Bangladesh, 2002; UNB, 2000; University of Leeds, 2000; Urk, 2001; Williams, 2001) have identified that the following programs are important:

(a) The recently concluded ‘Meghna Estuary Study’ that made an extensive study of the potential for integration of fisheries, agriculture and micro-credit system;

(b) The Char Development and Settlement Project phase II (2000-2005) that implemented a comprehensive integrated development program of sustainable livelihood for poor coastal people through community forestry, small-scale aquaculture and integrated agriculture in the area of Noakhali, Feni and Chittagong districts;

(c) The Estuary Development Project (2002-07) which is undertaking an extensive marine survey in the entire coastal area of Bangladesh and preparing a number of pilot engineering interventions through integrating existing socio-cultural and environmental dimensions, such as anti-erosion works, cross dams, shrimp aquaculture and others;

(d) A number of small-scale integrated projects such as coastal biodiversity improvement projects through small-scale aquaculture, integration of multipurpose-natural disasters pilot projects and other such projects that are now being implemented in the western part of coastal Bangladesh by the Local Government Engineering Department under the financial support
of International Fund for Agricultural Development, Asian Development Bank and the Netherlands; and finally,
(e) A new joint program of the Ministry of Water Resources of Bangladesh, the Netherlands Embassy, World Bank and Department for International Development focused on integrated coastal land and water development and management through a sectoral approach of coastal Bangladesh, where the relevant ministries are outlining an institutional and policy framework.

3.3 Barriers to sustainable integrated coastal development in Bangladesh

Coastal Bangladesh has many generic barriers to sustainable coastal development: high population growth, poverty and lack of information about alternative livelihoods (Khalequzzaman, 2000; Lowry, 1989); socio-economic-cultural-environmental conflict (Fabbri, 1998; Pernetta and Elder, 1993); lack of infrastructure for large-scale commercial enterprise development (Government of Western Australia 43, 2002); lack of integral understanding of policy-making processes and participatory community-based co-management (Aksornkoae, 1989); lack of people’s understanding of the trade-offs between development and socio-cultural-ecological environment; lack of awareness and motivation programs about sustainable integrated coastal development; inadequate application of rules and regulations to coastal resources management; and lack of the global civil-society network between local, regional, national and international levels (Pokrant, 1996; Salequzzaman, 2001; Weinberg 44, 2001):

I will briefly discuss below some of the specific barriers to sustainable coastal development in Bangladesh.

43 Focus on the future: The Western Australian State Sustainability Strategy: Consulting Draft is drafting by Professor Peter Newman, who is the Director of Sustainability Policy Unit, Department of the Premier and Cabinet, Government of Western Australia, September 2002.
44 Ms Stephanie Weinberg is the Representative of the Global Secretariat of the Structural Adjustment Participatory Review International Network (SAPRIN), Washington, DC, USA.
3.3.1 Unsustainable conversion of mangrove forests to other land uses

Coastal Bangladesh is endowed with the largest mangrove forest in the world, known as ‘the Sundarbans’ which was declared as a world heritage site in 2000. The mangrove Sundarbans provides a wide range of direct and indirect benefits and play a pivotal role for protection and maintenance of many critical, threatened and endangered species (Acharya and Kamal, 1994; Khan 1986; Mahmood, 1995). Presently, this mangrove faces many threats from unsustainable activities such as massive deforestation for agriculture, salt production, aquaculture, charcoal and building materials production, recreation and tourism, and other industrial and commercial activities including unsustainable fishing, land filling and municipal activities and, mining and extraction of mineral resources (Acharya and Kamal, 1994; Aksornkoae, 1989; Field 1995). As a result of these activities, various unexpected events are now occurring, such as pollution and the degeneration of water quality (Rajendran and Kathiresan, 1996; Stevenson, 2002), catastrophic flooding, salinity intrusion, and erosion (or accretion in other areas) (ESCAP, 1992; Salequzzaman and Bhuiyan, 2000) accompanied by the depletion of other resources (Mahmood, 1986; Mann, 2000; Narongrit, 1990). All of these cumulative activities are now impacting on the mangrove forests in such a way that many commercially important flora and fauna are already extinct (Hussain, 1995; Khan, 1986); others are endangered such as golpata (*Nipa sp*) and honey bees (Karim, 2000); some mangrove trees are affected by ‘top dying disease’ (such as sundari trees45); and many native species of birds, shrimps and fishes have become rare (Gain, 1998; Salequzzaman and Newman, 2002). This wholesale destruction of mangrove forest is an important barrier to sustainable coastal development.

3.3.2 Loss of biodiversity

Traditionally the coastal area was rich in biodiversity. The Sundarbans, itself, supports 330 species of plants, around 400 species of fish, at least 35 species of reptile, over 270 species of bird and 42 species of mammal (Hussain and Acharya, 1994).

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45 Personal communication with Professor Md. Abdur Rahman, Forestry and Wood Technology Discipline, Khulna University, Bangladesh.
1994). But this rich biodiversity is now seriously depleted through high fishing
density, coastal pollution and large-scale deforestation of the Sundarbans (Gain 1998;
Gupta et al., 2001; Salequzzaman, 2001). In the same way, the natural beauty of coral
reefs and the tourist attraction of Saint Martin Island of Cox’s Bazar are being
destroyed by coral mining, use of explosives and poisons to harvest reef fish (Alcala,
1981; Clark et al., 1989; Christie et al., 1994), and sedimentation from upland soil
erosion (Wells, 1993; White, 1996). Many important coastal fisheries are also
decreasing rapidly due to unsustainable heavy fishing pressure and are no longer
economically viable (Gupta et al., 2001; Mazid and Alam, 1995; Pearman et al.,
2002). This has resulted in reduced incomes for coastal fisher folk (Csavas, 1995;
Jackson et al., 2001; Pokrant, 1997) who now put damaging pressure on unsustainable
coastal resources (Hussain and Acharya, 1994; Mazid and Gupta, 1995; Salequzzaman,
2001). In this situation, many researchers and scientists recommend
that optimum fishing is desirable in coastal Bangladesh to ensure the longevity of
the industry (Johnson, 2001; Pauly and Chua, 1988).

3.3.3 Unsustainable aquaculture

The present land-use patterns of coastal Bangladesh are dominated by shrimp
aquaculture (Mazid and Alam, 1995; Salequzzaman, 2001; Verdegem and Verreth,
2001). But there is strong evidence that this fast-growing industry has threatened the
ecological sustainability of the coastal environment, even while the economic viability
of the local communities are dependent on it (Ahmed and Mirza, 2000; Alam, 2001).
Practically, shrimp and prawn farming and their associated destruction of mangrove
forests have increased coastal erosion and reduced the livelihoods of local people
(Salequzzaman, 2001; Sudara, 1996). The details of unsustainable aquaculture in
coastal Bangladesh will be discussed in Chapter V.

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46 The caught fisheries are greater amount than optimum fishing.
47 Optimum fishing occurs when year after year fisheries stocks remain constant through the
recruitment of young fish.
3.3.4 Coastal pollution

Pollution is now degrading the coastal environment of Bangladesh and creating different conflicts among various coastal resource users. It has impacted on coastal and marine environments and ecosystems through lowering environmental quality and, most significantly, by lowering natural production (Ahmed et al., 2000; PDOICZM, 2001; Salequzzaman, 2001a). Although the coastal environment has a significant role in absorbing and diluting coastal pollution (Shi et al., 2001), its assimilative capacity is over loaded by increased pollution, waste water from urban and agricultural run-off (Hodgson and Dixon, 1988; Hodgson and Dixon, 1992; Hussain and Acharya, 1994); fuel, hull antifouling paints and hazardous cargo spills from harbour dredging and shipping (Annual Environment Report, 2001); aquacultural waste water (Acharya and Kamal, 1994); and acidic leachates from coastal acid sulfate soils (Brodie, 1995; Howarth et al., 2001; Salequzzaman, 2001a). Pollution has had adverse impacts on the coastal environment, such as loss of fisheries, wetland biodiversity, aquacultural production and, human health (impacts and diseases) (Salequzzaman, 2001a). Therefore measures should be taken to prevent, treat, and dispose of coastal pollution in a more sustainable manner.

3.3.5 Lack of modern facilities

Coastal Bangladesh has few modern facilities. As mentioned above, electricity supply is one of the vital factors for the sustainable development of coastal Bangladesh (Annan, 2001). Presently, there is no access to electricity for more than 80% of the Bangladesh population, including coastal areas (BBS, 2000). These people use traditional fuels for their cooking and other daily activities that contribute not only greenhouse gases to the atmosphere, but also poisons to themselves (Ahmed et al., 1999; Biswas et al., 2001; Huq, 2001a). Remote coastal populations also suffer from a lack of coastal infrastructure including: protection facilities from natural disasters like cyclone and tidal surges; an appropriate communication system; a sufficiently high quality education system; and good health and sanitation facilities (Rahman and Huq, 1998; World Bank, 2001). Due to poor communications, they do not receive emergency information on time, including warning of natural disasters, piracy in

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48 Kofi Annan, Secretary General of the United Nations.
coastal waters\textsuperscript{49}, and other accidents (Kamal et al., 2001). For the above-mentioned reasons, very few international and national tourists visit coastal Bangladesh compared to other south Asian countries, not withstanding that this area is potentially an important potential site for eco-tourism. Coastal peoples are suffering from high levels of poverty and malnutrition, such as iodine deficiency (goitre disease\textsuperscript{50}) (Rasheed, et al., 2001). Again due to lack of modern facilities, they are not able to develop their desired skills that will make them employable to the industry or global open market (World Bank, 2001a).

3.3.6 Conflicts of different resource users

Coastal Bangladesh is enriched by many resources that stimulate rapid population growth which consequently increases the levels of conflict through increasing competition over allocation of resources related to housing, agriculture, fishing, industry, trade, tourism, national/marine parks/conservation areas and others (Flood et al., 1993; Golderg, 1994). As the human elements (social, cultural and economic processes) in this area interact so closely with maritime, terrestrial and riverine systems, any change can generate chain reactions that produce an imbalance in the system (Pokrant, 1996; Salequzzaman, 2001). The new environment may not be mutually compatible with the previous components/systems, which that may result in conflicts. For example, the differences which exist between shrimp aquaculture and paddy cultivation in coastal Bangladesh reach such a stage every year that people are killed through inter-factional fights (DFID Bangladesh, 1999; Mazid and Alam, 1995). Conflict also occurs between government departments and ministries which ultimately impact on the local resource users (GOB, 1999). Outsiders (who control the shrimp aquaculture and other land uses) have no respect for the local stakeholders (Hussain and Acharya, 1994). All of these conflicts create barriers to sustainable integrated coastal development which needs mutual understanding to reach solutions (Lowry et al., 1988; Masalu, 2000).

\textsuperscript{49} Pirates are powerful organised gangs with modern weapons and fast moving vessels, who frequently attack in the coastal area of Bangladesh. They snatch fish and often kidnap the fishers to collect ransom. Presently, piracy is the greatest threat for fishers especially in the Sundarbans area (Kamal et al., 2001).

\textsuperscript{50} Goitre disease is very common in certain rural and coastal areas of Bangladesh, though it is preventable with a pinch of daily salt fortified with iodine. In coastal Bangladesh, evaporating seawater makes salt and often people either do not eat the iodinated salt by choice or have no access to it due to poverty and ignorance.
3.3.7 Lack of good governance, transparency, coordination and political will

Coastal Bangladesh suffers from a lack of good transparent governance which is an important barrier to sustainable development. Sometimes corruption and lack of transparency creates complex situations as well. Political corruption is also evident. For example, a vast tract of coastal forestlands have been occupied by influential politicians with the help of terrorists and ‘musclemen’ for establishing shrimp projects or other land-uses. This type of corruption is happening because existing governmental structures, institutions and laws of coastal Bangladesh are multi-sectoral and very weak and there is a lack of strong coordination among various departments and organisations with many competing policies. These include: the National Tourism Policy (1992); National Environment Policy (1992); National Forestry Policy (1994); National Fisheries Policy (1998); National Policy for Safe Water Supply and Sanitation (1998); National Agricultural Policy (1999); National Water Policy (1999); Industrial Policy (1999); National Shipping Policy (2000); National Land Use Policy (2001); and others such policies (Gupta et al., 2001; PDOICZM, 2001; UNEP, 1995). These problems add to the existing ‘top down’ approach51 for coastal resource management. The top down approach inhibits local input in the planning process (World Bank, 2001a). Regardless of their technical skills, local officials, stakeholders, villagers, and others are far more knowledgeable about local problems than an amorphous leadership (Ruddle, 1994; Vallega, 2001). As local community participation is one of the pre-requisites for sustainable development, where local communities are recognised as more capable of developing sustainable management practices on the ground than the central authorities, the top down approach is not advisable in coastal Bangladesh (ESCAP, 1988; Ruddle, 2001; Salequzzaman and Newman, 2002).

3.3.8 Climate change and sea level rise

Coastal Bangladesh is one of the most densely populated low-lying areas in the world, where tropical cyclones and other natural disasters have occurred for centuries. Future global warming will increase the sea level significantly and enhance the effect of

51 The top down approach refers to one of the organisational design techniques which aim to describe functionality at a very high level, then partition it repeatedly into more detailed at the grass root levels.
these natural disasters (Chowdhury, 2001; Slessor, 2001; Toepfer, 2001). According to IPCC, the sea level rise will be in the range of 15 cm to 95 cm by the year 2100 which will inundate more than 2,500 square km (Huq, 2001; Huq, 2001a; World Bank, 2001). This potentially inundated area will cover between 2%-17% of the total land area of coastal Bangladesh and 0.6%-6.0% of the whole country. This potentially inundated area presently supports 13% of the country’s GDP (BSS, 2002; Chowdhury, 2001; Huq, 2001). Many researchers and scientists indicate that coastal Bangladesh is the most at risk area in the world from climate change consequences such as land subsidence, rising salinity in the coastal lands and waters, and drainage and sedimentation problems (Huq, 1999; Khan, 2001; Toepfer, 2001). These factors, as well as coastal erosion, ecosystem and biodiversity loss will constitute formidable socio-ecological, environmental and economic problems\(^\text{52}\) (Biswas et al., 2001; IPCC\(^\text{53}\), 2001; Khan, 2001). It is important to note that Bangladesh has made no major contribution to human induced greenhouse gases emissions leading to climate change (Huq, 1999; Toepfer, 2001; World Bank, 2001) (table 3.7), but the country remains on the receiving end of other countries’ excessive use and will suffer from the consequences (Huq, 2001; IPCC, 2001; Rahman and Mallick, 2002).

<table>
<thead>
<tr>
<th>Country</th>
<th>Total CO(_2) emissions (in thousand metric tonnes) (WRI, 2001).</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>5,300,991</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>22,959</td>
</tr>
<tr>
<td>Japan</td>
<td>1,167,666</td>
</tr>
<tr>
<td>Europe</td>
<td>6,124,896</td>
</tr>
<tr>
<td>World</td>
<td>23,881,952</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>Per capita emissions</th>
<th>Total contribution since 1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>19,674</td>
<td>186,114,027</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>190</td>
<td>269,959</td>
</tr>
<tr>
<td>Japan</td>
<td>9,284</td>
<td>31,157,964</td>
</tr>
<tr>
<td>Europe</td>
<td>8,414</td>
<td>264,991,558</td>
</tr>
<tr>
<td>World</td>
<td>4,157</td>
<td>718,514,064</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>In percent of World total</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>22.0</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>0.001</td>
</tr>
<tr>
<td>Japan</td>
<td>5.0</td>
</tr>
<tr>
<td>Europe</td>
<td>26.0</td>
</tr>
</tbody>
</table>

Climate change and sea level rise will change existing coastal water currents and movement, precipitation and run-off, and hence the tidal range of coastal Bangladesh (Rahman and Mallick, 2002; Salequzzaman, 2001; World Bank, 2001). The present

\(^{52}\) http://nation-online.com/200205/10/n2051001.htm (accessed on 10 May 2002).

\(^{53}\) Inter-governmental panel for climate change.
limit of tidal flow will extend further upstream both in depth and width and create potential tidal movement that will result in large areas of land loss and population displacement (Huq, 1999; Huq, 2001; Salequzzaman and Newman, 2002).

3.3.9 Gaps in existing programs and policies

One of the important barriers to sustainable integrated coastal development is the huge gap between existing coastal development programs and policies. There are many agencies, government departments, NGOs and other organisations working in coastal Bangladesh (for details, please see Appendix B & Appendix C), but their programs and policies are unsustainable due to lack of community involvement and lack of modern infrastructure (e.g. electricity). Workable micro-level model developments have not been possible due to lack of education, training, awareness and understanding (PDOICZM, 2001; Salequzzaman and Newman, 2002; World Bank, 2001a). Furthermore, the existing and past activities are not based on local socio-cultural practices. Local peoples always expected that any development should respect their local customs. This research will explore these socio-cultural issues in chapter VI.

3.4 Aims of sustainable integrated coastal development in Bangladesh

It is now clear from the preceding sections that the multifarious and multi-disciplinary coastal resource development and management systems in coastal Bangladesh are unsustainable because of over-exploitation, environmental degradation, escalating resource-use conflicts and many other problems (Kazmierczak and Caffey, 2001; Thomas, 2002). It is vital that the resources of coastal Bangladesh should be managed in an integrated, inter-sectoral manner on a sustainable basis in order to maximise the value of scarce resources and the environment over the long-term for the benefit of the nation as a whole, including minority groups and the poor (ADB/NACA, 1996; Dixon, 1989; Lowry, 1989). Therefore the present study suggests that coastal Bangladesh can overcome the barriers outlined above and achieve sustainable integrated coastal development, by focusing on the following general aims (Calderon and Alvarez-Villamil, 2000; Glaeser, 2001; Salequzzaman et al., 2001):
(a) Formulate an inclusive management framework in which government ministries, departments and agencies; NGOs, CBOs, local communities, scientists, researchers and others will work together that is, coordinate and negotiate among agencies and programs in coastal Bangladesh;

(b) Mitigate conflicts among the activities of agriculture, forestry, fish and wildlife management, flood control, transportation, industrial development, public health and water pollution control; and

(c) Enhance coastal development and management by considering both social equity and economic growth issues; increase understanding of rules and arrangements; improve the education system and awareness programs to activate community-based coastal co-management practices; make use of resources such as tidal power to protect/support sustainable economies in remote coastal areas (such as development of small-scale cottage industry, tourism activity, modern aquaculture); improve access to national and international markets, improve and conserve coastal biodiversity and socio-cultural beliefs; and, develop natural disaster protection and mitigation measures taking into account the climate change impacts.

The frameworks needed to achieve these above aims are both institutional and participatory. These are discussed below, while the substantive technical issues are covered in Chapters IV and V.

3.5 Frameworks for sustainable integrated coastal development

3.5.1 Institutional framework for renewable energy technology in coastal Bangladesh

Several government organisations (Bangladesh Power Development Board, Local Government and Engineering Department, Rural Electrification Board, etc), academic institutions (Bangladesh University of Engineering and Technology, Dhaka University, Bangladesh Institute of Technologies, non-government organisations (such as: Grameen Shakti, Centre for Mass Education and Science- CMES),
Bangladesh Rural Advancement Committee and some private companies are involved in the uptake of renewable energy technologies and their research in coastal Bangladesh (Barua, 2001; Biswas et al., 2001; Grameen Shakti, 2001). There is no national coordinating agency for renewable energy technologies in Bangladesh; however, the Ministry of Energy and Mineral Resources is the main authority responsible for energy related activities in the country (Roy, 2000).

### 3.5.2 Community-based coastal co-management of coastal Bangladesh

Community-based coastal co-management (or simply ‘co-management’) can be integrated into the existing local socio-cultural and environmental institutions and is an appropriate means to maintain the demands of local stakeholders in order to ensure the success of sustainable integrated coastal development of Bangladesh (Brokensha, 1986; Millat-e-Mustafa, 2000; Walker et al., 1991). Traditional natural resource co-management of coastal Bangladesh has been practised for centuries in many communities, such as management of agriculture, animal husbandry, fishing, forestry, ethno-medicine, and other renewable resources (Ruddle, 1994). This co-management has worked in a dynamic and equitable manner and, it seems has application in a modern sustainable management context for managing and enforcing the conservation of coastal natural resources (Ruddle, 1998). For example, in beel\(^54\) and boar\(^55\) fisheries management, a wide range of stakeholders including elected representatives, government employees, professional groups, traditionally knowledgeable old peoples and different voluntary groups have shared their responsibility in the decision-making process to maintain sustainable coastal fisheries management (Pokrant, 1996).

Traditional local knowledge is the basic design principle for sustainable coastal resources management and development in Bangladesh, because this knowledge provides empirical information on fish behaviour and habitat, coastal physico-chemical and biological environments, regularly successful catches and long-term sustainability of aquatic resources management (Cicin-Sain, 1993; Raychaudhuri, 

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\(^{54}\) Lowland water body that created by the branches of Death River where water may dry up from any of its area.

\(^{55}\) A branch of Death River which may disconnect from the main river at any time in a year.
For example, fish shoals in the coastal waters emit a fishy smell from which fishermen are able to judge the shoal’s route and movement. The hilsa (*Hilsa ilisha*) is pinkish in colour and experienced fishermen easily identify its movement in the deep sea/coastal water; these fishermen are vital to the sustainable catch management of the hilsa fishery (Raychaudhuri, 1980; Ruddle, 1994). In this way, coastal co-management is able to carry out stock assessments, environmental impact assessment, local hydrograph, mapping, fishing methods and techniques, fish systematics and biology (Miah, 2000; Pokrant, 1997; Ruddle, 2001). Various researches in Bangladesh and abroad recommend that community-based coastal co-management is an important method for sustainable integrated coastal development in Bangladesh (Ministry of Planning, 1995; NEMAP, 1997; Salequzzaman *et al*., 2001).

### 3.6 Sustainable integrated coastal development and tidal power

Sustainable integrated coastal development is considered essential to sustainable development in coastal Bangladesh both for the people, the government and the environment (Aich *et al*., 1991; Managing Shared Waters, 2002; NEMAP, 1997). Thus, the government of Bangladesh has taken an initiative to incorporate integrated development into the policy-making process. It is not a new concept and presently many integrated projects are being conducted in coastal Bangladesh (GOB, 1999; UNEP, 1995; World Bank, 2001). But in a real sense, most of these projects have failed to achieve the integration goal (McNally and Tognetti, 2002; MWR, 2001; SWMC, 2001), because they had little emphasis on involving the local community and its varied ecology such as coastal mangrove forests, wetlands and tidal flats (Hussain and Acharya, 1994; Soussan, 1999; University of Leeds, 2000).

This research seeks to identify an integrated tidal power model for sustainable coastal development in Bangladesh, which will be discussed more in Chapter VI. The proposed model could involve the local community on the basis of community-based coastal co-management principles. The technology of tidal power production will

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56 The national fish of Bangladesh. Anadromous (breed in deep sea, but young stage expend in river water or coastal estuarine water) characteristics; 80% of this fish found in Bangladesh territory.

57 An international conference held in Canada on June 23-28 2002.
utilise the existing infrastructure of coastal embankment and sluice gates, with mitigation of existing coastal resource-use conflicts and emphasis on modernisation of existing land use patterns by improving facilities like electricity supply (such as shrimp aquaculture production) (Bower and Turner, 1996; Chou et al., 1991; Cicin-Sain and Knecht, 1998). The integrated tidal power project must improve the existing education, training, and awareness systems (Pernetta and Elder, 1993; Urk, 2001); develop the infrastructure in such a way that it will improve the vulnerability of existing natural disaster mitigation systems; and, protect the natural resources and cultural heritage (Charlier, 1997; Elliott, 1996; Flint, 2000). Presently, lack of electricity is one of the important barriers for the sustainable integrated coastal development of Bangladesh, which might be improved by tidal power (Cicin-Sain and Knecht, 1998; Courtney and White, 2000; World Bank, 1993). As tidal power is a form of renewable energy and it produces no greenhouse gases (Blue Energy, 2001; Tidal Energy Inc., 1999; Tidal Impact, 2001), this innovative technology could mitigate greenhouse gases production and other climate change impacts around the world (Huq, 2001; Wallström, 2001). It is suggested that this factor will persuade technical innovation and financial support groups around the world to favour the proposed integrated tidal power development model in coastal Bangladesh (Wallström, 2001; White, 1997). Considering all of the factors, the thesis will propose a framework of integrating tidal power with various potential coastal resources in Bangladesh for its sustainable integrated coastal development that will discuss more in chapter IV and VI.

3.7 Conclusions

Coastal Bangladesh suffers from many problems, mainly due to remoteness and lack of modern infrastructural facilities, such as electricity and communications. Presently, many projects are being conducted in coastal Bangladesh, but there is a gap in coordination amongst them. The organisation of the projects has also a very weak community participation in local development processes; and a lack of a realistic development model for potential coastal resource use with the little integration between various coastal resources and most importantly, more of the projects has a renewable energy component. The research in the next chapter identifies the tidal power potential that could be developed from the existing coastal infrastructure of embankments and sluice gates. It also identifies the possibility that tidal power could
integrate with various coastal resources through the principles of community-based coastal co-management. The main benefit of such a project is that it could adapt and mitigate the future climate change consequences through the production of renewable energy like tidal power. The project could improve the socio-economic and environmental status for the coastal people of Bangladesh. It could also have global significance, because of greenhouse gases abatement. Therefore integration of a tidal power project in coastal Bangladesh could improve the livelihoods of the coastal community and could become an important model for future sustainable integrated coastal development.
CHAPTER IV
Chapter IV
TIDAL POWER

“The oceans are offering us an energy source of much higher density and greater reliability than any other renewable for the foreseeable future.”

Martin Burger

“Hopefully our moon will remain in the night sky for the foreseeable future. Barring any unseen catastrophe, the moon could be - much more than it is now - a reliable source of energy, RELIABLE TIDAL POWER, for a long, long time.”

Energies, 24 March 2002

Research Questions

(1) To what extent is tidal power a low-cost, long-term and appropriate technology? Why has it not been utilised extensively yet and when will it be feasible?

(2) How can tidal power be sustainably used as a small-scale technology, instead of on a large or medium scale, in a developing country like Bangladesh?

4.0 Introduction

Sustainability in the 21st century requires that world populations have a lifestyle that uses energy to meet their needs while protecting human health and the health of the biosphere (Barua, 2001; Raskin and Margolis, 1995; Wiser, 2000). Presently the world continues to use electricity in ever-increasing amounts, despite the problems associated with power generation that uses fossil fuels as outlined in Chapter III (Bala, 2003; David and William, 1986; Dincer, 2000; Roy, 2001). Therefore a shift from oil to renewable energy sources would be a strategic way to maintain environmental management and sustainable development (Joskow, 1998; Kaygusuz and Kaygusuz, 2002; Lipp, 2001). Lowe mentioned that:

“A sustainable society will have made a fundamental transition from the current energy system which transforms fossil hydrocarbons inefficiently into a range of energy services, to a new regime based

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58 President of Blue Energy, Canada.
60 Renewable energy means the energy generally cannot loss and renew again and again, which is unlimited, generally carbon free and essentially sustainable, such as wind, water, solar, tidal, energy-from-waste and energy-from-crops (bio-mass).
Currently oil, coal, natural gas and other biomass fuel including natural forest and wood are used at such a rate around the world that the most of these resources are already over-exploited and exceed the earth’s capacity to consume their waste and by-products (Fleay and Fox\(^61\), 2000; Howes and Fainberg, 1991; Joskow, 1998). For example, the total world energy use was 400 exajoules/year (85% fossil fuels, 8% renewable sources and 7% nuclear power) in 1997 and this trend of energy utilisation will continue to 900 exajoules/year in 2050 (Fleay and Fox, 2000; Koch, 2001). All hydroelectric sites around the world are currently fully exploited and further development meets strong resistance (Elliott, 1994; Nishat and Ullah, 2001; Ullman, 2002). Nuclear power has been a dramatic disappointment (Beckenstein \textit{et al.}, 1994; Nishat and Ullah, 2001; Sims, 1991).

Renewable energy like solar, photovoltaic, wind, wave and tidal power can provide a substitute for fossil fuels and other non-renewable polluting sources of energy, because they produce fewer toxic substances and greenhouse gas emissions, and can provide a quality of life adequate to sustaining human beings and while still protecting world biodiversity (Dincer, 2000; Newman, 1998; Wind Force 12, 2002; Wirojanagud, 1991). Therefore renewable energy is quickly becoming popular around the world (Keyun, 1997, Koch, 2001). For example, 5.3 million German residents are now using renewable energy and another 1 million people have applied for renewable energy supply to their houses; this growing industry could provide an additional 300,000 jobs by 2010\(^62\). The same thing is happening in USA, China, Netherlands, UK, Australia and other countries to reduce the environmental and health risks of conventional electricity generation\(^63\) (Ammunition, 2002; ENS, 2002; The Carbon Trader, 2002). This rapid growth of renewable energy will gradually reduce the use of non-renewable sources of energy, particularly in developing countries where increasing energy demands are necessary for significant improvements in the living

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standards of their peoples (Fleay and Fox, 2000; Lipp, 2001). Even so, renewable energy development has not been rapid enough due to comparatively cheap fossil fuel and various barriers to the popularisation of it use, especially dependence on required weather conditions and daylight use (ACRE, 1999; Koch, 2001). However the increasing demand for renewable energy in developing countries could be supplied by the application of appropriate new and more efficient energy technologies; easy access to an affordable and reliable energy supply tax exemption system; deregulation; successful marketing campaigns; and peoples’ response to the climate change impact of NRSE (Fleay and Fox, 2000; SEDA, 2001; Thomas, 2002).

Many scientists and researchers (such as Charlier, 1982; Day 1994; Koh, 1997; Lawton, 1972; Lewis, 1963; The Hearst Corporation, 2001; Wilson, 1973; Zu-Tian, 1989;) have stated that tidal power is an important source of renewable energy. The tide, governed largely by the moon's gravity, imparts tremendous energy to the earth64 (Baker, 1991; Day, 1994; Elliott, 1996). The technical potential of tidal power remains huge, despite the low energy density in the water, low efficiencies of low temperature thermo-dynamic cycles, and intermittent operation (Wavegen, 1999). According to Ray (2001), about 1 terawatt, or 25 to 30% of the total tidal energy dissipates in the deep ocean, the remainder is released in shallow seas and the continental shelf. The appropriateness of permitting tidal power development remains a site-specific issue which depends on its potential impacts on marine and bird life, and interference with shipping and radio communication (Charlier, 1982; Day, 1994; Newman et al., 1999).

This chapter will discuss the potentialities of tidal power around the world in the light of present socio-cultural, economic, and environmental points of view. The research also explores the underdevelopment of tidal power in the recent past and seeks to find out how tidal power could work for sustainable development in coastal and estuarine environments, in particular for developing countries such as Bangladesh.

4.1 Tidal power: principles and technologies

Tidal power is a form of hydro-electric generation where the energy resource is

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Fig. 4.1: Effects on tide through the gravitational force from Sun-Moon-Earth systems (Barnabe and Barnabe-Quet, 2000; Blue Energy, 2001; Elliott; 1994).
replenished by tidal movements twice per day which in turn are created by the gravitational attraction of the moon and sun acting on the oceans of the rotating earth (Baker, 1991a; Cavanagh et al., 1993; Charlier, 1993) (fig 4.1). The variable positions of the earth, the moon and the sun create many periodicities in the tides: the earth turns on its axis in 24 hours in relation to the sun, but the moon circles the earth in 24 hours 50 minutes (Day, 1994) (Appendix D). The distance and inclination of the moon in relation to the earth and of the earth in relation to the sun also varies throughout the year. (Elliott, 1996). Therefore the periodicities of the wavelength of the tides exhibit various rhythms, such as semi-diurnal, diurnal, bi-monthly, seasonal and annual (Barnabe and Barnabe-Quet, 2000). However the tide is daily moving with 2 high tides and simultaneously 2 low tides occurring every 24 hours and 50 minutes, with every rise and fall storing large amount of potential energy (Baker, 1991; Derby Hydro, 1999; Middleton, 2001). When the moon and the sun are aligned (about every 14 days), the tidal force is greatest (spring tide) and has maximum energy. When the sun and the moon are at right angles, the tide force is least (neap tide) and has minimum energy (Barnabe and Barnabe-Quet, 2000; Guilcher, 1979). Tides in the open ocean have maximum amplitudes of about 1m, whereas tides closer to shore can have substantially higher amplitudes under the influence of local topographic effects such as shelving, funnelling, reflection and resonance (Consultative Environmental Review, 1997).

Tidal power can be generated during the movement of the tide through its tidal range (difference between height of high tide and low tide point); this contains a large amount of potential mechanical energy (Day, 1994). The ocean tide comprises 75% of ocean’s mechanical energy, whereas wind comprises only 30% of total atmospheric mechanical energy (Twidell and Weir, 1997). The potential mechanical energy of the tide can be converted to electrical energy by using various technologies, such as a water wheel or turbine placed over a delta, estuaries, beaches or any other sites that are affected by tidal range (Charlier, 1982; Guilcher, 1979). A sluice gate containing a barrage or dam is the simplest form of this infrastructure. Here, a water wheel or turbine is set for electrical energy production where there are large differences in sea


A machine in which the kinetic energy of a moving fluid is converted to mechanical power by the impulse or reaction of the fluid with a series of blades arrayed about the circumference of a wheel or cylinder.
level between low and high tides (Carter, 1991; Davis and Swan, 1982; Salequzzaman, 2002). When the high tide comes in, water flows through the turbine or water wheel to create electricity. Generally the high tides allow the water to rush into the barrage, then the sluice gates of the barrage shut down when the water level is at its maximum height (Baker, 1991; Elliott, 1996). When the barrage is opened, electricity can be generated by water flowing out again (fig 4.2).

The above generation of electricity from tides is very similar to hydroelectric generation, except that water is able to flow in both directions and so electricity can be created utilising two-way turbines. Fig 4.2 shows a three-chambered enclosure that generates tidal electricity in sequences. The sequence can be optimised to meet the needs of the operator, e.g., whether or not there is a need for maximum output. All three enclosures generate only during the extreme high tide periods and the extreme low tide periods (Day, 1994). In this process, if continuous output is required, the chambers generate sequentially, reducing the over-all output, but providing continuous power (Ullman, 2002). The amount of electricity generated is strongly related to the size of the tidal range (Baker, 1991; Day, 1994; Wavegen, 1999). The output varies with the square of the tidal range, that is, if a tidal range of x gives a power output of y, then a tidal range of 10x will give a power output of 100y (Baker, 1991; Day, 1994; Tidal Energy Inc., 1999). This tidal power output is also directly related to the area of the impoundment structure (Appendix D) (Baker, 1991; Blue Energy, 2001).

Based on the above basic principles, there are many innovative technologies which have been used around the world to harness tidal power (Appendix D). These include single and double basin designs, where different types of turbines are used such as bulb turbine, rim turbine, tubular turbine, tidal fence, tidal turbine, etc (ACRE, 1999; Wadhwa, 1993). However the specific technology of tidal power depends on where, when and how it will be used (Salequzzaman, 2002).

67 The rotatable wheel, generally use for electricity generation.
Fig. 4.2: Tidal power generation system A: The basic concept, B: The design of a tidal barrage system, and C: The mechanism of tidal power production (Baker, 1991; Blue Energy, 2001; Tidal Energy Inc., 1999).
4.2 Renewability and sustainability of tidal power

Based on the principle of all renewable technologies, tidal power can be produced again and again from the same infinite resource of sea/ocean. Tidal power plant itself has a long life cycle, typically exceeding 120 years (Day, 1994). Maintenance costs are almost zero; it does not produce any waste streams and does not contribute any global warming in the generation of electricity (Baker, 1991; Day, 1994; Middleton, 2001). In addition, the technology of tidal power can be optimised to meet the needs of continuous power supply by means of damming of water (Baker, 1991; Gray and Gashus, 1972; Ullman, 2002). In the damming process and in the construction phase of plant, tidal power plant does produce CO₂ and/or other greenhouse gases like the construction phase of any other technology/industry, but this amount is small relative to the clean power produced over its life cycle (Elliott, 1996; Middleton, 2001). Therefore tidal power is an important source of clean and renewable energy. Long after fossil fuels have gone, the tides will still be running. It is increasingly important in a post Kyoto protocol world.

Tidal power avoids fuel costs, greenhouse gas mitigation costs and fuel price risks; and minimises environmental costs and ecosystem disturbance costs in its production system (Thomas, 2002). It displaces fossil fuels at nearly one million tonnes of carbon dioxide emissions per TWh electricity production (Day, 1994). Thus it is a renewable energy that overtakes fossil fuel as the lowest cost, least-risk investment (Day, 1994; Page, 1994). In addition, tidal power is an important source of renewable and sustainable energy for the reasons set out below.

(a) Sites suitable for the utilisation of tidal power exist in many places around the world. Notwithstanding from its massive capital cost, tidal power can provide

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68 Greenhouse gas trading has its origins in the United Nations Framework Convention on Climate Change (UNFCCC). Adopted in Rio de Janeiro, Brazil, in 1992, the UNFCCC established the goal for industrialised countries to return to their 1990 GHG emissions levels by the year 2000 and a long-term objective of stabilising atmospheric concentrations of greenhouse gas “at a level that would prevent dangerous anthropogenic interference with the climate system.” In 1995, the Parties reviewed their progress and concluded that the non-binding goal would not lead to the achievement of the Convention’s objective of atmospheric stabilisation. In response, Parties agreed to pursue a complementary agreement that would establish quantified emissions limitations and reduction obligations for developed countries. This culminated in the negotiation of the Kyoto Protocol in December 1997. The process to develop rules, mechanisms, and institutions necessary to bring the Protocol into force is ongoing, including the seventh Conference of Parties (COP-7), held in Marrakech, Morocco, during November 2001 (Huq, 2002).
extremely low cost energy per kWh, once it is built (Blue energy, 2001; Salequzzaman and Newman, 2001; Salequzzaman, 2002).

(b) Unlike wind, solar, PV and other renewable energy, tidal power is entirely predictable. It can be used like hydro, as a base-load power supply and is immune from climatic conditions and daylight requirements. The amount of power generated is predictable and strongly related to the size of tidal range (Tidal Energy Inc., 1999).

(c) Modern tidal power accessories and infrastructure are extremely durable and highly efficient (Tidal electric Inc, 1999). Monitoring equipment is capable of detecting the slightest variation in functioning, and adjustments are made instantaneously, thereby avoiding downtime (Salequzzaman, 2002; Ullman, 2002).

(d) The problem of the high capital cost of tidal power plant could be resolved by utilising small-scale technologies, innovative financing and involvement of local communities to ensure that all key impacts are manageable (Salequzzaman et al., 2000; Salequzzaman and Newman, 2002; Ullman, 2002). However in the long run, once the high capital cost have been paid off after 15 or 20 years, production costs will be nearly zero, and maintenance costs minimal (Newman et al., 1999). Therefore the long term costs of tidal power are competitive with other power sources (Salequzzaman and Newman, 2002).

(e) Electricity can be produced continuously from a tidal power plant, but the produced electricity is not utilised continuously, with smaller demands at night. The excess electricity could be used for hydrogen production through electrolysis which could provide a cheap, environmentally friendly fuel for future vehicles (Charlier, 1997; Government of Western Australia, 2002; Ullman, 2002).

(f) Climate change and consequent of sea level rises will increase the ocean tidal range, thus favouring tidal power production (Salequzzaman and Newman, 2001). The higher the tidal range, the greater the energy output from any type of tidal energy technology (Baker, 1991; Day, 1994; Derby Hydro, 1999; Gray and Gashus, 1972; Middleton, 2001).

(g) Tidal power could help community economic development through increasing tourism activity and other associated income generation activities; for
example, the tidal barrage in Nova Scotia has 36,000 visitors annually (Ullman, 2002).

(h) Tidal power is attractive to oil importing nations, because it will decrease or eliminate the need for fossil fuels and associated greenhouse gases (table 4.1) (Newman, 2000). Therefore it will help in the implementation of Kyoto Protocol principles, such as the clean development mechanism (CDM) and the UNCED69 commitments (Mashishi, 2002; Pew Center, 2002). Tidal power can also help some nations previously dependent on oil to achieve energy security by reducing their dependence on imported fuels.

Table 4.1: CO₂ emissions from fossil-fuelled electricity generation (Wind Force 12, 2002)

<table>
<thead>
<tr>
<th>Source of Fossil Fuel</th>
<th>CO₂ emissions (Tonnes/GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (various technologies)</td>
<td>751-962</td>
</tr>
<tr>
<td>Oil</td>
<td>726</td>
</tr>
<tr>
<td>Gas</td>
<td>428</td>
</tr>
<tr>
<td>Average</td>
<td>600</td>
</tr>
</tbody>
</table>

Presently two billion people lack reliable energy, most of them in remote areas in developing countries with little prospect of connecting to an electrical grid (Bala, 2003; Brinkworth, 1998). Low-cost renewable energy is the only hope (Bala, 2003; Newman et al., 1999). Tidal power could sustainably fill this gap for nations with significant tidal range (WRI, 2001; Salequzzaman, 2002).

4.3 Historical perspectives and lessons for modern tidal power development

4.3.1 Historical perspectives

Tidal power is one of the oldest forms of energy in human history. Historians reported that human beings were always interested in the potential energy from the restless tides in those areas of the world where the tides reach a substantial range. Mariano (1438 in Charlier, 1997) reported that the use of tidal energy was an integral part of the history of the sea. Charlier and Menanteau (1997), Gray and Gashus (1972), Taylor (1998) and many other scientists reported that there were many tidal power operations throughout Europe during 19th century (fig. 4.3).

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Fig. 4.3: Tidal power distribution in Europe during 19th century (Charlier and Menanteau, 1997).
CHAPTER V
Chapter V
SHRIMP AQUACULTURE IN COASTAL BANGLADESH

“Give a person a fish,
and that person will have food for a day.
Teach a person to grow fish,
and that person will have food for a life time.”
Chinese Proverb
RDV\textsuperscript{86} Technology Notes, 1998, P.3

“A failure to address the issue of the desirable speed and scale of preventative action is one of the fundamental causes of unsustainability in any system that can experience irreversibilities.”
Philip Sutton
Green Innovations Inc., Australia\textsuperscript{87}

Research Questions
(1) Is shrimp aquaculture sustainable at its current levels in coastal Bangladesh?
(2) What is the role of shrimp aquaculture in sustainable integrated coastal development in Bangladesh?

5.0 Introduction

Aquaculture\textsuperscript{88} can play an important role in supplying suitable aquatic protein for human body (Bailey, 1997; Boyd \textit{et al.}, 1998; Csavas, 1998; Verdegem \textit{et al.}, 1996). It was the world’s fastest growing food production system in the past decade with a growth rate of about 10\%/year (FAO, 1995). Worldwide, aquaculture production increased from 12 million tonnes in 1986 to 34 million tonnes in 1996 and is projected to reach 47 million metric tonnes by the year 2010 (Dar, 1999). Developing

\textsuperscript{86} RDV means Rural Development Department
\textsuperscript{87} http://www.green-innovations.asn.au/ (accessed on 14 June 2002).
\textsuperscript{88} Culture/production of aquatic organisms in aquatic medium, which have the commercial or industrial or socio-economic value. According to Food and Agricultural Organisations (FAO) (2000), aquaculture means farming of aquatic organisms including fish, molluscs, crustaceans and plants, with some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.
Asian countries including Bangladesh contribute about 90% of the world’s aquaculture production (Dar, 1999; Dewalt et al., 1996). Various forms of crustacean aquaculture have increased by 325% from 1984 to 1992, with 90% of this production in the form of marine shrimp (FAO, 1995; Stevenson, 2002). Although shrimp production has rapidly depleted the total fish stocks in coastal waters due to mainly habitat destruction, it has increased foreign exchange earnings (Pauly and Chua, 1988; Verdegem et al., 2001). Developing countries like Bangladesh have placed a high priority on coastal aquaculture (Salequzzaman, 2001). Coastal aquaculture, in particular shrimp\(^9\) aquaculture is presently an important coastal industry in Bangladesh (Thai-Eng et al., 1989). Commercial shrimp aquaculture plays an important role in the national economic development of the relevant countries which export production to meet increasing demand from the United States, Japan, and Western Europe (WTO, 2000). However this industry has come at a huge environmental cost to coastal communities and ecosystems (Salequzzaman, 2001; Yeh, 2002) because it is accompanied by mangrove destruction, loss of fishery communities and biodiversity, pollution of land and water, loss of employment activities, and even violation of human rights (Aksornkoae, 1989; Cicin-Sain and Knecht, 1998; Salequzzaman, 2001).

Shrimp aquaculture in coastal Bangladesh has increased at an average annual growth rate of 16.8% over the last ten years, contributing 36.7% of inland fish production and 25.3% of total fish production during 1993-1994 (Ali and Khan, 1993; Mazid and

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\(^9\) In this thesis, the term shrimp means both shrimp and prawn. Although in many countries including Bangladesh, the term ‘shrimp’ belong to marine/estuarine water origin and the term ‘prawn’ belong to fresh water origin. In reality, shrimp is an American usage, equivalent to prawn. However there is no scientific reason behind this terminology. According to scientific classification, the fresh water prawn is fallen into the class of Crustacea, but marine water shrimp (Penaeus monodon) belongs to the family of Penaeidae under the same order and class as the fresh water prawn. Therefore they are differentiated from the family level.
Gupta, 1995; Salequzzaman, 2001). This sector contributes nearly 4.7% of the national GDP\(^90\), 7% of the agricultural GDP, 10% of export earnings and about 80% of the country’s animal protein production (BBS, 2000). It provides full time employment for 1.2 million professional fishermen and 11 million part time fisher folks which comprise about 10% of the total population (Ali and Khan, 1993; MWR, 2001).

The seasons, climate, soil, water and cultural heritage favour commercial production shrimp aquaculture in coastal Bangladesh. Therefore it is growing rapidly in coastal Bangladesh, but it is not sustainable or profitable under its current management system (Salequzzaman and Newman, 2002; Thai-Eng et al., 1989; University of Leeds, 2000). Production efficiency is far below the optimal level (only 250 kg/ha from brackish water shrimp ghers\(^91\) which is far below from the international average). This is due to lack of practical knowledge of entrepreneurs, faulty selection of land, absence of modern methods in farming, lack of infrastructure (such as electricity supply and communication) and, lack of environmental and socio-economic facilities (Hussain, 1995; Mazid and Alam, 1995; Salequzzaman and Newman, 2002). In addition, shrimp aquaculture in its current form decreases ocean and coastal biodiversity through destruction of mangroves and wetlands, colossal loss of aquatic flora and fauna during wild shrimp seed collection and over exploitation of fresh water apple snails for shrimp feed (BCAS, 1999; Bhatta and Bhat, 1998; Chowdhury, 1988). There are other socio-economic and cultural problems including various conflicts between coastal land-use patterns (Ali and Khan, 1993; Anon, 1995;

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90 Gross domestic product. GDP is defined as the market value of all goods and services produced in a year of a country.
91 A gher is a coastal pond inside the coastal embankment of Bangladesh.
Uddin and Islam, 2000). Mangrove ecosystem has been destroyed to the extent that native bird life has vanished, and grazing fields with herds of cattle and goats have disappeared from coastal area (Ali and Khan, 1993; ESCAP, 1988; Salequzzaman, 2001). Consequently shrimp aquaculture has come under close scrutiny by environmental activists, donors and policy makers, and placed in ‘Amber-B’ category under the Environmental Conservation Act of 1997, so that it requires a detailed re-examination of the Initial Environmental Examination (IEE) (ECA, 1997). The situation is so bad that the Environment Minister of Bangladesh\(^92\) commented in a workshop in July, 1999 that:

“the country has been paying high ‘for indiscriminate shrimp culture’, ignoring its adverse impact on nature... which is affecting the profitability of the industry itself”.

Many scientists and researchers have recommended that modern methods of shrimp aquaculture (such as electric aerators) could increase per hectare production from 1000 to 1200 kg and could release a significant portion of existing coastal land for other land-use such as agricultural production\(^93\) (Corry and Newman, 2000; ISTP, 1999; Salequzzaman and Newman, 2002). The modern scientific system will also reduce environmental degradation and adapt the traditional and environmentally friendly ‘Bheri Fish Culture’\(^94\). Again, this scientific aquaculture could improve the socio-economic and environmental situation, if it was integrated into coastal land-use management and potential tidal energy production (Salequzzaman and Newman, 2002) which I will discuss further in Chapter VI. However coastal co-management

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\(^{92}\) Mrs. Sajeda Chowdhury was the Environment Minister of Bangladesh from 1996 to 2000.

\(^{93}\) Activities in Fisheries and Marine Resource Technology Discipline, Khulna University, A lecture by Dr. M. S. Shah, Professor and Head, Fisheries and Marine Resource Technology Discipline, Khulna, Bangladesh.

\(^{94}\) Traditional nature based fish aquaculture in Bangladesh.
will require active cooperation from shrimp farmers, the local community and all relevant coastal stakeholders to ensure its long-term sustainable development.

This chapter of the thesis will discuss past and present practices of shrimp aquaculture in coastal Bangladesh, and examine their sustainability by analysing environmental, economic, social and cultural points of view. The chapter will also identify the factors that are vital for the sustainability of present shrimp aquaculture operations. Finally the chapter will focus on how improved modern technology including the supply of electricity could reduce detrimental impacts on the environment.

5.1 History and development of shrimp aquaculture in coastal Bangladesh

‘Mache Vathe Bangali’ is a famous proverb in Bangladesh. The meaning of this proverb is: fish and rice are main components of Bangladeshi food. These two components are integrated with Bangladeshi culture, community and society including coastal community in such a way that these two things can not be separated from each other. Therefore the history and development of coastal Bangladesh are directly linked with fish including shrimp, because shrimp is generally recognised as fish by the common Bangladeshi for thousands of years. The following sections will now discuss on these aspects.
5.1.1 History

Traditionally, edible fish and other aquatic species were cultivated in fresh, coastal and marine waters in the ‘backyard fish pond’ of a family house and/or at rice and shrimp\(^{95}\) culture canals/lowland areas in Bangladesh and other South-East Asian countries like India, Vietnam and Thailand. In Bangladesh, this is known as ‘Bheri Fish Culture’. It produces low fish yields for family consumption, but was sustainable historically. This long-standing sustainable tradition is now being rapidly transformed into more productive, commercially oriented, improved-extensive and/or semi-intensive or intensive aquaculture practices that are causing severe environmental problems in coastal regions and the rest of the country.

‘Bheri Fish culture’ was in existence for centuries in Satkhira where fishermen encircled chunks of land with dwarf dykes constructed with small canals and wooden sluice gates that connected with tidal rivers or khal\(^{96}\). Traditionally both shrimp and prawn were much cheaper than fish in the local market and were not considered as an attractive food item by Bangladeshis. Tidal water carried juveniles of salt-water shrimps such as *Peneaus monodon* (Bagda Chingri), *Metapeneaus monoceros* (Horina Chingri), *Peneaus indicus* (Chaka Chingri), fresh water prawn *Macrobracium rosenbergii* (Golda Chingri), and other finfish to the enclosures during spring tides from February to April. The trapped young shrimps, prawns and finfish were then reared for about four months before they were harvested for marketing. At the onset of the monsoon, the land within the dykes was repeatedly washed with rain and so became suitable for growing local Aman rice from July to December.

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\(^{95}\) In this traditional system, rice grows in the specific season of the year and, shrimp and other fishes cultures on rest of the year.

\(^{96}\) A narrow and comparatively shallow sub-branch of the branched river.
The tradition of Bheri Fish Culture came to an end with the construction of the coastal embankment in the late 1960s. The coastal embankment was built mainly for protection of coastal peoples from natural calamities like cyclones, tidal surges and other disasters. However it caused damage to ocean and coastal resources through habitat destruction, waste disposal, exotic species and pathogen invasions, and depletion of wild biodiversity by collection of wild seed stock for shrimp aquaculture (Gain, 1998). Since the construction of the embankment, many coastal mangroves and wetlands have been transformed into shrimp ponds without any proper planning and environmental assessment (Khan-Hasan, 2001). As a result, a large mangrove in the Chittagong region, known as ‘Chokoria Sundarbans’\(^97\) has been lost forever (Acharya and Kamal, 1994).

Coastal shrimp aquaculture has rapidly expanded and enhanced the overall fisheries development effort in coastal Bangladesh. However, the average yield per hectare is still very low compared to other countries (Karim and Aftabuzzaman, 1999; Rahman, 1992). In the early 1970s, Bangladesh entered the world export market for shrimp export. Since that time, shrimp has become a very high-priced commodity thanks to some far-sighted entrepreneurs who began to look at coastal aquaculture and harvesting marine shrimp by trawling. However shrimp aquaculture has proved more rewarding than marine capture due to the turbulent nature of the Bay of Bengal, the wide fluctuations of tide and salinity, and the absence of any sheltered places. As a result, more and more coastal areas have been brought under brackish water coastal aquaculture and more people have been engaged in shrimp\(^98\) farming without any

\(^97\) Once Chokoria Sundarban was an unique coastal natural mangrove ecosystem in Chittagong region of Coastal Bangladesh, but presently it is almost extinct.

\(^98\) In this context, shrimp refers to both shrimp and prawn.
long-term environmental, economical and socio-cultural consideration. In this way, shrimp aquaculture has been a ‘Silent Revolution’ in coastal Bangladesh and many entrepreneurs quickly became multi-millionaires.

From 1970s to 1980s, these shrimp ponds were large, shallow, very poorly constructed and not scientifically prepared for aquaculture practices. A lot of predator fish and aquatic organisms entered the ponds with tidal water, as they were not eliminated by poisoning or screening. Some of the ponds became salinised, particularly in Khulna region because of the prolonged inundation by saline water. As a solution, some innovative farmers commenced paddy and fish cultivation by stocking fresh water prawns (*Macrobrachium rosenbergii*) in modified ponds during 1980s (Chapman and Abedin, 1998). The modification includes a trench that is covered by an outside dyke, which occupies up to half the area of the rice field. This is known as a ‘gher’ (fig. 5.1).

![Fig. 5.1: An Ideal/model gher in Khulna region of coastal Bangladesh.](image)

During the 1990s, gher technology soon evolved into a rotational cropping system of prawn and fish cultivation in the rainy season followed by a crop of boro rice (winter rice) in the winter season. After 1990, rotational gher technology expanded very rapidly at the household level in most coastal areas due to the high economic value of
shrimp, produced with paddy, other fish species and a variety of crops grown on top of the dykes (fruit, vegetables and trees) (Nabi et al., 2000). Generally the gher farmers stock post-larvae or juveniles in the months of April to June and harvest shrimp in November to December. In the initial stage of gher aquaculture, most farmers did not prepare their ghers before stocking with post-larvae, so production levels were low due to predators and the low natural fertility of the water. Theft also was becoming a problem. Later, guard shelters were constructed and some dried tree branches or bamboo poles were placed in the gher water to protect against poaching as well as to create shelter for prawns. Farmers initially stocked post-larvae directly into the gher at high densities, with no separate nursery area, which resulted in low production due to high mortality. To overcome this problem, the farmers started to feed the shrimps with the meat of a native snail (*Pila globosa*) that was harvested from the local beel⁹⁹ ecosystem (fig. 5.2) (Chapman and Abedin, 1998).

![Fig. 5.2: Destructive harvest and unsustainable utilization of apple snail, *Pila globosa* for prawn feeding (A: Snail trader carrying snail from the harvesters, B & C: Separating meat from shell).](image)

⁹⁹ Beel is a natural wetland depression, created by natural calamities like earthquakes or it is a separated portion of a dead river which may dry in summer season.
This system of feeding pollutes the gher water and results in high mortality of PL due to excessive and unsustainable use of inputs (feed and seed), which increased production costs. However this type of gher system allows for cultivation of summer and winter vegetables on the dykes. The system has evolved into a rotational integrated farming system which has doubled profits for small-scale farmers and reduced their exposure to the risk of disease, floods and other unplanned events. Presently 15,000 of this type of small-scale gher farms are present in Khulna region; they are created local economic benefits, and earned foreign exchange (Williams, 2001).

The above developments took place in the private sector with very little input from the government initially. The contribution of coastal shrimp aquaculture to the economy of Bangladesh has officially been recognised since 1980, when the Government declared this sector a high priority in the first year of its Second Five-Year Plan. Since then, various organisations, such as FAO/SIDA (Food and Agricultural Organisations/Swiss International Development Authority), Bay of Bengal Program, the First Aquaculture Development Project of ADB (Asian Development Bank), the Shrimp Culture Project of IDA (International Development Authority), the Second Aquaculture Development Project (ADB) and the Third Fisheries Project (World Bank) have been started to improve traditional shrimp aquaculture technology. New technology introduced includes nursery rearing of post-larvae and selective stocking, pre- and post- stocking pond preparation (by drying, liming and fertilisation), pest eradication and screening of water before it enters the pond and post-harvest care. In the recent past, shrimp aquaculturists have also started pond water management through large-scale awareness and training programs that include techniques of ensuring adequate natural food production in the pond;
maintaining appropriate levels of oxygen, pH, temperature and salinity; sampling and monitoring of water quality; data management of input raw materials, growth rate, yield and sale information; and data analysis for future improvement of aquaculture operations (BBS, 2000; Karim and Aftabuzzaman, 1999).

5.1.2 Current practices

In Bangladesh, commercial brackish water shrimps, such as Bagda (*Penaeus monodon*) and the white shrimp (*P. indicus*) expanded from 20,000 ha in 1980 to over 140,000 ha in 1994 (Karim and Aftabuzzaman, 1999). While gross production has increased, production per unit area is still very low, being 100-150 kg/ha in traditional extensive systems and about 250-350 kg/ha in improved extensive systems (FRI, 1994). Semi-intensive culture through higher stocking of PL, supplementary feeding, aeration and water exchange has indicated productions of 2,500 kg/ha (Karim and Aftabuzzaman, 1999). Dev (1998) has summarised the present shrimp aquaculture systems in the coastal regions of Bangladesh (table 5.1).

According to my analysis, the present coastal shrimp aquaculture systems of Bangladesh can be divided into the following categories.

(a) **Extensive system:** In extensive shrimp aquaculture, the coastal inhabitants make dykes or embankments along the estuaries and rivers, and allow entry of seawater along with shrimp fries and juveniles into their ponds. Shrimp grows there under natural conditions without any supplementary feed and any further stocking of fish or shrimp fries. As a result, the production of shrimp yield is very low and varies from 150 to 200 kg/ha (Das, 1992; Miah, 1993). Approximately 25% of the total shrimp culture area or 28,000 ha land is under this category. Karim and
Aftabuzzaman (1999) estimate that about 75% of the total cultured area falls into the extensive type.

Table 5.1: A comparative analysis of different coastal shrimp aquaculture systems in Bangladesh (Dev, 1998).

<table>
<thead>
<tr>
<th>Aquaculture System Characteristics</th>
<th>Traditional</th>
<th>Extensive</th>
<th>Improved Extensive/Semi-intensive</th>
<th>Intensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pond size</td>
<td>5 – 10 ha or larger</td>
<td>5 – 10 ha or larger</td>
<td>1 – 10 ha</td>
<td>&lt; 1 ha</td>
</tr>
<tr>
<td>Pond dykes</td>
<td>Low, ordinary</td>
<td>Low, ordinary</td>
<td>Strong</td>
<td>Designed, strong</td>
</tr>
<tr>
<td>Water control</td>
<td>No/ordinary, wooden gates</td>
<td>Ordinary, wooden gates</td>
<td>Strong concrete sluice</td>
<td>Strong concrete sluice</td>
</tr>
<tr>
<td>Design &amp; layout</td>
<td>None</td>
<td>Little or none</td>
<td>Planned</td>
<td>Well-planned &amp; designed</td>
</tr>
<tr>
<td>Technical manpower</td>
<td>Experience based</td>
<td>Experience based</td>
<td>Present</td>
<td>Present &amp; required</td>
</tr>
<tr>
<td>Fry source</td>
<td>Wild</td>
<td>Wild</td>
<td>Wild/imported</td>
<td>Wild/imported</td>
</tr>
<tr>
<td>Water management</td>
<td>Little or none</td>
<td>Occasional tidal exchange</td>
<td>Tidal exchange, pump &amp; aeration</td>
<td>Reservoir, pump, filter, wheels</td>
</tr>
<tr>
<td>Culture period</td>
<td>4 – 6 months</td>
<td>4 – 6 months</td>
<td>3 – 4 months</td>
<td>3 – 4 months</td>
</tr>
<tr>
<td>Crops/year</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>2 – 3</td>
<td>2 – 3</td>
</tr>
<tr>
<td>Feed used</td>
<td>Natural</td>
<td>Natural, little low cost feed</td>
<td>Natural &amp; pelleted feed</td>
<td>Formulated complete feed</td>
</tr>
<tr>
<td>Survival rate</td>
<td>50% or less</td>
<td>50% or less</td>
<td>60 – 70%</td>
<td>70 – 80%</td>
</tr>
<tr>
<td>Lime used kg/ha/yr</td>
<td>Little or none</td>
<td>&lt; 100</td>
<td>200 – 400</td>
<td>500 +</td>
</tr>
<tr>
<td>Fertilisers used kg/ha/yr</td>
<td>Little or none</td>
<td>Cowdung 500, little or no urea/TSP</td>
<td>Cowdung 2000 +, Urea 300 +, TSP 100 +</td>
<td>Cowdung 4000 +, Urea 500 +, TSP 200 +</td>
</tr>
<tr>
<td>Chemicals</td>
<td>None</td>
<td>None</td>
<td>Used</td>
<td>Widely used</td>
</tr>
<tr>
<td>Production kg/ha/yr</td>
<td>20 – 100</td>
<td>100 – 500</td>
<td>1000 – 3000</td>
<td>2000 – 5000</td>
</tr>
<tr>
<td>Labour days/ha/yr</td>
<td>50 – 100</td>
<td>150 – 250</td>
<td>1000 – 1500</td>
<td>2000</td>
</tr>
<tr>
<td>By-product</td>
<td>Salt, fish, rice</td>
<td>Salt, fish, rice</td>
<td>Occasionally fish/crab</td>
<td>Occasionally fish/crab</td>
</tr>
<tr>
<td>Acclimatisation of fry</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Done</td>
<td>Done</td>
</tr>
<tr>
<td>Manpower</td>
<td>Untrained</td>
<td>Untrained</td>
<td>Trained</td>
<td>Trained</td>
</tr>
<tr>
<td>Economics</td>
<td>Subsistence</td>
<td>Subsistence</td>
<td>Commercial</td>
<td>Entrepreneurial</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>None/little</td>
<td>None/little</td>
<td>Moderate to high</td>
<td>High</td>
</tr>
</tbody>
</table>

The production cost of this extensive culture system is low. The land under extensive coastal shrimp aquaculture increased from 51,812 ha in 1983-84 to 108,280 ha in 1988-89, and then remained almost static till 1992-93 (Salequzzaman, 2001). Total production of shrimp yield of the extensive system increased from 4,386 tonnes in 1983-84 to 260,000 tonnes in 1992-93. The average production was still only 240 kg/ha in 1994, but slightly increased to 243 kg/ha in 2002 (Haque, 2003; Hussain, 1994). In 2001, approximately 142,397 farms cultivated shrimp with an average farm size of 4.5 hectares where production growth rate increased by 20% per annum in the last 15 years (Haque, 2003). In most cases, the average size of pond in an extensive system is very large, therefore it is unmanageable and less productive. In addition, more than 90% of this land is leased by outside entrepreneurs who have money and
power (GOB, 1999). Multiple ownership is one of the important problems for the management of this land type. Presently coastal shrimp aquaculture of Bangladesh is managed by one of the following categories (fig. 5.3) (Alauddin and Tisdell, 1996):

(a) Single or household operations on their own land using their own or domestic labour;
(b) Single control on owned or rented land using hired labour;
(c) Multiple owners, all or most of whom participate in, and hence control, the farming operations;
(d) Small number of owners and local people who farm shrimp on land which is partly owned and partly rented; or
(e) Outsiders who control shrimp farming, using rented land and hired labour.

Fig. 5.3: Ownership and control of coastal shrimp aquaculture in Bangladesh (Alauddin and Tisdell, 1996).
Presently 76-95% shrimp farms in Khulna region and 35-53% farms in Cox's Bazar region have multiple ownership (FRI, 1994).

The land-use pattern of this extensive shrimp aquaculture system is now gradually improving with the introduction of the following methods:

i. **Monocrop**\(^{100}\) *Peneaus monodon (Bagda) cum salt production*: In many parts of the Cox's Bazar area, water salinity levels are too high (above 25 ppt\(^{101}\)) for Bagda aquaculture during the dry season (December-April). In this situation, local farmers now produce salt in the dry season.

ii. **Improved extensive system**: Sometimes the extensive shrimp aquaculture is managed by drainage systems through occasional water pumping, and/or supplementary feeding and adding shrimp fry, with production reaching up to 1000 kg/hectare (Karim and Aftabuzzaman, 1999; Salequzzaman and Bhuiyan, 2000).

(b) **Semi-intensive/intensive aquaculture**: Semi-intensive shrimp aquaculture is limited to only a few areas in coastal Bangladesh. With this method, it is possible to produce 5-6 tonnes of shrimp/hectare within 4-5 months (ESD, 2000). The characteristics of this aquaculture system are high stocking rates (25-60 m\(^2\)), heavy artificial feeding, pumping of water and using aerators for water oxygenation (Salequzzaman, 2001). In 1994, 36 shrimp farms covering an estimated area of 700 ha in Cox's Bazar were started as semi-intensive shrimp aquaculture systems. In that year, most of the farms suffered from mass mortality of shrimps through the new introduced disease called white spot syndrome. The same disaster also

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\(^{100}\) Only one yield annually.

\(^{101}\) Parts per thousand.
occurred in subsequent years. Later, scientific investigation found that unplanned and uncontrolled management with high intensity shrimp fry input in these farming systems were the main causes for mass shrimp mortality (Dev, 1998; Khor, 2002; Wheaton, 1977a). Adequate tidal inundation, pumping, feeding, aeration and a stocking density of 7-15/m² could improve this situation and increase production up to 2,300-4,500 kg/ha (Karim and Aftabuzzaman, 1999; Salequzzaman and Bhuiyan, 2000).

(c) **Polyculture of shrimp and finfish:** In this system, shrimp and finfish aquaculture can be accomplished at the same time in the same pond. It is an excellent system of brackish water aquaculture which has been practised in some semi-intensive shrimp aquaculture farms in coastal Bangladesh, such as Gazi Fish Culture Ltd. of Khulna. In this system, finfish species such as mullet and catfish are cultured with shrimp. This gives a better economic benefit with less capital-intensive production and less risk, because the shrimp are not natural prey species for the finfish.

(d) **Aquaculture of non-traditional species:** Besides shrimp and finfish, there are some potentially commercially viable and economically important non-traditional species such as mud crab (*Scylla serrata*). Mud crabs have a high export potential and could be farmed in coastal mangrove swamps, mud flats, creeks and other such locations. The trials utilising mud crab are currently being conducted by the Bangladesh Fisheries Research Institute (BFRI) at Paikgacha and in some other locations of Khulna and Satkhira.

(e) **Development of hatchery technology:** Seed is the main input for any aquaculture operation. Presently a major portion of the seed of bagda shrimp (*P. monodon*) is
collected from natural resources. However, the availability of seed from nature is declining, erratic and unreliable if exploited continuously. Post-harvest mortality is also high due to crude collection and transportation systems where biodiversity is adversely affected (FRI, 1994; Salequzzaman, 2001). Therefore the development of an appropriate shrimp hatchery (both for *P. monodon* and *M. rosenbergii*) is a prerequisite for the coastal shrimp aquaculture industry. Presently several shrimp hatcheries exist in the Cox’s Bazer and Khulna regions, but some hatcheries have already ceased their production due to uncertainty of electricity supply and lack of adequate salinity levels.

5.1.3 Positive consequences of aquaculture in Bangladesh

(a) Increases of foreign currency in Bangladesh: Bangladesh contributes around 5% to total global cultured shrimp production (BBS, 2000). The total marine and brackish waters shrimp production in 1994-1995 was 53,948 tonnes of which 30,503 tonnes came from coastal aquaculture (Karim and Aftabuzzaman, 1999). Export of 26,277 tonnes of shrimp earned US$ 326 million in 1994-95 which is equivalent to 10.36% of the total national export earnings (BBS, 2000). The growth rate of shrimp exports has risen by $4.9 \times 10^3$ times over the last two decades, putting it third after ready-mate garments and knitwear, then jute and jute products in terms of economic importance (Karim, 2000). The major markets for shrimp are USA, the EEC, Japan and Germany (Salequzzaman, 2001). Although Bangladesh has an opportunity to export more shrimp to foreign countries, it is not able do so, because the development of the coastal shrimp aquaculture industry has outgrown the supply capabilities of imported shrimp larvae and its feed. Local production of these inputs is inhibited by lack of
infrastructure including electricity supply in the remote coastal Bangladesh (Cooksey, 1995; Salequzzaman and Bhuiyan, 2000).

(b) **Trends in the shrimp industry in coastal Bangladesh:** Shrimp aquaculture has become a major industry in coastal Bangladesh. This sector has been steadily increasing in terms of area under cultivation, entrepreneurial involvement, associated with industries and manpower usage. The growth rate of this sector is illustrated in graph 5.1. Well over 200,000 people are directly employed in coastal shrimp aquaculture (BBS, 2000). This sector has also led to the establishment of various rural-based cottage industries which provide materials such as bamboo screens, cages, traps, baskets, mats, nets, wooden sluices, rickshaw vans, and boats (Masae and Rakkheaw, 1992).

![Graph 5.1: Trends of Shrimp Production in Bangladesh.](image)

**5.2 Concept of sustainable aquaculture**

Sustainable aquaculture is one of the essential foundations for rural development in most of the world, particularly in developing countries like Bangladesh. Sustainability
requires that systems are: environmentally sound, financially and economically feasible, and socially acceptable. Many factors influence the sustainable aquaculture system. This section and consecutive sections of this chapter will discuss these aspects.

5.2.1 The definition

After the definition of sustainable development in WCED (1987), the concept of sustainable aquaculture has been defined by the Food and Agricultural Organisation (FAO) in 1991. According to FAO, sustainable aquaculture is the management and conservation of the aquatic natural resources, and the orientation of technological and institutional development in such a manner as to ensure the attainment and continued satisfaction of human needs (such as food, shelter, etc) for present and future generations (FAO, 1991; FAO, 1997; FAO, 1998; and FAO,1998a). Many scientists and researchers (such as Barg et al., 1997; Braaten, 1997; Chien and Liao, 1998; Edwards, 1997; Hambrey, 1996; Liao, 1998; Surtida, 1998) mentioned that sustainable aquaculture conserves land, water, and plant and animal genetic resources, and produces the aquatic foods in such a way that is technically appropriate, environmentally friendly, economically viable, and socially acceptable. Braaten stated that:

"Sustainable aquaculture is a means to profitable aquatic production, efficiency of natural resources, best aquatic environmental practice and a way forward to keep pace with world aquaculture consumption without compromising the overall ecological integrity of ecosystems (Braaten, 1997, p.9)".

The sustainable aquaculture should have two inter-linked components - a best management component in terms of technology, economics, social and cultural perspectives, and an integrated approvals component (Briggs, 1994; Briggs and Funge-Smith, 1994). The best management component requires the best
environmentally balanced ecological management of aquaculture industry; and the integrated approvals component calls for the highest possible integration among maximum coastal resources for the well being of human society, nature and future generations (Chou et al., 1991; Folke and Kautsky, 1992; Rajendran and Kathiresan, 1996). These two components could work interdependently through community consultation processes i.e., through community participation, and proper socio-cultural, environmental and technical assessment and optimisation with the society’s need.

5.2.2 The objectives

The major objectives of sustainable aquaculture are twofold. Firstly, to develop environmentally friendly practices in marine, coastal estuary and land-based aqua farms, i.e., through the best management practices (Rajendran and Kathiresan, 1996); and secondly, to make the industry sustainable in the long-term i.e., through the integrated approvals (Liao, 1998; Salequzzaman, 2001; Thai-Eng et al., 1989). The specific objectives are (Salequzzaman, 2001; Tiro et al., 1986; Wickins, 1986):

a. To increase the aquatic food supplies of the rapidly increasing population of the world with mutual understanding of environment, economic, social and cultural aspects for the creation of a business climate and technological base for aquatic industry;

b. To develop the aquaculture technologies and methods both to improve production and safeguard the environment;

c. Enhance depleted wild fish stocks through aquaculture, thereby increasing the value of both commercial and recreational landings and improving the health of our aquatic resources;

d. To strengthen the technology dissemination and support services to aquaculture sector, particularly to the poor fish farmers; and
e. To blend innovation, research, conservation and educational awareness into a common goal of aquatic sustainability and demonstrate this through a successful commercial enterprise.

5.2.3 The process

Sustainable aquaculture practice depends on the species being cultivated and the location of cultivation. A technique that may be sustainable with one species is not necessarily sustainable with another species, or even with the same species at a different location. However the concepts that lead to sustainability are common in every practice. These include the need to determine the carrying capacity of the water body, that is, how much the farm can sustainably produce (Platon, 2002). Once the carrying capacity is determined, appropriate farming techniques have to be selected to ensure that relatively little negative impact will occur on its surrounding environment. One way to attain a sustainable aquaculture system is to create a small ecosystem, with a variety of species being harvested. This practice is called polyculture; the practice of culturing only a single species is called monoculture. Ideally the populations of the species in a polyculture should be arranged so that many of the nutrients introduced into the system are recycled among the organisms, thus reducing nutrient waste and pollution. One such example of polyculture is growing seaweed (phytoplankton, algae or aquatic plants) or oysters/snails along with another fish species. The seaweed and oysters/snails will act as a filtration system, utilising the wastes of the fish, which would otherwise be released into the surrounding environment, resulting in nutrient pollution. This increases the efficiency of the system, while minimising the impact of the farm on the environment, increasing production and profitability in the long term (Platon, 2002; Salequzzaman, 2001; Verdegem, 2001). There are other numerous small changes, which could be
implemented for sustainable aquaculture. One such change is the implementation of settling ponds where wastes and nutrients are collected and filtered out of the water before it is discharged back into the environment. This will help to reduce the pollution and eutrophication that afflicts waters surrounding aquaculture projects.

As mentioned before, sustainable aquaculture will be possible when it integrate the community through a community consultation process. This community consultation process will involve various groups of society including fishermen, indigenous peoples, poor farmers and others. Therefore the process will identify the foot-print of the society and integrate it into the main process. In this way, the society or community peoples will get significant benefit socially and environmentally from the sustainable aquaculture process.

5.3 Factors responsible for unsustainable shrimp aquaculture in coastal Bangladesh

According to the definition of sustainable aquaculture, the existing shrimp aquaculture in coastal Bangladesh is not sustainable, because the existing coastal shrimp aquaculture system has impacted regularly on socio-economic, environmental, ecological and cultural aspects of the region (Salequzzaman, 1989, 2001, Salequzzaman and Bhuiyn, 2000; Salequzzaman and Newman, 2002). The following factors will clarify why the present coastal shrimp aquaculture industry in Bangladesh is unsustainable.

5.3.1 Environmental and ecological factors

(a) **Irreversible land development**: Conversion of Bangladesh coastal low-lying lands to shrimp ponds/ghers can be characterized as non-trivial
irreversibility (Krutilla and Fisher, 1975), because the mitigation of attendant environmental impacts is either technically unfeasible or uneconomical. The term ‘irreversibility’ applies to this development for several reasons. Most importantly, once excavated and converted to shrimp ponds/ghers, the coastal environments are not easily restored to their natural state or function. Continued storage of salt water in shrimp ponds alters the chemical properties of the pond soil, making it unsuitable for crop production in the future. The ultimate danger of this irreversibility arises if and when the development reaches a point where shrimp production itself becomes unprofitable and, thus, even the management value fades away. Furthermore, shrimp is not an efficient converter of feed (Macintosh and Phillips, 1992) and, therefore, in commercial shrimp ponds, as much as 77.5% of nitrogen and 86% of phosphorous compounds in the feed are wasted (Bhatta and Bhat, 1998). This waste either accumulates in the sediment within the shrimp ponds, or is discarded to the environment (Csavas, 1995) and, over time, the shrimp lands can become unproductive for crops, and a source of runoff water contamination because of the build-up of nutrients (Sagoff, 1985). For example, recently many shrimp farms in coastal Bangladesh have been closed down due to the ‘China Virus’\textsuperscript{102}. In the ‘China Virus’ disease affected area, many farmers have no alternative but to restore their farm to its original status immediately, because the farms have lost their management and preservation values.

(b) **Change of flooding regime in coastal low land:** The Bangladesh Water Development Board (BWDB) started constructing the coastal embankment in 1958 to protect coastal people and their agricultural land from natural calamities including flood (fig. 5.4) and saline water. In the initial stage of construction, BWDB banned the entry of saline water into the polders\textsuperscript{103} from its canals along the embankment sides.

\textsuperscript{102} The disease of China Virus affected shrimp and other aquatic fauna is an epidemic in Bangladesh since 1990s. The disease is called as ‘white spot disease’, which is identify by ulcer in several part of the body. The origin of this disease is from China, but the disease has also been found in almost all South-East Asian Countries.

\textsuperscript{103} Ponds surrounded by embankment.
But later that embargo was broken and many shrimp farmers in Khulna and Satkhira districts set up shrimp aquaculture in the polders utilising saline water (fig. 5.5).

Presently, coastal shrimp farmers illegally alter the original structure of the embankment to change the flooding behaviour of coastal low land (MPO, 1990). This activity has also impacted on coastal aquatic systems, agriculture, fisheries,
navigation, salinity control, and water supply. For example, 814,000 ha of coastal floodplains have been destroyed since 1985, and 110,000 tonnes of finfish harvest are lost every year from the floodplain area (Jhingran, 1983; MPO, 1987).

(c) **Deforestation including mangrove destruction:** Coastal Bangladesh supports about 587,400 ha of natural mangroves and a further 24,120 ha of planted mangroves (Mahmood, 1986). However, almost 50% of this mangrove has been destroyed through unplanned and unsustainable coastal embankment construction and the subsequent increase of coastal shrimp aquaculture (Salequzzaman and Bhuiyan, 2000). Mangroves provide an important habitat, protection from natural disasters and nutrients for numerous fish, bird, mollusc and crustacean species. Therefore destruction of mangroves and other deforestation will destroy the coastal livelihood and ecosystem of many species (Mahmood *et al.*, 1994). For example, the abundance of shrimp post-larvae and juveniles are diminishing due to massive destruction of the mangrove Sundarbans (Salequzzaman, 2001). The worst destruction has occurred in Chakaria Sundarbans\(^{104}\), Cox's Bazar, through the expansion of shrimp aquaculture (Mahmood, 1995). In setting up shrimp aquaculture, influential persons forcibly occupy coastal lands and mangrove forests and later destroy them (20-30% of government khas\(^{105}\) lands are occupied by ‘influential persons’ from Teknaf) (Gain, 1998). This process of land acquisition creates conflicts between various land users (Das, 1992; Salequzzaman and Bhuiyan, 2000).

\(^{104}\) A mangrove on the banks of Maheshkhali channel and other rivers of Cox’s Bazar, Bangladesh.  
\(^{105}\) The land has no owner; it belongs to the government.
(d) **Salinisation of soil and water:** Freshwater flow and tidal action are two principal physical processes for controlling salinity penetration in coastal Bangladesh (Rahman, 1993). Saline water density is 1,028 kg/m$^3$ or 28 kg greater than that of freshwater (BIWTA, 1999; Salequzzaman, 2001). The introduction of shrimp aquaculture in the form of shrimp gher has created a barrier to tidal action resulting in prolonged inundation by saline seawater, which has, in turn, caused the soil to become salt affected. Thus the present coastal shrimp aquaculture activities increase the soil and water salinity of the region, particularly during the dry season (Hussain and Acharya, 1994; Rahman, 1993). As soil salinity has increased, coastal agricultural production has decreased, due to a decrease in the size of fresh water bodies, diminishing healthy fields and forests, and stunted tree growth (Hussain and Acharya, 1994). In the summer of 1997-1999, groundwater samples from Bagerhat and Gopalgonj districts indicated that wells closer to shrimp ponds/ghers were highly saline, with levels as high as 34% (1gm/kg) in the well located within a distance of 3.00 m from the shrimp pond. Another study estimated that the loss of potable water at 360 m$^3$ per hectare of shrimp pond every year (NEERI, 1995). The higher osmotic pressure of saline soil prevents adequate absorption of moisture and nutrients. Therefore the soil can no longer sustain the growth of many crops like lentils, mustard, coastal vegetables such as lalshak, pointed gourd, kakrol, balsam apple, snake gourd, ginger, cauliflower, cabbage, brinjal, lady's finger, onion, garlic, betel leaf and fruits like pineapples, jack fruit and banana (Karim and Aftabuzzaman, 1999). In addition, seasonal rice varieties such as Aus, Aman and Boro, maize, wheat, chickpeas, groundnuts and jute are all adversely affected by the shrimp industry (Salequzzaman, 2001).
(c) **Colossal loss of biodiversity:** Unplanned and unscientific methods of coastal shrimp aquaculture in Bangladesh have been destroying and drastically reducing the indigenous fish species and many flora and fauna of mangrove species (Menasveta, 1999; Muir and Beveridge, 1987). In the absence of adequate functional and productive shrimp hatcheries in coastal areas, the Sundarbans and other coastal shores are the sole natural source of shrimp fry for the industry. Poor local people collect shrimps fry and juveniles and causes colossal destruction of coastal aquatic flora and fauna as a result of bi catch (fig. 5.6). In addition, the number of fish year-classes is declining, leading to year-to-year variability of stock size (Ong, 1982; Surtida, 1998).

**Fig. 5.6:** Collection of shrimp fry by using different gears and water vehicles, and destroying other fisheries (A: Young boy entering Sundarbans Mangrove forest of Bangladesh to collect shrimp fry for shrimp farming; B: Gears and vehicles used in shrimp fry collection; and C&D; Colossal loss of fisheries by mass-scale fishing using current net\(^{106}\).)

\(^{106}\) Net by using invisible monofilament of nylon.
It is estimated that 70-73% of other shrimp larvae and 24% of finfish larvae have been destroyed during the collection of a mere 3% of targeted *P. monodon* larvae from the waters of the Sundarbans (Chowdhury, 1988; Hussain and Acharya, 1994). In another statistic, some 200 billion fish fry are destroyed in the course of gathering two billion shrimp fry from coastal water (Dewalt *et al.*, 1996; Salequzzaman, 2001). Acharya and Kamal (1994) stated that 641 species of other shrimp larvae along with 73 species of white fish and 1670 species of micro and macro zooplankton are destroyed for the collection of one tiger shrimp (*Peneaus monodon*) larvae from the coastal Khulna region.

(f) **Over-fishing of shrimp fry:** Over-fishing of shrimp fry and juveniles ultimately reduces the availability of mother shrimp in the long run (Johnson, 2001). Presently thousands of fishermen catch uncontrolled amounts of shrimp fry, using the local nets (such as current nets, dragnet, Pata Jal\(^{107}\), Thela Jal, mosquito net, behundi nets and other such devices) in the Bay of Bengal and other coastal areas during the breeding season (fig. 5.6B). This harvesting system is killing many species of shrimp and fish fry, resulting in a reduction of fish reserves (Salequzzaman, 2001; Islam and Chowdhury, 2000).

(g) **Snail exploitation and destruction of its habitat:** Fresh water apple snail (*Pila globosa*) is one of the major freshwater molluscs in Bangladesh. As the population density of any animal is dependent on the prevailing ecological factors of an area, the apple snail plays an important role in the food chain as a secondary consumer, and is a major food source for many birds, reptiles, amphibians, aquatic mammals and other animals. The snail is the major inhabitant in the beel\(^{108}\) ecosystem and has both medical and economic

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\(^{107}\) Net, locally called jal.

\(^{108}\) It is a kind of wetland that has been created by natural calamities (such as earth quack, volcano, etc) and/or from a dead river.
importance (Khalequzzamam and Wadud, 1978). In one of my previous studies, it was revealed that this snail has an important role in controlling wetland flora (through feeding) and water purification (acting as a biofilter) (Salequzzaman et al., 2000). In addition, the snail not only provides food for fish, reptiles and birds but the dead, decayed and eroded shells also act as good fertilisers for shrimp ponds. The snail population is decreasing every year (graph 5.2) due to its unplanned and unsustainable over exploitation in the shrimp industry (fig.5.2) (Huda, 2001; Ahmed et al., 2000). Consequently, it has been declared an endangered species\(^{109}\) by IUCN\(^ {110}\) Bangladesh (Salequzzaman 2001).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{snail_density.png}
\caption{Graph 5.2: Abundance of the apple snail, \textit{Pila globosa} during its hibernation period since 1990 to 1999 (Salequzzaman 2001).}
\end{figure}

\(h\) **Decline of environmental basis for renewable products:**

Presently, aquaculture is the main reason for global mangrove forest destruction,

\(^{109}\) A species in danger of extinction and whose survival is unlikely if the causal factors continue. Included are species whose numbers have declined to a critical level, or whose habitats have been so reduced that the species are considered to be in danger of extinction.

\(^{110}\) International Union for Conservation of Nature and Natural Resources, also known as the World Conservation Union.
and Bangladesh is no exception to this destructive process (Hussain, 1995). Historically, coastal Bangladesh has served as a source of renewable products such as food grains, horticultural crops, fish and shrimp. The existing coastal shrimp aquaculture has affected its physical environment on a long-term basis and this land conversion has lead to less productive agriculture. Cropland owners and prospective buyers are also forced out of competition with shrimp farmers due to the increase in irreversible land degradation (Csavas, 1995). For example, cropland in the immediate vicinity of many shrimp ponds has become completely uncultivable due to high levels of salinity (NEERI, 1995).

(i) Production of unmanageable wastes, and water and soil pollution: Unplanned and unsustainable expansion of coastal shrimp aquaculture in Bangladesh has increased water and soil pollution in and around the shrimp ghers (Salequzzaman, 2001). The organic wastes particularly from shrimp feed are now destroying mangrove forest, because the soils converted to acid sulphate conditions. This acid sulphate soil is not suitable for shrimp aquaculture (Narongrit, 1990; Ong, 1982), therefore most of these contaminated ponds have been abandoned within five years (Hussain, 1995), and mangrove forests are not readily colonised for a number of years due to the very high acidity of the abandoned ponds (Simpson and Pedini, 1985). For example, shrimps consume three times their harvested weight, whilst converting only 17% of this feed into edible flesh; each kilogram of shrimp generates 15,000 litre of effluent as excess feed, nutrients, fertilizers, dead algae, and shrimp shells (Lakshmi and Rajagopalan, 2000). According to Salequzzaman (2001), water parameters like
BOD (biological oxygen demand), hardness and some other factors increase in every step of developing the shrimp aquaculture practice (table 5.2).

<table>
<thead>
<tr>
<th>Aquaculture System Characteristics</th>
<th>Control site</th>
<th>Traditional</th>
<th>Extensive</th>
<th>Improved Extensive</th>
<th>Surroundings of Improved Extensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparency (cm)</td>
<td>21.00-31.00</td>
<td>18.00-33.00</td>
<td>21.00-36.00</td>
<td>20.00-35.00</td>
<td>20.00-150.00</td>
</tr>
<tr>
<td>DO (ppm)</td>
<td>7.20-9.00</td>
<td>5.00-16.00</td>
<td>5.00-18.00</td>
<td>5.00-11.50</td>
<td>5.00-10.50</td>
</tr>
<tr>
<td>BOD (ppm)</td>
<td>0.50-2.90</td>
<td>0.50-7.00</td>
<td>0.80-8.20</td>
<td>1.20-9.30</td>
<td>1.50-12.90</td>
</tr>
<tr>
<td>Dissolved CO₂ (ppm)</td>
<td>25.00-35.00</td>
<td>2.00-40.00</td>
<td>0.00-45.00</td>
<td>0.00-47.00</td>
<td>5.00-50.00</td>
</tr>
<tr>
<td>Total Hardness (ppm)</td>
<td>125.00-175.00</td>
<td>70.00-250.00</td>
<td>90.00-700.00</td>
<td>120.00-840.00</td>
<td>90.00-720.00</td>
</tr>
<tr>
<td>Zooplankton (x10⁴ individuals/l)</td>
<td>0.50-1.80</td>
<td>0.63-1.90</td>
<td>0.53-1.93</td>
<td>0.40-7.50</td>
<td>0.41-4.79</td>
</tr>
<tr>
<td>Phytoplankton (x10⁶ individuals/l)</td>
<td>1.10-1.40</td>
<td>0.42-1.47</td>
<td>0.30-1.75</td>
<td>0.85-2.86</td>
<td>0.21-2.00</td>
</tr>
<tr>
<td>Soil Iron (ug/g)</td>
<td>45.40-320.00</td>
<td>80.40-191.18</td>
<td>21.82-335.14</td>
<td>69.20-364.60</td>
<td>45.40-320.00</td>
</tr>
</tbody>
</table>

This pollution has had an increasingly deleterious impact on coastal shrimp farms and surrounding environments, which are in turn, detrimental to near shore water quality, natural fisheries, and human health (Pullin et al., 1993). The recent occurrence of china virus (commonly known as white spot disease) in coastal shrimp farms is one such consequence (COMPERE, 2001; ‘Prothom Alo’, May 25, 2001; Salequzzaman, 2001). Mortality rates for shrimp populations affected by this disease can reach 100% within 3 to 10 days from the onset of symptoms (O’Leary, 2001).

(j) **Climate change vulnerability:** Global warming, climate change and sea level rise will impact on the existing coastal, sea fishing and traditional aquaculture practices, in particular anadromous and catadromous fish stocks of the Bay of Bengal, (such as *Hilsa ilisha*). Upstream spawning migrations could be hampered by extensive habitat alterations associated with impoundment and
water quality deterioration with sedimentation and pollution (Brody and Hlohowskyj, 1998; IPCC, 1996).

(k) **Induction of exotic species to the native aquaculture system:** Presently, native and endemic fisheries are under stress because, since the 1980s, many exotic species and varieties have been introduced to Bangladesh through the aquaculture system. The long-term effects of the introduction of new species on the local ecosystem are not yet known. However, new species have already changed the habitat of native fisheries resources. For example, the introduction of Thai Catfish into the coastal wetlands has been associated with the decline of many small indigenous fish populations. It is assumed that the introduction of Thai shrimp fry might be a probable cause for the large-scale white spot disease in the coastal shrimp aquaculture of Bangladesh.

### 5.3.2 Socio-economic factors

(a) **Socio-economic instability of traditional coastal communities:** Signs of economic instability in communities traditionally dependent on coastal ecosystems are now evident. In a short span of five to ten years, several communities have lost their traditional livelihood. For example, labour-intensive rice production requires 350 man-days of labour per hectare whereas a shrimp farm would need only around 150 man-days of labour per hectare, with a net loss of jobs (Bhatta and Bhat, 1998).

(b) **Declining profitability of shrimp production:** The existing model of coastal shrimp aquaculture of Bangladesh has outgrown itself due to out-of-
state suppliers for seed and feeds and lack of infrastructural facilities (Anon, 1995). For example, the production of the existing system of shrimp aquaculture is only 100-400 kg/ha/year, which is among the lowest in the world (Salequzzaman, 2001), whereas semi-intensively managed shrimp farms produce more than 1,600 kg/ha/year (Asian Shrimp News, 1994).

(c) **Increased unemployment rate among local residents:** The current shrimp industry tries to promote itself as a boon to the local economies. However, its benefits go to the wealthy investors thus depriving local people of income. Because it is capital rather than labour intensive, it provides limited employment opportunities for coastal residents and most of those are typically poorly paid, seasonal and non-skilled jobs, offering no long-term job security. For example, cultivating 100 acres of land with rice employs 50 workers, but cultivating shrimp on the same land employs just 5 workers, which has resulted in the displacement of 40% of 300,000 inhabitants from Satkhira district into the country’s overcrowded cities (Salequzzaman, 2001).

(d) **High loan rates:** As most of the shrimp farmers are very poor and marginal in category, they usually depend on loan money from moneylenders with high interest rates (from 60 to 240% interest per year in Khulna and Bagerhat areas), locally known as ‘Dadon of depot malik’. These farmers generally avoid lower interest bank loans (only 15% interest rate) secured against the capital in their land because their land has joint ownership; they can not follow the complex

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111 Depot malik are the prawn and fish traders who have permanent establishment at village/Thana level to trade on, along with other business.
processes of negotiation with bank officials; and they are not aware at all about the Bank's loan system (Abedin et al., 2001). Thus the whole process of the existing loan system among the poor coastal shrimp farmers is unjust.

(e) **Social tension and conflicts between shrimp cultivation and other resource uses:** The current system of coastal shrimp aquaculture has achieved a very attractive rate of return. This has attracted entrepreneurs from urban areas who have leased coastal farmland, often forcefully, thus preventing local people from carrying out their traditional achieves. This practice is now creating social tension and conflicts between shrimp cultivators and other resource users in coastal Bangladesh (table 5.3). For example, 30% of the local people in Satkhira are the victims of this forceful occupation (Chowdhury, 1988). Poor paddy farmers cannot do anything against the forceful shrimp owners, because they are rich and have links with influential politicians or businessmen.

Table 5.3: Changes of land ownership of the coastal shrimp aquaculture farm of Bagerhat area of Khulna District (Karim, 2000).

<table>
<thead>
<tr>
<th>Categorisation</th>
<th>Land Ownership in 1975</th>
<th>Land Ownership in 1985</th>
<th>Land Ownership in 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area in Acre</td>
<td>% of Total</td>
<td>Area in Acre</td>
</tr>
<tr>
<td>Paddy Field</td>
<td>443.97</td>
<td>80.50</td>
<td>329.00</td>
</tr>
<tr>
<td>Shrimp Farm</td>
<td>0.60</td>
<td>0.11</td>
<td>139.15</td>
</tr>
<tr>
<td>Ponds</td>
<td>7.65</td>
<td>1.39</td>
<td>9.90</td>
</tr>
<tr>
<td>Canal</td>
<td>2.80</td>
<td>0.51</td>
<td>2.80</td>
</tr>
<tr>
<td>Homesteads</td>
<td>38.28</td>
<td>6.94</td>
<td>42.10</td>
</tr>
<tr>
<td>Hort. Garden</td>
<td>15.50</td>
<td>2.81</td>
<td>6.85</td>
</tr>
<tr>
<td>Fellow land</td>
<td>42.70</td>
<td>7.74</td>
<td>21.70</td>
</tr>
<tr>
<td>Total</td>
<td>551.50</td>
<td>100.00</td>
<td>441.50</td>
</tr>
</tbody>
</table>

Consequently, the irreversible expansion of coastal shrimp aquaculture has led to social conflicts over tenure and land use rights, leading to marginalisation of small rice farmers and irreparable damage to the environment and the socio-cultural ethos.
of the shrimp aquaculture areas. This trend bears all the elements of an unrealistic capitalist industry, where profit is the only consideration and the long-term effects on nature and society are totally ignored leading to deterioration in law and order in these areas (Das, 1992; Miah, 1993).

(f) Change of land use patterns: Shrimp aquaculture commenced production of shrimps without taking any account of the utility of different farm areas, such as agricultural fields, livestock production, horticulture management, etc. Therefore shrimp aquaculture has changed the traditional practices and land use patterns which are causing disputes over land ownership and creating other social problems, resulting in the ultimate decrease in production itself. For example, the intrusion of saline water with the growing shrimp cultivation in the area has destroyed the traditional plantation habitats of coastal areas. Many areas cannot produce vegetables in and around the homestead, and the intake of protein and calories has fallen sharply among the poor who are being deprived of the opportunity to catch fish or collect vegetables from traditional natural sources (table 5.4) (Rahman, 1993).

Table 5.4: Impact of coastal shrimp aquaculture on common homestead livestock population and poultry birds from 1975 to 1997 (Salequzzaman and Bhuiyan, 2000).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area in Acres</td>
<td>% of Total</td>
<td>Area in Acres</td>
</tr>
<tr>
<td>Cattle</td>
<td>315</td>
<td>24.14</td>
<td>214</td>
</tr>
<tr>
<td>Buffalo</td>
<td>83</td>
<td>6.36</td>
<td>40</td>
</tr>
<tr>
<td>Goat</td>
<td>166</td>
<td>12.72</td>
<td>128</td>
</tr>
<tr>
<td>Poultry</td>
<td>741</td>
<td>56.78</td>
<td>740</td>
</tr>
<tr>
<td>Total</td>
<td>1305</td>
<td>100.00</td>
<td>1128</td>
</tr>
</tbody>
</table>
5.4 Achieving sustainable coastal shrimp aquaculture in Bangladesh

According to the previous sections, sustainable coastal shrimp aquaculture means shrimp aquaculture should have to be sustainable at economic, social, cultural and environmental levels, and also improve the institutional capacities of coastal Bangladesh. However the current shrimp aquaculture industry is not sustainable or environmentally friendly and has caused serious problems in coastal Bangladesh. Production is also 20-30 times less per hectare than semi-intensive shrimp aquaculture which is also the lowest production compared to neighbouring countries (Hussain, 1995). To improve this situation, technological progress and modernisation of farms in terms of water supply, water distribution, water discharge or retention and aeration systems are vital (Barnabé and Barnabé-Quet, 2000; NEERI; 1995). It also necessary to ensure the availability of low cost shrimp seed from the hatchery-nursery systems while maintaining the ecologically sustainable process by using multiple species (Porter et al., 1996; Salequzzaman, 2001; Wheaton, 1977a). In addition, all relevant buildings should have heating systems\(^{112}\) by using conventional gas or electric resistance heaters (Hopkins et al., 1995; Salequzzaman, 2001; Wheaton, 1977a). Finally the whole process should be integrated in such a way that any input or output of the shrimp farm will not degrade the surrounding environment (Blomqvist, 2002; Boyd et al., 1998; Rönnbäck, 2001). To fulfil these outcomes, the following factors could be necessary for maintaining the sustainable level of coastal shrimp aquaculture in Bangladesh.

\(^{112}\) Because, hatchery system needs temperature control to hatch the egg and to develop the different stages of larvae. Heater also needs for feed preparation, such as egg custard.
5.4.1 Sustainable technology and technical systems for improved environmental outcomes

(a) **Convert the existing system to intensive shrimp aquaculture:** Using community-based co-management principles, the smaller farms should amalgamated to facilitate more intensive aquaculture practices, on a long-term basis (ADB/NACA\(^{113}\), 1996). A benefit of the new system will include the ability to afford well-trained and motivated staff who will be capable of developing and implement the more sustainable practices (Blomqvist, 2002; Fegan, 1996). An important aspect of this system is that it does not harm the mangroves (Menasveta, 1999; NACA, 1994; Tookvinas, 1996).

(b) **Ensure the supply of electricity:** Energy supply is the most important input to modern aquaculture, particularly intensive and semi-intensive shrimp aquaculture systems, needed to enable their successful management, profit and sustainability. Surtida (1998) stated that electricity supply is vital for aeration and water pumping in modern intensive shrimp aquaculture, enabling it to achieve much higher production levels than the extensive shrimp aquaculture system. Kristensen (2002) and Wheaton (1977) calculated that 80% of farm electric power is required for pond aerators, 10% for pumping, and 10% for food processing and workshops. Electricity supply will encourage private entrepreneurs to establish much-needed shrimp, prawn and fish hatcheries; will provide for ice plants in remote coastal areas; and will allow farmers to use pumps. Electricity will also contribute to the security of farm property and shrimp stocks.

\(^{113}\) Asian Development Bank and the Network of Aquaculture Centres in Asia-Pacific.
(c) **Development of essential infrastructure:** As well as electricity supply, the Government should urgently establish other essential infrastructure such as roads, waterways and telephone connections in the shrimp farming areas. Improved transportation systems will help maintain shrimp quality and its distribution and marketing systems.

(d) **Nutrition and feed management:** The growth in intensive/semi-intensive shrimp aquaculture farming practices has been accompanied by the increasing use of artificial feed, because it promotes faster growth and higher body weight (Durairaj *et al.*, 1992; Law *et al.*, 1990; Mazid and Mahmud, 1992). However some of the applied feed will be lost as waste, some will dissolve in the water and some will be deposited at the bottom of the pond during the feeding time (Boyd, 1992; Briggs and Funge-Smith, 1994). Thus nutrition and feed management are important factors for environmental sustainability. Nutrition is essential for shrimp’s weight gain on the one hand, but on the other hand, excess supply of feed is deteriorating the water quality (Boyd, 1992; Lin *et al.*, 1991). The unused feed is creating water pollution that is detrimental to aquatic animals. The following practices should assist better feed management in a shrimp aquaculture farm (Ahmed, 1999; Chisty and Rahman, 1999; Nabi *et al.*, 2000):

i. Reduce the protein (fishmeal and snail-meat) in shrimp feeds by increasing carbohydrate and lipid contents, and also reduce phosphorus content wherever possible and appropriate;

ii. Utilise alternative sources of protein (such as soybean) instead of snail-meat; and
iii. Utilise locally available ingredients for the development of well-formulated farm-made feed that has the benefits of cost-effectiveness and minimal waste.

(e) **Waste and sediment management**: Waste management in coastal shrimp aquaculture is a complex issue. Broadly, there are two types of waste coming from coastal shrimp farms, dissolved nutrients and suspended solids. A primitive physical treatment system (such as sedimentation) and filtration (such as biological treatment) will help to eliminate the production of suspended solids and effluent in shrimp ponds/gher at low cost prior to final discharge to the natural water body or surrounding environment (Wheaton, 1977a). Use of an air blower machine to promote oxygenation will enhance the sedimentation-filtration process. Oxygenation, sedimentation, filtration and lime treatments are the most successful wastewater treatment methods of any shrimp farm (Salequzzaman, 1996). These treatment methods should be an integral part of any commercial shrimp farm, especially improved extensive, semi intensive and intensive shrimp farms (Asian aquaculture, 1998; Platon, 2002; Salequzzaman, 1989). Regular exchange of 5% of pond/gher water is also needed for disease control in any coastal shrimp farm (Huda, 2001; Salequzzaman and Bhuiyan, 2000). In addition, the proper management of pond sediments by amelioration of pond soil is also an important factor for shrimp and other aquaculture system (Boyd, 1992; Fegan 1996).

(f) **Stocking density and seed management**: Supply of sufficient quality and quantity shrimp seed is an important prerequisite for sustainable
aquaculture. To maintain this prerequisite, it is essential to ensure the use of healthy and genetically strong and sound seed and brood stock from artificial hatcheries. This will also reduce fishing pressure on natural stocks. In addition, a proper stocking density of shrimp post-larvae should be maintained. For example, the average appropriate stocking density is approximately 10-20 PL/m² (Anantha et al., 2000; Briggs 1994; Salequzzaman, 2001). It is noted that coastal Bangladesh is an ideal place for establishing shrimp and prawn hatcheries (Karim and Aftabuzzaman, 1999; FRI, 2001; Macintosh and Phillips, 1992; Salequzzaman and Newman, 2002).

(g) Water management: Sufficient quality and quantity of water supply with the right degree of salinity is a crucial input to sustainable aquaculture development (Anantha et al., 2000; Lin et al., 1991; Salequzzaman, 1989). Unlike seed and feed management, water quality is, to a certain extent, beyond farmers’ control. Until recently, farms used an open system for water management, where dirty water was continuously flushed out from the ponds into the ocean via canals and clean water was pumped in from the ocean. However, as the number of farms increased within the region, the amount of water flushed out with excess nutrients increased, and at a certain point went beyond the coastal systems regenerative capacity to cleanse the polluted water (Lin et al., 1991). Moreover, accessing water from a common pool also meant a greater exposure to diseases transmitted from other farms in the area. Thus, one important technology for the future development of sustainable aquaculture is a recirculating aquaculture system. The recirculating aquaculture system is a kind of closed system, where water is recycled continuously and treated mechanically and
biologically to maintain a liveable environment for aquatic organisms including shrimp (Asian Aquaculture, 1998; Boyd, 1992; Salequzzaman, 1989). This water management system eliminates many risks, such as disease transfers to wild species, genetic dilution/alteration, discharges of antibiotics and bioaccumulants, ecosystem degradation and algal blooms (Hopkins et al., 1995; Sandifer and Hopkins, 1996). The RAS also improves feed utilisation, reduces consumption of chemicals, allows efficient removal of dead shrimp seeds, facilitates better monitoring activity and, reduces the capital cost of water transportation and management (Boyd et al., 1998; Sandifer and Hopkins, 1996). At the end of each crop cycle, the sediment must be scraped and removed. This sediment is now considered to be one of the more important environmental impacts of shrimp farming. It is highly toxic and saline and if improperly disposed of can cause serious problems to the shrimp sector and/or other land uses in the vicinity (Briggs and Funge-Smith, 1994). Therefore sediment has to be removed from the culture pond in a sustainable manner.

(h) **Introduction of Hazard Analysis Critical Control Point (HACCP):** Hazard Analysis Critical Control Point is a system to identify all possible food safety and non-safety hazards that are likely to occur in the shrimp and prawn processing operation, based on the species being processed and the process used, and analysing the risks related to those hazards, such as the prevention of economic fraud in relation to labelling, misgrading, weight and others. The HACCP system offers a rational and logical approach to controlling microbiological food hazards and avoids many weaknesses inherent in the coastal shrimp industry including its processing plant. As the coastal shrimp industry is
an important export oriented sector in Bangladesh, it is essential to introduce the HACCP system throughout the industry. Introduction of this system will definitely enhance the acceptability of Bangladesh’s shrimp aquaculture product in foreign countries.

(i) **Environmental assessment and monitoring:** Regular environmental assessment and monitoring are necessary to check and quantify the environmental impacts of aquaculture (Tookvinas, 1996). The information generated through such studies would be useful in formulating appropriate policy and management practices for sustainable aquaculture. For this purpose, governments and farm owners should develop effective environmental monitoring and assessment procedures. The active participation of farmers and other stakeholders is important for this assessment and monitoring process to be successful (Macintosh, 1996; Macintosh and Phillip, 1992; Phillips *et al.*, 1993).

### 5.4.2 Sustainable social, institutional and legal systems

#### 5.4.2.1 Sustainable social systems

(a) **Involvement of community-based co-management:**

Involvement of local people into shrimp aquaculture is an important factor for the sustainability of coastal Bangladesh (Stevenson[^114], 2002). Presently a large number of women are employed in shrimp aquaculture related activities such as shrimp fry collection from the coastal belt which are destroying coastal habitats.

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ecosystems. Therefore they should be encouraged to take up an alternative source of income for the protection of the coastal ecosystem as well as the long-term sustainability of the coastal shrimp industry. A good way of achieving this is the setting up of community-based co-management in the local area where such women can become involved in cottage industry, small business, or home-based livestock production, utilising the micro-financing facilities of the Grameen Bank (Siddiqui and Newman, 2000). In the same way, farmer associations or groups can apply community-based co-management to agriculture related activities. However a close relationship should be established with scientific research organisations in all of these associations to develop up to date, relevant, appropriate and effective technology for sustainable coastal development.

(b) **Incentive to farmers and extension workers:** An incentive system which rewards farmers and extension workers for productivity improvements should be developed to enhance profitability in coastal shrimp aquaculture (FAO, 2000; Khan and Hossain, 1996; Simpson and Pedini, 1985).

(c) **Training and education:** A training manual could be prepared and distributed among the relevant stakeholders under a specific funding program to ensure sustainable shrimp aquaculture training and education reaches relevant farmers, extension officers and Organisations.

(d) **Motivation and awareness program:** Motivation and awareness programs are useful tools to solve the many local conflicts and problems.
Therefore a sustained, comprehensive awareness-building campaign of sustainable coastal development, in particular sustainable shrimp aquaculture procedures should be carried out among all possible stakeholders in coastal Bangladesh. The program could include rural and urban youth, employed or unemployed persons. Appropriate revision to the school curriculum could be made and, subject to the local situation and requirements of the national level awareness programs on diverse aquaculture farming systems and aquacultural sustainability could be implemented.

(e) **Information sharing**: Relevant socio-cultural and environmental information sharing between countries and between regions within countries is important to take decision-making on sustainable coastal shrimp aquaculture. The main information exchange/sharing includes farm performance data and information on the key variables affecting shrimp and carp farm sustainability.

### 5.4.2.2 Development of institutional and legal frameworks

Coastal Bangladesh needs comprehensive policies and associated institutional and legal frameworks which support the ecologically sustainable development of shrimp aquaculture. This policy framework could be developed through improved communication, cooperation and coordination between institutions, research organisations, agencies and major stakeholders, thus strengthening the institutional capacity to manage coastal shrimp aquaculture and expanding knowledge through community-based co-management procedures. The following criteria could form a strong basis for this process:
(a) **Review of existing legislation and set up coastal shrimp aquaculture policy:** Respective Bangladesh government ministries and departments should review the existing legislation affecting aquaculture and determine the desirability of establishing a coherent legal framework for national aquaculture policy, with special emphasis on coastal shrimp aquaculture.

(b) **Set up small-scale aquaculture policy:** In recognition of the contribution to foreign currency generation made by small-scale shrimp farmers who are local in origin and poor, the GOB should pay special attention to capacity building for this group by providing adequate technical and financial assistance. Extension services could be extended to assist these traditional shrimp farmers to achieve better productivity and sustainability. By this system, it is expected the exploitation of poor farmers by wealthy powerful entrepreneurs will decrease significantly from coastal Bangladesh (Asian Aquaculture, 1998; Blomqvist, 2002; Salequzzaman, 1996).

(c) **Code of practice:** Coastal shrimp aquaculture requires a ‘Code of Practice’\(^ {115}\), so that the industry can become recognized as environmentally and socially sustainable (Donovan, 2001; Phillips et al., 1993). An approved code of practice has particular value as a defence to a charge of causing unlawful environmental harm. The ‘Code of Practice’ should reasonably support the

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\(^ {115}\) A Code of Practice in shrimp aquaculture means a self imposed set of rules for the carrying out of a specific activity which define the intended purpose and specify the particular operational practices to be adopted. A Code of Practice may become a legal document and may be called up to prescribe appropriate legal practices. Environmental harm is unlawful unless it is authorized under an environmental authority, environmental protection policy, an environmental management program, a license, an approval, an environmental protection order or an emergency direction (Department of Natural Resources, 1997; Donovan, 2001).
concept of ‘Ecologically Sustainable Development’ (ESD) which ensures that community’s resources are conserved and enhanced in such a way that quality of life, both now and in the future, is secured (Young, 1993). The Bangladesh government should develop a rigorous ‘code of practice’ which would give rise to an environmentally friendly, economically viable and responsible approach to both future developments and existing operations (Boyd, 1995; Chanratchakool et al., 1998; New Statesman, 1996).

(d) **Research and development:** A sustainable coastal shrimp aquaculture framework and policy will require close collaboration, research and development work between local stakeholders, the private sector, different donor agencies, relevant government departments, NGOs and research organisations.

### 5.4.3 Marketing strategy

Managing shrimp aquaculture optimisation of profits will require decisions to be made on various investment strategies that realise returns over different time frames (Liao, 1998; Salequzzaman, 2001) such as:

(a) **Short-term:** Optimising profits in the short-term is primarily related to input costs and the market value of output. In the short-term, only a small substitution is possible in feed and labour inputs at a low level of production, but it can make a difference especially if there is a concurrent development of marketing at end of the production cycle (Doupé et al., 2002). However, restructuring the aquaculture industry to strengthen its ability and to meet international competition is necessary.
(b) **Mid-term:** In the mid-term, options become available that allow capital investment to improve productivity and economies of scale, although the benefits will not necessarily translate to an immediate improvement in profits (Burbridge *et al.*, 2001). Development is necessary in the area of sustainable supply of shrimp aquaculture larvae and brood-stocks. For example, the shrimp aquaculture industry will need to develop farmers’ entrepreneurial ability and their organisational skills in hatchery operations in order strengthen the industry’s mid-term competitive position.

(c) **Long-term:** In the long-term, all production factors are variables and new ventures may enter the sector and change the mass of products in the market, while increasing cost-effectiveness through implementing innovations (Doupé *et al.*, 2002). For example, in the long-term shrimp aquaculture system, Bangladesh should increase overseas investment to enhance its influence in world aquaculture by setting up an international centre for the shrimp aquaculture industry which would also encourage input from private industry.

### 5.5 Conclusions

Coastal shrimp aquaculture is an important industry in Bangladesh because it is an important source of earning foreign currency. However the present practice of shrimp aquaculture is not sustainable, because it has damaged the local socio-economic, environmental, ecological and cultural environment of coastal Bangladesh on a long-term basis. The main reason behind this unsustainable aquaculture is the unplanned and unscientific methods of shrimp cultivation, and lack of integration among various components of local ecosystem. The integration optimises the use of land and water
resources, such as the wastes produced by aquaculture system minimises by other components of the ecosystem. In addition, the integration will enhance the protection and restoration of coastal ecosystems, ensure ecologically sustainable development, mitigate coastal resource use conflicts, increase employment opportunities and develop public participation in coastal management processes.

The research also suggests that shrimp farmers who adopt high stock densities and use large amounts of feed have generally experienced deterioration in the survival rate. It also demonstrates that those shrimp farms adopt closed water management system, tend to experience higher survival rates compared with the existing open water system of farming. Finally, the research recommends that the present aquaculture system could develop in a more sustainable way by utilising modern technology (such as electricity) and improving the knowledge of ecologically sustainable development principles. However the new process would need financial support and the involvement of the community through a community-based co-management process that enhances a balanced social, economic, cultural and ecological co-existence system (Flint, 2000). However the whole process depends on the formulation and regulation of an appropriate and sustainable shrimp aquaculture policy and its integration with a source of power. The details of this process will be discussed in Chapter VI.
CHAPTER VI
Chapter VI
INTEGRATED TIDAL POWER PROJECT FOR ACHIEVING SUSTAINABLE DEVELOPMENT IN COASTAL BANGLADESH

"Development is an integral, value-loaded, cultural process; it encompasses the natural environment, social relations, education, production, consumption and well-being."
Dag Hammarskjöld Institute (1975, p.7)

"We have to make best efforts with our limited resources through integration for advancement in science and technology to reduce poverty and hunger, and it is only in this way that we can achieve the cherished goal of building self-reliant and prosperous Bangladesh".
Dr. Abdul Moyeen Khan
Science and Information Communication Technology (SICT) Minister, Bangladesh (The New Nation, 12 December 2002116)

Research Questions
(1) What are the prospects for integrated development by using tidal power in coastal Bangladesh?
(2) How can tidal power be integrated with various resources in coastal Bangladesh?
(3) How can integrated tidal power bring about sustainable development in coastal Bangladesh?

6.0 Introduction
Coastal Bangladesh is a highly productive area which would benefit from sustainable development (Chapter III of this thesis). Existing development suffers from the problems of remoteness, lack of modern facilities and communities, little scientific knowledge about sustainable land-use management and, most importantly, the absence of integration between coastal resources and community participation (Chapter III and V of this thesis). In addition, coastal people live in fear natural calamities like cyclone and tidal surges, and the consequences of on-going climate change and sea-level rise (Chapter III of this thesis). In this regard, many researchers

and scientists recommend that Bangladesh needs integrated coastal development to ensure a sustainable future (Bijlsma et al., 1996; Salequzzaman and Newman, 2002; United Nations, 2002).

Electricity supply is considered an important precursor for economic, social and technological development (Bala, 2003; Biswas et al., 2001; Dincer, 2000; Taylor, 1998). It has been estimated that developing countries like Bangladesh will need a 300% increase in energy production (Kaygusuz and kaygusuz, 2002; Suganthi and Samuel, 2000; Taylor, 1998) to achieve reasonable progress over the next few decades compared with a 30% rise in developed countries (Mashishi, 2002; Munoz, 2000; Taylor, 1998). Based on existing global warming and energy resources scenarios, scientists, policy-makers, researchers and environmentalists are strongly recommending that this electricity demand should come from renewable energy sources like tidal power (Chapter IV of the thesis).

The research has identified that tidal power could be produced in coastal Bangladesh by utilising existing embankments and sluice gates. This would provide an important, pollution free, renewable energy favoured by the clean development mechanisms of the ‘Post-Kyoto Protocol Agreement’\footnote{John Schauble, ‘Global warming rate rings warning bells’, The Age, 23 January 2001, p.3, www.theage.com.au (accessed on 15 August 2002).} (Chapter IV of this thesis). The electricity could meet existing demand and the infrastructure of the tidal power plant could be integrated with aquaculture, agriculture and other resource producing land-use systems (MCRST-MOSTE, 1992; Wilson and Severn, 1972; World Coast Conference Report, 1993). It is assumed that the proposed project would also improve the existing coastal infrastructure and reduce the impact of deadly natural disasters, like cyclones in the Bay of Bengal, salinity and flooding (Khan and Hossain, 1996; Muir and Beveridge, 1987; Phillips et al., 1991). The proposed tidal power project would integrate with agricultural crop production, homestead vegetable production, shrimp aquaculture, livestock and poultry, fish culture and other activities that are extensively inter-linked in the coastal environment of Bangladesh (Keyun, 1997; McNally and Tognetti, 2002; UNCED, 1992). This inter-linkedness is one of the most important mechanisms of ecological sustainable development (Cohen and Tol, 1998; Underwood and Chapman, 1999). The integrated tidal power project would enhance...
sustainable development through effective community-based coastal co-management (Chapter II and Chapter III of this thesis).

This chapter of the thesis will propose a coastal development model that will integrate the proposed tidal power plant with the existing coastal infrastructure of embankments and sluice gates, allowing environmental, economic, social and cultural activities while fulfilling the following objectives:

(a) The development of a integrated model of coastal sustainable development where tidal power plant will play a central role in the process;

(b) The integration of coastal shrimp aquaculture, livestock production, rice cultivation, the creation of a green belt, waste water treatment and other associated activities;

(c) The creation of a successful ecologically sustainable development case study in coastal Bangladesh; and

(d) The adaptation of an innovative and participatory community-based co-management model.

6.1 Prospects of integrated tidal power development in coastal Bangladesh

Integrated tidal power development in coastal Bangladesh involves comprehensive tidal power development with the integration of coastal planning and management of various coastal systems and resources in such a way that ensures ecologically sustainable development over the long term (Annual Environment Report, 2001, World Coast Conference, 1993). This model includes the integration of agencies, issues, sectors and tiers of government, and the concept of a land-sea interface\textsuperscript{118}. The following description will explain why coastal Bangladesh needs integrated tidal power development.

Presently coastal Bangladesh suffers from a severe lack of electricity with the lowest per capita electricity supply in the world (Chapter III of this thesis). However the remote coastal people need sufficient electricity supply to meet their modest

requirements for lighting, communication and other purposes. For example, a village-based family needs at least 15 to 100 W of electricity for lighting, to power a small television or radio, and another household appliances\textsuperscript{119} (Winrock International, 2002). A very small percentage of coastal families obtain electricity from diesel-powered generators (gen-sets), bio-gas or solar power based photovoltaic. The majority of coastal peoples depend on fossil fuel-based options (such as, kerosene oil, cow dung, wood, candles, etc), which create greenhouse gas (Stoft et al., 1997). In addition, most rich coastal villagers use dry cell batteries for radios and flashlights. Some coastal people use rechargeable batteries for television which is managed on a community-basis. Given the above, coastal Bangladesh is looking for low-cost, locally available and appropriate technology for electricity generation. Chapter IV of the thesis has identified that tidal power plants are such a technology.

As previously mentioned in Chapter III and IV, Bangladesh has a long coastal belt, most of which is protected by costly infrastructure of coastal embankments and sluice gates that provide a great opportunity to develop small-scale to medium-scale tidal power plants (Corry and Newman, 2000; Salequzzaman et al., 2000; Salequzzaman and Newman, 2002). In the long run, future global warming may increase the tidal range in the coastal belt which will further increase the tidal energy potential (Corry and Newman, 2000; ISTP, 1999; Salequzzaman, 2002; Salequzzaman and Newman, 2002). Further construction on the existing embankments will raise their height to control the excess intrusion of seawater into the inland side (Ahmed and Mirza, 2000; Huq, 2001; World Bank, 2001).

Many scientists have examined how a barrage system (like coastal Bangladesh) could generate small-scale tidal power through simulation models and prove its potential for remote coastal areas around the world (Blue Energy, 2001; Elliott, 1996; Fujita Research, 2001). The Bangladesh coastal belt is characterised by two to eight metres tidal height (head) rise and fall, and 0.1-4.0 m/second maximum current velocities (Chowdhury, 2001; IPCC, 2001; Rahman, 2002). Most of this coastal belt is equipped with levees and sluice gates (Barua, 1993; BIWTA, 1999; ESCAP, 1992). Therefore

\textsuperscript{119} 1 kW electricity is needed for lighting of 10 to 20 rural households or power a solar irrigation pump and 1 MW electricity would be required for lighting of a town of around 3,000 families and some daytime industries such as agricultural mills, sawmills, arc welders, or baking ovens (Winrock International, 2002).
the infrastructure needed for small to medium-scale tidal power generation and the controlling the water flow through turbines for flood control are already present (Brinkworth, 1998; ISTP 1999; Lewis, 1963). This, therefore avoids the problem of high capital costs as the engineering is either already there or is needed for cyclone protection in any case (Salequzzaman and Newman, 2001 & 2002). Undershot paddlewheel will provide the optimum small-scale technology for tidal power and can be placed at sluice gates in the levees/barrages/embankments (Brinkworth, 1998; ISTP, 1999; Salequzzaman and Newman, 2001). These undershot paddlewheels could easily connect with recently developed variable speed electricity generation equipment and electronic controllers to regulate the power output from variable water flow (Brinkworth, 1998; Day, 1994; ISTP, 1999).

The area where the tidal wheel has to be placed is part of a reservoir that will fill on the incoming tide via the tidal wheel, and then the water is released back through the wheel on the ebb tide (Brinkworth, 1998). This system will produce electricity for most of a daily cycle ensuring the maintenance of water movement and draining excess water during the rainy season (ISTP, 1999). Thus the project offers improvements to the coastal flood control capabilities. Tidal power plant could also integrate future potential coastal resources such as the mining industry and make them available to community people. In some cases, tidal power plants will assist in ensuring the optimum utilisation of specific resources (Salequzzaman, 2001; Salequzzaman and Newman, 2002). For example, shrimp processing plants are now under-utilised, adding electricity will ensure their optimum utilisation. Shrimp seed is currently over exploited due to lack of hatchery facilities, electricity would enable the establishment of hatcheries. According to CARE-Bangladesh120, the average income from the sale of extra fish from the integrated gher/pond system has increased four fold (Chowdhury et al., 1999; Salequzzaman, 2001; Williams, 2001). It is suggested that lack of electricity is the main barrier to sustainable coastal development (Cicin-Sain and Knecht, 1998). Tidal power could improve this situation by providing clean, renewable energy (Blue Energy, 2001; Day, 1994; Tidal Energy Inc., 2000). This innovative technology could assist in the mitigation process of climate change impacts, making it a probable candidate for financial benefit from the CDM system.

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Based on the above factors, it is proposed that the integration of tidal power can play a major role in sustainable coastal development. However it will require a well-coordinated policy, more scientific research and cooperation from government and various national and international organisations. It is noted that the implementation of such an integration system is supported by many international organisations. For example, Global Environmental Outlook 2000 (GEO-2) has reported that integrated policies and an inter-sectoral approach is urgently needed to achieve sustainable development in developing countries like Bangladesh (Biswas et al., 2001; Rahman and Mallick, 2002).

6.2 The possible integration model of tidal power in coastal Bangladesh

Coastal Bangladesh is composed of many creeks and small rivers where 2-8 m tidal ranges occur twice daily (two incoming and two outgoing). In these tidal affected creeks and rivers, it would be possible to install a series of tidal power generators through utilisation of the existing flood control embankments and sluice gates that enclose the coastal main lands. The undershot tidal wheel/water wheel (paddle wheel) could be installed in tidal creeks/rivers at the sluice gates along the existing barrage. Each wheel would be linked to a generator and would feed electricity into a grid to serve the local community and/or electricity could be stored in transportable batteries as DC current. The tidal creeks would act as the reservoir that will fill on the incoming tide via the tidal wheel, and later the water would be released back through the tidal wheel on the ebb tide. This system will produce electricity for most of a daily cycle. Beside the tidal wheel, a pond would need to be dug out on the inland side of the embankment and a channel dug up to the seaside of the sluice gate. This can be done cheaply using traditional labour techniques, at the same time improving the channels’ navigability and providing pond for aquaculture (Corry and Newman, 2000). For small-scale electricity generation, a low-cost, locally available paddle wheel (a micro-tidal turbine) which has simple civil construction (fig. 4.10) will

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enable the placement of wheels at appropriate locations in the levees/barrages/rivers. The generated electricity from this micro-turbine will enable the electrification of nearby households, small-scale cottage industry, a proposed integrated aquaculture farm, government and NGO’s offices including the local hospital, school/college and other need-based organisations. However the production and distribution of this tidal electricity could be managed by a village-based co-operative using a community-based co-management model.

In the proposed model of an integrated tidal power/aquaculture project, an aquaculture pond would entail the construction of a bund wall (embankment), a series of ponds, an inlet settlement canal, a distribution channel, a discharge channel, secondary species ponds, and a water-return channel, plus sheds, a pump house, power lines, roads, and other resource utilisation facilities (fig. 6.1 and fig. 6.2).

This form of aquaculture farm could be organised and developed easily with the local community, providing employment and income generation opportunities for many local people, including women (Ruddle and Johannes, 1989; White and Lopez, 1991; World Coast Conference Report, 1993). The aquaculture ponds need to be dug to a depth of half a metre by 100 metres-square with walls to a height of two metres above ground level (Mazid and Alam, 1995). The floor of each pond would slope towards the outlet for draining and would be compacted, ensuring that the clay returns to a hard surface once the pond is drained and dried (Wheaton, 1977). This will reduce leaching of salt to groundwater and surrounding land.

The aquaculture pond would provide two shrimp yields a year. During the high salinity season saline water shrimp, *Penaeus monodon*, locally known as Bagda Chingri) would be harvested, along with other fish species for more efficient use of nutrients in the pond water (Salequzzaman and Newman, 2002). During the low salinity season the main harvest would be freshwater shrimp (*Macrobrachium rosenbergii*, locally known as Golda Chingri) along with other fish species (Salequzzaman, 1989).
Fig. 6.1: The proposed design of integrated tidal power project with aquaculture and other coastal resources of Bangladesh (Salequzzaman and Newman, 2001).
Both shrimp species will be bought as post-larvae from either the hatchery which situated inside the project or from natural seed. Local secondary species (such as oysters, scallops, plankton feeder fish, shell feeder fish, and catfish) will be used as bio-filters for treatment of wastewater in the secondary pond (Salequzzaman and Newman, 2001 & 2002; Wirojanagud, 2002). The shellfish and plankton feeder fish would remove algae, the shell feeder fish would utilise shells for their food, and catfish (such as *Clarias batrachus*) would remove excess sludge and calcium from the primary ponds (Mazid, 2000). The shellfish shell can also be used for food at the poultry farm inside the project. The bio-filtration activity will remove waste and
nutrients from the water before it is discharged back into the sea (Wheaton, 1977a). The fish (both catfish and plankton feeder fish) could be used for human consumption.

To maintain a proper water level in the pond, the construction of inlet and outlet will be arranged in such a manner that will allow passage of water without erosion. Thus the inlet and outlet gates will be constructed from concrete and have a sluice gate mechanism. At the inlet gate, a fine mesh screen will be used to prevent foreign species from entering the pond. The grow-out pond\textsuperscript{122} will be constructed by scraper, excavator, grader and roller. The bottom of the pond will be dug up to a depth of 0.5m below the existing ground level. The slope of the floor will be 1: 200 (Consultative Environmental Review, 1997). The excavated material will be used to construct the walls of the ponds. The slope of the wall will be 1: 1 with a height of 2m above ground level. The top of the wall will be 5m wide and the distribution canal site will be increased to a width of 7m. These pond-walls (dyke) could be used as roads.

The land space between the ponds could be utilised for paddy cultivation of a salt-tolerant, high-yield variety (HYV) of rice.\textsuperscript{123} Land adjacent to the aquaculture project would be used for livestock (cow, goat, hen, duck, and buffalo). The straw (biomass) from the paddy would be utilised as a feed for cows and buffaloes.\textsuperscript{124} The faeces and wastes from the farm would be utilised for the production of bio-gas which could be used for domestic cooking and lighting.\textsuperscript{125} The sludge from the bio-gas plant could be used as fertiliser in the paddy field, horticulture field and for grass production (goat and cow’s feed). In addition, part of this integrated project could be used for salt production during the dry season when the sea’s salinity levels increase\textsuperscript{126}. Salt production is a traditional practice in many parts of coastal Bangladesh. Electricity produced from the integrated tidal project could also be used in the shrimp hatchery as well as for other functions in the semi-intensive integrated shrimp aquaculture project,

\textsuperscript{122} The pond will use for the purpose of water storage.
\textsuperscript{123} Recently the Bangladesh Rice Research Institute (BRRI) successfully invented and adapted the HYV rice in the coastal saline environment.
\textsuperscript{124} Collecting straw from the rice fields for livestock feed is traditionally practiced throughout rural Bangladesh.
\textsuperscript{125} Presently, the Bangladesh government has an extensive biogas project that has successfully been expanded to the village level. The biogas project has multiple uses, such as small-scale electricity generation, cooking, and production of organic fertiliser.
\textsuperscript{126} Salt has been traditionally produced along the coastal periphery for centuries.
such as aeration and filtration of water, water pumping and mechanical irrigation of the paddy fields. Therefore it is evident that tidal power electricity is a means to modernise the integrated shrimp aquaculture and other income generating activities of coastal Bangladesh.

The produced electricity could be utilised through off grid systems by establishing DC (direct current) battery\textsuperscript{127} storage systems. Within any renewable system, the requirement to store energy is of paramount importance. DC technologies have an advantage over AC cabling. They significantly reduce the fault contribution to the onshore power network (Ackermann, 2002; Bala, 2002). Such energy efficiency is undoubtedly the most effective and economically rewarding short-term pathway to sustainability (Thomas, 2002). Renewable energies are ‘live’ sources, characterised by a peak of supply that does not necessarily coincide with the demand of the users. It is therefore necessary to trap this energy when it is available, retaining it for utilisation when required by the end users. This is particularly important for the remote coastal areas and the provision of batteries within such communities should lie at the core of the efforts for coastal electrification utilising renewable energy sources.

Presently, deep cycle, lead-acid batteries are already offered to rural households in Bangladesh as a low cost opportunity to provide basic electrification (Grameen Shakti, 2001). Battery based household systems are not only low cost but also efficient suppliers of electricity through avoiding conversion losses between ‘AC’ and ‘DC’, utilising energy efficient ‘DC’ appliances, and promoting demand side conservation of energy (Barua, 1998). The expansion of battery based household electrification can occur by recharging the battery from a tidal power plant allowing successful power dissemination within coastal households. This system will offer the highest utility at the lowest cost through the community-based microfinance process, utilising locally based bicycle rickshaw systems for the transportation of batteries (Yunus, 1998; Siddiqui and Newman, 2001). The microfinance or microcredit system could be utilised to extend loans to individual member households to enable the purchase of a system appropriate to the families needs and resources. The microcredit

\textsuperscript{127} Batteries are an electro-chemical energy storage device and can be classified into several broad groups. The most widely used battery in renewable energy systems is the gel type, maintenance free, lead-acid battery (Duryea \textit{et al.}, 1999).
cooperative would operate as a local resource for maintenance, training, system operation advice and demonstration of renewable energy from the tidal power plant and DC battery based households.

With regard to aquaculture ponds those between 1.5 and 4m in depth, with a surface area of less than a hectare might be used for rearing of fry, brood fish stocking and spawning purposes (Aich et al., 1991). In most cases, ponds with a surface area of up to a hundred hectares would be used for the main aquaculture of shrimp and other fish (Michael, 1987). The whole aquaculture system could be integrated in such a way that mangroves will regenerate on the dyke of the pond creating ‘Silvo-fisheries’ (Brody and Hlohowskyj, 1998; Quarto, 2002). Silvo-fisheries promote a harmonious co-existence between fishery species and mangrove trees in a semi-enclosed system while providing coastal protection and maintenance to the ecosystem (Baconguis, 1991). There is a variety of designs in the silvo-fishery system which seek to balance conservation and utilisation by maximising economic opportunity. In silvo-fisheries, mangroves are planted in a shallow central area covering 70-80% of the selected site and the remaining 20-30% are used to create a deeper pond along the dyke where brackish water aquaculture (fish, shrimp/prawn or crab) could develop (Baconguis, 1991). Presently silvo-fisheries exist in a number of countries including Indonesia, Hong Kong, Thailand, Vietnam, Philippines, Kenya, and Jamaica. They are labour intensive appropriate technology for individual or family aquaculture operations.

The integrated tidal power project could be considered as an overall integrated sustainable development strategy for coastal Bangladesh engaging the transition into more intensive aquaculture. Thus shrimp aquaculture could be redesigned as a polyculture system which is a more efficient farming option (than monoculture). A stocking density of 6,000-9,500/ha with 6.0-9.0 cm size fingerlings gives an average

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128 Silvo-fisheries is a form of integrated mangrove tree culture with brackish water aquaculture to conserve and utilise the mangrove resources by maintaining a relatively high level of integrity which capitalises on the economic benefits of brackish water aquaculture. It is an ancient coastal resource management concept that might prove invaluable as an alternative sustainable aquaculture management model. Source: WRM's bulletin, no. 51, October 2001, http://www.wrm.org.uy/bulletin/51/production.html (accessed on 25 November 2002).

129 Culture of different species of carp together is known as polyculture or mixed culture of carps, where fast growing compatible fish species of different feeding habits are stocked in different proportions in the same pond, so that all the ecological niches in the pond are proportionately occupied. Based on feeding habit, a suggested ratio of different species for polyculture system is surface feeders 40% (Catla catla 10% and Hypophthalmichthys molitrix 30% or Catla catla 30% and Hypophthalmichthys molitrix 10%), column feeder 20% (Labeo rohita and Puntius gonionotus ), bottom feeders 30% (Cirrhina mrigala and Cyprinus carpio ) and macro vegetation feeder 10% (Ctenopharyngodon idella ) (Mazid, 1995).
production of 4.0-5.0 tonnes/ha/year from improved extensive aquaculture systems (Hussain and Uddin, 1995). Polyculture of *Macrobrachium rosenbergii* with fish is more profitable than monoculture. In a monoculture system covering 15,000/ha, yields of 0.277-0.322 tonnes/ha/6 months can be achieved whereas using polyculture, yields of 3.0 tonnes/ha of fish and 0.20 tonnes/ha of prawn over 8-10 month periods at a stocking density of 10,000 juveniles prawn /ha and 5,000 fishes /ha can occur (Mazid and Alam, 1995). *Macrobrachium rosenbergii* has also been found suitable for concurrent culture with rice and a production rate of 0.30-0.40 tonnes/ha/6 months is obtained in such an operation (Mazid and Alam, 1995). My field surveys have shown that local farmers benefit nutritionally by consuming fish from polyculture systems over the long term (Haroon *et al*., 1994). In addition, the price of fish in coastal Bangladesh is much lower than prawn/shrimp (about 8-10 times lower) making it more easily available to lower income consumers (Graaf and Latif, 2002; Salequzzaman, 2001).

To maintain ecological sustainability, a fish passage/fish-way would be set up along the creek to reduce damage to aquatic species. A fish-way/passage is a modification to a natural or artificial waterway for the purpose of allowing safe fish passage. It may include attraction features, a barrier dam, entrances, auxiliary water system, collection and transportation channels, the fish ladder itself, trash rack, an exit, and operating and maintenance standards (Turnpenny, 1998). It can be a formal concrete structure, pools blasted in the rock of a waterfall, or log controls in the bed of a channel. Thus a variety of physical, hydrologic, and biological considerations will determine the selection of a suitable fish-way/passage which could be set up at the mouth of the tidal creek. A culvert fish-way consists of a sloping pipe flowing partly full with regularly spaced baffles or weirs on the bottom. However, before setting up a fish passage, the hydraulic effects of culvert size, slope, material and elevation to create depths and velocities, a hydraulic profile through the study of fish behaviour, motivation, preferences, migration timing, and swimming ability is necessary. The existing BIWTA’s embankment and sluice gate system is a kind of culvert that is made for irrigation and drainage purposes only. In the integrated project, the fish passage will be set up in the sluice gate area after a detailed study of the hydrology and hydraulics of the sluice gate area (Azad, 2002). The proper installation of culverts can reduce the
adverse effects on fish while maintaining hydraulic efficiency, reducing installation, maintenance, and retrofitting costs (Johnson and Orsborn, 1996).

In addition to the fish passage, an integrated pest management strategy would be followed in the paddy cultivation on the project’s dyke. The integrated pest management has been very effective and successful in the local community approach to ecologically sustainable agriculture and is becoming more widespread in rural Bangladesh (Sarker et al., 2000). This process controls pests naturally using aquatic animals including fish without any use of chemicals. Thus the community integrated pest management is now used as a strategic approach which puts farmers in control of planning and implementation.

6.3 Components of the model and specific needs for electricity
The model is developed for the purpose of sustainable coastal development of Bangladesh. Thus the components have been selected through consideration of the local geography, environment, socio-cultural and economic factors of coastal Bangladesh. The components of this integrated tidal power model are set out below.

6.3.1 Integration of shrimp aquaculture with tidal energy
Shrimp aquaculture production levels in coastal Bangladesh are very low compared to other countries, where modern technological development has occurred. The present production system is unsustainable, mainly due to the lack of modern facilities including electricity supply. Some semi-intensive shrimp aquaculture systems have been established in coastal Bangladesh, but these are not running well (Salequzzaman, 2001). Semi-intensive shrimp aquaculture requires high investment in the form of seed, feed and other appliances (aerator, pump, soil/water quality checker, etc.) (Hussain, 1995). Presently, *Penaeus monodon* aquaculture is the dominant species farmed, but this depends entirely on the collection of wild seed. Over-exploitation of shrimp seed in natural water is not only causing ecological imbalance but also resulting in severe scarcity. Therefore, in order to sustain shrimp aquaculture, the establishment of *Penaeus monodon* or *Macrobrachium rosenbergii* hatcheries is an urgent need. However a reliable 24-hour supply of electricity must be ensured for its
sustainability. The integrated tidal power project will meet the electricity requirements. The following sections will discuss this further:

(a) **Electricity needs for hatchery technology:** There are two types of prawn/shrimp hatcheries: open water system and closed water system (also known as a recirculating system). Both will be used in the proposed integrated tidal power project. The open system hatcheries change 20-30% of their water on regular basis. The recirculating system uses bio filters for water purification. It needs to maintain 10-12 ppt\(^{130}\) water salinity and a temperature of 29-30\(^\circ\)C during the entire production cycle. Artemia\(^{131}\) and egg custard are required for newly hatched shrimp/prawn fry’s feed (Salequzzaman, 1989). This feeding system will continue for their whole larval period (about 30-35 days) and post larval period (about 7-10 days). All of these activities will need a continuous supply of electricity that could be supplied by the tidal power plant unit in this integrated system. According to Nazrul (1999), the growth and survival rate of hatchery produced prawn post larvae (PL) in gher system is 81% higher than natural harvest with a benefit-cost ratio of 2:1. Hatcheries will ensure the supply of seeds throughout the year, where natural harvest cannot.

(b) **Electricity needs for nursery technology:** Nursery ponds are an important component in the integrated tidal power project where survival rates of prawn/shrimp post larvae have to increase as high as 80% (Williams, 2001). Maintenance of the shrimp/prawn nursery is the most important factor after the hatchery system to ensure sustainability. Generally farmers directly stock post-larvae without acclimatisation in the water of their shrimp ponds/ghers which increase the mortality of the post-larvae. However commercial aquaculture systems require electric powered aerators to ensure optimum levels of acclimatisation. One solution is to rear the post-larvae in pocket gher/ponds (fig. 6.3).

Normally, such a pocket gher/pond is 2-20 decimals\(^{132}\) in pond size and the stocking density is from 600-2000 PL/decimal (Williams, 2001). They feed in the

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\(^{130}\) Parts per thousands.

\(^{131}\) Artemia is a life feed that looks like zooplankton and hatched from artemia cyst.

\(^{132}\) 100 decimals = 1 acre of land.
gher twice a day, once in the morning and then again in the evening. After 30-45 days farmers harvest their PL and stock them in large ghters/ponds. Under this system, the survival rate is around 50-80% (Nabi et al., 2000 & 2000a). But this condition will improve if oxygen is increased in the nursery pond using electrical aerators, achieving an increased survival rate of up to 95% (Salequzzaman, 1989).

(c) Electricity needs for prawn/shrimp processing plants:

Traditional fish/shrimp/prawn marketing systems are rarely considered viable, primarily because of the lack of preservation and processing facilities. As a result, aquacultural product becomes putrid and deteriorates in quality. For example, 30-33% of all harvested shrimp/prawn/fish soon becomes unsuitable for human consumption. This economic waste could be reduced through provision of cold-storage facilities, insulated and refrigerated transport systems and adequate supplies of ice. Therefore, the coastal aquaculture industry needs processing plants, in particular at the very end of the prawn/shrimp marketing chain. Generally, the owners of processing plants purchase raw prawns/shrimps from growers, and then export them after processing and packing. This processing
includes visual examination, sorting, cleaning, grading, weighing, packing (based on grades) and freezing (Salequzzaman, 1989). Electricity supply plays an important role in this processing system. In remote areas, there are no processing plants due to the lack of electricity. Presently there are around 122 prawn/shrimp processing plants in coastal Bangladesh but only 65 are in operation. The remainders have no electricity supply. In the integrated tidal power project, the processing plant will use tidal power.

(d) **Electricity needs for water purification:** Intensive shrimp aquaculture produces high yields, but it produces several wastes which create many environmental problems. For example, only 16.7% of supplementary feed (by dry weight) is converted into shrimp biomass, the rest is leached as faeces, metabolites, and dissolved in the water\(^{133}\), contributing to deteriorating water quality, particularly in high-density ponds. In high density ponds, total nitrogen and phosphorous, nitrate, silicate, orthophosphate, dissolved oxygen, and biological oxygen demand is increased and water visibility decreased throughout the grow-out period (Salequzzaman, 1989; Wirojanagud, 1986). This situation may improve by the application of aeration, bio-filtration\(^{134}\) and water recycling\(^{135}\). Depending on design and application, bio-filters have the ability to remove ammonia, nitrites, dissolved organic solids, carbon dioxide, excess nitrogen and other dissolved gasses, and suspended solids. Continuous supply of electricity is the main pre-requisite to maintain the bio-filter and recycling system in workable condition. Water reuse reduces pumping costs and retains energy normally used to heat water.

\(^{133}\) [http://www.prc.dircon.co.uk/philippine_aquaculture_industry.htm](http://www.prc.dircon.co.uk/philippine_aquaculture_industry.htm) (accessed on 23 January 2003).

\(^{134}\) Biofilter means the collection of wastewater purifying bacteria and other microorganisms that are attached on a substratum through which water will pass. The bacteria and microorganisms can accumulate the nutrient from wastewater and purify the water from the effluent of re-circulating systems. Biofilter is one of the most important pieces of equipment in intensive, semi-intensive and super-intensive aquaculture, and hatchery systems in modern commercial aquaculture.

\(^{135}\) A typical recycling system consists of a water supply, a water distribution system, tanks for holding fish, a filtration system (fig. 6.4), an aeration/degasser system, a heating/cooling system, and a building to house the system. It enables production to occur in a controlled environment, where losses to predators and seasonal drought do not influence production plans. Finally, it permits a reduction in water consumption and the production of large numbers of fish in a small area.
6.3.2 Tidal power integration for wastewater treatment

As mentioned in Chapter III and Chapter V, coastal Bangladesh produces a significant amount of wastewater from various sources. All of this wastewater in each coastal location of the proposed tidal power plant can be collected into the eutrophication pond and treated biologically by mussels and snails through utilisation of their feeding behaviour or system\footnote{The feeding system of aquatic mussel and snail involves filter feeding of the detritus and soft aquatic plants. They are hardy and withstand low dissolve oxygen in water and organic pollution. In their feeding system, they break down the complex bond of water pollutant and release the simplest form of nutrients like nitrogen, phosphorus and potassium, and clean the water (Huda, 2001).} (Dardignac-Corbeil, 1990; Korringa, 1976; Thai-Eng et al., 1989). This wastewater has been enriched by many nutrients which can grow microalgae and supply food for mussels and snails (Barnabe and Barnabe-Quet, 2000; Verdegem, 1997). Artificial aeration will ensure quicker purification. Large pond or commercial-scale purification needs electricity that will be supplied by tidal power. However some hard substrates and long-lines (made of rope and hung in the water) have to be placed on the eutrophication pond to act as a niche for mussels and snails which enhance this purification process. Young mussels (spat) and snails are collected from naturally abundant areas and transferred to the proposed treatment plant. The mussels and snails will not only serve to purify the water but will also provide shrimp and livestock feed. Sometimes mussels and snails accumulate harmful substances such as heavy metals and other organic substances. Therefore the mussels and snails...
will be not considered for human consumption, but will be utilised as shrimp and livestock feed after proper laboratory examination (to confirm that it is harmless), such as examination by HACCP system as described in Chapter V. This integration will produce up to 250 tonnes (fresh weight) of mussels/ha/year (if ensure the favourable conditions of the water) (Barnabe and Barnabe-Quet, 2000). Mussels are amongst the most efficient filters of small particles, retaining objects 1-2 µm in size with maximum efficiency (Conover, 1976). They can filter between 2-5 litres of water/hour that is, 90,000 litres per day for one rope (Barnabe and Barnabe-Quet, 2000; Rheault, 1989; Smaal and Prins, 1993). Lubet (1994) showed the following filtering capacities of mussels and oysters:

(a) A mussel, *Mytilus edulis* (18 month old) filters between 0.3 and 2 l/h per gram dry weight;
(b) A Japanese oyster, *Crassostrea gigas* (2 years old) filters between 2 and 6 l/h per gram dry weight; and
(c) A flat (European) oyster, *Ostrea edulis* (2 years old) filters between 1 and 3 l/h per gram dry weight.

The mussels and snails could also be utilised for natural pearl production, in demand in international markets that can produce foreign currency income. According to a recent study, it has been proved that coastal Bangladesh is an ideal place for natural pearl production137. Nutrients such as nitrogen, phosphorous and potassium from coastal catchment area fertilise the ocean and grow plankton. Sometimes plankton blooms occur on the surface of the water, photosynthesising through the utilisation of carbon dioxide, a key greenhouse gas. This process stores carbon dioxide in the cells of the ocean vegetation, where it ultimately becomes fish feed or falls to the ocean floor, creating deep-sea mulch. Plankton feeder fishes such as swordfish, cod, haddock, monkfish, sea bass, etc eat this plankton and provide more food for diminishing populations of fish. Through this process, more fish would start growing in places where the fish population has already declined (Plotkin, 2002). Finally the water treatment systems restore the quality of the water and allow it to be discharged to pond/river/sea/lake systems or used directly for the production of fish. The effluent

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treatment systems also produce a by-product in the form of bacterial sludge and a multitude of other organisms, which is now proving to be a valuable resource\textsuperscript{138}.

6.3.3 Restoration of mangroves and development of social forestry

Restoration of mangroves as a green belt is an important component of the proposed integrated tidal power model. As mangroves appear to be more amenable to transplantation and restoration than most other halophytes, it will easily adapt with a wide salinity and temperature fluctuation on the bank of the embankment and on the edges of the ponds (Alongi, 1998; Field, 1995). The methodology of mangrove restoration has already been established, because it has been practised for many years in India, Malaysia, Thailand, Bangladesh, and Burma as a successful and profitable forestry business (Alongi, 1998; Fortes, 1989). However, the most common practice is the development of monocultures of \textit{Rhizophora}. This species is easily adapted in the coastal area (Rice, 1991). This type of integration of mangroves with a tidal power plant could increase both fish/shrimp production and mangrove forest production without disruption of tidal power production. Again it is assumed that the mentioned integration will work better with a social forestry system (Mutaleb and Shaheduazzaman, 2001; Walker \textit{et al.}, 1991). In principle, the benefits will be distributed among concerned community people, the managerial organisation and government in a community-based coastal co-management system. The co-management of social forestry is a successful tradition in coastal Bangladesh, particularly with coconut and betel nut trees. However, the production of coconut and betel nut trees has been decreasing recently, because of unplanned and unsustainable shrimp cultivation and increases in salinity in the area. The integration of a tidal power plant will attempt to develop these plantations along coastal belt as a part of social afforestation program.

Restoration of mangroves and development of social forestry will have great significance from the ecological, economic and social points of view. Ecologically mangroves will develop a stable ecosystem with rich biodiversity. Economically and socially they provide for a native community, where the community peoples depend totally on mangroves and social forestry for their livelihood, cultural behaviour and

\textsuperscript{138} http://www.drydenaqua.com/sustain_aqua/sustaina.htm (accessed on 24 September 2002).
other such activities. For example, traditionally, coastal Bangladesh was famous for indigenous people's mat production from mangrove marsh grass (Meley, *Ciperus* species). But now production of this non-wood mangrove plant is seriously decreasing. The flower stalks of this plant are used to weave mats, locally known as ‘Madur’ which is a lucrative and familiar handicraft throughout Bangladesh and other foreign markets. Historically thousands of local indigenous women weave mats as a part time occupation, but they are now deprived of this source of income due to the unavailability of the raw materials (Millat-e-Mustafa, 2000). Recently some NGOs have succeeded in cultivating Meley marsh grass experimentally in the coastal low land. This crop achieves higher profits than rice on even small-scale shrimp aquaculture. According to my field survey of September 2000, it is known that coastal indigenous people are the inventors of this traditional knowledge-based handicraft (Miah, 2000; Millat-e-Mustafa, 2000). Presently indigenous groups or tribes are few in number. Only 20 identified groups inhabit the South-West Coastal Region of Bangladesh; the women are the actual weavers of this kind of handicraft (Miah, 2000). The integrated tidal power project could take the initiative to further develop the *Ciperus* species on one part of the dyke around shrimp aquaculture ponds to provide weaving materials for the indigenous women.

### 6.3.4 Integration of paddy/fish-shrimp-paddy cultivation

Paddy/rice is the main food in Bangladesh, but paddy cultivation has seriously decreased since the commencement of shrimp cultivation in the coastal region, due to increased salinity. Salt accumulates in the crop-root zone in higher saline soils. More than 3 ds/ml soil salinity seriously affects crop seed germination, particularly at early vegetative and reproductive stages (Siddique and Chowdhury, 2000). Therefore development of salt tolerant high yielding varieties (HYV) of paddy and crops is an essential part of the sustainable agriculture system in coastal Bangladesh. Agricultural scientists have developed salt tolerant varieties of agricultural crops by using both traditional and modern biotechnological methods which involve identifying and developing salt-tolerant traits and species (Seraj and Salam, 2001). According to Seraj and Salam,

> “about 70 different cultivated plants have been selected by using both traditional and modern biotechnological methods in over 3,600 field tests on more than 15,000 individual agricultural tracts (of saline contaminated) in coastal Bangladesh without any negative occurrences (Seraj and Salam, 2001, p.25)”.

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These crops include rice, maize, wheat, oats and barley; soybean, sunflower pea and bean; cotton, sugar beet, tobacco, cocoa and coffee; tomato, papaya, many citrus fruits, and other fruits; and poplar and aspen trees (Aich et al., 1991). In the proposed integrated tidal power model, salt tolerant HYV varieties of rice and food crops including vegetables are important components that could maximise the sustainable benefit of crop production (Haroon and Alam, 1992). The integrated model will follow the methodology developed by the agricultural extension department of Bangladesh using rapid and deep tillage by power tillers that reduce soil salinity through breaking the capillary movement of saline groundwater and decreases the higher osmotic potential of salt. This proposed system will produce up to 6 tonnes/hectare paddy production by planting of BRRI 41 rice variety in the coastal reason of Bangladesh. Integrated paddy cultivation and aquaculture is a traditional practice in rural Bangladesh and many other Asian countries during the monsoon season (fig. 6.5).

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Fig. 6.5: Integration of rice-fish cultivation in coastal Bangladesh (Photograph: M. Salequzzaman, October 2000).

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139 Bangladesh Rice Research Institute (BARI) invented a salt tolerant rice variety.
This joint rice and fish/shrimp cultivation could support the cultural norms in coastal Bangladesh, given that rice is the main cereal food and fish is the main source of animal protein in the traditional rural diet (Asaduzzaman, 1979). This paddy cum fish/shrimp cultivation decreases the use of pesticides, due to fish feeding on the pest. Therefore traditional rice-fish/shrimp cultivation could be introduced into the integrated tidal power project with scientifically measured utilisation of space, time and resources to ensure sustainable increases in agricultural production. For example, crop residues (rice bran and straw) can be used to feed fish (bran) and livestock (bran and straw); pond mud can be used as manure in rice fields and vegetable plots, and livestock manure can be used for fertilising fishponds and rice fields. Bangladesh Fisheries research Institute (BFRI) has successfully invented this type of multi-community commodity farming and distributed the technology among many remote villages of Bangladesh (FRI, 2001; Mazid and Gupta, 1995). This multi-commodity farming system is more economical and environmentally sustainable than a monocropping system (Datta et al., 1999). In addition, there are two crops of paddy cultivation possible in the integrated system, such as long-stem transplanted Aman140 in Kharif season141 and HYV in Rabi season142.

In both seasons, a single crop of fisheries (both fish and prawn/shrimp) aquaculture could be integrated with paddy cultivation (Salequzzaman, 2001). These fisheries include the short-cycled fish and crustaceans, such as silver barb (Puntius gonionotus), tilapia (Oreochromis niloticus), common carp (Cyprinus carpio), prawn (Macrobrachium rosenbergii) and shrimp (Penaeus monodon) (Haroon and Alam, 1992; Aich et al., 1991). Estimated production levels are Aman rice 0.6-3.0 tonnes/ha and a second crop of HYV rice, up to 4.5-5.0 tonnes/ha, along with 0.70-0.80 tonnes/ha fish (major carps, common carp and silver barb at a stocking density of 6,000-9,000/ha) (Haroon et al., 1994). In this production system, there is no need for any feed or extra fertiliser other than those that are normally applied for paddy cultivation.

140 A variety of rice that grows well in wetland areas, the root planted in the bottom of water and the body semi-submersed in the water.
141 Summer and rainy seasons covering the duration of April-September.
142 Winter season covering the duration of October-March.
6.3.5 Integration of fish-shrimp-livestock production

The integrated fish/shrimp pond described above can also be integrated with poultry-duck farming. In this system, a poultry house is constructed to hang above the water of the pond in such a way that poultry droppings fall in the pond. The droppings produce plankton, providing food for plankton feeder fish, such as silver carp. To control the water quality of the pond, oxygen needs to be supplied at certain intervals by using either an electric aerator or charged battery operated aerator. In this way, the poultry droppings and pond wastes are recycled for fish production. This system also maintains good water quality for domestic purposes (except for drinking) and the fish do not require any supplementary feed or fertiliser. For example, 500 birds or ducks or chickens/per hectare have been found to be a standard density that produces 4.0-6.0 tonnes/ha/yr of fish, up to 240 eggs/bird/yr and a net profit of up to Tk. 0.16-0.18 m/ha/yr (Hussain and Uddin, 1995; Latif et al., 1993). To neutralise the excess toxic substances in water and soil, lime (CaCO₃) has to be mixed at a certain interval, and the whole pond dried once per a year. In addition, the fish yield has to be examined for human consumption (to ensure safe food) through the regular application of HACCP. If toxic levels increase at any time in the yield, application of lime will decrease this toxicity (FRI, 2001, Salequzzaman, 1989). Recently this integrated system was popularised widely in Bangladesh, because many jobless youth made themselves self-reliant economically through fish-livestock farming (fish-duck cultivation, fish-chicken cultivation, etc)¹⁴³. Therefore it is proposed that the coastal poor will benefit greatly from this tidal power project by enhancing integrated fish-shrimp-livestock production.

6.3.6 Integrated with horticulture

The integrated aquaculture-livestock farming could also be integrated with a horticulture system, with each component benefiting the others through proper utilisation of various components or wastes in the systems. In this integrated system, the pond dyke could be utilised for the production of large-scale seasonal horticulture (fig. 6.6). In this diversified gher/pond system, a dyke crop¹⁴⁴ yield would has to contribute a significant income to the local farmers.

¹⁴⁴ The crops culture on the dyke, called dyke crop.
from fruit, fuel wood, lumber and vegetables (tomato, bean, pumpkin, bitter gourd, mustard, brinjal, and others).

A dyke cropping system will increase the integration function between aquaculture and agriculture which will improve the irrigation system to existing agricultural practice of coastal Bangladesh. Presently this type of dyke cropping system has already been initiated in coastal district of Bagerhat. This practice has now increased the resource utilisation and conserved a diversity of flora and fauna. High diversity means having lots of different types of beneficial plants and animals. High diversity in horticulture helps with the goal of having back-up links through creation of greater interaction among plants and animals. It is better for the soil structure, and minimises pest problems typical of monoculture. When we have many layers of plants from ground covers to tall trees it is called ‘stacking’ or ‘layering’. Stacking provides microhabitats for plants and animals.

Fig. 6.6: Integration of horticulture on the dyke of shrimp aquaculture pond (Source: GOLDA Project, CARE-Bangladesh (Chapman and Abedin, 1998).

Sometimes the net profits of this seasonal horticulture might be much higher than that from the prawn/shrimp component of a typical gher/pond (Chapman and Abedin, 1998). In recent years, more farmers have become interested in dyke crops with fish or prawn/shrimp aquaculture (Ahmed and Shamsuddula, 2001). Current statistics show that coastal people are more interested in integrated dyke farming because they can produce shrimp/fish, poultry eggs, and vegetables from the same land without any fertiliser or pesticide. All of these products are organic in nature, therefore they are
better for people’s health. In this way, the integration of horticulture with a tidal power plant and other components might earn a large amount of money that could reduce the cost of loans for local poor people. In recent times, a similar type of study has shown a significant reduction of farmers’ dependency on loans in Bagerhat district of Bangladesh (Ahmed and Shamsuddula, 2001).

6.3.7 Integration of the mining industry

The beach sand of coastal Bangladesh contains several important heavy minerals like ilmenite, zircon, rutile, monazite, leucoxene, kyanite, magnetite, garnet and yitium leucoxine that are known as 'Black-Gold'. The estimated present reserve of this ‘black gold’ is about 4.30 million tonnes (Manik, 1999). Recently an Australian company expressed an interest in exploring the viability of this black gold, in an area of 14,700 hectares on the eastern coast of the Bay of Bengal (Manik, 1999). However, a prerequisite was a reliable electricity supply which could be generated by tidal power plant. Sometimes mining industries may create environmental impacts (such as many mining industry in Australia145) therefore a precautionary measure should be taken in integrating this component. In addition, environmental impact assessment (EIA) has to be conduct before the whole process.

6.3.8 Integration of the salt industry

Historically, coastal Bangladesh has been famous for quality salt production since the British regime (1757-1947) (fig. 6.7). This salt was distributed all over the country until 1970, and it was exported to many European Countries until 1945 (Haider, 1999). The traditional salt production system is still used in some coastal areas during May to September (before the rainy season starts). Generally, shrimp aquaculture is started as a supplementary yield, with ponds being created by throwing up embankments around tidally inundated lands after the end of salt production. Salt water is allowed into the ponds during the dry season where it is evaporated by the sun. Numerous coastal ethnic/indigenous families have been engaged in this activity over many generations (Lakshmi and Rajagopalan, 2000). However, this traditional salt production system is now becoming extinct. As a result, the government has decided to import a large quantity of salt to avert a possible

crisis in the country. For example, a total of 7.75 lakh\(^{146}\) tonnes of salt were produced in the country during the 2001-2002 season against the annual requirement of 8.82 lakh tonnes leaving a deficit of 1.07 lakh\(^{147}\) tonnes.

Most of this produced salt has no iodine content. Iodine is an important component of human body, which mainly comes from salt and marine food. As a result, a large proportion of the rural population of Bangladesh suffers from goitre disease, due to lack of iodine. More than 47\% of the total population (45 million people) are victims of goitre, another 25 lakh are hyperthyroid patients and some 20,000 are suffering from thyroid cancer - all caused by deficiency of iodine in the human body\(^{148}\). To ameliorate this situation, the proposed integrated tidal power project will facilitate the production of a large amount of quality sea-salt, ensuring the component of iodine in the produced salt (Rasheed \textit{et al.}, 2001).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure_6.7.png}
\caption{Traditional practice of salt production in aquaculture pond in Cox’s Bazar, Bangladesh (Photograph: M. Salequzzaman, October 2000).}
\end{figure}

\textbf{6.3.9 Integration of desalination process}

Access to safe drinking water is the fundamental right of every citizen of any country, and access to it is one of the

\(^{146}\) 10 lakh = 1 million.


\(^{148}\) Personal communication to President, Society of Nuclear Medicine, Bangladesh Atomic Energy Commission, Dhaka, November 2002.
most important determinants of health and socio-economic development (Cvjetanovic, 1986; Park, 1993; WHO, 1993). Presently, coastal peoples of Bangladesh have restricted access to sources of clean drinking water. Several factors are responsible for this situation, such as an increase in salinity in both surface and underground waters and arsenic pollution in underground water (Rahman et al., 2001; WHO, 1993). In the past, coastal peoples collected fresh water in a traditional large pond and preserved it by participatory management by the local community. Many of these ponds are now contaminated by saline water. The integrated tidal power project could supplement potable clean drinking water by developing a large-scale desalination plant powered by electricity. Salt will be produced as a by-product from this desalination process, which is fed into the salt industry. Again, the whole desalination plant could be managed on a community-based co-management system.

6.3.10 Integration of community finance and microcredit system

Most of the present coastal investment of Bangladesh is not sustainable due to high interest rates. As previously mentioned, most coastal people are very poor. They have little capacity to invest money into their land for shrimp aquaculture or agriculture and depend on borrowing money from moneylenders at high interest rates. In most cases, after harvest, they lose everything as they have to repay the moneylenders and thus local stakeholders (farmers) are getting poorer and poorer. As a result, their land holdings have moved to the control of outside business people, who are mainly interested in economics and not the livelihoods of the coastal people or coastal ecology. To overcome this economically unsustainable system, the proposed tidal

\[149\] Drinking of arsenic polluted drinking water will mobilise the arsenic in the human body that causes the disease of ‘arsenicosis’ (Rahman et al., 2001). Presently, this pollution is a serious environmental health issue in Bangladesh, because the peoples are mostly dependent on groundwater for drinking (Salequzzaman, 1996a). Thus, currently, millions of people in Bangladesh, including the coastal area, have been suffering from arsenicosis disease (Salequzzaman, 2001a). The original source of the groundwater arsenic pollution is controversial among scientists, researchers and policy-makers (Chakraborti, 2000; Ishiga, 2000). Most scientists believed that groundwater in Bangladesh is contaminated with As naturally in alluvial and deltaic sediments, although some believe that excessive and unplanned exploitation of ground water by hand tubewells and deep tubewells are the main reasons for this arsenic pollution (Nishimura et al., 1993; Robins et al., 2002; Salequzzaman, 1996).

power project will offer the microfinance/microcredit system\textsuperscript{151} of financial management for local small- and medium-scale farmers allowing local poor people to return the benefits. The coastal stakeholders through consultation among themselves on the basis of community-based co-management principles would manage this financial facility. This micro-finance and micro-credit system has recently been established in parts of Bangladesh by the Grameen Bank, CARE-Bangladesh, and some other organisations and its principles are now used world-wide (Abedin \textit{et al.}, 2001; Yunus, 1998). As this system has already been established and this thesis is more technically oriented, the thesis will not go into further details of micro-finance and micro-credit procedures. Siddiqui and other researchers are now working on the details of this financial system (Siddiqui and Newman, 2001). The main benefit of this system includes local stakeholder's access to low cost loan sources especially from banks, government organisations and some NGOs, strengthening the knowledge and skill of coastal people on banking loan policies, procedures and household financial management; efficient uses of resources and wealth maximisation; and enhancing the coordination between different banks and national organisations with local stakeholders (Siddiqui and Newman, 2001; Yunus, 1998).

Recently, some organisations have had success in applying this financial system in some parts of coastal Bangladesh. For example, the GOLDA\textsuperscript{152} project of CARE-Bangladesh has successfully operated the micro-finance/micro-credit system in the southern areas of Bagerhat and Khulna districts through the introduction of fresh water prawn (\textit{Macrobrachium rosenbergii}) and carp polyculture (Abedin \textit{et al.}, 2001). Under this system, the local stakeholders were willing to generate a common fund by saving small amounts of money through a-group approach at certain intervals (fortnightly/monthly) of the prawn aquaculture yield. Then they saved their collected money in a bank account, which is reliable and easily accessible. After a few months, the benefits would be disbursed among the members from this common fund. This system is also known as ‘self-help group’ which reduces the dependency of coastal

\textsuperscript{151} The microfinance/microcredit system is a process that always considers the benefit of local poor peoples, where financial authority does not lose their capital or business. Because they are receive their capital with interest without any intevention (Rutherford, 1994; Siddiqui and Newman, 2001).

\textsuperscript{152} Greater option for local development through aquaculture.
poor stakeholders on high cost loans. Women’s participation also seems significant in this approach (fig. 6.8).

Fig. 6.8: Women’s participation in-group situation for their socio-economic development through micro-finance activities in Bagerhat District, Bangladesh (Photograph: M. Salequzzaman, October 2000)

6.3.11 Integration of the battery charging stations

The concept of manually transporting batteries between charger shop¹⁵³ and household is now practised in some parts of coastal and other rural areas of Bangladesh. This system is becoming popular very rapidly, because it meets the peoples’ own electrification needs. Therefore, the integrated tidal power project will have a separate battery charging station near the main tidal power production area. The battery charging station will consider different battery charge capacities and the appropriate equipment system. The charged batteries would be manually transported (predominantly by bicycle) in order to be recharged at local charging stations. The financial resources would be made available by the community-based co-managed micro-credit/micro-finance system, where the community loan could be extended to individual households to enable the purchase of household electricity for family needs and small-scale commercial and industrial activities. The battery charging facility would also train the local community with operation advice and demonstration of DC¹⁵⁴-based equipments.

¹⁵³ The shop where DC (direct current) battery is to charge from the generator, other DC battery or grid connected electricity.
¹⁵⁴ Direct current.
6.3.12 Integration with education, training, electronic commerce and telecommunication systems

Modern scientific education systems rely on computers and other sophisticated equipment that require electricity. In addition, an electricity supply is the main prerequisite for electronic commerce and telecommunication systems. In addition, these modern systems need human management skills. All of these facilities and human skills are now absent in coastal Bangladesh. Telecommunication and electronic commerce are currently prime business factors in the modern world and in the globalisation process as they bring everyone much closer together.

A tidal power plant will ensure electricity supply in the remote locations of coastal Bangladesh. The tidal power plant project needs to include training, education and awareness programs for the development of human skills. Thus the process will be able to establish e-commerce and telecommunication facilities that will enhance the globalisation process from this remote coastal area. Recently, solar-powered community centres\textsuperscript{155} have been established in many remote locations around the world, where e-commerce and other associated facilities have been established allowing the community people to operate e-commerce of their native cultural products which earns a significant portion of foreign currency. It is assumed that the proposed integrated tidal power project could provide such facilities and bring wealth into the local coastal community of Bangladesh through marketing their indigenous products.

6.4 Prerequisites for achieving sustainability of the model

The sustainability of the integration of various components of the proposed tidal power model depends on it being not only technically feasible, but also economically proven, environmentally safe, and socially and culturally adaptable. Set out below are factors required for the sustainability of the model.

\begin{footnote}{155} Personal communication to Mr. John Haugland, Regional Economist at the U.S. Environmental Protection Agency, Region 5 (innovative approaches to sustainable development) \url{http://www.greenstar.org/introduction.htm} (accessed on 17 August 2002).\end{footnote}
6.4.1 Application of environmental impact assessment and maintaining biodiversity

Integration depends on all the elements working together to succeed. If one part of the integrated system collapses for social, technical or economic reasons, the whole system may also be jeopardised. This problem could be partially forestalled by the application of thorough and genuine environmental impact assessment\(^{156}\). Many environmental and socio-economic problems including the production cost of the tidal power plant have been significantly reduced since the 1970s, mainly due to the application of environmental impact assessment (Furubotn and Richer, 1991; Lincoln-Smith, 1998; Warnock and Wilson, 1972). Environmental impact assessment’s legislation was enacted in Bangladesh in 1992, requiring the model to be prepared and exhibited publicly for some types of developments and activities. The proposed integrated tidal power model has to be assessed for its environmental impact. It is noted that coastal Bangladesh has already been badly affected by the construction of embankment and sluice gates, because these were constructed without conducting environmental impact assessments. Therefore an environmental impact assessment is an essential component to ensure the sustainability of any coastal development (Frihy, 2001).

6.4.2 Political will and community-support

The introduction of tidal power plant in coastal Bangladesh is an innovative approach, so it needs strong political will and community-support for its long-term sustainability. Recently the government of Bangladesh has taken a decision in its development strategies that strong political will, efficient administration and people’s participation are essential for achieving sustainable development (United Nations, 2002). For this purpose, a strong commitment from both government and opposition is vital to support the activity of sustainable development by extending a helping hand to poor people to reduce poverty and income inequality, conserving nature and protecting the environment. The opposition parties and all community peoples will be required to cooperate with each with other and the government. Some successes have already been achieved through this strategy. For example, recently, a ban on polythene

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\(^{156}\) EIA is a tool for managing the environmental impact that includes assessment of existing environment in a system, the possible impacts of any interruption, and the possible mitigation measures with least cost involvement and least impact to the surrounding environment.
shopping bags\textsuperscript{157} and another on two-stroke three-wheeler vehicles\textsuperscript{158} have been successful through multi-parties cooperation among government, opposition, scientists, businessmen and community people, and the expression of strong political will. Strong support from political parties will facilitate the community participation\textsuperscript{159}. Thus it is believed that the success of integrated tidal power project depends on a strong political will and community-support.

6.4.3 People's participation

Local communities would be directly involved in the integrated tidal power project through a community-based co-management system which is an essential prerequisite for the success of the integration process and ensuring sustainable development (Prccebu, 2001). The greater the involvement of local communities in the co-management system in the form of assessment, planning and management process, the greater opportunity for sustainable outcomes (Prccebu, 2001). Through a participatory consultation process, the community will deliver essential information to enhance the sustainable development process (Ruddle, 2001). For sustainability, this community participation should have gender sensitivity, appropriately designed plans and programs that significantly focus on the community’s environmental, social, cultural and economic issues and be accepted and supported by the majority of community members from various stakeholder groups\textsuperscript{160} (Christie \textit{et al.}, 1994; Ruddle, 1998; White \textit{et al.}, 1994). Partnerships among the governments, NGOs, private sectors, different departments and institutions including commercial fisheries industry and other community groups can be encouraged by confirming their roles and responsibilities. When devolving management responsibility to local communities, preference would always be given to indigenous knowledge and resource management practices. In some cases, it may be necessary to adopt enabling legislation. Similarly, assistance may be needed for communities to develop managerial and organisational skills. In the whole approach, direct

\textsuperscript{157} Because, dumping of the shopping polythene bag to land and water creates environmental hazards, such as blockage of sewage line, decrease the agricultural production, etc.

\textsuperscript{158} Because, it emit air pollutants, such as NOx, CO\textsubscript{2}, other toxic gas and shoots.


\textsuperscript{160} The stakeholders in the fields of coastal integrated sustainable development are academicians, journalists, NGOs, CBOs (community-based Organisations), community people from all professions as well as autonomous and government development/agencies.
government intervention is necessary, particularly for the change of government staff’s attitudes and approach. There are numerous participatory tools available now to encourage community involvement in each step of the planning process. One of such tool is participatory coastal resource assessment\textsuperscript{161}, which could be successful through raising the public awareness that will enhance information and electric communication facilities among coastal residents (Precebu, 2001). The information and electronic communication are essential, in particular for the reduction of vulnerability to natural hazards, such as early cyclone warning.

\textbf{6.4.4 Building the institutional capacities for the integration process}

The institutions contributing to the integrated tidal power project will need to allocate sufficient resources in order to achieve the goals and strategy of integration. The engine to drive the process includes well-trained and experienced staff. The capacity to manage the process can be developed as part of the strategy. The following processes could maintain this institutional capacity (Beckenstein \textit{et al.}, 1995; Courtney and White, 2000; Sorensen and McCreary, 1990):

- (a) An equitable and efficient decision-making process;
- (b) Use of the best available knowledge about how the relevant ecosystems function;
- (c) Participation of resource users and all those affected by management decisions in the decision-making process;
- (d) Capacity to resolve differences of interest;
- (e) Ability to employ economic policy instruments strategically;
- (f) Integrated, simple and effective regulatory instruments; and
- (g) Public investment for the protection of coastal ecosystems and management of renewable resources.

\textbf{6.4.5 Maintaining biodiversity and ecosystem health}

“Integrated water resources management should be sustainable and optimise water security and human benefit per unit of water while protecting the integrity of ecosystems” (RBI News, 2002, p.3).

\textsuperscript{161} Participatory coastal resource assessment is a process of identification, quantification and management system of coastal resources by community peoples (Precebu, 2001).
Any natural resource management actions will revolve around resource allocation, trade-offs, careful monitoring and enforcement on the basis of ecological integrity (Keyun, 1997; Parkes and Panelli, 2001). In the integrated model, therefore, the management of integrated ponds and all other components must maintain ecological sustainability. This includes biodiversity of coastal resources, the indigenous community, native varieties of flora and fauna, and also the socio-cultural integrity of coastal Bangladesh.

### 6.4.6 Availability of finance

The global community has recognised the importance of global warming and the Kyoto Protocol that set binding targets for the developed countries to reduce their individual emissions of greenhouse gases within a specific time frame (Chapter III and Chapter IV of this thesis). The trading of carbon credits and the CDM would enable developing countries to trade their unused entitlements of greenhouse gas emissions to developed countries. The resulting funds should be used to support sustainable development by targeting the most vulnerable countries through the specific adaptation goal/goals. As Bangladesh is a developing country and vulnerable to climatic threat, it is considered a prime candidate for allocated funds to finance the sustainable integrated development of coastal Bangladesh through small-scale tidal power plant. Smaller scale ‘new renewable’\(^{162}\) and energy efficiency projects will benefit from simplified CDM rules and procedures, which were finalised in Marrakesh\(^{163}\). The board of COP7 (Conference of Parties 7) recommended simplified modalities and procedures for small-scale CDM project activities on renewable energy projects with a maximum output capacity equivalent of up to 15 MW\(^{164}\) (Beck, 2002). The proposed small-scale tidal power projects can produce electricity in the range of 2 MW-10 MW from each combined plant. Therefore, the integrated tidal power projects of coastal Bangladesh are eligible for this fund.

\(^{162}\) New renewable sources include: small-scale hydro, wind turbines, photovoltaics, solar and geothermal, biomass, tidal and wave energy.


\(^{164}\) Mega-watt.
The small-scale tidal power project is also a probable candidate for the UNEP\textsuperscript{165} Financial Services Initiative given that the proposed project includes dam and dyke-building that will keep rising sea-level out of coastal cities and farmlands, control damage to farmlands and crops resulting from weather extremes created by greenhouse gas. Thus coastal Bangladesh needs renovation of the roads and infrastructure that are associated with extreme weather, such as cyclones and tidal surges (Toepfer, 2001). The Global Environment Facility (GEF) may also fund the tidal project as a mitigation measure of climate change. However Bangladesh must also do a number of things in order to take advantage of the international negotiations on climate change. It must recognise the issue of climate change in the medium to long term and prepare for it accordingly. In the short term, it needs to use its own resources to maximum benefit in this area (Huq, 2001; Simms, 2001).

6.5 Sustainable development in coastal Bangladesh through integration of tidal power plant
As mentioned before coastal Bangladesh has an insignificant supply of electricity which is an important precursor for its sustainable development. This section will discuss tidal power as an option for integration of sustainable coastal development in Bangladesh.

6.5.1 Adaptation of small-scale, low-cost and locally available technology
Many researchers and scientists (such as Brinkworth, 1998; Brokensha, 1986; Calderon and Alvarez-Villamil, 2000; Kazmierczak and Caffey, 2001; Ruddle, 1999; Sutton, 2001; Thomas, 2002; Yencken and Wilkinson, 2000) suggest that small-scale development from a grass-roots level in a remote location is the most favourable option for the sustainable development of the coastal region, in a developing country like Bangladesh. Charlier stated:

“….‘small is beautiful’ either out of financial necessity or, more probably, because a major plant would provide power to a large region, without solving the plight of many small areas for the electrical energy needed to support an embryonic industry or to save it from abandon due to the lack of price competitiveness (Charlier, 2001, p. 407)”.

\textsuperscript{165} United Nations Environmental Program.
The waterwheel or paddle wheel is one of the oldest known sources of small-scale hydropower which would now be adapted to the generation of tidal power (Frau, 1993; Day, 1994). Small-scale tidal power plants can be built by additional civil engineering construction work on existing coastal embankments (ESCAP, 1998; ISTP, 1999). The extra work required is simple and low-cost, mainly for the support of the tidal wheel in between the sluice gate opening. The water of the impounded barrage on the inland side is released through the tidal wheel, once the tide on the ocean side has receded. The sluice gate structures of the coastal embankments in Bangladesh allow the inflow of water over a relatively short period of time to maximise water movements (Salequzzaman and Newman, 2001). The tidal wheels can be made locally, making them comparatively inexpensive to build and install. It is assumed that new environmental impacts would be minimal as the existing tidal barrages that were built for flood protection have already affected the surrounding environment (Newman et al., 1999). Therefore it becomes possible to utilise tidal power without the high capital cost and significant environmental impacts of paying for the coastal engineering normally required.

### 6.5.2 Maximum integration of coastal resources

The proposed integrated model of tidal power has to bring together various coastal resources, sectors and values. The proposed integrated model involves the ecological, economic, cultural, social and other coastal values associated with all relevant resources and their usages that will affect decision making at various levels of governments, departments and authorities, NGOs and, other community and industrial organisations (DANCED/EPU, PMD, 1994; Demuth, 1999; UNCED, 1992). If successful, this integration will lay a foundation for sustainable coastal management, because it involves the adjustment of human activities in such a way that local communities will receive maximum benefits through community development, protection of lives and livelihoods, while mitigating the consequences and conflicts of human activity (Crawford, 1991). The proposed integrated model would also involve the community-based co-management of coastal resources that follow the sustainability principles of Agenda 21. The benefits derived from such management accrue to the local residents, thus it is imperative that the project is implemented successfully (White, 1989). Multiple uses of tidal barrages and generator housings may also assist the financial sustainability of the whole concept. The same multiple
utilisations also exist in the largest tidal power project at La Rance in Canada (Charlier, 2001).

Although the power produced from the proposed tidal wheel will not be very large, its value lies in how it can be applied to create a more sustainable coastal development. The model (fig. 6.1) sets out how a coastal village could create wealth from shrimp farming and livestock production, along with rice cultivation, in a way that is more sustainable than what currently occurs. The main requirement for the success of this project is electricity, enabling a more efficient, focused development involving integrated waste management. Therefore the integrated tidal power model will fulfill the basic sustainable development principles, such as the protection of the ecology, socio-cultural (or community) development and economic prosperity (United Nations, 2002). Sustainability is unique in its extent, including such varied sectors as energy, natural resource use, climate, waste management, technology, agriculture, water supply, international security, politics, community and family relations, and human values (Flint, 2000; Keyun, 1997). In addition, the proposed model not only embraces wisdom and stewardship in the management of natural resources, but also considers fulfilment of basic human needs for present generations, without compromising the ability of other species sharing our world or future generations to meet their own needs (UNCED, 1992).

The integrated model will again provide ecological integrity through the development of a green belt, wastewater treatment plant and environmental monitoring and evaluation systems. This diversity and integration enhance ecologically sustainable development because the whole system will develop multiple links to support each element (for example, paddy cum shrimp cum livestock cum horticulture production).

The economic development of the integrated model is very closely linked to a locale's stewardship of natural resources, environments, and people (Flint, 2000). The model again reintroduces traditional tidal irrigation (off-tide and in-tide) and fertilisation systems, where the production of native local variety of crops (such as, rice, pulses, etc) would be enhanced on a cyclic rotation over the whole year (Gupta et al., 2001). This rotation of crops, particularly leguminous fodder and forage production, would enhance promote the livestock feed situation as well as add ample biomass to the land.
to reduce hardness and salinity and increase its fertility. In addition, the aquaculture pond would be fertilised by application of either mineral fertiliser or manure in the form of fresh droppings, dried dung and others. After these inputs, mineralisation of organic matter would occur through natural process of bacterial decomposition following ecological sustainable development principles such as, oxygenation, recycling of water, controlling the chemical composition of water and pH (Costa Pierce, 1989). The following discussion will explain how the proposed tidal power plant will maximise the integration in coastal Bangladesh.

6.5.2.1 Forestation, salinisation, desalinisation and alternative cropping will increase integration and ecological sustainability

The reintroduction of mangrove forest and other native forests would decrease salinisation of the area and increase biodiversity in the integrated tidal power project. In addition, the planting of appropriate salt tree species, extraction of freshwater by desalinisation, irrigation of freshwater by flushing cultivation of salt tolerant paddy and shrimp, alteration of salt tolerant shrimp and freshwater prawn aquaculture, and natural salt production would better control the salinisation process (Barua, 1993; White, 1997). The new ‘greenbelt’ would provide habitat for birds, reptiles, molluscs, and other species, and the aquaculture system will produce fish and shrimp species from the hatchery through artificial insemination techniques. Therefore many rare and endangered aquatic species could be saved by this facility. Bagda (Penaeus monodon) and Golda (Macrobrachium rosenbergii) are salt and fresh water shrimp varieties, respectively. But if they have a long physiological adaptation, both can grow in fresh water and saline water (Nabi et al., 2000a). Thus in the integrated tidal power project, Bagda and Golda can grow over the whole year by adding aeration and acclimatisation technology (FRI, 2001; Salequzzaman, 1989; Salequzzaman, 2001; Wheaton, 1977). In addition, both Golda and Bagda can be profitably produced with different kind of fresh water and marine commercial fishes, such as Catla catla, Hypophthalmichyes molitrix, Labeo rohita, Mugil sp., Ctenopharyngodon idela, Puntius gonionotus, Cyprinus carpio, Cirrhinus mrigela, etc (Karim and Aftabuzzaman, 1999).

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166 Source: Informal interview from agricultural extension department of Bangladesh.
In order to control ground water salinity, the surface water would be used for irrigation in such a manner that the irrigated lands intercept drainage waters before they are returned to the freshwater ponds (FAO, 1992; Newman and Mouritz, 1996). When the drainage water quality has deteriorated, it would be released through a special outlet to primary treatment pond. This strategy would conserve water, sustain crop production and minimise salted land and groundwater (FAO, 1992).

### 6.5.2.2 Decrease the colossal loss of biodiversity

The hatchery unit of the integration would produce healthy fry of different categories of prawn, shrimp, and coastal fish, based on demand in the market thus decreasing dependency on naturally collected seed larvae (Thai-Eng et al., 1989; Wheaton, 1977; Wickins, 1986). The reliability and demand for quality hatchery-produced fry is always higher than for naturally caught fry (Baconguis, 1991; Salequzzaman, 2001). They are comparatively larger in size and their survival and growth rate is better than that of PL obtained from the wild (Williams, 2001). Use of farmed fry would reduce the loss of biodiversity of many species of aquatic organisms and fish, and their habitats (Gain, 1998). Local people would manage the hatchery, and hence the local poor may benefit if the project is implemented well (Kay and Alder, 1999).

### 6.5.2.3 Waste minimisation

Waste management in coastal Bangladesh is a complex issue. Large amounts of waste arise from shrimp aquaculture in the form of dissolved nutrients and suspended solids. Primitive treatment systems such as natural sedimentation to eliminate suspended solids are in use before final discharge at a very limited number of farms. The effluent produced by coastal shrimp ponds could be treated before final discharge to the natural water body or surrounding environment by using sedimentation (physical treatment) and filtration (biological treatment) with minimal cost (Salequzzaman 1996 & 1996a; Wheaton 1977a; Wirojanagud, 2002). Use of an oxygenation process becomes possible through the availability of electricity as it allows the use of an air-blower machine to enhance the sedimentation-filtration process (Wheaton, 1977a). Surface aerators may also reduce the problem of China virus (O’Leary, 2001).

### 6.5.3 Social equity and community capacity building

Social equity refers to fairness among community members; that is, even handedness
both economically and environmentally as well as in all aspects of social wellbeing (Danner, 2000). The successful implementation of the proposed model would aim to develop an equitable distribution of economic and environmental costs and benefits, critical community services (such as education, health care, communication and others), and opportunities for local communities to participate in the decision-making process, including the most disadvantaged groups such as, women, young people, indigenous people, and/or racial/ethnic minorities, thus improving their quality of life. Danner stated:

“Sustainable actions truly occur when we find the means to balance economic development with environmental protection, while also insuring that the most disadvantaged people in our society are provided the ability to improve their quality of life (Danner, 2000, p.3)”.  

Equity is central to sustainable development: without equity considerations, the sustainability objective cannot be achieved. The proposed integration project would incorporate this equity in the following ways and play an important role in community capacity building activities:

6.5.3.1 Develop community-based microfinance
The proposed integration model would provide microfinance to marginal fisherman, farmers, local poor people, deprived women’s groups and other coastal stakeholders. This microfinance would help to develop socio-economic and cultural integrity, and improve the livelihood of coastal stakeholders. For instance, shrimp aquaculture practices in coastal Bangladesh require large amounts of capital to enable commercial operations due to the high cost of inputs\textsuperscript{167}. Microfinance would provide this money to disadvantaged groups in the coastal region.

6.5.3.2 Improve the income of local farmers
The integrated tidal power project would encourage local farmers to use integration techniques because integration would be more profitable than non-integration of resources. For example, the integration of prawn/shrimp farming with those of rice,

\textsuperscript{167} Taka 34772 (approximately taka 55=US$ 1 in 2001) is needed as one season’s operating cost for one acre of integrated shrimp aquaculture (excluding the gher construction) (Abedin \textit{et al.}, 2001).
vegetables and white fish is 1.8 times more profitable than that of solely culturing prawns/shrimp (Nabi et al., 2000; Williams, 2001).

6.5.3.3 Empowering local deprived people including women

The immediate beneficiaries of the integrated tidal power project would be the people who live in the vicinity of the project site including women. Women may be involved in new economic activities such as dyke cropping, prawn/shrimp feed preparation and distribution, paddy husking, poultry rearing, tree nursing, vegetable production in homesteads area, small-scale cottage industry (such as weaving and painting on cloth), prawn harvesting, gher weeding, and other such activities (Pradhan, 2002; Barua, 2001). The availability of electricity would empower the women by-

(a) Allowing housewives to take up some income generating activities (such as basket making at night168, net weaving, tailoring etc);
(b) Eliminating the health hazards of kerosene lamps thus providing a better environment;
(c) Helping to improve children’s education and ensure the women’s security; and
(d) Developing a women-based micro-enterprise zone, such as electric sewing, ice-making, rice-husking etc where women will be encouraged to participate.

As a result of female involvement in different economic activities with the expansion of the integrated tidal power project, women could take part in the decision-making process concerning their children’s education and marriages and expanding the households’ use of consumer goods. Women would improve their organisational and management abilities through the increase of awareness of NGOs/GOs activities. In addition, poor women would be able to take loans from microfinance and community-microfinance systems, earn and save money, giving them the confidence and ability to access small-scale business processes. They could also access training in community consultative processes and thereby become more aware of their rights and their ability to contribute more to their families. During my field visit, I saw that women were going outside of the homestead field and working in the ghers/ponds of the CARE-Bangladesh controlled project. Therefore it could be said that women could be more involved in the farming process and have enhanced social status in the integrated tidal

168 Because, most women of Bangladesh are engaged house keeping activities during daytime.
power project scenario situation because they would make more decisions, would be able to raise loans, mobilise savings, participate in development-oriented work, and of course, earn an income.

6.5.3.4 Enhance sustainable livelihoods

Per capita consumption of electricity has been used as one indicator to quality of life. Presently most of the Bangladeshi population do not enjoy this facility, particularly in the coastal regions. The integrated tidal power project could improve this situation. It has been estimated that every separate coastal area in Bangladesh (small island, such as Sandwip) may produce approximately three megawatts electricity from the present infrastructure of coastal embankments and sluice gates by using more than 30 tidal wheels (ISTP, 1999). In this way more than 1000 megawatts electricity may be generated by the proposed tidal power project from the whole coastal area of Bangladesh which is enough to power over 20 million households at their present needs for electricity (Corry and Newman, 2000). Tidal power in coastal Bangladesh would displace millions of tonnes of greenhouse gases especially carbon dioxide every year. Thus it would make a major contribution to cutting pollution from fossil fuels, the major cause of climate change. In addition, the integrated project may add electricity to multipurpose cyclone shelters, where modern electronic communication media could be set up that can quickly communicate warnings for disaster preparedness. Electricity would enhance the operational facilities of health centres/hospitals for preservation medicine. The project would assist the modernization of educational centres/institutions/schools by providing electricity for computers and night-shift education. Electrification of business centres would enhance the take up of electronic commerce and develop better telecommunication systems. The establishment of an integrated tidal power project in the coastal

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169 A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (DFID Bangladesh, 1999).

170 Present per capita consumption of energy is only 85 kWh/yr in Bangladesh, whereas that of USA is 12,711 kWh/yr (Roy, 2000).

171 Recently, it has been proved that developing a sustainable system of computer software and networking would manage better way the natural calamities in coastal Bangladesh. Because the development of a computer software on Bangladesh’s disaster, will provide more technical knowledge to Bangladesh about how to manage future natural calamities in a planned and coordinated manner through computer networks (Source: http://dailystarnews.com/200210/31/n2103110.htm#BODY3 (accessed on November 01 2002)).
Bangladesh would thus enhance the status of local people. They would become more educated and aware of the needs of natural resource management under a community-based co-management system. The integrated model would also help to reduce the gender gap by giving priority to women’s education, training and employment and special support for education of girls (LaRocco, 2002).

From this discussion, it is clear that the electricity from integrated tidal power could bring multiple positive results in terms of women’s welfare, children’s education, employment, income generation and alleviating poverty. Access to electricity may also be used for demand forecast\textsuperscript{172} appliances, offering improvements in the quality of night lighting, access to information through radio/TV, and cooling through the use of fans. It will expand working, selling and shopping hours at night and access to income generation opportunities through cottage industries and women-led micro-enterprises, such as Nakshi Knatha\textsuperscript{173}, poultry, rice husking, basket making, electronics repair, carpentry workshops, tailoring, stores, fish net weaving and many other such activities. Electrification in remote local areas could also assist the relation of local dialect, prevalent customs and culture so that all sections of the population are afforded the opportunity to contribute towards the enrichment of national culture. It could make ‘Community Radio\textsuperscript{174}’, accessible to all.

Finally even it may be seen as a round-about method, the electrification of the coastal community could bring about voluntary reductions in fertility and should contribute to limiting population growth (Ushiyama et al., 2001). This is because electrification will make it easier to obtain entertainment and information through television and radio and increase knowledge of health and sanitary matters. Sanitary education will reduce infant mortality thereby reducing very high birth rates (NOAA, 1998).

\textbf{6.5.3.5 Improve the maintenance of coastal embankment}

Presently most of the coastal embankments are inadequately protected, thus existing land-use patterns are at risk particularly from cyclones and other natural disasters. Sometimes during excess calamities, local people are forced to cut the embankment or

\textsuperscript{172} Demand forecast is an estimate of the level of energy or capacity that is likely to be needed at some time in the future.

\textsuperscript{173} A kind of handicraft made with cloth and thread that shows the local culture and beliefs.

\textsuperscript{174} http://dailystarnews.com/200209/24/n2092409.htm#BODY3 (accessed on September 25 2002).
local polder system to discharge excess water that threatens their agricultural system. These destructive occurrences happen due to poor institutional capacity with regard to the operation and lack of maintenance of coastal embankments. The National Water Policy of 1999 aims to protect coastal lands from tidal flooding and cyclone surges with an emphasis on planning and implementing schemes for reclamation of land from sea and river. The proposed integration model could strengthen the present maintenance of coastal embankments by a strong participatory community-based co-management system which would educate users through awareness and motivation programs.

**6.5.4 Tidal power integration could increase international linkages and globalisation in Bangladesh**

Presently the way that shrimp and other agricultural products come to market is not sustainable or manageable. The current institutional structures of coastal Bangladesh generate an inappropriate price structure that ignores the social and ecological costs to the community (Sutton, 1995 & 1995a)\(^{175}\). Sustainability not only depends on the ‘greenest products’, but also depends on the restructuring of the market itself through introduction of eco-taxes, eco-investment strategies and institutional changes (Sutton 1995a & 1996). In the proposed integrated tidal power project, all resource-users would be active partners in seeking institutional reform for effective market management and sustainable biodiversity (Collins and Porras, 1994; Lloyd, 1990). As the project is based on the sustainability principles, it would provide a great opportunity to develop an eco-tourism-based industry around an innovative approach that utilises natural as well as historic components like tidal wheel.

Eco-tourism promotion must be supported by a nature-based economy that can produce individual income as well as legislative generated revenue streams, providing major economic infusions to the local economies (Flint, 2000). Coastal Bangladesh has a rural population that possesses a rich, long tradition of relying on agriculture, forestry, and fishing to support its economy. The natural setting of coastal Bangladesh is made attractive by the low cost of land and ‘day-trip’ accessibility which would be

further enhanced by the addition of the tidal power project\textsuperscript{176}. The implementation of this tourism potential through the tidal power project would improve the coastal socio-cultural conditions, the infrastructure of poor communities and overall economic prosperity through marketing socio-cultural and indigenous products from coastal Bangladesh. Tidal power project would improve access roads, airports, helipads, utility services, and others with the full support of Bangladesh government\textsuperscript{177}. If this government support continued to improve access and other facilities in the project area, the private sector, including foreign private investors, are likely to show much greater interest in investing in eco-tourism related projects. In this way, the proposed integrated tidal power model would assist the coastal communities and urban neighbourhoods to build diverse, prosperous, and self-reliant economies in coastal Bangladesh.

6.6 Policy Recommendations

6.6.1 Institutional aspects of the integration

(a) A national strategy including clear goals, objectives and guidelines of integrated sustainable coastal development through tidal power should be formulated. This strategy could be reviewed on the basis of the national goals, objectives and guidelines among the various sectors and tiers of government and stakeholders;

(b) Based on the national strategy of integration, a legal framework of the national coastal integrated sustainable development (CISD) policy should be developed;

(c) To implement coastal integrated sustainable development, an extensive coordination network should be established between relevant institutions, research organisations, and implementation agencies of government; and

(d) The new coastal integrated sustainable development policy should be developed in such a way that the integration will come through mobilizing maximum possible resources, policies and institutions. It should also involve all segments of the population of the coastal community.

\textsuperscript{176} The process of electrification would enable tourists to visit and stay comfortably, and also people would come to see the tidal power plant.

\textsuperscript{177} http://nation-online.com/200211/16/n2111602.htm (accessed on 17 November 2002).
6.6.2 Managing the cost of tidal power

A separate policy regarding the cost of tidal power development should be developed. The calculation of the cost should take into account funding all sources and costs from Bangladesh government, community groups and donor agencies, finance from CDM, GEF and other international organisations; operation and maintenance costs, and any other costs (McNally and Tognetti, 2002; Rose, 2002; Rosenzweig et. al., 2002). Bangladesh is a developing country, which produces an insignificant amount of greenhouse gases (Huq 1998), and therefore could take advantage of the CDM finance opportunity from the developed countries to establish a tidal power project (LaRocco, 2002). The Kyoto Adaptation Fund could be used to further protect Bangladesh from floods caused by climate change. Other funding for this project includes a mix of donor aid money, mixed credit with private sector contributions, and ‘soft loans’ for community capacity-building activities (Salequzzaman et al., 2000). In the long run, the cost of tidal power will decline, because the tidal power plant has more longevity in terms of lifecycle and low operational costs (Day, 1994; Salequzzaman and Newman, 2000 & 2002). The government should also consider a subsidiary process in conjunction with tidal power plant set-up. To encourage market sustainability, the government should develop a mandatory approach for the purchase of tidal power or any kind of renewable energy by the community peoples, and other commercial and industrial sectors. For example, tidal power or any green energy/renewable energy retailers who fail to meet the target reduction of greenhouse gases will be fined up to A$15.00 for each tonne of carbon dioxide equivalent in Australia (Nichols, 2002). The cost of NOx emission credits is US $4-50$/Ib (pound) in California of USA (ANA, 2001). In Australia, black coal fired power stations are built at a cost of around A $1.4 million per MW of capacity, which will emit greenhouse gases that will accounts for 0.9 tonnes of CO2/MWh electricity. Tidal power plants do not emit any sort of NOx or CO2, therefore all of these cost

178 Soft loan is a kind of loan, which is generally sanctioned at low rates of interest or no interest at all, to be given on condition of agreed criteria, particularly purposes and objectives. Generally, the poorest countries can be given soft loans by the World Bank and different international banks or developed countries to support projects without any requirements that oblige the recipient country to purchase goods. Soft loans can also be used for social sector projects or environmental projects in somewhat wealthier countries. The investments best suited for soft loan financing are those that can generate revenue, but the revenue is not sufficient to cover the entire cost, for example investments in railways, extensions of the electricity network in rural areas, or solid waste management.

179 Personal communication to Anna Reynolds, Climate Action Network Australia, http://www.climateaustralia.org (accessed on 23 February 2003), email: anna@climateaustralia.org
calculations should be covered in tidal power plant maintenance cost (Salequzzaman, 2002).

6.6.3 Establish community-based co-management

The integration of tidal power plant in coastal Bangladesh requires community participation through community-based coastal co-management. Sustainability principles emphasise public participation and local democracy (Agenda 21, 1992). Therefore the integration of a tidal power model would need a framework of community co-management. This co-management should recognize all community factors including social, cultural, economic and environmental impacts upon community well-being, arts and cultural development, community safety, economic development, environmental sustainability, housing, leisure and recreation, and, public and environmental health (Twidell and Weir, 1997). In this community-based co-management model, community consultation is a vitally important element of the bottom–up approach. Community-based sustainability cannot be imposed in a top-down fashion (Environment Australia, 2002). The consultation process would identify the needs that guide individual and institutional actions and the resources that different parties can contribute to sustainable development. In addition to local community involvement, this consultation process should include the following stakeholders:

(a) **Governments:** Governments should play a more active role in the implementation of an integrated tidal power project in coastal Bangladesh such as facilitating the transfer of internationally agreed principles to national and local actions in exchange for the financial support (such as CDM of Kyoto Protocol).

(b) **Non-governmental organisations:** NGOs should continue to participate in policy-making and implementation and represent the interests of stakeholder groups. They should present clear and viable options for action raise awareness and knowledge of their integrated coastal management procedures. In addition, professional and scientific organisations, with their impressive wealth of knowledge and experience, should contribute to the proposed integrated tidal power project by widening the professional scope to include more interdisciplinary and cross-sectoral approaches.
(c) **The private sector:** Private companies ranging from international enterprises to small local service providers, including financial institutions, should become involved in this integrated tidal power project to maintain sustainable governance, financing and capacity building.

(d) **The international community:** The international community should become involved in this proposed innovation to promote transparent intergovernmental negotiations with multi-stakeholder participation, and use internationally agreed principles to support integrated coastal development policies, the establishment and enforcement of regulatory and economic instruments, particularly those that focus on rights of the poor and other exposed groups. The United Nations and other international bodies and global partnerships should facilitate the sharing of benefits from international coastal environments as a catalyst for regional, national and local development and security.

### 6.6.4 Develop strong co-ordination and co-operation

Coastal Bangladesh is an area of institutional weakness. Though several government agencies and departments are working in the coastal region, there is hardly any linkage between them and institutional fragmentation is common (BUET-BIDS, 1993). Only bilateral communication takes place between the Ministry of Land and other executing agencies when the latter require land for construction purposes. Further the agencies responsible have hardly any presence at the local level. Most of these agencies operate only from their thana/upazilla\(^{180}\) level offices; although this is not the case for all the departments who are responsible for programs concerning the coastal areas. Therefore a stronger co-ordination is necessary between government departments, NGOs, CBOs, and other such organisations to implement the integrated tidal power project.

### 6.6.5 Develop law and order

As previously mentioned coastal Bangladesh suffers from a poor law and order situation with lack of governance. The proposed tidal power project would require

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\(^{180}\) Unit of the local government.
greater law and order enforcement and would look for the improvement of governance in the coastal community. Governance arrangements should ensure coastal resources management; which is sustainable, integrated and optimises the human benefits of the coastal environment while protecting the integrity of ecosystems. The governance arrangements should improve accountability, introduce and enforce appropriate legal provisions against corruption, monitor performance for development, develop codes of conduct, and invite civil society to play an active role in these processes.

6.6.6 Other recommendations

(a) There should be an emphasis on more research and information dissemination about the integrated tidal power project;
(b) Training, education and awareness programs, conferences and seminars should be utilised as a process of motivating the local people and other stakeholders of the coastal community;
(c) Pilot/demonstration projects should be established; and
(d) Strong support from different spheres of government is vital, not only through arrangements such as partnerships, but also perhaps through other more tangible means, such as funding and appropriate coastal policy frameworks and developing protocols for effective processes for cooperation between governments.

6.7 Conclusions

Bangladesh has a long coastal belt, which suffers from frequent natural disasters and the ongoing scourge of economic poverty. Current knowledge and the existing coastal embankments are able to protect coastal people from further economic poverty, but are not able to improve their situation. One of the important reasons behind this poverty is the lack of electricity. This research has determined that coastal Bangladesh could be electrified through tidal power generation using the coastal embankments. Access to electricity via the use of small-scale tidal power plant offers the potential to overcome the long-lasting economic poverty in the area. To be sustainable the design must be part of an integrated coastal development approach that involves a range of new products and more efficient methods and technologies, such as modern
aquaculture. It would also enable improved waste management, reduced collection of wild aquatic species, and better rehabilitation of land, including ways of reducing saline contaminated land.

Sustainable development truly occurs with the means to balance economic development with environmental protection whilst ensuring the most disadvantaged people in the society are provided with the ability to improve their quality of life. The proposed integrated model does this. Future generations of coastal Bangladesh would, if such a project were implemented, enjoy a high quality of life whilst guaranteeing the integrity of coastal natural resources through this proposed integrated tidal power development. In addition, tidal power could be further developed in many coastal countries in South-east Asia and around the world that share the same characteristics as coastal Bangladesh. Thus tidal power offers significant benefits and potential for sustainable coastal development, both in Bangladesh and worldwide.
CHAPTER VII
Chapter VII

CASE STUDIES OF INTEGRATED SUSTAINABLE COASTAL DEVELOPMENT IN BANGLADESH USING TIDAL POWER

"On a global scale- islands are small when one considers size, population, energy consumption, and emission of greenhouses gases. But they are huge when it comes to the effective promotion of renewable energy worldwide. Islands in particular can be global front-runners and showcases for renewable energy technologies and show the way to a sustainable energy future."

The Alliance of Small Island States (AOSIS) (1999)181

Research Question

How can the sustainable integrated coastal development model be applied to small islands and other coastal projects that already have embankments and sluice gates?

7.0 Introduction

The resources necessary to provide the energy to protect and enhance the quality of life are, at the same time precious ecological resources of the country and its future generations. Therefore sustainable energy provision remains one of the core issues for the future development of countries such as Bangladesh. Such sustainable energy provision requires technologies that are locally innovative and, socially, economically and environmentally friendly. The proposed ‘integrated tidal power model for sustainable coastal development’ is such a technology, featuring technical, social and environmental innovativeness. Technically, it will be the world’s first utilisation of

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181 AOSIS is a coalition of 43 small islands and low-lying coastal countries that share similar development challenges and concerns about the environment. AOSIS is the islands' primary spokesman effectively advocating their concern about climate change and its feared impacts, especially sea level rise. The alliance functions primarily as an ad hoc lobby and negotiating voice for small island developing states (SIDS) within the United Nations system.
generated small-scale tidal power and local aquaculture management. Socially, it will be a model of local capacity building; and, environmentally; the model will be an ecologically sustainable initiative.

To justify the proposed integrated model, the research has identified an integrated small-scale tidal power plant on the small coastal island of Sandwip, and an existing, comparatively improved and semi-integrated aquaculture project operated by the Gazi Fish Culture Ltd. Presently both locations are separately situated and are protected by coastal embankments and sluice gates. Thus the chapter will analyse how simple paddle wheel technology can generate power from the tides (Salequzzaman and Newman, 2002, Newman et al., 1999). In particular the chapter will examine in case examples:

1. The technical feasibility of utilising Bangladesh flood control coastal engineering infrastructure as a basis for creating a small-scale tidal power source;
2. The integration of improved water management, agriculture, aquaculture, livestock and other opportunities with the tidal power development concept; and
3. Analysis of how the tidal power project can work effectively for the purpose of sustainable integrated coastal development.

7.1 Case study 1: Sandwip integrated tidal power proposal

Sandwip is a small island in Bangladesh which is totally disconnected from the mainland. The island is situated in a very remote area and lacks both an electricity supply and modern facilities. However the island has great potential for developing
electricity from the tides of the surrounding sea. This case study examines how diversified, decentralised, small-scale, community-based renewable tidal power can be produced by using the existing embankment and sluice gate. The case study will also examine how Sandwip Island could take advantage of the opportunities offered through the sustainable integrated development of energy provision in such a remote location.

This integrated tidal power development model has been developed after extensive visits to the area, informal interviews and various meetings with key persons on Sandwip. The elected member of the Bangladesh Parliament from Sandwip, late Md. Mustafizur Rahman\(^\text{182}\) took part in the field visit (fig. 7.1).

\[\text{Fig. 7.1: Meeting with Sandwip administration during my field survey in September’ 2000 (picture from left, Sandwip Fisheries Officer, myself (Md. Salequzzaman), late MP Md. Mustafizur Rahman, and Administrative Head (Mr. Bisha Nath Banik)) (Photo: M. Salequzzaman, October 2000).}\]

\(^{182}\) His entire family were drowned in the Meghna River during a cyclone in 2001.
7.1.1 Characteristics of Sandwip Island

(a) **Location and population:** Sandwip is a deltaic island in the Bay of Bengal region of Bangladesh, adjacent to Chittagong and a mere 15 km from the mainland. The population is around 330,000 on an area of 240 km$^2$ (ISTP, 1999). The entire island is a mudflat created from the Ganges delta (fig. 7.2).

![Fig.7.2: The location map of Sandwip, Bangladesh (Mohammad, 1999).](image-url)
This island is not a tourist destination and is rarely visited by other Bangladeshis. The average 5m tides experienced at Sandwip result in poor accessibility, with the island constantly surrounded by mud flats, except during high tides (fig. 7.3A). A flood control barrage exists around the entire island and this contains 28 sluice gates (fig. 7.3B, 7.3C & 7.3D).

(b) **Natural hazards:** The island is situated in the middle of the Meghna estuary where strong storm surges propagate deep into the mainland through the river channel. The storm surge height is higher than at any other part of
coastal Bangladesh. Thus the coast of Sandwip is very vulnerable to cyclones and flooding (fig. 7.4)\textsuperscript{183}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig_7.4.png}
\caption{A general overview of damage by cyclone (A & B) and flooding (C) of Sandwip Island (Photo: M. Salequzzaman, August 2000).}
\end{figure}

In 1991, over one thousand people were drowned in flooding as a result of a cyclone. Erosion and accretion of the surrounding river is also a regular phenomenon of the island (fig. 7.5). The continuous river erosion constantly changes the map of the island that emerged from the Bay of Bengal about 3,000 years ago (Rahman, 2000; Haider, 1999). Although there are no official statistics, local people observed that about a quarter of the island has already been devoured by the Meghna River during the last few decades. About 20,000 families on the island have already been left homeless by erosion.

\textsuperscript{183} Personal communication to the World Bank’s Information shop at telephone: 202-458-5454, fax: 202-522-1500, email: pic@worldbank.org
About 75% of the islanders do not have any land for homesteads and most of them are landless (Haider, 1999).

(c) **Infrastructure:** Sandwip is one of the oldest islands in the Chittagong region. Much of its natural and historical heritage has been drowned in the Meghna River through the erosion process. Most of the peoples of this island are very poor. Therefore apart from some private building, most of the concrete buildings on the island belong to the government including the multipurpose cyclone shelter (fig. 7.6), government office, primary and secondary schools and the college. Only a small part of the island’s roads are concrete, the majority are earthen/soil. Most of the island’s boundaries are

![Fig. 7.5: Erosion of Sandwip island towards Meghna riverside (Photo: M. Salequzzaman, August-September, 2000).]
covered by the earthen embankments and concrete sluice gates and protect the main land from saline water. All other infrastructures of this island are built of low-cost local bamboo and other locally available raw materials.

Fig. 7.6: Multipurpose cyclone shelter of Sandwip (Photo: M. Salequzzaman, October 2000).

(d) **Electricity characteristics:** Electricity is considered to be one of the essential inputs for improved quality of life. As a matter of fact, the per capita consumption of electricity is taken as a development indicator of Sandwip Island, because the growth in population and industries has resulted in greater demand for energy. Most of the energy in Sandwip is derived from fossil fuel (mainly from biomass, coal and oil) which is not a good option for sustainable development. However, in common with the predominantly agro-based population of the rest of Bangladesh, bio-fuel is mostly used for cooking in Sandwip. On the other hand, lighting needs are met by using kerosene. Expenditure on lighting is minimized by short evening hours and limited nighttime activities. However a short electricity grid is available linking the main commercial areas on the island. Two diesel generators of 200 kW run for

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184 The building is used for various purposes, such as school and college education, cyclone shelter during cyclone, and other such activities.
a few hours in the late afternoon/early evening to supply this grid electricity (fig. 7.7A), mainly for commercial use. A few battery-charging shops (fig. 7.7B) charge and sell batteries in the main administrative area. However, only a few rich households use charged batteries for lighting and/or television (7.7C). Some diesel generators are used for powering rice threshers and recharging of batteries (fig. 7.7D). In addition, a PV system is used to maintain a fridge for vaccines in the health centre (7.7E). None of the island's schools, colleges or hospitals has an electricity supply (7.7F). Therefore, the opportunities for expansion of electricity-based industry are limited.

In this context, the need for developing energy, in particular renewable energy\(^\text{185}\) carries a greater sense of urgency on this island. The present research emphasises tidal power due to global considerations of climate change as well as the opportunity presented by the geographical location of Sandwip. The nature of coastal Sandwip will favour decentralisation and adaptation of tidal power amongst coastal community people (ISTP, 1999). Sandwip and many other remote coastal rural locations, have no infrastructure for conventional energy supply except coastal embankments and sluice gates.

The innovation of tidal power will bring many advantages for women’s welfare, children’s education, employment and income-generation, and considerable improvements in rural coastal life through alleviating poverty. According to my research survey, it has been estimated that the energy required for cooking within rural and coastal households of Bangladesh is

\(^{185}\) Because of the present global need due to climate change and sea level rise.
approximately 26.4 GJ/household/year and minimum-loading average of each household is 0.112 kWhr per day, sufficient to run two low power lights and a fan for several hours per day. A 100 A.hr battery can supply the electrical energy necessary to run this system for 5 to 6 days.

Fig.7.7: Present facilities of electricity supply in Sandwip (A: Diesel generator, B: Battery charging shop, C: Lighting and enjoying TV through battery supply electricity, D: Rice threshers milled by supplying electricity from diesel generators, E: PV cell for electrifying fridge the local hospital, and F: No electricity in the hospital) (Photos: M. Salequzzaman, July-October 2000; Corry and Newman, 2000).
Thus the research will recommend a charge controller be built into the battery that will protect it from unnecessary damage. The proposed tidal power will be mainly distributed through the battery charging system which can be undertaken by either local entrepreneurs or micro-credit cooperatives under a community-based co-management system.

(e) **Agricultural characteristics:** The mud flats and soils of Sandwip are highly fertile; hence, it is easy to grow a variety of food crops that play an important role in the agriculture sector (fig. 7.8).

![Fig. 7.8: Present agricultural activities in of Sandwip, Bangladesh (A: Irrigation through diesel-based power system, B: Manual preparation of land, C: Bumper rice production from mud flat soil, and D: Manual harvesting of rice (Photos: M. Salequzzaman, July-October 2000).]
Agriculture is the main source of food supply in the coastal community and includes a broad range of activities with a variety of products such as paddy cultivation, cereal crops, livestock, fishing and aquacultural activities, horticulture and others. This agricultural production makes an extremely important contribution to the local economy and to national agricultural production. The island is an exporter of rice and is largely self-sufficient in vegetables and fruits. However, the use of diesel-based irrigation to grow HYV of rice and other high yielding crops is increasing air pollution and GHG emission. The present research suggests that the proposed tidal power can replace diesel. Some traditional aquacultural activities are now also practiced on the island with paddy cultivation. This traditional, but integrated system provides raw materials to traditional and indigenous industry, such as the mat-based handicraft industry.

(f) **Characteristics of community management:** Most of the peoples of Sandwip are very poor, but they are organised locally in specific communities. Many organisations are now working on community development. For example, some government departments, international organisations and NGOs are now active in credit programs for income generation, capacity building, adult education, non-formal education, nutritional education, public health and family planning, adolescent education, social afforestation, water supply and sanitation, and the community-based co-managed agro-forestry industry (fig.7.9). The participation of local people and other stakeholders is now recognised as a key element in ensuring sustainable achievement in their community.
(g) **Lifestyle characteristics:** The human–resource relationships that operate at present on Sandwip are characterised by:

i. Widespread poverty, limited livelihood opportunities (especially outside agriculture) and poorly developed economic linkages, including poor access to national and international markets;

ii. Poor levels of service provision and very poorly developed institutional structure (with both government and non-government institutions);

iii. Highly unequal social structure, high levels of conflict and poor law and order;

iv. A few powerful people dominate the mass of the coastal population;

v. Rapid decline in key common resources, such as marine and freshwater fisheries;

vi. The constant threat of cyclones and storm surges;

vii. The long-term effects of climate change, with predicted rises in sea levels, possible increases in the frequency of major storms and changes in rainfall patterns;
viii. Active land erosion and accretion processes;

ix. Changing patterns of land use, such as the growth of shrimp and salt production, the effects on the coast’s morphology and water resources characteristics;

x. Widespread pollution and resource degradation;

xi. Very poor access to infrastructure and technology; and

xii. Salinisation of water and soil, including saline intrusion into freshwater aquifer.

(h) **Communication characteristics:** The island has a very poor transportation system in most areas causing great hardship to the people. Lack of good transport blocks the growth of trade and commerce. There are hardly any paved roads on the island and even the number of katcha (beaten earth) roads is very inadequate. In most places, there are no connecting roads between cyclone shelters and human habitations. Generally people travel by boat and trawler from one place to another (fig.7.10). When the river becomes rough, travel to the mainland of Sandwip becomes impossible. However traditional bullock cart (locally known as Gorur Gari) is used for the main vehicle in Sandwip and most of the coastal community of Bangladesh. Besides road communication, there is no electro-communication system, except the walkie-talkie and a very poorly managed telephone system.
Fig. 7.10: Walking, Traditional Country Boat and Bullock Cart are the main travelling vehicles of Sandwip peoples (A: Fishing and Travelling by using country boats, B: Walking, C: Bullock cart is using for load transfer, and C: Passenger country boat) (Photo: M. Salequzzaman, October 2000).

(i) **Women's development:** Traditionally and culturally, Sandwip women are housewife-managers within their families. They also work with other family members to further their economic development. Due to education and modernization, women are becoming more visible in many areas on Sandwip, as well as other parts of Bangladesh. Presently, they are involved in areas such as handicraft development, traditional cloth making and working in the shrimp/prawn processing industry (fig. 7.11). Most of the women are illiterate and are very poor. However, several NGOs and government organisations are encouraging their education and self-dependency by developing the micro-credit system, small-scale industry, and developing cooperatives through the community-based co-management system (Siddiqui and Newman, 2001).
7.1.2 The proposal

The proposed Sandwip project offers a range of small-scale technological and economic innovations that possess a unique potential to adapt to the culture and ecology on this island. In aiming to ensure such innovations meet the deeply felt needs of the local people, the project requires a comprehensive needs assessment, sensitive capacity building and recognition of appropriate social structures. This community assessment and mobilisation process would be undertaken within Phase I of the Project (see in section 7.1.3). However, the focus of the present conceptual outline is to attempt to define the major technological components that will be incorporated within the broad goals of the project. Generally, this involves utilising
the present flood control coastal embankments and sluice gates to develop a tidal power system (Box 7.1).

**Box 7.1: Decentralised Tidal Power**

The tides in Sandwip demonstrate roughly a 5 hour ‘in’ and 7 hour ‘out’ cycle (table 4.7 in chapter IV). Traditional tidal technology would generate large quantities of energy during approximately 6 hours of this cycle (Baker, 1991; Gorlov, 1979). Flow driven tidal technology (as proposed in fig. 7.12, 7.13 and 7.14) has the capacity to generate far less power, but over a greater time period (ISTP, 1999).

Utilising paddle wheel technology, and by lagging the flow by 1-2 hours through the restriction of both in-flow and out-flow, enables generation for approximately 11 hours of a 12 hour cycle (Charlier, 1982 & 2001). Here generation occurs when the water is flowing both in and out, with the change in rotation occurring during a flowing tide. Therefore the static state of high tide is still characterised by subsequent flow through the sluice gate and hence power generation. (The effect of this lagging of the tidal generation regime through sluice gate restriction is shown in fig. 7.12). In order to create the two-way tidal flow system some development of the existing tidal channels and inland ponds will be necessary. This will be essential to ensure adequate generation capacity, however such development will also furnish other local benefits. The largest tidal channels can be used to provide 24-hour navigable channels, presently not available on the island.

The inconvenience of the loss of electricity experienced when the turbines are in a stalled state will be diminished through the grid connection of a series of power generators around the island (fig. 7.15). The differentiation in the timing of tidal extremes (due to tidal currents) around the island should ensure 24 hour power supply.

The integration of electronic controls on the generators can enable these variations in power to be phased in and regulated into the grid. During the night the excess power produced can be directed into battery charging. These batteries can be provided for households living off the grid. Backup diesel generation, can be used to supplement the power supply at peak demand times.

This will require some deepening of channels and ponds on the island, though when done in conjunction with the potentially very rewarding industry of shrimp aquaculture, this is likely to be at a manageable cost (Box 7.2). Furthermore, it will have benefits for navigation and flood control (Box 7.3). Thus tidal power and water management become linked as a tool for integrated island development as set out (Box 7.4).
Fig. 7.12: Comparison between Tidal Range and Assumed Inlet Height using Tidal Wheel Generator (ISTP, 1999).

Fig. 7.13: Plan View of Tidal Wheel Generator Proposal (ISTP, 1999).
Box 7.2: Water Management

The island can be seen in cross section in fig. 7.2. The goal of the water management concept is to deepen the sluice gates in several key places to enable a larger head of water for generation of tidal power. This means that in those key locations it would be possible to have navigable water 24 hours a day to the edge of the barrage. Apart from high tide times, at present, people need to walk through mud (or be pushed in small boats through the mud) to reach the main boats for travelling across the Bay of Bengal.

The deepening of the channel can be begun by existing manual processes and, along with the lagoon storage system, would occur by natural scouring once the system was begun. The inland lagoons exist in most places but will need to be deepened in order to create sufficient volumes of water for the flow back to the ocean to produce power. Deepening of the ponds is a process well known by locals using human and animal power. The mud scoured out can be used to reinforce the barrage or shape the aquaculture ponds. This work will need to be closely supervised by the Local Government Engineering Department and BWDB\textsuperscript{186}, but is still much dependent on local 'know-how' and skill.

All of the conceptual details are elaborated on in the following discussions of the individual sectors:

(a) Electricity production, distribution and management, and

(b) Water management for aquaculture, flood control and navigability.

\textsuperscript{186} Bangladesh Water Development Board, is the main body responsible for the maintenance of coastal embankments and sluice gates.
Box 7.3: Shrimp Aquaculture

Bangladesh has not had a long tradition of aquaculture. There is now a thriving local industry based on shrimp collection from the mud flats in the Bay of Bengal. This is, however, not as controlled nor as optimised for production as can be obtained in a pond system.

The local shrimp survives the variations in fresh water/salt water through the seasons and is of course adapted to the tidal flows. It is possible to mimic these conditions by adapting the many 'beels' on the island for aquaculture (fig. 7.19). They will need to be constantly flushed and hence allowing water to come in and out with the tides is ideal. This will also clean the ponds and provide new nutrients regularly. The aquaculture concept needs to be researched further with local sources.

(a) **Electricity production, distribution and management:** The needs of the island, the innovation of the project and its early development phases could be investigated jointly by the Rural Electrification Board (REB) and the Bangladesh Water Development Board (BWDB) who together would be the ideal implementation agency. The success of the project will depend on the development and refinement of appropriate generation and distribution energy technology.

![Fig. 7.15: Distribution system of tidal power in Sandwip, Bangladesh (Ellery, Forthcoming PhD Thesis).](image)

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187 A kind of natural wetland, where most of the year filled with water.
Although the use of tidal power dates back to the 11th Century, application today is extremely limited (for details please see Chapter IV). The main reason the technology is not used more extensively is that it requires large-scale expensive coastal engineering to tap the potential energy of the tides. Once built, tidal power is extremely cheap (like hydro). Most systems employ a dammed coastal inlet, predominantly relying on pressure differentials to power turbines. Although flow-based generation systems are older than pressure-based systems, their utilisation is extremely low due to their lower generation capacities and efficiencies (Clark, 1997; Elliott, 1996).

The existing Rural Electrification Board technology and infrastructure will be utilized within the project, including the diesel generation system for power provision during peak periods and providing a baseline of costing information for electricity generation on the island. The Rural Electrification Board distribution grid system can also be utilised for distributing electricity to users and its community mobilisation processes will also be employed. In order to develop local responsibility for electricity provision, Rural Electrification Board are engaged in promoting rural cooperatives, which are trained to take over the operation, maintenance and full financial responsibility for their distribution system. This often involves international donors providing the necessary capital for construction of the systems. It is hoped to pursue this model with a strong emphasis on training in energy management/energy efficiency as part of the technology transfer. CMES and Grameen Shakti will assist in this capacity.

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188 Derby, Western Australia (accommodating an 11m tidal range) is currently subject to a project proposal to utilize this tide to generate 120 MW of power. The project proponents are Tidal Energy Australia (TEA), who will be the main technical consultants on this project for Bangladesh.
189 The Centre for Mass Education in Science
190 A sister organisation of the Grameen Bank of Bangladesh.
building process. In keeping with the broadly integrated nature of this program, it is proposed that alternative renewable energy sources will also be assessed during initial site investigations. Additional renewable inputs would realise greater installed capacity and, thus, broaden the scope of energy-based development activities. Energy processes such as biomass for product drying and Solar PV for refrigeration broaden the energy base and reduce the risks associated with energy delivery.

i. **Electricity calculations from small-scale/micro-tidal generation project:** According to Bangladesh Tide Charts, for the year 2000, at the SatalKhal sluice gate site on Sandwip Island, the following observations were made:

1. Maximum tidal fluctuation = 6.0 m (occurring on July 02 and 03, and August 02 2000)
2. Minimum tidal fluctuation = 1.7 m (occurring on September 07 and October 07 2000)
3. Maximum monthly average tidal fluctuation = 4.4 m (occurring in August 2000)
4. Minimum monthly average tidal fluctuation = 3.0 m (occurring in January 2000)
5. Average tidal fluctuation = 3.8 m

For the following calculations (Ellery, Forthcoming PhD Thesis), it will be assumed that the reservoir capacity is that which may be approximated by a square form tidal canal and is 6 km long and averaging 10 m wide.
Determine design differential pressure (for 3.8m tidal variation): With a power generation profile based on the deliberate lagging of the height in the polder behind the tidal height, it is necessary to determine a design pressure differential, which will enable maximum generation. Based on an average tidal range of 3.8 m for this design condition, the estimated total work available (given variable differential pressure) is set out below.

In calculating power generation capacity, the pressure differential across the turbine ($H_{av}$) has been varied from 0.5 m to 1.5 m in steps of 0.1 m. It is noted that as the pressure differential increases, so the volume flow rate through the turbine decreases. The rate of these changes is such that the power generation capacity grows to a maximum and then begins to fall. However, the maximum power generation point is affected by the time at which this power is generating. Thus, in order to determine the point of maximum energy generation potential, it has been assumed that for each gain of 0.1 m in differential pressure, there is a loss of 6 minutes of generation time in every 6 hours tidal cycle.

Assuming 0.5 m pressure differential at the point of generation, $H_{av} = 0.5$ m
The working range of the inlet = TWL – LWL = (Max tide - $H_{av}$) – (Min tide + $H_{av}$) = (3.8 – 0.5) – (0 + 0.5) = 2.8 m
For an inlet, of dimensions 6 km long and 10 m wide,
Working Volume = (TWL – LWL) * length * width = 2.8*6000*10 = 168,000 m$^3$
For a discharge/fill over 6 hours period,
$Q_{av} = $ Working Vol. / time = 168,000 / 6 / 60 / 60 = 7.78 m$^3$/s
Thus the Average Power Available is,

$$P_{av} = \rho \cdot g \cdot H_{av} \cdot Q_{av} = 1000 \cdot 9.81 \cdot 0.5 \cdot 7.78 = 38.15 \text{ kW}$$

Assuming, $5^{1/2}$ hours generation per 6 hours cycle, the power generated per day is,

Work = $38.15 \cdot 5.5 \cdot 4 = 839.3 \text{ kW.hr/day}$

The Total Energy Generation Capacity for variable $H_{av}$ is shown in table 7.1.

<table>
<thead>
<tr>
<th>$H_{av}$ (m)</th>
<th>$Q_{av}$ (m$^3$/s)</th>
<th>$P_{av}$ (kW)</th>
<th>Gen. Time (hrs/6 hrs)</th>
<th>$Q_{av}$ (kW.hr/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>7.78</td>
<td>38.15</td>
<td>5.5</td>
<td>839</td>
</tr>
<tr>
<td>0.6</td>
<td>7.22</td>
<td>42.51</td>
<td>5.4</td>
<td>918</td>
</tr>
<tr>
<td>0.7</td>
<td>6.66</td>
<td>45.78</td>
<td>5.3</td>
<td>970</td>
</tr>
<tr>
<td>0.8</td>
<td>6.10</td>
<td>47.96</td>
<td>5.2</td>
<td>988</td>
</tr>
<tr>
<td>0.9</td>
<td>5.56</td>
<td>49.05</td>
<td>5.1</td>
<td>1000</td>
</tr>
<tr>
<td>1.0</td>
<td>5.00</td>
<td>49.05</td>
<td>5.0</td>
<td>980</td>
</tr>
<tr>
<td>1.1</td>
<td>4.44</td>
<td>47.96</td>
<td>4.9</td>
<td>940</td>
</tr>
<tr>
<td>1.2</td>
<td>3.88</td>
<td>45.78</td>
<td>4.8</td>
<td>878</td>
</tr>
<tr>
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<td>3.34</td>
<td>42.51</td>
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<td>1.5</td>
<td>2.22</td>
<td>32.70</td>
<td>4.5</td>
<td>588</td>
</tr>
</tbody>
</table>

Thus, given an average tidal fluctuation of 3.8 m, designing a system based on a head differential ($H_{av}$) of 0.9 metres across a turbine, possesses the maximum work generation potential$^{191}$. Given an average tide of 3.8 m, and using a design differential head ($H_{av}$) across the turbine of 0.9 m, the average generation flow rate ($Q_{av}$) is 5.56 m$^3$/s and thus the average hydraulic power available for generation ($P_{av}$) is 49.05 kW. Given this average power available for generation, it remains to be determined how much mechanical power, and therefore the total electrical power, that this can generate. In calculating the mechanical power delivered it is assumed that hydro efficiency represents both the hydraulic and the volumetric

$^{191}$ For a 3 m tide, the maximum generation occurs at pressure differential of 0.75 m. For a 4 m tide, maximum generation occurs at pressure differential of 1.0 m. For a 5 m tide, the maximum generation occurs at a pressure differential of 1.1 m.
efficiencies. It is also assumed that the hydro-efficiency remains constant and does not vary with the various changes in differential head (which is actually not the case, especially at these low heads). The mechanical efficiency of gears, bearings and others is so high by comparison, that it has been ignored.

The hydro efficiencies of conventional paddle wheels are relatively low. Of the different types of paddle wheels, the overshot design is the most efficient, demonstrating efficiencies in the order of 60 to 65%. Undershoot paddle wheels, however, are capable of maximum hydro efficiencies of only 25% (Ellery, Forthcoming PhD Thesis). In the particular case, given the requirement to generate power using bi-directional flow, it is not feasible to contour the blades to absorb greater flow energy. A paddle wheel fitted with flat vanes, will generate bi-directional power however the efficiencies of conversion will be less, say 20%. Thus assuming a paddle wheel hydro-efficiency ($\xi_{\text{hydro}}$) of 20%, gives an average mechanical power at the shaft, $P_{\text{shaft}} = 49.05 \times 0.2 = 9.81$ kW. The actual power generated will vary with the speed of the shaft, which is dependent on the changing value of the differential pressure head. This differential pressure head varying both within a tidal cycle as well as across different tidal cycles. With this variable speed characteristic, it is most efficient to generate in ‘DC’. DC generation is most able to utilise whatever power is available, rather than waiting for the unit to achieve a synchronous speed, as is the necessary case with ‘AC’ generation. ‘DC’ electrical power generation is assumed to convert mechanical power into electricity at an overall efficiency ($\xi_{\text{elec}}$) of around 80%, $P_{\text{elec}} = 9.81 \times 0.8 = 7.85$ kW. For 5.1 hours generation per cycle, the total energy generated per day is represent by,
\[ W_{\text{out}} = 7.85 \times 5.1/6 \times 24 = 160.1 \text{kWhr/day} \text{ (table 7.2).} \]

With a sluice gate size of 1.5 m, the flow velocity at the average condition is 2.46 m/s, which is reasonable as a design velocity. The maximum velocity (recorded during the maximum spring tide) of 5.2 m/s is slightly high for an undershot paddle wheel and would most probably be accompanied by a falling off in paddle wheel efficiency.

Table 7.2: Total energy generation per day.

<table>
<thead>
<tr>
<th>Tidal swing/head</th>
<th>Q&lt;sub&gt;av&lt;/sub&gt;</th>
<th>V&lt;sub&gt;av&lt;/sub&gt; (for 1.5*1.5 sluice)</th>
<th>P&lt;sub&gt;avail&lt;/sub&gt;</th>
<th>P&lt;sub&gt;shaft&lt;/sub&gt; (\xi_{\text{shaft}}=20%)</th>
<th>P&lt;sub&gt;elec&lt;/sub&gt; (\xi_{\text{elec}}=80%)</th>
<th>W&lt;sub&gt;out&lt;/sub&gt;@5.1 hours/cycle</th>
<th>P&lt;sub&gt;av&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m</td>
<td>0.56 m&lt;sup&gt;3&lt;/sup&gt;/s</td>
<td>0.24 m/s</td>
<td>4.9 kW</td>
<td>0.98 kW</td>
<td>0.78 kW</td>
<td>16 kWhr/day</td>
<td>0.6 kW</td>
</tr>
<tr>
<td>3 m</td>
<td>3.34 m&lt;sup&gt;3&lt;/sup&gt;/s</td>
<td>1.48 m/s</td>
<td>29.43 kW</td>
<td>5.88 kW</td>
<td>4.70 kW</td>
<td>96 kWhr/day</td>
<td>4.0 kW</td>
</tr>
<tr>
<td>3.8 m</td>
<td>5.56 m&lt;sup&gt;3&lt;/sup&gt;/s</td>
<td>2.46 m/s</td>
<td>49.04 kW</td>
<td>9.8 kW</td>
<td>7.48 kW</td>
<td>160 kWhr/day</td>
<td>6.67 kW</td>
</tr>
<tr>
<td>4 m</td>
<td>6.12 m&lt;sup&gt;3&lt;/sup&gt;/s</td>
<td>2.72 m/s</td>
<td>54.0 kW</td>
<td>10.8 kW</td>
<td>8.64 kW</td>
<td>176 kWhr/day</td>
<td>7.34 kW</td>
</tr>
<tr>
<td>5 m</td>
<td>8.88 m&lt;sup&gt;3&lt;/sup&gt;/s</td>
<td>3.94 m/s</td>
<td>78.48 kW</td>
<td>15.7 kW</td>
<td>12.56 kW</td>
<td>256 kWhr/day</td>
<td>10.7 kW</td>
</tr>
<tr>
<td>6 m</td>
<td>11.7 m&lt;sup&gt;3&lt;/sup&gt;/s</td>
<td>5.2 m/s</td>
<td>103 kW</td>
<td>20.6 kW</td>
<td>16.48 kW</td>
<td>336 kWhr/day</td>
<td>14.0 kW</td>
</tr>
</tbody>
</table>

In order for a paddle wheel to generate power under all conditions (from maximum to minimum spring tide), it is necessary that the radius of the paddle wheel just exceed the maximum water height in the polder. With a tidal variation of 6 m, and a maximum height in the polder of 0.9 m, it is suggested that the wheel must exceed 5.1 m in radius (fig. 7.16). One would expect therefore that the diameter of the paddle wheel would be in the order of 10.6 metres in diameter.

With an average daily power generation capacity of 160 kWhr/day, it is suggested that a local ‘AC’ network will be the most effective form of distributing this power. It is, however, the variations in power generation that pose the greatest challenge for the distribution system. Thus, in an effort to utilise as much of the energy potential as possible, it is proposed that the distribution system will be divided into 4 separate
loads. Each grid consisting of loads not exceeding 3 kW. Assuming that each system is actually comprised of a load of 2.7 kW, and assuming that the power factor for the load is 0.8, then the real power of the load is 2.7 * 0.8 = 2.16 kW.

If it is assumed that this power is used for lighting then this equates to powering 36 * 60 w globes in each network. Alternatively, during the day, this power could be used to power a television set and so on. Assuming that each of the 4 networks are comprised of a load of 2.7 kVA.

![Fig. 7.16: Calculation of tidal wheel.](image)

For the average tidal condition that is represented by a tidal fluctuation of 3.8 m and a mean power generation of 7.84 kVA let us assume that 2 of the 4 networks are stitched ‘on’. This equates to an average ‘AC’ load of 5.4 kVA. In transforming the signal from ‘DC’ to ‘AC’ there will be power losses, most of which will occur in the inverter (table 7.3).

Allowing for an inventor efficiency of 85%, the load of the network on the ‘DC’ system is therefore 6.4 kVA. To minimise system losses and cable sizing the ‘DC’ system shall be based on generation and transfer in 48 V. In order for this draw of 6.4 kVA to be sustained during the estimated 54 minutes of ‘no generation’, a
total of 6.4 * 54/60 = 5.76 kVA.hr of energy will need to be supplied from the battery bank. Given a battery efficiency of 90% this output requires an input of 5.76/0.9 = 6.4 kVA.hr.

Table 7.3: The conversion of DC power to AC power.

<table>
<thead>
<tr>
<th>Tidal Swing</th>
<th>48 V ‘DC’</th>
<th>240 V ‘AC’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P_{elec}</td>
<td>P_{Charging}</td>
</tr>
<tr>
<td>2 m</td>
<td>0.8 kVA</td>
<td>0.8 kVA</td>
</tr>
<tr>
<td>3 m</td>
<td>4.7 kVA</td>
<td>0.9 kVA</td>
</tr>
<tr>
<td>3.8 m</td>
<td>7.84 kVA</td>
<td>0.2 kVA</td>
</tr>
<tr>
<td>4 m</td>
<td>8.64 kVA</td>
<td>1.0 kVA</td>
</tr>
<tr>
<td>5 m</td>
<td>12.6 kVA</td>
<td>1.1 kVA</td>
</tr>
<tr>
<td>6 m</td>
<td>16.5 kVA</td>
<td>1.2 kVA</td>
</tr>
</tbody>
</table>

Given generation cycle of 5.1 hours, an average charge rate 6.4/5.1 = 1.25 kVA (or 26.1 AMPs) will be necessary to charge the systems’ batteries during the generation period. The remaining 0.28 kVA (5.8 Amps) may then be utilised in the battery charging station, in the charging of individual batteries for use in remote locations.

ii. **Battery Bank**

1. **Battery bank sizing:** Design of batteries for 54 minutes of storage at a draw of 6.4 kVA at an operational voltage of 48 V, will require a battery bank with capacity to supply 6400 * 54/60/48 = 120 A.hr. Providing 120 A.hr from a nominal 100 A.hr Rahimafroz\(^{192}\) 6 BC120P/3 battery. Given a C\(_1\) rating of 36 A.hr and assuming a maximum depth of discharge of 50% and nil temperature correction, requires (120/(36 * 0.5)) = 6.7 batteries (Say 7 battery banks). Meeting the system voltage of 48 V batteries, will

\(^{192}\) Rahimafroz is a local company of battery manufacturer.
require 4 batteries, connected in series, within each battery bank (fig. 7.16). Thus total of 28 batteries of 100 A.hr capacity will be required to meet the average conditions. To meet the maximum draw of 12.8 kVA and assuming a maximum battery discharge of 70%, requires 40 batteries of 12 V and 100 A.hr capacity (i.e. 10 banks of 4 batteries). Maximum charge rate, during 6 m tide is 2.5 kVA. At 48 V this equates to 2500/48 = 52 Amps. Given 10 banks of batteries the maximum charge rate equals 5.2 Amps per battery (√O.H. does not exceed 0.25 of the C₁₀ battery rating of 70 Amps i.e. 15.5 Amps).

2. **Battery charging station sizing:** For a maximum charge rate to the batteries of 2.8 kVA. At a supply voltage of 48 V, this equates to a charge feed rate of 58.3 Amps. Allowance for maximum charge rate of the C₁₀ battery rating of 70 Amps, i.e. 15.5 Amps. Then the charging station battery requires connections to suit at least 3 banks of batteries, i.e. 12 off, 12V, 100 A.hr batteries connected at the charging station. Allowance for full charging over a 5 hour period, means that 58.3*5 = 292 A.hrs delivered to the batteries. For 100 A.hrs batteries, 60% discharged, and with a charging efficiency of 90% this equates to a charge of 292/(100*0.6)*0.9 = 4.4 (≈ 5 battery banks), i.e. 20 off, 12 V, 100 V A.hr batteries connected to the charging station.

3. **Inverter sizing:** Size inverter for a continuous rating of 7.5 kVA and assume an overall inverter efficiency ≈ 85%.
iii. **Alternative generation means: an alternative solution of the submersible bi-directional axial flow turbine of brushless ‘DC’ Generator:** It is alternatively suggested that a bi-directional axial-flow turbine close-coupled to a submersible brushless ‘DC’ motor /generator offers a far greater power generation capacity than paddle wheel technology. This form of generation would require no major civil modifications to the existing sluice gate sites of Sandwip or any other part of Bangladesh. The mounting of this equipment could utilise the existing guide rails provided to locate stop-logs during routine maintenance. Although available as independent technology, this particular form of power generation technology is not yet commercially available. However,

1. Submersible brushless ‘DC’ motors are currently utilized in solar bore pumping systems and display extraordinary electrical efficiencies (in excess of 90%) (Ellery, Forthcoming PhD Thesis). Non-submersible brushless ‘DC’ motors are used as generators in some models of wind turbines. Under external excitation these motors produce an rpm\(^{193}\) dependent, 3 phase, AC voltage which is then converted into ‘DC’ using a solid-state array.

2. Axial flow turbines for low head applications are readily available for hydropower generation applications. To date, however, there has been little need for bi-directional axial flow turbines. Although, submersible axial flow tidal power turbine is currently undergoing research and development attention, these turbines are uni-directional, rotating on a single pole mount via a rudder to determine flow direction.

3. Guide of rail technology enabling the remote installation and sealing of waterways is well established in the submersible sewage pump industry.

\(^{193}\) Rotation per minutes.78.48 kW
From previous calculations, given an average tide of 3.8 m, a design differential head (H\text{av}) across the turbine of 0.9 m, the average generation flow rate (Q\text{av}) is 5.56 m\textsuperscript{3}/s and thus the average hydraulic power available for generation (H\text{avail}) is 49.05 kW.

The hydro efficiencies of axial flow turbines are generally in excess of 80\% and at higher heads they often demonstrate efficiencies above 90\%. Assuming an efficiency in the forward directional of 80\%, and a performance in the reverse direction that is 50\% lower than that in the forward direction, the overall hydro efficiency (\(\xi\text{hydro}\)) of the turbine will be 65\% (let us say 60\%). Thus the average mechanical power available at the shaft, H\text{shaft} = 49.05 \times 0.6 = 29.4 kW. With this turbine close coupled to a submersible brushless ‘DC’ motor the conversion efficiency to a ‘DC’ electrical output (\(\xi\text{hydro}\)) is estimated at 80\%. Thus the average electrical output, P\text{elec} = 29.43 \times 0.8 = 23.54 kW. For 5.1 hours generation per cycle, the total energy generated per day (W\text{out}) is represented by, W\text{out} = 23.54 \times 5.1/6 \times 24 = 480 kWh/day (table 7.4).

Table 7.4: The production of tidal power by using axial flow turbines.

<table>
<thead>
<tr>
<th>Tidal swing</th>
<th>Q\text{av}</th>
<th>V\text{av} (for 1.5\times1.5 sluice)</th>
<th>P\text{avail}</th>
<th>P\text{shaft} (\xi\text{hydro}=60%)</th>
<th>P\text{elec} (\xi\text{elec}=80%)</th>
<th>W\text{out} @5.1 hours/cycle</th>
<th>P\text{av}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 M</td>
<td>0.56 m\textsuperscript{3}/s</td>
<td>0.24 m/s</td>
<td>4.9 kW</td>
<td>2.94 kW</td>
<td>2.35 kW</td>
<td>48 kW.hr/day</td>
<td>2 kW</td>
</tr>
<tr>
<td>3 m</td>
<td>3.34 m\textsuperscript{3}/s</td>
<td>1.48 m/s</td>
<td>29.43 kW</td>
<td>17.7 kW</td>
<td>14.1 kW</td>
<td>288 kW.hr/day</td>
<td>12 kW</td>
</tr>
<tr>
<td>3.8 m</td>
<td>5.56 m\textsuperscript{3}/s</td>
<td>2.46 m/s</td>
<td>49.04 kW</td>
<td>29.4 kW</td>
<td>23.5 kW</td>
<td>480 kW.hr/day</td>
<td>20 kW</td>
</tr>
<tr>
<td>4 m</td>
<td>6.12 m\textsuperscript{3}/s</td>
<td>2.72 m/s</td>
<td>54.0 kW</td>
<td>32.4 kW</td>
<td>25.9 kW</td>
<td>529 kW.hr/day</td>
<td>22 kW</td>
</tr>
<tr>
<td>5 m</td>
<td>8.88 m\textsuperscript{3}/s</td>
<td>3.94 m/s</td>
<td>78.48 kW</td>
<td>47.1 kW</td>
<td>37.7 kW</td>
<td>768 kW.hr/day</td>
<td>32 kW</td>
</tr>
<tr>
<td>6 m</td>
<td>11.7 m\textsuperscript{3}/s</td>
<td>5.2 m/s</td>
<td>103 kW</td>
<td>61.8 kW</td>
<td>49.4 kW</td>
<td>1009 kW.hr/day</td>
<td>42 kW</td>
</tr>
</tbody>
</table>

Thus the continuous power rating for the system, P\text{av} = 80.05 kWhr/day/24 hrs = 20 kW. The design velocity of 2.5 m/s, as well as the velocity peaks are considered to be within the operational ranges for axial flow turbines.
**Alternative approach based on water current of Sandwip channel:** Sandwip channel is much deeper than its surrounding’s Hatia channel.

Therefore the water variation through tidal propagation is higher in the northern tip of Sandwip and Hatia channels\(^{194}\) (fig. 7.17).

In this situation, between the northern tip of Sandwip and Hatia channels is suitable for tidal power production on the basis of tidal stream turbine technology (fig. 7.18)\(^ {195}\). Tidal stream turbines are basically wind turbines located in the high tidal flow areas of the sea, but do not suffer from the problems of visual intrusion or undesired land use. They could provide a variable source of energy, but one which is totally predictable. They would usually be located in areas of strong tidal flow, but could also be set up in river estuaries and thermal current areas. However the technology needs more research to apply in the practical field for a sustained situation in coastal Bangladesh.

\(^{194}\) Personal communication to Mr. Mamunul H. Khan, Natural resources Management Specialist, USAID, American Embassy, Baridhara, Dhaka 1212, Bangladesh, email: mkhan@usaid.gov

The most significant aspect of this technology is that the structure could enhance the accretion of land in the coastal Bangladesh. Land accretion is important in terms of Bangladesh’s socio-economic, cultural and environmental point of view.

iv. **How much power this would represent, and is it significant?**

The rural electrification board of Bangladesh usually provides 10 kVA transformer for 42 families in rural villages which means $10 \times 0.8 = 8$ kW is assigned for 42 families. Hence 20 kW can be used to provide electricity to 105 families. In general, to charge a 12V battery from a 220 V AC. voltage source, $220 \times 2.5 \times 0.8 = 440$ W is needed and 20 kW can be used to charge 45 number of 12 V battery simultaneously (Bala, 2003). In other word for the case of grid connection, generally 2 lights, 1 fan and 1 TV are used for each family in rural settings. The total battery need per family is $2 \times 40$ w (lighting) + $1 \times 70$ w (fan) + $1 \times 150$ w (TV) = 300 w. For a 20 kW grid connection, the supply could be electrified to
around 66 families (after the calculation of system loss, transmission loss, etc.) in battery system (DC system), energy needs per family per day could be calculated as

\[ 8 \text{ w}^{196} \times 2 \times 4 \text{ hr}^{197} \text{ (lighting)} + 15 \text{ w} \times 1 \times 4 \text{ hr} \text{ (fan)} + 20 \text{ w} \times 1 \times 2 \text{ hr} \text{ (TV)} = 165 \text{ whr}. \]

Based on a calculation of 50% discharge rate of effective capacity 60 Ahr (12 V, 100Ahr/120) (0.7 kwhr), this will run \( 0.7/0.165 = 4 \) days by a 12V battery. In the present situation of rural coastal Bangladesh, this amount of electricity supply (20 kW) is more than sufficient and an extraordinary innovation to the coastal community.

![Fig. 7.19: Traditional beel in Sandwip (A) for extensive shrimp aquaculture (B)](image)

(Photos: M. Salequzzaman, September 2000).

(b) **Water management for aquaculture, flood control and navigability:** The Local Government Engineering Department (LGED) and Bangladesh Water Development Board (BWDB) are experienced at managing water through deepening channels and building lagoons and managing water levees utilising local knowledge, expertise and labour. The impacts of the coastal

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196 Generally CFL (compact fluorescent light) will consume less amount of electricity than the normal light (40 w), therefore rural Bangladesh use this CFL.

197 Generally, it is assumed that a rural family can use lighting for 4 hours at night.
engineering on existing patterns of water use by the community are not fully understood. For example, flushing will re-arrange the existing pattern of ponds and, therefore, may create social tensions among farmers or farmer groups. A critical component of initial assessments will be to look at aspects of land tenure and the present allocation/utilisation of land between land owners/users. The proposed establishment of aquaculture processes and markets will require significant research of environmental, social and economical issues. The development and subsequent training in appropriate methodologies for aquaculture management will comprise a large part of the project. This will necessitate assistance from local Department of Fisheries sources and experts in aquaculture management (Box 7.3). In the establishment of aquaculture, it will be necessary to verify the latent comparative advantages of Sandwip in order to assess its (shrimp aquaculture) relative competitive advantage in the local export (international/mainland) market; that is, the extent and quality of factor assets, production capability and associated activities, regulatory barriers, cost structures and so on.

Other important considerations are the prospects for value adding to indigenous resources/local activities. With prawn/shrimp production as an example, what are the prospects and processes necessary to develop/strengthen dry prawn exports? Experience shows that local knowledge amongst farmers, mixed with desire and ambition, can produce very creative ideas.

In order to ensure broad replicability, the Grameen Bank would oversee the establishment of cooperatives and furnishing of loans to local people by applying the principles of the community based co-management process. The use of the
existing flood control barrage system for the generation of small-scale tidal power has obvious advantages in terms of the large civil costs normally associated with the establishment of tidal energy systems. In addition, the daily operation of the system ensures that the system is maintained and available to drain water from the island in the event of excess rain. At present when there is a large build up of fresh water, the island administration is forced to break the barrage so that the excess water can be drained.

Box 7.4: The link between tidal power and integrated coastal development of Sandwip Island (Salequzzaman et al., 2000)
Thus the project offers improvements to the flood control capacity of the island. The viability of this project is enhanced by the multi-dimensional aspects of the concept, which offer scope to incorporate a range of value adding processes. The extent to which this actually occurs will depend on the community development focus.

7.1.3 Community benefits and problems

Various pathways for sustainable development can be argued convincingly. However the need to base the conceptualisation of a development process on local socio-economic conditions is paramount. Thus the proposed integrated tidal power project concept has to develop a foundation based on further field-assessment of demographic patterns/dynamics, economic base, social organisation, and community infrastructures – health, education and other. Subsistence island economies generally demonstrate characteristics of reliance on transfer income, low job growth, poorly paid day labour and rural-urban migration. Therefore to reduce the rate of rural-urban migration, local job opportunities must be created.

Electricity will improve the existing agricultural (through modernisation) and non-agricultural economy of Sandwip. Expansion of the non-agricultural economy in Sandwip is important for several reasons: the bulk of the population are poor landless farmers / marginal farmers; and, most agricultural practice is carried out by traditional methods, where production is limited to mainly cereals and a few cash crops. Furthermore, the agriculture sector in its present form in Sandwip is saturated and does not have the capacity to employ additional manpower. Finally, this sector masks considerable underemployment or disguised unemployment in the local community.
Economic progress in the rural areas in this situation points to the need for quick expansion of new forms of employment, assets and earnings. Through electrification, small-scale cottage industry, and utilisation of powered machines and other equipment can generate considerable employment in the area.

The priorities of different issues will need to be addressed at the community level, through the undertaking of a ‘Community Needs Assessment’. Following on from this needs assessment, project planning would focus as a priority on ‘Community mobilisation through the building of community partnerships’, commonly known as ‘Community-based co-management’ (Coastal community network, 2000; Pokrant, 1996). Finally the project has to evaluate ‘how the integrated development concept could improve health, education, access, safety, the economy and community life on Sandwip Island’, once the research has scoped out any potential problems associated with changes to the local hydrology, through technical assessments and detailed discussions with the people involved (Albanza, 1989; Nishat, 1986; Wilson and Severn, 1972). This participation enables different socio-economic interest groups in the Sandwip area to develop their capabilities and to play a dynamic role in developing initiatives. It also strengthens the commitment of a wide cross-section of stakeholders, elected representatives, government employees, professional groups, and voluntary groups including NGOs and community based organisations by giving them an opportunity to share responsibility in key decisions. More importantly, the Sandwip integrated tidal power model enables the planner to make use of local knowledge about the environment, specific land and water regimes and land and water use by different socio-economic groups. A good plan always depends on technical feasibility, resource availability, the institutional base, endorsement of the conceptual framework by the stakeholders and their participation right from the beginning.
Therefore community participation in the Sandwip tidal power model will identify various issues/problems and devise workable solutions for its vital role in sustainable development.

The integrated research model of tidal power will organise the community peoples and develop the specific community organisations that can find the solutions to community problems. This can be enhanced by the direct assistance of non-government organisations who have experience organising community peoples. Non-government organisations can transfer analytical and organisational skills to the community leaders and members. A core part of community organisation is to raise ecological awareness and make clear to people the importance of tidal energy and the linkage between resource degradation and threats to their livelihood. The organisation of the community in the process of community-based co-management could establish several small-scale projects which would provide alternative livelihoods, such as marine-based mussel culture, fish cage culture, and passive fishing projects, or land-based fish processing and marketing, mat making, or handicrafts. The active participation of community organisations plays a critical role in community-based co-management of coastal resources in the conceptualisation, planning, implementation and evaluation stages. Without the full participation of the community organisations by direct involvement as the implementers of the management scheme, the program/plans will remain a useless and expensive experiment. They are the primary stakeholders, as well as the resource users, and should have a say in how to use, control and manage their resources.

The integrated tidal power model for ‘Integrated Sustainable Sandwip Island Management’ will create a basis for addressing existing issues such as uncertainty of
livelihood in the shrimp aquaculture industry, marine resources, the accretion of new land, and other coastal ecosystems, tourism and leisure activities. The key challenge to ‘Integrated Sustainable Sandwip Island Management’ is to realise these potentials whilst mitigating or adapting to the vulnerabilities through a process that enhances the livelihoods of the people and provides communities with inputs to, and support from, external institutions. Such goals will need to be realized by a significant improvement in communication between local interests and the responsible government institutions. Thus the initiative must be taken by government institutions in approaching and establishing grass-root links and evolving a process for incorporating the wishes and aspirations of the community within integrated tidal power policy frameworks.

(a) **Women’s involvement:** Coastal community issues and problems are multifaceted and must therefore be addressed holistically in an integrated manner. Therefore coastal communities must build popular organisations with the necessary strength to support marginalized fisher folk and farmers, and women who are largely affected by the degraded status of the coastal resources. Women comprise 50% of the population and are the most deprived in Bangladeshi society, but they are most important stakeholders for the development process. In the proposed tidal power project, the desired economic and social outcomes possess a substantive female focus and require substantial female involvement. Equal participation of women throughout the engineering phase will necessitate a high level of female participation at the management level of the process. Thus it is proposed that the participation of women during the initial and design phases will be fundamental in ensuring their participation throughout the whole project life cycle. It is suggested that this may take the form of a women-based ‘steering
committee’. Assessments of household electricity requirements should be based on ascertaining the respective needs of males and females for demand-end electrification appliances. As such, the provision of quality lighting for the purposes of female education or food preparation by women shall be enhanced by electrification. Furthermore, it is recognised that it is necessary, within the needs assessment process, to ensure adequate representation of women’s income generation possibilities which would be enhanced through electrification as well as by the application of micro-finance (fig. 7.20).

7.1.4 The Phases of the Pilot Project on Sandwip Island

Given the multi-faceted elements of this program, it is proposed that its successful implementation would be best assessed through the application of a pilot project. This
pilot project would manage the full cycle of assessments, design, implementation and evaluation at one site - prior to undertaking the development of the 28 sites identified on the island.

The first stage of the proposal is to install an initial pilot plant at a strategic creek location on the island. This location is at the end of a main thoroughfare and is adjacent to the mainland. It is estimated that the plant would supply electricity to an existing small village which would increase its potential to become a regional centre due to its strategic location. It is anticipated that output from the pilot tidal wheel would produce electricity through the harnessing of power on both the flood and the ebb tide. The process for determining an appropriate program through the implementation of a Pilot Project would be phased as follows:

**Phase I: Feasibility:** This will include the identification of relevant organisations and their role in hybrid/tidal power production to promote sustainable island development. Issues to be addressed include:

i. Tidal power/ renewable hybrid potential (technology, supply-side estimation, costs/tariffs, financial recovery factors);

ii. Latent socio-economic development impacts (demand-side estimation – community needs analysis, ability to pay, manage development activities, maintain systems);

iii. Institutional Stakeholders (Rural Electrification Board, Power Development Board, Local Government Engineering Department, Bangladesh Water Development Board – capacity to implement, oversee maintenance etc., plans and existing programs);
iv. Community groups (local NGOs – capacity to mobilise community partnership in the project, plans and existing programs);
v. Community members (development needs assessment, capacity and adaptive potential/strategies, especially gender impacts through community-based co-management approach); and
vi. Local infrastructure for pilot project implementation (island access, equipment transport logistics, capacity to local manufacture deficiencies/gaps etc.).

(b) **Phase II: design and installation:** This step of the integrated tidal power system includes water management and aquaculture development with co-requisite community/institutional mobilisation activities, monitoring and evaluation activities at one defined site. Activities include:

i. Identification/arrangement of pilot ponds for shrimp/prawn growing and harvesting;

ii. Identification/arrangement for pilot commercial and domestic energy applications;

iii. Identification/arrangement for channel deepening exercises;

iv. Development of product/production concept and processes;

v. Community/Institutional Mobilisation;

vi. Tidal/hybrid renewable energy trial;

vii. Development impact assessment; and

(c) **Implementation agencies:** Success throughout all stages of this integrated model, and, importantly, its on-going viability as a catalyst for sustainable community development will only be achieved by strong support from the Government of Bangladesh. The operational facets of this project, including long-term community involvement through a community-based co-management process, will only be achieved through shared enthusiasm and collective effort by local development institutions with partnership links to the communities at the centre of this project. The model would need several implementing agencies, for instance:

i. Bangladesh Water Development Board (improvement of embankment and sluice gate for tidal power design suitability);

ii. Rural Electrification Board (electricity management);

iii. Local Government Engineering Department (water management);

iv. Ministry of Fisheries (aquaculture);

v. Sandwip Island Administration (community development); and

vi. Ministry of Planning/Planning Commission (overall direction of project).

The model also needs support from non-government organisations, such as:

i. The Centre for Mass Education in Science to provide program direction, training and technical innovations;

ii. The Grameen Bank to assist with micro-credit/micro-finance cooperative schemes designed to enable the establishment of ponds and the purchase of demand based electricity services;
iii. The Institute for Sustainability and Technology Policy (ISTP) to provide the unique opportunity to incorporate Bangladeshi and international PhD students, holding specific expertise, in research aspects of the project;

iv. An international NGO (for example, the Centre for the Application of Solar Energy (CASE) in Western Australia) to work as a core agency in the commercialisation of tidal power/ renewable energy technologies; and

v. Tidal Energy Australia (TEA) to some expertise in the development of tidal power technology.

(d) Replication: The details of the replication of the project will need to be established – firstly to other sites on Sandwip and then to other islands. However, the lessons learned during the pilot phase will be invaluable. Observers will also be keenly interested in project management details, for example, dealing with island access, logistics of equipment transfer, field communications for experts, occupational health and safety, recruitment and organisation of local workers and gender and environmental aspects. Once this concept of sustainable integrated coastal development has been tested on Sandwip, the potential is there to replicate the project in other parts of coastal Bangladesh, where barrages and sluice gates exist.

7.1.5 The significance of the Sandwip integrated tidal power project

The potential to expand and extend the concept of the ‘Sandwip Integrated Tidal Power Project’ to other parts of Bangladesh is obvious. The proposed integrated tidal model would produce electricity that could be utilized for various purposes in shrimp hatcheries and other functions in the semi-intensive, integrated shrimp aquaculture
project. These include aeration and filtration of water, water pumping, and mechanical irrigation of the paddy fields. The electricity could also help to improve the modernisation of agriculture, organise the small-scale businesses that depend on electricity such as agro-based processing industries, improve the communication facilities, modernise the education system, empower women and improve the socio-economic status of coastal community. Thus the electricity produced from this integrated tidal power model is very important for the sustainable development of Sandwip Island.

Other islands such as Char Kukri Mukri, Char Patila, Dhala Char, Char Nizam, Char Motahar, Char Zahiruddin and Nijhum Dwip have similar tidal characteristics and an integrated tidal power model could be established at these sites. The production of tidal power may play a significant role in minimising the production of greenhouse gases globally. The opportunity to attract international funds through the ‘Clean Development Mechanism’ is thus apparent. Future climate change impacts will enhance the existing coastal engineering of Sandwip Island, where tidal power offers an added benefit to moves designed to improve barrages and water management. In addition, future climate change could bring positive impacts to the production system of the project through increasing tidal flows, which may, in fact, be advantageous to Bangladesh.

7.2 Case study 2: Gazi Fish Culture Ltd.

The case study of Sandwip proposes the feasibility of using coastal embankments and sluice gates as a readymade structural base for small-scale tidal power technology, which could be integrated with local socio-economic and environmental resources. The Gazi Fish Culture Ltd. is an existing aquaculture business set up in the 1980s, which has been chosen as a suitable vehicle to assess the viability of a limited scale integrated tidal power project case study. The following sections will describe the possibility of integrating tidal power development into an existing aquaculture project.

7.2.1 Location

The Gazi Fish Culture Ltd. is a joint venture project of Saudi-Bangla Fish Feed Ltd and the Arab Bangladesh Bank. The project is situated in the southwestern part of
Bangladesh about 3 hours journey on a Speedboat from the main land of Khulna City and adjacent to the southwestern corner of the Sundarbans Mangroves. The total area of the project is approximately 175 acres. Two rivers pass beside the project area exerting strong-tidal influences (fig. 7.21).

Fig. 7.21: The location and model of Gazi Fish Culture Ltd. in Khulna, Bangladesh (Photo: M. Salequzzaman, November 2000).
7.2.2 Infrastructure

Gazi Fish Culture Ltd’s operation consists of 23 ponds of 1.88 acres, 18 ponds of 2.03 acres, and 24 ponds of 1.67 acres respectively. Each pond is connected through several long, wide drainage systems. The whole area is surrounded by embankments and sluice gates. Two sluice gates are used for the inlet of tidal water and 7 sluice gates are used for disposal of used water (fig. 7.22).

Fig. 7.22: Different sluice gates and their tidal water inflow at the Gazi Fish Culture Ltd. (A: Inlet, B: Outlet) (Photos: M. Salequzzaman, November 2000).

In addition, each pond has separate inlets and outlets. On site facilities include office and storage buildings, 2 buildings for labour dormitories, a manager’s residence and guesthouse and well-equipped laboratory and hatchery buildings.
Initially, the project ran successfully using 450 diesel motors of 1 HP (horse power) each, 40 diesel motors of 5 HP each, and several other small-unit electricity producing generators. As the operation was initially designed as a composite semi-intensive aquaculture project, a large amount of electricity was needed every day. Within a few years, the project failed mainly due to the uncertainties related to expensive electricity-consumption activities such as aeration to hatchery water and other pond systems, cold storage, processing plant, and lighting. These intensive electricity requirements required 12 electricians to maintain the system and consumed 2200-2500 litres of diesel and 50 litres of mobil oil per day. Consequently, the project soon changed in character from a semi-intensive to an extensive aquaculture system.

7.2.3 Tidal range and infrastructure for potential tidal power generation

The Gazi Fish Culture Ltd. operation is located on the bank of the river Vadra which feeds the Shibsha estuary, adjacent to the Bay of Bengal and which is characterized by its strong tidal action. According to my field survey and the project officials at the farm, the average tidal range at the inlet and outlet sluice gates is 3.0-5.0 m. As I described in the Sandwip case study, a 3.0-5.0 m tidal range is more than sufficient for the production of small-scale tidal power using a tidal wheel. Experts have suggested that this project’s location is more favourable for small-scale tidal power production than the Sandwip project (Corry and Newman, 2000), because the area is free from erosion and the aquaculture farm has the infrastructure necessary for tidal

198 For details, please contact: Gazi Fish Cultural, 138 Majid Sharani, Sonadanga, Khulna, Bangladesh, Phone: 88-041-722526/722526, Fax: 88-041-761285.
power generation such as a long, deep and wide pond system for tidal water storage (fig. 7.23).

![Fig. 7.23: A long, deep and wide pond system of Gazi Fish Culture Ltd. for small-scale tidal water storage (Photos: M. Salequzzaman, November 2000).](image)

It also has an existing water control structure, electricity supply grid lines, excess electricity storage batteries and other associated materials available for use with a small-scale tidal power generation plant. All that would be required is the necessary construction to hang the tidal wheel in the sluice gate area.

### 7.2.4 Current activities of the farm and tidal power integration prospects

Presently, the farm carries out extensive and sometimes improved-extensive aquaculture that consists of shrimp, prawn, catfish, carp fish and some exotic fishes. The production rate is not satisfactory, mainly due to lack of electricity for aeration and other purposes. However, according to my assessment, there are excellent prospects of improving the viability of this aquaculture farm through modernization to a semi-intensive or intensive or super intensive system, with production yields raised
to 5-20-times of present production. As described in the Sandwip case study, the existing infrastructure of embankments, ponds and sluice gates could be utilized for the production of small-scale tidal power using a tidal wheel. The electricity generated could then be used for the modernization of the Gazi Fish Culture Ltd.

The electricity produced may also be utilised to integrate other farm activities with shrimp/fish aquaculture. For example:

(a) Irrigating horticulture using tidal electricity-powered motors;

(b) Integrating livestock (goat/cow/ship/buffalo) and poultry (duck/chickens) with aquaculture farming, using electricity to treat wastewater from the livestock farm;

(c) Improving the shrimp/prawn mono-culture system and poly-culture of fish with shrimp/prawn by using electric aerators;

(d) Electric farm lighting, security, feed preparation, and other such activities;

(e) Integration of electricity into the hatchery system and for overall wastewater treatment system;

(f) Conducting laboratory experiments and analysis;

(g) Integrating paddy-shrimp/prawn/fish cultivation using irrigated water;

(h) Electrifying the agro-based processing industry, such as fruit preservation and pickle preparation; and

(i) Introducing computer systems and the Internet for electronic commerce and other business and farm activities.

It is evident from the above that tidal power could be utilized for many activities in an integrated aquaculture farm which would increase its viability both in economic and sustainable development terms.
This single PV cell is currently the only electricity production facility in Gazi Fish Culture Ltd. What about the diesel engines?

Water reservoir for hatchery activities and a part of water treatment system.

Small-scale nursery tank/pond for shrimp/prawn/other fish hatchery system.

Horticulture activities on the dike of the pond.

Paddy cultivation in the middle of aquaculture pond.

Livestock production on the dike of existing aquaculture.

Fig. 7.24: Various existing activities of the Gazi Fish Culture Ltd. that favour the sustainability of an integrated small-scale tidal power plant (Photos: M. Salequzzaman, November 2000).
Fig. 7.24 illustrates how one PV cell can be used for energy production, usually to watch television. The establishment of the proposed tidal power plant model would meet all of the electricity requirements of the farm. In addition, excess electricity could be used to charge batteries for on-selling to neighbouring villagers. During low demand periods, excess electricity could be switched to hydrogen production through water electrolysis. This produced hydrogen could be utilised for car/vehicle energy, which is a 100% clean fuel. In this way, the farm may become an excellent example of ecologically sustainable integrated development. With its innovative approach, the farm might be considered as a model for ecological tourism. Above all, this new innovative technology could easily qualify for international funding, such as CDM or GEF. Finally, the technology may be exported to other coastal areas and other countries with similar landforms and development requirements.

### 7.3 Sustainability of both projects

At a national level, the predictions of significant growth in energy consumption in Bangladesh suggest energy should essentially come from sustainable, rather than unsustainable sources. Tidal power is a potential renewable energy which is vital for the long-term development of Bangladesh.

At a project level, the current delivery of energy services to consumers on the islands of Sandwip and the Gazi Fish Culture Ltd. are manifestly unsustainable. The electricity supply in both areas currently requires transportation of raw materials

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199 The GEF (Global Environmental Facility) is a financial mechanism, which provides grant and concessional funding for recipient countries for projects and activities that address climate change, biological diversity, international waters, and depletion of the ozone layer. The World Bank shares the responsibility for implementing GEF activities with the United Nations Development Program (UNDP) and United Nations Environment Program (UNEP).

(drums of diesel or re-charged lead-acid batteries) from the mainland. Substantial transportation costs are incurred as well as creating an energy supply from non-renewable sources.

More fundamentally, at a local level, sustainability is a function of involvement of the beneficiary community (Addessi, 1993; Newman, 1996). This is facilitated through the incorporation of the community in all stages of the project process – from conceptual design through implementation, operation and management through to project assessment. This will involve complex exchanges seeking to both understand and elaborate end-user needs, understandings and expectations; the cultural relevance of electricity; societal organisational/management structures and the empowerment of women.

Sustainability at a financial level requires that electricity service provision must be economically viable at a local level as well as institutionally. The financial sustainability at a local level will be based on the provision of affordable electricity services. This can be marginally offset by increased opportunities for income generation. However such opportunities will not affect sustainability significantly. The institutional financial sustainability will determine whether or not the service provider can viably replicate the projects.

### 7.4 Conclusions

Renewable energy technologies are likely to play a significant role in the future development scenario of coastal Bangladesh, especially when the capital costs of such technologies become competitive with grid electricity. This is expected to happen
globally within the next few decades as there is a historical trend of capital cost reduction for tidal power technology like other renewable energy generators all over the world. Until that time, however, developing countries like Bangladesh need to make efforts to establish the technical reliability and social acceptability of renewables like tidal power technologies through demonstration/pilot projects. Sandwip and Gazi Fish Culture Ltd. can provide such trials. It is notable that this type of project is currently supported by subsidies from governments in other developing countries.

Both of these projects are innovative as the demonstration of the proposed model of tidal power developments will be integrated with sustainable coastal development schemes. The trials will need to be developed through a community consultative and approvals process. Economic opportunities arise from utilising the impounded or controlled body of water for aquaculture and related industries. Lifestyle opportunities are also created through the provision of infrastructure to control water movements, minimizing flooding and generally providing access, where previously land based access was not possible (Newman, 1974). Other related development is also possible through the provision of boat access or navigation. The project could offer socio-economic and environmental sustainability through negotiation of conflicts, maintenance of biodiversity and improvements to the income generation activities of local coastal peoples and the projects themselves.

Finally, it may be said that sustainable development has a long-term vision unlike most current development. The value of tidal power is that it is inherently long term and will force the financial community to relate to these more sustainable time-lines. It is hoped that tidal power stations on Sandwip and at Gazi Fish Culture Ltd. will
prove the financial viability of the technology as a part of an integrated coastal development process.
CHAPTER VIII
Chapter VIII
RECOMMENDATIONS AND CONCLUSIONS

“Sustainable development will not happen of its own accord. We need a break with the harmful practices of the past and a break in the political stalemate that prevails on too many environmental issues”

Kofi Annan
Secretary General of the United Nations
The International Conference Centre, Dhaka, Bangladesh
14th March 2001

8.0 Introduction

Sustainable development involves mutually supportive interconnections and integration among social, cultural, economic and environmental activities. As has been described in previous chapters, it is apparent that the implementation of the proposed integrated tidal power project in coastal Bangladesh, on a community-based co-management approach, would help to ensure the sustainability of coastal resources both now and in the future. This approach recognises the need for social equity between various community groups on an intra and inter-generational basis and the necessity of understanding and respecting the biological and cultural diversity of coastal Bangladesh.

This chapter will discuss the questions raised at the beginning of the research project with regard to the integrated tidal power concept and will recommend some specific pre-requisites or factors required for successful implementation to ensure sustainable integrated coastal development. Lastly, a final conclusion on the outcomes of the research will be given.
8.1 Have research questions been answered?

8.1.1 Can tidal power promote sustainable coastal development?

The answer to the fundamental question behind the thesis is yes, with several provisos. Presently, the technology is available to produce small-scale tidal power from low ranges of tidal head. The technology ranges from locally available, low-cost paddle wheels to sophisticated turbines and is such that tidal power can be harnessed from tidal ranges as low as 2m and up to 12m or higher. This technology is now cost competitive with other sources of renewable energy, such as solar power, photovoltaics, wind energy and wave energy and has the added benefit of longevity. As the paddle wheel technology recommended in this proposal requires no inputs apart from water which is freely available with the tide, the capital costs can be repaid over a relatively short period (say 20 years) and ongoing maintenance and running costs would be minimal.

Tidal power is not a new concept. Its use has been recorded since the 11th century in Europe and the Middle East. However, with the introduction of massive non-renewable sources of energy during the 18th Century, tidal power was displaced as a primary energy source. Researchers have, in recent years, taken up the concept of tidal power generation again as a relatively simple, low cost source of renewable energy that can deliver large improvements in quality of life, especially in less developed countries.

This thesis has shown that by utilising the existing infrastructure in coastal Bangladesh, small-scale tidal power could be produced using low-cost, locally
available paddle wheels which can be installed in the sluice gates. Obviously, if finances were unlimited, a much more significant amount of tidal energy could be produced from this area by using sophisticated equipment, such as the ‘Davis Turbine’. However, the technical potential of tidal power is only a small part of the challenge.

The “provisos” to the positive answer to the thesis question involves several human questions. One related to management of the tidal power and the other to how the coastal development is managed.

**Tidal power management**

The sustainability of tidal power generation and its related infrastructure will depend on how well the power station and associated infrastructure are managed to ensure the well being of local people, the surrounding environment and ecosystems. Environmental impacts can be measured by conducting a thorough Environmental Impact Assessment (EIA) to assess the possible negative effects of the technology on the surrounding ecosystems and infrastructure and ways in which these could be mitigated. Social impacts can be assessed with interpretive social assessment involving thorough and genuine consultation. The on going management of the tidal power system will also need to be integrated closely into the coastal community.

**Coastal development management**

A small-scale tidal power project can theoretically produce ongoing energy in the rural coastal location of Bangladesh. However, this innovative, integrated tidal power concept will need to focus on the following crucial factors to achieve real sustainable integrated coastal development in Bangladesh:
(a) Although the increased availability of electricity would be welcomed by the coastal population as a whole and would provide significant improvements in quality of life, it is vital that the proposed tidal power project be integrated as much as possible with the local traditional lifestyle. This could be achieved by working closely with local community groups right from the beginning of the project on a community co-management basis.

(b) The majority of people living in the coastal area are very poor and would require financial assistance to take up the opportunities presented by a reliable source of electricity. The integrated tidal power project would invite micro-credit/micro-finance organisations, such as the Grameen Bank to establish links between small-scale entrepreneurs (mainly poorer farmers and women) and the economic opportunities presented by the tidal power project.

(c) The proposed integrated tidal power model should encourage further coastal economic activity over the medium to long-term by creating opportunities in aquaculture and cottage industries. This will only be sustainable if it is developed by improving the welfare of women and other disadvantaged groups, and facilitating other income generating activities for the whole local community. If the tidal power is used to create wealth for a few people only it would not be considered a sustainable result.

Further detail on these conclusions is outlined below.
8.1.2 How can tidal power work in coastal Bangladesh where coastal shrimp aquaculture is dominating coastal land-use patterns?

As discussed in Chapter III and V, the present land use patterns of coastal Bangladesh are dominated by shrimp/fish aquaculture. These aquaculture systems use the coastal infrastructure such as embankments and sluice gates to create their shrimp ponds and by so doing prevent other coastal land-use patterns and threaten biodiversity. In contrast, these existing embankments and sluice gates would be more usefully employed in the generation of low-cost, tidal wheel based energy which would enable the operation of more productive but less environmentally damaging aquaculture systems which can be integrated with other land-use patterns.

8.1.3 How will integration of tidal power bring about sustainable coastal development?

Power or electricity is the life-blood of modern economic activity in any country. The Bangladesh economy is growing very slowly due to lack of sufficient electricity to meet the demands of business and other consumers. The sustainable development of coastal Bangladesh can be achieved by introducing more modern facilities including electricity supply as well as undertaking a fundamental change in all of its present development practices. A practical move toward a more sustainable future will depend on three important factors:

(a) eco-efficient innovation in technological, economic and management strategies;

(b) greater understanding of and respect for ecological processes; and
(c) genuine forms of community empowerment in the coastal community (Heij, 2001; Serageldin and Steer, 1994; Yencken and Wilkinson, 2000).

The present research has identified the potential for electricity supply using small-scale tidal power plants and low-cost appropriate technology. The research has also identified solutions to improving income generation, land-use conflict mitigation and restoring the biodiversity of the coastal environment and community through the integration of tidal power technology with coastal resources through a community-based coastal co-management process. The new approach would convert the presently unsustainable shrimp/fisheries aquaculture to more scientific and sustainable practices. In addition, the proposed integrated model would intensify the diversification of agriculture replacing monoculture which has sharply reduced the traditional practice of paddy and cereal cultivation in the coastal area. Mono cropping reduces soil fertility and biodiversity. Healthy soil results from careful crop rotation. The proposed tidal power model would also integrate dairies, poultry, cattle rearing and other such activities that are presently becoming unviable. The proposed new concept is more likely to provide an environmentally friendly, balanced agriculture system, such as paddy-shrimp/fish cultivation in conjunction with rotational oil seed, pulses, spices, paddy, wheat, etc. This new agricultural system would increase income generation activities and ensure employment opportunities.

The success of the concept depends on a new management model. The new model will:

(a) Identify environmental and social issues and integrate these into strategic planning processes, conserve ecological values (biotic diversity, biotic rarity,
abiotic diversity, abiotic rarity and others) and ensure ecologically sustainable development;

(b) Ensure the appropriate economic, cultural, environmental and social information is made available to decision makers, with priority being given to developing appropriate policy and regulations which would maintain sustainable development;

(c) Carry out a thorough environmental impact assessment (EIA) prior to commencement of the project and make any changes necessary to the model to ensure appropriate solutions and management for sustainability are put in place;

(d) Consult widely with the local community to determine appropriate site selection for tidal power plants in order to minimise environmental and social impacts; and

(e) Take the appropriate measures to avoid or minimise impacts on neighbouring ecosystems, including protection and conservation of biodiversity, wilderness and other such resources.

The above model will help realise the potential for tidal power to be integrated into coastal development in a sustainable way. It has the potential to empower citizens to have a voice in economic policymaking that will benefit the country and contribute to change at the global level. Similar small-scale tidal power technology could also be applicable in other countries which share similar infrastructure and tidal characteristics (for example, India, Vietnam, China, Philippines and Indonesia) (ESCAP, 1992b).
8.2 Recommendations for the implementation of tidal power integrated into sustainable coastal development of Bangladesh

8.2.1 Political will

All political parties (government and opposition) and other powerful stakeholders (bureaucrats, civil society, intelligentsia, mass media and donor agencies) have a moral responsibility to initiate sustainable development processes to protect present and future generations in any country of the world. Bureaucrats can assist politicians through research; civil society, including the private sector, can support the effort of political parties by providing technical and financial help; the mass media can assist with communication efforts; and, finally these collective and collaborative efforts can lead to effective government policy and regulation of sustainable coastal development. Bangladesh will need a strong political will to achieve sustainable development in the coastal region as well as in the whole country (Lowry, 1989). The research has recognised that there is a serious lack of political will in Bangladesh to achieve all of the above in its development processes. The success of the proposed integrated tidal power model will require all coastal stakeholders to play an important role in promoting participatory governance to implement the goal of furthering sustainable development in this region.

8.2.2 Community participation

Participation by key stakeholders, including policy makers, academics, technocrats and the local community, in the decision making process is a key factor in achieving the outcomes outlined above. In particular, there is a greater potential for successful
outcomes through encouraging the involvement of community stakeholders who can contribute essential local knowledge to the process (Ruddle, 2001). In this regard, care should be exercised to ensure that all sections of the community are represented including women, indigenous people and other disadvantaged groups (Christie et al., 1994; White et al., 1994).

8.2.3 Governance and transparency

There is a strong national consensus in Bangladesh that better governance is essential to reduce poverty, achieve prosperity, improve quality of life and implement overall sustainable development. It is a widespread belief that the people of Bangladesh are ready for improved governance. The demand for better governance is thus in the first instance a compelling domestic demand. Better governance is also an issue for financial donors, because most development assistance comes from domestic taxpayers in donor countries. Taxpayers will not be convinced until their contributions are being well used (without fraud and corruption). Countries that reform their policies and institutions and improve governance will get a larger share of the global aid pie. Presently, governance in coastal Bangladesh, is characterised by large scale corrupt activities and lack of transparency. Poor governance retards the rate of economic growth, encourages increasing levels of corruption and lowers the quality of governance itself. It is evident that ‘good government’, ‘governance and accountability’ and ‘transparency’ in the community and administration will be necessary to maintain sustainable coastal development. The main responsibility for the proposed integrated tidal power project will lie with the local government authority, which will have to liaise with the various stakeholders and take responsibility for planning, protection, legislation, regulation and revenue collection.
(White et al., 1997). In this regard, strict accountability rules must be enforced at all tiers of the civil administration and measures will have to be taken to enforce the same strictly and scrupulously. The accountability procedures and penalties must not be limited to the regular civil service but should extend to government owned corporations, national financial institutions, other semi-autonomous bodies and private sector organisations.

8.2.4 Coordination and cooperation

Coordination and cooperation of different stakeholders and relevant organisations and government departments are important factors for achieving sustainable development in coastal Bangladesh. The research has found that there is a big gap in this area both in coastal Bangladesh and across the country as a whole (Lowry, 1989). The management of the integrated tidal power project will have to implement a programme to ensure well-maintained lines of communication and cooperation between the project managers, local government and other stakeholder organisations. This is particularly vital in areas requiring complex technical analysis such as hydrology, geology, ecology, engineering and cartographic aspects of the project to ensure they work as a team rather than in isolation. Following on from this project, there should be opportunities for further cooperative research to formulate an ideal model of how tidal power technology can be integrated into coastal Bangladesh.

8.2.5 Motivation, awareness, training and education programs

Awareness is an important factor in motivating community participation and an important prerequisite for the sustainability of any innovative technology. As tidal power will be a new technology in coastal Bangladesh, it needs appropriate
motivation and awareness programs to familiarise the concept within the community. The program may include drama, a poster campaign, advertisements, public lectures, seminars and training programs. It should also include discussion of emerging climate change and rising sea level issues and how these could be mitigated or adapted using the proposed tidal power technology which would be integrated with local farming and business operations. More importantly, the awareness campaigns should focus on taking advantage of the country’s indigenous knowledge and experience in coping with such extreme events that have occurred in the past, as preparation for future eventualities.

Coastal Bangladesh has experienced frequent natural hazards, such as salinisation, cyclones and tidal surges which cause a significant sea level rise during specific seasons of the year. The training and educational programs should present to various stakeholder groups the means by which the integrated tidal power will alleviate these disastrous situations without further damaging the environment. Additional vocational training and education will also be required to enhance the opportunities for the local community to take up alternative occupations like poultry husbandry, tailoring, embroidery and textile technology utilising the electricity generated by the integrated tidal power project.

8.2.6 Consider climate change scenarios

When conducting vulnerability assessment in coastal environments, it is important to recognise that climate change and sea level rise impact on an evolving coastal landscape. Embankments and sluice gates presently protect coastal Bangladesh. In future climate change scenarios, rising sea levels would, necessitate raising the height
of coastal embankments to protect people and resources. This future scenario would definitely increase the tidal range, which will further increase the tidal power possibilities in coastal Bangladesh. Thus, the future climate change scenario will require an effective long term management strategy, which includes the integration of tidal power with existing coastal resources and infrastructural settings in coastal Bangladesh to ensure successful ecologically sustainable development in this area (Milliman et al., 1989; World Bank, 2001).

Tidal power integration involves the comprehensive assessment, setting of objectives, planning and management of coastal systems and resources, while taking into account traditional, cultural and historical perspectives and conflicting interests and uses. It is an iterative and evolutionary process, which includes adaptation to climate change and sea-level rise by developing and implementing a continuous management capability that can respond to changing conditions.

**8.2.7 Subsidy and financial support**

As tidal power is a green energy, the government should develop a subsidy scheme to support its development. In addition, the project can get financial support from international organisations and commitments, such as the Clean Development Mechanism of the Kyoto Protocol Agreement (Hinrichs-Rahlwes, 2001). The Kyoto mechanisms facilitate the provision of funding by developed countries (who are responsible for most of the GHGs emissions) to finance international emissions trading, joint implementation (credits for joint projects between developed countries) and the Clean Development Mechanism (credits for joint projects with developing countries) (Tony, 2002). Once operation of the Clean Development Mechanism is left
to market forces alone, Clean Development Mechanism projects and transfer of technology (such as tidal power) will tend to be concentrated in developing countries like Bangladesh. Besides, according to the successful negotiation of the Bonn Agreement, active cooperation with developing countries under the UNFCCC is aimed at capacity building, technology transfer and adaptation. The small-scale tidal power project is a probable candidate for the UNEP Financial Services Initiative, given that the proposed project includes dam and dyke-building that will keep rising sea-levels out of coastal cities and farmlands, and control damage to farmlands and crops resulting from weather extremes created by greenhouse gases. It is also suitable for the Prototype Carbon Fund for emission reduction efforts. The Global Environment Facility could also fund the tidal project as a mitigation measure of climate change. Industrialised countries and multilateral organisations can help Bangladesh to better cope with the challenges of climate change (Huq, 2001). In addition, the World Bank, the Asian Development Bank and some other donors may provide soft loans on easy terms and conditions to this integrated tidal power project. However in order to take advantage of the international negotiations on climate change, Bangladesh must recognise the issue of climate change in the medium to long term and prepare for it accordingly. In the short term, it needs to use its own resources to maximum benefit in this area (Simms, 2001). Finally to obtain the best

202 United Nations Environmental Program.
203 Personal communication to Dr. Mizan R. Khan, who wrote COP6 at The Hague. The author is Policy Specialist at the UNDP-supported Sustainable Environment Management Program (SEMP), implemented by the Ministry of Environment and Forest of Bangladesh.
204 A soft loan is a kind of loan which is generally sanctioned at low rates of interest or no interest at all, to be given on condition of agreed criteria, particularly purposes and objectives. Generally, the poorest countries can be given soft loans by the international organisations or developed countries to support projects without any requirements that oblige the recipient country to purchase goods. Soft loans can be used for social sector projects or environmental projects in somewhat wealthier countries. The investments best suited for soft loan financing are those that can generate revenue, but the revenue is not sufficient to cover the entire cost, for example investments in railways, extensions of the electricity network in rural areas, or solid waste management.
advantage from the international funding opportunities which may be available for this kind of project, it is recommended that the government of Bangladesh develop strong foreign policy relationships and rapport with possible donor countries and organisations.

8.2.8 Linkage of international organisations and bilateral programs with different research groups

The thesis has found that the integration of tidal power with coastal resources in Bangladesh is the best option for sustainable coastal development. However it needs further research for its broader application throughout the coastal areas of Bangladesh and other South-East Asian countries. Funding for the research and development program may come from some developed countries as a part of the Clean Development Mechanism or other such initiatives (Huq, 2001).

8.2.9 National coastal development policy

A national policy on sustainable coastal development, supported and agreed at the proper administrative level, will be needed in order to support and strengthen the implementation of the integrated tidal power concept in coastal Bangladesh. This new policy document will be complementary to existing sectoral policy documents and will be developed with the full participation of sectoral ministries, agencies, coastal communities and all relevant stakeholders.

For this purpose, a database of tidal range data should be established in order to cover the entire coastline under a computer network system. Under the new system, government should adopt a separate policy and plan, with a separate budget for
electrification of remote coastal areas and encourage local bodies and the private sector to play a part in its implementation. The integrated tidal power concept should be part of this (in addition to the present efforts of REB - Rural Electrification Board and BPDB- Bangladesh Power Development Board). To enhance this process, direct and indirect subsidies should be given both to entrepreneurs and consumers for contributions to the development of an integrated, sustainable coastal development concept.

8.2.10 Develop appropriate rules and regulations to pursue the integrated tidal power concepts in coastal Bangladesh

There are many laws in coastal Bangladesh to regulate the natural environment, but most of the laws are out-dated and inactive. Therefore the existing laws on coastal area management need to be carefully reviewed for more practical and enforceable regulation. In addition, it needs appropriate new legislation through the adaptation of existing relevant rules and regulations for the sustainability of a new innovative technology in any society (Chou et al., 1991; Hotta, 1995). As the integrated tidal power concept assumes a new innovative technology, thus a new legislation system should be introduced through a long-term community consultation process to facilitate the integration of coastal resources development, with tidal power where feasible, to attain maximum benefit for the coastal community. This legislation should lock in and give effect to the community’s commitment to create an ecologically sustainable economy in coastal Bangladesh.
8.2.11 Develop community-based co-management approach

As community participation is one of the important prerequisites for sustainability of any developmental activity, the integrated tidal power concept should follow a participatory community-based co-management approach (Agenda 21, 1992). In this community-based co-management model, community consultation is a vital element of the ‘bottom–up approach’\(^\text{205}\). Community sustainability cannot be imposed in a ‘top-down fashion’\(^\text{206}\) (Environment Australia, 2002). However, this community consultation has to follow the existing and proposed rules and legislation for community involvement in order to avoid conflicts and to attain real sustainability in the coastal community.

8.2.12 Empowering women

The empowerment of women at the grassroots is a revolutionary economic change agent in Bangladesh in the attempt to alleviate hunger and poverty in the rural community. This empowerment process is also the key to social progress in areas of health, education, nutrition, sanitation and income generation. In addition, the economic solvency of women in remote communities will increase the bargaining power of families that crucially shape the resource allocation decisions households make, such as improving access to common property, children’s education, credit, public works schemes and legal and institutional rights. According to the Bangladesh experience, the empowering of women can transform society. The provision of micro-credit to poor rural women, e.g., through the micro-credit program of the Grameen Bank and the Bangladesh Rural Advancement Committee (BRAC), has become the new development mantra for international donors, international financial institutions,\(^\text{205}\) The development approach that starts from grass roots level of the community.\(^\text{206}\) The development approach that starts from top level of the community.
and national development programs. It results in an improvement in the quality of life across the broadest spectrum. It contributes positively to economic progress, to democracy, to good governance and to human rights – in short to peace, stability and progress for a country, for a region, for the world. As micro-credit has already played a significant role in the achievement of economic self-sufficiency for women in Bangladesh, the proposed project will definitely further empower women in remote coastal areas. This project should run on a participatory coastal co-management basis which will utilise the micro-credit system to assist with the provision of shelter and livelihood, combining it with health-care, education, nutrition, family welfare services and community development in a comprehensive anti-poverty initiative. However findings from a combination of sample survey and case study data reveal that the micro-credit program needs a strong central focus on education about the role of credit and its rules to make the program function successfully (Rahman and Boulder, 2000).

8.2.13 Environmental impact assessment (EIA)

EIA should be conducted in any coastal development process, except those developments that will not have any substantial adverse environmental or ecological effect. In the EIA process, adverse effects to public health and safety and hazards to the environment should be clearly weighed, with possible mitigation measures discussed through the planning process. Therefore, the integration of tidal power in coastal Bangladesh should include the EIA process. It has been found that many environmental and economic problems, including the production cost of the tidal power plant, have been significantly reduced since the 1970s, mainly due to the
application of the EIA process (Furubotn and Richer, 1991; Lincoln-Smith, 1998; Warnock and Wilson, 1972).

**8.2.14 Organisations and institutions**

The proposed integrated tidal power model should have an appropriate bottom-up approach that includes government and other organisations including NGOs, CBOs and the local community. The institutions and organisations need to have sufficient research capability and administrative resources to run the relevant policies and programs to ensure the ecological sustainability of the integrated tidal power development. As the administration and government of coastal management in Bangladesh are interdisciplinary and multi-sectoral in nature, improved coordination between the various stakeholder organisations is vital to build an ethos of collaborative organisation building. To ensure sustainability and transparency, the organisational set-up for the integrated tidal power project should comprise an inter-ministerial steering committee, a technical committee and a project development office.

**8.2.15 Marketing strategy**

In the proposed integrated tidal power project, all resource-users would be active partners in seeking institutional reform for effective market management and ecological sustainability (Collins and Porras, 1994; Lloyd, 1990). As the project is based on the principles of ecologically sustainability, it would provide a great opportunity to develop an international market, such as marketing of small-scale tidal power plants in remote coastal locations around the world. It also enhances the eco-tourism industry around an innovative approach that utilizes natural as well as historic components like tidal wheels. The implementation of this eco-tourism potential
through the tidal power project would improve coastal socio-cultural conditions, the infrastructure of poor communities and overall economic prosperity through marketing socio-cultural and indigenous products from coastal Bangladesh.

8.3 Limitations of the research and recommendations for further research

(a) Due to lack of funding, this research has discussed the hypothetical potential of tidal power prospects in coastal Bangladesh and its integration into other coastal resources. Therefore, there is a further need for its practical application and field trial.

(b) The research has concentrated on the innovation of tidal power prospects where coastal embankments and sluice gates already exist. Further detailed study is required including details of environmental impacts, cost-benefit analysis, infrastructure facilities, conflict mitigation processes and the relationship of tidal power with coastal hydrobiology and the socio-economic culture of the local environment.

(c) The research was conducted over a short time span. Tidal power has long-term implications. Therefore it needs a long-term study of the impact on the coastal environment, particularly changes to mangrove forests, bio-geo-chemical cycles and other kinds of impact. Further study should also include the life-cycles analysis of different tidal power technologies around the world.

(d) The research is based largely on the secondary literature and therefore would require further research, based on practical engineering, before any such project could be implemented.
(e) Extensive research is recommended to cover the relationship between tidal power and future climate changes and sea level rise scenarios. It should also include the Clean Development Mechanism opportunities for future scenarios of climate change.

(f) This study has discussed case studies of only two coastal sites in Bangladesh. Extensive study of different coastal sites both in Bangladesh and in South-East Asia is now required.

(g) The research does not include the barriers to tidal power establishment in real situations in coastal Bangladesh which is an area that should be extensively explored.

(h) This study has only analysed tidal power prospects in coastal Bangladesh, not other renewable energy sources, thus future research could be extended to include the potential of other renewable energy sources in coastal Bangladesh.

(i) The research does not cover tourism in detail, particularly eco-tourism opportunities. Therefore further assessment is needed of the tourism potential in the integrated tidal power project proposed in this thesis and the preparation of an action plan for such tourism developments.

(j) The research does not thoroughly examine the tidal power integration prospects with the existing infrastructure of multipurpose cyclone shelters. Therefore it is suggested that further research take place on how the existing multipurpose cyclone shelter program in the storm surge prone area could be utilised in the proposed integrated tidal power model.
8.4 Conclusions

A sustainable society in the future is technically possible, economically feasible, and environmentally and socially desirable. However it needs to be built in steps through innovative projects. In Bangladesh, it may be made possible through integrated coastal development involving tidal power. An integration of tidal power into coastal development offers potential benefits in economic, social and environmental improvement. However, as set out in this thesis, it would need to be managed by involving local people through community-based co-management. In the integrated coastal development process, multi-sectoral activities would contribute to the sustainable livelihood of the communities, where tidal power would help to improve and modernise the economy of the coastal community. However the full approach requires an integration of aquaculture, livestock, poultry, agriculture, public health, and micro-credit systems. Therefore a national strategy and policy for integrated tidal power coastal development is strongly recommended as a means of implementing sustainable coastal development in Bangladesh. This strategy can build on the questions answered by this thesis. It can provide insight into those questions that require further work. The key step in this thesis has been the recognition of potential synergies between tidal power and coastal development and the kind of management system that would be required to achieve results that are considered sustainable.