1 Introduction

The Ghanaian coastline stretches some 550 km from Togo to Cote d'Ivoire in the Gulf of Guinea (figure 1). There are about 100 coastal lagoons in Ghana which make them an important feature of this sandy coastline, especially as the lagoons provide many benefits and values to human populations (Gordon 1987, 1996). Locally, the lagoons provide valuable resources for trade and consumption. Large quantities of fish and crabs are caught and traded, either smoked or dried. Reeds and other plants are cut for thatch and for weaving mats for sale at markets near and far. Vegetables are grown in sandy garden beds irrigated by water drawn by hand from wells along the edges of the lagoons. Salt is extracted by both intensive and extensive methods. The socio-economic benefits of the lagoons to the local people are apparent to even the most casual of observer.

In recent years, the immense conservation value of these same lagoons has been recognised both nationally and internationally. As with wetlands elsewhere in the world the value of the lagoons as migratory waterbird habitat has received recognition (Ntiamoa-Baidu & Grieve 1987, Ntiamoa-Baidu 1991, 1993, Ntiamoa-Baidu & Gordon 1991, Piersma & Ntiamoa-Baidu 1995, Ntiamoa-Baidu et al 1998). The broader values of these habitats are gradually receiving greater attention as conservation is being increasingly considered as an integral component of sustainable use of the wetland resources, rather than as an issue in isolation.

However, it is evident that the values and benefits provided by the lagoons are under increasing threat from over-exploitation and degradation (Ntiamoa-Baidu & Gordon 1991). The very resources that provide the values and benefits are under pressure from the expanding human population. For the socio-economic values of the lagoons (ie the products and functions) to be maintained it is necessary to ensure that the basic ecological character of the lagoons is maintained. The products and functions of any wetland can not be treated separately from the ecological processes from which they are derived (Finlayson 1996a). Thus, to maintain the resources of the lagoons the pattern of usage must ensure that the ecological processes that support the products and functions valued by the human population are not degraded and, in the worst case, lost forever. Whilst traditional patterns and levels of use can be sustainable in Ghana (Gordon 1990), expanding population pressures can all too quickly degrade the basic resource(s) being used (World Bank 1996). The situation is made more acute in Ghana, where the coastal zone represents less than 7% of the total land area, however, it holds over 25% of the nation's population. The continued trends of the drift from rural to urban centres, the industrialisation of coastal districts as well as the high population growth rate of 3%, place increasing stress on the coastal ecosystems.

In view of such increasing pressures on wetlands the Ramsar Wetlands Convention has proposed management and monitoring processes for Wetlands of International Importance. Integral to these are guidelines for the wise use of wetlands (Davis 1993) and the maintenance of their ecological character (Finlayson 1996b). From a management perspective, the ecological character must first be described (to a minimum necessary level) and key features identified and then monitored to ensure that they are not degraded or lost. Thus, description of the ecological character and the development of a suitable monitoring framework are two steps that are increasingly being seen as essential components of making wise use of wetlands (Finlayson 1996a,b).

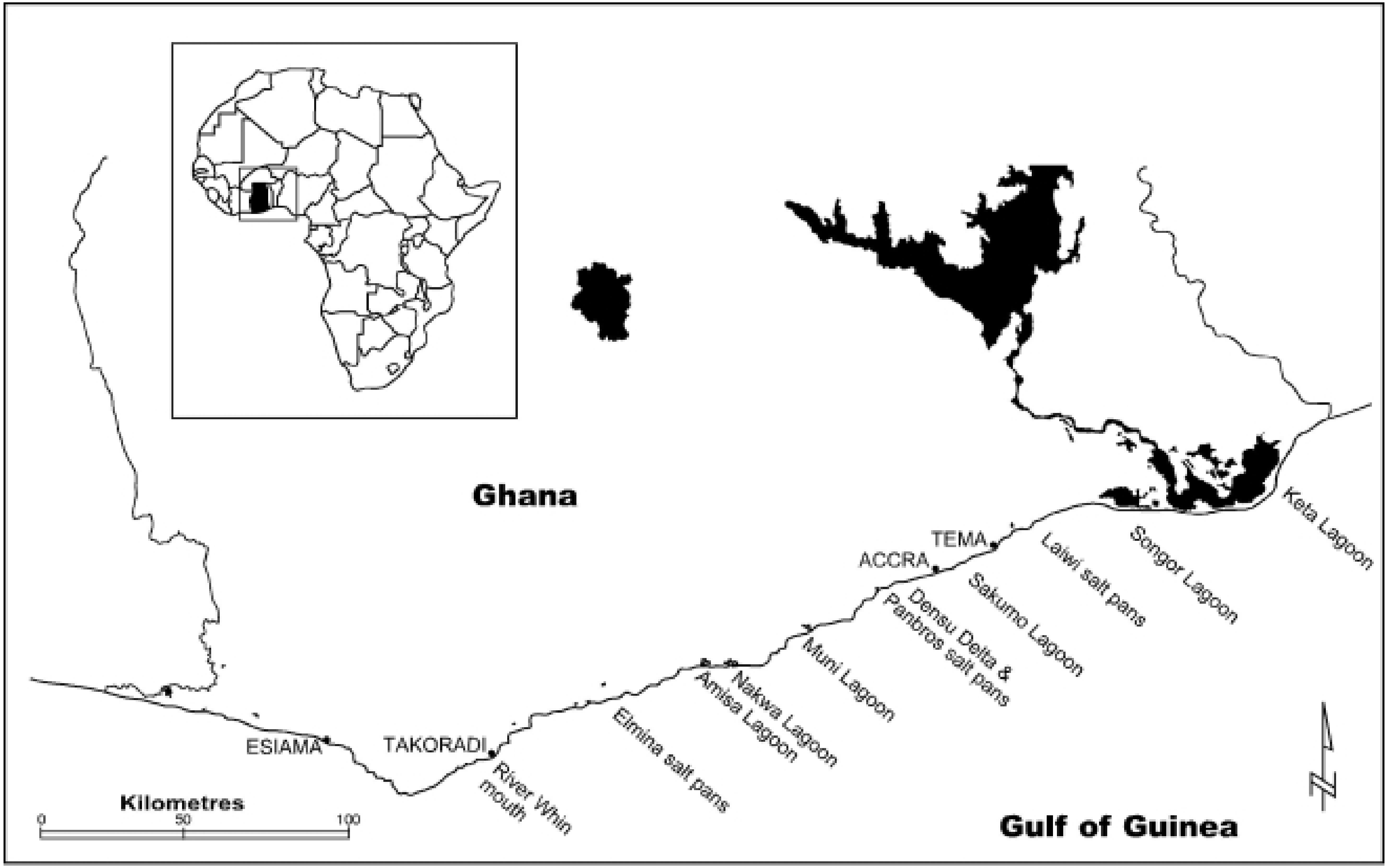

Figure 1 The Ghanaian coastline from Togo to Cote d'Ivoire in the Gulf of Guinea

In this report we provide a description of the ecological character of the Keta and Songor lagoons in the Lower Volta region of Ghana (figure 2) and present a framework for monitoring changes in their ecological character. It is anticipated that the long-term monitoring programs advocated will provide a more detailed temporal description of the ecological character of the lagoons. Keta and Songor lagoons are both internationally important wetlands designated as Ramsar sites on the basis of their total waterbird populations and the occurrence of internationally important numbers of several species (Ntiamoa-Baidu & Gordon 1991, Piersma & Ntiamoa-Baidu 1995, Ntiamoa-Baidu et al 1998). The lagoons and surrounding floodplains support large numbers of people through fishing, salt extraction, reed cutting and water supply. The information on the ecological character and monitoring of these lagoons is presented in line with the current concepts of the Ramsar Wetlands Convention for managing and monitoring wetlands. As such, this information also provides a basis to test the adequacy of the guidelines drawn up to interpret these international concepts.

1.1 Coastal wetlands management project

The Ghana Coastal Wetlands Management Project (CWMP) is implemented by the Ghana Wildlife Department as part of the Ghana Environmental Resource Management Project, funded by the Global Environmental Facility (GEF). The general aim of the CWMP was to manage five coastal wetland sites to maintain their ecological integrity and enhance the benefits derived from the wetlands by local communities.

1.1.1 Background

The genesis of the CWMP can be traced back to 1985, when the Government of Ghana entered into an agreement with BirdLife International (formerly the International Council for Bird Preservation) and the Royal Society for the Protection of Birds, to protect seashore birds, specifically the Roseate Tern (*Sterna dougalii*). To implement the agreement the Save the Seashore Bird Project–Ghana (SSBP-G) was set up to monitor bird populations along the coast of Ghana. The SSBP-G established the importance of several coastal wetlands for migratory shorebirds (Ntiamoa-Baidu 1988).

The information provided by the SSBP-G formed the basis for Ghana to become a signatory to the Ramsar Convention on Wetlands and the Bonn Convention on Migratory Species in 1988. During this same period Ghana was preparing an Environmental Action Plan, under the auspices of the then Environmental Protection Council. As part of the preparatory background documents a Coastal Zone Indicative Management Plan (CZIMP) was prepared (Agyepong et al 1990) which highlighted the need to protect some of the more important coastal sites. Subsequent to this local consultants were commissioned to prepare a base document (Ntiamoa-Baidu & Gordon 1991) for submission to the World Bank for GEF funding. The project was approved in 1992.

1.1.2 Scope

To achieve the overall goal the project set out to:

- develop a technical information base on the interactions between the biotic and abiotic elements of the wetlands
- describe the ecological character of five lagoons
- develop a monitoring framework as part of an overall management strategy for the long-term sustainable use of these lagoons.

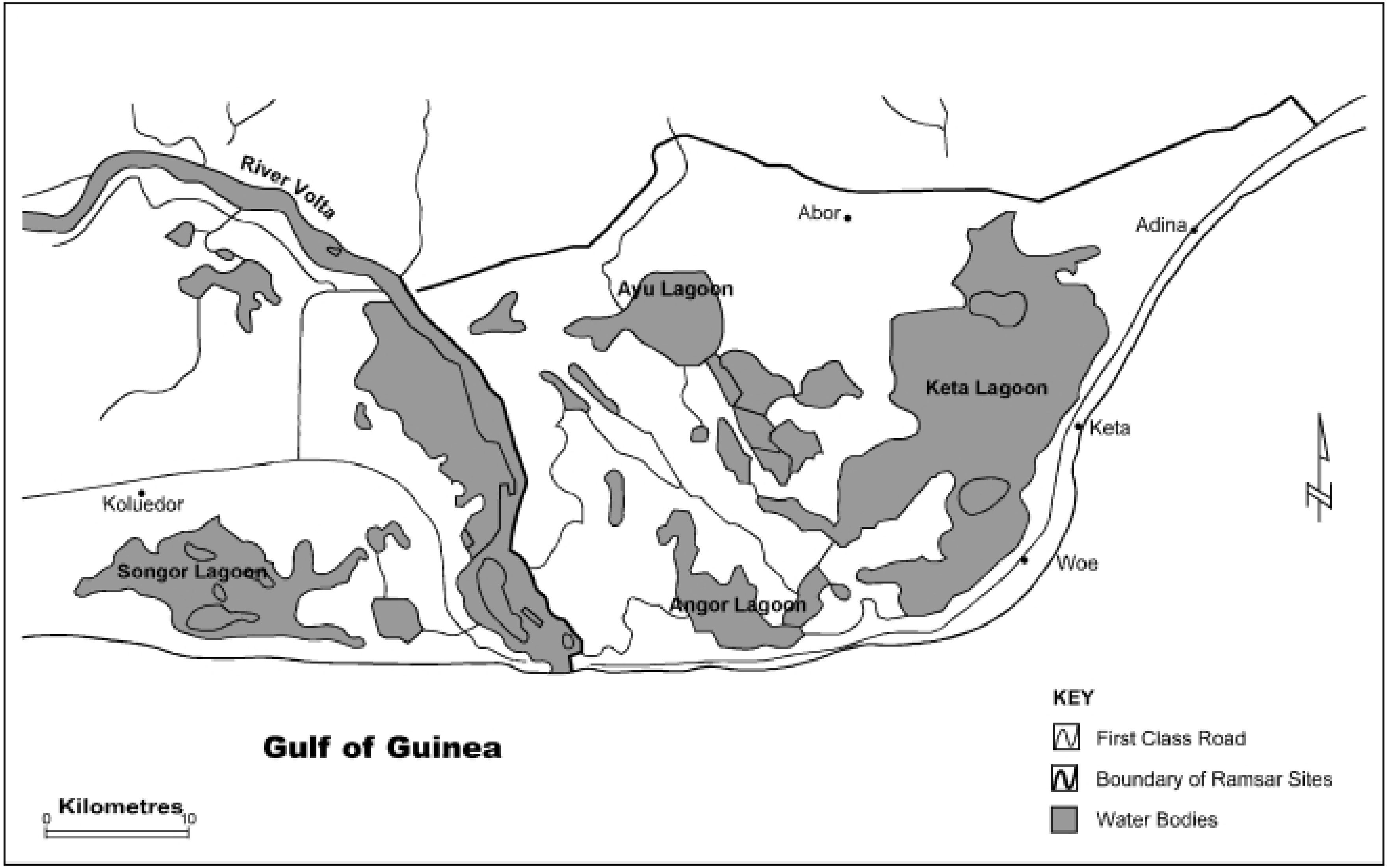

Figure 2 Schematic map of the general project area

Activities planned for the 5-year life span of the project included:

1 Management of the sites including the maintenance of boundaries and trail systems, monitoring of wildlife populations, habitat management, erosion control, tree planting, and training of community rangers/wardens in the principles of wildlife management and conservation.

2 Baseline studies for the current aquatic ecosystems and catchment areas and regular monitoring of key hydrological, limnological and biological indicators.

3 Socio-economic and technical studies of compatible development options on intensified fisheries management, development of aquaculture and salt production with the establishment of an investment fund to finance pilot schemes and infrastructure that will lead to the realisation of the identified options.

4 Environmental education and public awareness programs including the construction and staffing of community education facilities at each site.

5 Preparation of a National Wetlands Strategy to provide a policy framework for general wetland conservation in Ghana to address the conservation issues in wetland sites other than the five coastal Ramsar sites.

1.1.3 Specific objectives and terms of reference

Based on the broad goal given above the aquatic/wetland ecology components of the CWMP had the following specific objectives for the Keta and Songor lagoons in the lower Volta:

- collate available biophysical information and collect data to provide a basis for describing the ecological character of the lagoons, especially the hydrology, physico-chemistry, and the aquatic/wetland invertebrate fauna and the flora;
- identify the major values and benefits derived from the lagoons, especially those related to domestic water supply and the harvest of useful plants and animals;
- identify the major threats to the sustainable use of products harvested from the lagoons, especially those due to water pollution and hydrological regulation;
- establish reference collections of key aquatic/wetland species collected from the lagoons;
- provide training and develop the practical expertise of Ghana Wildlife Department staff;
- provide recommendations for further management of the lagoons, especially regulation of the water regime, to enhance the development of sustainable levels of resource exploitation;
- develop monitoring protocols to enable further description of the ecological character of the lagoons and to provide early warning of adverse ecological change;
- provide advice to the Convention on Wetlands of International Importance on the adequacy of guidelines for establishing and monitoring the ecological character of wetlands and for promoting wise use and management planning.

This study was preceded by an ornithological investigation (Piersma & Ntiamoa-Baidu 1995) and followed by specific investigations of the terrestrial fauna, as well as the fish and fisheries potential of the lagoons (Ryan & Ntiamoa-Baidu 1998). Further, the overall social context of the management and use of resources from the lagoons will be provided by a socio-economic study and the development of the national wetland policy, which will include an integrated monitoring program. Thus, the aquatic/wetland investigations described in this report are part of a larger holistic concept for the management of the major coastal lagoons of Ghana.

1.2 Information required for wetland management

Over the past few decades considerable effort has been directed worldwide towards the management of wetlands. Under the Ramsar Wetlands Convention this involved the promulgation of guidelines and the development and implementation of appropriate national policies for the wise use of wetlands.

The concept of wise use of wetlands was formulated in 1971 with an article in the Ramsar Convention that stated:

> The Contracting Parties shall formulate and implement their planning so as to promote … as far as possible the wise use of wetlands in their territory.

A definition of wise use, based on the concept of sustainable utilisation, was adopted in 1987 (Davis 1993, 1994). Thus, the wise use of wetlands is their sustainable utilisation for the benefit of humankind in a way compatible with the maintenance of the natural properties of the ecosystem. In turn, sustainable utilisation is the human use of a wetland so that it may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.

More recent attention to the maintenance of the ecological character of wetlands has highlighted that the wise use and management of wetlands is dependent on a large and holistic information base. According to Dugan (1990) and Finlayson (1996a) the information base required for wetland management has been sub-divided into the following subject categories: wetland classification; wetland inventory; ecological characterisation; wetland values and benefits; management planning; and monitoring. These categories are briefly considered within the context of the information base required for wetland management in Ghana.

1.2.1 Wetland classification

The classification of wetlands is beset with difficulties (Finlayson & van der Valk 1995a) and these seemingly multiply when a regional or an international approach is sought (Scott & Jones 1995). The purpose of wetland classification is to standardise and define the terms being used to describe various wetland types. At an international level a uniform set of terms is needed (Cowardin & Golet 1995, Scott & Jones 1995, Zoltai & Vitt 1995) but at a national level this may not be necessary (Pressey & Adam 1995).

Scott and Jones (1995) issued a warning concerning the level of sophistication required for classification in relation to the amount of information required for management. The important point in classifying wetlands is not the detail of the classification, but the usefulness of the classification for management purposes.

Many national wetland classifications now exist (see Finlayson & van der Valk 1995b). These invariably incorporate local terms and definitions that are not necessarily known or accepted elsewhere. Thus, even at the national level it can be extremely difficult to develop a classification that is consistent and acceptable to all wetland scientists and experts (Cowardin & Golet 1995, Lu 1995, Pressey & Adam 1995).

The wetland habitat classification used by the Ramsar Convention has increasingly been adopted for national and international purposes (Scott & Jones 1995). However, this contains many inconsistencies (Semeniuk & Semeniuk 1995, 1997), namely:

- not all types of wetlands are clearly or unambiguously described;
- repetition of types that are named ‘marshes;

- some wetlands remain ill-defined and encompass a number of types;
- mixed criteria are used to separate wetlands.

Due to the nature of the problem, and despite the deficiencies of the Ramsar classification scheme, Ghanaian wetlands can be fitted adequately into the existing Ramsar Classification scheme. The main advantage of this approach is that the terms used have international recognition and save time and effort in drawing up a National Classification scheme for Ghana.

1.2.2 Wetland inventory

Much of the information required for wetland management can be collected in a directory or inventory of wetlands. A directory and inventory are used to compile the same type of information, but the former is limited to current information and may not be comprehensive (Finlayson 1996a). An inventory usually includes investigative steps to obtain more information and thereby present a comprehensive coverage of sites. Thus, a directory may be the precursor of an inventory. In reality, the terms are used interchangeably.

The information collected through wetland inventories is regarded as a prerequisite for wetland conservation and management (Dugan 1990, Hollis et al 1992, Taylor et al 1995, Hughes 1995, Naranjo 1995, Scott & Jones 1995). Dugan (1990) considers an inventory as the first step in assembling an information base for wetland management. In fact, Contracting Parties to the Ramsar Convention undertake to compile an inventory as part of the process of developing and implementing a national wetland policy for the wise use of all wetlands on their territory. A strategically developed wetland inventory should provide managers and policy makers with the information base that they require not only to manage individual wetlands or threats, but to also place the conservation value of wetlands within the context of broad scale land use and sustainable development priorities.

To be effective in promoting the sustainable use and conservation of wetlands an inventory must be available to and understood by all those formulating and implementing wetland management policies (Naranjo 1995, Pressey & Adam 1995, Wilen & Bates 1995). Thus, they must be framed in a manner suitable for management purposes. Additionally, to remain useful tools for management they need to be regularly reviewed and updated (Naranjo 1995, Scott & Jones 1995, Wilen & Bates 1995). Information categories often used in wetland inventories are shown in table 1. Many of the categories do not relate directly to biophysical information, but are management oriented. Costa et al (1996) summarised the conclusions of a Mediterranean analysis of wetland inventory and the key points are given below as a guide to compiling a wetland inventory.

Objectives of a wetland inventory (Costa et al 1996)

To identify where wetlands are, and which are priority sites for conservation

To identify the functions and values of each wetland

To establish a baseline for measuring change in a wetland

To provide a tool for planning and management

Table 1 Information categories used by Hughes and Hughes (1992) and Scott (1993) in wetland directories

Category	**Information**
Hughes & Hughes 1992 – *A directory of African wetlands*	
Title/Location/Nearest town	Name of wetland/Coordinates/Name of town
Area/Altitude	Area/Height above sea level
General	Description of wetland and environs
Hydrology and Water quality	General features
Flora/Fauna	Important species and populations
Human impact and utilisation	Land uses and changes
Conservation status	Nature protection
Scott 1993 – *A directory of wetlands in Oceania*	
Title/Location	Name and reference number/Coordinates
Area/Altitude	Area and/or length of rivers/Average
Overview	Summary description of site
Physical/Ecological features	Hydrology, soils, climate, vegetation and habitats
Land tenure	Ownership of wetland and surrounding land
Conservation measures taken/proposed	Details of protected areas/Further proposals
Land use/Possible changes in land use	Human activities/Development plans and ideas
Disturbances and threats	Existing and possible threats
Hydrological-biophysical/Social-cultural values	Principal features/Values
Noteworthy fauna/flora	Important species
Scientific research/Conservation education	Major research/education activities and facilities
Management authority and jurisdiction	Responsible authority(ies)
References	Key published literature
Reasons for inclusion in Directory	Reason(s) designated as important

In order to achieve the objectives the following recommendations were made:

Means of achieving the objectives of an inventory (Costa et al 1996)

Use standardised methods for classification, data collection and storage, delineation and mapping

Incorporate qualitative and quantitative data to provide a baseline for monitoring wetland change and loss

Facilitate analysis of loss of wetland functions

Be regularly updated

Be easily disseminated and made available to wetland managers, decision-makers and the general public.

For the above to be achieved careful planning and testing of techniques is required. A secure funding source is needed and all changes to protocols should be well documented and assessed. Critically, any limitations on the use of the information should be made apparent at the outset.

1.2.3 Ecological characterisation

An important obligation under the Ramsar Wetland Convention is for each Contracting Party to 'designate suitable wetlands within their territory for inclusion in a List of Wetlands of International Importance'. The Convention also states that wetlands should be listed according to their 'international significance in terms of ecology, botany, zoology, limnology or hydrology'. Whilst listing a site as internationally important is an important obligation under the Convention, it may not constitute anything more than a passive conservation step. Thus, the Convention also contains an obligation to '… formulate and implement their planning so as to promote the conservation of the wetlands included in the List' and inform the Ramsar Bureau '… if the ecological character of any wetland in their territory and included in the List has changed, is changing, or is likely to change as the result of technological developments, pollution or other human interference'.

A working definition of ecological character was agreed at the Ramsar Wetland Convention in 1996 based on material supplied by Dugan and Jones (1993) and Finlayson (1996b) and updated in 1999. This is given below:

> Ecological character is the sum of the biological, physical, and chemical components of the wetland ecosystem, and their interactions, which maintain the wetland and its products, functions, and attributes.

This definition provides a theoretical basis for describing the ecological character of a wetland, but does not assist with the practical issues of describing the character. Thus, there is a level of consensus on the concept of ecological character, but questions relating to the ecological meaning of change when it is detected have yet to be answered. Monitoring can provide the necessary information, but it does not necessarily provide the basis for interpreting the significance of change.

Within the context of the Ramsar Convention, change in ecological character was considered as meaning adverse change. This concept is captured in the definition of change in ecological character that was adopted from material provided by Dugan and Jones (1993) and Finlayson (1996b) and updated in 1999.

> Change in ecological character is the impairment or imbalance in any biological, physical, or chemical components of the wetland ecosystem, or in their interactions, which maintain the wetland and its products, functions and attributes.

However, even with this definition we are no closer to ascertaining what exactly constitutes an unacceptable ecological change. To define an unacceptable ecological change we need to firstly establish the values and benefits of the wetland, assess the ecological status of these and then monitor them to ascertain when (if) an adverse change is likely to or has actually occurred. Thus, there is broad agreement on the basic need to assess and describe the ecological character of a wetland, but further attention is required to assessing the significance of any change.

1.2.4 Wetland values and benefits

All wetlands provide values and benefits to people. Values and benefits are taken to include a range of wetland functions, products and attributes that have been previously defined within the Ramsar context (Dugan 1990, Davis 1993, 1994) as follows:

- *Functions* performed by wetlands include the following: water storage; storm protection and flood mitigation; shoreline stabilisation and erosion control; groundwater recharge; groundwater discharge; retention of nutrients, sediments and pollutants; and stabilisation of local climatic conditions, particularly rainfall and temperature. These functions are the result of the interactions between the biological, chemical and physical components of a wetland, such as soils, water, plants and animals.

- *Products* generated by wetlands include the following: wildlife resources; fisheries; forest resources; forage resources; agricultural resources; and water supply. These products are generated by the interactions between the biological, chemical and physical components of a wetland.
- *Attributes* of a wetland include the following: biological diversity; geomorphic features; and unique cultural and heritage features. These have value either because they induce certain uses or because they are valued themselves.

The combination of wetland functions, products and attributes gives the wetland benefits and values that make it important to society. The relative importance of these values and benefits varies between sites due both to the biophysical features of the wetland and the lifestyles of the people.

1.2.5 Management planning

> Wetlands are dynamic areas, open to influence from natural and human factors. In order to maintain their biological diversity and productivity and to allow wise use of their resources by human beings, some kind of agreement is needed between the various owners, occupiers and interested parties. The management planning process provides this overall agreement (Davis 1993).

Further, management planning is a flexible and dynamic way of thinking and contains three basic components: description of the site; evaluation of the main features of the wetland and expression of management objectives; and plans or prescriptions for specific actions. It is also recommended that the plan contain a preamble that broadly reflects the policies of organisations concerned with the production and implementation of the management plan. A summary of the main principles is given below.

Principles for management planning

It is a way of thinking, which involves recording, evaluating and planning and is subject to constant review and revision and is therefore flexible and dynamic.

It involves three basic steps of describing the features of the site/area, defining operational objectives and taking necessary management actions.

Preparation of an elaborate plan is not an excuse for inaction or delay.

Review of the plan may lead to revision of the site description and operational objectives.

It should be a technical, not a legal document, although it may be supported by appropriate legislation.

Finlayson (1996a) notes that the Ramsar guidelines sound simple, but adds that there are major pitfalls, such as making the plan too complicated, making the plan the goal rather than the tool, making the plan inflexible and not allocating resources to ensure that the plan can be implemented.

Underpinning the planning exercise is the establishment of a rationale for management and the setting of obtainable operational objectives. Monitoring is therefore essential. In other words, implementation of a management plan should proceed hand-in-hand with a process to ensure that the objectives of the plan are obtained or accordingly modified in response to new information (Finlayson 1994, 1996b).

1.2.6 Monitoring

Wetland monitoring has received more and more attention in recent years. At a global level this has arisen as awareness of the extent of wetland degradation and loss has increased. Such is the concern at the extent of global wetland degradation that more and more effort is being directed towards developing effective management processes and responses to problems. In many instances this effort is being held back by a lack of relevant information on the nature of the problem, the cause of the problem and the effectiveness of management procedures and actions. Effective monitoring programs can overcome these deficiencies.

In a general sense monitoring addresses the issue of change or lack of change through time and at particular places. Thus monitoring can be defined as the systematic collection of data or information over time. It differs from surveillance by assuming that there is a specific reason for collecting the data or information (see Spellerberg 1991, Hellawell 1991, Furness et al 1994). Thus, whilst it is built upon survey and surveillance, it is more precise and oriented to specific targets or goals (Hellawell 1991, Spellerberg 1991).

> ***Definitions of survey, surveillance and monitoring***
>
> *Survey* is an exercise in which a set of qualitative observations are made but without any preconception of what the findings ought to be.
>
> *Surveillance* is a time series of surveys to ascertain the extent of variability and/or range of values for particular parameters.
>
> *Monitoring* is based on surveillance and is the systematic collection of data or information over time in order to ascertain the extent of compliance with a predetermined standard or position.

A framework for assisting with the design of a monitoring program has been presented by Finlayson (1996b,c). The framework applies to all forms of monitoring (eg changes in the area of a wetland, the ecological health of a wetland, or the underlying reasons behind the loss of wetlands) but it is not prescriptive. Rather, it presents a series of steps that will assist those charged with designing a monitoring program make decisions suitable for their own situation.

In a general sense, monitoring is needed to prevent further unchecked exploitation and degradation of wetlands. Thus, there is a need to assess the impact of human development and minimise ecological change. Success in such programs will depend on our ability not only to detect and monitor changes in the quality of wetlands, but also to provide early indications of likely change and thereby take action to prevent this change from occurring. Thus, with all monitoring techniques there is a need to establish a starting point or to obtain baseline data that identifies the key functions and values of the site.

2 Coastal lagoons in Ghana

2.1 Description of lagoons

Simplistically the lagoons of Ghana can be classified into two types: the open lagoons that are associated with large rivers and have a permanent connection to the sea and the closed lagoons that are formed behind sandbars, with no permanent connection to the sea (Boughey 1957, Kwei 1977, Mensah 1979, Gordon 1987). In ecological terms, open lagoon systems are more stable and faunistically diverse due to the influence of the sea. The closed lagoons are functionally more unpredictable, with conditions changing very rapidly from one point in time to another. These lagoons are usually saline and can be further described as follows:

Open: with one or more narrow opening(s) to the sea most of the time and therefore known as classical open lagoon, eg Nakwa, Amisa and Nyanya lagoons. In Ghana, the mouths of some lagoons have been made permanently open through the intervention of humans for the purposes of road/harbour construction, eg Sakumo II and Benya lagoons at Tema and Elmina respectively.

Closed: cut off from the sea by a sandbar during greater part of the year. The bar may be breached naturally or by humans during the Rainy season. These are classical closed lagoons, eg Sakumo I and Muni lagoons at Bortianor and Winneba respectively. Some closed lagoons receive seawater overflows during spring tides. These are called spring tide-fed closed lagoons, eg Bormis lagoon at Moree.

The functions of lagoons include sediment/toxicant retention, nutrient retention, biomass export, water transport and recreation/tourism. Wildlife resources and fisheries are the main products, but freshwater (isolated) lagoons provide water supply for domestic purposes. The lagoonal attributes are biological diversity and uniqueness to culture/heritage.

In addition to the brackish water lagoons, Ghana has several coastal freshwater lagoons, these coastal freshwater lagoons are found mainly in the Western Region where rainfall in excess of 2000 mm per annum produces conditions of high runoff and stream flow. The underlying rocks in these areas have also undergone profound leaching giving rise to waters, which are extremely ion poor. Typically these lagoons are open to the sea either directly or by a channel. They are also fairly small – the largest of this type, the Amansuri lagoon, is about 2.5 km^2 in area. Other examples include the Domini and Ekpuekyi lagoons, both of which are under 1.0 km^2. As with the brackish and saline lagoons, the functions of lagoons include sediment/toxicant retention, nutrient retention, biomass export, water transport and recreation/tourism. Wildlife resources and fisheries are the main products. These freshwater lagoons also provide water supply for domestic purposes. The lagoonal attributes are biological diversity and uniqueness to culture/heritage.

The actual number of coastal lagoons in Ghana is not precisely known. Published estimates range from 50 (Mensah 1979, Gordon 1987) to over 90 (Gordon 1996, Yankson & Obodai in press). The lack of precision is partly due to the ephemeral nature of many of the smaller lagoons which require rainfall to create a freshwater lagoon habitat behind a sandbar; these sandbars then break to allow sea water to penetrate. Dry conditions result in re-creation of the sandbar, and loss of water by evaporation causes the lagoon to dry up. The smaller lagoons of areas under 0.1 km^2, and maximum water depths of under 1 m, can go through this cycle in a matter of months.

2.2 Management approaches

The management of the coastal lagoons has traditionally been vested in the ‘owners’ of the lagoon. These are usually local clans, fetishes or stools. Traditional knowledge or culture is the way in which Ghanaian ethnic groups use traditional values and knowledge, structured within specific organisational frameworks, towards solving particular issues and tasks (World Bank 1996). The organisational framework of these societies is the kinship system, or more specifically families, lineages and clans. On the various levels of this framework, specific rights and obligations, dealing with issues like authority, control, adjudication of conflicts, inheritance, succession and land ownership are vested in the members. At each of the organisational levels within the framework, there will be a chief, usually hereditary in lineage, who functions as a custodian or caretaker. Many of the traditional management strategies were geared at controlling resource use by placing limits on access, both spatially and temporally, through the use of taboos and outright bans. For many years, this traditional approach has been sufficient to maintain the ecological integrity of the lagoon environment (Gordon 1992, Ntiamoa-Baidu 1992). Unfortunately, education, religion and acculturation have resulted in the breakdown of traditional management systems. Many of the areas, operate under ‘common property’ laws. With rising economic pressures, these areas are being exploited unsustainably with local fines and punishments being ignored or disregarded.

The modern system for natural resource management in Ghana follows a three tier approach (Government of Ghana 1995 [Vision 2020]). The three tiers are the district, regional and national levels. Planning and management is heavily predicated on:

- decentralisation of political and state power in order to enhance participatory democracy through local level political institutions with the District Assembly as the focal point;
- decentralisation of administration, development planning, implementation and budget making in which local authorities are actively involved.

One key institution is the District Environmental Management Committee, which has representation from the decentralised departments, such as Fisheries, Forestry and Wildlife. For coastal wetlands, in particular the five Ramsar sites, Muni-Pomadze, Densu Delta, Sakumo, Songor and Keta all have site management committees with representation from primary stakeholders.

The site management committees comprise the Senior Technical Adviser (as Chairman), a Representative of the Environment Protection Council (as Secretary), the Coastal Wetlands Conservation Programme Coordinator, the Game Warden in charge of the site and representatives of appropriate institutions. From the conception of the CWMP (Ntiamoa-Baidu & Gordon 1991), it was emphasised that the successful management of the coastal wetlands would require a multi-disciplinary approach. The Department of Wildlife was therefore to seek the expertise and involvement of relevant organisations for the execution of programs. Another identified crucial factor for the success of the coastal wetland conservation program was the support and involvement of the communities who live in the coastal zone. These are the people whose lifestyles are interlinked with the coastal wetlands and whose activities directly affect the wetland ecosystem. Protection of the wetlands should therefore be ‘for’ the people and not ‘against’ them. Every effort has been made to secure the people’s participation and involvement; and to integrate their needs with the management processes. Apart from the general community, groups whose involvement was to be specifically sought include the traditional administrators (Chiefs, elders, etc), the town development committees, local political groups such as the District Assemblies, and NGOs such as the 31st December Women’s Movement.

3 Ecological surveys of Keta and Songor lagoons

3.1 Sampling strategy

Sampling of each lagoon and the surrounding wetland vegetation was based on a stratified grid drawn at intervals of 1' latitude and longitude (ie ≈ 1.8 x 1.8 km). The points of intersection of the grid were used as the basis for selecting sites for sampling. These points were coded according to the name of the lagoon (K = Keta, S = Songor) and with an alphabetic code for the northing and numeric code for the easting (ie 'KQ15' was located at Keta lagoon at the intersection of the northing or horizontal grid line labeled 'Q' and the easting or vertical grid line labelled '15'). Samples were also collected from the Angor channel that connects the Keta lagoon with the Volta River. These were labelled C1–C12 and located where the sampling grid crossed the channel. The coordinates for each site were taken from 1:50 000 Ghana topographical maps (sheets 0600D4, 0500B2, E0601C3 & E0501A1 for Keta and 0500A2 and 0500B1 for Songor) that were based on aerial photography flown in December 1974.

The sampling grid is shown in figures 3 and 4. A list of site codes and coordinates read from the maps are given in tables 2 to 7. In the field the sites were located with a hand-held Global Positioning System (GPS) recorder (Garmin GPS 38 or 45) with an accuracy of about 100 m. The aquatic sampling sites were located within 300 m of the map coordinate whereas those in the channel were located by GPS and recorded as such. As access to some of the vegetation sites was far more difficult (see below), a GPS reading was taken at the actual point sampled. The GPS readings for each site are shown in tables 2 to 7.

The sampling strategy was divided into two components – one aquatic and the other wetland/terrestrial. All intersecting grid points within the lagoons were used for aquatic sampling (ie physico-chemical and biological parameters). These sites were reached initially by wading and/or hiring wooden canoes poled by local fishermen. An aluminium dinghy with an outboard motor (15 hp) was later used in Keta lagoon and greatly reduced the time and effort spent getting to sites in deeper water.

The wetland sampling was initially undertaken from the landward side of the lagoons and was severely limited by access through extensive stands of reeds (up to 4 m in height) and grasses in water reaching more than 1.5 m depth. Sampling was based on a series of grid points located along the landward side of the lagoon shorelines. The number of sample sites at Keta lagoon was initially limited by logistical issues (ie access and sample processing times) and a subjective choice of sites was made around the perimeter (see table 2). When a boat and outboard motor became available all grid points within 2 km (approx) of the lagoon were visited from either the land or the water side. Once the initial sampling near the edge of the lagoons was completed, sites for phenological sampling in the extensive swamps stretching east of Songor and west of Keta towards the Volta delta, and as far north as Sogakope were added. Sampling was also conducted in the Angor channel from Keta lagoon to the Volta River with vegetation phenological sampling conducted along the grid given in figure 3. The sampling coordinates recorded at these sites are presented in appendix 6.

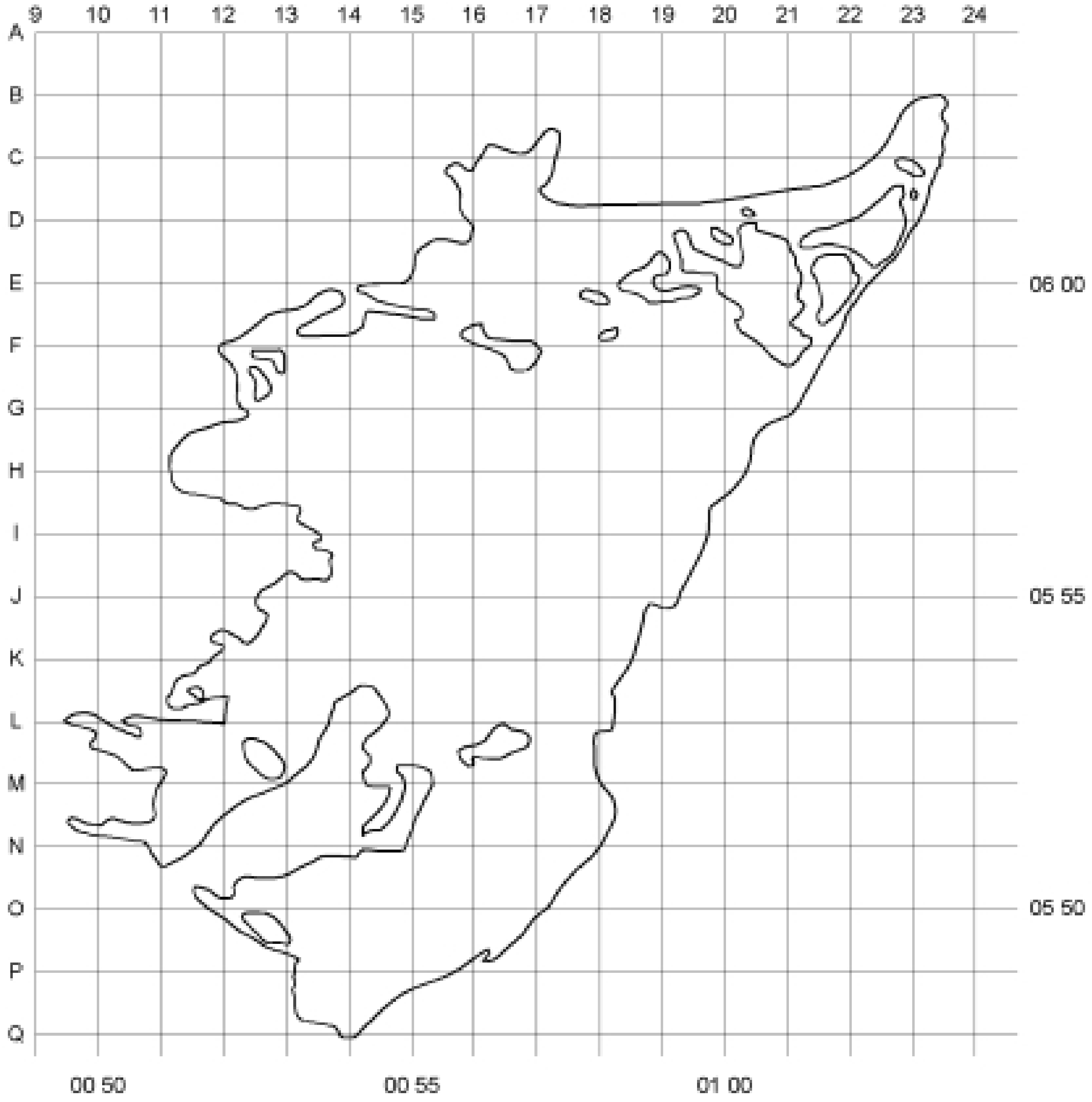

Figure 3 Sampling grid for the Keta Ramsar site

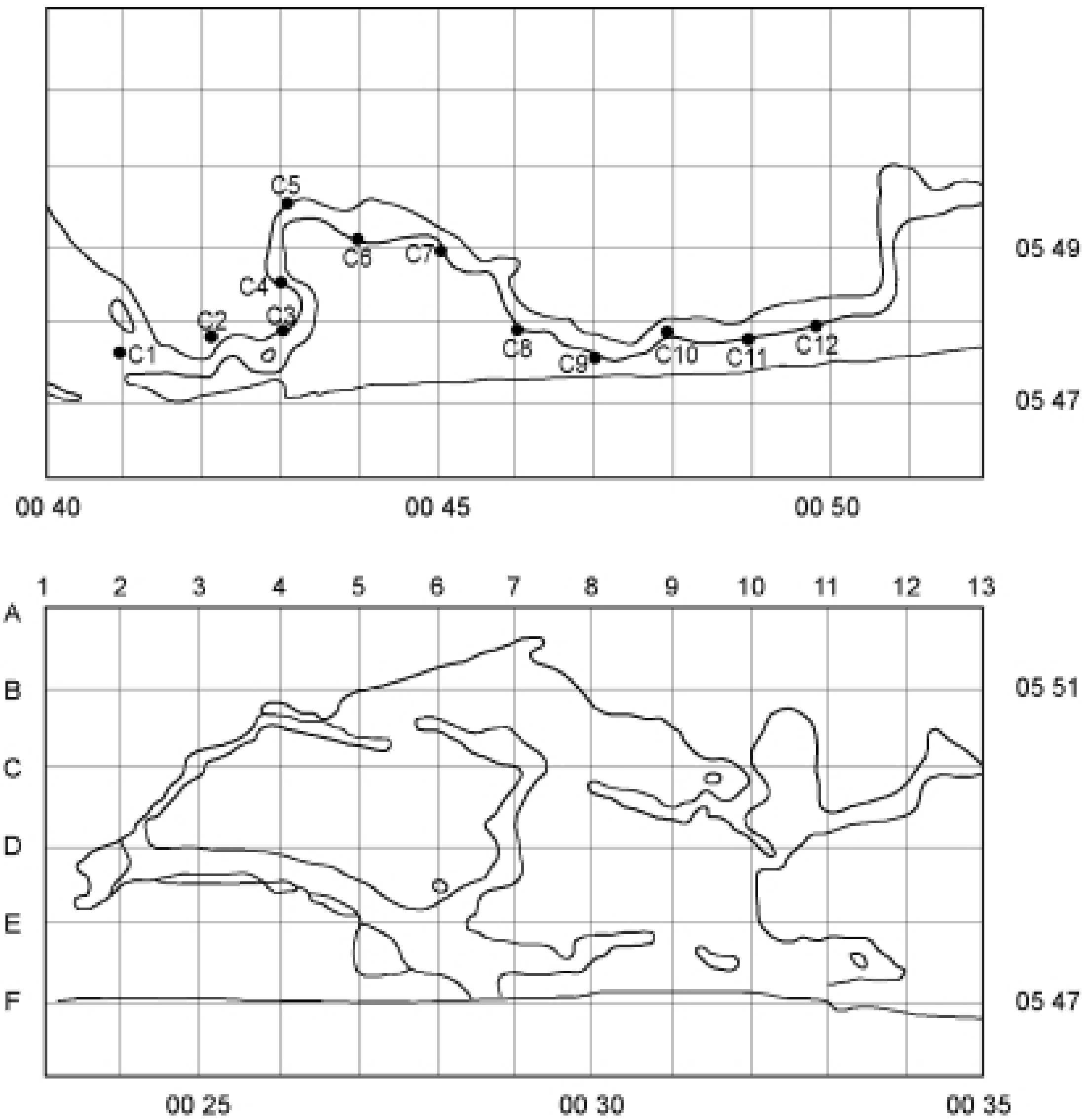

Figure 4 Sampling grid for (top) the Angor channel that connects Keta lagoon to the Volta River and (bottom) the Songor Ramsar site

Table 2 Sites used for wetland vegetation sampling at Keta lagoon

Site code*	Coordinates		Date	Field coordinates		Vegetation sampling	
	N	E		N	E	Phenology	Biomass
KB17	06 03	00 57	16/11	06 03.4	00 56.9	P	
KB23	06 03	01 03	16/11	06 02.9	01 03.0	P	
KC16	06 02	00 56	16/11	06 02	00 55.8	P	B
KC18	06 02	00 58	16/11	06 01.8	00 58.0	P	B
KC20	06 02	01 00	16/11	06 01.4	01 00.0	P	
KC22	06 02	01 02	16/11	06 01.7	01 02.1	P	B
KC23*	06 02	01 03	28/11	06 02.0	01 03.0	P	
KC24	06 02	01 04	16/11	06 02	01 04.0	P	B
KD15	06 01	00 55	16/11	06 00.9	00 55.0	P	
KD22*	06 01	01 03	28/11	06 01.0	01 03.0	P	
KD23	06 01	01 03	16/11	06 00.1	01 02.9	P	
KE14	06 00	00 54	17/11	05 59 8	00 53.9	P	B
KE15*	06 00	00 55	28/11	06 00.2	00 54.9	P	
KE19*	06 00	00 59	28/11	06 00.0	00 59.0	P	
KE20	06 00	01 00	19/11	06 00.0	01 00.0	P	B
KE21	06 00	01 01	19/11	06 00.0	01 01.0	P	
KE22*	06 00	01 02	27/11	06 00.0	01 02.0	P	
KF11	05 59	00 51	17/11	05 59.1	00 51.7	P	
KF16*	05 59	00 56	28/11	05 59.1	00 56.0	P	
KF21	05 59	01 00	19/11	05 59.0	01 00.0	P	
KF22	05 59	01 02	16/11	05 59.1	01 01.7	P	B
KG01*	05 58	00 41	9/12	05 58.1	00 41.0	P	
KG09*	05 58	00 49	6/12	05 59.0	00 49.0	P	
KG12	05 58	00 52	21/11	05 57.9	00 52.0	P	B
KHO8*	05 57	00 47	6/12	05 57.1	00 47.0	P	
KH11	05 59	00 51	17/11	05 57.2	00 51.0	P	
KI 01*	05 56	00 41	9/12	05 56.1	00 41.0	P	
KI09*	05 56	00 49	6/12	05 56.0	00 49.0	P	
KI11*	05 45	00 50.9	6/12	05 56.0	00 50.9	P	
KI12	05 56	00 52	21/11	05 56.6	00 52.1	P	
KI13*	05 56	00 52	21/11	05 56.4	00 52.9	P	
KJ02*	05 55	00 42	9/12	05 55.1	00 42.2	P	
KJ12	05 55	00 52	21/11	05 54.5	00 52.6	P	
KK03*	05 54	00 42	9/12	05 54.0	00 42.0	P	
KK11	05 54	00 51	19/11	05 54.1	00 51.0	P	B

Site code*	Coordinates		Date	Field coordinates		Vegetation sampling	
	N	E		N	E	Phenology	Biomass
KK12*	05 54	00 51	21/11	05 53.9	00 51.0	P	
KK19	05 54	00 59	19/11	05 54.0	00 59.0	P	
KL04*	05 53	00 44	9/12	05 53.1	00 44.0	P	
KL10	05 53	00 50	18/11	05 53.0	00 50.1	P	
KL11*	05 53	00 51	21/11	05 53.0	00 51.0	P	
KL12*	05 53	00 52	19/11	05 53.0	00 52.0	P	
KL14	05 53	00 54	15/11	05 53	00 54.0	P	
KM07*	05 52	00 47	28/11	05 52.0	00 47.0	P	
KM10	05 52	00 50	18/11	05 52.0	00 49.9	P	B
KM11*	05 53	00 51	20/11	05 53.1	00 50.9	P	
KM13	05 52	00 53	15/11	05 52	0053.0	P	B
KM15*	05 52	00 55	20/11	05 52.1	00 55.0	P	B
KM18	05 52	00 58	19/11	05 52.0	00 58.0	P	B
KN06*	05 51	00 46	28/11	05 51.0	00 46.0	P	
KN08*	05 51	00 47	28/11	05 51.0	00 47.9	P	
KN12	05 51	00 52	15/11	05 51.2	00 51.9	P	
KO07*	05 50	00 47	28/11	05 50.0	00 47.0	P	
KO09*	05 50	00 49	28/11	05 50.0	00 49.0	P	
KO11	05 50	00 51	15/11	05 50.1	00 51.0	P	B
KO12*	05 50	00 52	20/11	05 50.0	00 52.0	P	
KO17	05 50	00 57	20/11	05 49.9	00.57.1	P	
KP08*	05 49	00 48	15/11	05 49.0	00 48.1	P	B
KP10	05 49	00 50	15/11	05 50.0	00 49.8	P	
KP12	05 49	00 52	20/11	05 49.3	00 52.2	P	
KP13*	05 49	00 53	20/11	05 49.0	00.52.0	P	
KP16	05 49	00 56	20/11	05 49.0	00 56.1	P	B
KQ03*	05 48	00 42	5/12	05 48.0	00 42.9	P	
KQ05*	05 48	00 45	5/12	05 48.0	00 45.0	P	
KQ09	05 48	00 49	15/11	05 48	00 48.8	P	B
KQ11	05 48	00 51	15/11	05 47.3	00 51.0	P	
KQ13	05 48	00 53	14/11	05 47.5	00 53.1	P	B
KQ15*	05 48	00 55	9/12	05 48.2	00 55.0	P	
KR02*	05 47	00 42	5/12	05 47.2	00 42.0	P	
KR06*	05 47	00 46	5/12	05 47.0	00 46.0	P	
KR08*	05 46	00 48	5/12	05 46.8	00 48.0	P	
KR10*	05 47	00 50	28/11	05 47.0	00 50.0	P	

The coordinates for each site were read from the Ghana 1:50 000 topographical maps and positioned in the field with hand-held GPS recorders.

The sampling undertaken at each site is indicated (P = phenological sampling; B = biomass sampling) along with the date (day/month) they were collected.

* Sites not included in the initial survey and subsequently added for further phenological recordings.

Table 3 Sites used for wetland vegetation sampling at Songor lagoon

Site code	Map coordinates		Date	Field coordinates		Vegetation sampling	
	N	E		N	E	Phenology	Biomass
SA13*	00 51	00 34	26/11	00 51.7	00 34.0	P	
SB04	05 51	00 25	22/11	5 51.0	00 25.0	P	
SB05	05 51	00 26	22/11	5 51.0	00 26.1	P	B
SB06	05 51	00 27	22/11	05 51.3	00 27.1	P	
SB07	05 51	00 28	22/11	05 51.1	00 28.0	P	
SB08	05 51	00 29	22/11	05 51.0	00 29.1	P	
SB09	05 51	00 30	22/11	05 51.0	00 30.0	P	B
SB10	05 51	00 31	22/11	05 50.9	00 31.0	P	
SB11*	05 51	00 32	25/11	05 50.9	00 32.0	P	
SB12*	05 51	00 33	25/11	05 50.9	00 33.0	P	
SB13*	05 51	00 34	26/11	05 50.0	00 34.0	P	
SB14*	05 51	00 35	26/11	05 51.0	00 35.0	P	
SC03	05 50	00 24	22/11	05 58.1	00 24.1	P	B
SCO5*	05 50	00 26	26/11	05 50.1	00 26.0	P	
SC11*	05 50	00 32	25/11	05 50.1	00 32.0	P	
SC12*	05 50	00 33	25/11	05 50.0	00 33.0	P	
SC13*	05 50	00 34	26/11	05 49.9	00 33.9	P	
SC14*	05 50	00 35	26/11	05 50.1	00 34.9	P	
SD01	05 49	00 22	23/11	05 49.0	00 22.0	P	
SD09*	05 49	00 30	26/11	05 49.1	00 3.1	P	
SD10*	05 49	00 31	26/11	05 49.0	00 31	P	
SD11*	05 49	00 32	25/11	05 49.0	00 32.0	P	
SD12*	05 49	00 33	25/11	05 49.1	00 32.9	P	
SD13*	05 49	00 34	26/11	05 48.9	00 34.0	P	
SD14*	05 49	00 35	26/11	05 48.6	00 34.9	P	
SE01	05 48	00 22	23/11	05 48.0	00 22.1	P	
SE02	05 48	00 23	23/11	05 48.3	00 23.1	P	
SE05	05 48	00 26	23/11	05 48.0	00 26.1	P	B
SE06	05 48	00 27	23/11	05 48.0	00 27.0	P	
SE10*	05 48	00 31	25/11	05 48.1	00 31.0	P	
SE11*	05 48	00 32	25/11	05 47.9	00 32.0	P	
SE12*	05 48	00 33	25/11	05 48.0	00 33.0	P	
SE13*	05 48	00 34	26/11	05 48.0	00 33.9	P	
SE13*	05 48	00 35	26/11	05 48.0	00 34.9	P	
SE15*	05 48	00 36	26/11	05 48.0	00 46.0	P	
SE16	05 48	00 37	24/11	05 48.0	00 37.0	P	

Site code	Map coordinates		Date	Field coordinates		Vegetation sampling	
	N	E		N	E	Phenology	Biomass
SF08	05 47	00 29	24/11	05 47.26	00 28.9	P	
SF09	05 47	00 30	24/11	05 47.1	00 29.9	P	
SF10	05 47	00 31	24/11	05 47.16	00 31.0	P	
SF11	05 47	00 32	24/11	05 47.0	00 31.9	P	
SF12	05 47	00 33	24/11	05 47.0	00 33.0	P	
SF13	05 47	00 34	24/11	05 47.1	00 34.1	P	
SF14	05 47	00 35	24/11	05 47.1	00 35.1	P	
SF15	05 47	00 36	24/11	05 47.2	00 36.1	P	
SF16	05 47	00 37	24/11	05 47.2	00 37.0	P	

The coordinates for each site were read from the Ghana 1:50 000 topographical maps and positioned in the field with hand-held GPS recorders.

The sampling undertaken at each site is indicated (P = phenological sampling; B = biomass sampling) along with the date (day/month) they were collected.

* Sites not included in the initial survey and subsequently added for further phenological recordings.

Table 4 Location of transects used for wetland vegetation point and block sampling

Code	Name	Date	Field coordinates		Bearing
			N	E	
1	Blekusu	20/12/96	05 58 59.9	01 01 43.0	300º
2	Tasikome	20/12/96	06 01 47.3	01 02 00.5	170º
3	Tegbi	21/12/96	05 51.59.7	00 57 58.2	250º
4	Fiahor	21/12/96	05 50 48.0	00 53 57.0	150º
5	Alakple	21/12/96	05 51 58.6	00 53 00.7	320º
6	Norlopi	21/12/96	06 01 40.9	00 55 49.0	80º
7	Woe	22/12/96	05 48 51.5	00 56 00.1	10º
8	Totokpoe	22/12/96	05 47 05.5	00 31 00.9	19º
9	Wasakuse	22/12/96	05 51 15.9	00 34 01.4	190º

Table 5 Keta aquatic sampling

Site code	Map coordinates		Date	Field coordinates		Parameter			
	N	E		N	E	C	M	F	S
KC17	06 02	00 57	18/11	06 02	00 57	x	x	x	
KD17	06 01	00 57	18/11	06 01	00 57	x		x	
KD18	06 01	00 58	18/11	06 01	00 58	x		x	
KD19	06 01	00 59	16/11	06 01	00 59	x	x	x	
KD20	06 01	01 00	16/11	06 01	01 00	x		x	x
KD21	06 01	01 01	16/11	06 01	01 01	x	x	x	
KD22	06 01	01 02	18/11	06 01	01 02	x		x	
KE15	06 00	00 55	18/11	06 00	00 55	x	x	x	

Site code	Map coordinates		Date	Field coordinates		Parameter			
	N	E		N	E	C	M	F	S
KE16	06 00	00 56	18/11	06 00	00 56	x		x	
KE17	06 00	00 57	18/11	06 00	00 57	x	x	x	
KE18	06 00	00 58	23/11	06 00	00 58	x		x	
KF13	05 59	00 53	22/11	05 59	00 53	x		x	x
KF14	05 59	00 54	22/11	05 59	00 54	x		x	
KF15	05 59	00 55	18/11	05 59	00 55	x	x	x	
KF18	05 59	00 58	22/11	05 59	00 58	x		x	
KF19	05 59	00 59	23/11	05 59	00 59	x		x	
KF20	05 59	01 00	23/11	05 59	01 00	x		x	
KG13	05 58	00 53	22/11	05 58	00 53	x		x	x
KG14	05 58	00 54	22/11	05 58	00 54	x		x	x
KG15	05 58	00 55	22/11	05 58	00 55	x		x	
KG16	05 58	00 56	22/11	05 58	00 56	x		x	
KG17	05 58	00 57	19/11	05 58	00 57	x		x	x
KG18	05 58	00 58	19/11	05 58	00 58	x	x	x	x
KG19	05 58	00 59	22/11	05 58	00 59	x		x	
KG20	05 58	01 00	17/11	05 58	01 00	x	x	x	
KG21	05 58	01 01	16/11	05 58	01 01	x		x	
KH12	05 57	00 52	22/11	05 57	00 52	x		x	x
KH13	05 57	00 53	22/11	05 57	00 53	x		x	x
KH14	05 57	00 54	22/11	05 57	00 54	x		x	
KH15	05 57	00 55	22/11	05 57	00 55	x		x	
KH16	05 57	00 56	21/11	05 57	00 56	x		x	x
KH17	05 57	00 57	19/11	05 57	00 57	x	x	x	
KH18	05 57	00 58	19/11	05 57	00 58	x		x	
KH19	05 57	00 59	21/11	05 57	00 59	x		x	x
KH20	05 57	01 00	17/11	05 57	01 00	x		x	
KI14	05 56	00 54	21/11	05 56	00 54	x		x	
KI15	05 56	00 55	21/11	05 56	00 55	x		x	x
KI16	05 56	00 56	21/11	05 56	00 56	x		x	x
KI17	05 56	00 57	19/11	05 56	00 57	x		x	
KI18	05 56	00 58	19/11	05 56	00 58	x	x	x	x
KI19	05 56	00 59	21/11	05 56	00 59	x		x	
KJ13	05 55	00 53	21/11	05 55	00 53	x		x	x
KJ14	05 55	00 54	21/11	05 55	00 54	x		x	
KJ15	05 55	00 55	21/11	05 55	00 55	x		x	x
KJ16	05 55	00 56	21/11	05 55	00 56	x		x	x
KJ17	05 55	00 57	19/11	05 55	00 57	x	x	x	x

Site code	Map coordinates		Date	Field coordinates		Parameter			
	N	E		N	E	C	M	F	S
KJ18	05 55	00 58	17/11	05 55	00 58	x		x	
KJ19	05 55	00 59	17/11	05 55	00 59	x		x	x
KK12	05 54	00 52	21/11	05 54	00 52	x	x	x	x
KK13	05 54	00 53	21/11	05 54	00 53	x		x	
KK14	05 54	00 54	21/11	05 54	00 54	x		x	x
KK15	05 54	00 55	21/11	05 54	00 55	x		x	
KK16	05 54	00 56	21/11	05 54	00 56	x		x	
KK17	05 54	00 57	19/11	05 54	00 57	x	x	x	
KK18	05 54	00 58	17/11	05 54	00 58	x		x	
KL13	05 53	00 53	15/11	05 53	00 53	x		x	x
KL15	05 53	00 55	20/11	05 53	00 55	x		x	x
KL16	05 53	00 56	20/11	05 53	00 56	x		x	x
KL17	05 53	00 57	19/11	05 53	00 57	x		x	
KL18	05 53	00 58	16/11	05 53	00 58	x		x	
KM12	05 52	00 52	15/11	05 52	00 52	x		x	
KM16	05 52	00 56	20/11	05 52	00 56	x		x	x
KM17	05 52	00 57	19/11	05 52	00 57	x	x	x	x
KN11	05 51	00 51	15/11	05 51	00 51	x	x	x	
KN15	05 51	00 55	20/11	05 51	00 55	x		x	x
KN16	05 51	00 56	18/11	05 51	00 56	x		x	
KN17	05 51	00 57	19/11	05 51	00 57	x	x	x	
KO13	05 50	00 53	20/11	05 50	00 53	x		x	x
KO15	05 50	00 55	20/11	05 50	00 55	x		x	
KO16	05 50	00 56	20/11	05 50	00 56	x		x	x
KO17	05 50	00 57	14/11	05 50	00 57	x		x	
KP3	05 49	00 43	5/12	05 48 36.4	00 43 07.3	x		x	
KP4	05 49	00 44	5/12	05 48 11.4	00 44 01.6	x		x	
KP13	05 49	00 53	23/11	05 49	00 53	x		x	
KP14	05 49	00 54	20/11	05 49	00 54	x		x	
KP15	05 49	00 55	20/11	05 49	00 55	x		x	x
KP16	05 49	00 56	20/11	05 49	00 56	x		x	x
KQ3	05 48	00 43	5/12	05 47 36.5	00 42 59.7	x		x	
KQ5	05 48	00 45	5/12	05 47 57.2	00 45 02.4	x		x	
KQ10	05 48	00 50	20/11	05 48	00 50	x		x	
KQ11	05 48	00 51	20/11	05 48	00 51	x		x	
KQ12	05 48	00 52	20/11	05 48	00 52	x		x	
KQ14	05 48	00 54	23/11	05 48	00 54	x		x	x
KR1	05 47	00 41	5/12	05 46 42.5	00 40 58.6	x		x	

Site code	Map coordinates		Date	Field coordinates		Parameter			
	N	E		N	E	C	M	F	S
KR2	05 47	00 42	5/12	05 46 52.7	00 42 14.7	x		x	
KR3	05 47	00 43	5/12	05 46 56	00 43 02.5	x		x	
KR6	05 47	00 46	5/12	05 46 56.1	00 46 02.4	x		x	
KR7	05 47	00 47	5/12	05 46 36.0	00 47 00.9	x		x	
KR8	05 47	00 48	5/12	00 46.53.0	00 48 00.4	x		x	
KR9	05 47	00 49	15/11	05 46 44.9	00 49.4	x		x	x
KR10	05 47	00 50	15/11	05 47	00 50	x		x	

The coordinates for each site were read from the Ghana 1:50 000 topographical maps and positioned in the field with hand-held GPS recorders.

The sampling undertaken at each site is indicated (C = water chemistry; M = metals and nutrients; F = fauna [benthos and zooplankton]; S = sediment) along with the date (day/month) they were collected.

Table 6 Songor aquatic sampling

Site code	Map coordinates		Date	Field coordinates		Parameter			
	N	E		N	E	C	M	F	S
SB6	05 51	00 27	25/11	05 51	00 27	x		x	
SB7	05 51	00 28	25/11	05 51	00 28	x		x	
SB13	05 51	00 34	11/12	05 51 09	00 34 08.0	x		x	
SC3	05 50	00 24	08/12	05 50	00 24	x		x	x
SC4	05 50	00 25	08/12	05 50	00 25	x		x	
SC5	05 50	00 26	08/12	05 50	00 26	x		x	x
SC6	05 50	00 27	08/12	05 50	00 27	x		x	x
SC8	05 50	00 29	08/12	05 50	00 29	x		x	x
SC9	05 50	00 30	25/11	05 50	00 30	x		x	
SC10	05 50	00 31	25/11	05 50	00 31	x		x	x
SC12.5	05 50	00 33.5	11/12	05 50	00 33 22.9	x		x	x
SD2	05 49	00 23	08/12	05 49	00 23	x		x	x
SD3	05 49	00 24	09/12	05 49	00 24	x		x	
SD4	05 49	00 25	09/12	05 49	00 25	x		x	x
SD5	05 49	00 26	09/12	05 49	00 26	x		x	x
SD6	05 49	00 27	09/12	05 49	00 27	x		x	x
SD7	05 49	00 28	09/12	05 49	00 28	x		x	
SD8	05 49	00 29	09/12	05 49	00 29	x		x	x
SD9	05 49	00 30	09/12	05 49	00 30	x		x	
SD10	05 49	00 31	25/11	05 49	00 31	x		x	x
SD11	05 49	00 32	11/12	05 49 14.3	00 31 51.7	x		x	x
SE6	05 48	00 27	09/12	05 48 13.9	00 26 53 0	x		x	
SE7	05 48	00 28	09/12	05 48	00 28	x		x	
SE8	05 48	00 29	09/12	05 48	00 29	x		x	

Site code	Map cordinates		Date	Field coordinates		Parameter			
	N	E		N	E	C	M	F	S
SE9	05 48	00 30	09/12	05 48	00 30	x		x	
SE10	05 48	00 31	09/12	05 48	00 31	x		x	
SF9	05 47	00 30							x
SF10	05 47	00 31	11/12	05 47	00 31	x		x	
SF11	05 47	00 32	11/12	05 47 07.8	00 31 58.4	x		x	
SF12	05 47	00 33	11/12	05 47 06.1	00 33 05.9	x		x	

The coordinates for each site were read from the Ghana 1:50 000 topographical maps and positioned in the field with hand-held GPS recorders.

The sampling undertaken at each site is indicated (C = water chemistry; M = metals and nutrients; F = fauna [benthos and zooplankton]; S = sediment) along with the date (day/month) they were collected.

Table 7 Angor channel aquatic sampling

Channel code	Map cordinates		Date	Parameter			
	N	E		C	M	F	S
C1	5 46 42	0 40 58	5 Dec	X		X	
C2	5 46 53	0 42 07	5 Dec	X		X	
C3	5 46 56	0 43 02	5 Dec	X		X	
C4	5 47 36	0 42 59	5 Dec	X		X	
C5	5 48 36	0 43 07	5 Dec	X		X	
C6	5 48 11	0 44 01	5 Dec	X		X	
C7	5 47 57	0 45 02	5 Dec	X		X	
C8	5 46 56	0 46 02	5 Dec	X		X	
C9	5 46 36	0 47 00	5 Dec	X		X	
C10	5 46 53	0 48 00	5 Dec	X		X	
C11	5 46 45	0 49 00	5 Dec	X		X	
C12	5 47 55	5 49 50	15 Nov	X		X	

The coordinates for each site were read from the Ghana 1:50 000 topographical maps and positioned in the field with hand-held GPS recorders.

The sampling undertaken at each site is indicated (C = water chemistry; M = metals and nutrients; F = fauna [benthos and zooplankton]; S = sediment) along with the date (day/month) they were collected.

3.2 Sampling methods

The sampling methods are outlined below with a summary of the field sampling protocols given in appendix 1.

3.2.1 Hydrological and meteorological

The work carried out to describe the hydrological and meteorological conditions at the two sites consisted of both field and office activities. As part of the survey, hydrological, hydrogeological and hydrometeorological data relevant to the study area were acquired from various sources including the Hydro Division of the Architectural and Engineering Services Corporation (AESC), the Ghana Water and Sewerage Corporation (GWSC), Water Research Institute (WRI) and the Meteorological Services Department (MSD). The field visits and measurements were carried out with the view to better describing and analysing the hydrology of the sites and to recommending engineering options necessary to enhance the ecological integrity of the wetland ecosystems.

Field work on all aspects of the study started in November 1996 and was completed by the end of the year. The work carried out for the hydrological aspects of the study of the sites included:

- collection and collation of hydrometeorological and hydrogeological data;
- study of field/topographic sheets covering the relevant areas;
- field measurements, by standard hydrometric techniques of flows into the lagoons, notably the Avu and Keta lagoons which are fed by the Todzie River and the Volta estuary as at time of study;
- measurement of static water levels at selected wells within the study area.

Field measurement of conductivity, salinity and total dissolved solids (TDS) of water collected from the wells by a Hach CO18 meter (model 50150) and establishment of the location of these wells with a Garmin 45 GPS.

3.2.2 Physico-chemical

Field analysis

Over 120 stations were visited at the two sites over the study period. At each station the following parameters were measured: water depth, transparency, pH, water temperature, conductivity, total dissolved solids (TDS), salinity, and dissolved oxygen (concentration and percent saturation). Water depth was measured at most stations by a metre rule with readings rounded up to the nearest centimetre. Transparency was measured with a plain white homemade Secchi disc (30 cm diameter); two readings averaged (disappearance, reappearance) to the nearest centimetre. Hydrogen ion concentration was measured by a pH meter (table 8). Water temperatures were recorded from water taken 20 to 30 cm below the surface, and read by the oxygen meter. Conductivity, TDS and salinity were read using the HACH meter (table 8).

The HACH meter had been calibrated by standard salt solutions in the laboratory before use in the field. Dissolved oxygen was read by an Aqualytic meter, which had been checked for accuracy by cross reference to samples tested by the Azide modification of the Winkler method. All data were recorded in the field on data sheets. The time and date of visit to each station was also recorded.

Table 8 Meters used for taking field measurements of physico-chemical parameters

Parameter	Meter	Range/Accuracy
pH	Hach EC10 Model 50050	+/- 0.02
Conductivity/Salinity/TDS	Hach CO18 Model 50150	Range 1; 0–199.9µS, Range 2; 200–1999µS, Range 3; 2–19.99 mS, and Range 4; 20–199.99mS. Accuracy of all ranges +/- 0.5% of full scale Salinity range 0–80 ppt +/- 0.1% TDS Range 0–19900 mg L^{-1} +/- 0.1%
Dissolved oxygen	Aqualytic OX1 921	Range 0–50mg L^{-1} +/- 0.1 mg L^{-1} or 0–199% +/- 1% temperature -5– 45^{0}C +/- 15%. Temperature compensated probe

Laboratory analysis

All water chemistry parameters were measured at the Water Research Institute laboratory – the only laboratory in Ghana accredited under the GERMP. The methods used all follow the 14th edition of Standard Methods (APHA 1984). Analysis was carried out on 44 samples from the sites for major ions: sodium and potassium by flame emission photometry at 589 and 766.5 nm respectively; calcium and magnesium by EDTA titration; sulphate by the turbidimetric method; and chloride argentometrically. Other analyses included: alkalinity by titration; total phosphate by the stannous chloride method; suspended solids gravimetrically after drying in an oven to constant weight at 105ºC; zinc, lead and copper by Atomic Absorption Spectroscopy using a Perkins-Elmer spectrophotometer at 213.9, 217.0 and 324.7 nm respectively.

Sediment samples were collected from the top 30 cm of the lagoon bottom by digging, from over 50 stations at the two lagoons and were analysed by staff of the Volta Basin Research Project at the Department of Soil Science, Legon. After air drying the bulk samples, the particle size composition was determined by dry sieving through a graded set of sieves for the sand fractions, and by sedimentation for the silt and clay fractions.

3.2.3 Biological

Benthos

At each of the 120 stations in the two lagoons, five sediment cores were taken to examine the benthos. Hand held PVC corers with a core area of 0.00196 m^2 were used. Each core was washed separately through sieves of 300 micron mesh, and all material retained on the sieves removed. The core depths ranged from 5–15 cm depending on substrate type, substrates with large amounts of shell being more difficult to sample (see Piersma & Ntiamoa-Baidu 1995). Each invertebrate sample was placed in a 250 ml container for preservation with 4% formalin to which Rose Bengal at 1 mg per litre had been added. The samples were sorted by eye and by compound low power microscopes and all the organisms found identified and counted.

Zooplankton

Due to the extreme shallowness of many of the stations, plankton nets could not be towed in the lagoons, neither could Schindler traps be deployed. As such, 50 litres of water were collected by bucket (5 times 10 litre buckets) from an area undisturbed by previous sampling and poured through a plankton net. The net had a mesh of 200 microns. Material collected by the net was washed into 60 ml tubes and treated as the benthos above.

Phytoplankton

Water samples for phytoplankton identification and density counting were collected from the 120 stations within the lagoons. As with the zooplankton, 50 litres of water were collected from beneath the water surface and immediately poured through a plankton net (mesh 80 microns), the retained material was placed into a 60 ml tube and preserved with Lugol’s solution (APHA 1984). Twenty-five of the preserved samples were used for species identifications. After an initial cursory examination approximately 10 ml of each sample was boiled in 70% nitric acid to clear all organic materials from the cell walls of the diatomaceous species present. These were then washed in deionised water and centrifuged to remove all remains of the acid. The cleared samples were then mounted in the medium ‘Naphthrax’ and permanent slides made for retention in the International Diatom Herbarium (Curtin University, Perth, Western Australia) and identification using the specialised literature (J John pers comm). Given an absence of taxonomic expertise in the project team it was not possible to treat all 120 samples in this manner.

Chlorophyll

For chlorophyll analysis, between 0.25 and 1.0 litres of water (dependent on the turbidity) were filtered through Whatman GFC paper (nominal pore size 1 micron). After filtration, the paper was placed in 10 ml of 90% methanol and stored on ice. The samples were kept cold for a further 24–26 hours and then analysed with a spectrophotometer at the field base. A HACH field spectrophotometer with a 1 cm wide cuvette was used to measure pigment levels after extraction, with optical density (OD) readings being taken at 750, 664, 647 and 630 nm wavelengths according to the trichromatic method (Jeffrey & Humphrey 1975, APHA 1984) for chlorophyll a, b, c_1 and c_2. The optical density at 750 nm was subtracted from each of the other readings. The chlorophyll concentration (mg L^{-1}) in the extracts was calculated by the following equations and then multiplied by the volume of extract (mL) divided by the volume of the filtered sample (L):

Chlorophyll a = [11.85(OD664) – 1.54(OD647) – 0.08(OD630)]

Chlorophyll b = [21.03(OD647) – 5.43(OD664) – 2.66(OD630)]

Chlorophyll c = [24.52(OD630) – 7.60(OD647) – 1.67(OD664)]

The phaeophytin component in each sample was then determined by acidifying the sample with one drop of 1M HCl and taking a further reading at 665 nm. After subtraction of the reading at 750 nm the concentration of phaeophytin (mg L^{-1}) was calculated by the following equation and then multiplied by the volume of extract (mL) divided by the volume of the filtered sample (L):

Phaeophytin = 26.7[1.7(OD665) – (OD664)]

Macrophytes

The aquatic macrophytes at each grid point within the lagoons were collected in five replicate 0.31 x 0.31 m quadrats, giving an area of 0.1 m^2. All above-ground plant material within the quadrats was removed by cutting, placed into plastic bags and returned to the field base. (The same samples were used for collecting macroinvertebrates.) The plant material was initially sun-dried and then oven dried to a constant weight at 70ºC and weighed.

The wetland macrophytic vegetation sampling initially involved species occurrence and phenological recordings being made at each site with above-ground biomass at every other site in the initial surveys. All sites were used to record species presence and dominance whilst only every other site in the initial survey was used for biomass sampling. Tables 2 and 3 list all sites surveyed and whether or not biomass samples were collected.

At each site a species list was made within approximately 50 m radius. The dominant 1–3 species were identified and five 1 m^2 quadrats randomly placed approximately 5 m apart within the area occupied by the dominant species for semi-quantitative recordings of species biomass dominance, ground cover and phenological state. The biomass dominance was recorded in a numeric descending order. The ground cover and proportional estimates of phenological state were recorded on a six-point scale that reflected the percentage ground cover and phenological states, respectively.

Scale	1	2	3	4	5	6
Percentage	1%	2–25%	26–50%	51–75%	76–99%	100%

The phenological recordings included estimates of the proportion (percentage) of plants flowering, fruiting and seeding along with estimates of the proportion of juvenile, mature and senesced plants in each quadrat. These recordings were done on the basis of the six-point scale given above and, where applicable, covered the occurrence of flowering, fruiting, seeding, juveniles, adults and senescence of the dominant species within each quadrat.

Above-ground biomass sampling was confined to the dominant 1–3 plant species at each site. Five replicate 0.25 m^2 quadrats were placed approximately 5 m apart within the area occupied by each species and all above-ground plant material removed by cutting, placing into plastic bags and returning to the field base. The plant material from each bag was cut into smaller pieces, sun-dried and then oven-dried to a constant weight at 70ºC and weighed.

Nine stations, roughly equidistant around the Keta lagoon, were selected for vegetation transects. After locating the transect on the ground with a GPS, a 200 m line (pre-marked at 1 metre intervals) was laid perpendicular to the water's edge. When practicable, the 100 m mark on the line was placed at the water land interface. Two methods were then used for recording presence and absence of vegetation. In the 'point' method, a pole was placed vertically on each meter mark on the line and every plant the pole touched was recorded. In the 'block' method, two observers walking on either side of the line noted all species found in blocks of 1 x 5 m, delimiting the distance away from the line by one metre sticks.