Mapping ecosystem change in a data poor environment
A description of research steps to gain system understanding

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Introduction

In order to evaluate ecosystem resilience and ecosystem structure it is necessary to understand how an ecosystem develops over time, what species or species groups are involved and how major external perturbations alter the system (how the system responds). These concepts of system understanding require some background knowledge of an ecosystem and its physical setting. The level of detail this that can be obtained depends on the extend of the existing research done, (data density, frequency and consistency) as well as the duration over which the data has been collected.

When extensive or consistent data is not available for a region one is often left with fragmented studies that need to be tied together to create a reasonable understanding of the ecosystem being explored. In this report I detail the steps taken to compile fragmented information. The methodology is focused around generating spatial frameworks of ecosystems and habitats and for each combining first had scientific studies with data from satellite imagery, anecdotal sources (recorded and unrecorded), observation (first and second hand). Pooling the information gathered from literature, media, observation, oral input and quantitative studies is then used to map out the study region at specific time intervals centered around a significant change, in this case, construction of a port. Following on this, an attempt is made at projecting ecosystem change resulting from further anthropogenic activity (port expansion)

Case study

The Tema area of the greater Accra region of Ghana is an area where such system understanding is lacking. Initial exploration revealed that data on the area was sporadic and comprehensive surveys of the coastline and coastal area were absent. Detailed studies of some of the elements of the coastal ecosystem were available, in particular, the Ramsar wetland area, Sakumono Lagoon (1–5). The remainder of the coastline was only sporadically studied with particular focus on coastal erosion processes (6). Detailed and consistent studies of the ecosystem structure along this portion of the coast is limited. Environmental Impact Assessments (EIA’s) were restricted to the direct surroundings of regional lagoons. EIA’s detailed little to nothing on coastal environments including beach, tidal zone, subtidal zone and terrestrial zones of the coastline. Perhaps due to existing use of these areas these were waived for consideration.
Approach

Quantifying the System (Identifying Ecotopes & Systems)

1) Mapping the system
   a) Literature
   b) Remote sensing
      i) Satellite Images, Photos, Video
      ii) Comparative analysis
   c) Anecdotal data and local knowledge

2) Understanding underlying Ecosystems
   a) Literature
   b) Mapping the past
   c) Ecological models/ principles/ local knowledge
1 Mapping the System

a) Literature
As a first step to understanding the Tema area, marine, coastal strip, lagoon and urban, a broad literature search was conducted. Any reports, thesis, articles and datasets available were researched to compile an overview of the various ecosystems in the area. For each system the key characteristics & species were compiled to generate an overview of they type of system in question.

Table 1: tabular assessment of ecosystem types in the Tema case study region and source of information.

<table>
<thead>
<tr>
<th>Area</th>
<th>Ecosystem type</th>
<th>Re-evaluated Ecosystem type</th>
<th>Source (*direct; ** Comparative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sakumono Lagoon</td>
<td>Semi open lagoon</td>
<td>Non-tidal semi closed estuary</td>
<td>(7–9)*, (4,10,11)**</td>
</tr>
<tr>
<td>Coastal strip</td>
<td>Sandy/ Rocky</td>
<td>Rocky</td>
<td>(12,13)**</td>
</tr>
<tr>
<td>Urban area (Tema)</td>
<td>Urban paved</td>
<td>Urban Paved and Unpaved Park</td>
<td>(5)*</td>
</tr>
<tr>
<td>Urban Area Sakumono Community</td>
<td>Urban semi paved</td>
<td>Observation*, remote sensing*</td>
<td></td>
</tr>
<tr>
<td>Port area</td>
<td>Industrial paved</td>
<td>Industrial Paved &amp; artificial garden</td>
<td>Observation*, remote sensing*</td>
</tr>
<tr>
<td>Lashimi Urban Area</td>
<td>Urban semi paved</td>
<td></td>
<td>remote sensing*</td>
</tr>
</tbody>
</table>

b) Remote sensing

i) Satellite Images, Photos, Video
To map the geography and place habitat types in context we used satellite imagery (Google & Landsat). A map of the Tema area of Ghana was extracted and a coarse habitat division was overlaid using QGIS mapping systems. Boundaries of habitat types were determined visually.

Each distinct area was cross referenced with literature data collected in 1a and visually distinct areas on satellite images where no literature or published data was available were identified.

Using partners on the ground in Ghana and online resources photo and video material additional information was acquired to corroborate observed habitat composition.

ii) Comparative analysis
To fill in remaining blanks and supplement more detailed system information (species interactions etc.) a comparative analysis of other areas was employed.

The Western coast of Ghana was found to have been more extensively studied from an ecosystem perspective than the area East of Accra. Comparable biomes were identified in areas where more detailed scientific reports were available. Placing satellite imagery alongside each other allowed for color and pattern recognition to be used to approximate the habitat type and its composition. (Fig 2).
c) **Anecdotal data / local knowledge**

Not all zones identified in satellite imagery could be characterized owing to 1) lack of direct data, 2) no comparable reference areas and 3) lack of visual evidence.

In these cases, anecdotal information was found to provide some insight. Two sources of reference were found. 1) Direct descriptions of the area in question sourced from locals. 2) Indirect descriptions of other regions with comparable geomorphology.

Particularly stories describing coastal vegetation provided insight into nearshore and inland habitat types. Sufficient information could be pieced together concerning habitat structure and dominant species. Together with general principles of ecology and derivative thinking a broad understanding of the system composition could be derived.

![Fig. 2: Comparative assessment satellite imagery. Left image, a similar well-studied system (Densu Delta). Red circles denote areas of similar patterning in each region. Dominant habitat vegetation sourced from Densu Delta studies. Bottom right, validation image of habitat type obtained from secondary sources.](image)
Fig 3: Image of Tema region illustrating zonation and data sources leading to identification of habitat types.
2. Understanding the system

a. Literature
Using literature sources each ecosystem type identified was studied and a broad description of the system processes and key species compiled. Sources included FAO and state fish catch data, land use reports, research reports ((4,9,11,14–17)).

b. Mapping the past
A system’s response to perturbation is a useful tool to understand the systems functioning. To do this (depending on scale) a significant perturbance needs to be identified and the change undergone by the system assessed.

The method of approach adopted was as follows:

Step 1: understand the existing state of the system
Step 2: identify a significant perturbance of the system
Step 3: map the system before this perturbance
Step 4: identify the significant changes in the system resulting from the perturbance
Step 5: repeat the process to map further back in time

Step 1: described in section 1.

Step 2: In the context of Tema, Ghana, the construction of the Tema Port itself in the late 1950’s was one of the post significant perturbances of the existing system. The placement of solid structures protruding from the coastline, urbanization of the hinterland and placement of connecting trunk routes along the coastal strip affected hydrodynamic and geomorphological processes as well as redefining landscape elements such as dune landscapes, coastal forest and estuarine discharge.

Step 3: To map the Tema area prior to the construction of the port and associated structures several processes were employed.

Historical data: Mapping and spatial planning data were obtained from various literature sources (5). Scale maps from the original architectural drawings were overlaid onto satellite imagery using QGIS systems. Landmarks were identified and pinned to correctly scale the sketches to the maps. There overlays were then used to reconstruct the geomorphology of the area prior to the 1950’s development of the port and new urban areas (Fig 4)
Figure 4: Iterative process to map historical state of Tema region using historical sketches (left) and topographical maps (right).
Reference areas: The limited urbanization along the western coast of Ghana meant that data on these areas gave insight into the state of some of the elements of the Tema coastal systems prior to perturbation. Comparative assessment gave insight into the potential functioning of the system. Insights into comparable systems were obtained for more detailed scientific studies of more pristine regions in the western coastal region of Ghana (2, 18–20). Coupled with corroborations from anecdotal sources and observations in the field (Fig. 4). Figure 5 illustrates the deductive process using comparison with reference areas (Butre lagoon ~20km West of Takoradi in Western Ghana) coupled with direct evidence in the subject area (Sakumono Lagoon) where marine bivalve shells (Anadara senilis) were found in the sandy sediment in the lower reaches of the Lagoon. This marine species confirms that the species either made its habitat is the lagoon or were deposited as part of marine sediments, meaning open access to the coastal strip and (occasional) tidal inundation.

Anecdotal information & Tradition: The systems and system function of the Tema region were further explored using various sources of anecdotal information. Both recorded oral histories (21, 22) as well as information on traditional usage. For example, the Ga-Dangme peoples of the Tema region were principally a farming community where fishing contributed a small portion of the subsistence (21). Fishing methods consisted primarily of canoe cast netting and later, hook and line fisheries. These methods are often typical for regions with rocky subtidal outcrops (these prevent methods such as beach sine fisheries. Deductive conclusion; the coastline in the Tema region historically consisted of sandy beaches with rocky outcrops. Using reference studies from other areas in the region species composition and coastal system understanding can be derived.
**Step 4:** identify the significant changes

After compiling the system situation at T0 (Present) and T-1 (Past) prior to the construction of the port of Tema. An assessment of change resulting from port construction can be made.

Habitat maps were reconstructed using data and information gathered as detailed above these were mapped out Using GIS mapping tools (See Fig 7 & 8). These maps could be overlaid to assess habitat change (size, connectivity). Changes leading to system function change could also be identified using these maps (closure of estuary mouth, paving of vegetated or open substrate, placement of breakwaters, quays etc. See Table 2). Further more detailed analysis of species compositions were also assessed to improve understanding of function change within habitat types (species losses, new species, changes in vegetation etc.)

*Figure 6: A Flow chart illustrating the approach to understanding change in a system and projection trajectories that may be extrapolated*
Figure 7: mapping exercise to identify change in the Tema region
Figure 8: Overlay of T-2 (pre-port), T-1 (post port) and T0 (present), illustrating changes in scale of lagoon and alterations in coastal habitat.
### Table 2: Habitat change over time and associated function change. T-2 = Pre Port (~1950), T-1 = Post Port (1964), T0 = Present (2015)

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Scale (Km²)</th>
<th>Composition change</th>
<th>Function change</th>
<th>Characteristic species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T-2</td>
<td>T-1</td>
<td>T0</td>
<td>T-2</td>
</tr>
<tr>
<td>Lagoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brackish /hypersaline</td>
<td>12.6</td>
<td>11.5</td>
<td>10</td>
<td>Brackish /hypersaline</td>
</tr>
<tr>
<td>Mangrove</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal forest</td>
<td>6.2</td>
<td>3.9</td>
<td>3.4</td>
<td>Coastal forest</td>
</tr>
<tr>
<td>Marsh</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
<td>Marsh</td>
</tr>
<tr>
<td>Salt marsh</td>
<td>4.3</td>
<td>2.8</td>
<td>0.6</td>
<td>Salt marsh</td>
</tr>
<tr>
<td>Dune</td>
<td>5.9</td>
<td>2.4</td>
<td>0.6</td>
<td>Consolidated dry dune</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Scale (Km²)</th>
<th>Composition change</th>
<th>Function change</th>
<th>Characteristic species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T-2</td>
<td>T-1</td>
<td>T0</td>
<td>T-2</td>
</tr>
<tr>
<td>Beach</td>
<td>1.6</td>
<td>1</td>
<td>0.2</td>
<td>Steep sandy/rocky</td>
</tr>
<tr>
<td>Shallow subtidal</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Rocky, silty</td>
</tr>
<tr>
<td>Open savannah</td>
<td>29.1</td>
<td>24.5</td>
<td>7.7</td>
<td>Palm tree savannah</td>
</tr>
<tr>
<td>Urban</td>
<td>1</td>
<td>14.5</td>
<td>42.5</td>
<td>Unpaved urban</td>
</tr>
<tr>
<td>Artificial rock</td>
<td>0</td>
<td>0.06</td>
<td>0.1</td>
<td>Port structures</td>
</tr>
<tr>
<td>Coastal Waters</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Main changes and associated ecosystem changes

<table>
<thead>
<tr>
<th>Change</th>
<th>Ecosystem change</th>
</tr>
</thead>
</table>
| Loss of beach sediment     | • Change of species assemblage from small crustaceans and bivalves to crabs, barnacles, limpets and macro algae  
                               • Alteration of nearshore fish assemblages  
                               • Loss of wading bird foraging habitat |
| Closure of estuary         | • Loss of coastal sandbars and beach  
                               • Change from tidal flats to saltmarsh  
                               • Stabilization of brackish, hypersaline and freshwater zones  
                               • No/little species exchange with marine environment (isolation) |
| Eutrophication             | • Increased nutrient load bacterial and fungal assemblages on coastal rock  
                               • Loss of mangrove stands increase of marsh grassland |
| Urbanization               | • Habitat loss (dune & savannah)  
                               • Habitat fragmentation (dune & savannah)  
                               • Non-native species introduction  
                               • Reduction of estuary footprint  
                               • Increased flash flood frequency  
                               • Increased domestic and industrial pollution  
                               • Reduced river input to estuary/lagoon (dam structures)  
                               • Reduced rainwater infiltration (groundwater depletion) |
| Port structure             | • Increased vertical rockface (probable) increased vertical zonation  
                               • Increased steepness of coastal strip  
                               • Loss of intertidal zone.  
                               • Creation of sheltered bay (possible) function as species shelter |
Projecting the future

Understanding the changes that occurred between T-2, T-1 and T0 allow projections to be made as to how the system may further change in the face of new disturbances.

Currently Port expansion to the west of the Tema port is ongoing. This region was (until 2016) the last remaining open dune/beach environment in the immediate vicinity (see fig. 9). Construction of the planned port structures will alter this habitat into a paved container terminal. The coastal strip will be altered from a gradual eroded rocky coastline with some sandy beach sections into a quay wall and breakwater. Based on changes recorded in Table 2 and Table 3. The following may be projected.

1. Loss of habitat (beach and dune)
2. Loss of groundwater percolation
3. Increased vertical rock habitat
4. Sheltered rocky habitat (port basin) with disturbed (dredging) silty bottom
5. Connectivity loss between terrestrial and marine system

This shortlist of changes in all likelihood will have some unforeseen cascading effects both on the socioeconomic environment of Tema as well as on ecosystem functioning. Overall the system will move from an isolated dune coastal strip to an urbanized industrial environment where, from an ecological perspective, generalist scavengers will thrive, and specialist species and vegetation reliant species will decline or disappear. Species that rely on periodic inundation by tides will likewise lose habitat while sedentary marine species that reside on bare rock will gain ground. Specifically, species that benefit from reduced hydrodynamic stresses such as macro algae, sea squirts. etc.

Figure 9: Projected change in coastal strip resulting from Tema Jubilee port expansion
References


12. Resources Center C, of the Nation F. Assessment of Critical Coastal Habitats of the Western Region, Ghana. Integrated Coastal and Fisheries Governance Initiative for the Western Region of Ghana. Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island.; 2011.


18. Gordon C. Coastal lagoons of Ghana. 1984;


