# Integrating Biophysical and Social Economic Data for Sustainability Analyses in Sango Area, Uganda.

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## 1. Abstract

The availability of relatively cheap computer hard- and software to developing countries furthered into the application of remote sensing and GIS techniques for sustainable land management. The call for sustainable land use in Uganda has resulted in the introduction of geo-information systems to generate spatial information that may help decision making about the sustainable use of land resources. The use of Geo-information for sustainable land management is very crucial in Uganda because of land use conflicts between local subsistence farmers, industrialists and biodiversity conservationists. Government policy makers, development and conservation agencies do not only need geo-data but also analyses to generate geo-information for land management in some regions of Uganda. This paper discusses the use of relevant techniques that were used in the Sango Bay area, Uganda, not only to generate geo-information, but also to use the generated information for land suitability analyses. The overall aim of the study was to carry out land use zoning in an area (Sango Bay) that is important for its biological diversity resources and related human exploitation such as agriculture, fishing and forest logging.

Remotely sensed data were used to identify and map the different land cover types in the area. Biodiversity and socio-economic surveys were conducted to find out the status of the biological resources (both fauna and flora) and how these natural resources are used by the local people to meet their needs. The biophysical and socio-economic data were integrated in a GIS environment to zone Sango Bay area into suitability land use and management types. The results were used as a basis to develop a land use management proposal that has been submitted to international organizations for possible funding.

## 2. Introduction

Of the numerous ways of minimizing land use conflicts, suitability analyses of Geo-information provide the necessary facts for decision-making parties. Data collected by remote sensing and field survey techniques can be integrated into a GIS environment for easy processing and analysis.

Remotely sensed data, specifically satellite data, are being used for updating land use and cover maps worldwide. In the case of Uganda, both SPOT and Landsat data have been used for the assessment of the status of the land resources in the last 6-7 years. A national biomass study project has completed a manual exercise of producing a rather generalized land use and cover map for the whole of Uganda, using SPOT data (GOU, 1996). Locally based land resources suitability analyses need more detailed geo-information than the national spatial database mentioned above can provide. A number of natural resource assessment exercises, including Sango Bay, at local scales have been carried out using

Landsat TM data and automated image classification techniques (Mugisha *et. Al*., 1996; 1997).

This paper describes the use of remote sensing, field surveys and GIS techniques in land suitability analyses for Land Use Management in Sango Bay area, Uganda. It considers the integration and analysis of biophysical and socio-economic data for the generation of geo-information used in turn as a basis for establishing a Land Use Management Project in Sango Bay. It is internationally recognized for its biological diversity (tropical forests, wetlands and water bodies), but at the same time a threat to the biodiversity from local people. Because conservation agencies (both national and international) loathed the apparent unsustainable use of the land resources, *Global Environmental Facility* (GEF) and *Darwin Initiative for the Survival of Species* (through the Institute of Terrestrial Ecology, ITE, based at Monks Wood, UK) provided funds for the production of a Land Use Management map for Sango Bay area, (Fuller *et al*., 1996). The objectives, techniques and results of the study are described below.

## 3. Objectives

The main project objectives of the study were to:

- Produce an updated land use and cover map showing the major ecosystems of Sango Bay area
- Integrate the land use and cover information with biological (fauna and flora) data to determine which of the various ecosystems and sites within the Sango Bay area were of the greatest biodiversity value.
- Integrate biodiversity values, and population information to carry out suitability analyses for multiple land use management

## 4. Methods

The techniques adopted for the study were intended for long-term and wider applications in natural resource assessments and land suitability analyses for Uganda (and other countries in the East African region). Such goals demanded low costs in terms of both hard- and software. A PC (16Mb RAM, P5-120, 2Gb hard disk); a high resolution monitor and other accessories such as a digitising tablet, colour plotter and printer, and data backup facilities were acquired. TNTmips software was used as both an image processing system and GIS. TNTmips was preferred because of its advantages over many other systems in that the software has fully developed and professional image processing, raster, vector and CAD modules.

A decision to use Landsat TM was made because it had been noted that TM has the additional infrared band 5 (1.55 - 1.75micrometers) important for discriminating between different vegetation types (Fuller, et al., 1989; Townshend, 1992). Landsat TM imagery acquired in 1990, 1989, 1984 were used. Presence of cloud cover and lack of Landsat data for most of East Africa during some periods made using old images of 1984 inevitable. However, the 1984 images were only used for a small portion of the study area.

### 4.1 Land Use and Cover Map Production

After importing the Landsat TM images into TNTmips format, the data were trimmed to the region of interest. The images were enhanced to maximize different land cover types found in Sango Bay. The data were then geo-referenced i.e. brought into alignment with a map projection commonly used in Uganda (UTM). Geo-referencing involved selection of common points (such as road junctions) appearing both on the topographic base maps and on the images, as displayed on the screen. The images were then resampled and used for land use and cover identification and mapping.

Supervised image classification was used. Sample image pixels representing all targeted land use and cover types were selected and used as “training data”. The training data were selected from about 400 different field sites. The method of selecting training pixels was done interactively in the ‘feature map’ of TNTmips. A number of supervised classifiers (Maximum Likelihood, Suits maximum Relative and Minimum Distribution Angle) were tested in order to select the best performer. Maximum Likelihood and using a combination of three bands (3,4 & 5) gave the best results.

**Table 1. Land use and cover types in the Sango Bay area, Uganda**

| Cover Class | $Km^2$ | % |
|---|---|---|
| **Water and Swamps** | | |
| Water (excluding lake Victoria) | 36 | 1.6 |
| Papyrus swamps | 198 | 8.6 |
| Tall grassy swamps | 389 | 16.9 |
| | **623** | **27.2** |
| **Dry grasslands** | | |
| Medium height grass | 417 | 18.2 |
| Short grass | 242 | 10.6 |
| | **659** | **28.7** |
| **Degraded woody vegetation** | | |
| Scrub, bush, & thickets | 47 | 2.0 |
| Degraded forest | 90 | 3.9 |
| | **137** | **6.0** |
| **Semi-natural woody vegetation** | | |
| Swamp forest | 80 | 3.5 |
| Riverine woodland | 12 | 0.5 |
| Forest | 262 | 11.4 |
| | **354** | **15.4** |
| **Intensive land use** | | |
| Eucalyptus plantation | 4 | 0.2 |
| Tea plantation | 1 | 0.0 |
| Cultivated land | 510 | 22.2 |
| Urban, villages, bare ground | 7 | 0.3 |
| | **521** | **22.7** |
| **Total mapped land use and cover** | **2295** | **100.0** |
| | | |
| **Unclassified (cloud cover)** | **203** | **8.1** |
| | | |
| **Grand total Sango Bay area** | **2497** | |

There were some isolated misclassifications on the resulting map. The image misclassifications, if contextual in nature, were removed by application of techniques developed by Groom et al (1996). These methods of create a series of masks using the draft maps to re-map misclassified land use and cover types. For example, some isolated pixels of papyrus were misclassified as cultivated land. Since papyrus should only occur in poorly drained areas (fluvial valley landforms), it was easy to mask out the misclassified pixels and rename them using GIS-raster operations of TNTmips. The resulting land use and cover maps were then mosaicked together to produce a single spatial product. The land use and cover map was validated using 240 GPS-field observations with a resultant accuracy of 85.8%.

Table 1 shows the results obtained after Landsat image classification. The results revealed that intensive land use (mostly cultivation) makes up 22.7% of the Sango Bay area. Most other areas are natural or semi-natural. The natural vegetation habitats such as forests, swamps and grass make up the largest coverage of about 62%. The resulting land use and cover information was used for predicting biodiversity values of the mapped habitats of

Sango bay. This was done by integrating the land use and cover information with biodiversity data, generated from field inventories as described below.

## 4.2 Biodiversity Value Predictions

Biodiversity field surveys were carried out using a sampling technique based on the land use and cover map produced as described above. Existing plant species surveys for Sango Bay were not be used as these data could not necessarily be related to the map classes. Most sample points were located near roads as the accessibility of the study area was a problem. Five survey sites per natural and semi-natural land cover class were pre-defined within 500m of roads, using the buffer zone constructed in the TNTmips vector GIS.

**Table 2. Number of occurences of cover classes per site**

| Cover Class | Number of Species | | | | | | |
|---|---|---|---|---|---|---|---|
| | site1 | site2 | site3 | site4 | site5 | site6 | mean |
| **Water & swamps** | | | | | | | |
| L. Victoria | - | - | - | - | - | - | - |
| Papyrus swamps | 4 | 5 | - | - | - | - | 5 |
| Tall grassy swamps | 9 | 33 | 10 | 5 | 10 | - | 13 |
| | | | | | | | |
| **Dry grasslands** | | | | | | | |
| Medium height grass | 27 | 43 | 40 | 32 | 18 | - | 32 |
| Short grass | 45 | 24 | 41 | 15 | 4 | - | 26 |
| | | | | | | | |
| **Degraded woody vegetation** | | | | | | | |
| Scrub, bush, thickets | 15 | 42 | 68 | 34 | 44 | 14 | 36 |
| Degraded forest | 32 | 17 | 8 | 53 | - | - | 28 |
| | | | | | | | |
| **Semi-natural woody vegetation** | | | | | | | |
| Swamp forest | 40 | 45 | 33 | - | - | - | 39 |
| Riverine woodland | 29 | 16 | - | - | - | - | 23 |
| Forest | 86 | 58 | 60 | 28 | 68 | - | 66 |
| | | | | | | | |
| **Intensive land use** | | | | | | | |
| Eucalyptus plantation | - | - | - | - | - | - | - |
| Tea plantation | - | - | - | - | - | - | - |
| Cultivated land | - | - | - | - | - | - | - |
| Urban, village, bare ground | - | - | - | - | - | - | - |

**Table 3: Summary of recorded fauna and flora at Sango Bay**

| Group | Species recorded[1] | % of Uganda's total |
|---|---|---|
| Flowering plants | 1000 | 20 |
| Dragonflies | 72 | 34 |
| Butterflies | 257[2] | 29 |
| Fish | 48 | 15 |
| Amphibians | 32 | 33 |
| Reptiles | 15 | 13 |
| Birds | 387 | 39 |
| Mammals | 68 | 20 |

Table 2 shows the number of species recorded per site. It should be mentioned that the low number of plant species in waterlogged sites could have been due to poor accessibility of the wetlands. It should be noted that there is a great variety of plant species within a given land cover class because it is difficult to identify and map individual plant species using satellite data. Table 3 presents a summary of all biodiversity data (both fauna & flora) recorded in the field, and then used in biodiversity value predictions.

In order to predict the biodiversity value for each major ecosystem, field-collected data (fauna & flora) were tabulated to facilitate comparisons. Two independent measures of biodiversity were used: species richness and species uniqueness. Species richness referred to the total number of species per site. Assuming equal fieldwork effort per site, the site with the most species was given a score of 5, then 4 and so on. The results are shown in the lower part of Table 4.

On the other hand species uniqueness referred to the total number of sites at which each species occurred. A species found at only one site scored 3 for that site; species found at two sites score 2 for both sites; species found at 3 or more sites scored 1 per site. The total scores for each site were then ranked; the top site scored 5, next 4 and so on. The results are shown in lower part of Table 4.

Finally, the two rankings (species richness and uniqueness) for each site were totaled up to give the summation of all the scores (bottom line of Table 4). The biodiversity rating was substituted, as appropriate, for each land cover class and thus used to produce the biodiversity map of Sango Bay area, according to the scheme shown in Table 5.

Before each land cover class was given its biodiversity value, the raster map was converted from raster to vector data type (using the TNTmips raster to vector conversion module). It was then easy to select each land cover class or classes and assign the appropriate biodiversity value. The statistical outcome of biodiversity value prediction is shown in Table 6. The resultant biodiversity spatial information was then integrated with selected biophysical and socio-economic data for suitability analyses.

**Table 4. Species richness, species rarity and overall biodiversity assessment scores for Sango Bay biodiversity survey sites**

| **Habitat** | | **Wetland sites** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | | AP | BI | BS | DS | GS | LK | KG | MS | MY | NK | NN |
| Land cover class | | W | P/TG | W | SG/W | MG/W | SG/W | $SG_{sg}$ | $SG_{sd}$ | TG | TG | TG |
| Score for spp. richness | Plants | 5 | 0 | 3 | 0 | 4 | 0 | 2 | 0 | 0 | 1 | 0 |
| | Mammals | - | - | - | - | - | - | - | - | - | - | - |
| | Birds | 5 | 0 | 1 | 4 | 3 | 0 | 0 | 2 | 0 | 0 | 0 |
| | Amphibians | 3 | 5 | 4 | 3 | 2 | 2 | 0 | 0 | 0 | 1 | 2 |
| | Butterflies | - | - | - | - | - | - | - | - | - | - | - |
| | Dragonflies | 5 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 1 |
| | Fish | 0 | 0 | 0 | 3 | 4 | 3 | 4 | 0 | 1 | 2 | 5 |
| **Total** | | **18** | **5** | **11** | **10** | **13** | **9** | **6** | **2** | **1** | **4** | **8** |
| Scores for spp rarity | Plants | 5 | 0 | 1 | 2 | 4 | 0 | 3 | 0 | 0 | 0 | 0 |
| | Mammals | - | - | - | - | - | - | - | - | - | - | 4 |
| | Birds | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Amphibians | 3 | 4 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 4 |
| | Butterflies | - | - | - | - | - | - | - | - | - | - | - |
| | Dragonflies | 5 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Fish | 0 | 0 | 0 | 2 | 4 | 0 | 3 | 0 | 0 | 0 | 5 |
| Total | | 13 | 7 | 4 | 5 | 8 | 1 | 6 | 2 | 0 | 0 | 13 |
| **Overall total** | | **31** | **12** | **15** | **15** | **21** | **10** | **12** | **4** | **1** | **4** | **21** |

| Habitat | | Dry/Wet Sites | | | Dryland sites | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | | AC | AS | MI | BA | KI | KS | KT | KY | MG | ML | MP | NA | NG | PS |
| Land cover class | | RW | SG/ MG | MG | DF | F | SG/ SB | F | MG | SG | MG | F | F | SG | MG |
| Score for spp. richness | Plants | 0 | 1 | 0 | 5 | 0 | 3 | 0 | 0 | 0 | 0 | - | 1 | 2 | 0 |
| | Mammals | 0 | 0 | 5 | 2 | 0 | 0 | 0 | 2 | 4 | 0 | - | 0 | 0 | 0 |
| | Birds | 3 | 1 | 5 | 0 | 0 | 4 | 0 | 2 | 0 | 0 | - | 0 | 0 | 0 |
| | Amphibians | 0 | 0 | 0 | - | $0^a$ | - | - | - | - | - | - | $0^a$ | - | - |
| | Butterflies | 5 | 0 | 0 | 3 | 4 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 0 |
| | Dragonflies | 0 | 0 | 2 | $0^a$ | $0^a$ | - | - | - | - | - | - | - | $0^a$ | $0^a$ |
| | Fish | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - | - | - |
| **Total** | | **8** | **2** | **12** | **10** | **4** | **7** | **1** | **4** | **4** | **0** | **2** | **1** | **3** | **0** |
| Scores for spp rarity | Plants | 0 | 0 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | - | 3 | 0 | 2 |
| | Mammals | 3 | 0 | 5 | 2 | 0 | 3 | 0 | 0 | 0 | 1 | - | 4 | 2 | 0 |
| | Birds | 4 | 3 | 5 | 0 | 0 | 3 | 0 | 0 | - | 0 | - | 2 | 0 | 0 |
| | Amphibians | 0 | 4 | 2 | - | $5^a$ | - | - | - | 0 | - | - | $3^a$ | - | - |
| | Butterflies | 4 | 0 | 0 | 3 | 5 | 2 | 0 | 1 | - | 0 | - | 0 | 0 | 0 |
| | Dragonflies | 0 | 0 | 2 | $0^a$ | $3^a$ | - | - | - | - | - | - | - | $0^a$ | - |
| | Fish | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - | - |
| Total | | 11 | 7 | 14 | 10 | 15 | 9 | 0 | 1 | 0 | 1 | - | 12 | 5 | 2 |
| **Overall total** | | **19** | **9** | **26** | **20** | **19** | **16** | **1** | **5** | **4** | **1** | **2** | **13** | **8** | **2** |

**0 = no score; - = no data; $^a$ = streams in drylands**

**KEY:**

Land cover class code: Site codes:

W **Water**
P **Papyrus**
TG **Tall grass swamp**
MG **Medium height grass**
SG **Short grass**
RW **Riverine woodland**
SB **Scrub, bush & thicket**
DF **Degraded forest**
F **Forest**
sd **sand**
sg **sedges**

**dry/wet sites:**
AC **Acacia woodland**
AS **Airstrip savanna**
MI **Mityebili**

**Wetland sites:**
AP **Airstrip ponds**
BI **Bikira swamp**
BS **Byante stream**
DS **Diimu lake shore**
GS **Goma lake shore**
LK **Lake Kayanja**
KG **Lake Kayugi**
MS **Malembo shoreline**
MY **Lake Manywa**
NK **Nakigga**
NN **Nabugabo**

Dryland sites:
BA **Bale Forest Reserve**
KI **Kirala Forest Forest Reserve**
KS **Kayanja savanna**
KT **Kitasi Forest Reserve**
KY **Kyotera South**
MG **Malembo grassland**
ML **Malabigambo grassland**
MP **Malembo palms**
NA **Namalala Forest Reserve**
NG **Nabugabo grassland**
PS **Phoenix savanna**

**Figure 5. Biodiversity ratings based upon species richness and species uniqueness *for dryland and wetland parts of Sango Bay***

| Sites/Scores | | Biodiversity ratings |
|---|---|---|
| **Dryland sites** | | |
| | scoring 25 and above | Very high |
| | scoring from 15 to 20 | High |
| | scoring 10 to 15 | Medium |
| | other | low |
| **Wetland sites** | | |
| | scoring 20 and above | High |
| | scoring 10 to 15 | Medium |
| | scoring less than 10 | Low |

**Table 6. Tabular data of predicted biodiversity values**

| Predicted biodiversity value | Area ($km^2$) | % |
|---|---|---|
| **1. Dryland sites** | | |
| | | |
| High | 319 | 14 |
| Medium | 200 | 8.8 |
| Low | 1191 | 52.2 |
| **2. Wetland sites** | | |
| High | 36 | 1.6 |
| Medium | 508 | 22.2 |
| Low | 28 | 1.2 |
| **TOTAL** | **2282** | **100.0** |

## 4.3 Land Suitability Analyses for Conservation and Multiple Land Use Types

The biodiversity value information was integrated with selected biophysical and socio-economic data so as to carry out suitability analyses. River, road, gazetted and population data layers were integrated with the biodiversity value map. Relief data, though available, were not used because most of Sango Bay is of flat terrain. The integration was carried out in TNTmips, using the vector modules and the data base management system of the software. 'If - then' queries were used to carry out suitability analyses based on pre-defined conditions such as biodiversity value, population density, accessibility to roads and rivers and so on.

The suitability analyses were carried out specifically for three land utilization types: Pure biodiversity conservation, multiple use and human settlements. The results indicated that most of the nature protection areas may be managed as pure conservation areas and multiple use zones, hence calling for a new approach of land resource management in Sango Bay area.

# 5. Discussion

Satellite data, though not fit to allow identification and mapping of different plant species, are normally used to map different ecosystems (Settle & Drake, 1993). Standard image classification techniques were successfully used to produce a land cover map of Sango Bay. As expected, the land cover map produced was ecosystem-oriented rather than a plant species map.

The prediction of biodiversity values was possible when field recorded biodiversity data were ranked and then integrated with the land cover classes. It should be emphasized that the methods used for biodiversity value prediction relied on numerous assumptions about map accuracy and the representativeness of the sample species data. In practice, it was recognized that the maps incorporate errors:

- the cover types show within-class variations
- the field data recorded only a small part of Sango Bay for a limited period of time
- many biological groups were not covered hence there could be many more species yet to be recorded and related to habitat and vegetation cover in Sango Bay.

Further more, the analyses used were simple. However, the study was designed to provide a preliminary biodiversity map of Sango Bay, which in turn was integrated with other biophysical and socio-economic data for land suitability analyses.

The suitability analyses yielded an operational utilization map with three major zones: pure conservation, multiple-use and human settlement. The resultant information was used as a basis for putting together a proposal called '*Integrated Conservation and Development*

*Project'* submitted by the government of Uganda to the Global Environmental Facility (GEF) for possible funding.

The results of the suitability analyses may be viewed as recommendations based on biophysical and socio-economic data. However, not all the relevant data have been included. For example land ownership (tenure system) was not included in the analyses with the implications that the proposed zones may not be applicable in all areas. However, areas that have been reserved for pure conservation are either already protected areas (but being exploited by the managing agencies) or inaccessible such as extensive waterlogged swamps. In a nutshell, one should regard the results of suitability analyses as preliminary ones, which would be revised with the integration of more biophysical and socio-economic data, if the need arises.

## 6. Conclusion

The availability of remotely sensed data, together with the technological advances in information systems now available to developing countries have resulted in suitability analyses which are vital to generate geo-information for sustainable land management. In Uganda, the application of geo-information systems for land management is being adapted for a number of government departments and NGOs. One hopes that our land resources will be better managed and land use conflicts minimized because of the availability of geo-information.

## 7. References


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